**ANAS Transactions Earth Sciences Special Issue / 2023**

http://www.journalesgia.com

# HYDROCARBON SYSTEMS AND MUD VOLCANOES: PARAGENESIS OR ASSOCIATED DEVELOPMENT

**Guliyev I.S.[1], Yusubov N.P.[2], Huseynova Sh.M.[2]**

*[1]Presidium of the Azerbaijan National Academy of Sciences*

*[2]Oil and Gas Institute of the Ministry of Science and Education of the Republic of Azerbaijan: huseynova_shalala@yahoo.com*

***Keywords:*** *The South Caspian basin, hydrocarbon system, mud volcano, Maikop Group*

***Summary.*** The South Caspian basin containing the significant part of the world's hydrocarbon resources is a region of extensive mud volcanism. All the oil and gas fields within the basin are associated with mud volcanoes evidencing active petroleum systems. Relationship between hydrocarbon accumulations and mud volcanoes remains the most relevant research issue for a long time. The present paper introduces the results of the comprehensive analysis of hydrocarbon systems and the geodynamic processes creating mud volcanoes within the Azerbaijani sector of the South Caspian basin based primarily on the seismic data. The results of the study suggest that the mud volcanoes are the key element of the petroleum systems of the basin. Mud volcanism appears to be synchronized in time and space with the growth of folds, providing an associated development of mud volcanoes and oil and gas fields. The origin and formation of mud volcanoes have been investigated in the context of the evolution of the South Caspian Basin. The results of study might significantly contribute to the better understanding of petroleum systems and mud volcanism within the South Caspian basin and prove genetic link between mud volcanoes and hydrocarbon accumulations.

© 2023 Earth Science Division, Azerbaijan National Academy of Sciences. All rights reserved.

## Introduction

The South Caspian basin (SCB) contains the significant part of the world's hydrocarbon resources. The multiple giant oil and gas fields have been uncovered and a number of promising structures are recorded within the basin. The prolific oil and gas content of the basin evidences the active petroleum systems. The basin is characterized by the availability of all elements of petroleum system and the processes necessary for hydrocarbon accumulations to be formed (Huseynov and Huseynova, 2014; Huseynova, 2019; Huseynova and Afandiyeva, 2019). Thus, the sandy layers of the Low Pliocene Productive Series (PS) are the main reservoirs; the shaly layers of PS serve as the seals for the hydrocarbon accumulations; the Oligocene – Lower Miocene Maikop Group is recognized as the main source rocks; the Upper Pliocene Aghjagil shales are considered to be the regional seal rocks. The most uncertain and thus relevant issue while analyzing petroleum systems and the whole basin is the mechanism of hydrocarbon migration and formation of their accumulations.

The South Caspian basin is the world's largest area of mud volcanism development. According to the 2D and 3D seismic survey within the Azerbaijani sector of the SCB performed in 1990-2014 approximately 100 local uplifts are associated with mud volcanoes. (Fig. 1) Some structures are complicated by two and more volcanoes (Shah-deniz – 4, Absheron – 2, Mashal – 2, Shafag – Asiman – 5) (Yusubov et al., 2023). That kind of association evidences the closest relationship between oil and gas deposits and mud volcanoes, in other words, mud volcanoes are specific type of hydrocarbon seepage manifestation indicating oil and gas accumulations. That is why, the mud volcanism has been remained one of the most relevant research issue in terms of application to prospecting and exploration of hydrocarbon resources for a long time.

The most previous researches did not apply the seismic data to describe the elements of the petroleum systems and mud volcanoes of the SCB. The present research represents a comprehensive analysis of the South Caspian basin based primarily on the seismic data. The aim of the study is to investigate relationship between hydrocarbon systems and mud volcanism. For this purpose, the origin and formation of mud volcanoes have been investigated in the context of the evolution of the South Caspian Basin. The results of study might significantly contribute to the better understanding of petroleum systems and mud volcanism within the South Caspian basin and prove genetic link between mud volcanoes and hydrocarbon accumulations.

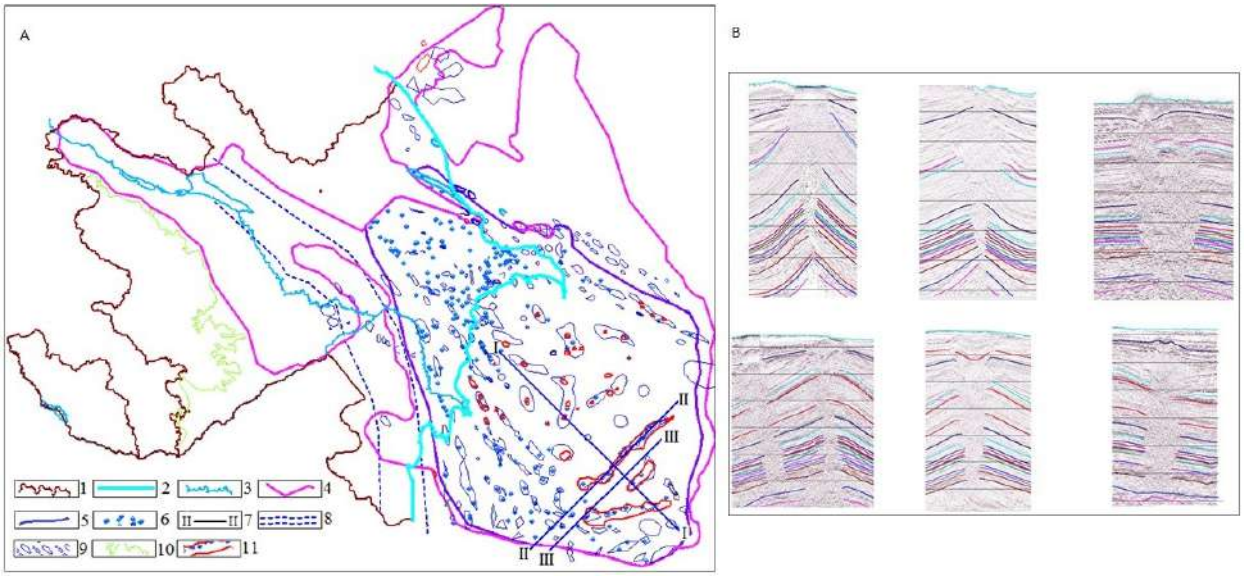


**Fig. 1.** The area of accumulation of Maikop deposits and development of mud volcanism (A): 1 – state borders, 2 – Caspian coastline, 3 – Kura and Araz Rivers, 4 – boundary of the Maikop deposits, defined by seismic survey, 5 – area of mud volcano distribution, 6 – mud volcanoes, 7 – seismic lines, 8 –boundaries of the Talysh-Vandam gravity maximum, 9 – structures discovered according to geological and seismic surveys, 10 – outcrops of Mesozoic deposits, 11 – mud volcanoes revealed according to seismic data (along the top of Surakhany Suite of PS). Cross-sections through the oil and gas fields associated with mud volcanoes (B)

**Method and database**

The study involves analysis of the hydrocarbon systems and mud volcanoes of the South Caspian basin integrating a huge amount of geological, geophysical, geochemical and other relevant data. The geophysical database includes well logging data and seismic survey by the common depth point method (CDP), performed within on- and offshore of the Azerbaijani sector of the South Caspian basin.

**Results and discussion**

The SCB is characterized by high subsidence and sedimentation rates, especially in Pliocene-Quaternary period, resulted in the thick sedimentary filling of about 20.5 km according to the recent results of seismic data interpretation (Yusubov et al., 2018, 2019, 2020). The results of study show that the Low Pliocene Productive Series represented by alternation of the sandy and shaly layers (the main reservoirs and seal rocks) were formed due to activity of several paleo-river systems. (Yusubov et.al., 2020) These rivers provided clastic material from provenances of three different orientations: the northwest (Paleokura), the north (Paleopirsagat, Paleovelvelechai, Paleosamur, Paleovolga) and northeast (Paleoamudarya) (Javanshir et al, 2015; Alizade et al., 2018; Alizade et al., 2018; Abreu and Nummedal, 2007; Hinds et al, 2007; Abdullaev et al., 2010; Abdullaev et al., 2011). As the basin filled, depending on the tectonic processes that cause the transgression and regression of the sea coastline, the river channels periodically changed their flow directions, occupying the same areas. The process was of an inherited character and branching river systems functioned within a certain space. Thus, a multistorey complex of deposits of the Low Pliocene Productive Series represented by isolated geological bodies of various shapes, sizes, and lithologies were formed above the organic rich shale of Oligocene – Lower Miocene Maikop Group (the main source rocks). Due to rapid burial Maikop deposits have not been compacted, keeping water and being very plastic and uncompact.

The structure and formation mechanism of the mud volcanoes have been studied based on interpretation of the significant 2D/3D seismic and well logging data from the Azerbaijani sector of the South Caspian Basin. A “giant” mud volcano system has been recognized in the area with multiple groups of channels rooting from common feeder source. Locations of the mud volcanoes were specified and a series of new mud volcanoes have been recorded. Stratigraphically, the mud volcanoes root from the base of Oligocene – Miocene Maikop Group and eruptive channels appear to branch out at the level of the top of PS.

The results of seismo-geological modeling show that the mud volcanism initiated in Early Miocene and continues at present and the eruptive channels of mud volcanoes do not extend below Maikop deposits.

The boundaries of paleobasins of Maikop and Productive Series have been specified and mapped. both approximately coincide. The area of mud volcano distribution occupying 57000 km$^2$ does not extend outside the boundaries of Maikop and PS evidencing their relationship. The thickness map of Maikop Group was constructed. According to the map the thickness of Maikop deposits does not exceed 2600 m.

In previous research (Guliyev et al., 2020) the authors suggested the mechanism of mud volcano formation based on the Rayleigh – Taylor phenomenon. According to the mechanism the clayey Maikopian sediments are considered as a liquid with the non-Newtonian properties. The overlying sediment loading forces plastic Maikopian sediments to extrude into the upper denser space initiating mud volcano development. With further increase in overburden thickness and consequently in lithostatic pressure the mud mass continues intruding in the upper medium forming the mud volcano channels. Simultaneously the mud intruding into the upper medium causes a system of extensional fractures providing additional pathways for liquefied mud squeezed up towards the earth's surface.

Paleoreconstructions of seismic cross-sections demonstrate that the formation of mud volcanoes initiated in Miocene and continues simultaneously with sedimentation until present. According to the paleoreconstruction results mud volcanism appears to be synchronized in time and space with the growth of folds (Fig. 2).

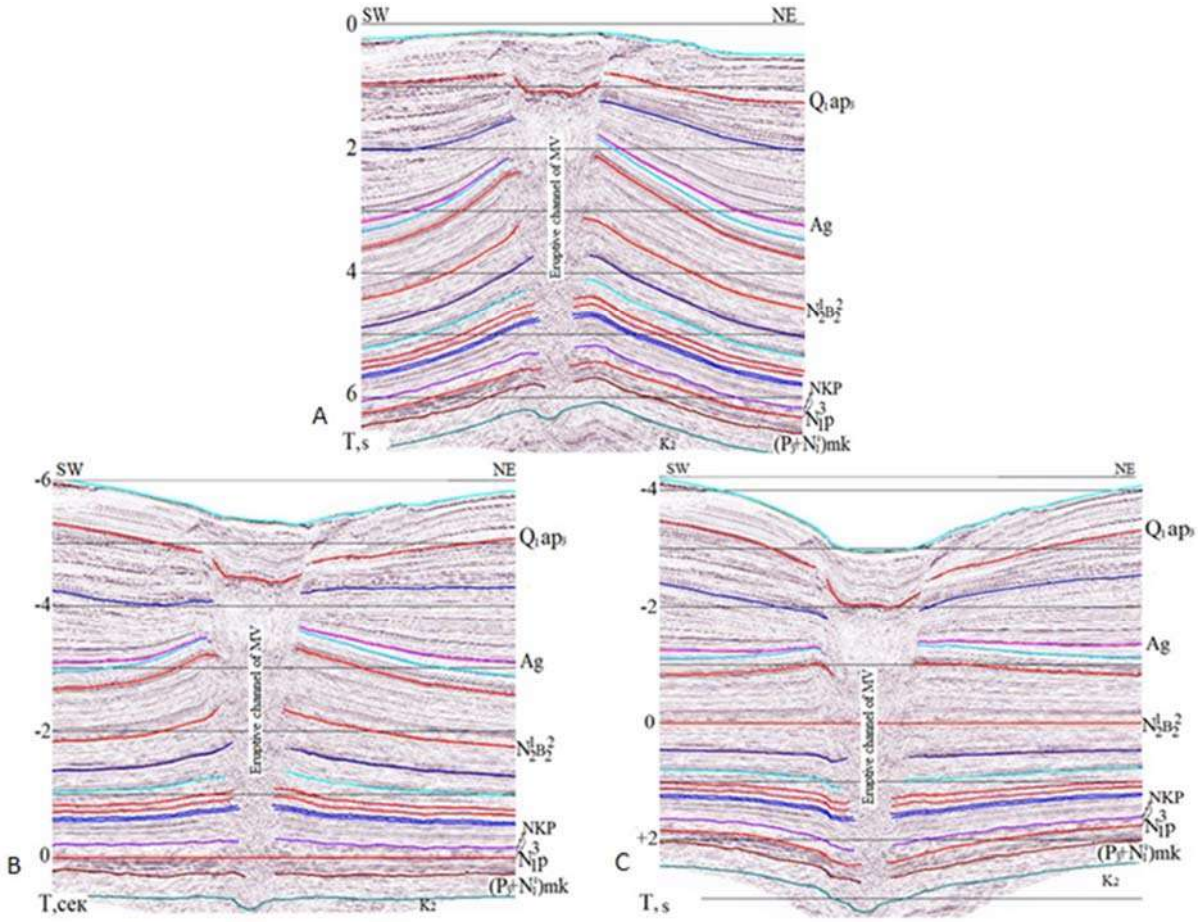


**Fig. 2.** Vertical slice of 3D seismic cube (A). Reconstructions of seismic cross-sections on the surface of Pontian (B) and Surakhany (C) deposits

The sedimentary filling of the SCB composed of complex interrelations of geological bodies represented by lithological varieties formed in marine, continental and transitional sedimentation conditions. One of the main properties of a geological section formed in such hydrodynamic conditions is their hydraulic isolation, in other words, the absence of the lateral and vertical permeable channels between the reservoir as was confirmed by the results of the authors' previous studies (Yusubov and Yusubov, 2010; Yusubov and Guliyev, 2015; Yusubov et al., 2020).

According to the previous researchers the deep faults are considered to be the main migration pathways within SCB. However, the results of the seismic data interpretation by common depth point method obtained over the past 10 years do not reveal the deep faults connecting source rocks to reservoirs. Faults recorded in the upper part of the section are supposed to be formed as a result of mud volcanism activity.

The results of our study allow to suppose that Maikopian mud mass, containing the generated hydrocarbons, on its way upward initially fills the reservoirs with gas, oil and water. The process continues until, the pressure that injects the fluid into the reservoirs, higher than geostatic pressure. Thus, the eruptive channels of

the mud volcanoes and accumulations of oil and gas are created (Fig. 3). The results of the study suggest that formation of oil and gas accumulations in the South Caspian basin is associated to mud volcanism and the eruptive channels of the mud volcanoes serve as the main pathways for hydrocarbon migration (Fig. 4).

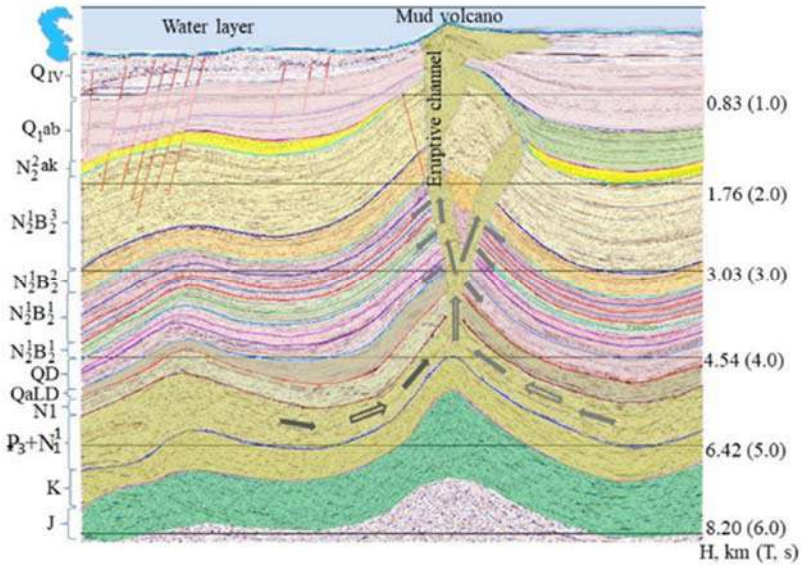


**Fig. 3.** Scheme of hydrocarbon migration through the eruptive channel of mud volcano by example of the seismic cross-section through Azeri – Chirag – Guneshli oil field

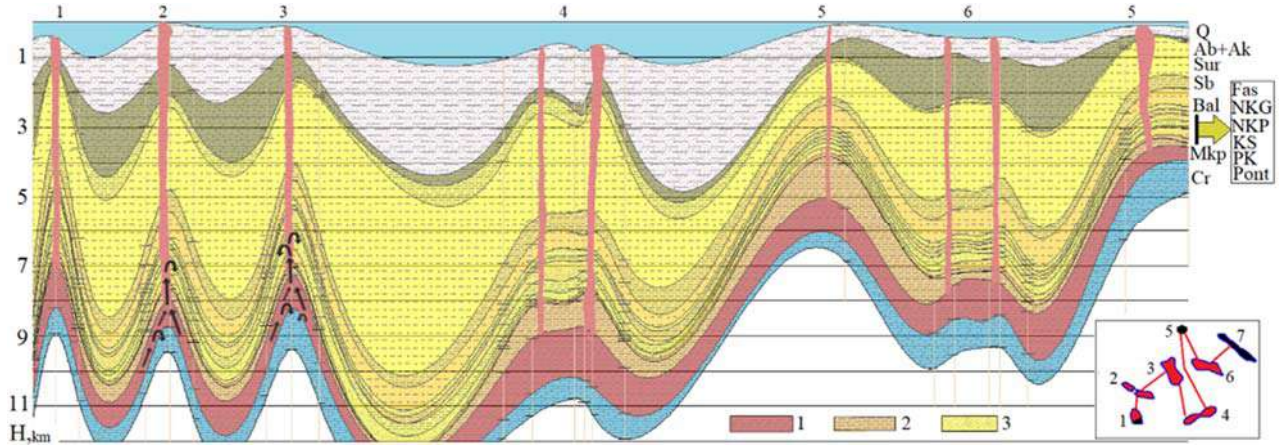


**Fig. 4.** The model of the hydrocarbon system according to seismic and deep drilling data: 1 and 2 – source rocks (Maikop and Miocene); 3 - reservoirs of Productive Series. Black arrows show directions of hydrocarbons migration

## Conclusion

The results of the study suggest that in the South Caspian basin mud volcanism appears to be synchronized in time and space with the growth of anticlinal folds. Formation of oil and gas accumulations is associated with mud volcanism. The channels of mud volcanoes are supposed to be the main pathways for hydrocarbon migration and the key element of petroleum system.

## REFERENCES

Абдуллаев, Н.Р., Райли, Г., Грин, Т., Бауман, Э. (2010). История осадконакопления продуктивной толщи в Южном Каспии с учетом погружения бассейна (часть I). Азербайджанское нефтяное хозяйство, №9, 8-17.

Абдуллаев, Н., Райли, Г., Бауман, Э. (2011). История осадконакопления продуктивной толщи в Южном Каспии с учетом погружения бассейна (часть II). Азербайджанское нефтяное хозяйство, №5, 8-14.

Abreu, V., Nummedal, D. (2007). Miocene to Quaternary Sequence Stratigraphy of the South and Central Caspian Basins in P.O. Oil and Gas of the Greater Caspian Area, edited by Yilmaz and G.H. Isaksen. AAPG Studies in Geology, 55, 65-86.

Ализаде, А.А., Гулиев, И.С., Мамедов, П.З., Алиева, Э.Г., Фейзуллаев, А.А., Гусейнов, Д.А. (2018). Продуктивная толща Азербайджана. В 2-х т., М.: ООО «Издательский дом Недра», Т. I.

Ализаде, А.А., Гулиев, И.С., Мамедов, П.З., Алиева, Э.Г., Фейзуллаев, А.А., Гусейнов, Д.А. (2018). Продуктивная толща Азербайджана. В 2-х т., М.: ООО «Издательский дом Недра», Т. II.

Guliyev, I.S., Yusubov, N.P. and Guseynova, SH.M. (2020). On the formation mechanism of mud volcanoes in the South Caspian Basin according to 2D and 3D seismic data. Izvestıya, Physıcs of the Solıd Earth, 56, 5, 131–138

Hinds, D.J., Simmons, M.D., Allen, M.B., Aliyeva, E. (2007). Architecture Variability in the Pereriva and Balakhany Suites of the Neogene productive series, Azerbaijan: Implications for reservoir quality in P.O. Oil and Gas of the Greater Caspian Area, edited by Yilmaz and G.H. Isaksen. AAPG Studies in Geology, 55, 87-107.

Huseynov D.A., Huseynova S. ( 2014) HC Generation and Migration at the Western Flank of South Caspian Basin - Results of Basin Modeling. 76th EAGE Conference & Exhibition 2014. Amsterdam RAI, The Netherlands, 16-19 June 2014.

Huseynova Shalala. (2019) Hydrocarbon source rocks within the western flank of the South Caspian basin (Azerbaijan): geochemical study and petroleum system modelling. In book: Advances in Petroleum Engineering and Petroleum Geochemistry (Proceedings of the 1st Springer Conference of the Arabian Journal of Geosciences, Tunisia 2018). Editors: Banerjee, Santanu, Barati, Reza, Patil, Shirish (Eds.). Springer, 2019, P. 157-160

Huseynova S., Afandiyeva M. (2019) Geochemical study and modeling of petroleum systems within the western flank of the South Caspian basin. 81st EAGE Conference & Exhibition 2019, London, UK, 3-6 June 2019

Javanshir, R.J., Riley, G.W., Duppenbecker, S.J., Abdullayev, N.R. (2015). Validation of lateral fluid flow in an overpressured sand-shale sequence during development of Azeri-Chirag-Gunashli oil field and Shah-Deniz gas field: South Caspian Basin, Azerbaijan. Marine and Petroleum Geology, 59, 593-610.

Yusubov, N.P., Yusubov, X.N. (2010). About prediction of petrophysical and hydrodynamic models of Galmaz gas storage based on well logging data. Geophysical News in Azerbaijan, № 3, 28-32 (In Azerbaijani)

Юсубов, Н.П. Гулиев, И.С. (2015). Литолого-фациальные модели месторождений Гарадаг, 8-Марта, Сангачалы-дениз, Дуванный-дениз, Булла-адасы и Булла-дениз, приуроченные к "свите перерыва" по данным ГИС. Азербайджанское нефтяное хозяйство, №5, 3-8.

И.С.Гулиев, Н.П.Юсубов, Ш.М.Гусейнова. (2020) Палеообстановки осадконакопления, грязевой вулканизм и миграция углеводородов в Южно-Каспийском бассейне. Геофизический журнал, № 3, Т. 42, 2020, с. 195-205.

Yusubov, N.P., Quliyev, I.S., Köçərli, Ş.S. (2023) Cənubi Xəzər çökəkliyindəki nəhəng palçıq vulkanları sahələrinin neftqazlılığı haqqında. Azərbaycan neft təsərrüfatı, 1, 4-9.

## KARBOHİDROGEN SİSTEMLƏRİ VƏ PALÇIQ VULKANLARI: PARAGENEZ VƏ YA ƏLAQƏLİ İNKİŞAF

**Quliyev İ.S.[1], Yusubov N.P.[2], Hüseynova Ş.M.[2]**
*[1]Azərbaycan Milli Elmlər Akademiyasının Rəyasət Heyəti*
*[2]Azərbaycan Respublikası Elm və Təhsil Nazirliyinin Neft və Qaz İnstitutu*

**Xülasə.** Dünyanın karbohidrogen ehtiyatlarının əhəmiyyətli hissəsini özündə saxlayan Cənubi Xəzər hövzəsi palçıq vulkanizminin geniş inkişaf etdiyi ərazidir. Hövzədəki bütün neft və qaz yataqları palçıq vulkanları ilə əlaqələdir bu da aktiv neft sistemlərinin mövcudluğunu təsdiq edir. Karbohidrogen yığımlarının palçıq vulkanları ilə əlaqəsi, uzun müddət öyrənilməsinə baxmayaraq, ən aktual tədqiqat məsələsi olaraq qalır. Bu işdə Cənubi Xəzər hövzəsinin Azərbaycan sektorunda palçıq vulkanlarını yaradan geodinamik proseslərin və karbohidrogen sistemlərinin hərtərəfli təhlilinin nəticələri, xüsusi ilə də seysmik məlumatlar əsasında, təqdim olunur. Tədqiqatın nəticələri göstərir ki, palçıq vulkanları hövzənin karbohidrogen sistemlərinin əsas elementidir. Palçıq vulkanlarının və neft və qaz yataqlarının əlaqəli inkişafını təmin edən proseslərin və qırışıqların inkişafı zaman və məkanda sinxron baş verməsi görünür. Palçıq vulkanlarının mənşəyi və formalaşması Cənubi Xəzər hövzəsinin təkamülü kontekstində tədqiq edilmişdir. Tədqiqatın nəticələri Cənubi Xəzər hövzəsində palçıq vulkanları ilə karbohidrogen yığılmaları arasında genetik əlaqəni sübut edir, həmçinin karbohidrogen sistemlərinin və palçıq vulkanizminin daha yaxşı başa düşülməsinə əhəmiyyətli töhfə verə bilər.

***Açar sözlər:*** *Cənubi Xəzər hövzəsi, karbohidrogen sistemi, palçıq vulkanı, Maykop lay dəstəsi*