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ARTICLE

Comparative Geodynamics and Oil-Gas Potential of the Mexican-Caribbean and the Caspian-Caucasus Regions

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ABSTRACT

All over the world and in the Russian Federation, the problem of forecasting and exploration of new deposits at great depths is acute. In September 2009, the Tiber oil field was discovered in the Gulf of Mexico at a depth of more than 10 km. In Kazakhstan, within the framework of the Eurasia project, it is planned to drill an ultra-deep well in the Pre-Caspian depression. In this regard, a comparative analysis of the geodynamics and oil and gas potential of the Caspian Basin and the Gulf of Mexico, as well as the Caspian-Caucasian and Caribbean-Mexican regions, is of particular importance. The Pre - Caspian depression and the Gulf of Mexico are the largest oil and gas provinces in the world. In the structure and geodynamics of structures, certain features of similarity are observed. The rise of hot asthenospheric diapirs determines the oil and gas content of sedimentary basins and the formation of large oil and gas fields. The solution of the problem of mechanical and mathematical modeling makes it possible to estimate the magnitude of the rise of the mantle diapir under the Pre-Caspian depression.

Keywords: Alpine Belt; Caribbean Region; Gulf of Mexico; Pre-Caspian Depression; Mantle Diapir; Plate Tectonics; Oil and Gas Potential; Modeling

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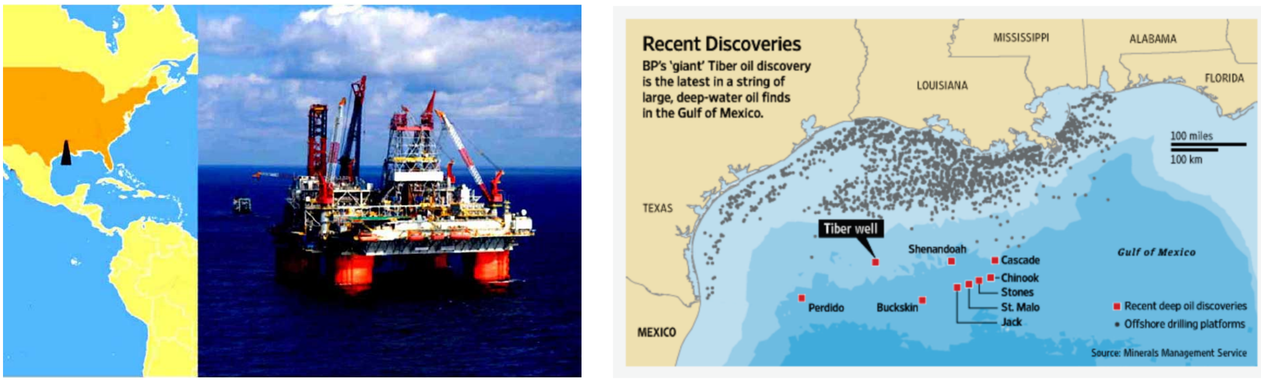
1. Introduction

Due to the high degree of exploration and depletion of hydrocarbon reserves, especially oil, in the main oil and gas provinces of the Russian Federation, the problem of forecasting and exploring new deposits at great depths is becoming more and more acute. In 2009 and 2010 in the Gulf of Mexico and the Brazilian sector of the Atlantic, large oil fields were discovered at depths of 10.5 km, and 5 km respectively (**Figures 1** and **2**).



(**a**) (**b**)

Figure 1. The giant Tiber oil field in the Gulf of Mexico. (**a**) Description of what is contained in the first panel Position of Tiber well and Tiber platform (Available from: https://s0.rbk.ru/v6_top_pics/resized/590xH/media/img/3/77/754793828602773.jpg); (**b**) Description of what is contained in the first panel. Tiber well position.

Figure 2. The Libra field on the Brazilian shelf (Available from: https://s0.rbk.ru/v6_top_pics/resized/590xH/media/img/2/68/754410725692682.jpg).

The Libra field on the Brazilian shelf was discovered in 2010. The reserves are 8–15 billion barrels of oil. Libra is located on the shelf of the Atlantic Ocean, 200 km south of Rio de Janeiro. Oil deposits are located at a depth of 5 km under the seabed, and the water depth is 2 km. Libra is the largest oil field in Brazil. The rights to its development belong to a consortium of companies led by the Brazilian concern Petrobras.

The Tiber field in the Gulf of Mexico was discovered in 2009. The reserves are 4–6 billion barrels of oil. The Tiber field was open and developed by BP. It is located 400 km southeast of Houston. Tiber is considered one of the deepest deposits in the world: oil lies at a depth of 10.6 km, and the depth of the ocean in this place is 1.3 km. In addition to BP, Conoco, Philips and Petrobras are involved in the development. This required drilling a 10,685 m (35,056 ft) deep well under 1,260 m (4,130 ft) of water. This is one of the deepest wells ever drilled.

The Tiber oil field was drilled using the fifth generation Deepwater Horizon semi-submersible oil rig. The rig is owned by Transocean. The operator of the complex is British Petroleum (BP). Exploration drilling began in March 2009. Much of the bay's deepwater reserves are buried under thousands of feet of salt, which presents a challenge to seismic surveys. Previously, BP had developed exploration methods to circumvent this difficulty. Oil has been discovered at several levels.

The discovered deposit was announced on September 2, 2009. British Petroleum shares rose 3.7 percent on that news. As the Tiber field joins near ten other promising Lower Tertiary explorations in this area, analysts took information as a sign of a harbinger of renewed interest in offshore Gulf of Mexico production.

After the Tiber discovery, while drilling the next well in Macondo, the drilling rig was destroyed in an explosion [1]. The accident at the Macondo well of BP in the Gulf of Mexico occurred on April 20, 2010 and is the largest in the history of the world oil- gas industry. 11 drillers were killed. An oil platform in the Gulf of Mexico sank after a fire broke out, and oil began to be released from the Macondo well into the sea. The mixture of oil and gas began to flow into the waters of the bay with a flow rate of about 10,000 tons per day. The event qualifies as the largest environmental and man-made disaster (**Figure 3**).

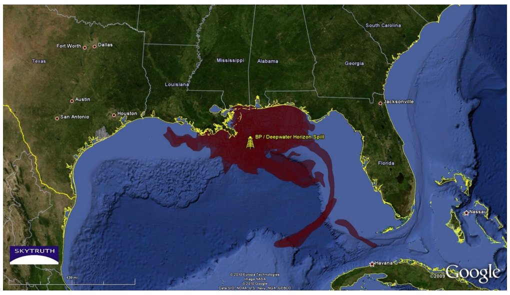


Figure 3. Disaster at the Macondo well. Oil spill (Available from: https://skytruth.org/wp-content/uploads/2010/07/SkyTruth_cumulative_BP_spill_16jul10-1.jpg). Map showing cumulative oil slick footprint from BP/Deepwater Horizon oil spill, based on satellite images taken between April 25 and July 16, 2010.

A 75-ton steel cap began to collect up to 85% of all oil entering the bay. At the same time, its inflow was constantly decreasing as a result of the continued injection of cement into the well. On September 19, 2010, BP management announced that the well was "virtually dead", implying it was completely sealed off.

The accident showed that the modern equipment, materials and technologies used in offshore drilling did not prevent a catastrophe. In this regard, it is very important to learn lessons from the tragedy against the backdrop of intensive development of offshore drilling operations by the Russian oil and gas complex, which means raising the quality and safety requirements for the construction of offshore wells.

1.1. Project "Eurasia"

The implementation of the "Eurasia" project, within which a super-deep 15-kilometer well in the Pre-Caspian depression is planned to be drilled, will not only ensure a consistently high level of oil production in Kazakhstan, but also allow mastering new technologies. The results of work on the study of deep layers in the Pre-Caspian depression will provide materials not only for petroleum geology, but also for the history of the Earth's development.

1.2. Stages of the Eurasia Project and Drilling of an Ultra-Deep Well

The decline in oil production in Kazakhstan may begin in 10–15 years. Today Kazakhstan is one of the world's leading oil-producing countries, with about 80–85% of oil and gas production being carried out in the Caspian basin. Therefore, Russia and Kazakhstan have launched a project to study the deep-lying strata of the Pre-Caspian depression "Eurasia", which is expected to open unique large deposits [2].

The project is being implemented in three phases. The first stage of the project is the collection, analysis and generalization of all geological and geophysical data since the 1970s. When processing data, advanced technologies are used, which allows creating a real geological model of the deep structure of the Pre-Caspian depression.

The second stage is a field study on the site to a depth of about 20–25 km. At this stage, objects of future production at great depths will be identified, which will be distributed depending on the assessment of their resources and prospects. Then, in areas up to 100,000 sq. km, additional work will be carried out, in particular airborne geophysical research, remote sensing of the Earth and others. The second phase will cost about 120–150 million dollars, and at the end of the stage a report will be drawn up, which will be presented at the international level.

In the third phase of the project, the location of the first ultra-deep well with a depth of up to 15 km will be determined. It is also necessary to determine the requirements for equipment and materials, since for work at such depths they must withstand high temperatures and pressures. In addition, for drilling an ultra-deep well, it will be necessary to create an appropriate drilling rig. The cost of the third phase is about 30–50 million dollars. This will be the drilling of one ultra-deep well. It is planned to study the entire sedimentary complex of the Caspian Basin by drilling an ultra-deep well with the

1.3. Prospects for Oil Production in Kazakhstan

Approximately 60–63% of the total oil production in Kazakhstan falls on three main fields - Kashagan, Karachaganak and Tengiz, located in the Caspian basin, while there are 15 sedimentary basins in the republic, in seven of which oil and gas fields have been discovered. Kazakhstan is planning to carry out new regional work in little-studied basins, including the North Torgai basin, the Syrdarya basin in the south of the republic, and the Aral Sea basin. Today, the Aral Sea is practically absent, and Uzbekistan, on the drained land of the Aral Sea, together with the Russian companies Lukoil and Gazprom, is working there.

In the next five to seven years, Kazakhstan will go beyond 100 million tons of oil production; within 15–20 years, Kazakhstan plans to discover giant and large deposits of light oil and gas at great depths of the Caspian basin and other sedimentary basins (**Figures 4** and **5**).

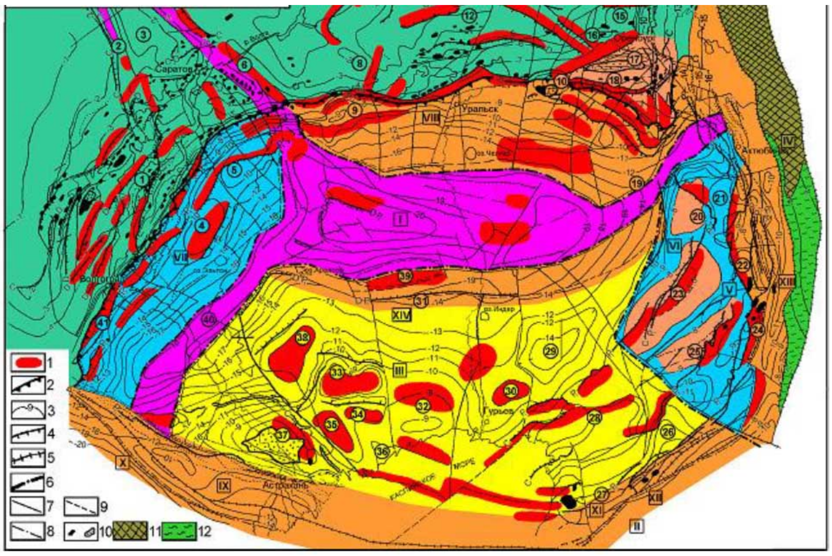


Figure 4. Structural and geodynamic map of the Caspian region with known and predicted zones of oil and gas accumulation, 1997 (Gazprom, Available from: https://www.google.com/url?sa=i&url=https%3A%2F%2Fvniigaz.gazprom.ru%2Fd%2Fjournal%2F22%2F34%2Fvgn-5-%252816%2529-2013.pdf&psig=AOvVaw2zpvJfNbLwfhF49Hih1WPp&ust=1742326002841000&source=images&cd=vfe&opi=89978449&ved=0CBQQjRxqFwoTCJiP0evskYwDFQAAAAAdAAAAABAE).

Symbols: 1 - predicted zones oil and gas accumulation; 2 - Lower Permian side ledge of the Pre-Caspian depression, 3 - isohypses of the surface of the basement (km), 4 - flexures in the Devonian (D), Carboniferous (C), and subsalt Lower Permian (P1) deposits; 5 - lines of divergence of plates; 6 - boundaries of the main plate-tectonic elements; 7 - tectonic disturbances: a - according to seismic horizon "F", b - along the seismic horizon "P2", c - along the seismic horizon "P1"; 8 - oil and gas deposits in Paleozoic deposits; 9 - pre-Upper Paleozoic folded complex of the Urals on the day surfaces; 10 - pre-Upper Paleozoic folded complex of the Urals under the Meso-Cenozoic cover, 11, 12 – surrounding territories.

MAIN STRUCTURAL ELEMENTS OF THE FOUNDATION SURFACE (numbers in circles): 1 - Umetovsko-Linevskiy trough, 2 - Rtishchevskiy rift, 3 - Atkarskiy ledge, 4 - Dzhanybek ledge, 5 - Pallasovsky ledge, 6 - Marksovsky rift, 7 - Zhiguli-Pugachevsky ledge, 8 - Klintsovsky ledge, 9 - Altatinsko-Ozinkovskaya step, 10 - Karachaganak ledge, 11 - Melekes depression, 12 - Buzuluk depression, 13 - Serno-Vodsko-Abdulinsky rift, 14 - East Orenburg ledge, 15 - Olshansky rift, 16 - Syrtovsky ledge, 17 - Ural-Sakmara rift, 18 - Sol-Iletsky ledge, 19 - Novo-Alekseevsky rift, 20 - Ashikolsky ledge, 21 - Yenbek ledge, 22 - Aransaysky (Temirsky) ledge, 23 - Koskulsko-Karaulda (Gzyldzharsky) ledge, 24 - Zharkomyssky ledge, 25 - Akshun-Kola trough, 26 - Sarykum trough, 27 - South Emba trough, 28 - Biikzhal stubble, 29 - Dosor trough, 30 - Karabatan trough, 31 - Bagyrdai step, 32 - Novobogatinsky ledge, 33 - Myntobinsky ledge, 34 - Oktyabrsky ledge, 35 - Kobyakovsky ledge, 36 - Zhambay trough, 37 - Astrakhan ledge, 38 - Azgirsky ledge, 39 - Kushumsky ledge, 40 - Sarpinsky rift, 41 - Karasal step.

MAIN PLITOTECTONIC ELEMENTS according to V.S. Shein (numbers in squares): I - Central Caspian rift, II - Ustyurt microcontinent, III - Guryev microcontinent, IV - Ural fold system topic, V - Kyzyldzhar marginal plateau, VI - Kyzyldzhar transform margin, VII - Aralsor transform margin, VIII - Karachaganak passive margin, IX - Astrakhan passive margin, X - Karakul passive margin, XI - Emba passive margin, XII - Mynsulalmas passive margin, XIII - Aktobe passive margin, XIV - Biikzhal passive margin.

MAIN STRUCTURAL ELEMENTS OF THE FOUNDATION SURFACE (numbers in circles) 1–41.

MAIN PLITOTECTONIC ELEMENTS according to V.S. Shein (numbers in squares) I–XIV.

Figure 5. Russia-Kazakhstan border along the Caspian Sea (Available from: https://www.google.com/imgres?q=Russia-Kazakhstan%20border%20in%20Caspian&imgurl=https%3A%2F%2Fsovereignlimits.com%2Fwp-conent%2Fuploads%2Fsites%2F2%2F2023%2F08%2FKazakhstan_Russia.png&imgrefurl=https%3A%2F%2Fsovereignlimits.com%2Fboundaries%2Fkazakhstan-russia-maritime&docid=jLBsmexq_d_wnM&tbnid=45k0Mkv7xwFaUM&vet=12ahUKEwjDyLL267aMAxVpHRAIHXAAHe8QM3oECBwQAA..i&w=1000&h=730&hcb=2&ved=2ahUKEwjDyLL267aMAxVpHRAIHXAAHe8QM3oECBwQAA).

2. Sedimentary Basins with Deep Oil

The problem of forecasting and exploring new oil and gas deposits at great depths is becoming more and more acute. The search for oil and gas deposits at great depths is one of the main problems of oil and gas geology. The main objectives of research are comparative geological-geophysical investigations of oil and gas bearing sedimentary basins with deep-seated oils. The main methodology and research methods are comparative analysis of geological-geophysical data, comparative geodynamics, basin analysis, mechanical-mathematical modeling for sedimentary basins. **Figure 6** shows a scheme of the location of oil and gas basins, including those with deep oil.

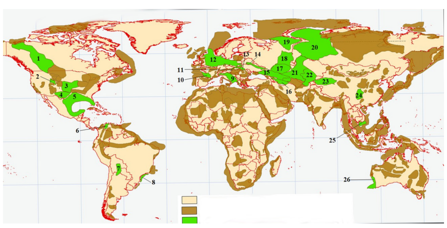


Figure 6. Scheme of distribution of oil and gas bearing basins on different continents. Designations: basins with deep-seated oils: 1 - Western Canadian, 2 - Green River, 3 - Western Internal, 4 - Permian, 5 - Gulf of Mexico, 6 - Maracaiba, 7 - Central Pre-Andean, 8 - Santos; 9 - Adriatic, 10 - Aquitaine, 11 - Vienna, 12 - Central European, 13 - Carpathian, 14 - Dnieper-Pripyat, 15 - North Caucasian, 16 - South Caspian, 17 - Caspian, 18 - Volga-Ural, 19 - Timan-Pechora, 20 - West Siberian, 21 - Turan, 22 - Afghan-Tajik, 23 - Tarim, 24 - Sichuan, 25 - Vung-Tau; 26 - Perth. Beige - territories of continents, brown - oil-gas bearing basins, green - oil-gas bearing basins with deep-seated oil deposits [3].

The Caspian region has significant hydrocarbon resources, which include the Caspian, Pre-Caucasian-Mangyshlak oil and gas provinces (OGP), the South Caspian oil and gas basin (OGB), the exploration of which has reached 40–50%. In the Caspian oil and gas province, resources are estimated at 40 billion tons of fuel equivalent (including in the Russian Federation more than 7 billion tons). In the Ciscaucasian-Mangyshlak region, resources are estimated at about 7 billion tons (including in the Russian Federation 4.6 billion tons), and in the South Caspian OGB at least 8 billion tons [4]. Due to the high exploration of the main horizons to depths of 5 km in these oil-producing regions, most of the resources are predicted at greater depths (5–8 km). The high potential of the Caspian province allows the possibility of discovering within its limits about two dozen large (more than 300 million tons) and several unique deposits [4]. One of the most important factors for preserving the properties of reservoirs and hydrocarbon deposits is the presence of a powerful evaporite screen and associated abnormally high formation pressures (AHFP) (**Figure 7**). In this regard, it is of great interest to compare the geodynamic history of the formation and evolution of geological and oil and gas bearing structures of the Alpine-Himalayan belt and the Caribbean-Mexican region, in particular, the Pre-Caspian depression and the Gulf of Mexico (**Figures 8** and **9**) [5–12].

Figure 7. Distribution of sedimentary strata containing evaporites in coastal zones of the Atlantic Ocean (USGS). Gulf of Mexico is in the center between Americas and Africa.

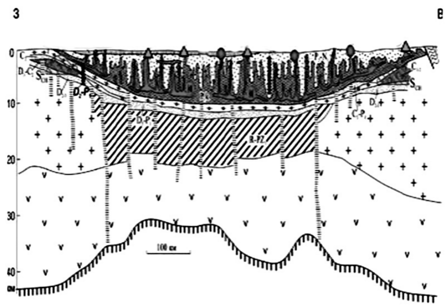


Figure 8. Geological profile through Pre-Caspian Depression, from West to East [4].

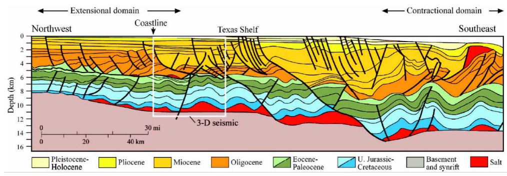


Figure 9. Cross section of the Texas coastal zone with tectonic setting and stratigraphy (USGS).

3. Comparative Geodynamics of the Mexican-Caribbean and the Caspian-Caucasus Regions

Mantle diapirs determine the formation of basins in Alpine belt and Caribbean region. Mantle diapirs are the consequences of density inversion in the asthenosphere–lithosphere geosystem. This inversion provides a driving force for increasing heat flow on the background of convergence of Africa and Eurasia (in the case of Alpine belt) and North and South Americas (Caribbean region) in the Cenozoic. In Alpine belt, the mantle diapirism forms new basins of intercontinental seas at the final stage of Africa–Eurasia convergence in the Cenozoic. In the Caribbean region, the mantle diapirism first disjoined the North and South Americas in the Mesozoic, and then provided convergence of these continents in the Cenozoic (**Figures 10–13**) [12–18].

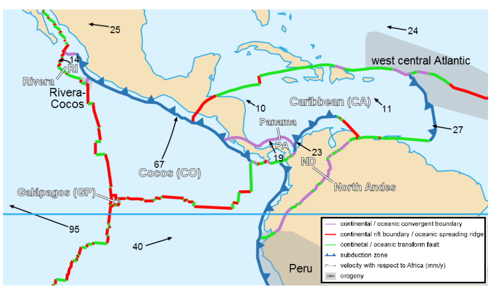


Figure 10. Caribbean plate tectonics (Available from: https://cdn.mos.cms.futurecdn.net/NHwWXe8TUEtcEua8Nz6cWD-800-80.jpg.webp).

Figure 11. Caribbean region with depths (USGS).

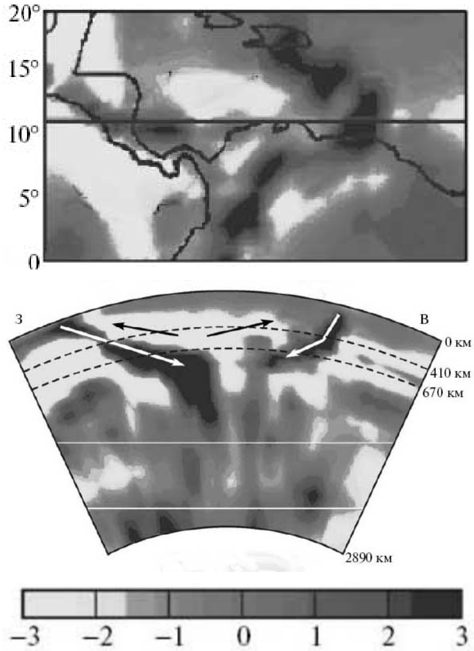


Figure 12. Variations in P-wave velocities (%) in the mantle under the Caribbean region [19].

4. Thermo-Gravity Model for Sedimentary Basins

4.1. The Pre-Caspian Depression Geology

The Pre-Caspian Depression is a unique sedimentary basin with a sedimentary cover thickness of nearly 24 km. The mantle diapir existence there is confirmed by geophysical data that fix two gravity maxima (Hobdinsky and Aralsorsky) and the complex of higher electroconductivity at the depth of 70–100 km. Also there is higher deep heat flow in the center of basin. Moho and basement morphology is characteristic for the mantle diapir upwelling (**Figures 14** and **15**) [20, 21].

Figure 13. Mediterranean sea. Alpine belt (Wikipedia, Available from: https://www.google.com/imgres?q=%D1%81%D1%80%D0%B5%D0%B4%D0%B8%D0%B7%D0%B5%D0%BC%D0%BD%D0%BE%D0%B5%20%D0%BC%D0%BE%D1%80%D0%B5&imgurl=https%3A%2F%2Fupload.wikimedia.org%2Fwikipedia%2Fcommons%2Fthumb%2F1%2F1c%2FMediterranean_Sea_16.61811E_38.99124N.jpg%2F280px-Mediterranean_Sea_16.61811E_38.99124N.jpg&imgrefurl=https%3A%2F%2Fru.wikipedia.org%2Fwiki%2F%25D0%25A1%25D1%2580%25D0%25B5%25D0%25B4%25D0%25B8%25D0%25B7%25D0%25B5%25D0%25BC%25D0%25BD%25D0%25BE%25D0%25B5_%25D0%25BC%25D0%25BE%25D1%2580%25D0%25B5&docid=rRyaxiVEfyVsuM&tbnid=u9KMUM_RLJbVxM&vet=12ahUKEwj8tOnN_JOMAxVZFRAIHUJrF3cQM3oECBYQAA..i&w=280&h=205&hcb=2&ved=2ahUKEwj8tOnN_JOMAxVZFRAIHUJrF3cQM3oECBYQAA).

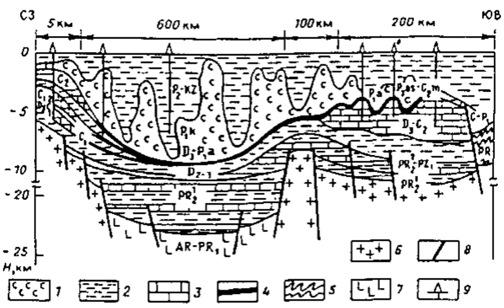


Figure 14. Geological section of the Pre-Caspian Depression. rocks: 1 - salts, 2 - terrigeneous, 3 - carbonates, 4 - clays, 5 - condensated, complexes: 6 - granitic, 7 - basalts; 8 - faults, 9 - deep boreholes[21].

Triangle rifts in the basement, such as Pachelmsky, Novoalekseevsky and Safpinsky, on the stage of swell formation can be explained by the upwelling of mantle diapir in the early Riphean.

Regime of slow upwelling of the mantle diapir provides deep syncline formation in Pre-Caspian Depression. Detailed information about sedimentary cover structure gives possibility to reconstruct picture of the basin evolution.

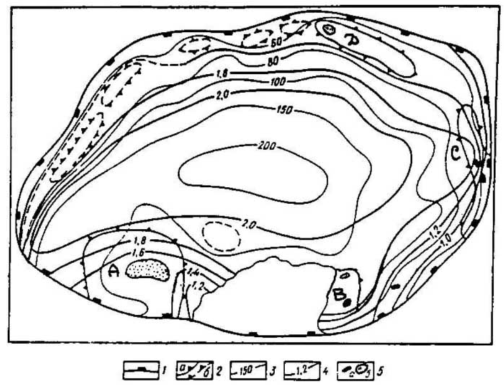


Figure 15. Scheme of the thermal-pressure conditions of subsalt deposits of the Pre-Caspian Depression. Boundaries: 1 - of the Pre-Caspian oil-gas potential province, 2 - of the oil-gas potential zones(a - known, b - forecasted); 3 - the geoisotherms on the subsalt deposits surface, C; 4 - the isolines of anormal layer pressure coefficients; 5 - oil /a/ and gas /b/ deposits. Main oil-gas deposits: A - Astrahan, B - Tengiz, C - Kenkijak, D - Karachaganak[20].

4.2. Geothermics of Sedimentary Basins

There are quick periods (3–4 MY) of the geological structures development and rather long periods (30–40 MY) of stable development in the history of the Earth's evolution. For modeling of geothermal evolution of sedimentary basin it can be accepted that T = 0 °C at the upper surface, T = 1200 °C at the lithosphere-asthenosphere boundary. Grad T at the upper surface depends on the thickness of sedimentary cover and the history of the structure evolution[22–25].

Geothermal field of the Pre-Caspian Depression is characterized by the next features. Heat-flow density increases from North to South and from East to West. Near the Caspian sea the surface heat flow is 50 mW/m^2 and 25–33 mW/m^2 in the North-East part of Depression (**Figure 16**)[22–27]. **Table 1** demonstrates geothermal zones of Depression.

Table 1. The main geothermal zones of the Pre-Caspian Depression.

Zone	T °C 5 km Depth	Grad T °C/100 m
KENKIJAK	76–90	1.7–2.0
CASPIAN	162–186	2.8–3.1
TENGIZ	160–167	2.8–3.2
ASTRAHAN	124–156	3.0–3.6

The temperature for Eastern part of Depression at the depth of 3.7–4.5 km was 110–125 °C, which is 40–

50 °C higher than modern temperature, as paleotemperature reconstruction by vitrinite reflectance shows. For stable stage of evolution the results of research show that the smaller lithosphere thickness is, the larger surface heat flow is. Maximum surface heat flow is above the mantle diapir in the centre of Depression. It is confirmed by geothermal data. Increase of sedimentary cover thickness h influences on decrease of surface heat flow q. It explains the low heat flow of Black sea.

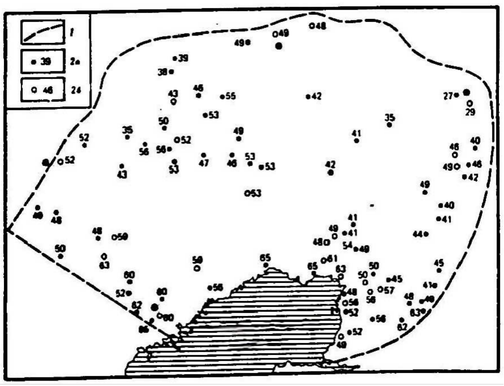


Figure 16. Heat flow for the Pre-Caspian Depression, mW/m^2. 1 - boundaries of the Pre-Caspian Depression, 2 - points of heat flow determination: a - separate, b - groups [26, 27].

Salt domes and salt layers complicate the temperature distribution. It is especially remarkable in south-eastern part of the Depression, as the salt layer there is not deep (100–500 m). The temperature is 3–5 °C higher above salt diapir than that in moulds on the same depth. In comparison with surrounding complexes, there are geothermal "depressions" in the salt diapirs for deep horizons. At 500–1000 m depth, the changing of temperature is 10–21 °C. In western part of Depression the salt domes are deeper (1500–2000 m) and their influence is smaller (**Table 2**) [26, 27]. Geothermal modelling confirms these results [22–27].

Table 2. Temperature distribution for 500–1000 m depths in salt dome structures for eastern and western parts of the Pre-Caspian Depression.

Depth m	East T °C	West T °C
500	21.2–31.9	23.4–28.4
750	27.0–42.1	37.3–43.0
1000	31.5–52.4	51.4–56.0

4.3. Methodology

Thermo-gravimetric Model for the Determinatio of the Lithosphere Thickness

The modeling is provided on the basis of the heat transfer equation and the condition of isostatic compensation for the multilayered medium of the Pre-Caspian Depression and East European Platform lithosphere in Equation (1) (**Figure 17**):

$$\begin{gathered} \mathrm{T}^* = 0\,^\circ\mathrm{C} \\ \frac{\partial^2 \mathrm{T}_1}{\partial \mathrm{z}^2} = -\frac{\mathrm{Q}_1}{\mathrm{k}_4} \\ \mathrm{T}_* = 1200\,^\circ\mathrm{C} \\ [\mathrm{T}_1] = 0,\ \left[\mathrm{k}_\mathrm{i}\frac{\partial \mathrm{T}_1}{\partial \mathrm{z}}\right] = 0 \end{gathered} \tag{1}$$

k_i - heat conductivity, Q_i - heat generation, T^* - temperature of the day surface, T_*- temperature of the lithosphere-asthenosphere boundary, i = 1÷4.

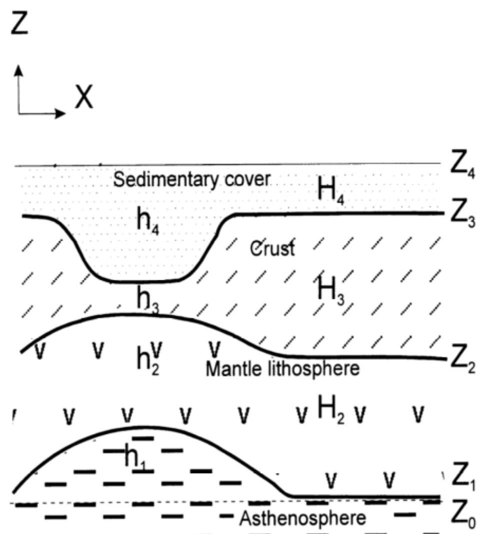


Figure 17. Principal scheme of the lithosphere structure for the Pre-Caspian Depression and East European Platform. z - day surface, z - basement surface, z - Moho discontinuity, z - lithosphere-asthenosphere boundary, z - level of isostatic compensation.

It is possible to get surface heat flow as shown in Equation (2):

$$\mathrm{q}^*(\mathrm{x}) = -\frac{\mathrm{T}_* + \sum_2^n \mathrm{h}_\mathrm{i}^2 \frac{\mathrm{Q}_\mathrm{i}}{2\mathrm{k}_\mathrm{i}} + \sum_{\mathrm{i}=2}^{n-1}\left(\frac{\mathrm{h}_\mathrm{i}}{\mathrm{k}_\mathrm{i}}\right)\sum_{\mathrm{j}=\mathrm{i}+1}^{n} \mathrm{h}_\mathrm{j}\mathrm{Q}_\mathrm{j}}{\sum_2^n \frac{\mathrm{h}_\mathrm{i}}{\mathrm{k}_\mathrm{i}}} \tag{2}$$

It is possible to put $Q_2 = 0$ in the mantle lithosphere, as radioactive elements are distributed mostly in the crust. Then the mantle lithosphere thickness can be calculated according to Equation (3):

$$h_2(x) = -\frac{T_* + q^* \sum_3^n \frac{h_i}{k_i} + \sum_3^n h_i^2 \frac{Q_i}{2k_i} + \sum_{i=3}^{n-1} \left(\frac{h_i}{k_i}\right) \sum_{j=i+1}^{n} h_j Q_j}{\frac{q^* + \sum_3^n h_i Q_i}{k_2}} \tag{3}$$

The data for geological-geophysical parameters are: h_4 = 24 km - thickness of sedimentary cover in the center of Depression, H_4 = 3 km - thickness of sedimentary cover of the Platform, h_3 = 12 km - thickness of consolidated crust for Depression, H_3 =40 km - thickness of consolidated crust for Platform, Q_4 = 1 mcW/m^3 , Q_3 = 0.5 mcW/m^3 (basalts), Q_3 = 2 mcW/m^3 (granites), k_4 = 3 W/(mK) (1.7–2.1 for terrigeneous rocks and 5.4–6.6 for salt), k_3 = 2.5 W/(mK), q* =50 mW/m^2 for Depression, q* = 40 mW/m^2 for Platform. Hence it is possible to get: $h_2 + h_3 + h_4$ = 110 km and $H_2 + H_3 + H_4$ = 180 km, i.e., asthenosphere upwelling is equal to 70 km under Depression.

For gravimetric model of the Pre-Caspian Depression the Depression and surrounding Platform are isostatically compensated at the Z_0 - level of compensation.

Then it is possible to get Equation (4):

$$\sum h_i \rho_i = \sum H_i \rho_i \qquad \sum h_i = \sum H_i \tag{4}$$

ρ_i- densities.

And we can get (5):

$$h_1 = \frac{(\rho_4 - \rho_2)(h_4 - H_4) + (\rho_3 - \rho_2)(h_3 - H_3)}{\rho_2 - \rho_1} \qquad H_2 - h_2 = \frac{(\rho_4 - \rho_1)(h_4 - H_4) + (\rho_3 - \rho_1)(h_3 - H_3)}{\rho_2 - \rho_1} \tag{5}$$

For ρ_4 = 2.3 g/cm^3 (sedimentary cover), ρ_3 = 2.7 (granite)–2.9g/cm^3 (basalt), ρ_2 = 3.3 g/cm^3 (lithosphere), ρ_1 =3.4 g/cm^3 (asthenosphere) it is possible to get h_1 = 70 km, $H_2 - h_2$ = 60 km. Hence asthenosphere upwelling from gravimetric model is equal to the same value from geothermal model. It confirms correctness of the model. The same applies to the thickening of the mantle lithosphere. The same parameters are defined from two different methods. And the results are close. It confirms the result reliability. Thus thermo-mechanical modeling gives the possibility to evaluate the mantle diapir upwelling under Depression.

5. Discussion

The magnitude of the thickness of the lithosphere is confirmed by geological and geophysical studies, as well as seismic tomography (**Figures 18** and **19**)[18, 25–34]. The mechanical-mathematical model gives more specific and reliable values, based, in particular, on obtaining the same parameters by different methods both from the solution of a geothermal problem and from isostasy conditions.

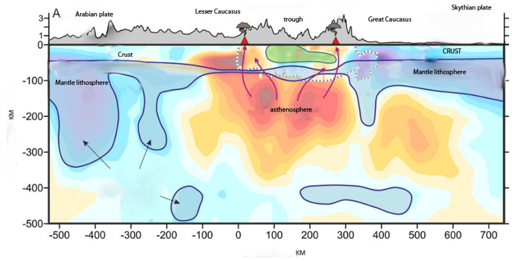


Figure 18. Seismotomographic cross-section of the Caucasus region[33]. Lesser Caucasus, Great Caucasus, Caucasus Trough. Red and yellow - asthenosphere, dark blue - mantle lithosphere, light blue - crust, green - higher density crust.

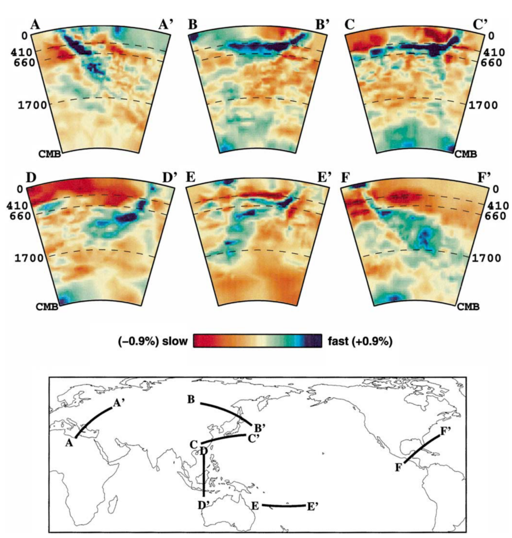


Figure 19. Slab structure illustrated by vertical mantle sections across: (A) the Hellenic (or Aegean) arc; (B) the southern Kurile arc; (C) Izu Bonin; (D) the Sunda arc (Java); (E) the northern Tonga arc, and (F) central America[31].

Comparison of the geodynamics and oil and gas potential of the Pre-Caspian depression and the Gulf of Mexico can serve as a search indicator for the discovery of deep-seated oil fields in the Caspian Sea. Seismic tomography data reveals mantle diapirs in the Caribbean and other regions of the world. A similar diapir should be expected in the Gulf of Mexico, as well as in the basins of the Alpine belt. The solution of the problem of mechanical and mathematical modeling makes it possible to estimate the magnitude of the rise of the mantle diapir under the Pre-Caspian basin. A similar rise in the asthenospheric diapir should be expected in other sedimentary basins of the Alpine belt, although the geological and geophysical parameters are different there and the condition of isostatic compensation cannot be used everywhere, and therefore the depth of the diapir in different basins can differ significantly. So, the depth of asthenosphere under South Caspian depression is 40–60 km, along the periphery it is submerged for 100–120 km [30]. The typical scheme for the sedimentary basins deep structure is presented in **Figure 20**. The rise of a hot asthenospheric diapir determines the oil and gas content of sedimentary basins and the formation of large oil and gas fields.

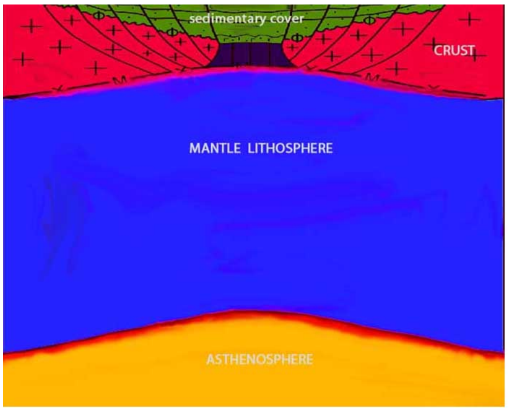


Figure 20. Typical scheme for the sedimentary basins deep structure.

Against the background of the intensive development of offshore drilling by the Russian oil and gas complex [20], as well as in connection with the implementation of the "Eurasia" project, the lessons of the accident in the Gulf of Mexico at the MS-252 well should be taken into account and the quality and safety requirements for the construction of offshore and deep wells should be increased.

6. Conclusions

The Mexican supergiant is a reference salt and oil - gas basin. In specific basins, including giant ones, various aspects of salt-hydrocarbon ratios are considered in numerous publications [20]. One of the largest in the world and the most studied Mexican salt and oil and gas supergiant can serve as a reference and model object. Reflecting the typical features of both salt and oil and gas basins, the Mexican basin, even among most other giants, is distinguished by the scale of spatial indicators and an extremely vivid manifestation of many of the most important characteristics - geological, oil and gas, fluid dynamics. It also focuses on the main contrasting trends in the modern development of oil and gas geology and oil production: on the one hand, the rapid development of ever deeper areas, due to the colossal achievements of science, technology and their integration; on the other hand, just as rapid, and sometimes even a more rapid increase in complexities, and most importantly, threats from the subsurface areas that are increasingly difficult to control. It is in the Mexican Basin that records have been set for almost all indicators of oil drilling: both total depth and deep water, including subsalt reservoirs, and productivity. But at the same time, the accident rate increases, which was especially clearly highlighted by the Deepwater Horizon accident.

Most of the salt and oil and gas basins, including the Pre-Caspian Basin, are comparable to the Mexican basin in terms of key indicators and are also among the most highly promising and highly accident-prone. These indicators make the salt and oil-gas basins both the most promising for prospecting and oil production, and the most dangerous. Various ratios between salts and hydrocarbons in the processes of migration and unloading create a variety of spatial relationships between oil and gas deposits with salt bodies in the bowels.

The main common features of Caribbean region and Alpine belt are their positions in collision zones and mantle plumes upwelling on the base of plate tectonics. Caribbean region can be considered as American Mediterranian. Both structures consist of sedimentary basins, sea depressions, back-arc basins, subduction zones [32–34].

In Alpine belt, the mantle diapirism produces new basins of intercontinental seas at the final stage of Africa–Eurasia convergence in the Cenozoic. In the Caribbean region, intensive mantle diapirism first disjoined the North and South Americas in the Mesozoic, and then played the same role as in Alpine belt for the convergence of these continents in the Cenozoic. The main common features of the Mexican Gulf and Pre-

Caspian Depression are their geodynamical positions in connection with the Caribbean Sea and the Mediterranean, high heat flow, high thickness of sedimentary cover, high oil-gas potential, and the existence of salt domes and salt layers. The development of the Gulf of Mexico can be compared with the Caspian Basin in relation to the Alpine Belt, when impulses of mantle activity formed new sedimentary basins. Just as the Gulf of Mexico Basin is older than the Caribbean basins, so the Pre-Caspian Depression is older than the South Caspian Basin and the Mediterranean basins (**Figure 21**).

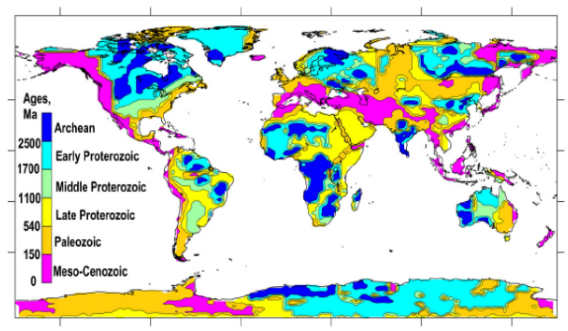


Figure 21. Age of continental crust (USGS).

In the near future, judging by all forecasts, one of the main objects of attention will remain precisely the largest salt and oil and gas basins, in which, along with the already established giant ones, even larger accumulations are expected, and in ever deeper waters areas where big oil is confidently assumed. Deep-seated subsalt reservoirs are particularly hopeful, although they also carry extreme risks. In this regard, it is very important to learn lessons from the tragedy in the Gulf of Mexico against the backdrop of intensive development of drilling operations on the shelf by the Russian oil and gas complex [20], which means raising the quality and safety requirements for the construction of offshore and deep wells.

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Data Availability Statement

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Conflicts of Interest

The author declares no conflict of interest.

References

[1] Malyukov, V.P., Sushok, A.A., 2013. Technological, environmental and economic problems as a result of the accident at the Macondo well of British Petroleum in the Gulf of Mexico. RUDN Journal of Engineering Research. (1), 90–99. (in Russian).
[2] Leonov, Y.G., Volozh, Y.A., Antipov, M.P., et al., 2015. Oil from deep horizons of sedimentary basins in Russia and neighboring countries. Monitoring. Science and technology. 2015(4), 6–15. (in Russian).
[3] Yashchenko, I.G., Krupitsky, V.V., Polishchuk, Y.M., 2021. Features of changes in the physico-chemical properties of oils in connection with great depths. Georesursy/Georesources. 23(3), 99–108. (in Russian).
[4] Volozh, Y.A., Dmitrievsky, A.N., Leonov, Y.G., et al., 2009. On strategy of the upcoming exploration phase in the north Caspian petroleum province. Geology and Geophysics. 50(4), pp. 341–362.
[5] Antipov M.P., Bykadorov V.A., Volozh Y.A., 2009. Problems of the origin and development of the Caspian depression. Geology of Oil and Gas. 323(2), 11–19. (in Russian).
[6] Belenitskaya, G.A., 2014. Salts and naphthides: global spatial and kinetic relationships. Regional Geology and Metallogeny. 59, 97–112.
[7] Bogdanov, N.A., 1989. Geology of deep depressions of back-arc seas. Nedra: Moscow, Russia. p. 221. (in Russian).
[8] Condie, K.C., 2001. Mantle plumes and their record

in Earth history. Cambridge University Press: Cambridge, England. p. 306.

[9] Davies, G.F., 1999. Dynamic Earth: Plates, Plums and Mantle Convection, 1st ed. Cambridge University Press: Cambridge, UK. p. 458.

[10] Gee, D.G., 1996. Lithosphere Dynamics: Origin and Evolution of Continents. Uppsala University: Uppsala, Sweden. p. 138.

[11] Goncharov, M.A., Koronovskii, N.V., Svalova, V.B., et al., 2015. The contribution of mantle diapirism to the formation of newly formed basins of the Mediterranean and the Caribbean and the surrounding centrifugal-vergent folded-overlapped orogens. Geotectonics. 6, 80–93.

[12] Svalova, V., 2022. Geodynamics of Alpine belt and Caribbean region: Plate - tectonics and plume – tectonics. Journal of Basic & Applied Sciences. 18, 126–139.

[13] Sharkov, E., Svalova, V., 2011. Geological-geomechanical simulation of the Late Cenozoicgeodynamics in the Alpine-Mediterranean mobile belt. In: Sharkov, E. (eds.). New Frontiers in Tectonic Research – General Problems, Sedimentary Basins and Island Arcs. INTECH: Zagreb, Croatia. pp. 18–38.

[14] Svalova, V.B., 2020. Geodynamics and Geothermy of the Pre-Caspian Depression and the Eastern Segment of the Caucasus Region. Geology and Geophysics of the South of Russia. 10(4), 52–69. DOI: https://doi.org/10.46698/VNC.2020.92.72.004 (in Russian).

[15] Svalova, V.B., 2021. Comparative geodynamics and geothermy of the Alpine and Pacific belts. Mechanical and Mathematical Modeling. Geology and Geophysics of the South of Russia. 11(3), 76–92. DOI: https://doi.org/10.46698/VNC.2021.52.15.007 (in Russian).

[16] Svalova, V.B., Sharkov, E.V., 1991. Formation and evolution of back-arc basins of the Alpine and Pacific belts (comparative analysis). Pacific Geology. 5, 49–63. (in Russian).

[17] Svalova, V.B., Sharkov, E.V., 1992. Geodynamics of the Baikal rift zone (petrological and geomechanical aspects). Geology and geophysics. 5, 21–30. (in Russian).

[18] Svalova, V.B., Soloviev, B.A., Ivanova, T.D., 1993. Geodynamics and geothermy of the Pre-Caspian Depression. Geothermy of seismic and no-seismic zones. Nauka: Moscow, Russia. pp. 119–132. (in Russian).

[19] Van der Hilst, R.D., Spakman, W., 1989. Importance of the reference model in linearized tomography and images of subduction below the Caribbean plate. Geophysical Research Letters. 16(10), 1093–1096.

[20] Aksenov, A.A., Goncharenko, B.D., Kalinko, M.K., et al., 1985. Oil-gas potential of subsalt deposits. Nauka: Moscow, Russian. p. 205. (in Russian).

[21] Maksimov, S.P., Dykenshtein, G.H., Zolotov, A.N., et al., 1990. Geology of oil and gas of East-European platform. Nedra: Moscow, Russia. p. 274. (in Russian).

[22] Svalova, V.B., 2014. Mechanical and mathematical modeling of the formation and evolution of geological structures in connection with deep mantle diapirism. Monitoring. Science and technology. 2014(3), 38–42. (in Russian).

[23] Svalova, V.B., 1992. Mechanical-mathematical models of the formation and evolution of sedimentary basins Science de la Terre, Series Informatics, Nancy. 31, 201–208.

[24] Svalova, V.B., 1993. Mechanical-mathematical simulation of geological structures evolution. Geoinformatics. 4(3), 153–160.

[25] Zanemonetz (Svalova), V.B., Kotelkin, V.D., Miasnikov, V.P., 1974. On the dynamics of lithospheric movements. Izvestia of the USSR Academy of Sciences., Series Physics of the Earth. 5, 43–54. (in Russian).

[26] Gordienko, V.V., Zavgorodnjaja, O.V., 1985. Heat flow of the Pre-Caspian Depression. Geothermal investigations in Middle Asia and Kazakhstan. Nauka: Moscow, Russia. pp. 251–255. (in Russian).

[27] The Global Heat Flow Database of the International Heat Flow Commission. Available from: http://heatflow.org (cited 2 March 2025)

[28] Anderson D.L., Dzevonsky A.M., 1984. Seismic tomography. In the World of Science. 12, 16–26. (in Russian).

[29] Geological and geophysical modeling of oil and gas bearing territories. 1993. In: Nevolin N.V., Kovylin V.M. (eds.). Nedra: Moscow, Russia. p. 208. (in Russian).

[30] Volvovsky, B.S., Starostenko, V.I., 1996. Geophysical Parameters of the Lithosphere in the Southern Sector of the Alpine Orogen. Naukova Dumka: Kyiv, Ukraine. p. 215. (in Russian).

[31] Kárason, H., van der Hilst, R.D., 2000. Constraints on mantle convection from seismic tomography. In: Richards, M.R., Gordon, R., van der Hilst, R.D. (eds.). The History and Dynamics of Global Plate Motion, volume 121. American Geophysical Union: Washington, DC., USA. pp. 277–288.

[32] Khain, V.E., Lomize, M.G., 2005. Geotectonics with the basics of geodynamics. KDU: Moscow, Russia. p. 560. (in Russian).

[33] Koulakov, I., Zabelina I., Amanatashvili, I., et al., 2012. Nature of orogenesis and volcanism in the Caucasus region based on results of regional tomography. Solid Earth. 3, 327–337.

[34] Van der Meer, D.G., Van Hinsbergen, D., Spakman, W., 2018. Atlas of the underworld: Slab remnants in the mantle, their sinking history, and a new outlook on lower mantle viscosity. Tectonophysics. 723, 309–448. DOI: https://doi.org/10.1016/j.tecto.2017.10.004