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WHERE DID THE INITIAL SOURCES OF THE ALLOCHTHONOUS OCEANIC CRUST IN THE SOUTHERN EASTERNMOST MEDITERRANEAN ORIGINATE?

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Summary. For a long time, it was believed that tectonic movements in the southernmost Eastern Mediterranean (EMM), located south of the Aegean-Anatolian Plate, were linked to the transcontinental shears originating from the Atlantic Ocean. However, an integrated analysis of numerous geological and geophysical data has led us to conclude that the primary structures in the EMM are not associated with these shears but instead with the spreading and collision processes of the Neotethys Ocean. Over the Neoproterozoic orogenic belt, a Mesozoic terrane belt (MTB) has been identified within the Arabian and Sinai lithospheric plates. The westernmost part of this belt contains allochthonous oceanic crust. We propose that the characteristics of total collision processes are influenced by the presence of a large, deep, counterclockwise-rotating structure. A significant finding in this context is the identification of an ancient block of oceanic crust in the western portion of the MTB, which corresponds to the reversely magnetized Kiama hyperzone (Early Permian). This block has moved along transform faults originating from the Neotethys region, which is roughly aligned with the current location of Eastern Arabia. The movement of the MTB terranes has, for example, contributed to the formation of the Mt. Carmel ophiolites in northern Israel. Therefore, we conclude that a comprehensive geophysical-geological assessment – which includes 3D magnetic-gravity modeling and transformations, thermal field analysis, GPS vector behavior, seismotomographic data, and analyses of paleomagnetism, paleobiogeography, petrology, and tectonic structure – clearly indicates the allochthonous nature of the MTB and the oceanic crust of the EMM. These findings necessitate a reevaluation of the tectono-geodynamic evolution of the Easternmost Mediterranean and suggest a reassessment of hydrocarbon exploration prospects in this region.

1. Introduction

The Easternmost Mediterranean (EMM) is a region situated in the transition zone between the two most prominent tectonic structures of the Earth: Eurasia and Gondwana (McKenzie, 1972; Ben-Avraham et al., 2002; Stern and Johnson, 2010). In the Cenozoic, four lithospheric plates were formed in this region: the Nubian, Arabian, Aegean-Anatolian, and Sinai plates. The area is characterized by unique geodynamics that simultaneously express the elements of the geodynamic collision associated with the Tethys Ocean evolution (Le Pichon and Kreemer, 2010; Stampfli et al., 2013) and the initial spreading of the Red Sea rift system (Bosworth et al., 2005). However, to date, the EMM's paleogeodynamics remain poorly understood. One of the main problems is the origin of the EMM's oceanic crust. The tectonic processes in the southern Easternmost Mediterranean (EMM), situated south of the Aegean–Anatolian Plate, have long been attributed to transcontinental shear propagation from the Atlantic Ocean (e.g., Neev, 1975).

The geodynamic–geophysical models developed in this study are primarily grounded in the integrated geophysical identification of the giant, counterclockwise-rotating mantle structure (CRMS) in the Eastern Mediterranean (Eppelbaum et al., 2021). Independently, the counterclockwise rotation of the Levant Basin and the Arabian Plate, inferred solely from geological evidence, was previously demonstrated by Le Pichon and Gaulier (1988). We propose that the primary mechanism of the rotational influence is thermal convection. The essential role of thermal convection in deep geodynamics is underlined by many authors (e.g., Anderson, 2007).

Addressing such complex geodynamic phenomena, however, requires an integrated multidisciplinary approach that combines geological and geophysical analyses. The present result corroborate our earlier hypothesis (e.g., Eppelbaum and Katz, 2015) that the southern sector of the Easternmost Mediterranean (EMM) crust is allochthonous in nature and was transported into the studied region from the northeast.

2. Combined gravity, magnetic, and GPS data analysis

The oceanic crust block relating to the Kiama paleomagnetic hyperzone has been detected in the EMM (Ben-Avraham et al., 2002; Eppelbaum and Katz, 2015; Eppelbaum et al., 2014). We suggested that this oceanic block was formed in the region near the present position of the Persian Gulf (Eppelbaum et al., 2014). Nevertheless, how did this block get there? Figure 1 shows a combination of the residual satellite-derived gravity anomaly (Eppelbaum et al., 2021, 2024a), GPS vector behavior (Eppelbaum et al., 2021, 2025), and the smoothly averaged ΔZ magnetic map compiled for the 2.5 km over the mean sea level (msl) (Eppelbaum et al., 2024a, 2025). The revised quantitative analysis of the residual gravity anomaly yields a center mass location at a depth of approximately 1450 km. On average, a comprehensive analysis of seismotomographic data (Li et al., 2008; Trifonov and Sokolov, 2018; Eppelbaum et al., 2025) indicates that depths are underestimated by approximately 4-5%. These data, combined with the detailed paleomagnetic analysis (Eppelbaum et al., 2021, 2025) and other geological-geophysical data, enabled the unambiguous determination that the deep mantle experienced counterclockwise rotation (Eppelbaum et al., 2021, 2024a, 2025). Without hesitation, this deep structure rotation affects the layers and slabs above. The onset of mantle structure rotation, inferred from numerous geological and geophysical factors, was estimated to be 160-180 million years ago (Ma) (Eppelbaum et al., 2024b).

Satellite-derived gravity data enabled delineation of the deep mantle oval and identification of local structures within the Mesozoic terrane belt (MTB) and other components of the tectonosphere (Eppelbaum et al., 2024a). Mainly by magnetic and paleomagnetic data analysis, in the central zone of the deep structure projection, the block of ancient oceanic crust of the Kiama hyperzone was discovered (Eppelbaum et al., 2014), and active geodynamics to the north of it, in the Cyprus region, was outlined (Eppelbaum et al., 2021). The constructed smooth map of the magnetic field Δ**Z** (Figure 1) was first presented by Eppelbaum et al. (2024a) to illustrate the reality of apical center rotation in the axial zone of the deep mantle structure in the Eastern Mediterranean.

Here, regions of magnetic field behavior coincide with gravity isolines of the deep-mantle structure oval (Figure 1). It is easy to see that the residual satellite-gravity anomaly, GPS vector behavior, and the magnetic field pattern create a joint ensemble.

3. Development of the biopaleogeographical map

Examining paleobiogeographic data confirms deep structure rotation and its relationship with near-surface structures. The region under consideration is crucial for analyzing the Neotethys Ocean's development stage (mainly Mesozoic) and its adjacent parts of Gondwana and Laurasia. Special attention is drawn to anomalous biogeographic indicators, particularly shell remains of the giant Ethiopian brachiopods Septirhynchia–Somalirhynchia and Mediterranean brachiopods *Pygope* (Eppelbaum and Katz, 2015; Eppelbaum et al., 2021). Based on the analysis of numerous sources, three paleobiogeographic provinces were selected (Figure 2): Boreal (Eurasian shelf), (2) Mediterranean (Mediterranean Basin), and (3) Ethiopian (Eastern Africa and South Arabia).

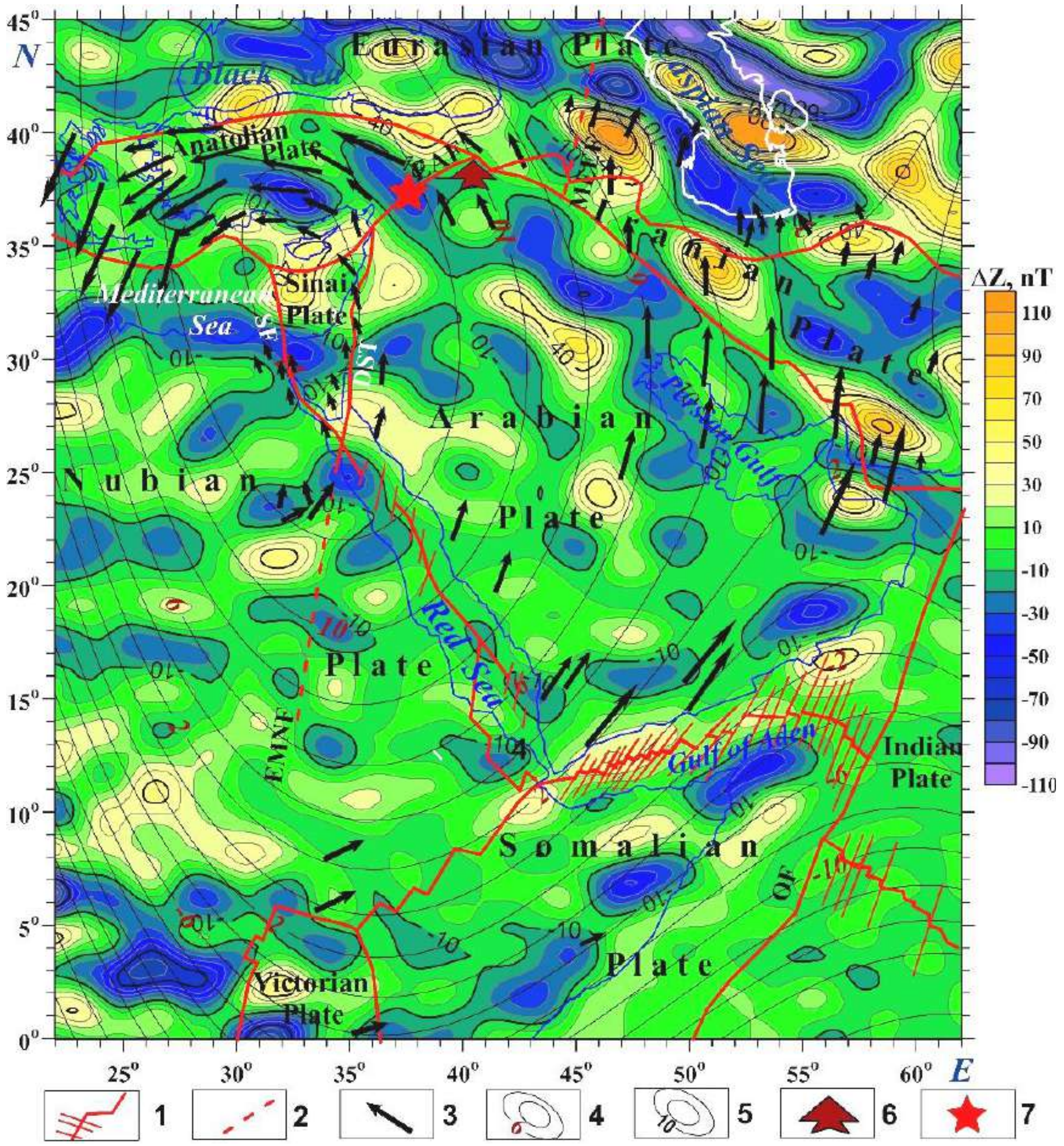

Fig. 1. Smoothly averaged magnetic Δ*Z* map recalculated to one common level of 2.5 km over the msl (initial data from https://geomag.colorado.edu/magnetic-field-model-mf7.html) for the African-Arabian region with the main tectonic elements, the behavior of the GPS vectors, and overlaid residual gravity anomaly.
(1) intraplate faults, (2) interplate faults, (3) GPS vectors (after Reilinger et al. (2006), Khorrami et al., 2019; Kadirov et al. (2024), (4) residual gravity field isolines (after Eppelbaum et al. (2021)), (5) magnetic field isolines (after Eppelbaum et al. (2025)), (6) distal part of the MTB, (7) epicenters of two main catastrophic earthquakes in eastern Turkey (February 06, 2023) ((6) after (Karabulut et al. (2023)). SF, Sinai Fault, DST, Dead Sea Fault, EMNF, Eastern Mediterranean-Nubian Fault, MEEF, Main Eastern European Fault, EAF, Eastern Anatolian Fault

The constructed map (Figure 2) illustrates the phenomenon (indicated by the red arrow rotating counterclockwise) of the geodynamic transfer of tectonic blocks, including remnants of Ethiopian fauna, from the present position of the Persian Gulf to the Levant, and ultimately to the Egyptian Eastern Desert. This fact demonstrates the counterclockwise movement of the eastern and central parts of near-surface projections of the anomalous deep structure in the Jurassic and Early Cretaceous periods.

Thus, the foreland sediments of Northern Arabia and Eastern Nubia are tectonically discordantly attached to the allochthonous Mesozoic terrane belt, which rotated counterclockwise toward the Gondwana paleocontinent. This geodynamic feature enables, for the first time, an explanation for the uniqueness of the biogeographically anomalous zone of terrane block attachment to the Gondwana paleocontinent during the Levantine phase of tectonic activity (Eppelbaum and Katz, 2015). To the north of this belt, within the marginal oceanic zone (along with the transform arc faults), an allochthonous block with the Kiama paleomagnetic hyperzone moved to the west to the current Levantine basin (Figure 2).

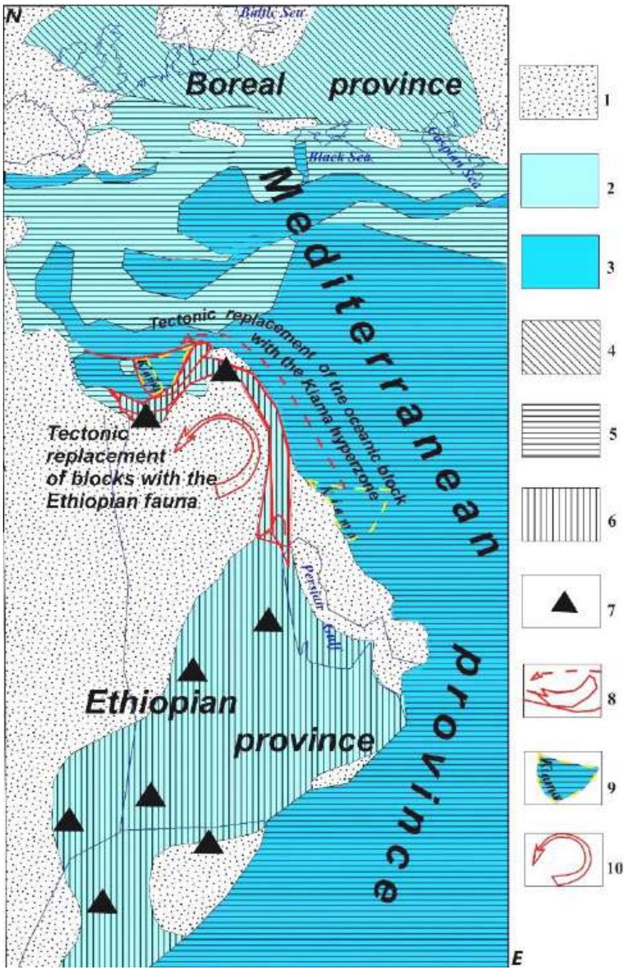

Fig. 2. The **s**chematic Late Jurassic paleobiogeographic map of the transitional region of Eurasia and Gondwana with elements of the subsequent Early Cretaceous geodynamics of the MTB. The blue lines show the boundaries between the seas and land. The following paleobiogeographic data were used (Arkell, 1956; Makridin et al., 1968; Feldman, 1987; Hirsch, 1988; Hirsch and Picard, 1988; Cooper, 1989; Lapkin and Katz, 1990). The tectonic-geodynamic data were reconstructed from (Scotese, 1991; Hall et al., 2005; Stampfli and Kozur, 2006; Eppelbaum and Katz, 2015; Alizadeh et al., 2016).
(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) points with the revealed Ethiopian brachiopods *Septirhynchia-Somalirhynchia*, (8) tectonic lines of the discordant paleobiogeographic replacements, (9) block of the oceanic crust with the Kiama hyperzone, (10) counterclockwise rotated tectonic blocks

4. Development of the tectonic-paleomagnetic map of the Easternmost Mediterranean

The developed map (Figure 3A) and paleomagnetic scale (Figure 3B) reflect the stages of formation of autochthonous and allochthonous structures in the EMM. This map was developed based on the most suitable paleomagnetic classification presented in Pechersky et al. (2010). Particularly distinct at the level of paleomagnetic analysis is the Mesozoic terrane belt with the Cretaceous and more ancient traps and ophiolites (Eppelbaum et al., 2023) and a block of anomalous ancient oceanic crust (relating to the Kiama paleomagnetic hyperzone of inverse polarity) in the Levant basin (Ben-Avraham et al., 2002; Eppelbaum et al., 2014; Eppelbaum and Katz, 2015). This block is discordantly attached to the younger (mainly Middle Cretaceous) crust of the Nubian and Aegean-Anatolian plates, as well as the north-western part of the Sinai Plate (Eppelbaum et al., 2023). This map will undoubtedly be refined and detailed as new paleomagnetic data are obtained.

5. Influence of the rotating mantle structure on the asymmetry of the sedimentary basins

Figure 4 presents a comparison between the residual satellite gravity-GPS map and the tectonic background of the region under study, revised after Eppelbaum et al. (2025). It includes a map of earthquake epicenters along the Dead Sea Transform (DST) and surrounding areas for the years 1983-2017, reconstructed from Sharon et al. (2020). The arc-shaped arrangement of the DST, along with the locations of numerous earthquake epicenters (Fig. 4B), closely aligns with the combined tectonic-geophysical map (Fig. 4A). This suggests that the bending of the DST, and consequently the epicenter locations of earthquakes, can be logically explained by the counterclockwise rotation of deep geological structures, which subsequently affects the overlying lithospheric blocks. Here, we observe a combination of shear and rotational movements.

Let us delve into the rotational effect on the asymmetry of sedimentary basins. In the Dead Sea region, as well as in the Eilat (Israel–Jordan) graben system, the axial part of the graben is confined to the east, while the flattened portion of the structure extends to the west (Ben-Avraham, 1985, 1992; Garfunkel and Ben-Avraham, 1996). The tectonic–geomorphological and magmatic asymmetry between the eastern and western coasts of the Dead Sea basin is well-documented, with the east side exhibiting higher amplitude and greater activity (Garfunkel and Ben-Avraham, 1996). Based on the generally gently arcuate structure of the DST (Smit et al., 2010), we propose a new geodynamic concept to explain the asymmetry of tectonic types associated with the deep displacement of graben-like structures. This concept posits that the regional development involves not only shear displacements but also rotational displacements of crustal blocks, which we consider fundamental to understanding the asymmetry of the regional basins.

The Sea of Galilee (also known as Lake Kinneret) is situated in northern Israel, along the northern extension of the DST. It has long been recognized that the axis of the deep-water basin of Lake Kinneret is shifted towards its eastern shore, while the axis of its shallow-water basin is displaced towards the western coast (Eppelbaum et al., 2007). In earlier studies, a model of tectonic shear along a line or system of transform fault lines was proposed (Ben-Avraham, 1992). However, an analysis of paleomagnetic data (Eppelbaum et al., 2023) collected from areas adjacent to the Galilee region, along with structural mapping data, has identified widespread arcuate faults within the shear zone (Smit et al., 2010). This data helps clarify the dominant geodynamic processes in the region. These processes are associated with the counterclockwise axial rotation of continental crustal blocks in the Arabian-Nubian region, which aligns well with GPS monitoring data.

The asymmetry of local sedimentary basins in relation to the deep rotating structure is highlighted by the geomorphological features of the Arabian–Nubian zone of Gondwana during the Late Cenozoic. In the western part, corresponding to the junction of the Nubian Plate and the Red Sea rift zone, the elevation of the plateau and the Nile River valley generally does not exceed 500 meters. In contrast, the eastern part (the Arabian–Sinai zone), where these lithospheric plates meet the Red Sea rift zone system and the Dead Sea shear zone, exhibits elevations that clearly exceed 500 to 1000 meters (Eppelbaum et al., 2021). Along the marginal zones of the Arabian and Sinai plates, mountain ranges with heights exceeding 2000 to 3000 meters have formed. We suggest that this regional geomorphological asymmetry on either side of the Red Sea rift zone is geodynamically influenced by the counterclockwise rotation of the region.

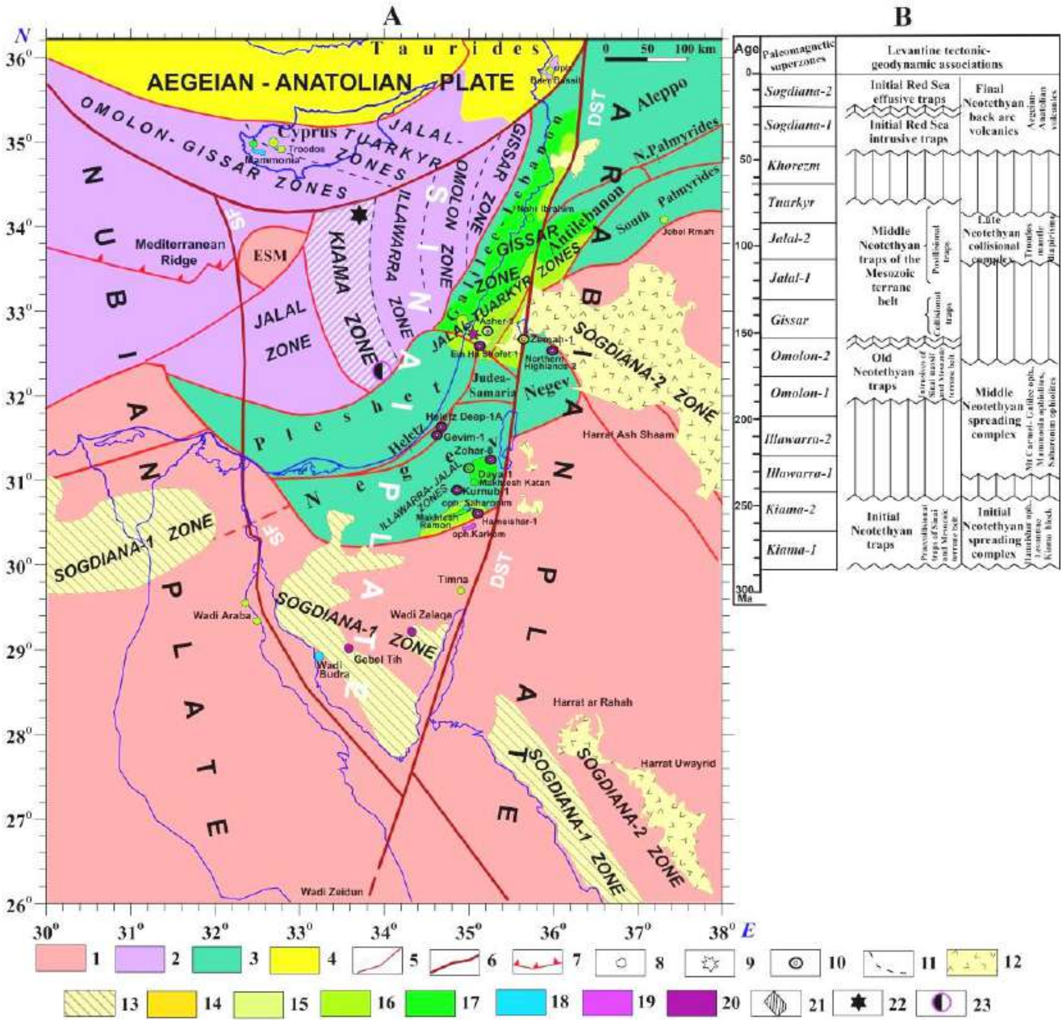

Fig. 3. Tectonic-paleomagnetic map of the Eastern Mediterranean and Near East (**A**) and its paleomagnetic scale (**B**). (1) Neoproterozoic belt of the Eastern Gondwana, (2) oceanic crust of the relict Neotethyan depression, (3) Mesozoic terrane belt (MTB), (4) Alpine-Himalayan fold belt, (5) intraplate faults, (6) interplate faults, (7) Mediterranean accretionary ridge, (8) outcrops of magmatic bodies, (9) xenoliths in the Cretaceous volcanics, (10) magmatic bodies in the boreholes, (11) suggested boundaries between the paleomagnetic hyperzones, (12) effusive traps of the Sogdiana-2 superzone, (13) intrusive traps of the Sogdiana-1 superzone, super- and hyperzones detected by radiometric data (14-20): (14) Khorezm, (15) Tuarkyr, (16) Jalal-1 and Jalal-2, (17) Gissar, (18) Omolon, (19) Illawarra, (20) Kiama, (21) contour of the Kiama paleomagnetic hyperzone revealed in the EMM by geophysical data, (22) point of the extremely low heat flow measurements: 13.9±2.9 mW/m^2 (after Eckstein, 1978, corrected for the sedimentation rate), (23) zone of the low-temperature anomaly (after Kahn, 2025). The paleomagnetic scale (**B**) was constructed based on the classification presented in Pechersky et al. (2010). SF, Sinai Fault, DST, Dead Sea Transform, ESM, Eratosthenes Sea Mount

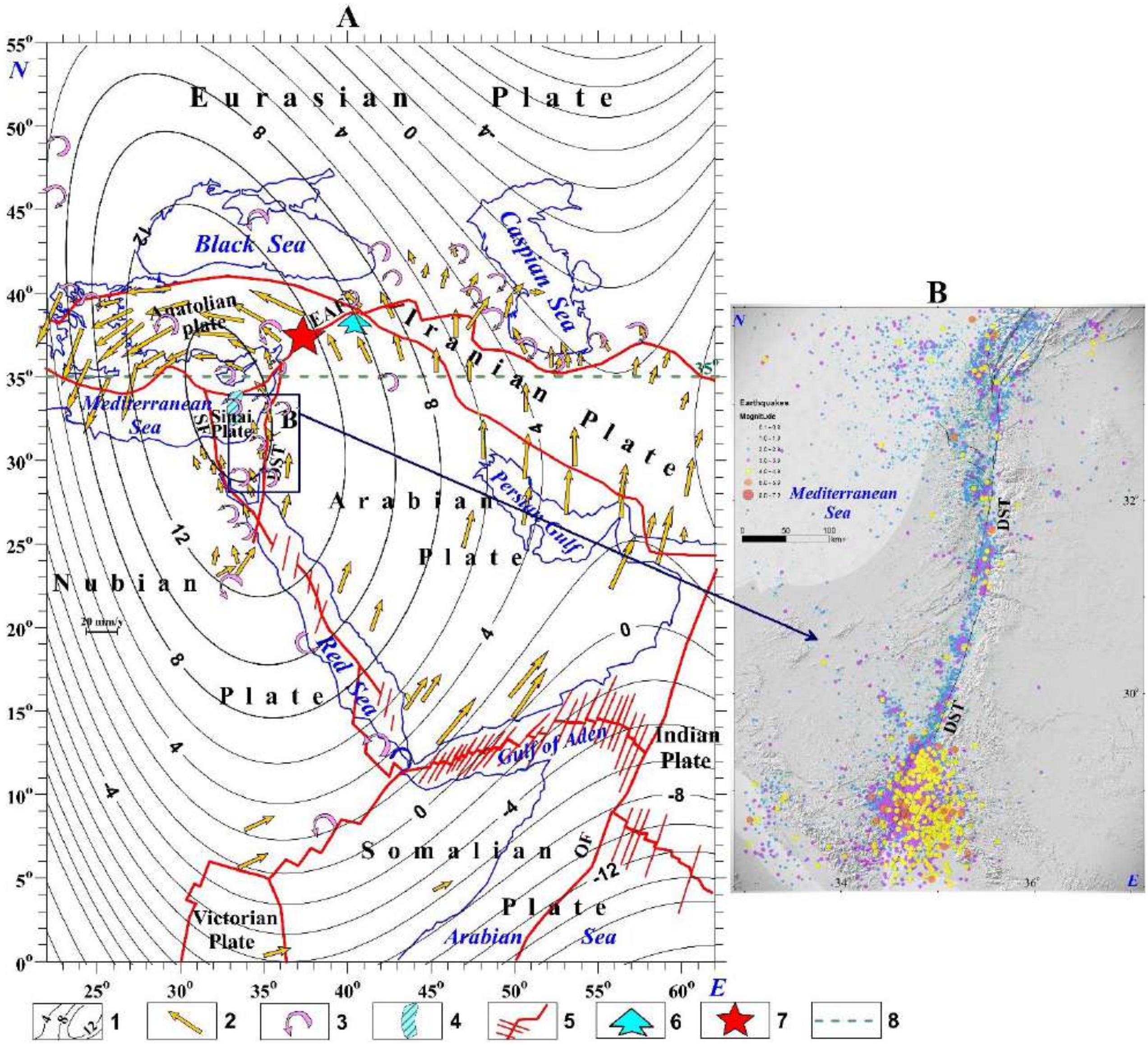

Fig. 4. Comparison of the combined tectonic-geophysical map (A) (revised and supplemented after Eppelbaum et al., 2025) and map of the earthquake epicenters along the Dead Sea Transform and surrounding areas for 1983-2017 years (B) (modified after Sharon et al., 2020).

(1) isolines of the residual satellite gravity anomaly (after Eppelbaum et al., 2021), (2) GPS velocity vectors (after Reilinger et al. (2006), Khorrami et al. (2019), Kadirov et al. (2024)), (3) rotation geodynamic elements (obtained mainly from the paleomagnetic data) indicating clockwise and counterclockwise rotations (see detailed explanations in Eppelbaum et al., 2025); (4) contour of the oceanic crust block relating to the Kiama paleomagnetic hyperzone (after Eppelbaum et al., 2014), (5) main intraplate faults, (6) distal part of the Mesozoic terrane belt, (5) center of the high magnitude seismogenic zone in the Eastern Turkey (*February 06, 2023*; Hancilar et al. (2023)), (8) critical latitude of the Earth (after Véronnet (1912)). OF, Owen Fault, DST, Dead Sea Transform, EAF, Eastern Anatolian Fault

6. Discussion

The region was previously geodynamically associated with latitudinal and diagonal movements from the Atlantic rifts in the transcontinental direction (Neev, 1975). The Aegean-Anatolian part of the EMM was identified with the collisional geodynamics of the final stages of the Neotethys Ocean development Le Pichon and Kreemer, 2010). On the other hand, concerning the southern part of the Eastern Mediterranean, data from paleobiogeographical (Figure 2), structural-sedimentological (e.g., Hall et al., 2025; Eppelbaum and Katz, 2015), and geophysical studies (e.g., Ben-Avraham et al., 2006; Eppelbaum et al., 2023), we suggested the allochthonous nature of the continental and oceanic crust located here (Eppelbaum and Katz, 2015; Eppelbaum et al., 2014, 2021, 2025). The allochthonous structure was referred to as the Mesozoic terrane belt (MTB), and the stage of its discordant attachment to the Gondwanaland foreland along deep-seated shears was termed the Levantine phase of tectonic activity (Eppelbaum et al., 2015; Eppelbaum et al., 2023).

The critical latitude of 35° on the Earth (Véronnet, 1912) is of great importance, as it nearly coincides with the projection of the center of the identified mantle structure (Eppelbaum et al., 2021). The interplay between mid-latitudes, rotation factors, and global geodynamics has been discussed by Khain (2001) and Anderson (2007). Additionally, Levin et al. (2017) explored the specific characteristics of critical latitudes within the context of the Earth's rotating ellipsoid. They established a connection between a body's degree of compression and its angular velocity of rotation, suggesting that geodynamic activity increases at and near the critical latitudes. The instability of the Earth's mantle and lithosphere, especially below and near the Earth's critical latitude, along with the rotation of geological structures, may have contributed to the movement of crustal blocks from their origination in the eastern Arabia to the current location in the southern part of the Eastern Mediterranean.

The determined oceanic crust block with the Kiama hyperzone (Eppelbaum et al., 2014) was formed over more than 1,000 km northeast (Eppelbaum and Katz, 2015), near the current position of the Persian Gulf. Let us examine this issue in more detail to ensure everything is clear between the modern and paleo-coordinates. It is well known that the Neo-Tethys began to form in the Early Permian near eastern Arabia (Hall et al., 2005) at the border with the MTB (Eppelbaum et al., 2021). This belt developed here until the Jurassic-Cretaceous boundary. After that, it moved counterclockwise along the arc transform faults until the middle of the Early Cretaceous (133 Ma), pending consolidation with the northern ledge of the Arabian part of Gondwana. After this, a similar movement occurred along the arc-transform faults of the terrane, composed of the primary (mainly Permian-Triassic) oceanic crust. It formed north of the MTB. The terrane block was located 150-200 km north of the north-western edge of the Persian Gulf, at 32° northern latitude, i.e., almost at the same latitude as in the modern allochthonous position. Considering the arcuate movement within the Arabian salient, this block descended into the Eastern Mediterranean trough from the northeast, from latitude of 38°–39° to 32° in modern coordinates.

A combined analysis of geological and geophysical materials suggested that this movement began approximately 160-180 million years ago. The determined age and direction of the movement coincided with the recently determined great breakup in Pangea (Le Pichon et al., 2023) and the tectonic constructions presented in Stampfli et al. (2013).

The anomalous joining of oceanic block crust with reversely magnetized basalts to the Eratosthenes Sea Mount (ESM), a continental block of thinned continental crust, is reliably contoured through a thorough analysis of seismic, gravity, and magnetic data (Ben-Avraham et al., 2002). The Eratosthenes block belonged to the marginal zone of the Neoproterozoic belt and was torn off during the movement of the Anatolian belt massifs to the north. After that, the ESM was geodynamically assembled along a deep thrust system with the Kiama oceanic block, which moved from the east (Eppelbaum and Katz, 2015).

The oceanic block of the Levant with an anomalously ancient crust – up to the late Paleozoic (Kiama paleomagnetic hyperzone) (Figure 3B) was studied by geophysical method integration (Eppelbaum et al., 2014, 2021; Eppelbaum and Katz, 2015) and by correlation with the extensive field of the Carmel–Lower Galilee ophiolites (Eppelbaum et al., 2023). Geologically, radiometric, facial, and petrological methods were comprehensively applied to study this area (e.g., Segev, 2000, 2009; Fleischer and Varshavsky, 2012). A series of four ophiolite nappes with a total thickness of up to 4,000 m and a length of up to 40 km has developed here. At the same time, the youngest nappe, containing mélange and ophiolites (with an age of up to 164.3 Ma), is created at the base of the sequence. The most ancient nappe of the olivine-basalt mélange (up to 222.4 Ma old) occupies the top part of the section (Dvorkin and Kohn, 1989; Eppelbaum et al., 2023). This phenomenon indicates that the attachment of the marginal part of the ophiolite belt near the Galilee-Lebanon terrane was carried out not by linear shifts but by rotation of the oceanic plate in a counterclockwise direction (Figure 5).

Moreover, its oldest part (relating to the paleomagnetic Kiama hyperzone) forms the marginal western boundary of the Levantine oceanic terrane and, according to seismic data (Ben-Avraham et al., 2002), is thrust over the younger autochthonous Levantine crust (Figures 3A, B).

The data of the paleogeography of the Jurassic seas of Central Gondwana (Arkell, 1956), along with extensive studies in the field of paleobiogeographic zoning of the Jurassic basins of Eurasia and Gondwana (Makridin et al., 1968) showed a paradoxical discrepancy in the position of brachiopod localities in the Eastern Mediterranean (Figures 2 and 5), sharply isolated from the central area of the Ethiopian Basin and separated from the Eastern Mediterranean by a vast land mass. The allochthonous nature of the *Septirhynchia–Somalirhynchia* brachiopod fauna in the Levant, several thousand kilometers from the main East Arabian-Ethiopian area, has not been adequately explained.

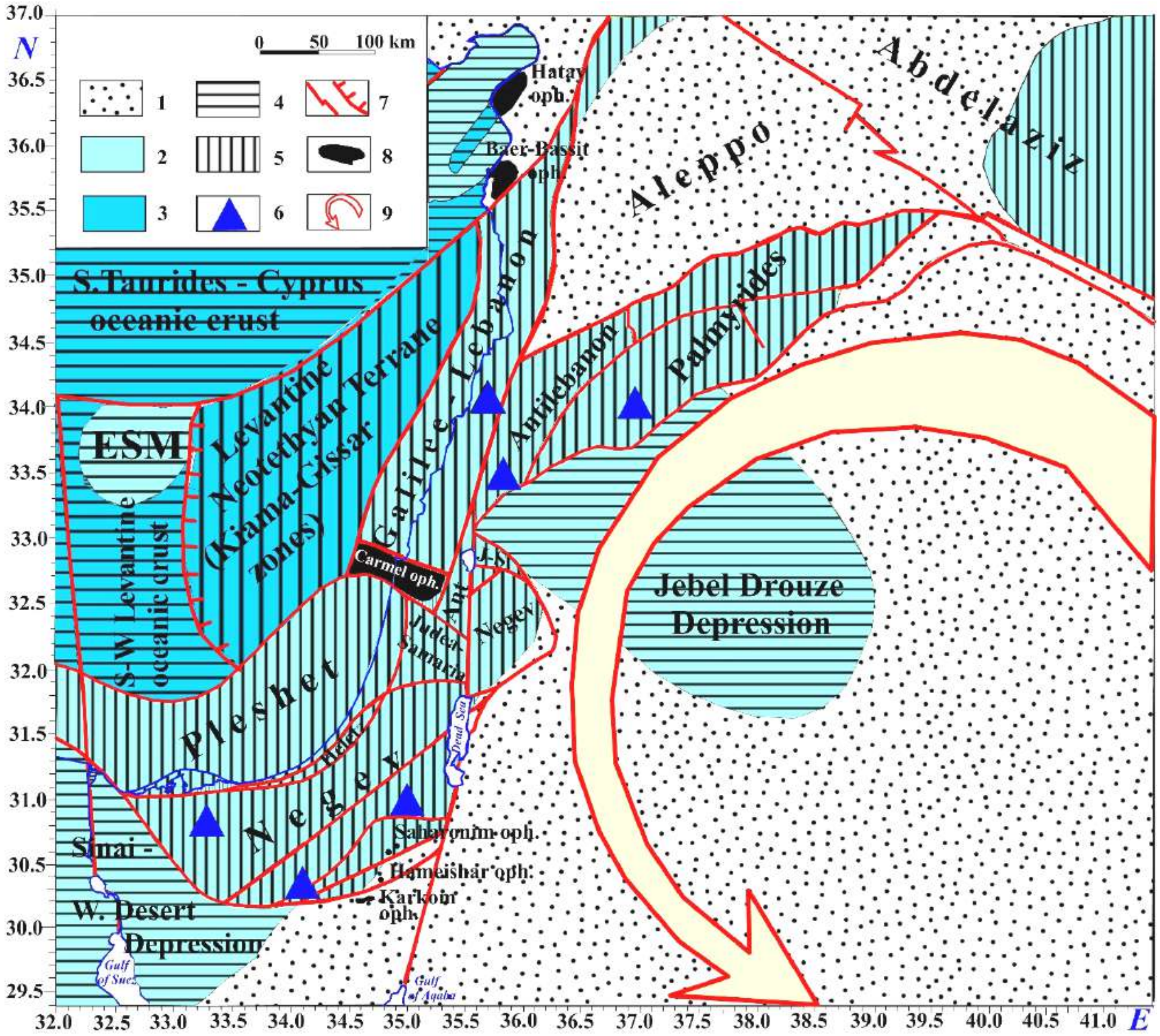

Fig. 5. Structural and geodynamic scheme of the relationship between autochthonous and allochthonous biogeographic systems of the Easternmost Mediterranean.
(1) Nubian-Arabian shield, (2) oceanic crust blocks, (3) continental crust terranes, (4) west of the Neotethyan autochthonic block system, (5) Ethiopian allochthonous block systems, (6) points with *Septirhynchia–Somalirhynchia* Ethiopian Jurassic brachiopods, (7) tectonic faults, (8) ophiolites, (9) direction of the regional counterclockwise rotation of tectonic blocks with the Ethiopian fauna. ESM, Eratosthenes Sea Mount, Ant, Antilebanon, J-S, Judea-Samaria

At that time, plate tectonics had not yet found a sufficient theoretical basis for setting up work in the field of geodynamic cartography. One way or another, the revealed paradox of the allochthonous nature of the Jurassic fauna in the Levant was the first evidence in the field of the complexity of the Levantine geodynamic processes, and it showed the need for extensive geological-geophysical studies to identify geodynamic processes in the complex zone of interaction between Eurasia and Gondwana. Over the past decades, these studies have mainly been implemented due to the progress of innovative geological and geophysical research by teams from many countries of the world (e.g., Ben-Avraham et al., 2002, 2006; Hall et al., 2005; Jimenez-Munt et al., 2006; Reilinger et al., 2006; Muttoni et al., 2009; Stern and Johnson, 2010; Burov, 2011; Stampfli et al., 2013; Faccenna et al., 2014; Eppelbaum et al., 2021, 2025; Le Pichon et al., 2023; Bosworth, 2024).

Historical-planetological analysis indicates that the final phase of the Paleozoic represents the most extreme period of the Phanerozoic in terms of tectono-thermal, paleomagnetic, hydrospheric, and climate-sedimentation activity (Lapkin and Katz, 1990; Eide and Torsvik, 1996). During this period, a stable geomagnetic regime characterized mainly by reverse polarity coexisted with significant thermal and geodynamic activity in the lithosphere and upper mantle. This activity reflects the convective geodynamics related to the plate tectonic interactions of the Pangea and Panthalassa structures (Eide and Torsvik, 1996). Recent paleomagnetic reconstructions (Muttoni et al., 2009; Domeier et al., 2012) analyze the geodynamic situation within models of Late Permian Pangea A and Early Permian Pangea B. The Pangea B reconstruction, which includes the authors' supplements, is illustrated in Figure 6. This reconstruction clearly shows that the oceanic crust of Neotethys, along with surrounding terrane belts, was located to the east of the present-day area of the Easternmost Mediterranean (EMM). A key geodynamic feature of Pangea B is the triple plate junction boundary, which corresponds to zones of spreading, subduction, and deep displacement (intra-Pangea dextral shear). Notably, displacements of oceanic and continental crust blocks, as well as the mantle lithosphere, have occurred over significant distances during various stages of the Neotethys Ocean evolution in the Late Mesozoic and Cenozoic eras (Jimenez-Munt et al., 2006; Burov, 2011; Yamasaki and Stephenson, 2011; Stampfli et al., 2013).

According to the plate tectonic concepts and sequence of opening of the Neo-Tethys rift system, the Kiama hyperzone extended in a SE-NW direction immediately adjacent to the terrane belt, and the younger Illawarra and Omolon hyperzones adjoined in the form of strips to the northeast of it. Moving along the transform fault in the northwest, the uplift of the Arabian Shield of Gondwana (Figure 2) rotated this terrane 180° counterclockwise. It encountered the Galilee-Lebanon terrane, which is characterized by the youngest strip zone of the oceanic crust. Then, as the terrane rotated and moved into the Levantine basin, pressure from the surrounding masses of the autochthonous oceanic crust and the Taurid structures caused more ancient band anomalies of the allochthonous terrane complex to collide. After a counterclockwise rotation of almost 360°, the Kiama block assumed an orientation close to its adopted orientation, which is now in place (Figures 2 and 3). The features of such movements are identified using various multiscale techniques and methods of geological-geophysical mapping, with careful consideration of the diverse geological and geophysical data.

Fig. 6. Early Permian Neotethys position within the Pangea B–Panthalassa reconstruction (after Muttoni et al. (2009), with supplements from Stampfli et al. (2013), Golonka and Ford (2000), and some authors' supplements).
(1) Neotethyan ocean spreading center, (2) intra-Pangea dextral shear, (3) transform oceanic faults, (4) subduction zones, (5) direction of the strike-slip motion, (6) triple junction

Discovery of the mantle counterclockwise rotating mantle structure (Eppelbaum et al., 2021, 2025), influencing the above lithospheric blocks and geological layers, supported the assumption that the oceanic crust of the present southern EMM was displaced from the northeast (apparently, along the transform faults). Among twelve independent geophysical-geological factors confirming this counterclockwise rotation, we can note here the GPS counterclockwise rotation (Figure 1) (Reilinger et al., 2006; Khorrami et al., 2019; Karabulut et al., 2023; Kadirov et al., 2024), a combination of the residual satellite-derived (Figure 1) and land/sea gravity anomalies (Eppelbaum et al., 2021), smoothly averaged magnetic Δ**Z** map (Eppelbaum et al., 2025) (Figure 1), Late Jurassic paleobiogeographical map (Figure 2), numerous paleomagnetic-geodynamic data (e.g., Morris et al., 2002; Borradaile et al., 2010; van Hinsbergen et al., 2010; Uzel et al., 2015; Kaymakci et al., 2018; Çabuk and Cengiz, 2021; Eppelbaum et al., 2021, Lazos et al., 2022; Cengiz and Karabulut, 2023; Eppelbaum et al., 2025), tectonic-paleomagnetic map (Figure 3), geoid isolines map (Eppelbaum et al., 2024a), seismotomographic data (Li et al., 2008; Trifonov and Sokolov, 2018; Eppelbaum et al., 2025), analysis of last seismological data (Karabulut, 2023; KeAi, 2023), and diverse tectonic-geodynamical and mineralogical-petrological data (Eppelbaum et al., 2014, 2024a; Eppelbaum and Katz, 2015).

It is assumed that the significant impact of the deep-rotating structure prevented the Kiama oceanic crust block (possibly including other oceanic crust blocks) from subducting and preserving its current location. The average thermal flow in the eastern Mediterranean: from 11.5 to 40 mW/m^2 (Erickson et al., 1977; Eckstein, 1978; Cermak, 1980; Verzhbitsky, 1996; Elgabry et al., 2013) is several times less than average values in the central and western Mediterranean, likely to reflect the older crust (e.g., Sclater et al., 1980). The minimum observed value (11.5 mW/m^2; uncorrected for the sedimentation rate) is in the northern part of the reversely magnetized Kiama zone (corresponding to the most ancient block of the oceanic crust adjacent to the Aegean-Anatolian Plate). The recent temperature field analysis enabled us to recognize a circular low-temperature anomaly at different depths in the EMM (4, 6, 8, and 10 km) (Kahn, 2025) corresponding to the southern end of the ancient oceanic crust block with the Kiama paleomagnetic hyperzone (Figure 3A).

The prolonged counterclockwise rotation of the deep structural elements has significantly influenced the asymmetry of sedimentary basins (see Figure 4). Additionally, the anomalous en-echelon Late Cretaceous troughs of the Antilebanon and Galilea-Lebanon terranes (Figure 5) exhibit a similar asymmetrical pattern. In this region, the sedimentary deposits have varying thicknesses: (i) a maximum thickness of up to 1453 m and 1550 m in the eastern part of the zone, and (ii) a minimum thickness ranging from 300 to 449 m in the western part of the zone.

Finally, our previous investigation of the beginning of this mantle structure rotation was expected to be 160-180 Ma (Eppelbaum et al., 2024b). This period was reasonably sufficient for the Earth's crust displacement from the region north of the present position of the Persian Gulf to the Easternmost Mediterranean. Based on paleomagnetic data analysis, the velocity of the counterclockwise rotation of the Cyprus Island over the last 70 million years has been calculated (Eppelbaum et al., 2025). The velocity was estimated to be 18 mm per year, which is consistent with modern GPS velocity data (e.g., Reilinger et al., 2006). If we extrapolate this rotation velocity to the period of 180 Ma, we obtain the total displacement of tectonic blocks as approximately 3200 km. This value is in good agreement with other independent estimates, such as those performed by Khalafly (2006) for the Lesser Caucasus (most of whose structure is influenced by the deep structure rotating counterclockwise).

The geodynamic features of the block structures in the continental and oceanic crust of the Eastern Mediterranean are revealed in the analysis of trap and ophiolitic complexes (Figures 3 and 5), which were studied using radiometric and paleomagnetic methods (Eppelbaum and Katz, 2015).

This was especially evident when comparing the ages of the oceanic crust of the Aegean-Anatolian and Levantine segments. Within the Aegean-Anatolian Plate are young ophiolites, which mark young oceanic crust (corresponding to the upper parts of the Jalal and Tuarkyr paleomagnetic zones). There are ophiolitic complexes of Baer-Bassit (Jalal zone), Hatay, and Troodos (Jalal-Tuarkyr zones) (Figures 3 and 5).

The age of the Levant ophiolites (Saharonim basalts, Hameishar basaltic boudinites) and the paleomagnetic age of the Karkom ophiolites exceed 200 million years. These data are consistent with the average radiometric ages of the Carmel ophiolites (Eppelbaum et al., 2025).

Thus, according to the presented analysis, the oceanic crust of the Levant has a more ancient, Permian-Triassic age, compared to the oceanic crust of the southern part of the Aegean-Anatolian lithospheric plate, whose age on average corresponds to the Late Mesozoic – mainly the end of the Cretaceous period.

Let us especially note the geodynamic consequences of the two strongest earthquakes in eastern Turkey (06.02.2023), when the combination of counterclockwise rotation of the Earth's crust blocks and accumulated stress in the Earth's crust resulted in a shift of sections of the Aegean-Anatolian Plate more than eleven m to the southwest (Hancilar et al. 2023; Karabulut et al., 2023) (i.e., counterclockwise). The probability of all the above data being a random coincidence of all the mentioned factors is very low.

6. Conclusions

The main conclusions of the studies are the following:

1) Previously, the direction of the dominant geodynamic stresses in Central Gondwana was traced from the West (Atlantic Ocean). However, innovative geological and geophysical analyses have revealed a wide range of geodynamic connections in the Arabian-Nubian segment of Gondwana, pointing towards the East,

2) The allochthonous oceanic crust in the southern part of the Eastern Mediterranean formed more than 1,000 km to the northeast, near the current position of the Persian Gulf,

3) The deep rotating structure exerted a significant influence that hindered the subduction of ancient oceanic crust blocks. The interaction between collisional and spreading processes, combined with the effects of the counterclockwise-rotating deep structure, created a unique tectono-geodynamic environment,

4) The above facts necessitate a reevaluation of the geodynamic evolution of the region under study.

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ГДЕ БЫЛИ СФОРМИРОВАНЫ ИСТОЧНИКИ АЛЛОХТОННОЙ ОКЕАНИЧЕСКОЙ КОРЫ ЮЖНОЙ ЧАСТИ ВОСТОЧНОГО СРЕДИЗЕМНОМОРЬЯ?

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Резюме. Долгое время считалось, что тектонические движения в южной части Восточного Средиземноморья (ВС), расположенного к югу от Эгейско-Анатолийской плиты, связаны с трансконтинентальными сдвигами, исходящими из Атлантического океана. Однако комплексный анализ многочисленных геолого-геофизических данных привёл нас к выводу, что первичные структуры ВС связаны не с этими сдвигами, а со спрединговыми и коллизионными процессами океана Неотетис. Над Неопротерозойским орогенным поясом в пределах Аравийской и Синайской литосферных плит выявлен мезозойский террейновый пояс (МТБ). Западная часть этого пояса представлена аллохтонной океанической корой. Мы предполагаем, что характеристики процессов коллизии в данном регионе в основном определяются влиянием крупной глубинной структуры, вращающейся против часовой стрелки. Значимым открытием в этом контексте является выявление древнего блока океанической коры в западной части МТВ, соответствующего обратно намагниченной падеомагнитной гиперзоне Киама (относящейся к ранней перми). Этот океанический блок был перемещен вдоль трансформных разломов из региона, примерно совпадающего с современным положением Восточной Аравии. Движение террейнов МТВ способствовало, например, формированию офиолитов горы Кармель на севере Израиля. Таким образом, мы приходим к выводу, что комплексная геофизико-геологическая оценка, включающая трехмерное магнито-гравитационное моделирование, анализ теплового поля, трансформации потенциальных полей, поведение векторов GPS, сейсмотомографические данные, анализ палеомагнетитных, палеобиогеографических и петрологических данных, а также характерных тектонических особенностей, ясно указывает на аллохтонную природу МТВ и океанической коры ВС. Эти результаты требуют пересмотра тектоно-геодинамического развития Восточного Средиземноморья и предполагают необходимость переоценки перспектив разведки углеводородов в этом регионе.

Ключевые слова*: Восточное Средиземноморье, структура океанической коры, аллохтонная происхождение, палеомагнитная гиперзона Киама, комплексный анализ*

ARALIQ DƏNİZİNİN CƏNUB-ŞƏRQİNİN ALLOKTON OKEAN QABIĞININ MƏNBƏLƏRİ HARADA ƏMƏLƏ GƏLMİŞDİR?

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Xülasə. Egey-Anadolu plitəsinin cənubunda yerləşən Şərqi Aralıq dənizinin (ŞAD) cənub hissəsindəki tektonik hərəkətlərin Atlantik okeanından qaynaqlanan transkontinental qırılmalarla əlaqəli olduğu çox əvvəllər qəbul edilirdi. Bununla belə, çoxsaylı geoloji və geofiziki məlumatların hərtərəfli təhlili bizi belə nəticəyə gətirdi ki, Şərqi Aralıq Dənizinin ilkin strukturları bu qırılmalarla deyil, Neotetis okeanının həm spredinq, həm də kolliziya prosesləri ilə əlaqəlidir. Mezozoy Terran Qurşağı (MTQ) Ərəbistan və Sinay litosfer plitələri üzərindəki Neoproterozoy orogenik qurşağının üstündə müəyyən edilmişdir. Bu qurşağın qərb hissəsi allokton okean qabığı ilə təmsil olunur. Biz təklif edirik ki, bu regionda toqquşma proseslərinin xüsusiyyətləri əsasən saat əqrəbinin əksinə fırlanan böyük dərin strukturun təsiri ilə müəyyən edilir. Struktur-geodinamik analiz, əsas geoloji-geofiziki amillərlə yanaşı, Efiopiya əyalətinin allokton yura faunasının ŞAD-də geniş yayılmasını göstərən paleobiocoğrafi məlumatlar ilə də dəstəklənir. Bu kontekstdə əhəmiyyətli kəşf MTQ-nın qərb hissəsində əks maqnitləşmiş paleomaqnit Kiama hiperzonasına (erkən Perm dövrünə aid) uyğun gələn qədim okean qabığı blokunun müəyyən edilməsidir. Bu okean bloku Şərqi Ərəbistanın müasir mövqeyi ilə təxminən üst-üstə düşən bölgədən transformasiya qırılması boyunca yerini dəyişmişdir. MTQ terranlarının hərəkəti nəticəsində İsrailin şimalında Karmel dağında ofiyolitlərinin meydana gəlməsinə kömək etmişdir. Beləliklə, belə qənaətə gəlirik ki, 3D maqnit-qravitasiya modelləşdirməsi, istilik sahəsinin təhlili, potensial sahə transformasiyaları, GPS vektorlarının davranışı, seysmik tomoqrafik məlumatlar, paleomaqnit, paleobiocoğrafi və petroloji məlumatlar, o cümlədən xarakterik tektonik xüsusiyyətlər, o cümlədən, inteqrasiya olunmuş geofiziki-geoloji qiymətləndirmə MTQ-nin və ŞAD yer qabığının alloxton xarakterini aydın göstərir. Bu nəticələr Şərqi Aralıq dənizinin tektono-geodinamik inkişafının yenidən nəzərdən keçirilməsini tələb edir və bu regionda karbohidrogen kəşfiyyatı perspektivlərinin yenidən qiymətləndirilməsinin zəruriliyini irəli sürür.

Açar sözlər: *Şərqi Aralıq dənizi, okean qabığının quruluşu, allokton mənşəli, Kiama paleomaqnit hiperzonası, inteqrasiya olunmuş analiz*