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# TECTONIC MAGNETIC-PALEOMAGNETIC MAPPING OF HETEROGENEOUS MEDIA: IMPLICATION FOR THE EASTERNMOST MEDITERRANEAN (NORTHERN ISRAEL)

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***Summary.*** The quantitative analysis of magnetic anomalies has been performed using advanced methodologies allowing the application of interpretation procedures under conditions of (1) oblique magnetization, (2) rugged terrain relief, and (3) superposition of anomalies of different ranks. Examples of unconventional magnetic anomaly analysis are presented for several geologically complex areas in northern Israel: the Sea of Galilee, Carmel, and Malqishon. The methodology of paleomagnetic mapping of such transition zones is based on the integration of the mapping techniques for both continental and oceanic platforms: paleomagnetic reconstructions, results of radiometric dating of magnetically active rocks, satellite data examination, tectonic-structural reconstructions, biogeographical studies, and utilization of the results of various geophysical surveys. In northern Israel, for the combined paleomagnetic mapping, were selected: (1) the Sea of Galilee with the adjoining zones (preliminary constructed schemes for these areas were revised and supplemented), (2) the Carmel area, and (3) Atlit area (internal part of the Carmel area). The paleomagnetic profile for the Carmel area on the top of the Lower Cretaceous traps accumulative surface indicates the complex history of the region's paleogeodynamic evolution. This testifies to the effectiveness of combining magnetic anomaly quantitative interpretation with the paleomagnetic mapping of complex media. The constructed palinspastic reconstruction map (for the period of 3.6-2.0 Ma) unmasks important tectonic-magmatic features of that geological time.



## 1. Introduction

The Easternmost Mediterranean is a region belonging to the transition zone of large tectonic-geodynamic structures of the Earth – Eurasia and Gondwana (McKenzie, 1972; Хаин, 2001; 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 characterrized by unique geodynamics, which simultaneously expressed the elements of the tectonic collision associated with the evolution of the Tethys Ocean (Ben Avraham and Ginzburg, 1990; Le Pichon and Kreemer, 2010; Stampfli et al., 2013), and the initial spreading of the Red Sea rift system (Bosworth et al., 2005).

This tectonic-geodynamic circumstance determines the extreme complexity and variegation of the structure of the developed here tectonic elements and the rock complexes of the Earth's crust. They form a very bizarre knot, which combines heterogeneous blocks of the continental and oceanic crust, ophiolite belts, traps, folded island-arc and terrane complexes, and the complex zones of the tectonic strike-slip, thrusts, and underthrust faults (Picard, 1959; Ben Avraham, 1978; Rotstein and Ben-Avraham, 1986; Robertson, 1998; Hall et al., 2005; Eppelbaum et al., 2021).

The widespread development of the magmatic associations of different ages and origins triggered the employment of the magnetic methods in the region under study (e.g., Ben-Avraham and Hall, 1977; Ben-Avraham et al., 1976; Eppelbaum et al., 2004, 2007; Rybakov et al., 2008; Eppelbaum, 2015a; Eppelbaum and Katz, 2015a, 2021a). However, considering the presence of practically all possible positions of the magnetization vector, the use of the paleomagnetic methods is essential. At the same time, the importance of the paleomagnetic approaches goes beyond just explaining the magnetic anomalies. Paleomagnetic mapping has methodologically successfully and widely recommended itself for deciphering the structure of the intricate targets from the subsurface up to the great depths in the continents and oceans (Храмов и др., 1982; Молостовский, Храмов, 1997; Tauxe, 2003; Eppelbaum and Katz, 2015a).

The paleomagnetic method was applied more limitedly in the transition zones from ocean to continent (Кумпан, Sholpo, 1986), but the prior experience of our studies in this region (Ben Avraham et al., 2002; Eppelbaum et al., 2004, 2007, 2014, 2021; Eppelbaum and Katz, 2014, 2015b, 2015c, 2020) indicates that it surpasses in its effectiveness for analyzing the complex structures of the Easternmost Mediterranean all others geophysical methods. Therefore, we have significantly expanded the techniques and methods of the paleomagnetic mapping of the Easternmost Mediterranean, combining them with the data of the deep geophysics, geodynamics, and structural analysis of the crustal formations discussed below.

## 2. Advanced Analysis of Magnetic Anomalies

### *2.1. Main Principles*

The major principles of the quantitative interpretation, formalized for vertical magnetization, do not work in the conditions of oblique magnetization in the low and central latitudes. The inclination of the total magnetic field in Israel ranges from 46$^o$ in the north to 42$^o$ in the south. Such conditions enormously complicate the interpretation of magnetic data using conventional procedures.

It should be noted that $\Delta\mathbf{T}$ anomaly distortions occur both due to the inclination of the magnetization vector to the horizon plane and the different orientations of the horizontal magnetization projection from the body's axes (e.g., Parasnis, 1997). Besides the geomagnetic field inclination, the orientation of the body's axes relative to the horizontal component of the geomagnetic field is also significant. Therefore, the analysis of field graph maps is insufficient and is often necessary to analyze the field isolines maps (Eppelbaum and Khesin, 2012).

In the conditions of oblique magnetization, the "reduction to pole" procedure is often used to calculate the pseudogravimetric anomalies (Blakely, 1995). However, the procedure is suitable only when all interfering bodies in the studied area are magnetized parallel to the geomagnetic field and simultaneously when the bodies have subvertical dipping. Only the magnetic fields can be recalculated correctly; the obtained graphs would be symmetrical, and further interpretation using the conventional methods can be made. Besides this, the "reduction to pole" cannot calculate such disturbing factors as the rugged terrain relief and practically always available aspect of superposition of the magnetic anomalies with the various wavelengths. Similar approaches based on the transformation of the observed magnetic field: analytic signal (e.g., Roest et al., 1992), wavelet transform (e.g., Moreau et al., 1999; Vallée et al., 2004); Euler deconvolution (e.g., Beiki, 2013; Florio and Fedi, 2014) have the same limitations.

The developed interpretation methods involve applying methods developed especially for the quantitative interpretation of magnetic anomalies in complex physical-geological environments (Khesin et al., 1996; Eppelbaum et al., 2001; Eppelbaum, 2011; Eppelbaum and Mishne, 2011; Eppelbaum, 2015b). Unlike other techniques, these methods (improved versions of tangents, characteristic points, and areal methods) are applicable in the conditions of oblique magnetization, rugged relief, and unknown levels of the normal field (superposition of magnetic anomalies of different orders). The five main interpretation models are used: thin bed, thick bed, horizontal circular cylinder (HCC), sphere, and thin horizontal plate. In addition, Eppelbaum (2015b) showed that a fairly representative class of models that take intermediate forms between the thick bed and the thin horizontal plate could be interpreted using the methodologies developed for the thick bed. Thus, the developed advanced techniques can analyze anomalies from the vast majority of the geological targets.

### *2.2. Quantitative interpretation of magnetic anomalies in the Sea of Galilee (Lake Kinneret)*

The Sea of Galilee (Lake Kinneret) is located in the northern Jordan Valley at the central part of the Dead Sea Transform (DST) (Fig. 1). This small sea (lake) is Israel's primary source of fresh water, with an average surface of 166 km$^2$ and an average volume of $4.3 \cdot 10^9$ m$^3$. The geological studies indicate the rock outcrops in this area and samples discovered in the wells surrounding the sea range from Jurassic to Quaternary. In contrast to the area around the sea, the structure below it is not fully understood. The drilling of boreholes in the lake is forbidden due to environmental restrictions.

There are two phases of significant basaltic volcanism in the Sea of Galilee region – Early Cretaceous and Late Cenozoic. The thickness of the Early Cretaceous basalts in the vicinity of the sea is minimal for northern Israel; hence, their contribution to the total magnetic field is negligible (Eppelbaum et al., 2004). The Late Cenozoic basalts range from Miocene to the Pleistocene. Most of the surface outcrops surrounding the sea's basalts are of the Pliocene and Pleistocene ages (Heimann et al., 1996).

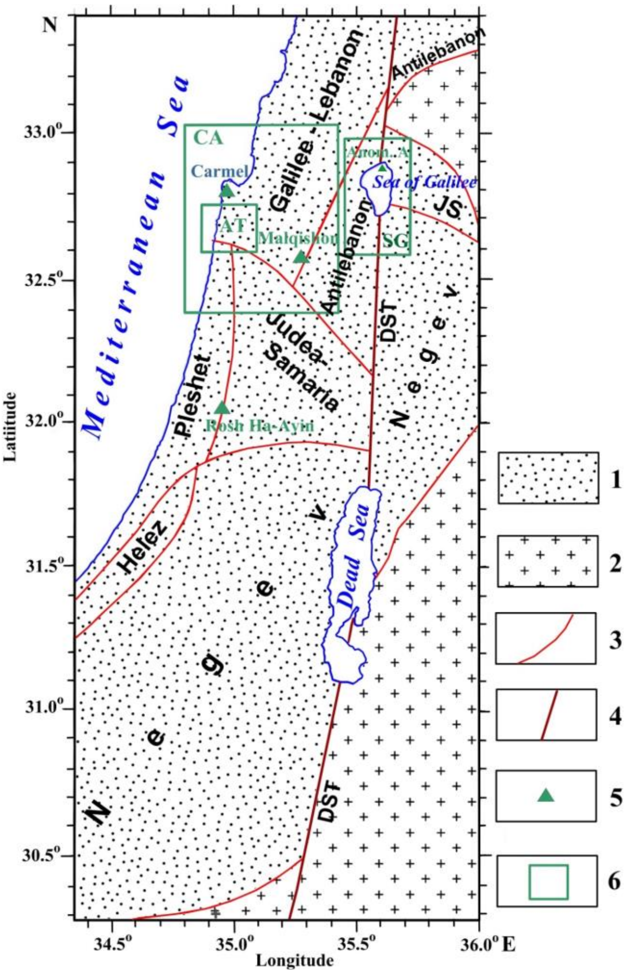


**Fig. 1.** Simplified areal-tectonic map of examined magnetic anomalies and paleomagnetic areas

The basaltic volcanism of different ages caused severe difficulties in quantitative analysis: in the sea and around it, the magnetic anomalies of different signs and intensities were recognized (Eppelbaum et al., 2004). About fifteen significant anomalies were selected and interpreted (Eppelbaum et al., 2004, 2022). Results of the interpretation of anomaly 'A' (located in the northern part of the sea (Fig. 1)) are presented in Fig. 2. Anomaly A was interpreted using the thin bed model; the anomalous body's depth is 920 m, and its magnetization $I \cong 2.7$ A/m.

### *2.3. Quantitative interpretation of Carmel magnetic anomaly*

The Carmel anomaly is located on the western edge of the Galilee-Lebanon terrane (Fig. 1). The Carmel structure differs from other coastal plain structures of the Eastern Mediterranean by essential tectonic amplitudes, geomorphological characteristics, broad development of magmatic formations (from Mesozoic to Cenozoic), high gradients of gravity and magnetic fields, and significant intensity of seismic events (Gvirtzman and Steinitz, 1982; Gvirtzman et al., 1990; Ginzburg and Eppelbaum, 1993; Eppelbaum et al., 2006; Eppelbaum and Katz, 2015a). The magnetic analysis of the Carmel anomaly has been carried out with the application of the advanced developed methodologies of tangents and characteristic points (Fig. 3). The depth of the upper edge of this anomalous body is about 6.5 km, and average magnetization is about 3000 mA/m. It is essential that the determined position of the magnetization vector does not coincide with the normal one and is vertical (90°). Later, the validity of the obtained model was confirmed by the results of 3D combined modeling of the magnetic and gravitational fields (Ginzburg and Eppelbaum, 1993). Geologically this model is interpreted as an uplift of the magnetic crystalline basement. An exciting fact confirming the modeling data is the coincidence of the apical part of the Carmel magnetic anomaly with the zone of the location of the highest hypsometric marks of this ridge reaching 528-546 m (see Fig. 3).

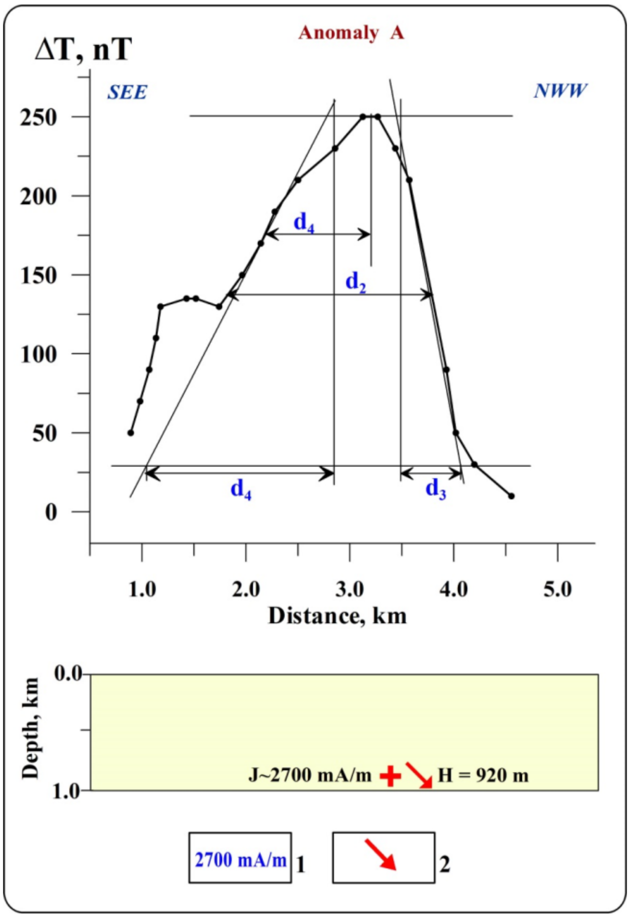


**Fig. 2.** Sea of Galilee: Quantitative analysis of magnetic anomaly A (see its location in Fig. 1)
(1) excess magnetization of the anomalous body, (2) position of the magnetization vector

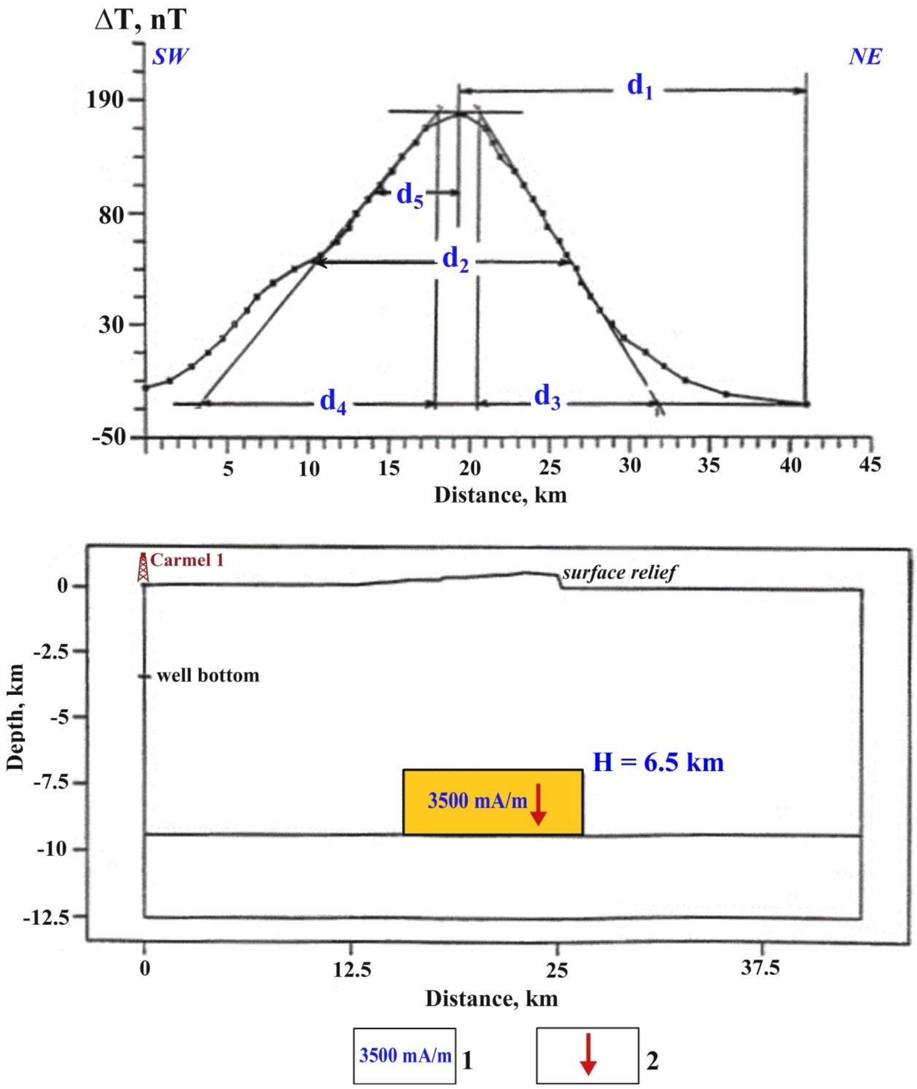


**Fig. 3.** Quantitative analysis of magnetic anomaly Carmel (see its location in Fig. 1)
(1) excess magnetization of the anomalous body, (2) position of the magnetization vector

### *2.4. Quantitative interpretation of Malqishon magnetic anomaly*

The Malqishon magnetic anomaly is located in the southwestern block of the Antilebanon terrane, near its border with the Galilee-Lebanon terrane (Fig. 1). The main, northeastern block of this terrane (where Hermon Mt. is located) is displaced relative to the southwestern block by over 100 km along the Dead Sea Transform. For the Malqishon magnetic anomaly analysis, the same interpretation methods were applied. The depth of the upper edge of this anomalous body consists of 4.5 km, and the magnetization is about 2800 mA/m. The position of the magnetization vector also does not coincide with the average for the northern Israel direction ($45^o$) and is about $105^o$ (Fig. 4). We suggest that it is also an uplift of the crystalline basement but is at a lower depth and narrower than in the Carmel area.

### *2.5. Nature of the Carmel, Malqishon, and Rosh Ha-Ayin magnetic anomalies*

The Rosh-Ha-Ayin magnetic anomaly (its location is shown in Fig. 1) has been analyzed using the magnetic and gravity methods (Eppelbaum, 1996). It was established that the depth of the anomalous body's upper edge occurs at about 6.5 km, and its origin is close to the anomaly Carmel. The Carmel, Malqishon, and Rosh-Ha-Ayin magnetic anomalies most likely correspond to the Permian-Triassic Illawarra paleomagnetic zone and are allochthonous, like the Israeli terranes themselves. The source of the extensive magnetic intrusions was probably the hot spots of the active spreading zone of the emerging Neotethys Ocean, where the initial massif of the Levant terranes was located (Eppelbaum and Katz, 2015a) and tectonically unloaded. Outside this zone, on the Gondwana foreland, only the sporadic dikes and alkaline ring intrusions of the Permian-Triassic are developed (Hall et al., 2005; Said, 2017), which do not form significant magnetic anomalies.

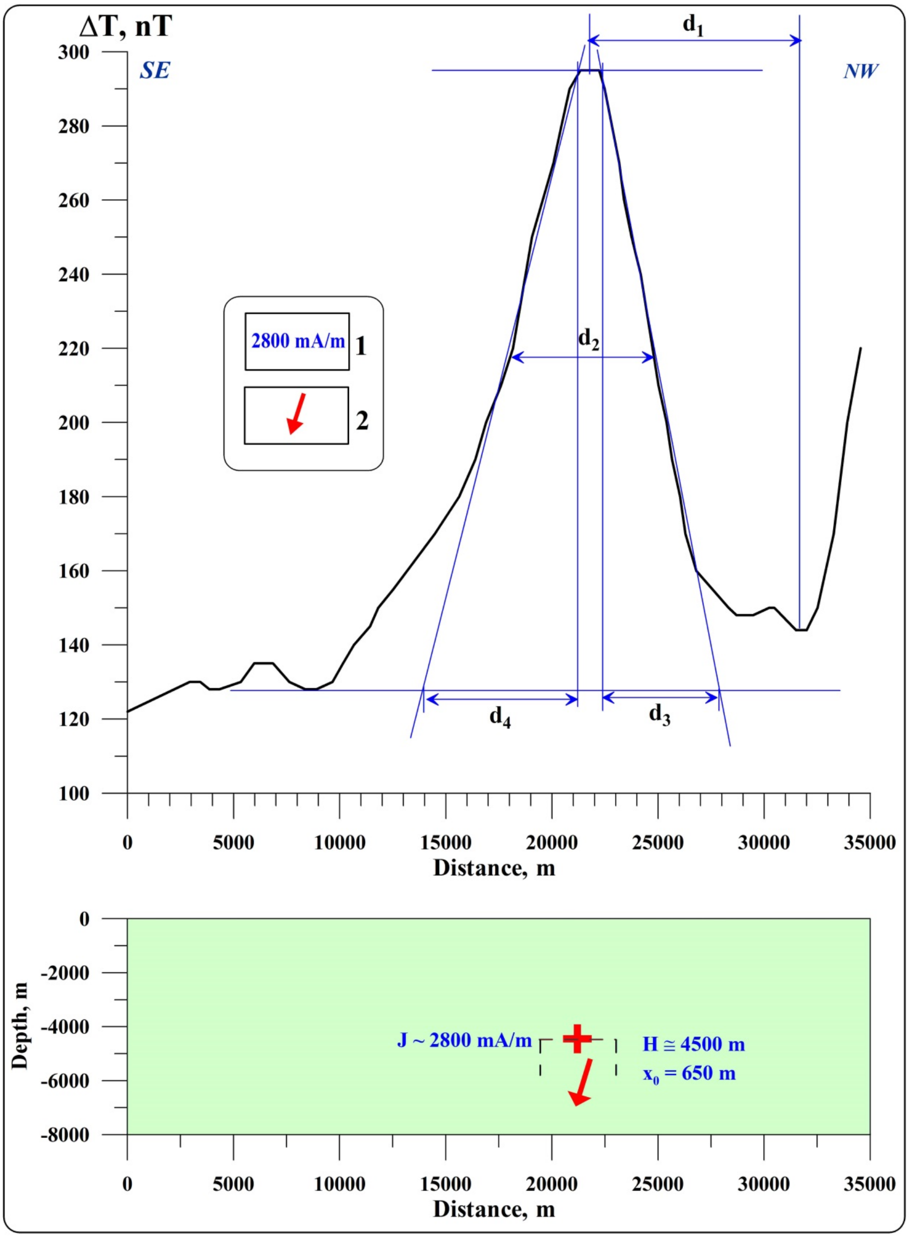


**Fig. 4.** Quantitative analysis of magnetic anomaly Malqishon (see its location in Fig. 1) excess magnetization of the anomalous body, (2) position of the magnetization vector. Symbol **+** designates the location of the middle of the upper edge of the anomalous body, and value $x_0$ indicates the distortion of the maximum of the magnetic anomaly from the middle of the upper edge due to oblique magnetization

## 3. Tectono-Paleomagnetic Mapping and its Role in Geological-Geophysical Integration

The paleomagnetic research is widely accepted as a powerful independent tool for geodynamic and tectonic analysis, studying deep structures, searching for economic minerals, and other studies (e.g., Храмов и др., 1982; Opdyke and Channel, 1996; Tauxe, 2003). Sometimes the geological-geophysical conclusions reached from the paleomagnetic data analysis cannot be obtained from any other geophysical or geological methods (Eppelbaum and Katz, 2015a). The regional and the local magnetostratigraphic schemes are widely applied to unify the stratigraphic schemes and correlate the numerous local subdivisions. The paleomagnetic mapping (zonation) allows "jumping" from the single measurements to some areal reconstructions. This fact can meaningfully increase the effectiveness of the paleomagnetic method application. At the same time, integration of the paleomagnetic data with the set of the geophysical-geological methods (Fig. 5) often strongly increases the effectiveness and the significance of the combined research.

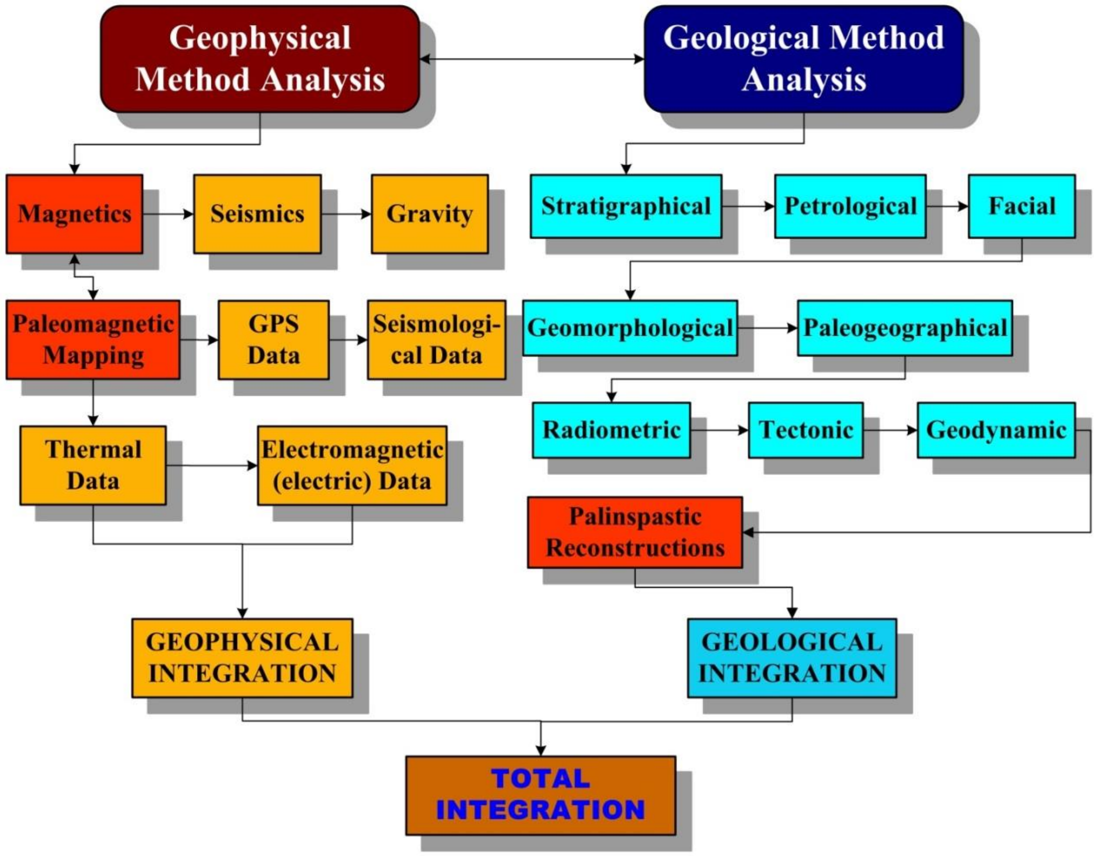


**Fig. 5.** Paleomagnetic mapping as a necessary element of geological-geophysical mapping of heterogeneous media (most important components of the current investigation are red colored)

The methodology known as paleomagnetic mapping was precipitated by developing two main scientific directions: (1) paleomagnetic stratigraphy and (2) examination of the magnetic anomalies in the World Ocean.

Obviously, the first paleomagnetic stratigraphic studies in sedimentary rocks were associated with the studies of Creer et al. (1954) and Irving and Runcorn (1957). The authors detected normal and reversed magnetic polarities at more than ten samplings of the Proterozoic Torridonian Sandstones and rocks from Scotland's Devonian and Triassic ages. For the Torridonian Sandstones, an attempt was made to correlate the observed polarity zones in stratigraphic sequences (after Laj and Channell, 2007).

Khramov's (1960) investigation was intended to analyze magnetic polarity stratigraphy in Pliocene-Pleistocene sediments from western Turkmenistan (Central Asia), where he carried out chronostratigraphic interpretations based on the equal durations of polarity intervals. Picard (1964) successfully applied the magnetostratigraphic studies to Triassic red sandstones of the Chugwater Formation (Wyoming, USA). Irving (1966) discovered the Kiama paleomagnetic zone of inverse polarity in Upper Paleozoic rocks in Australia and defined its interrelation with covering the Illawarra zone of normal polarity. This discovery has played a vital role in subsequent paleomagnetic investigations (Opdyke and Channel, 1996).

The development of the first paleomagnetic maps was associated with mapping ocean bottoms, where a series of direct and inverse magnetization zones were interpreted to be spreading zones (Vine and Matthews, 1963; Vine and Wilson, 1965; Pitman et al., 1974). At present, the paleomagnetic ocean reconstructions include magnetization stages from the Cretaceous and Cenozoic (Cande and Kent, 1992) to Middle Jurassic (Shreyder, 1993; Tominaga et al., 2008). McDougall et al. (1977) effectively integrated paleomagnetic analysis with radiometric dating to examine basaltic formations in western Iceland.

Molostovsky (Молостовский, 1986) and Molostovsky and Khramov (Молостовский, Храмов, 1997) presented several detailed examples of paleomagnetic mapping sedimentary deposits in Russia's Volga-Ural and Caucasus regions. The methodology of a paleomagnetic mapping of the volcanogenic association of the Miocene traps of Transcarpathia was shown in Glevasskaya and Mikhailova (Глевасская, Михайлов, 1986). The foundations of the geodynamic paleomagnetic zonation with examples from the Easternmost Mediterranean, various areas of the USA, New Zealand, and some other regions were reported in Kissel and Laj (1989). Opdyke and Channel (1996) presented some generalizations for paleomagnetic mapping. Halafov et al. (Халафов и др., 1986) successfully applied paleomagnetic zonation of the Upper Cretaceous volcanogenic-sedimentary deposits in the eastern part of the Lesser Caucasus. Goguitchaichvili et al. (2009) have reliably mapped the Gilbert-Gauss geomagnetic reversal in the Pliocene volcanic sequences in the Lesser Caucasus.

Nur et al. (1989) carried out the first geodynamic paleomagnetic zonation of transition zones from the ocean to the continent in northern Israel. Here the mentioned authors revealed several tectonic blocks of the predominant counterclockwise rotation.

Eppelbaum et al. (2004, 2007) have successfully applied integrated paleomagnetic and magnetic data analysis and the radiometric dating to the tectonic-structural analysis in the region of the Sea of Galilee. As a result, this area's initial magnetic-paleomagnetic-radiometric map (scheme) was developed.

Kristjansson and Jonsoon (2007) extended perspectives of paleomagnetic mapping in Iceland. Paleomagnetic mapping of a speleothem from the southern Pacific was carried out by Fukuyo et al. (2019).

Eppelbaum et al. (2014) discovered the Kiama zone of inverse polarity in the Easternmost Mediterranean. It triggered the development of the first paleomagnetic map of the Easternmost Mediterranean based on the integrated interpretation of different geophysical fields and comprehensive analysis of the surrounding sedimentary and volcanogenic structures (Eppelbaum and Katz, 2015a, 2015b, 2015c, 2020).

Paleomagnetic-geodynamic mapping (Eppelbaum et al., 2014; Eppelbaum and Katz, 2015a, 2022) of the Easternmost Mediterranean, between the Laurasia and Gondwana, where the Eurasian, Aegean-Anatolian, Nubian, Sinai, and Arabian plates converge, made it possible to clarify and substantiate the boundaries and nature of the crust of these formations. For the first time, ophiolite outcrops were identified and mapped in the distal regions of the foreland adjacent to the southern Tethys zone. A new tectonic map of the region has been obtained, where the Mesozoic Terrane Belt with pre-collision, collision, and post-collision traps was identified and mapped for the first time.

At the same time, the dynamics of the diverse movement of terrane and subterrane blocks were revealed (Eppelbaum and Katz, 2015a, 2015b). In addition, the Eastern Mediterranean–Nubian Volcanic Belt (EMNVB), containing magnetoactive diamond-bearing bodies of kimberlites and lamproites, was mapped and geodynamically substantiated (Eppelbaum et al., 2006, 2021).

Significantly, the paleomagnetic data showed a counterclockwise rotation of the ring magmatic structures of this belt, which corresponds to the dynamics of the deep mantle structure under the magma belt (Eppelbaum et al., 2020). Under the conditions of the closure of the Neotethys Ocean (Gamkrelidze, 1986), the EMNVB finds a direct (however, eastward) continuation to the north where the submeridional Main East European Fault (MEEF) separates the Eastern and Western Caucasus (Eppelbaum et al., 2021). Currently, MEEF is located outside the deep structure projection. According to paleomagnetic and GPS data analysis, the western flank of the MEEF is turning clockwise, and the eastern side is turning counterclockwise (Eppelbaum et al., 2021).

It should be noted that the specificity of the Easternmost Mediterranean, where two different types of geodynamics converge, collision and spreading, may be used as a polygon for testing the paleomagnetic mapping methods. With a wide range of applied analytical, search and survey methods, this gives reason to believe that it can become a reference for mapping techniques for transition zones from the ocean to the continent. Besides this, this methodology can be used for many geologically complex regions (e.g., the Lesser and Greater Caucasus, the Alps, and the Himalayas).

## 4. Paleomagnetic Mapping of Several Areas in Northern Israel

The combined paleomagnetic mapping has been performed for the following geologically complex areas in northern Israel: (1) the Sea of Galilee and its vicinity, (2) the Mt. Carmel and surrounding areas, and (3) the Atlit area as part of the Mt. Carmel paleomagnetic map (it was caused by the high complexity of the Mt. Carmel map). Separately a paleomagnetic profile across the Carmel-Galilee region was developed.

### *4.1. Combined paleomagnetic scheme of the Sea of Galilee and its vicinity*

The region of the Sea of Galilee (Lake Kinneret) is a kind of reference object for the paleomagnetic mapping transition regions from the ocean to the continent in terms of both structural historical-geological and methodological approaches. The uniqueness of this object follows from the fact that here developed the phenomena and structures of the collisional type caused by the closure of the Neotethys Ocean and the elements of the initial phases of the Red Sea – East African Rift system spreading.

It has long been used as the largest freshwater reservoir in the Middle East and as an etalon region for monitoring and accounting for seismicity in the area of active housing construction and areas of industrial and agricultural facilities development.

There are several fault systems in this area, the main ones being the N–S transform system and the E–W and NW–SE fault systems that break up Galilee. The seas, and the plain to its south, are located in a depression bounded on the east and west by active fault scarps with steep gradients (Garfunkel et al., 1981). The superposition of vertical displacements perpendicular or oblique to the transform impedes the structural interpretation of the investigated basin (Ben-Avraham et al., 1996).

At the end of the twentieth century, various geological and geophysical surveys raised the question of developing the generalizing tectonic-geodynamic model (e.g., Ben Avraham et al., 1980, 1996). Further studies (Eppelbaum et al., 2004, 2007; Eppelbaum and Katz, 2015a) showed that the solution to this problem is to develop a methodology for the paleomagnetic mapping by an optimal linkage of the methods of magneto-geophysics adopted in the study of the oceans and the methods of the paleomagnetic stratigraphy assumed for the continents, and supported by a set of independent geological-geophysical investigations. This map also generalizes the results of the quantitative interpretation of numerous magnetic anomalies in the Sea of Galilee (Fig. 6).

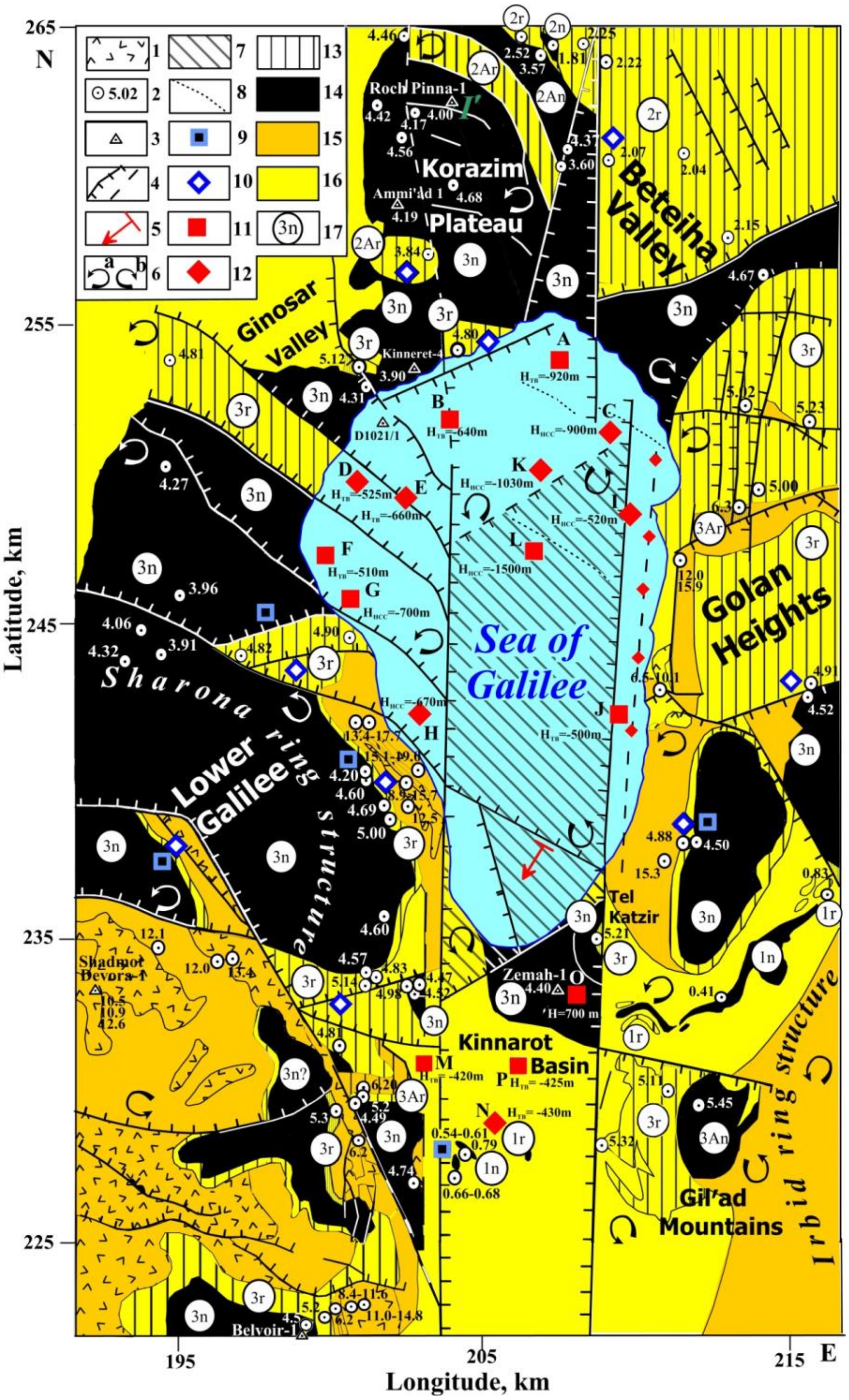


**Fig. 6.** Integrated paleomagnetic scheme of the Sea of Galilee (see its location in Fig. 1)

(1) outcropped Cenozoic basalts, (2) points with radiometric age of basalts (in m.y.), (3) boreholes, (4) faults, (5) general direction of the proposed buried basaltic plate dipping in the southern part of the Sea of Galilee, (6) counterclockwise (a) and clockwise (b) rotation of faults and tectonic blocks, (7) pull-apart basin of the Sea of Galilee, (8) suggested boundaries of the paleomagnetic zones in the sea, data of land paleomagnetic measurements: (9 and 10) (9) reverse magnetization, (10) normal magnetization, (11 and 12) results of magnetic anomalies analysis: (11) normal magnetization, (12) reverse magnetization, (13) reversely magnetized basalt fields, (14) normal magnetized basalt fields, (15) Miocene basalts and sediments with complicated paleomagnetic characteristics, (16) Pliocene-Pleistocene basalts and sediments with complicated paleomagnetic characteristics, (17) index of paleomagnetic zonation.

Tectonic setting after Heimann (1990); Ben-Avraham et al. (1996), Sneh et al. (1998), Hurwitz et al. (2002). 1n, 2n, 3n, 1Ar, 2Ar, and 3Ar are the indexes of paleomagnetic zones (see Fig. 6).

Radiometric data (K-Ar and Ar-Ar) after Heimann (1990), Shaliv (1991), Heimann et al. (1996), Heimann and Braun (2000), Segev (2017). Paleomagnetic data after Freund et al. (1965), Nur and Helsey (1971), Ron et al. (1984), Heimann (1990), Shaliv (1991), Heimann et al. (1996), Heimann and Braun (2000), Mor (1993), Dembo et al. (2015), Behar et al. (2019).

$H_{HTB}$, $H_{THP}$, and $H_{HCC}$ designate calculated depths of basaltic bodies in the basin: $H_{HTB}$ is the upper edge for the model of a thin bed, $H_{THP}$ is the upper edge for the model of a thin horizontal plate, and $H_{HCC}$ is the center for the model of a horizontal circular cylinder.

This development was the first experience of such research in the areas transitional from the ocean to the continent. In the context of the regional geological-geophysical studies of the African-Arabian region, paleomagnetic mapping of the area of the Sea of Galilee has been significantly expanded and detailed (Eppelbaum and Katz, 2015a, 2015b; Eppelbaum et al., 2020, 2021; Eppelbaum and Katz, 2020, 2021a).

The supplemented edition of the Sea of Galilee paleomagnetic map was extended to the south, where the Belvoir uplift was developed (Fig. 6). A deep well was drilled here, and a set of the radiometric dating of the Cenozoic traps was obtained. The map was significantly detailed, attracting new structural, radiometric, and paleomagnetic analyses for the studied area.

Methodologically, in such a manner, we nailed the mapping of the transition region from the ocean to the continent to the methods widely used in the paleomagnetic mapping of the oceanic regions (Eppelbaum and Katz, 2015a), and optimally compiled with the geodynamic principles (Kessel and Laj, 1989). A novel variant of the paleomagnetic map of the Sea of Galilee and adjacent areas (Fig. 6) includes an anomalous pull-apart basin, areas of development of the circular structures (Eppelbaum and Katz, 2015a; Eppelbaum et al., 2021), the arc faults, and the rotational markers of the crustal block rotation identified from the structural and paleomagnetic data (Ron et al., 1984; Heimann and Ron, 1993; Ben Avraham et al., 1996).

Here are presented two comparatively large ring structures. The first is the Sharon trap depression located in the central-western part of the map, and the second is the Irbid ring structure, bounded by conical dikes and partially presented in the southeastern part. Significantly, the largest rotation amplitude of 58$^{o}$ counterclockwise is registered in the Sharona ring structure (Fig. 6). It emphasizes the complexity of the geodynamics of the zones of trap genesis. A different nature has an Irbid ring structure that is also prone to counterclockwise rotation (Fig. 6).

### *4.2. Carmel and Atlit paleomagnetic maps*

The Mt. Carmel structure (see Fig. 1) differs from other coastal plain structures of the Easternmost Mediterranean by numerous geological-geophysical characteristics (Gvirtzman and Steinitz, 1982; Gvirtzman et al., 1990; Ginzburg and Eppelbaum, 1993; Eppelbaum et al., 2006).

Paleotectonically, the Carmel structure is located at the boundary between the Galilee-Lebanon and Judea-Samaria terranes (Ben-Avraham and Ginzburg, 1990). Neotectonically, this boundary coincides with the zone of seismic activity within the Yagur fault branch system; it continues onshore and divides the area into the southern and northern sectors (Garfunkel and Almagor, 1984). The most recent analysis shows that this boundary is displaced a few km south of the Atlit fault zone.

The Carmel tectonic node is vital in estimating the spatial interaction of the continental and oceanic zones in the region under study. The oldest discovered deposits are the Triassic associations, an overlying series of the magmatic and sedimentary rocks of the Early Mesozoic (Asher Volcanics) (Gvirtzman and Steinitz, 1982). The last associations covered by younger Mesozoic-Cenozoic deposits are affected by the prolonged complex deformation of the postaccretional tectonic stage (> 130 Ma).

Earlier, it was assumed (Gvirtzman and Steinitz, 1982; Garfunkel, 1989) that the Early Mesozoic formation of the Asher Volcanics was generated within the graben structure. Gvirtzman et al. (1990) suggested that the formations composing this graben have a predominantly continental genesis since they include the soils and coal. According to other data (Garfunkel and Derin, 1988; Dvorkin and Kohn, 1989), the Asher Volcanics relate to a deep basin with a possible ocean-like crust; the results of our investigation (Katz and Eppelbaum, 1999; Eppelbaum et al., 2014; Eppelbaum and Katz, 2015a, 2015b) partially agree with the last proposition.

Discovering numerous mantle minerals (Esperanca and Garfunkel, 1986; Mittlefehldt, 1986; Apter, 2014; Kaminchik et al., 2014; Dobrzhinetskaya, 2018; Griffin et al., 2018) also has confirmed the mentioned suggestion. It should be noted that an anomalously high content of the Permian zircons was found in the xenoliths of the Cretaceous volcanoes (Griffin et al., 2018). Based on the analysis of the ratios of trace elements, the authors above believe these zircons are associated with the magmatic complexes of the Earth's crust of the oceanic type.

In the current work, we have expanded the paleomagnetic mapping of the northern part of the Easternmost Mediterranean by the attraction of the geologically and geophysically well-studied area of Mt. Carmel and the adjacent territories of the Galilee and the Mediterranean shelf (Fig. 7).

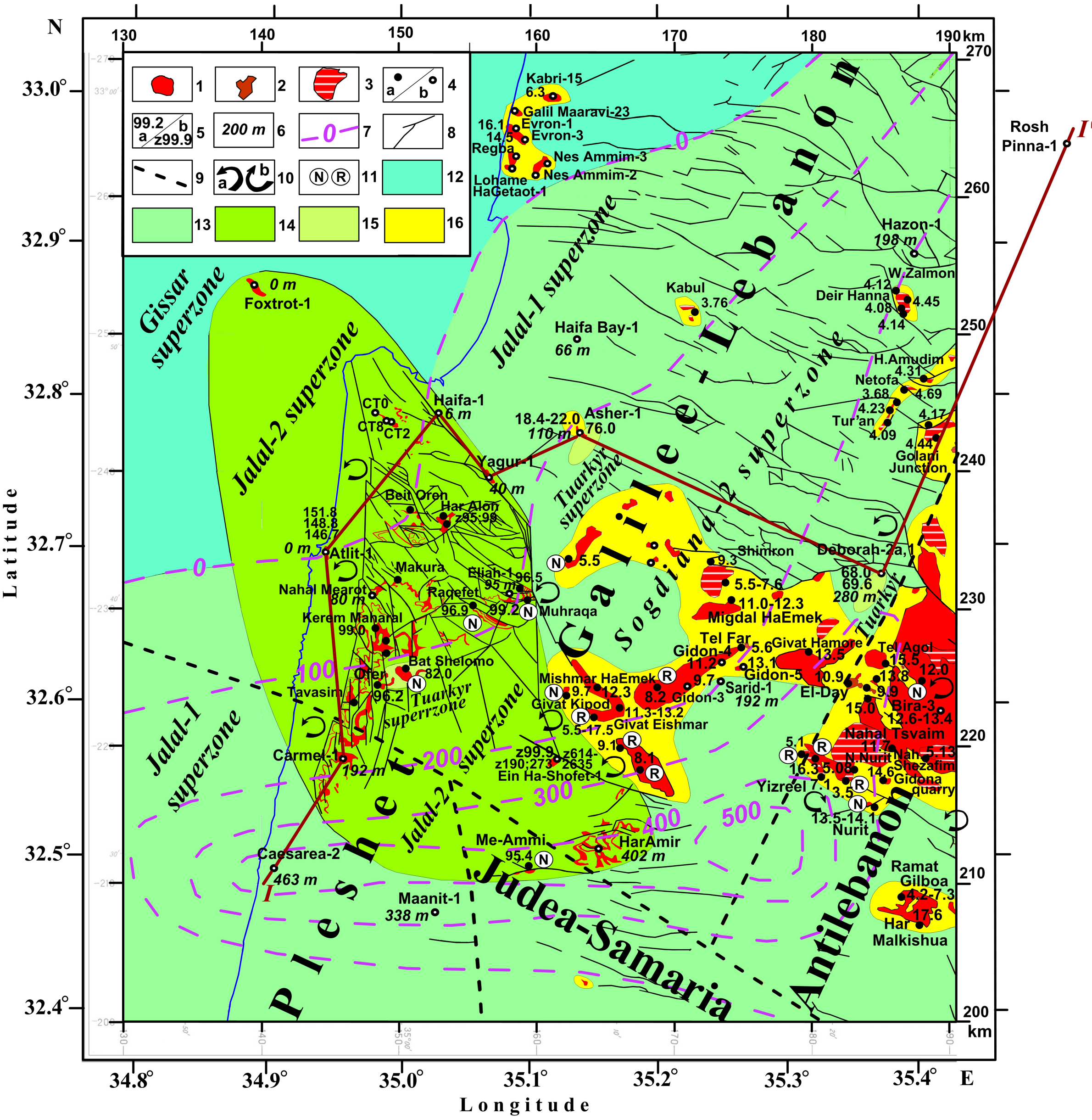


**Fig. 7.** Geodynamic-paleomagnetic map of the Mt. Carmel – Galilee region (see its location in Fig. 1).
Geodynamic-paleomagnetic map of the Mt. Carmel – Galilee region (see its location in Fig.1).
(1) Cretaceous-Miocene basalts, (2) Miocene gabbroid intrusive, (3) Pliocene Cover basalts, (4) outcrops (a) and boreholes (b) with the Mesozoic-Cenozoic magmatic complexes, (5) radiometric age of magmatic rocks and minerals from K-Ar, Ar-Ar methods (a) and zircon geochronology (b), (6) thickness of the Lower Cretaceous traps (in m), (7) isolines of the Lower Cretaceous traps thicknesses (in m), (8) faults, (9) boundaries of terranes, (10) counterclockwise (a) and clockwise (b) rotation derived from tectonic and paleomagnetic data, (11) data of paleomagnetic measurements of magmatic rocks with normal *N* and reverse *R* polarities, (12-15) paleomagnetic s: (12) Gissar, (13) Jalal-1, (14) Jalal-2, (15) Tuarkyr, (16) Sogdiana-2.
The bold brown line shows the location of the paleomagnetic profile *I – I'*.
The following main works were used for this map construction: Nur and Helsey, 1971; Lang and Mimran, 1985; Lang and Steinitz, 1989; Nur et al., 1989; Shaliv, 1991; Mor, 1993; Heimann et al., 1996; Sneh et al., 1998; Katz and Eppelbaum, 1999; Segev, 2000, 2009; Segev et al., 2002; Ilani et al., 2001, 2005; Segev and Sass, 2009; Karcz and Sneh, 2011; Sass et al., 2013; Kaminchik et al., 2014; Dembo et al., 2015; Sneh, 2013, 2018; Sneh et al., 2014; Eppelbaum and Katz, 2015a, 2015b; Griffin et al., 2018

The Atlit paleomagnetic map (Fig. 8) occupies the central-northern part of the Carmel paleomagnetic map. Tectonically, this area belongs mainly to the Galilee-Lebanon terrane and the marginal parts of the Pleshet, Judea-Samaria, and Antilebanon terranes (Fig. 8). Geophysically, this area is significant for explaining the Carmel regional magnetic-gravity anomaly. Its apical part almost coincides with the top part of the Carmel Plateau, with hypsometric elevations up to 546 m. The Carmel anomaly marks the southern part of the Galilee-Lebanon terrane, where significant differences in the basement depth and thrust of the ophiolite sheets are developed. The latter enclose the magmatic complexes and mélange (Eppelbaum and Katz, 2015a).

The second geophysical boundary structure (besides the Carmel anomaly) located near the junction of the Galilee-Lebanon, Antilebanon, and Judea-Samaria terranes is the Malqishon magnetic anomaly (see Figures 1 and 4). We mention these anomalies in connection with the fact that their geological nature, in contrast to the geophysical one, has been insufficiently studied and requires additional data on paleomagnetic mapping, presented below. This mapping became possible due to numerous new data on paleomagnetic, radiochronological, mineral, petrological, and structural-tectonic analyses of the magmatic and sedimentary complexes developed here. In general, the paleomagnetic mapping of this area made it possible to reveal at the surface (and in the subsurface) the outcrops of the paleomagnetic superzones: Gissar, Jalal-1, Jalal-2, Tuarkyr, and Sogdiana-2 (here the paleomagnetic classification suggested by Molostovsky et al. (2007) was applied).

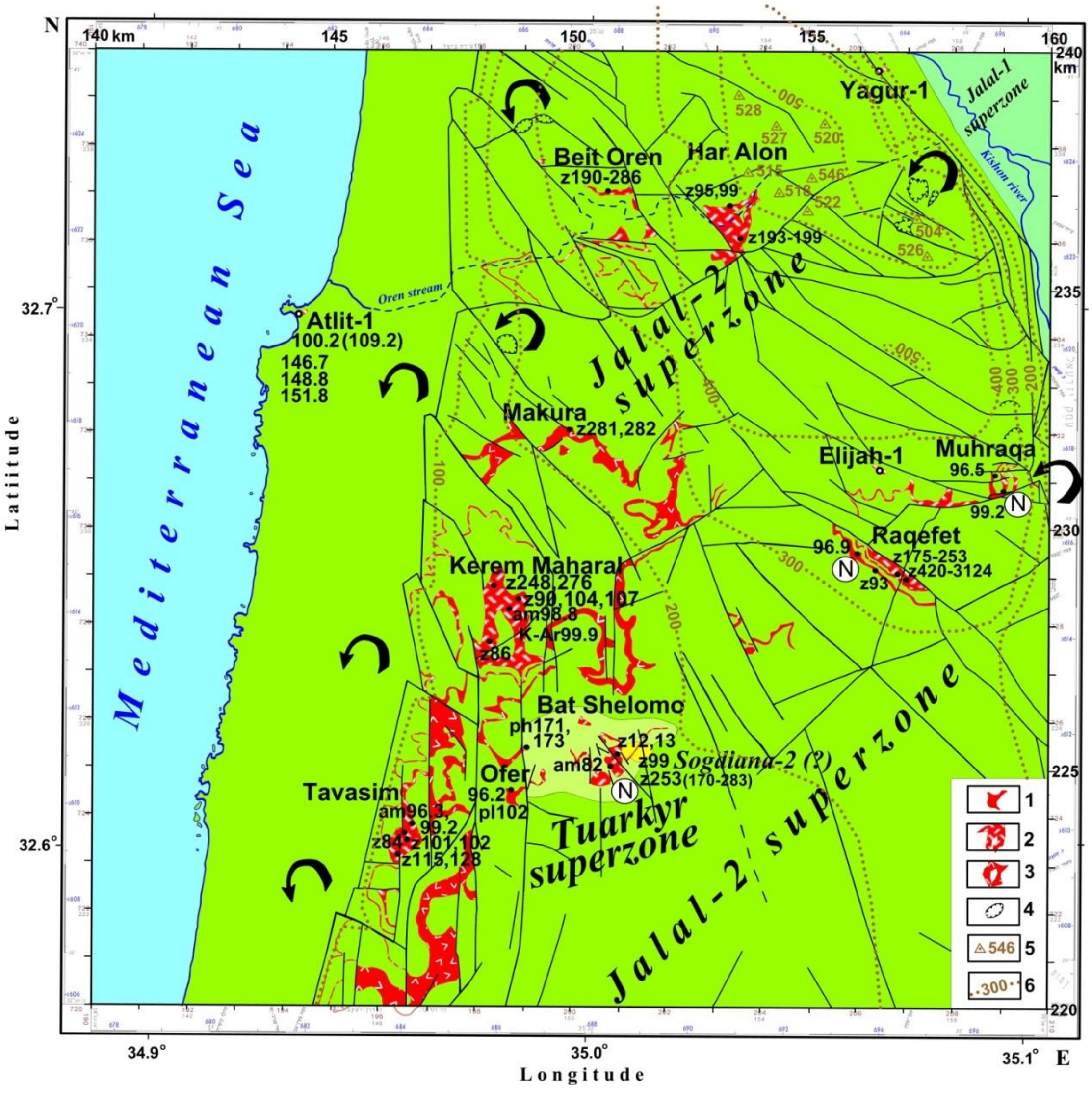


**Fig. 8.** Geodynamic-paleomagnetic map of Atlit area (the middle part of the Carmel area) (see its location in Fig. 1). This map was developed on the basis of a geological map (Segev and Sass, 2009)
(1) basalt lava flows, (2) basalt tuffs, (3) tuffs and flows of basalt volcanic units, (4) landslide scars, (5) highest hypsometric marks, (6) hypsometric lines

The data on the Gissar and Jalal-1 superzones (Eppelbaum and Katz, 2022) were obtained from numerous boreholes, where these formations' thickness and radiometric age were studied. Due to this data, the geological boundary of the Gissar and Jalal-1 superzones was mapped, corresponding to the pinching out of collisional-postcollisional effusive trap strata reaching a thickness of 463 m (Caesarea-3 borehole) and to the east, the vertical thickness of the deep source of the Malqishon magnetic anomaly, probably exceeds 500 m.

The paleomagnetic phenomenon of the Mt. Carmel region is the development of the Upper Cretaceous (Cenomanian) diamondiferous volcanics of the Jalal-2 superzone, stratigraphically and radiometrically dated in the natural outcrops and the wells Foxtrot-1, Eliah-1, Carmel-1, and Ein Ha-Shofet (Segev, 2009; Griffin et al., 2018) and in outcrops (Segev and Lang, 2002; Segev, 2009; Segev and Sass, 2009). It is pretty indicative that the outline and dimensions of the outcropping area of the paleomagnetic Jalal-2 superzone generally coincide with the distribution area of both magnetic (Folkman, 1976; Ginzburg and Eppelbaum, 1993) and gravity (Ben-Avraham and Hall, 1977; Ginzburg and Eppelbaum, 1993) anomalies of the Mt. Carmel and its outskirts.

The data mentioned above join the deep-geophysical mechanisms of different levels – the mantle plumes from the deep mantle and the movements of the basement of the Earth's crust, which are sources of the shallow anomalies of the gravity and magnetic fields (Eppelbaum et al., 2020, 2021). The Tuarkyr, confined in this area to the Senonian, was developed in the form of insignificant areas at the surface as scattered outcrops of the Bat Shelomo effusive rocks in the south of the Carmel Plateau, a radiometric age of 82 Ma (Segev and Lang, 2002).

The other two finds in this superzone are associated with the radiometrically dated sills from the Asher-1 borehole (Ilani et al., 2005) and tuffs in the Devorah-2 borehole (Lang and Steinitz, 1989) corresponding to the Campanian and Maastrichtian. Paleomagnetic investigations of the Late Cretaceous volcanic rocks of the Jalal-2 and Tuarkyr superzones outcropping on the surface in a few areas testify to their normal polarity (Segev et al., 2002).

The Sogdiana-2 paleomagnetic superzone, concerning to the more ancient Mesozoic superzones submeridionally extending, occurs discordantly, ranging from the giant outcrop of the Cenozoic Ash Shaam traps diagonally stretching from the SE to the NW. In this area, the belt of the Cenozoic traps forms the scattered outcrops within the Cretaceous and Paleogene rocks, often combining with them in a narrow space – in the Asher-1 borehole (Ilani et al., 2005), and even using the ways of introducing the Mesozoic traps, as it was discovered (Griffin et al., 2018) in the field of the Santonian Bat Shelomo volcano.

### *4.3. Paleomagnetic profile across the Carmel-Galilee region*

The paleomagnetic profile crosses the area of Mt. Carmel, Northern Galilee, and the Korazim Plateau of the DST region (north of the Lake Kinneret), from SW to NE from the Pleshet terrane through the Galilee-Lebanon terrane to the Antilebanon terrane (Fig. 9). This profile is constructed along the top of the accumulative leveling surface of the Lower Cretaceous traps belonging to the Jalal-1 paleomagnetic zone (131-105 Ma). The Pleshet and Antilebanon terranes are somewhat uplifted tectonically than the Galilee-Lebanon terrane.

The underlying Triassic-Jurassic sequences that make up the cover of the carbonate platform of the Mesozoic Terrane Belt contain dikes and sills of Tithonian-Neocomian basaltoids (132-153 Ma) and belong to the Gissar paleomagnetic zone. Concerning the terranes themselves, the carbonate platform represents an autochthonous complex; however, both carbonates and intrusive traps were formed in the pre-collision stage, when the terranes bordered the southern part of the Neotethys Ocean at the boundary with the Gondwana foreland. The profile clearly shows that in the Galilee-Lebanon terrane, above the carbonate platform, an allochthonous complex of ophiolites is developed, forming four sheets of different ages. The lowest of them, the youngest, is composed of keratophyre mélange aged 162-164 Ma (Omolon paleomagnetic zone) and is covered with relatively deep-water Upper Jurassic carbonates penetrated by intrusive traps of the Gissar zone. Two middle ophiolite plates are composed of spilite and olivine-basalt mélange (188-206 Ma) and deep-water Jurassic carbonates and generally belong to the Omolon paleomagnetic zone. Finally, the upper ophiolite plate, the oldest, 197.4 – 222.4 Ma, is composed of basalt mélange and covered with Jurassic carbonates (174 Ma), which generally corresponds to the Illawarra-Omolon paleomagnetic zones (Fig. 9).

The dynamics of sequential attachment of ophiolite sheets during collision and shear movements of oceanic plates and the Galilee-Lebanon terrane during the Levantine phase of tectogenesis at the boundary of the Early and Late Hauterivian was considered earlier (Katz and Eppelbaum, 1999). These authors have shown that the amplitude of horizontal displacements of ophiolite plates could reach 120 km.

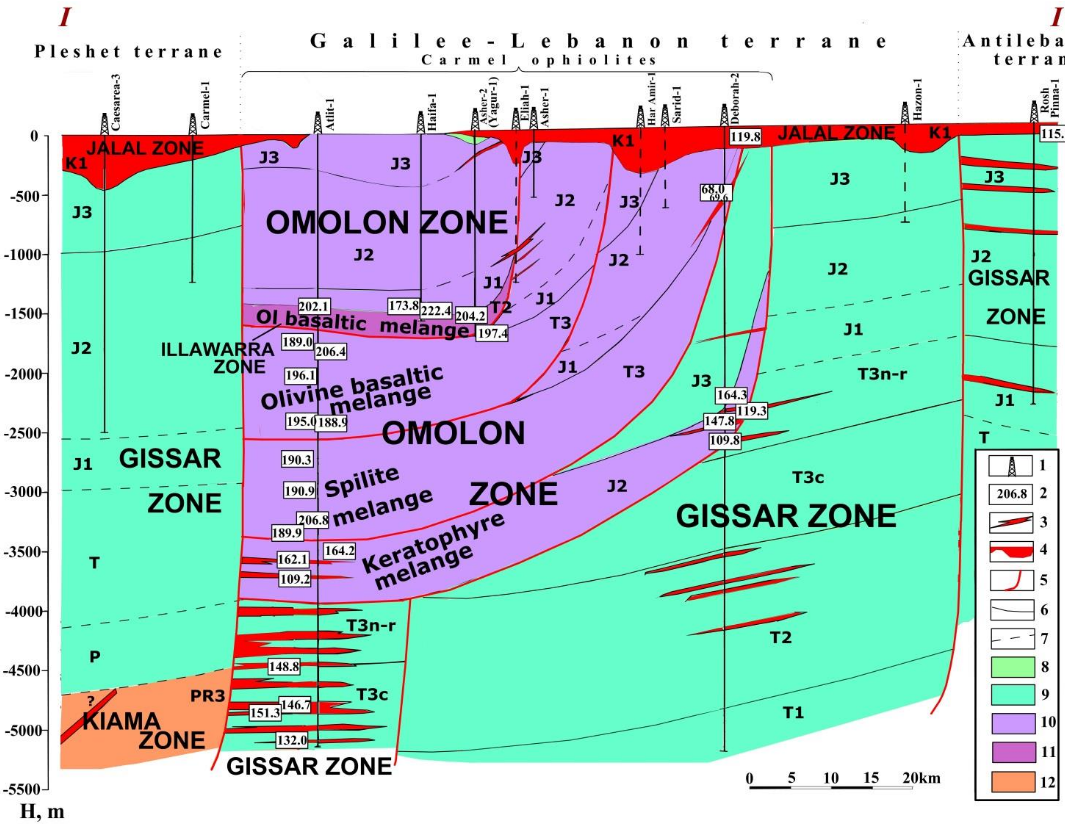


**Fig. 9.** The paleomagnetic profile of the Carmel-Galilee region along the top of the Lower Cretaceous traps' accumulative surface (this profile's location is shown in Fig. 7)
(1) borehole, (2) radiometric age, (3) dykes and sills, (4) traps, (5) faults, (6) established stratigraphic boundaries, (7) supposed position of the stratigraphic boundaries, (8-12) paleomagnetic zones: (8) Jalal, (9) Gissar, (10) Omolon, (11) Illawarra, (12) Kiama

Many years of paleomagnetic mapping experience in the Eastern Mediterranean (e.g., Eppelbaum et al., 2004, 2007, 2022; Eppelbaum, 2015a; Eppelbaum and Katz, 2015a,b,c; Eppelbaum and Katz, 2022) showed that the structural and temporal analysis of magnetostratigraphic elements is not sufficiently investigated due to significant displacements of tectonic blocks. In this paper, we tried to identify aspects of the geodynamics of the area of the Sea of Galilee during the Akchagylian maximum (3.6 – 2.0 Ma) to correlate the tectonic-thermal events of the Tethys and Paratethys basins.

For this purpose, a palinspastic reconstruction in the Hula – Sea of Galilee – Kinnarot basins and framing uplifts of the DST has been carried out. One of the most important problems here is a geological imagination of the displacement amplitude. According to regional data, the total amplitude of the shear zone is 100 km (Hall et al., 2005). At the same time, the activation (movement) time, derived from the radiometric and geodynamic data (Bosworth et al. 2005), is 20 Ma.

Thus, after the end of the Akchagylian hydrospheric-geodynamic maximum (~2.0 Ma) (Eppelbaum and Katz, 2021b), the eastern side of the DST was moved along the left strike-slip to the north by a distance of about 10 km. A palinspastic reconstruction of the area under study for a period of 3.6-2.0 Ma is shown in Fig. 10.

An essential element of the paleomagnetic-geochronological reconstruction is the reduction of young trap and sedimentary complexes that formed 3.6-2.0 Ma mainly in the east, the northern part of the Golan Plateau, and partly in the Hula and Kinnarot basins. Integrating paleogeographic analysis with the paleomagnetic mapping enabled us to assess the Akchagylian stage, which is as thoroughly studied paleomagnetically in the stratotype region (South Caucasus – Middle Asia) but much more qualitatively studied radiometrically in Northern Israel from trap complexes.

The paleomagnetic analogs of the Paratethys Akchagylian are compactly distributed near the basin of the Sea of Galilee. Subchron C2An (Gauss Chron) is developed on the northern slope of the Korazim Plateau and, to a lesser extent, in the pull-apart basin of the Hula basin, and on the northernmost slope of the carbonate platform of the Neoproterozoic belt, at the boundary with the Hermon terrane (Fig. 10). Thick traps of the Northern Golan Plateau (Ortal basalts –1.8-0.89 Ma and Golan basalts – 0-0.85 Ma), comparable to the Miocene basalts of Galilee, are missing from a palinspastic reconstruction compiled for an older epoch (> 2 Ma).

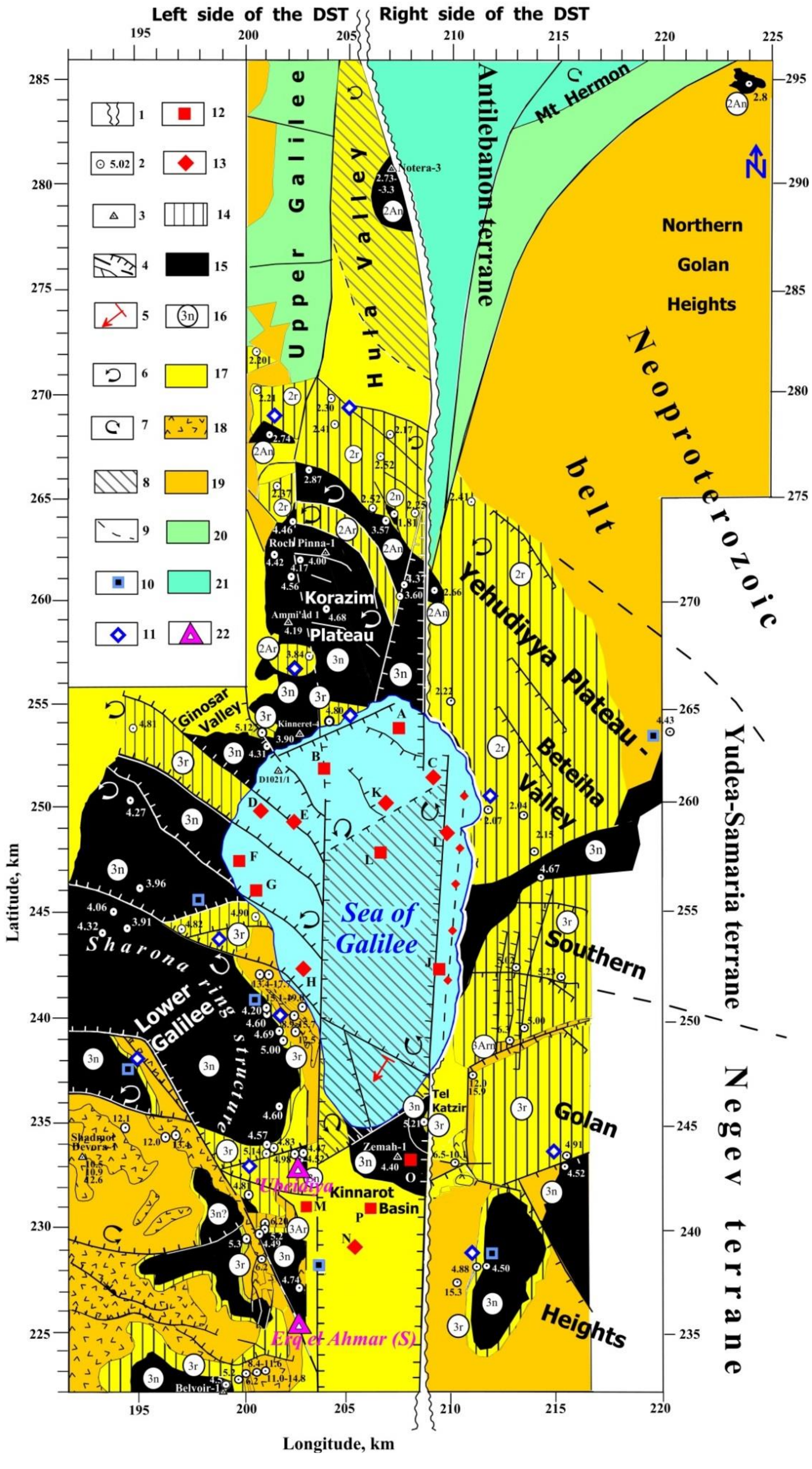


**Fig. 10.** Tectonic-paleomagnetic palinspastic map of the Hula – Sea of Galilee region for the period of 3.6 – 2.0 Ma
(1) area of joining of the left and right DST blocks on the palinspastic reconstruction, (2) outcrops with the radiometric ages of basalts (in Ma), (3) boreholes, (4) faults, (5) general direction of the proposed buried basaltic plate dipping in the southern part of the Sea of Galilee, ( 6-7) rotation of faults and tectonic blocks, (6) counterclockwise, (7) clockwise, (8) pull apart basins within the DST, (9) marginal boundaries of pull apart basins, (10-11) data of the land paleomagnetic measurements: (10) normal magnetization, (11) reversal magnetization, (12-13) results of magnetic anomaly analysis: (12) normal magnetization, (13) reversal magnetization, (14) reversely magnetized basalt fields, (15) normal magnetized basalt field, (16) indexes of paleomagnetic zonation, (17) upper part of the Sogdiana superzone, (18) Miocene basalts of the Sogdiana superzone middle part, (19) Tuarkyr-Khorezm superzone, (20) Jalal superzone, (21) Gissar superzone, (22) paleomagnetically investigated outcrops of the Akchagylian age (Piacenzian and Gelasian) in the DST fluvial facies

The traps of the zone of the lower part of the Matuyama Chron (C2r) are widely developed on the Yehudiyya Plateau and in the transition zone of the Korazim Plateau and the Hula basin (Fig. 10).

Post-cover basalt traps – Eitar basalt (2.6-3.6 Ma) and Ruman basalt (2.04-2.52 Ma) correspond to the lower and middle Akchagylian and, according to palinspastic mapping, are characterized by a reasonably compact occurrence.

Paleomagnetic mapping of traps in the area of the Sea of Galilee is complemented by magnetostratigraphic data from examining sedimentary rocks in the Jordan Basin, where the lacustrine-alluvial complexes of the Erk el Ahmar and Ubeidiya formations (Fig. 10) are developed. These formations mainly relate to the Gauss and Matuyama Chrons, respectively.

**5. Discussion and Conclusions**

The presence of hard-explained phenomena of magneto-geophysics prompted the organization of comprehensive research in paleomagnetic mapping aimed at revealing the dynamics and history of the development of structures based on the reconstruction of their paleomagnetic age. Paleomagnetic mapping includes the procedures for determining the age and the typification of the magnetized objects, making it possible to apply the concept of plate geodynamics. It enables the description of the stages of development of various forms of magmatism under transition conditions from the ocean to the continent. It should be emphasized that the broad integration of paleomagnetic mapping with other geophysical and geological methods seriously increases the efficiency of its application.

Tectonic-paleomagnetic mapping as a new type of geological-geophysical survey contributed to a necessary amendment to understanding the nature and structure of the Easternmost Mediterranean. The studied areas in northern Israel: Carmel, Atlit, and the Sea of Galilee, are unique objects from the geological point of view, and they are well studied in various ways. However, their structure, geodynamics, and other critical questions of genesis are not clear and inexplicable. Therefore, we decided to apply the combined paleomagnetic mapping to investigate these intricate targets.

For the paleomagnetic mapping examination, a wide diapason of investigations was used: from the Paleozoic (Permian – Carboniferous) – Kiama paleomagnetic superzone in the Easternmost Mediterranean (Eppelbaum et al., 2014) to the Holocene – almost modern volcano with a lake in the Birkat Ram crater in the Golan Heights (Frank et al., 2002). Without hesitation, the present study became possible only thanks to Israeli geologists and geophysicists' many years of painstaking work, who created a vast database of paleomagnetic and radiometric studies, geological mapping, and tectonic reconstructions for the territory of Israel.

After the change of the well-developed geosyncline theory by the plate tectonics (convective geodynamics), and the decreasing the standard geocartographic research all over the world, a methodological vacuum arose associated with the lack of development of the mapping methods in the field for the construction of the regional and the world tectonic, paleogeographic and other maps. Our comprehensive studies in the African-Arabian region of the junction of Eurasia and Gondwana (e.g., Eppelbaum et al., 2021) with the widespread application of paleomagnetic mapping techniques are the testing instrument for the development of new kinds of combined investigations of geologically complex areas. The paleomagnetic profile constructed along the top of the accumulative leveling surface of the Lower Cretaceous traps (Fig. 9) is of particular interest. It unmasks the geodynamic history of the Carmel-Galilee region, which other geophysical methods cannot distinguish.

Overall, paleomagnetic methods have established themselves as powerful tool for geodynamic mapping. At the same time, its effectiveness and significance without optimal integration with other geological-geophysical methods may be significantly reduced. Interestingly, our geophysical-geological set of methods (see Fig. 5) practically almost was applied for the combined paleomagnetic mapping (Eppelbaum and Katz, 2015a, 2021a, 2022).

The palinspastic reconstruction (3.6-2.0 Ma) in the Hula – Sea of Galilee – Kinnarot basins and framing uplifts of the DST (Fig. 10) indicate the importance of the developed map. The area under study is well studied by numerous geophysical, geological, and geochemical methods, but nevertheless, its tectonic-magmatic history should be reconsidered.

Based on the research done, we can draw the following main conclusions.

The applied methods for quantitative analysis of magnetic anomalies (improved modifications of tangents, characteristic points, and areal methods) demonstrated high accuracy and reliability under complex physical-geological conditions of the Easternmost Mediterranean.

The side of the plate tectonics concept confirmed that the dominance of the geodynamics of the region in the Mesozoic and Cenozoic was carried out not from the western (Atlantic) but the eastern (Neotethyan) direction. Paleomagnetic data and paleomagnetic mapping made it possible to evaluate the previously identified structures of various ranks from the standpoint of statics and geodynamics, which is novel due to the optimal combination of various applied applications of geological-geophysical methods.

The area of development of the Sea of Galilee pull-apart basin has been identified, experiencing differentiation under the left DST shift conditions and the formation of the faults and ring structures rotating counterclockwise in the adjacent zones. This phenomenon was explained at the level of the extended integrated geophysical studies using 3D modeling and structural-geodynamic analysis (Eppelbaum et al., 2020, 2021).

Integrated analysis of geological-geophysical data from the Sea of Galilee and Carmel (Atlit) areas indicates that both mentioned terranes and the Mesozoic Terrane Belt (MTB) were moved in the Mesozoic from the east to the west in a counterclockwise direction. The paleomagnetic studies in the Carmel area showed in a new way that the Triassic-Jurassic ophiolite complex underlying the Aptian-Albian traps of the Mt. Carmel within the Galilee-Lebanon terrane contrasts sharply with the Mesozoic and sedimentary rocks penetrated by traps. The Late Jurassic-Neocomian age of these traps precedes the Late Jurassic-Neocomian phase of joining the MTB to the Gondwana.

The paleomagnetic profile constructed the Carmel-Galilee region along the top of the accumulative leveling surface of the Lower Cretaceous traps enabled the unmasking of the complex geodynamic history of the Easternmost Mediterranean.

According to the paleomagnetic mapping, the Cenozoic stage of development in the region looks discordant with the paleomagnetic structures of the Mesozoic and Cenozoic. This discordance was explained in light of the latest deep-geodynamic studies (Eppelbaum et al., 2021). The axis of the discovered deep mantle structure in the middle of the Cenozoic began to turn more intensively in the counterclockwise direction. It is caused by the development of the lithospheric plate disruptions and the formation of the topologically displaced zones of the dyke complexes and younger effusive traps.

The palinspastic reconstruction of the area of Hula – Sea of Galilee – Kinnarot basins allowed unmasking the tectonic-magmatic history of this geologically complex region.

The proposed methodology of advanced magnetic-paleomagnetic mapping under complex physical-geological environments may be effectively applied to solving different geological-geophysical problems in various geologically complex regions of the world (for instance, in the Lesser and Greater Caucasus).

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## ТЕКТОНИЧЕСКОЕ МАГНИТНО-ПАЛЕОМАГНИТНОЕ КАРТИРОВАНИЕ НЕОДНОРОДНЫХ СРЕД: ЕГО ЗНАЧЕНИЕ ДЛЯ ВОСТОЧНОГО СРЕДИЗЕМНОМОРЬЯ (СЕВЕРНЫЙ ИЗРАИЛЬ)

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***Резюме.*** Наиболее сложными регионами Земли являются области перехода от океана к континенту, а также зоны спрединга и сочленения литосферных плит. Восточное Средиземноморье, являющееся ярким примером вышеуказанных областей, расположено на стыке крупнейших литосферных сегментов Земли: Евразии и Гондваны. Количественный анализ магнитных аномалий выполнен с использованием передовых методик, позволяющих применять интерпретационные процедуры в условиях (1) наклонной намагниченности, (2) пересеченного рельефа местности и (3) наложения аномалий разного ранга. Представлены примеры детального анализа магнитных аномалий для нескольких геологически сложных районов на севере Израиля: Галилейского моря, Кармеля и Малкишона. Методика палеомагнитного картирования таких переходных зон основана на комплексировании методов картирования как континентальных, так и океанических платформ: палеомагнитных реконструкций, результатов радиометрического датирования магнитоактивных пород, изучения спутниковых данных, тектоно-структурных реконструкций, биогеографического анализа и использования результатов различных геофизических исследований. Геодинамическое палеомагнитное картирование позволяет выявить не только многоуровневые структурные неоднородности среды, но и отобразить сложные элементы разновозрастной геодинамики, присущие зонам сочленения (перехода). В северном Израиле для комплексного палеомагнитного картирования были выбраны хорошо изученные палеомагнитными и радиометрическими методами (а также структурно-тектонически) районы: (1) Галилейское море с прилегающими зонами (ранее построенные схемы этих районов были откорректированы и дополнены), (2) район Кармель, и (3) район Атлит (внутренняя часть района Кармель). Построенный палеомагнитный профиль для района Кармель по кровле аккумулятивной поверхности нижнемеловых траппов наглядно показывает сложную историю палеогеодинамического развития региона. Сделан вывод об эффективности сочетания процедур количественной интерпретации магнитных аномалий с палеомагнитным картированием сложных сред. Палинспастическая реконструкция, разработанная для периода 3.6-2.0 млн. лет назад, выявила важные тектоно-магматические особенности этого геологического периода.

***Ключевые слова****: палеомагнитное картирование, палеомагнитное профилирование, анализ магнитных данных, тектоно-структурная интерпретация, комплексный анализ, палинспастическая реконструкция*

## QEYRİ-BİRCİNS MÜHİTİN TEKTONİK MAQNİT-PALEOMAQNİT XƏRİTƏLƏNMƏSİ: ONUN ŞƏRQİ ARALIQ DƏNİZİ (ŞİMALI İSRAİL) ƏRAZİSİ ÜÇÜN ƏHƏMİYYƏTİ

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***Xülasə.*** Okeandan kontinent zonasına keçid, həmçinin cprediŋq və litosfer plitələrinin qovuşma məkanları Yerin geoloji baxımdan ən mürəkkəb regionlarındandır. Yerin ən böyük: Avroasiya və hondvana litosfer plitələrin qovşağında yerləşmiş Şərqi Aralıq dəniz ərazisi bu deyilənlərə parlaq nümunədir. Maqnit anomaliyalarının kəmiyyət analizi mürəkkəb relyefin maili maqnitləşmə (1) və müxtəlif dərəcəli anomaliyaların üstə-üstə düşməsi şəraitlərində interpretasiya əməliyyatları tətbiq etməyə imkan verən qabaqcıl metodikalardan istifadə etməklə yerinə yetirilmişdir. İsrailin şimalında – Qaliley dənizi, Karmelan və Malkişon kimi bir neçə mürəkkəb geoloji rayonların maqnit anomaliyalarının dəqiq analizi nümunələri təqdim olunmuşdur. Belə keçid zonalarının paleomaqnit xəritələnməsinin metodu həm kontinental, həm də okean platformalarının paleomaqnit rekonstruksiyaları, maqnitoaktiv süxurların radiometrikliyinin qeydiyyat nəticələri, peyk məlumatlarının öyrənilməsi, tektonik-struktur rekonstruktursiyalar, biocoğrafi təhlil və müxtəlif geofiziki tədqiqat nəticələrinin istifadəsinə, xəritələmə metodlarının kompleksləşdirilməsinə əsaslanmışdır. Geodinamik paleomaqnit xəritələmə nəinki mühitin çoxsəviyyəli struktur qeyri-bircinsliyini, həmçinin qovuşma (keçid) zonalarına xas olan müxtəlif yaşlı geodinamikanın mürəkkəb elementlərini əksetdirməyə imkan verir. İsraildə kompleks paleomaqnit xəritələnməsi üçün paleomaqnit və radiometrik metodlarla (həmçinin struktur-tektonik üsullarla) öyrənilmiş rayonlar seçilmişdir: 1) ətraf zonalarla (əvvəllər bu rayonların qurulmuş sxemləri korrektə edilmiş və əlavələr edilmiş) birlikdə Qaliley dənizi, 2) Karmel rayonu və 3) Atlit rayonu (Karmel rayonunun daxili hissəsi) Karmel rayonu üçün Alt təbaşir traplarının akkumulyativ səthinin tavanı üzrə qurulmuş paleomaqnit profil regionun paleogeodinamik inkişaf tarixinin mürəkkəbliyini bariz şəkildə nümayiş etdirir. Mürəkkəb mühitlərin paleomaqnit xəritələnməsilə yanaşı maqnit anomaliyalarının kəmiyyətcə interpretasiya əməliyyatlarının birlikdə aparılmasının effektivliyi haqqında nəticə çıxarılmışdır. 3.6-2.0 mln il əvvəlki dövr üçün işlənilmiş palinspatik rekonstruksiya bu geoloji zaman kəsiyinin mühüm tektonik-maqmatik xüsusiyyətlərinin aşkarlanmasına imkan verir.

***Açar sözlər:*** *paleomaqnit xəritələmə, paleomaqnit profilləmə, maqnit məlumatlarının təhlili, tektonik-struktur interpretasiya, kompleks analiz, palinspatik rekonstruksiya*