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GEOFLUID DYNAMICS OF OIL AND GAS CONTENT OF DEEP STRATA

The studies of the world and domestic experience in geological exploration of deep strata, as well as the analysis of extensive factual material indicate that formation of oil and gas potential at great depths depends on a significantly larger number of factors than at traditional depths. The fundamental research of oil and gas formation and accumulation in deep strata are of current importance. The research makes it possible to develop the theoretical framework for the oil and gas content concept which governs efficiency of oil and gas exploration to a great extent. This paper considers a set of qualitative criteria for predicting oil and gas content at great depths as a case-study of the South Caspian basin. The result of the research is a geofluid-dynamic concept of oil and gas formation in deep strata.

Keywords: *deep strata, geofluid-dynamics, great depths, oil and gas potential, hydrocarbons, South Caspian Basin*
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Volumes of gas released from mud volcanoes of Azerbaijan

Mud volcanoes in Azerbaijan	Years of eruptions	Volume of gas released, m^3
Mud volcanoes in Azerbaijan	Over 1.81 Ma (Quaternary)	$\approx 178 \cdot 10^3$ billion m^3
250 mud volcanoes	Over the period of 1810–1997	≈ 250 mln m^3
Bolshoi Maraza mud volcano	1902	120 mln m^3
Toragai mud volcano	1946	≈ 500 mln m^3
Ostrov Duvanny mud volcano	1961	≈ 65 mln m^3
Dashgil mud volcano	2001	40 thousand m^3/day

Introduction

Geofluid dynamic stress of the subsurface (systems of hydro- and litho-dynamic flows in zones of geodynamic stress release) and, above all, intense upward discharge of various mobile fluids and their components are associated with the geodynamic activity of regions.

The Caspian region studied in this work is characterized by a seismotectonic stress state of the subsurface and by high geodynamic activity. A striking manifestation of geodynamic activity is seismicity, intense disjunctive faulting, mud and explosive, in the recent past, volcanism, as well as abundance of gas-saturated water mineral springs. [1–4]. The convergence of continents lasts at a rate of up to ~20–30 mm/yr [5–7] predominantly along strike–slip faults which are characterized by maximum neotectonic activity. Also significant is the manifestation of thermobaric anomalies studied based on continuous geodynamic observations.

The implemented research shows that local geodynamic deformations induce most earthquakes within the sedimentary cover. It is estimated that more than 55% of earthquakes and manifestations of explosive magmatism within the Caspian Sea–Black Sea region occurred at the Mesozoic–Cenozoic boundary [8–10] and within the Cenozoic interval of geological section.

The main signs confirming our suggestion on possible replenishment of buried hydrocarbon deposits are the following:

Periodic eruptions of mud volcanoes, bringing up tens and hundreds of million cubic meters of gas over the past hundreds of years [10–21]. Based on the volume of mud breccia, it was calculated that there were several thousand eruptions. The data on historical eruptions show that several tens of trillion cubic meters of gas were released into the atmosphere over the recent activity of mud volcanoes (**Table**).

The discovery of a large number of natural long-lived gas emissions in the form of macro- and microseeps, pockmarks, and mud volcanoes on the Caspian Sea floor and adjacent land in the Lower Kura and Gobustan–Apsheron troughs in Azerbaijan and other regions [3, 8, 9, 15, 16, 22–26].

Long-term operation of production wells in mined-out oil-and-gas fields [17, 27, 28]. Such fields are known in many oil-and-gas producing regions: the Grozny Region (Chechen Republic, Russia), Tatarstan (Republic of Tatarstan, Russia), etc. In Azerbaijan, among such fields are the Balakhany–Sabunchi, Ramany, Bibi-Eibat, etc., the estimated reserves of which were developed several decades ago.

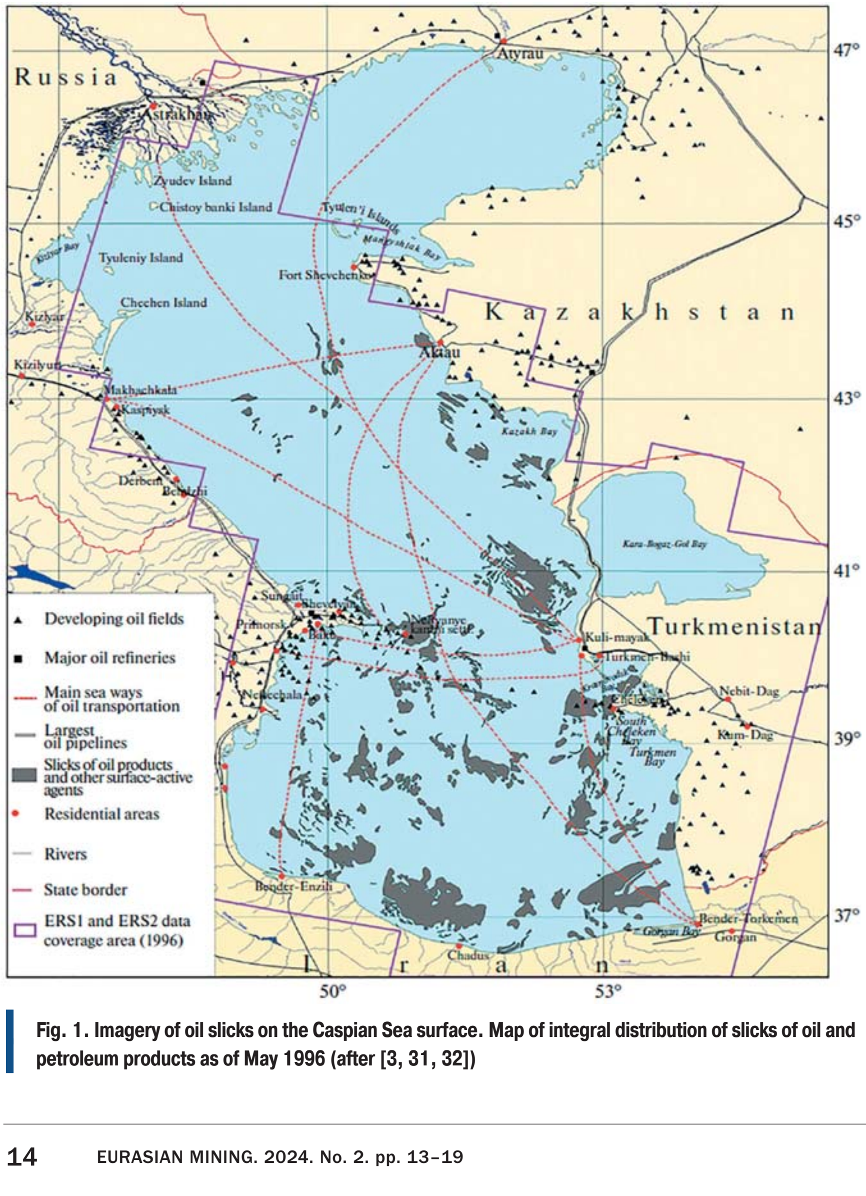

Fig. 1. Imagery of oil slicks on the Caspian Sea surface. Map of integral distribution of slicks of oil and petroleum products as of May 1996 (after [3, 31, 32])

Study methods

Geochemical research

The geochemical studies carried out made it possible to obtain direct evidence about the sources of modern hydrocarbon replenishment in the centers of their generation and the residual generation potential of oil and gas source strata.

To assess the generation potential and capabilities of modern processes for replenishing hydrocarbon reserves, the following geochemical parameters were used: organic carbon content (total organic carbon—TOC), degree of its maturity (T_{max}) and type of organic matter (OM). The use of the Rock-Eval [29, 30] pyrolytic method allowed interpretation of the data from which total organic carbon was estimated, divided into the following elements: organic carbon capable of conversion to hydrocarbons and not generating hydrocarbons; kerogen, generating and not generating hydrocarbons; residual hydrocarbons contained in source rocks (SR) at present.

To quantify the results of the implemented studies, the following calculations were carried out: catagenetic consumption of organic matter for the formation of hydrocarbons (liquid and gaseous) and non-hydrocarbon products (water, carbon dioxide, hydrogen sulfide, nitrogen); reduction in the mass of organic matter at each stage of the transformation process. The resulting assessment of residual concentrations of organic matter in rocks (TOC_{res}) showed the residual generation potential — a source of replenishment of hydrocarbon reserves.

Analysis of space radar data

The clusters of oil slicks recorded by the radars result from the activity of underwater mud volcanoes and seeps (**Fig. 1**), with the releases of small gas, water and oil volumes reflective of active fluid-dynamic periods in hydrocarbon systems.

The results obtained point at the intensive and active modern fluid-dynamic processes occurring in the Caspian Sea, which are initiated by impulses of elastic deformation originated at a depth of the Caspian Sea. The sources, dynamics and behavior of natural oil release in the Apsheron part of the Caspian Sea Basin, including the Bay of Baku, indicate hydrocarbon systems that provide replenishment of hydrocarbon resources and reserves. Gas flares are recorded in CDPM seismic images. Gas seep sites are usually found in the water column at a depth of 50 to 800 m. Often, gas streams mix with bottom sediments and form high-density vertical mudflows upwelling to the sea surface; the gas streams inter-mix and form gas bubble jets.

Modeling hydrocarbon systems

Basin analysis and modeling of HC systems were conducted using Schlumberger's PetroMod software package and modeling technology. Modeling of hydrocarbon systems is an up-to-date modification of basin analysis which uses numerical modeling of geological processes — sediment accumulation, compaction, thermal regime, generation of hydrocarbons, their migration and accumulation. Modeling begins with the formation of a set of initial data. As part of this work, numerical modeling of the evolution of hydrocarbon systems was performed, which made it possible to provide qualitative spatial and quantitative forecasts of oil and gas content.

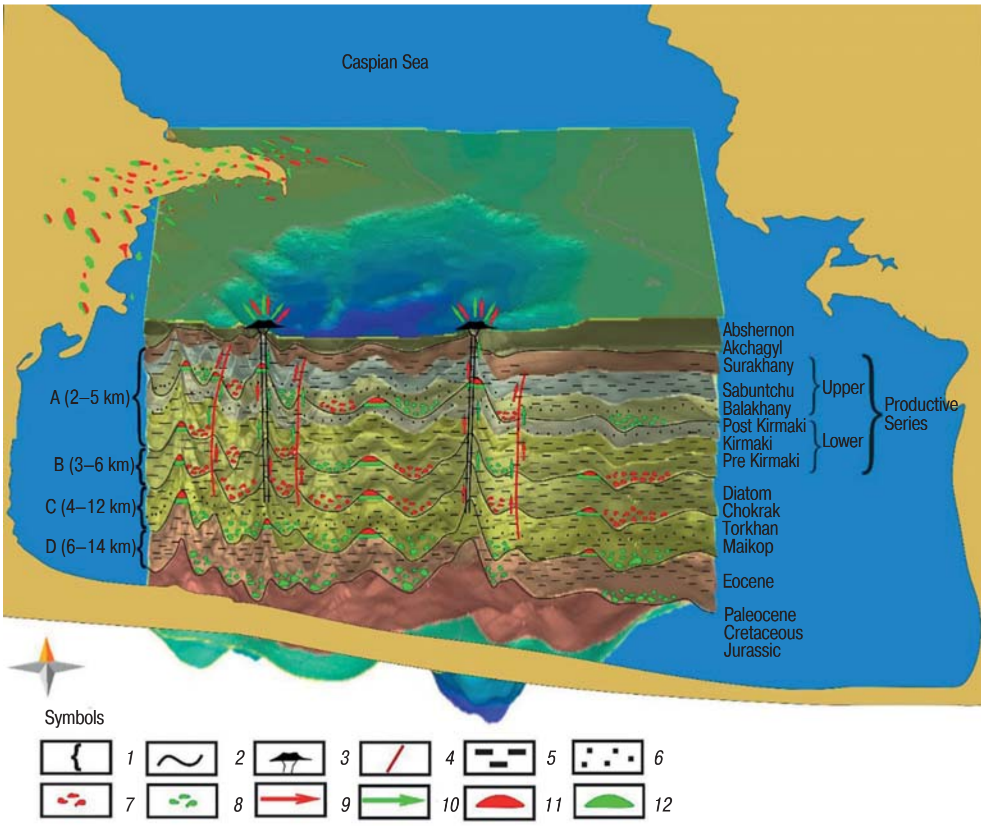

Fig. 2. Structural-spatial model of distribution of hydrocarbon systems in the South Caspian basin:
A – Miocene–Pliocene; B – diatom; C – Oligocene–Miocene; D– Eocene
Legend: *1* – boundary of test formation; *2* – boundary of strata; *3* – mud volcano; *4* – fault; *5* – clayey rocks; *6* – sandy rocks; *7* – gas source; *8* – oil source; *9* – gas migration paths; *10* – oil migration paths; *11* – gas deposit; *12* – oil deposit

Results

The results of the pyrolytic studies were interpreted for five complexes of sediments: productive sequence, diatom suite, Tarkhan–Chokrak sediments, Maykopian series and Paleocene–Eocene complex. The results of the studies made it possible to characterize the Cenozoic-age oil and gas source sedimentary strata located at great depths, and enabled evaluation of their generational features.

According to the results of basin modeling, four hydrocarbon systems are distinguished in the Cenozoic unit of the South Caspian Basin (SCb): Miocene–Pliocene, diatomaceous, Oligocene–Miocene and Eocene, which are polyfocal hydrocarbon systems (**Fig. 2**). In different sources, hydrocarbon generation occurs at different rates, which leads to differences in the residual generation potential of oil source rock in different parts of the basin. To identify and assess the residual generation potential of modern sources of replenishment, it is necessary to study the catagenetic transformation of organic matter and determine the degree of its depletion. As a result of the influence of geodynamic processes, destabilization occurs with subsequent activation of the geofluid dynamic system and the excitation of hydrocarbon generation centers [33–36].

According to the results of modeling hydrocarbon systems in source rock of the diatom hydrocarbon system, the process of hydrocarbon generation continues at the present time (**Fig. 3**). However, in the centers of oil and gas formation, the degree of generation can reach a critical point, which is also evidenced by increased S1 contents in a certain part of the samples. In this regard, the diatomaceous formation can be considered as one of the main oil and gas generating units in the South Caspian basin. Maykopian source rock are located in depth intervals in the main oil formation zone (oil window), where generation of hydrocarbons occurs at the maximum activity, including light hydrocarbons (up to 4%). With the transition to the MC4 zone, Maykopian sediments begin to generate gaseous hydrocarbons. The results of modeling hydrocarbon generation in sediments of the Maykopian series show that in most of the basin the degree of generation can reach a peak and arrive at the stage of completion of hydrocarbon formation.

It should be noted that during the formation of oil and gas potential in the South Caspian basin, a situation was observed when source rocks from deep-seated hydrocarbon systems fed hydrocarbon reservoirs of overlying (younger) hydrocarbon systems.

The unique reservoir of the productive stratum is saturated due to migration of hydrocarbons from several source rocks, mainly of the Miocene and Maykop age. This is confirmed by the studies of bitumen extracts from the Cenozoic sediments, which reveal differences in individual stratigraphic complexes in the carbon isotope composition [1, 37, 38].

According to the values of isotope ratios, oils of the SCb are grouped into two classes:

isotope-light with $\delta^{13}C$ values from –28.0 to –27.0 ‰ for total carbon and from –29.1 to –27.0 ‰ for carbon in the alkane fraction. The most isotopically light oils in the Cenozoic unit are characteristic of the Eocene deposits (–28.32‰; –27.86‰), then for the Maykop (–28.05‰; –27.64‰) and Chokrak units (–27.95 ‰; –27.5‰).

isotope-weighted with $\delta^{13}C$ values from –26.5 to –24.0 ‰ and from –26.5 to –24.5 ‰, respectively. A sharp isotopic weighting of oil occurs during the transition to oil from the diatom suite (–26.45‰; –26.13‰).

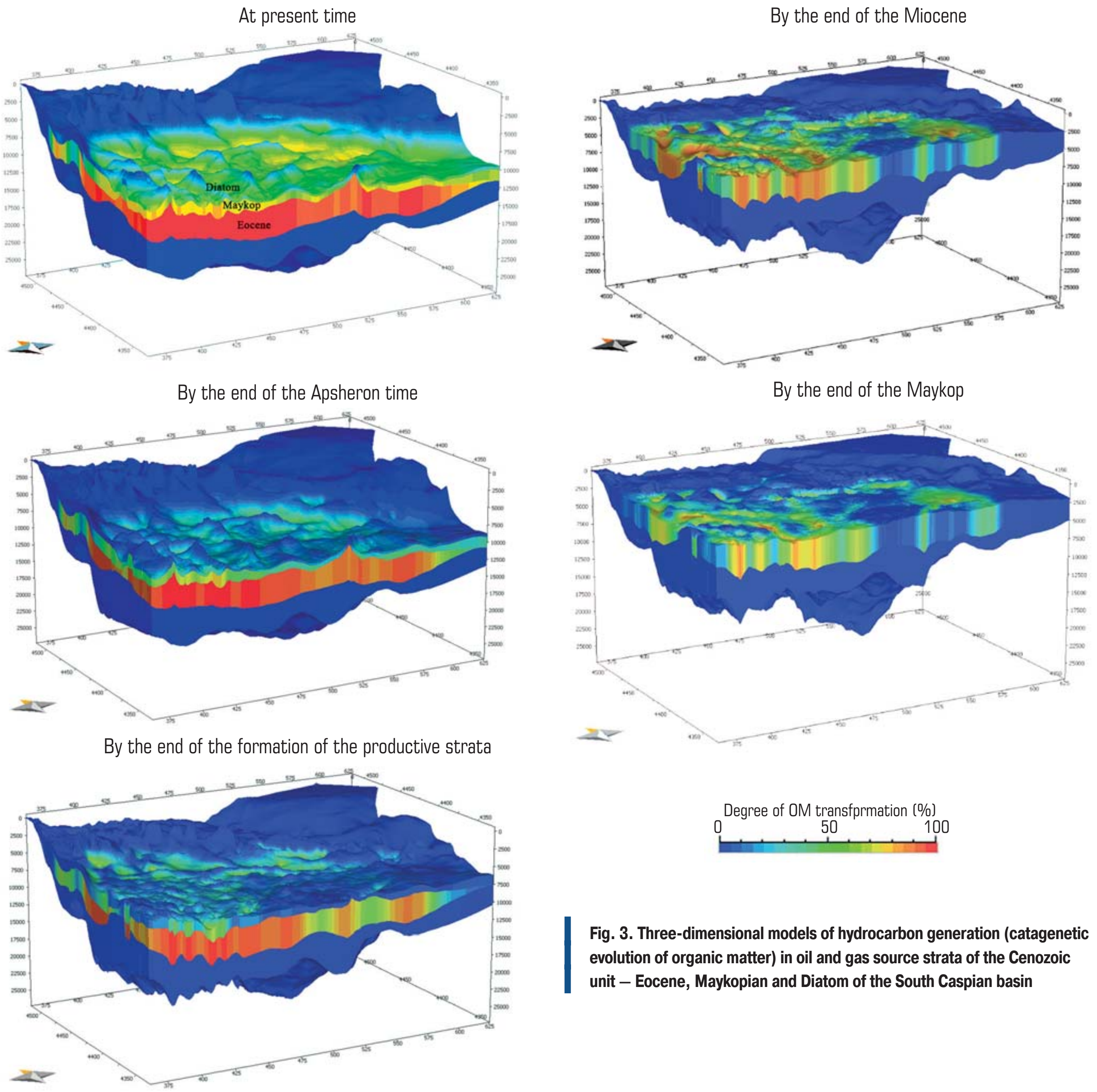

Fig. 3. Three-dimensional models of hydrocarbon generation (catagenetic evolution of organic matter) in oil and gas source strata of the Cenozoic unit — Eocene, Maykopian and Diatom of the South Caspian basin

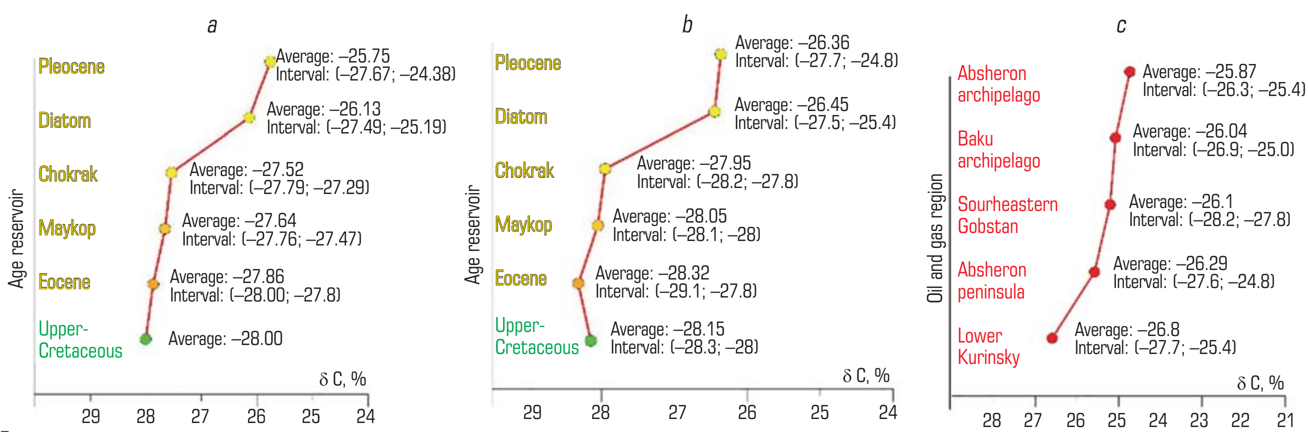

Fig. 4. Diagrams of variations in isotope ratios of total carbon (*a*), carbon in alkane fraction (*b*) of oils from reservoirs of different ages and in different oil- and gas-bearing regions (*c*) of SCb [1, 11, 39]

The heaviest oils are confined to the reservoirs of the lower and upper Pliocene age (–26.35‰; –25.75‰) (**Fig. 4**).

The oil of the Pliocene reservoir is a mixture of oil from various deep-seated oil source rocks of the Eocene, Oligocene–Miocene (Maykop), Miocene (Tarkhan–Chokrak and Diatom) ages, the role of which in each specific geological situation (as on the scale of the region as a whole, and within individual oil and gas bearing areas) is different.

Discussion

At the moment, none of the existing classical hypotheses and models of hydrocarbon generation and migration are able to fully cover and explain the entire range of issues related to them at great depths. We can only talk about the degree of approximation of existing theoretical and model concepts. When studying geofluid dynamic factors for predicting oil and gas content of the subsoil at great depths, as a general principle, it is necessary to take into account that the migration–accumulation process is one of the partial derivatives of more general hydrogeological processes controlled by the mechanisms and laws of regional and local geofluid dynamics.

Other serious factors that impede the lateral movement of fluids are: the obligatory refraction of stream lines with a large loss of pressure in areas of sharp facial heterogeneity; their non-Newtonian behavior in fine, low-permeability sections of sections, characterized by very insignificant regional hydraulic slopes [4, 7, 19]; a sharp increase in horizontal hydraulic resistance along the path of the proposed elision watercourse; a significant deficit of pore fluid released from consolidated clays below depths of 2000 m, which together is not able to provide a continuous hydrodynamic flow.

When assessing the areal scales of lateral migration processes, the relative spatial arrangement of large shielding discontinuous dislocations and their position relative to the areas of feeding and unloading of the elision system are important. The analysis shows that none of the deep basins fits with the geological conditions that can ensure wide areal hydraulic connectivity of all adjacent geological basins. In all regions, areas of fluid discharge — zones of side frames that fill the main belts of oil and gas accumulation — are cut off by large disjuncts from the central parts of the basins, hypothetically considered areas of their elision supply. It is obvious that such migration in a specific geological setting in basins can be carried out over relatively short distances within individual steps and until it intersects with disturbances that refract the direction of filtration.

Against the background of the practical absence of infiltration water exchange and significantly limited elision water exchange in all basins, the following phenomena are identified: vertical hydrochemical zoning, mosaic in area and strictly subject to the laws of mixing of waters in the lower and overlying intervals; wide distribution of local hydrogeochemical, piezometric, geotemperature, isotopic, palynological and other disturbances of the corresponding regional fields; mud volcanism; effusion of high-pressure hydrotherms onto the surface.

These phenomena indicate the large-scale implementation of powerful vertical interformation fluid flows through a system of high-amplitude rock discontinuities. This allows concluding about the functioning of a fundamentally new type of hydrogeodynamic systems — pulsating flow–injection systems. They cover large stratigraphic and hypsometric ranges of sedimentary strata [19].

Oil and gas potential in all geological settings is a complex function of the interaction of factors and multi-scale multi-vector fluid-dynamic mechanisms and processes: generation of hydrocarbons, their primary and secondary migration, formation and spatial distribution of fields and reservoirs, conservation and dissipation of oil and gas accumulations. These factors are an integral effect of the mutual influence of geodynamic and geofluid dynamic processes.

This circumstance determines the possibility of identifying relationships between the oil and gas content and the parameters of the geofluid-dynamic field of the regions — hydrogeochemistry, groundwater dynamics and other parameters. It is proposed to use the parameters as fairly reliable exploratory qualitative criteria and quantitative indicators of hydrocarbon saturation, ensuring minimization of risks and increasing the efficiency of geological exploration.

Thus, a geofluid-dynamic concept [19] of migration processes and the formation of hydrocarbon fields and reservoirs is proposed with regard to both the specific geological conditions of the oil and gas potential of these regions, and the features of migration effects. The main provision of this concept is the recognition of the fact that the dominant form of movement of natural fluids in geological space is their large-scale subvertical interformation pulsation–injection migration. Such migration takes place along the planes of conductive disjuncts, zones of increased fracturing, contacts of diapiric intrusions, eruptions of mud volcanoes, lithofacies unconformities and other rock discontinuities, occurring synchronously with the activation of paleo- and neotectonic processes.

The theoretical framework of the fluid dynamic concept on oil and gas content includes the following fundamental principles:

1) the main condition ensuring formation of oil or gas accumulation in a natural reservoir is the mandatory preliminary liberation of its void space from previously filled syngenetic sedimentogenic waters and thus the creation of free accumulating volumes capable of saturation;

2) in any tectono-structural, stratigraphic, litho-facial setting, geological bodies acquire the capacity of natural hydrocarbon reservoirs only if their hydrodynamic drainage is implemented;

3) the formation of hydrocarbon deposits is carried out only in the zones of a sufficiently active hydrodynamic regime — drainage of natural reservoirs. In a hydraulically closed geological space, accumulation of oil and gas is significantly limited.

The integrated geochemical and hydrochemical studies of bottom sediments, silt solutions and sea water of the Caspian Sea show that in the central part of the South Caspian basin, a stable multicomponent anomaly is clearly traceable based on a set of geochemical, hydrogeochemical and gas indicators [10].

In the central deep-sea part of the South Caspian depression, characterized by the greatest thickness of the sedimentary cover, reaching 22 km, a multicomponent anomalous zone is identified, the presence of which confirms the existence of a powerful source of hydrocarbon generation and fluid flow in this zone.

It should be especially emphasized that the analysis of data on earthquakes and recorded eruptions of mud volcanoes that occurred in the South Caspian region over the past two centuries revealed a connection between the intensification of mud volcanic activity and seismicity. It is proved that earthquakes play the role of a "trigger mechanism" in the mud volcanic process [11].

The studies carried out show how large the scale of fluid activity is in the Southern Caspian Sea. The constant leakage of huge volumes of hydrocarbon fluids in the southwestern part of the South Caspian Sea is the result of high permeability of fracture structures, especially in places where channels of mud volcanoes are localized. The data obtained indicate that the Apsheron water area of the Caspian Sea is an arena of active modern fluid-dynamic processes driven by elastic deformation processes. The sources, dynamics and behavior of natural oil discharge in the Apsheron waters of the Caspian Sea indicate a high probability of hydrocarbon accumulations being found in its depths.

The study of abnormally high pressures in hydrodynamic units in the South Caspian basin provides the basis for the following fundamentally important conclusion — the presence of significant pressure gradients between adjacent layers of clays and reservoirs indicates not the presence of a hydrodynamic connection between them, but, on the contrary, their mutual hydraulic isolation. This conclusion brings new understanding to the problems of primary and secondary migration of hydrocarbons and the formation of oil and gas deposits.

The clear general trend of a consistent decrease in the average values of the anomaly coefficients of reservoir pressures upward the section gives grounds to consider subvertical interformational fluid and mass transfer as the main mechanism for the formation of the geofluid-dynamic regime in such regions as the South Caspian basin.

The determining condition for the generation of hydrocarbons and the most important factor characterizing the conditions of migration and accumulation of oil and gas in deep-lying strata of sediments is the geotemperature regime. The significant role of the Earth's deep heat shows up not only in its regulating influence on the course of transformations of the original organic matter, but also on all subsequent physicochemical changes in the composition of natural fluids, controlling their mobility in migration processes and phase state. Deep heat also has an applied aspect, which is very significant for forecasting oil and gas content and choosing the optimal directions for geological exploration.

Conclusion

Thus, the results of the study allowed the authors to formulate the following geofluid dynamic concept of the oil and gas potential of deep-lying strata.

Generation, migration and accumulation of hydrocarbons are an integral part of the processes of transformation and redistribution of matter at great depths, which occur as a result of geodynamic and geofluid-dynamic processes. Within the limits of changes in the redistribution of volumes, centers of phase transitions arise — the centers of excitation, where some sedimentary material transits from a structured layered state to an amorphous brecciated mass. It is these centers of excitation that are the place of generation and migration of hydrocarbons at great depths and at later stages of the basin's evolution. Generation in the centers of excitation is accompanied by spontaneous decompression of sedimentary strata and are distributed discretely, not throughout the entire volume; they are characterized by significant spatiotemporal variability. Migration of fluids initiates subvertical channels of bizarre shape in the sedimentary cover, and these channels are filled with decompressed sedimentary material.

The generation and migration of hydrocarbons occurs periodically and at high speeds during excitation phases correlated in time and scale with periods of activation of modern geodynamic processes — seismicity, earthquakes and mud volcanism, which are also interrelated with solar activity, lunar-solar tides, sea level fluctuations and changes in electromagnetic fields. These geological events determine the intensity of geofluid dynamic processes and activate processes in the centers of excitation. The comparative intensity of fluid dynamic processes can be assessed on the basis of the intensity of manifestations of fluid seeps, geochemical and temperature anomalies on the land surface and on the seabed.

Geodynamic processes control the spatial development of geofluid-dynamic systems for the transformation of matter of the sedimentary cover into energy and chemical raw materials. The unstable, time-varying tectono-stressed state of the earth's crust is an active force for the activation of migration processes.

Zones and areas of oil and gas accumulation in deep-seated strata are obligatory associated in space with sources and areas of discharge of geofluid-dynamic systems. Such unloading occurs during interformational and interstratal vertical–horizontal fluid flows through disjunctive systems, zones of increased fracturing, contacts of diapiric intrusions, eruptions of mud volcanoes, etc. The presence in the sections of tectonic, lithological-reservoir and other conductive unconformities that provide drainage is a necessary condition for the formation of oil and gas potential.

The determining condition for the generation of hydrocarbons and the most important factor characterizing the conditions of migration and accumulation of oil and gas in deep-lying strata is the geotemperature regime. The significant role of the Earth's deep heat shows up not only in its regulating influence on the course of transformations of the original organic matter, but also on all subsequent physicochemical changes in the composition of natural fluids.

In deeply buried strata of fold belts, abnormally high pore pressures in clayey strata are mainly of syngenetic origin. When they play the role of seals over hydrocarbon deposits characterized by high altitude, an epigenetic component is superimposed on the syngenetic pore pressures, governed by the halo penetration of high-pressure fluids from underlying accumulations into the pore space of clays.

The main mechanism for the formation of the geofluid-dynamic regime of the sedimentary fill of the Alpine geosynclinal regions is the vertical fluid mass transfer from the lower to the upper intervals of the section, regulated by the porosity of the conductive paths, the possibility and extent of unloading of the water pressure system.

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GEOLOGICAL ASPECTS OF URANIUM DEPOSITS FOR IN-SITU LEACHING APPLICATION TO DEVELOP ENERGY POTENTIAL OF KAZAKHSTAN

Kazakhstan is among the top ten countries – holders of the largest uranium resources in the world. The main uranium deposits were discovered in the late 1970s and, then, in the mid-1990s. This article describes the geological aspects of the uranium deposits in Kazakhstan with a view to using the in-situ leaching method toward development of the energy potential of the country. In total burning out of 1 kg of uranium enriched to 4%, the energy release is equivalent to combustion of 100 t of high-grade coal (1.5 carload) or 60 t of oil (1 fuel truck). Uranium fission liberates neutrons which collide with the other uranium nuclei and split them. Uranium decay products and neutrons possess high kinetic energy and, when they collide with other atoms, this energy is converted into heat.

Keywords: *geology, structure, power generation, technology, uranium production, in-situ leaching*
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Introduction

The present-day methods of uranium production in the world’s countries, including Kazakhstan, involve the following processes: delivery of chemical solutions via injection well, delivery of pregnant solutions via production wells. Such wells can be laid out in linear or square patterns.

A new formulation of the innovative technology of hydrogen uranium production dictates execution of research activities in two directions — accessing and extraction of the raw material; disclosure of shortages of uranium mining technologies with a view to eliminating them completely. There exists a new innovative technology of uranium mining [1–6]. The authors cultivate efficiency of innovative technologies for hydrogenous-type uranium deposits. A patter of piston wells is