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THE RELATIONSHIP BETWEEN THE PALEOBIOGEOGRAPHY OF THE NORTHERN AND SOUTHERN SIDES OF THE NEOTETHYS AND THE DEEP GEODYNAMIC PROCESSES

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Summary. Several of our previous studies substantiated the discovery of the phenomenon of a deep mantle structure rotating counterclockwise, influencing tectonics and various geological-environmental processes in the South Caucasus and the Eastern Mediterranean. This study made it possible to estimate the onset of the influence of the deep structure and characterize the structural-tectonic changes that occurred in different geological eras. The widespread use of paleontological data has made it possible to classify the migration of organisms from distant provinces and obtain data on the formation of basins based on the study of the geodynamics of terrane belts, island arcs, shear zones, and deep movements determined by the nature of mantle convection. The role of paleobiogeography, sedimentation tectonics, and paleogeography in assessing autochthonous and allochthonous structures is essential to the deep geodynamics of past and present geological eras. The geodynamic evolution of the Mesozoic Terrane Belt (MTB) located on the Neotethys southern side (the Gondwana northern part) was investigated. Our comprehensive studies showed the MTB's allochthonous nature and confirmed previous data on the terrane nature and the Mesozoic age of the displaced tectonic blocks. In the Lesser Caucasus, biogeographical and tectonophysical studies sharply separated the eastern (Azerbaijanian) part of the Lesser Caucasus from the ophiolite belt in its southwestern continuation. The structural-geodynamic uniqueness of the mixed Late Cretaceous fauna of the Garabakh region (western Azerbaijan) has received a comprehensive justification. An assessment was made of the beginning of the influence of the mantle structure on near-surface tectonic-structural elements.

1. Introduction

Hallam (1975) was among the first to point out an essential relationship between the Jurassic paleobiogeographical indicators and geodynamic processes. The distribution of Mesozoic Tethys biocenoses in connection with changes in biotic and abiotic environmental factors is a crucial problem. It is being developed as a factor in solving practical problems of the geological survey (Dixon and Robertson, 1984; Khain, 1994; Hall et al., 2005; Krasheninnikov et al., 2005; Leonov, 2007; Alizadeh et al., 2016, 2024), as well as theoretical problems of geosciences and issues for monitoring of natural processes (e.g., Gamkrelidze, 1986; Khain, 2000; Ben-Avraham et al., 2002; Golonka, 2004; Zakariadze et al., 2007; Şengör, 2009; Le Pichon and Kreemer, 2010; Eppelbaum and Khesin, 2012; Kadirov et al., 2013; Faccenna et al., 2014; Kadirov and Gadirov, 2014; Alizadeh et al., 2016; Said, 2017; Eppelbaum et al., 2018, 2023b).

In this regard, two crucial regions of practical importance are distinguished: (1) the Near and Middle East and (2) the Transcaucasus. The first marks the processes of geological development on the southern (Gondwana) side of the Neotethys, and the second marks the northern (Eurasian) frame of this Mesozoic Ocean. Both mentioned structural-biogeographic zones form the most constricted part of the collisional Alpine-Himalayan Fold Belt (AHFB) (Eppelbaum and Katz, 2023) (Fig. 1). It successively articulates three structures of different ages: (1) the ancient Precambrian Arabian Platform, (2) the folded-metamorphic Neoproterozoic belt, and (3) the blocky Mesozoic Terrane Belt (MTB). The same map illustrates another significant similarity between the two marked regions: they are dissected by two deep faults (cutting belts of different ages), creating their structural-geodynamic contrast. The first case is the Eastern Mediterranean-Nubian Fault (EMNF), which is seismically active and marked by the Meso-Cenozoic traps with the manifestations of the alkali-kimberlite mantle intrusions (Eppelbaum and Katz, 2012). The second major fault, Main Eastern European Fault (MEEF), is also seismically and tectonic-thermally active. It is significant that it discordantly cuts the Caucasus in half – into East and West. The generalized paleomagnetic data (Eppelbaum et al., 2021) shown in Fig. 1 indicate their geodynamic differences: the structures of the Western Caucasus rotate in a counterclockwise direction, and those of the Eastern Caucasus rotate clockwise.

This map indicates that the zone of the catastrophic Turkish earthquakes of 06.02.2023 is at the boundary between the MTB and AHFB. Besides this, a fold-block arc of the MTB deeply advanced to the north into the zone of the AHFB (Eppelbaum and Katz, 2023). Its distal part is shown with the corresponding designation (Fig. 1). It is significant that in the zone of this joint, the width of the Alpine belt of the Pontic-Caucasian zone is reduced to a minimum (Tye et al., 2022) – of about 500 km. Furthermore, to the west, from the Cyprus arc to Eastern Crimea, the width of the Alpine belt exceeds 1,200 km.

2. Brief Tectonic-Geophysical Background

The Easternmost Mediterranean (EMM) is a region belonging to the transition zone of the most prominent tectonic structures of the Earth – Eurasia and Gondwana (McKenzie, 1972; Ben-Avraham et al., 2002, 2006; Muttoni et al., 2003; Stern and Johnson, 2010). In the Cenozoic, four lithospheric plates were formed here: Nubian, Arabian, Aegean-Anatolian, and Sinai (Ben-Avraham et al., 2006). The area is characterized by unique geodynamics, which simultaneously expresses the elements of the geodynamic collision associated with the Tethys Ocean evolution (Le Pichon and Kreemer, 2010; Stampfli et al., 2013) and the Red Sea rift system's initial spreading (Bosworth et al., 2005). However, until now, the EMM's paleogeodynamics has not been entirely understood. The foreland sediments of Northern Arabia and Eastern Nubia are tectonically discordantly connected to the allochthonous Mesozoic Terrane Belt, which rotated counterclockwise in the direction of the Gondwana paleocontinent (Eppelbaum and Katz, 2015a, 2015b; Eppelbaum et al., 2021).

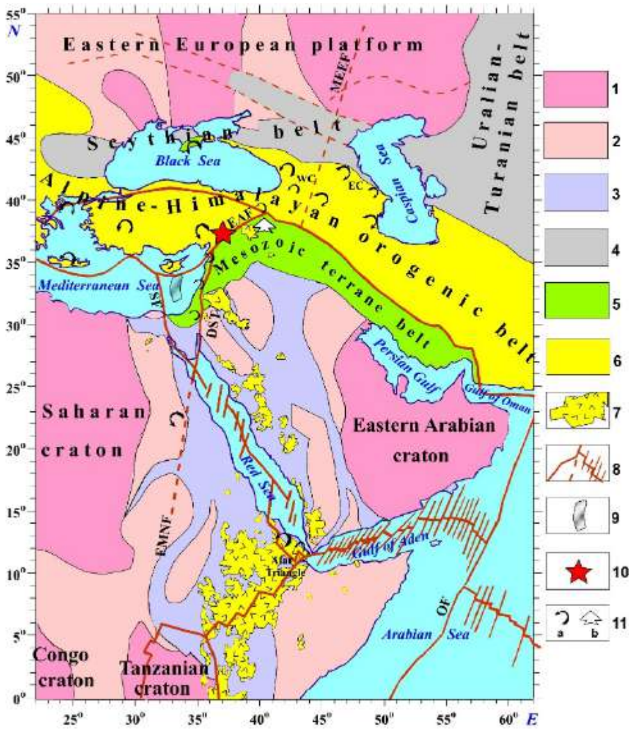

Fig. 1. The tectonic-geodynamic scheme of the region under study (modified after (Eppelbaum et al. (2021)).

(1) Archean cratons, (2-4) folded belts: (2) Paleo-Middle-proterozoic, (3) Neoproterozoic, (4) Late Paleozoic (Hercynian), (5) Mesozoic Terrane Belt (MTB), (6) Alpine-Himalayan orogenic belt, (7) Cenozoic traps of the African-Arabian rift belt, (8) main fault systems, (9) contour of the Kiama paleomagnetic hyperzone of inverse polarity (Eppelbaum et al., 2014; Eppelbaum and Katz, 2015b), (10) high magnitude seismogenic zone in Eastern Turkey (February 06, 2023), (11) **a**: rotational geodynamic elements derived from paleomagnetic data, **b**: distal part of the MTB. SF, Sinai Fault, DST, Dead Sea Transform, MEEF, Main Eastern European Fault, EMNB, Eastern Mediterranean Nubian Belt, OF, Owen Fault, WC, Western Caucasus, EC, Eastern Caucasus, EAF, Eastern Anatolian Fault.

Since the processes of plate geodynamics controlled the facies and structures of the habitat zones of ancient biocenoses, one should consider the actualistic model shown in Fig. 2. Here, for example, three geophysical fields are summarized (in fact, there are many more of them (Eppelbaum et al., 2024)): (1) smoothly averaged magnetic field ΔZ recalculated to one common level of 2.5 km over the msl, (2) residual gravity field map obtained from the satellite gravimetric observations, (3) GPS vector distribution from the satellite triangulation data

(Mahmoud, 2003; Reilinger et al., 2006; Khaffou et al., 2023; Eppelbaum and Katz, 2023).

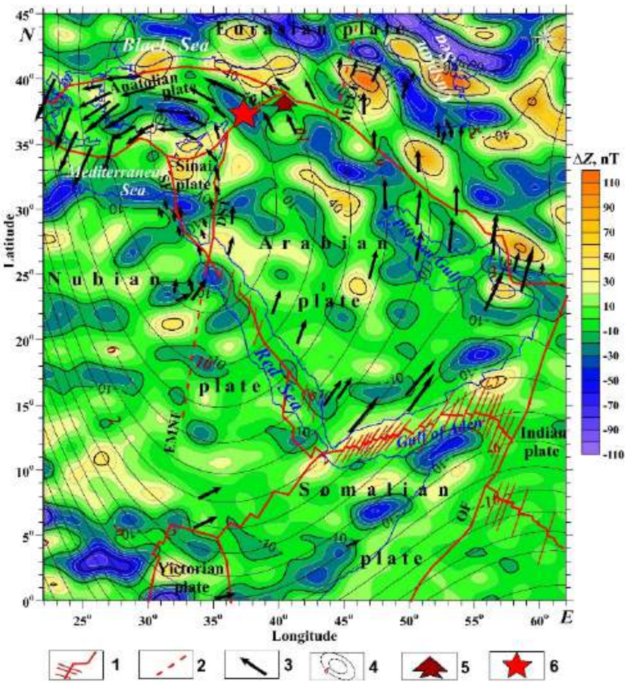

Fig. 2. Smoothly averaged magnetic Δ*Z* map recalculated to one common level of 2.5 km over the msl (initial data from https://geomag.colorado.edu/magnetic-field-model-mf7.html) for African-Arabian region with the main tectonic elements (Eppelbaum et al., 2024), the behavior of the GPS vectors (after Mahmoud, 2003; Reilinger et al., 2006; Khaffou et al., 2023) and overlaid residual gravity anomaly (Eppelbaum et al. (2021)).

(1) intraplate faults, (2) interplate faults, (3) GPS vectors, (4) residual satellite-gravity field isolines, (5) distal part of the Mesozoic Terrane Belt, (6) epicenters of two main catastrophic earthquakes in Eastern Turkey (February 06, 2023).

The geophysical map (Fig. 2) goes well with the tectonic map (Fig. 1). For explaining the paleogeography and biogeography of the geological past, important not only the structural-facial features of the development of ancient biocenoses but also various factors of the geodynamics of their formation since they reflect different levels of their intensity and significance in the migration and ecosystem biosphere process. In this regard, the geodynamic factors have long been taken into account, which has been well developed in the analysis of the relationships between ophiolitic, island-arc, and terrane associations in the aspect of correlation with the biocenoses of deep- and shallow-water zones (Dixon and Robertson, 1984; Katz, 1986; Ben-Avraham and Ginzburg, 1990; Lapkin and Katz, 1990; Kazmer, 1993; Hall et al., 2005; Alizadeh et al., 2016; Eppelbaum et al., 2021).

In the case of our research, an important role is played by the assessment of innovative geophysical studies that complement plate geodynamics, in particular, geoid, rotational, and mantle-convective factors that determine changes in the abiotic and biotic environment (Katz, 1986; Reilinger et al., 2006; Kadirov et al., 2012, 2013; Eppelbaum and Katz, 2021a, 2021b; Eppelbaum et al., 2024). First, we must pay attention to the development of a deep mantle sub-oval structure in the Arabian-Caucasian region, manifested in no less than fifteen anomalous geophysical and geological factors (Eppelbaum et al., 2024). Examples of the distribution of three anomalous fields: GPS vectors, magnetic field, and residual gravity field anomalies both in the Eastern Mediterranean and the Ponto-Caspian and Caucasus are shown in Fig. 2. This geodynamic factor can undoubtedly be very significant in assessing complex and inexplicable biogeographical phenomena identified in the Caucasian Mesozoic (Alizadeh, 1972; Alizadeh et al., 1983; Abdulkasumzadeh, 1988), which was traced based on geological and geophysical analysis of the formation of water areas and biocenoses of the Akchagylian stage in the Late Cenozoic basins of the Mediterranean and Ponto-Caspian Sea (Eppelbaum and Katz, 2021a, 2022, 2024).

The methodology for the linking between the biosphere and anthroposphere processes in connection with deep geophysical phenomena was developed using the example of the Akchagylian phenomenon, which manifested itself both in different facies basins of the Crimean-Caucasus region and in the Middle East – in the Levant and Nubia (Chumakov, 1967; Alizadeh et al., 2016; Eppelbaum and Katz, 2021a, 2024). Therefore, it is advisable to consider the features of the Mesozoic biogeography manifested in the phenomenon of sharp faunal differences between the Lesser Caucasus and the Levant in the same tectonic-geodynamic aspect.

Based on the above, the present study needs to pay attention to the Cenozoic stage when the Neotethys Ocean began to shrink under the influence of collision phenomena and was divided into two isolated residual basins: the southern Mediterranean and the northern Paratethys. The biogeographical and tectonophysical processes were in sharp contrast and incompatible with the stage of spreading geodynamics between Laurasia and Gondwana in the Mesozoic era.

3. Analysis of the Geodynamic Movements Combined with the Paleontological and Paleobiogeographical Data

Tectonic-geodynamic reconstructions of the transitional region between Eurasia and Gondwana (Scotese, 1991; Stampfli and Kozur, 2006), supplemented by paleobiogeographic and geodynamic data (Eppelbaum et al., 2024) show that in the Jurassic period, there were the most incredible distances between these supercontinents. The northern side of the

Neotethys adjoined Laurasia, and the southern side adjoined Gondwana. These two boundary zones differed biogeographically (Makridin et al., 1968; Hallam, 1975; Hirsch, 1988).

With the evolution of the Neotehys Ocean, the pelagic facies and nektonic organisms reached their maximum dominance. However, the ecosystems of the Boreal and Ethiopian provinces were located on the continental shelf and bordered the vast expanses of land in the northern and southern parts of Pangea (Fig. 3). At the present stage of the Mesozoic Ocean collision, the northern and southern sides of the Neotethys are geodynamic connected to a single structure associated with the deep mantle uplift. It is manifested in the numerous GPS studies in the Caucasus and surrounding regions (e.g., Reilinger et al., 2006; Kadirov et al., 2012, 2013; Eppelbaum et al., 2021a, 2023b).

In the Jurassic period, the southern Arabian-Levantine and northern Crimean-Caucasian sides of the Neotethys were at a considerable distance and could not be geodynamically connected. The present studies tested this indirect conclusion based on a comparative paleobiogeographic analysis of the Tethyan faunas of the western and eastern (Caucasian) parts of the Neotethys. In Fig. 3, we show the development of a specific fauna of the Late Jurassic (Kimmeridgian-Tithonian) *Pygope* brachiopods, indicators of the relatively deep-sea Neotethys zone (Kazmer, 1993), and widespread throughout the western part of this basin from the Rif Mts. to the Alpine-Carpathian Basin and Greece (Barczyk, 1972; Dibni and Middlemiss, 1981; Sandy, 1988, 1991; Vörös, 1993; Benzaggargh and Atrops, 1997; Énay et al., 2005; Bujtor et al., 2020). The significant factor is the discovery of this critical Tethys biogeographical indicator in the east – in various points of the Lesser Caucasus, carried out by Askerov (1965) (see Abdulkasumzade (1988)). Along with the *Pygope* finds, a typically Mediterranean complex of the Upper Jurassic brachiopods was identified here: *Lacunosella*, *Cheirothyris*, *Ismenia*, *Goniothyris*, *Sphaeroidothyris*, *Ptyctothyris, Aulacothyris* and some others (Askerov, 1965; Abdulkasumzade, 1988).

Examining paleobiogeographic data confirms the deep structure rotation and its relationship with the near-surface structures (Eppelbaum et al., 2024). Like the paleomagnetic ones, they show earlier stages of deep structure rotation and its reflection in surface geology. The region under consideration is essential for analyzing the development spreading stage (mainly Mesozoic) of the development of the Neotethys Ocean and adjacent parts of Gondwana and Laurasia. Special attention is drawn to anomalous biogeographic indicators, particularly shell remains of giant Late Jurassic brachiopods *Septirhynchia–Somalirhynchia*, Late Cretaceous brachiopods *Praeneothyris* and giant shells of Triassic endemic myalinid bivalves *Ramonalina*, (Katz, 1962; Makridin et al., 1966, 1968; Feldman, 1987; Cooper, 1989; Yancey et al., 2009; Feldman et al., 2014; Eppelbaum et al., 2024).

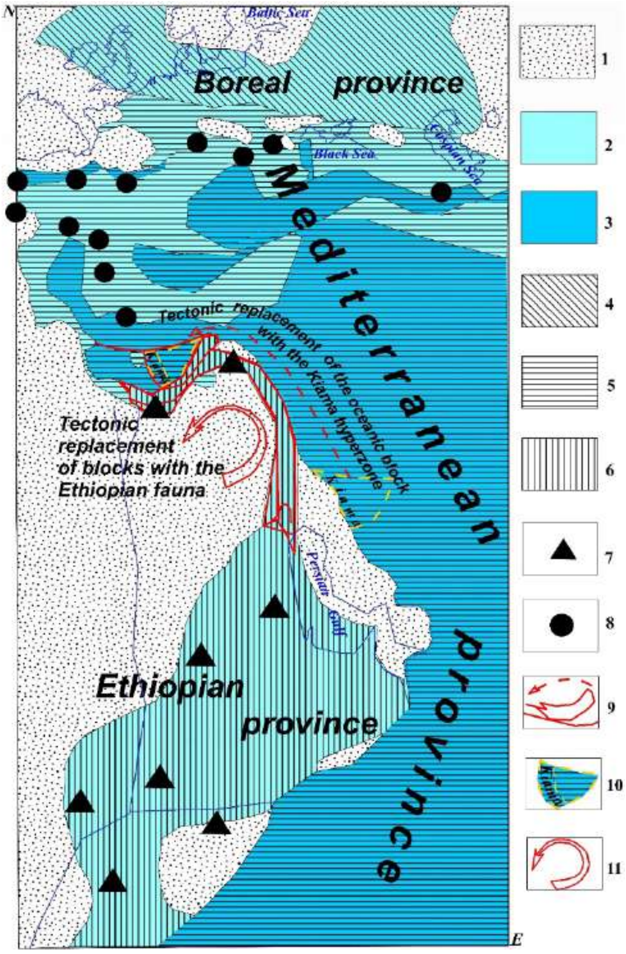

Fig. 3. The schematic Late Jurassic paleobiogeographical map of the transitional region of Eurasia and Gondwana with the elements of the subsequent Early Cretaceous geodynamics of the Mesozoic Terrane Belt. The blue lines show the modern boundaries between the seas and land.

(1) land, (2) continental shields and arcs, (3) oceanic plateaus and rifts, (4) Boreal paleobiogeographic province, (5) Mediterranean paleobiogeographic province, (6) Ethiopian paleobiogeographic province, (7) location points with the Ethiopian brachiopods *Septirhynchia-Somalirhynchia*, (8) location points with the Mediterranean brachiopods *Pygope*, (9) tectonic lines of discordant paleobiogeographic replacements, (10) block of the oceanic crust with the Kiama hyperzone, (11) counterclockwise rotated tectonic blocks.

This map was constructed using paleobiogeographic data from Arkell (1956), Askerov (1965), Makridin et al., 1968; Barczyk, 1972; Tchoumatcuenko, 1978; Feldman, 1987; Abdulkasumzade, 1988; Hirsch, 1988; Hirsch and Picard, 1988; Cooper, 1989; Golonka and Ford, 2000; Hall et al., 2005; Énay et al., 2005; Kazmer, 1993; Bujtor et al., 2020; Eppelbaum and Katz, 2023) and tectonic-geodynamic data from Scotese (1991), Stampfli and Kozur (2006), Eppelbaum et al. (2021), Eppelbaum and Katz (2023).

3.1 Late Jurassic paleobiogeographical map

The biogeographical mapping was based on the works of Scotese (1991), Stampfli and Kozur (2006), and previous authors' investigations (Eppelbaum and Katz, 2015b, 2020). In the region under study (Arkell, 1956; Makridin and Katz, 1966; Feldman, 1987; Hirsch, 1997; Hirsch and Picard, 1988; Cooper, 1989; Alizadeh et al., 2016), three paleobiogeographical provinces were selected (Fig. 3): Boreal (Eurasian shelf), (2) Mediterranean (Mediterranean Basin), and (3) Ethiopian (Arabia – Southeastern Africa).

At the same time, the ecosystems of the Boreal and Ethiopian provinces were located on the continental shelf and bordered by vast expanses of land in the northern and southern parts of Pangea. The constructed map (Fig. 3) shows the phenomenon (see the red arrow rotating counterclockwise) of the geodynamic transfer of tectonic blocks with the remains of the Ethiopian fauna from the present position of the Persian Gulf to the Levant (up to the Egyptian Western Desert). This fact proves the counterclockwise movement of the eastern and central parts of near-surface projections of the anomalous deep structure in the Jurassic and Early Cretaceous.

All of those mentioned above enabled us first to use geophysical and geodynamic characteristics to explain the uniqueness of the biogeographically anomalous zone of terrane block attachment to the Gondwana paleocontinent in the middle of the Early Cretaceous in the Levantine phase of tectogenesis (Eppelbaum and Katz, 2015b; Eppelbaum et al., 2024).

These studies are critical in terms of the separation of Tethys and Ethiopian Late Jurassic basins. Their biogeographical contact in the Levant in the context of the existence of an extensive barrier of the Western Arabian land (Makridin et al., 1968) was inexplicable for many decades until the development of tectonic-geodynamic studies in the region using deep geophysical studies (Ben Avraham and Ginzburg, 1990; Ben Avraham et al., 2002, 2006; Eppelbaum and Katz, 2011, 2015b, 2023), when the tectonically allochthonous nature of terrane blocks with the Ethiopian fauna was proven displaced in a counterclockwise rotation direction over a distance of more than 1,500 km from the area adjacent to the northwestern part of the modern Persian Gulf position. Similarly, the Neotethys terrane block of the primary oceanic crust, containing the oldest discovered oceanic crust of the Kiama paleomagnetic zone, was moved into the Levant (Eppelbaum et al., 2014).

In the plate-tectonic reconstruction of the Jurassic location of the MTB (Fig. 4), the identified theoretical data of a biogeographical and structural-paleogeographical nature are essential as a secondary criterion of a qualitative nature. It is significant that they are complemented by precise criteria for the primary orientation of the terrane blocks and are very important for analyzing the relationship of the Mesozoic Terrane Belt with the Gondwana foreland and the deep-sea basins of the Neotethys Ocean.

3.2 Geodynamics of the Mesozoic Terrane Belt in the Jurassic period

Biogeographical, deep structural-geophysical, and geodynamic data are the most critical regional aspects in the plate-tectonic position of the terrane belts. However, their direct paleotectonic mapping requires a criterion for the local relative position and orientation of terrane blocks, as shown in mapping the Hercynian belt of Avalonia (Cope et al., 1992). No less elegant works were performed in the Middle East for localization of the Neoproterozoic belt of the Arabian-Nubian region (Stern, 1994; Al-Husseini, 2000; Stern et al., 2004; Johnson and Kattan, 2008) where, in a complex range of the collision belt structures, multi-scale, including striped, terrane blocks appear.

We correct their relative position and orientation in pre-collision plate-tectonic reconstructions using three criteria: (1) the sequence of the final collision junction (Eppelbaum and Katz, 2015b), (2) the combination and nature of the relationship between the zones of syn-sedimentary uplifts and troughs, which we developed earlier (Eppelbaum and Katz, 2011, 2015b), and (3) data paleomagnetic-geodynamic mapping of terrane blocks indicating their rotation based on the orientation data of dike swarms of different ages (Eppelbaum et Katz, 2015a) and consistent reconstruction of the orientations of the terrane blocks themselves over time (Eppelbaum and Katz, 2022; Eppelbaum et al., 2023a).

In this work, we study the Middle East – Caucasus geodynamics problem in more detail, using the plate tectonic analysis of the terrane block movement, both MTB and the more ancient Tauride Belt (Channell et al., 1996; Golonka, 2004; Zakariadze et al., 2007), to explain several Mesozoic biogeographical paradoxes of the Middle East and the Caucasus (Alizadeh, 1972; Alizadeh et al., 2016; Eppelbaum and Katz, 2020, 2021b). These data are considered below.

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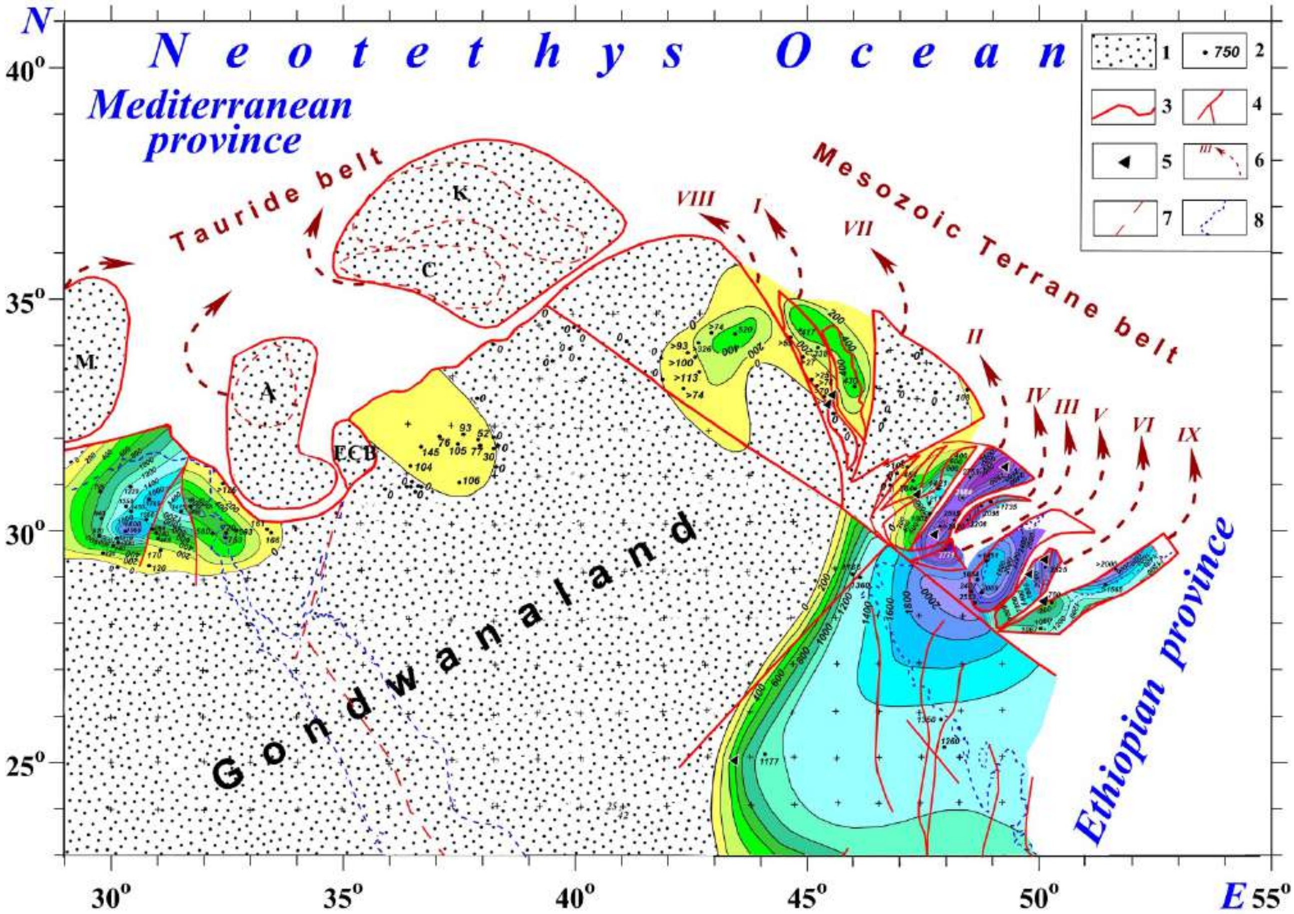

Fig. 4. Geodynamics of the Mesozoic Terrane belt (MTB) in the Jurassic period with elements of the Gondwana-Neotethys paleogeography and biogeography. The following primary sources were used for this map development: Arkell, 1956, Dixon and Robertson, 1984; Feldman, 1987; Cooper, 1989; Al-Husseini, 2000; Dercourt et al., 2000; Hall et al., 2005; Zakariadze et al., 2007; Feldman et al., 2014; Eppelbaum and Katz, 2015b; Said, 2017; Eppelbaum and Katz, 2023.

(1) Gondwanaland and MTB, (2) boreholes and outcrops with the Jurassic sediment thicknesses, (3) boundary of the Gondwana and MTB blocks, (4) syn-sedimentary Jurassic faults, (5) outcrops of the Ethiopian fauna *Somalirhynchia*-*Septirhynchia*, (6) counterclockwise rotating of the MTB concerning to the Jurassic collision system (the Roman numbers designate an order of the conjunction with the west Arabian part of Gondwana), (7) postcollisional faults, (8) modern land-sea boundaries.

ECB, Eratosthenes continental block. Precambrian massifs in the Tauride belt terranes: A – Alanya, C – Central Tauride, K – Kirsehir, M – Menderes.

Classic plate tectonic reconstructions are dominated by planetological methods considering the position of expansion and rotation poles of major tectonic plates and paleomagnetic measurements aimed at reconstruction of paleolatitudes and paleolongitudes (e.g., Van der Voo et al., 1991; McElhinny and McFadden, 2000; Tauxe, 2002). In addition to mentioned, various data from paleogeography, sedimentology, and palinspastic reconstructions are used (Khramov et al., 1974; Cope et al., 1992; Dercourt et al., 2000; Golonka and Ford, 2000; Stampfli and Borel, 2002; Muttoni et al., 2003; Khramov and Iosifidi, 2012; Stampfli et al., 2013; Uzel et al., 2015; Eppelbaum and Katz, 2021a, 2024; Le Pichon et al., 2023). In our case of the extraordinary structural complexity of the region under study, we used combined data for tectonic-geodynamic reconstructions with the attracting of paleobiogeography, syn-sedimentary tectonics, regional geodynamics, and detailed paleomagnetic mapping (Eppelbaum and Katz, 2015b, 2020, 2024; Eppelbaum et al., 2014, 2021, 2023a).

According to these studies, the allochthonous nature of most parts of the tectonic structures of the continental and oceanic crust of the Eastern Mediterranean was proven. An analysis of the relationship between the boundary structures of the Gondwana continent and the Neotethys Ocean indicates that in the Jurassic, the northwestern part of its Arabian segment was uplifted relative to the southeastern margin adjacent to the modern Persian Gulf (Fig. 4). Therefore, during the reconstruction, blocks of the Tauride ophiolite belt were placed in the northwestern part of the region. Blocks of the MTB were placed in the southwestern part by their syn-sedimentary and biogeographical sequence, which is depicted on the developed map. Paleobiogeographic data also confirm this phenomenon. In the Upper

Jurassic, in the sections of the Arabian Plate and the Negev, Galilee-Lebanon, Anti-Lebanon, and Palmyrides terranes, remains of **Somalirhynchia-Septirhynchia** of the Ethiopian province are widely developed (Fig. 4).

The most essential element of the reconstruction is the location of the MTB directly on the northern shore of the Persian Gulf's current position. Now, it is the boundary between the ancient Precambrian Arabian platform and the Zagros terrane. Consensus data (Bordenave, 2008) indicate that the Zagros terrane is allochthonous (Eppelbaum and Katz, 2017). While thick strata of the Jurassic sediments are developed in the Persian Gulf region, Jurassic sediments are practically absent throughout the vast Zagros terrane (Bordenave, 2008). Thus, the primary location of the small linear MTB terranes looks tectonically correct. Their orientation, which differs from the modern one, was revealed earlier during paleomagnetic-geodynamic mapping (Eppelbaum et al., 2023a), the results of which are discussed in Section 3.3.

Paleo-structurally, analysis of the MTB demonstrates its connection with the geodynamics of the eastern end of the Arabian Gondwana (Eppelbaum and Katz, 2017), adjacent to the sharply subsided margin of the Mesozoic Neotethys Ocean. An active zone of graben-like structures developed here, which appeared in the Late Jurassic as favorable oil and gas deposits and seals of the world's largest fields in Saudi Arabia, Qatar, and Kuwait (Al-Husseini, 2000). These submeridional faults continue in the terrane belt outside Gondwana, creating an extraordinary contrast of syn-sedimentary uplifts and troughs. Moreover, these unusual structures are complicated by the mantle alkali-basalt and alkaline intrusions – swarms of the Jurassic dikes and stocks of different ages (Eppelbaum and Katz, 2015b; Eppelbaum et al., 2023a).

The unusual, banded junction of terrane blocks adjacent to the ancient Precambrian Arabian Platform is because the belt is allochthonous (Eppelbaum and Katz, 2015b) and is composed of the relatively young Late Precambrian crust covered by the Paleozoic and younger sedimentary rocks and trap complexes. The fact that the most minor and narrowest blocks, such as the Heletz terrane and the Hameishar, Ramon, and Avdat subterranes of the Negev terrane, are adjacent to the sharply lowered western flank of the Jurassic trough of the eastern margin of Gondwana indicates that at that time, the axial part of the deep mantle uplift was located here. Judging by the sedimentation data (the age of sedimentary rocks of the Gondwana foreland), it was formed at the Carboniferous-Permian boundary, and at the end of the Jurassic period, it began to rotate in a counterclockwise direction.

3.3 Geodynamic-paleomagnetic map of the Makhtesh Ramon area (southern Israel)

In the process of innovative geoscience mapping using remote sensing techniques and comprehensive modeling aspects, we are faced with the analysis of complex geological structures with the need to use well-developed criteria of a multidisciplinary methodology, where the numerical data of the exact sciences are well-combined with the versatile qualitative data of basic research in the field of evolutionary paleontology and careful ecological and taxonomic research. The developed geodynamic-paleomagnetic map of the Makhtesh Ramon Canyon (southern Israel) is entirely unexpected and indicative (Fig. 5).

Our comprehensive analysis indicates that the Negev terrane (based on the results of paleomagnetic-geodynamic analysis of the dike complex in the Makhtesh Ramon subterrane (Fig. 5B)) has rotated from the mid-Jurassic period in a counterclockwise direction by more than 90 degrees compared to its modern orientation (Eppelbaum et al., 2023a). This process's global character is confirmed by Cyprus's counterclockwise rotation in the Eastern Mediterranean (Eppelbaum et al., 2024; Hepworth et al., 2024).

3.4 Geodynamics of the Mesozoic Terrane Belt on the accretion stage

The developed tectonic-paleobiogeographic maps (Figs. 3-5) allow us to construct a geodynamic map of the Mesozoic Terrane Belt (MTB) during the accretion stage (Fig. 6). By the middle of the Early Cretaceous (at the boundary of the Early and Late Hauterivian), during the Levantine phase of tectogenesis, the rotating blocks of the MTB were attached along a system of transform arcuate faults to the western Arabian-Nubian part of Gondwana (Eppelbaum and Katz, 2015b). The sequence of the discordant junction of the terranes of the MTB with Western Gondwana is indicated in Fig. 6. Here, this sequence is illustrated both in the structural-geodynamic and paleobiogeographic terms in the form of paleo-faunistic indicators, indicators (inline form) belonging to certain biogeographic provinces of the Jurassic Sea basins, developed in the zone of development of both continental and oceanic crust. In this form, we, for the first time, consider together the relationship of tectonic and paleobiogeographic mapping, indicating the movement of terranes embedded in both continental and oceanic crust. By a complex movement in the counterclockwise direction along a system of transform faults, these terranes formed the complex collisional structure of the Eastern Mediterranean.

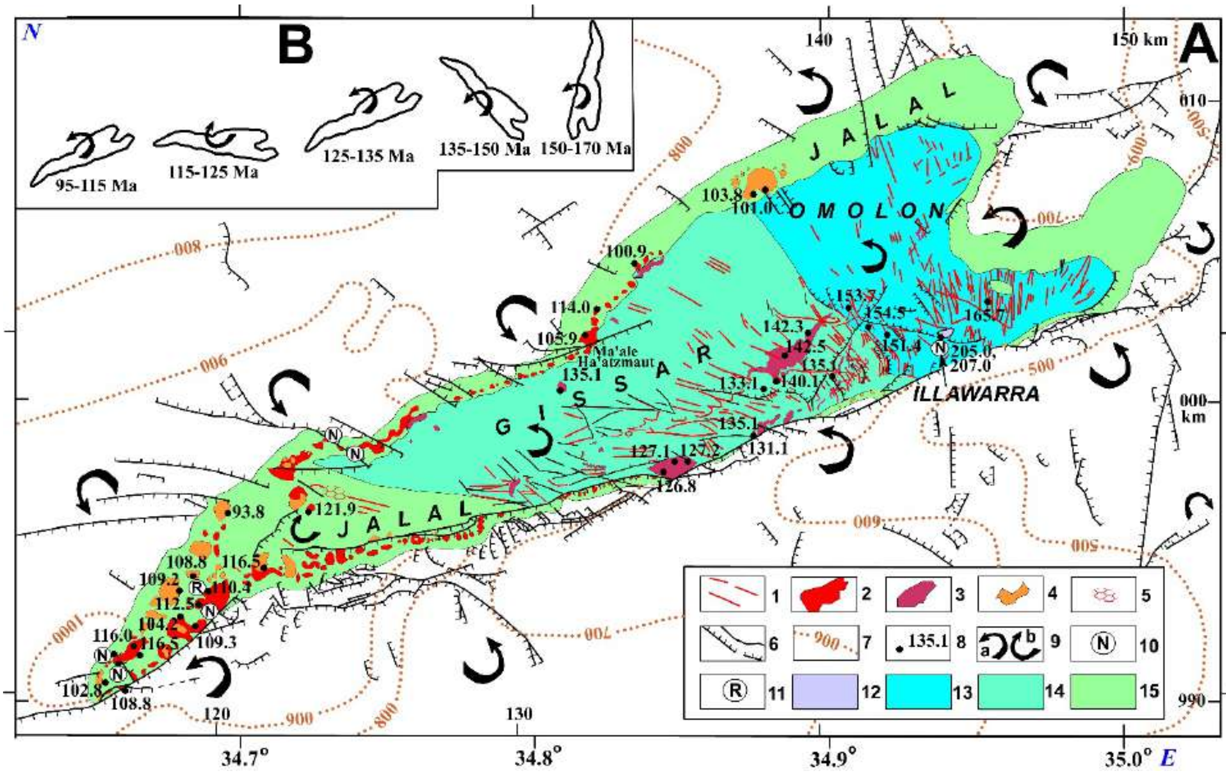

Fig. 5. Geodynamic-paleomagnetic map of the Makhtesh Ramon Canyon (southern Israel) (modified and supplemented after Eppelbaum and Katz, 2015b). **A**: Geodynamic-paleomagnetic indicators. **B**: Geodynamic changes of the Makhtesh Ramon subterrane displacement in the Middle Mesozoic.

(1) precollisional-collisional basalt dikes, (2) postcollisional alkali olivine basalt flows and volcanoclastic rocks, (3) precollisional association of alkali olivine gabbro, monzogabbro and syenites, (4) postcollisional association of basanites and nefelinites, (5) quartzitic hexagonal prisms, (6) faults, (7) hypsometric isolines within the Makhtesh Ramon plateau (1-7 from Garfunkel and A. Katz (1967), Zak (1968), Baer and Reshes (1991), Baer (1993), Sneh et al. (1998), Avni (2001), Zilberman and Avni (2004a, 2004b); Vapnik et al. (2007), Yudalevich et al. (2014), Eppelbaum and Y. Katz (2015b), Avni et al. (2016, 2017), Baer et al. (2017), Yudalevich and Vapnik (2018), (8) radiometric age of the magmatic rocks (from Lang and Steinitz (1989), Segev (2000), Segev et al. (2005)), (9) counterclockwise (a) and clockwise (b) rotation of the linear structures (faults, dykes and volcanic ridges), (10)-(11) magmatic rocks with normal (10), and reversal (11) paleomagnetic polarity (from Ron and Baer (1988), Gvirtzman et al. (1996), Baer et al. (1995), (12)-(15) paleomagnetic zonation within the magmatic complexes: (12) Illawarra, (13) Omolon, (14) Gissar, (15) Jalal.

Tectonic-geodynamic mapping of the study area was expanded to include other stages of development for the region under study. First, the connection between the deep geodynamics and the development of its structures, basins, and ecosystems in other periods of geological history is fascinating.

3.5 Geodynamics of the Mesozoic Terrane Belt in the Triassic period

For comparison with the Jurassic period of development of the MTB's structures and sedimentary basins of the Gondwana foreland, a Triassic plate-tectonic reconstruction was carried out using a similar methodology (Fig. 7). According to the data of syn-sedimentary paleotectonic analysis (Eppelbaum and Katz, 2011; 2015a, 2015b, 2023; Eppelbaum et al., 2021, 2023a) and paleomagnetic-geodynamic mapping with associated identification of the tectonothermal activity cycles, there is an insignificant contrast of tectonic-magmatic phenomena in the Permian and the Triassic in the Arabian segment of Gondwana. In this regard, the conclusion that the deep mantle structure, which determined this region's rich and very complex geodynamics in the Late Mesozoic and Cenozoic, was still in its infancy looks understandable. The Permian formations in the pericratonic depressions of the described part of Gondwana and within the MTB were very shallow and thin – up to 600-800 m, and igneous formations lie at their base and correspond to the Kiama paleomagnetic hyperzone. The Permian strata are broken through by younger intrusions (Hall et al., 2005). The picture for the Triassic is almost similar; however, during this period, the intensity of the amplitude of the sedimentation tectonics processes increases more than twice compared to the Permian stage. Meanwhile, the contrast of troughs and uplifts is not comparable to the Jurassic period's tectonics. In addition, the intensity of magmatism development was almost not manifested.

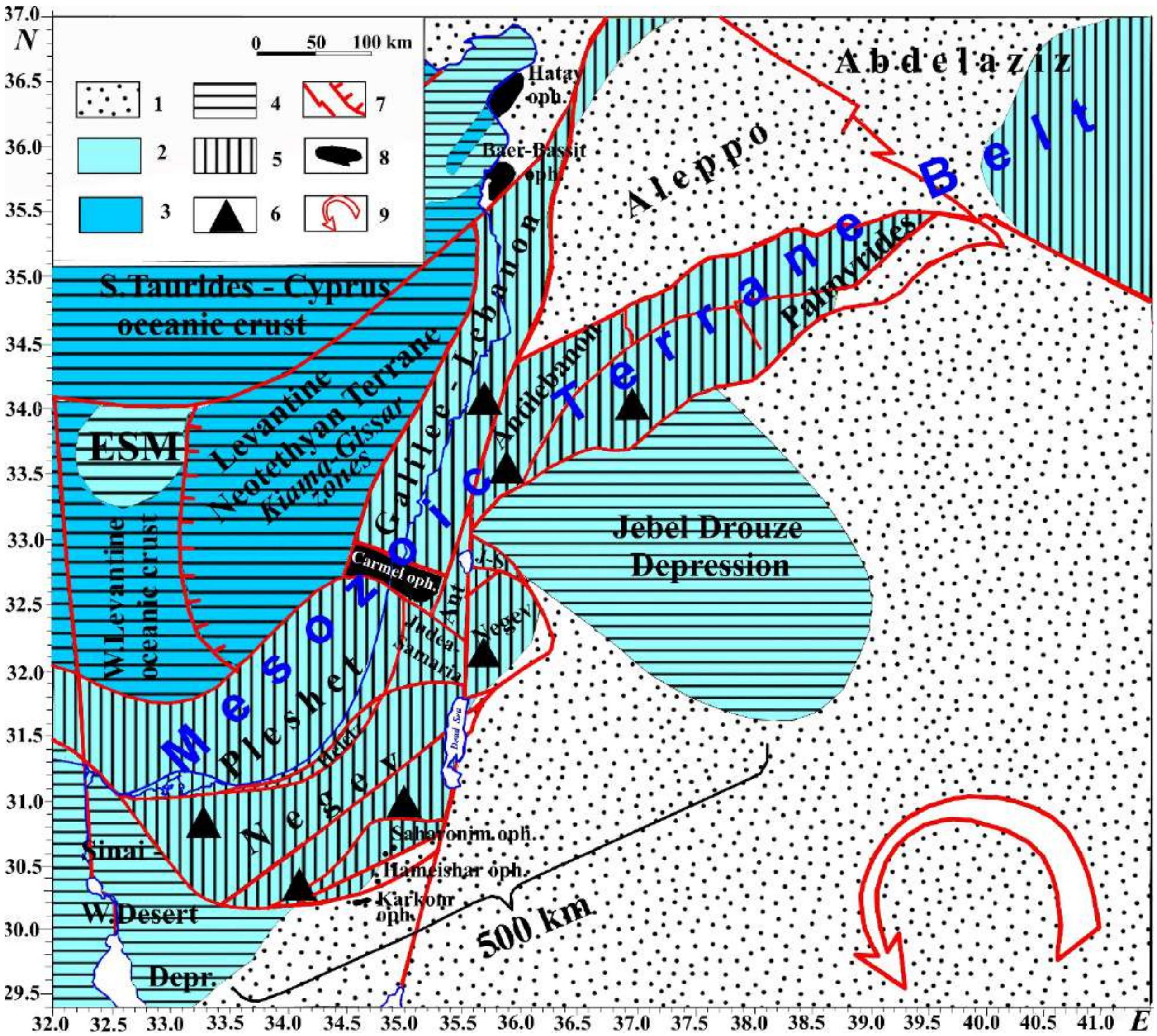

Fig. 6. Geodynamics of the Mesozoic Terrane Belt (MTB) on the accretion stage with the Gondwana-Mediterranean tectonic-paleobiogeographical elements. The following main sources were used for this map development: Feldman, 1987; Hall et al., 2005; Feldman et al., 2014; Eppelbaum and Katz, 2015b, 2023; Eppelbaum et al., 2024.

(1) Jurassic land, (2) Jurassic aquatics with the continental crust' structures, (3) Jurassic aquatics in the structures with oceanic crust, (4) Mediterranean province, (5) Ethiopian province, (6) outcrops of the Ethiopian fauna *Somalirhynchia-Septirhynchia*, (7) faults, (8) ophiolites, (9) MTB counterclockwise rotating. ESM, Eratosthenes Seamount.

Therefore, when constructing a tectonic map of the Triassic period (Fig. 7), we located terrane blocks in almost the same places and with the same orientation as in the Jurassic period reconstruction. The actual data coincided with the mapping data of the syn-sedimentary structures of the MTB and the Gondwana foreland. It is new that the maximum of the belt subsidence (almost up to 2,600 m) is confined to the Galilee-Lebanon terrane near its border in the Neotethys oceanic trough. The second element is the reconstruction of the proposed axis of formation of the deep mantle structure, which is confirmed by the development of ring alkaline intrusions (220 and 229 Ma) in the South Eastern Desert of Nubia (Said, 2017) and almost coeval magmatic manifestations (231 Ma) in the southernmost part of the Negev terrane in the Hameishar borehole in the boundary zone between the terrane and the Sinai uplift of the Neoproterozoic belt (Eppelbaum and Katz, 2015b).

These points of development of Triassic magmatism probably mark the formation of a deep mantle structure, the presumed axial line of which is depicted as a conditional fault with the supposed appearance of the first hot spots. In biogeographical terms, in the Triassic, there was no significant differentiation of data on cephalopods and conodonts of different parts of the Neotethys are very similar (Hirsch, 1997; Le Nindre et al., 2023). Undoubtedly, the marine biocenoses of the Neotethys basin contain a significant number of endemics, among which giant shells of myalinid bivalves, assigned to the new genus **Ramonalina**, were described in the Triassic of the Negev terrane in outcrops of the Makhtesh Ramon basin (Yancey et al., 2009). Significantly, these authors described these large bivalves discovered in reef facies; over the past fifteen years, their remains have not been found anywhere else.

3.6 Paleobiogeographical map of the Maastrichtian basins of the Neotethys Ocean's western part

Of significant interest in paleobiogeography and geodynamics is the analysis of the marginal Neotethys basins in the Late Cretaceous and especially at its end – in the Maastrichtian (Fig. 8). At this time, the ocean basin of both the North and South Atlantic had already opened widely (Zonenshain and Savostin, 1979), the Indian Ocean had expanded significantly (Ali and Krause, 2011), and the Hindustan platform with a colossal area of Maastricht basalt traps approached the northern side of the Neotethys. The extensive Maastrichtian Neotethys shelf was represented by typically Mediterranean biotas, among which the most striking indicators were goblet-shaped bivalves (rudists) homeomorphic to corals, which only occasionally formed biocenoses in the southern margins of the basins of the European province. However, its most crucial paleobiogeographic indicator was the intrashell cephalopods – belemnites (Alizadeh, 1972). Through the Turgai Strait, there was an exchange between the biotas of the European and Boreal-Pacific provinces, which was clearly shown based on the distribution of the brachiopod fauna (Katz, 1986).

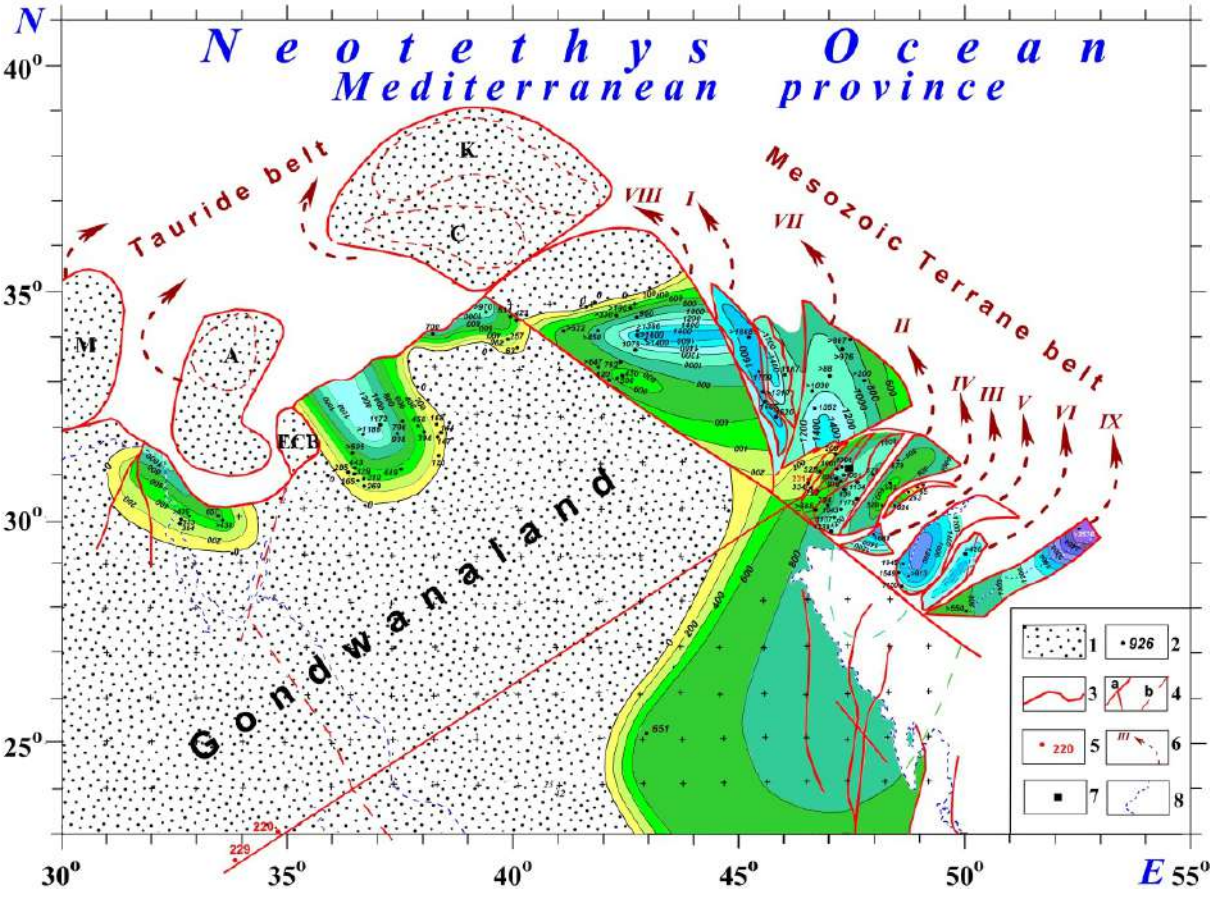

Fig. 7. Geodynamics of the Mesozoic Terrane Belt (MTB) in the Triassic period with the elements of Gondwana-Neotethys tectonic and paleobiogeographical elements. The following main sources were used for this map development: Al-Husseini, 2000; Hall et al., 2005; Krasheninnikov et al., 2005; Yancey et al., 2009; Eppelbaum and Katz, 2015b; Said, 2017.

(1) land of the Gondwana and MTB, (2) boreholes and outcrops with thickness of Triassic sediment thicknesses, (3) boundary of the Gondwana and MTB blocks, 4(**a**, **b**): **a**: syn-sedimentary Triassic and Jurassic faults, **b**: postcollisional faults, (5) boreholes and outcrops with radiometric dating of the Triassic magmatic rocks, (6) counterclockwise rotating of the MTB concerning to the Jurassic – Early Cretaceous collision system (the Roman numbers designate the conjunction order with the western Arabian part of Gondwana), (7) outcrop of the endemic bivalvia *Ramonalina* in the MTB, (8) modern land-sea boundaries.

ECB, Eratosthenes continental block. Precambrian massifs in the Tauride belt terranes: A – Alanya, C – Central Tauride, K – Kirsehir, M – Menderes.

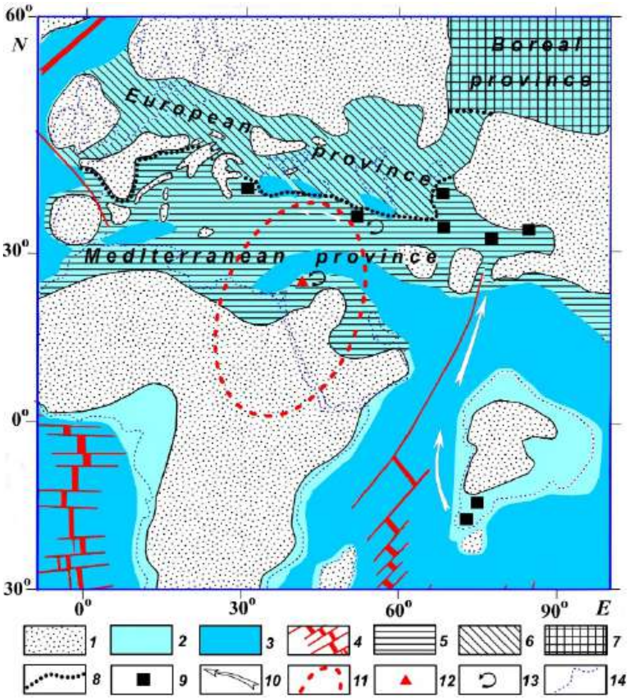

Fig. 8. Paleobiogeographic map of the Maastrichtian basins of the Neotethys Ocean's western part and the adjacent shelf seas of Eurasia and Gondwana with the elements of deep geodynamics. The following main sources were used for this map development: Tzankov, 1930; Katz, 1962; Makridin and Katz, 1966; **Zonenshain and Savostin, 1979;** Alizadeh et al., 1983; Gasanov, 1986; Nur et al., 1989; Golonka, 2004; Khalafly, 2006; Adamia et al., 2011; Ali and Krause, 2011; Alizadeh et al., 2016; Eppelbaum et al., 2023a.

(1) land, (2) areas of shelf seas of continental margins and intra-oceanic rises, (3) intra-oceanic troughs and rises with the oceanic crust, (4) oceanic rift zones, (5-7) paleobiogeographic provinces: (5) Mediterranean, (6) European, (7) Boreal, (8) boundaries between provinces, (9) outcrops of the giant Tethyan brachiopods *Praeneothyris spp*., (10) directions of migration of *Praeneothyris* within the Neotethys basins, (11) boundaries of the outlines of the suboval deep mantle structure, (12) Mt. Carmel (northern Israel) geodynamic block in the apical part of the deep mantle structure, (13) identified paleomagnetic counterclockwise rotation zones of the Levant (Mt. Carmel) and the Lesser Caucasus (Garabakh, Azerbaijan) regions, (14) outline of the modern boundaries of land and sea and the intracontinental margins of discordant zones of continental platforms.

4. Discussion

The distant migration of paleontological species (see previous section) makes us turn to the interaction of biotas emerging in the Cretaceous period in the Indian and Southern Oceans with more northern biotas of the Mesozoic Neotethys Ocean. Bulgarian paleontologists discovered shells of the giant Maastrichtian brachiopods (e.g., Tzankov, 1930) on its northern side, like modern inhabitants of the southern (Notal) biogeographical province. In South India, in the same Maastrichtian deposits, paleontological forms very similar to them were identified. Special studies in Central Asia at the turn of the 50-60s revealed the widespread development in this region of the described southern migrants from the opening Indian Ocean basin, assigned to the new genus *Praeneothyris* (Katz, 1962). However, findings identified for these southern migrants are extended in a submeridional direction from Hindustan to Central Asia. A biogeographic hiatus existed between this range and a scattered locality in Bulgaria. It was filled more than 20 years later (Alizadeh et al., 1983) when an extensive complex of organisms was discovered and studied in the Lesser Caucasus, including a unique composition of biotas of the Mediterranean, European type (Alizadeh, 1972), along with those migrating from the south migrants *Praeneothyris*.

The biogeographical paradox of mixing various biotas in the Lesser Caucasus requires an explanation from the standpoint of paleogeography and plate geodynamics. First, the Lesser Caucasus is in the narrowest place of the collisional Alpine belt between the Eurasian and Arabian plates, where the processes of collision of the Neotethys Ocean are most active. In addition, the zone of the oceanic trench at the intersection of the end of the Neotethys and the Indian Ocean rift comes closest here. The third geodynamic factor is the location of the Lesser Caucasus near the most active northern end of the deep mantle uplift, which rotated counterclockwise. The apical part of this uplift was located near the modern horst of Mt. Carmel (Israel). A system of ring concentric faults complicates the structure of the mentioned horst and, according to paleomagnetic data (Ron et al., 1984; Nur et al., 1989), rotates in a counterclockwise direction. The modern GPS data (Reilinger et al., 2006; Le Pichon and Kreemer, 2010) show that these movements, developed in the Aegean-Anatolian lithospheric plate, are geodynamic most intense in the northern zone.

Paleomagnetic data for the Upper Cretaceous of the Azerbaijani part of the Lesser Caucasus (e.g., Khalafly, 2006) indicate that this area experienced counterclockwise rotation, which contributed to the further migration of ecosystems and biocenoses of the Lesser Caucasus to the west. The mixed nature of the Maastrichtian biotas of the Lesser Caucasus is because to the east of it, like the modern geodynamic situation (based on analysis of GPS data (e.g., Reilinger et al., 2006; Kadirov et al., 2013)) in the meridional zone between the Pontus and the Caspian, there is a divergence in rotation directions (Eppelbaum et al., 2021, 2024). A similar picture is observed in the Maastrichtian age when the belemnites and brachiopod fauna moved from the nearest basins of the European province of Transcaucasia to the Mediterranean Basin of the Lesser Caucasus. At the same time, the Indian Ocean brachiopods *Preneothyris* at the larval stage experience migration diverging near the marginal part of the projection of the deep mantle structure slope both counterclockwise and clockwise (Fig. 8).

This study attempts to explain the paleobiogeography of the Mesozoic Neotethys Ocean based on a combination of methods of structural-geological analysis and geophysical surveys using data from satellite technologies and advanced modeling. Based on the synthesis of paleobiogeography and tectonophysical studies, we have proposed a new methodology for complex dynamic cartography. It significantly expands the boundaries of the previous plate tectonics and allows us to identify new branches of geodynamics. This is primarily: (1) analysis of tectonothermal processes in the zone of development of local deep mantle structures, (2) geodynamics of surface (crustal and crust-mantle) terrane belts, ophiolite plates, mantle diapirs, and trap complexes, (3) geodynamics of shear zones, transform rotation structures and ring tectonic-magmatic structures. In addition, it is planned to develop new methods of paleomagnetic mapping using palinspastic reconstructions, cyclic analysis of trap complexes and facies heterogeneities determined by deep geodynamics and the completeness of the section of sedimentary strata as elements of hydrosphere disturbances.

In our work, we showed the relationship between the biogeographical phenomena of the Neotethys Ocean ecosystems and its geodynamic evolution – from initial spreading to the widespread development of collision processes towards the end of the Mesozoic era (Gasanov, 1986; Adamia et al., 2011). These relationships, along with other factors, made it possible to explain the phenomenon of biogeographical heterogeneity of the Maastrichtian faunas of the Garabakh region (western Azerbaijan), where associations of three paleobiogeographical provinces were paradoxically combined: Mediterranean, European, and Indian. Tectono-geodynamic mapping made it possible to elucidate the evolution of the deep mantle structure for the first time. The biogeographical allochthonous nature of the Mesozoic Terrane Belt, containing the *Somalirhynchia-Septirhynchia* fauna and the Levantine oceanic terrane, including the Kiama and Illawarra-Gissar paleomagnetic zones, was finally proven.

However, the most important conclusion is the significant paleobiogeographic differentiation of the Jurassic and Cretaceous ecosystems of the northern and southern sides of the Neotethys (see Figs. 3, 4, and 8), which allows us to draw a meaningful conclusion about the time when the influence of the deep structure on the near-surface blocks of the Earth's crust began. According to our estimates, this time can be 160-180 Ma.

Conclusions

The most significant research results boil down to the following conclusions.

(1) A new methodology for combined dynamic cartography is proposed based on synthesizing tectonic-geodynamic characteristics with paleomagnetic mapping, palinspastic reconstructions, and consolidated structural analysis.

(2) The age of activation of the influence of the deep mantle structure on the near-surface (surface) tectonic-structural elements of the studied region was estimated.

(3) The connection between the biogeographical phenomena of the Neotethys Ocean ecosystems and its geodynamic evolution is shown, starting from initial spreading to the widespread development of collision processes towards the end of the Mesozoic era.

(4) The biogeographical heterogeneity of the Maastrichtian faunas of the Garabakh region of Azerbaijan is explained.

Acknowledgment

The formulation of very unconventional research between the migration-ecosystem (biogeographic) and deep-geodynamic processes became possible only thanks to multidisciplinary research conducted over many decades by specialists from various fields of knowledge as part of fundamental projects set up and implemented by Professor Academician Akif Agamekhti Alizadeh. We consider him our teacher and, therefore, tried to explain several biogeographical paradoxes identified during his research from the standpoint of tectonophysics. Naturally, it is a great honor for us to dedicate this work to his 90th anniversary.

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СВЯЗЬ ПАЛЕОБИОГЕОГРАФИЧЕСКИХ ИНДИКАТОРОВ СЕВЕРНОГО И ЮЖНОГО БОРТОВ НЕОТЕТИС С ГЛУБИННЫМИ ГЕОДИНАМИЧЕСКИМИ ПРОЦЕССАМИ

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Резюме. В ряде наших предыдущих исследований (Eppelbaum et al., 2021, 2023b, 2024) было обосновано открытие феномена глубинной мантийной структуры, вращающейся против часовой стрелки, очевидно, влияющей на тектонику и различные геолого-экологические процессы на Южном Кавказе и в Восточном Средиземноморье. Данное исследование позволило оценить время начала влияния глубинной структуры и охарактеризовать структурно-тектонические изменения, произошедшие в разные геологические эпохи. Широкое использование палеонтологических данных дало возможность классифицировать миграцию организмов из отдалённых провинций и получить данные о формировании бассейнов, основанные на изучении геодинамики террейновых поясов, островных дуг, сдвиговых зон и глубинных подвижек, обусловленных характером мантийной конвекции и топологии глубокой мантии. Показана роль палеобиогеографии и конседиментационной тектоники и палеогеографии в оценке автохтонных и аллохтонных структур как необходимого дополнения в тектонике плит прошлых геологических эпох и современности. Исследована геодинамическая эволюция Мезозойского террейного пояса (МТБ), расположенного в южном регионе Неотетиса (северная часть Гондваны). Наши комплексные исследования показали аллохтонную природу МТБ и подтвердили ранее полученные данные о террейновой природе и мезозойском возрасте перемещенных тектонических блоков. На Малом Кавказе биогеографические и тектонофизические исследования резко отделили восточную (азербайджанскую) часть Малого Кавказа от офиолитового пояса в его юго-западном продолжении. Структурно-геодинамическое своеобразие смешанной позднемеловой фауны Гарабахского региона (Западный Азербайджан) получило всестороннее обоснование. Наконец, была произведена оценка начала влияния мантийного структуры на приповерхностные тектоно-структурные элементы.

***Ключевые слова**: геодинамика, глубинная вращающаяся структура, палеобиогеографические карты, тектонофизическая интерпретация, океан Неотетис*

NEOTETİSİN ŞİMAL VƏ CƏNUB TƏRƏFLƏRİNİN PALEOBİOCOĞRAFİ İNDİKATORLARININ DƏRİNDƏ BAŞ VERƏN GEODİNAMİK PROSESLƏRLƏ ƏLAQƏSİ

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Xülasə. Bir sıra əvvəlki tədqiqatlarımızda Cənubi Qafqazda və Şərqi Aralıq dənizində aydın şəkildə tektonikaya və müxtəlif geoloji və ekoloji proseslərə təsir edən, saat əqrəbinin əksi istiqamətində fırlanan dərin mantiya strukturu fenomeninin kəşfi əsaslandırılmışdır (Eppelbaum et al., 2021, 2023b, 2024). Bu tədqiqat dərin strukturun təsirinin başlanğıcını qiymətləndirməyə və müxtəlif geoloji dövrlərdə baş verən struktur və tektonik dəyişiklikləri xarakterizə etməyə imkan verəcəkdir. Paleontoloji məlumatların geniş istifadəsi orqanizmlərin uzaq əyalətlərdən miqrasiyasını təsnif etməyə və müəyyən edilmiş ərazi qurşaqlarının, mantiya konveksiyasının təbiəti və dərin mantiyanın topologiyasına əsaslanan ada qövslərinin, sürüşmə zonalarının və dərin qatlarda hərəkətlərin geodinamikasının öyrənilməsi əsasında hövzələrin əmələ gəlməsinə dair məlumatlar əldə etməyə imkan vermişdir. Avtoxton və alloxton strukturların qiymətləndirilməsində paleobiocoğrafiya və konsedimentasiya tektonikasının və paleocoğrafiyanın rolu keçmiş geoloji dövrlərin və indiki dövrün plitə tektonikasına zəruri əlavə kimi göstərilir. Tədqiqatlarımızdan əvvəl, Şərqi Aralıq dənizində Qondvananın kənarlarının riftoqenezi və Ölü dəniz qırılması boyunca yeni transform yerdəyişmələri ilə əlaqəli avtoxton Kaynozoy Suriya Tağı müəyyən edilmişdi. Bizim hərtərəfli tədqiqatlarımız bu strukturun alloxton xarakterini göstərmiş və yerdəyişmiş tektonik blokların terreyn xarakterini və mezozoy yaşı haqqında əvvəlki məlumatları təsdiqləmişdir. Eynilə, Kiçik Qafqazda biocoğrafi və tektonogeofiziki tədqiqatlar göstərmişdir ki, Kiçik Qafqazın şərq (Azərbaycan) hissəsi onun cənub-qərb sərhədindəki ofiolit qurşağından kəskin şəkildə ayrılmışdır. Azərbaycanın Qarabağ bölgəsinin qarışıq son təbaşir faunasının struktur və geodinamik unikallığı hərtərəfli əsaslandırılmış və təsdiqlənmişdir. Nəhayət, ilk dəfə olaraq mantiya strukturunun səthə yaxın tektono-struktur elementlərə təsirinin başlanğıcı ilə bağlı qiymətləndirmə aparılmışdır.

***Açar sözlər**: geodinamika, dərin fırlanan struktur, paleobiocoğrafi xəritələr, tektonofizik şərh, Neo-Tetis okeanı*