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FORMATION CONDITIONS OF SEDIMENTARY BASINS IN THE BLACK SEA–CASPIAN REGION

The article discusses formation conditions of sedimentary basins in the Black Sea–Caspian region. The system of basin-like structures includes three mega basins–Precaspian, Mysian and Aegean, and two large basin systems–Scythian–Turan and Black Sea–South Caspian. In the Paleogene–Neogene, shaping of sedimentary basins was connected with the formation of a foredeep ahead of the front of the Greater Caucasus folding. The longitudinal strike of the belt of the basin-like structures in the north of the region under consideration obeys the general strike of the zone of interaction between the Greater Caucasus folding orogeny and the Scythian Platform, which points at the dominating, at least, in the center, submeridional vectors of the regional stresses responsible for the formation of the piedmont mega basin. Farther from the mountains and toward the platform, the basin-like structures in the study region degrade, and sedimentation in the platform area, where sedimentation is geologically possible, occurs not like a basin but like a mantle.

Keywords: *formation conditions, sedimentary basins, Black Sea–Caspian region, basin morphometry series, basin analysis, sedimentary mantle, structural map*
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Introduction

The basin-like structures in the Black Sea–Caspian region include three mega basins—Precaspian, Mysian and Aegean, and two large basin-like structures—Scythian–Turan and Black Sea–South Caspian [1–7]. The Paleogene–Neogene age of the sedimentary basins is connected with the formation of a foredeep ahead of the front of the Greater Caucasus folding. The pattern of the Cenozoic basin-like structures characterizes the contemporary age of this region. The east–west strike of the belt of the basin-like structures in the north of the study regions obeys the general strike of the zone of interaction between the orogenic folded structure of the Greater Caucasus and the Scythian Platform, which points at the dominating, at least in the center, submeridional vectors of the regional field stresses responsible for the formation of the piedmont mega basin [8–12]. The Eastern Precaucasus basin, which embraces the test region, partly follows the deeper structural layout. Farther from the mountains toward the platform, the basin-like structures in this region degrade, and sedimentation in the platform area, where sedimentation is geologically possible, occurs not like a basin but like a mantle [13–16].

Research procedure

Classification of sedimentary basins uses the concept of morphometry (shape+size) and distinguishes structures in a basin-type row from a mega basin (basin-like system) to a basin and to a sub-basin, which distinctly defines the relationship between the orders of the depression structures. In accordance with this concept, the Precaucasus sediment basins are mapped. For revealing formation conditions of the sedimentary basins in the Black Sea–Caspian Region, the basin modeling was carried out, and the structure and thickness of each sedimentary basin were mapped. The mapping quality was checked using the borehole information and the state geological map. Based on the analysis of the structures, in the sedimentation thickness maps, the elements of the internal basin structure were determined per intervals of the cross-section with the contour detection.

The averaged reference values of the thickness, to define the configurations of the basin-like structures, were assumed to be 0.5, 0.8–1.0 and 1.5–2.0 km. The former value describes an area (mega basin) of a steady downwarping where the continental or marine sedimentation conditions were maintained within the geological age period under consideration. The middle value defines complications within the sedimentation areas, which cause formation of localized sedimentary basins or their structurally or tectonically governed grouping (sag zones, rift zones). Finally, the latter value characterizes the basin-like structures described with the higher rates and volumes of sedimentation, which can be represented by avalanche processes in places.

The basin analysis used sedimentary basin modeling software PetroMod, Schlumberger.

This modeling technique is the main strategic tool of exploration risk assessment and various decision-making in the oil and gas industry. The framework is numerical modeling of geological processes—accumulation of sedimentaries, their compaction, thermal conditions, generation of hydrocarbons, their migration and accumulation in sedimentary basins.

For the analysis of the formation conditions and spreading patterns of hydrocarbon systems and their source areas, 3D modeling of generation, migration and accumulation of hydrocarbons was performed.

Results

For the basin analysis, using available geological and geophysical information, the structural maps were drawn for the roofs of the Pre-Upper Jurassic, Upper Jurassic, Cretaceous, Eocene, Maykop, Sarmat and Pliocene (**Figs. 1** and **2**). Verification of the mapping quality involved the borehole information and the state geological map information.

The analyses of the thickness maps allowed tracing displacement of sedimentation depocenters during the period of the sedimentary cover formation, revealing their generation features, delineating their boundaries and identifying large areas of steady downwarping in the test territory (**Fig. 3**).

Thus, within the modern limits of the Scythian Platform, four large depressions (basins) with the sedimentary cover more than 5 km thick stand out: Karkinit, Indolo-Kuban, East Kuban and Terek–Caspian. The **Table** compiles the main characteristics of the basins.

Based on the obtained results, the models of the sedimentary basins were constructed for the Jurassic, Cretaceous and Paleogene–Miocene (Maykopian) sedimentation cycles. Moreover, for the whole sedimentation cross-section of the Black Sea–Caspian region, the consolidated model was constructed with the delineation of all three levels of the basin-like structure and with the systematized assortment of the identified basins.

Jurassic sedimentary basins (see Fig. 3). The basins of this age occupy the continental–sea belt uniting the modern orogenic folding structures of the Crimea, Caucasus and Kopet Dag, and the adjoining trenches of the Black Sea and Caspian Sea. One more proveniance of the Jurassic basins is the region of the Middle and North Caspian and the adjoined areas in the west and east.

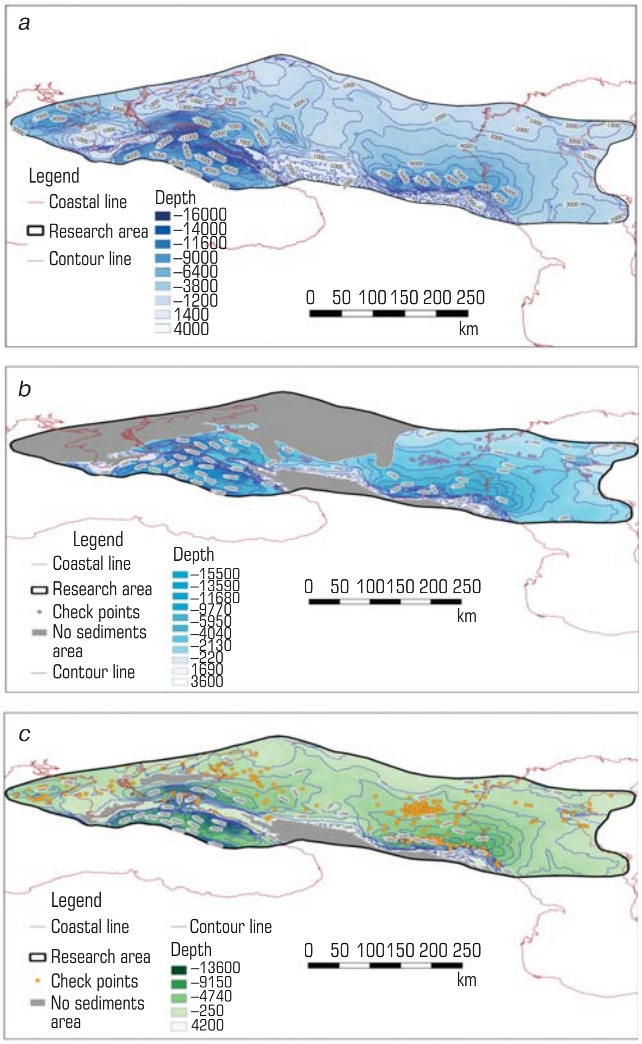

Fig. 1. Structural maps of roofs of Pre-Upper Jurassic (*a*), Upper Jurassic (*b*) and Cretaceous (*c*) sediments

The Crimea–Caucasus (continental–sea) belt in the Jurassic age held a vast sedimentary basin (see Fig. 2) with the maritime-intensive sedimentation. In particular, these processes were probably most vigorous in the area of the modern East Caucasus.

A feature of the Jurassic basin-like structures in the range of the modern Caspian and the adjoining areas is their tree-like configuration.

The axis of the main *trunk* of this *tree* goes from the southwest to the northeast, from the modern Agrakhan Peninsula, where the linear basin develops into the vast East Caucasus area of sedimentation, to the North Caspian western segment of the South Emba zone of sags and, further, to the South Ural.

The *trunk* connects with the side transversal sublatitudinal basin-like structures. The largest structures are the Dzhanai–Zyudev in the west and Segendyk–Zhazgurly in the east.

Regarding the deep tectonics, the northeastward-strike basin-like structure (conditionally, Agrakhan–Emba) develops almost along its total length within the discussed region above the Agrakhan–Guriev (Atyrau) deep fault accompanied lengthwise with the Triassic sedimentation structures [16]. The side basin-like structures inherited structural trends of

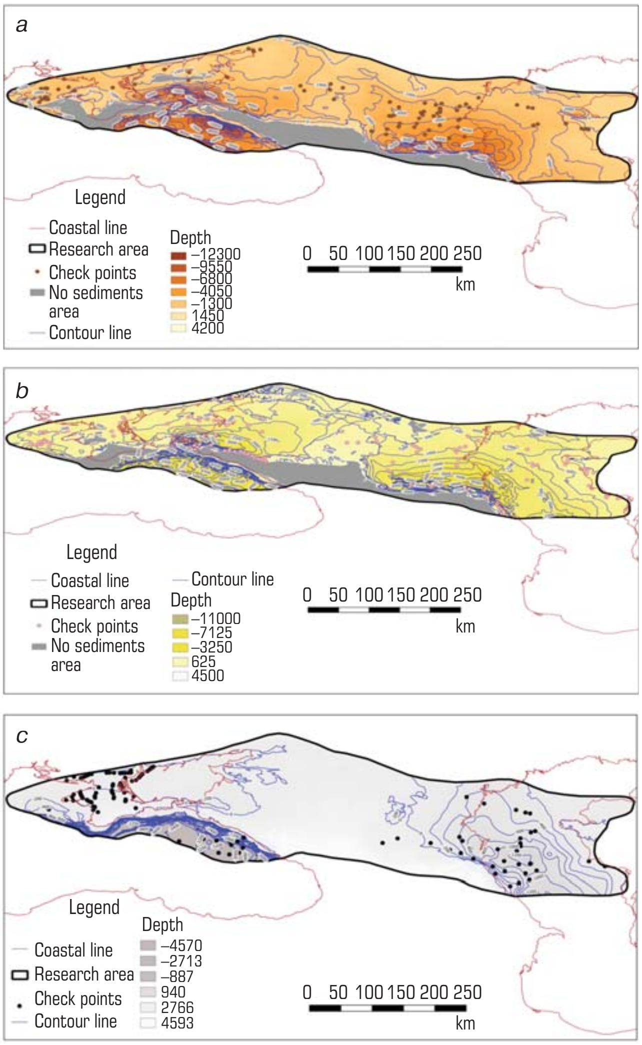

Fig. 2. Structural maps of roofs of Eocene (*a*), Maykopian (*b*) and Pliocene (*c*) sediments

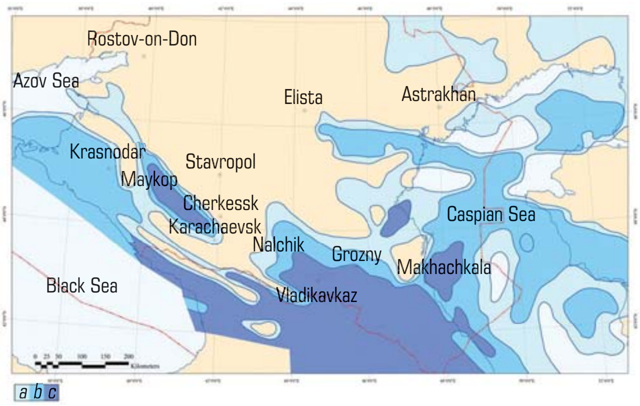

Fig. 3. Black Sea–Caspian region

Sedimentation thickness: *a* – more than 0.5 km, *b* – more than 0.8–1.0 km, *c* – more than 1.5–2.0 km

Description of sedimentary basins

Basin	Sedimentary cover thickness, m		Area, km²
	minimum	maximum	
Kirkinit	6000	9000	25092.48
Indolo-Kuban	5000	11500	50193.09
East Kuban	5000	6700	5946.98
Terek–Caspian	4300	9500	102519.44

tectonics of the Paleozoic–Cimmerian sedimentation cover in the east of the region.

The correlation of the basin structures with the deeper seated structures allows suggesting that the layout of the basins formed in consequence of the graben–rift activation in the zone of the tectonic contact between the Scythian and Turan Platforms (the Agrakhan–Atyrau fault) under geodynamic wedging-out effect from the side of the East Caucasus basin and, probably, the underlying local mantle diapir fold (extrusion/dome/plume?) which initiated and/or maintained relative tension–uncovering of the basin.

Cretaceous sedimentary basins (**Fig. 4**). As against the Jurassic basins, the structural layout of the Cretaceous sedimentary basins essentially changed. Within the boundaries of the region under discussion, two vast areas of basin-like sedimentation appeared with their interface represented by a submeridional belt of uplifts of complex configuration.

This belt stretches from the western Transcaucasia northward, through the Greater Caucasus and the Stavropol uplift toward the East European Platform. There are the Azov–Black Sea basin and the Precaspian–Caspian basin to the west and east of the belt, respectively.

Morphologically, the belt of uplifts formed owing to folding, origin of uplifts in places of sag of the Lesser and Greater Caucasus and their connection via saddles, and due to partial downwarping of outskirts of the Jurassic-age off-basin zone in the northwest of the region.

The Azov–Black Sea areal of downwarping includes the large Black Sea–South Azov basin which inherits, with some changes in configuration in the zone of the Caucasus orogeny, the earlier Jurassic basin and the northward and northeastward sedimentation zones conditionally defined as the North Azov–East Kuban and the Tuzla–East Rostov [17].

The mutual layout of these basin-like structures may result from the pressure applied from the southwest, from the side of the northeast of the Black Sea–South Azov basin, and from the response to this pressure by the Later Paleozoic structures—the Azov and Kanevskaya–Berezanskaya swells and the Rostov extrusion. The response meant distribution of the uplift and sag zones which conditioned positions of sedimentary basins.

The Precaspian–Caspian areal of basin-like sedimentation partly preserves some elements of the northeastern and sub-latitudinal structural trends of the basin layouts. On the whole, the Cretaceous sedimentation areas essentially expand and embrace the territories of the modern West Precaspian, Mangyshlak and North Caspian. The expansion and reconfiguration of the basin engaged the Segendyk–Dzhazgurly zone of the East Precaspian. In connection with the East Caucasus orogeny, the East Precaucasus sedimentary basin acquires its own (independent) configuration [18–20].

The Cretaceous-age basin-like sedimentations and their interface could be reflective of two active major sources of geodynamic pulsed horizontal compression–tension at that time. One source could locate in the east of the modern Black Sea depression, and the other source could occur in the South Caspian–Transcaspian area. The counter geodynamic pulses emitted from these sources could initiate the mega regional basin-like and inter-basin structures on the level of the Cretaceous-age sedimentation cover.

The probability of such sources enters in no disagreement with the model of the Alpine structural geodynamic systems of the Black Sea–Caspian region.

Cenozoic sedimentary basins (**Fig. 5**). The layout of the basins of the Cenozoic age, which is the contemporary history stage, differs from the above-described Cretaceous thickness.

Fig. 4. Map of Cretaceous sedimentary basins in the Black Sea–Caspian region.

Thickness of sedimentary basins: *1* – more than 0.5 km, *2* – more than 1.0 km

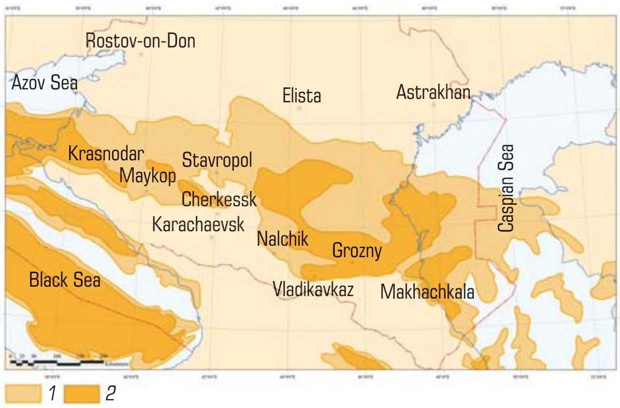

Fig. 5. Map of Cenozoic sedimentary basins in the Black Sea–Caspian region.

Thickness of sedimentary basins: *1* – more than 0.5 km, *2* – more than 1.0 km

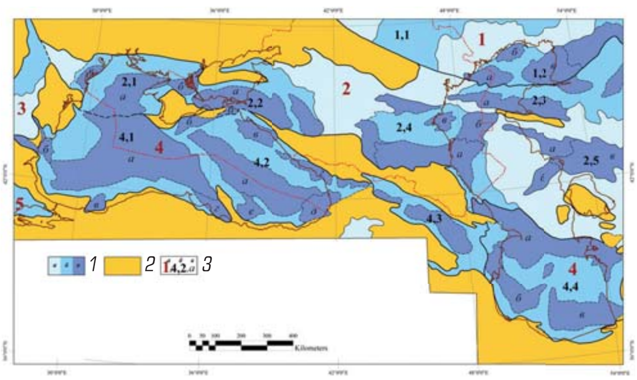

Fig. 6. General map of sedimentary basins with the total Mesozoic–Cenozoic cross-section thicknesses more than 1 km in the Black Sea–Caspian region

Legend: *1* – basin-like structures: *a* – basins/mega basins, *b* – basins, *c* – sub-basins; *2* – off-basin areas; *3* – indexes of basin-like structures: *a* – basins/mega basins, *b* – basins, *c* – sub-basins (within water areas and transition zones).

Basin-like structures. *1* – PRECASPIAN MEGA BASIN. Basins: 1.1 – Sarpinsky, 1.2 – South Emba–North Caspian (sub-basins: a – Ukat, b – Burdy, c – Primorsko-Prorvinsky). 2 – SCYTHIAN–TURAN BASIN SYSTEM. Basins: 2.1 – Northwest shelf of the Black Sea (sub-basins: *a* – Karkinit, *b* – Sivash–North Crimea, *c* – Krylov), 2.2–Azov–Kuban (sub-basins: a – Indolo-Kuban, *b* – Taman), 2.3 – Buzachi–Ustyurt (*a* – Southern Buzachi sub-basin), 2.4 – East Precaucasus (sub-basins: *a* – Terek–Caspian, *b* – Segendy, *c* – Kizlyar), 2.5 – Southern Mangyshlak (sub-basins: *a* – Karaginsky, *b* – Aksu–Kendyrly, c– Zhazgurly). 3 – MYSIAN MEGA BASIN. 4 – BLACK SEA–SOUTH CASPIAN BASIN SYSTEM. Basins: 4.1 – Western Black Sea (sub-basins: *a* – Deep Water/Odessa–Sinop, *b* – Burgas, *c* – Akchakodzha–Alaply, *d* – Sinop), 4.2 – Eastern Black Sea (sub-basins: *a* – Deep Water/Crimean–East Pontic, *b* –Sorokin, *c* – Tuapse, *d* – Kolkhida, *e* – Guria, *f* – Ordu), 4.3–Rion–Kurinsky (*a* – Evlakh–Agdzhabedi sub-basin), 4.4 – South Caspian (sub-basins: *a* – Apsheron–Pribalkhash, *b* – Gilyan, *c* – Pre-Elbrus), 5 – AEGEAN MEGA BASIN, Thracian basin

The latitudinal strike of the belt of the basin-like structures in the north of the region under discussion follows the general strike of the interaction zone between the Greater Caucasus folding and orogeny and the Scythian Platform, which points at the dominating, at least in the center of the Black Sea–Caspian region, sub-meridional vectors of the regional stresses responsible for the formation of structures of the piedmont mega basin [21–27]. The basin-like structures within this system, namely, West Kuban, East Kuban and East Precaucasus basins, partly obey the deeper structural layouts. Farther from the mountains toward the platform, the basins in the region degrade, and sedimentation in the platform area, where sedimentation is geologically possible, occurs not like a basin but like a mantle [28–34].

The basin-like structures in the south of the region in question are mostly bounded by the outlines of the trenches of the Black Sea and Caspian Sea, and by the adjoined intermountain and submontane troughs.

The general map of sedimentary basins in the Black Sea–Caspian region (**Fig. 6**). This general map is an integral model of distribution of the basins within the whole sedimentation cross-section, both on land and asea.

As follows from the map, the areas of the sedimentation cross-section with the total thickness of more than 1.5 km occupy the largest part of the Black Sea–Caspian region. Sediments are absent or have the thickness smaller than 1.5 km in the areas of the Anatolian–Iran boundary of the Black Sea–Caspian region, at its Balkan and East Mysian (Dobrudzha) limits, in the areas of the Ukrainian shield, Folded Donbass and some parts of the Karpinsk ridge, which limit the region in the north, and at some inner and marginal uplifts in the region [35–37]. The latter are the orogenesis—Caucasus, Crimean and Mangyshlak, and some dome-like and swell-like uplifts—the Arkhangelsk uplift in the Black Sea, Azov swell and Central Crimean and Karabogaz swells, as well as the smaller size structures.

The system of the basin-like structures holds three mega basins (see Fig. 6) – Precaspian, Mysian and Aegean, and two large basin-built systems – Scythian–Turan and Black Sea–South Caspian.

Conclusions

In the framework of the analysis, it is found that the Mesozoic-age basins under study partly constituted the Black Sea–South Caspian basin-like system, while at the later stages of evolution, some of them participated in the tectonic dislocations and, concerning the modern tectonic zoning, partly constitutes the Alpine folded zone. In this connection, for the specific and more comprehensive understanding of the development features of these basins, the detail analysis went beyond the Scythian–Turan basin-like system. The Scythian and Turan Platforms occupy the larger part of this area. It also includes the southern margin of the East European Platform, the Terek–Caspian downfold, the Crimea–Caucasus folding, as well as the northeast of the Black Sea–South Caspian system of downfolds.

In accord with the concept of the two-level basement of young platforms, the Scythian Platform contains two levels: the ancient (Baikal consolidation) crystalline basement and the upper transitional structure formed as a result of different-intensity folding deformations in the earlier platform mantle of the Hercynian and, partly, Cimmerian stages of tectonogenesis. The ancient basement formed in the geosyncline system which deposited in the south periphery of the ancient platform at the late Proterozoic (Riphean) time. As compared with the basement rocks, the transitional deposits have a moderate-to-weak degree of dislocation and metamorphism (mostly, dynamic metamorphism), which decreases bottom-up and is the most pronounced inside and nearby the fault zones.

The transitional deposit is composed of the Middle-to-Late Paleozoic era rocks as well as the Mesozoic rocks from the Triassic to the Middle Jurassic. The stratigraphic interval of the transitional deposits is inconsistent and varies subject to the tectonic development features of the Scythian Platform blocks. Irrespective of that, the platform mantle includes the Late Mesozoic (J3)–Cenozoic deposits. Since those ages, comparatively calm tectonics settled on the most part of the territory. It should be mentioned that the southern periphery of the platform experienced later tectonic deformations in connection with the Caucasus orogeny, while the center and the east areas were involved in low-rate uplifting (1.2 cm/thousand years).

According to the research findings, the platform mantle in the region under study is composed of carbonate and terrigene deposits of the Upper Jurassic–Cretaceous ages, as well as of mostly terrigene deposits of the Cenozoic. It is divided by the inconsistency surfaces into seven units: Upper Jurassic, Cretaceous, Paleocene–Eocene, Maykopian, Low-to-Middle Miocene, Upper Miocene–Pliocene and Quaternary.

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