KEY FEATURES OF SEISMO-NEOTECTONIC PATTERN OF THE EASTERN MEDITERRANEAN

Lev Eppelbaum and Youri Katz

Tel Aviv University,
Ramat Aviv 69978, Tel Aviv, Israel
E-mail: levap@post.tau.ac.il

The Eastern Mediterranean is a tectonically complex region located in the midst of the progressive Afro-Eurasian collision. The recent increasing geotectonic activity in this region highlights the need for combined analysis of seismo-neotectonic signatures. For this purpose, this article presents the key features of the tectonic zonation of the Eastern Mediterranean. Map of derivatives of the gravity field retracked from the Geosat satellite and novel map of the Moho discontinuity illustrate the most important tectonic features of the region. The Post-Jurassic deformation map of surface leveling reflects the modern tectonic stage of Eastern Mediterranean evolution. The developed tectono-geophysical zonation map integrates the potential geophysical field analysis and seismic section utilization, as well as tectonic-structural, paleogeographical and facial analyses. Tectonically the map agrees with the earlier model of continental accretion (Ben-Avraham and Ginzburg, 1990). Seismicity map of the Eastern Mediterranean tectonic region (for the period between 1900 and 2012) overlaying on the tectonic zonation chart reveals the key features of the seismo-neotectonic pattern of the Eastern Mediterranean. The results have important implications for tectono-seismological analysis in this region.

Introduction

The Eastern Mediterranean is tectonically complex region evolving in the midst of the progressive Afro-Eurasian collision. Its geological-geophysical structure has been studied for years but is still not fully charted. The Eastern Mediterranean represents a classic area for the emergence of plate tectonics (e.g., Ben-Avraham, 1978; Robertson and Dixon, 1984; Ben-Avraham and Ginzburg, 1990; Ben-Avraham et al., 2002; Le Pichon and Kreemer, 2010; Eppelbaum and Katz, 2011). The recent upsurge in seismological activity in the world (2009-2012) and particularly within the Afro-Eurasian collision zone makes it imperative to re-explore the seismo-neotectonic pattern of the Eastern Mediterranean. In addition, the discovery of significant hydrocarbon deposits in this region (e.g., Schenk et al., 2010; Montadert et al., 2010; Noble, 2010; Eppelbaum and Katz, 2011, 2012) during last few years clearly underscore the need for new regional tectonic-structural substantiation of hydrocarbon structures to support the prospecting. To achieve these goals, a combined geophysical (potential geophysical fields and seismics) and geological (formational, facial, tectonic-structural and paleogeographical) investigation are currently being conducted (Eppelbaum and Katz, 2011). This paper reports on some of the key findings in this investigation.

Specifically this article is a synthesis of geological-geophysical and seismic monitoring data covering an observation period more than 100 years (1900-2012). The geological materials and methodology are described in detail in Eppelbaum and Katz (2011). These data were used to revise an earlier Moho discontinuity map (Eppelbaum and Pilchin, 2006), draw up a deformation map of the Post-Jurassic surface of leveling and conduct an analysis of contemporary geodynamic events (along with a tectonic scheme and satellite-derived gravity data).

The findings showed that the new generation of the satellite derived gravity data could be used effectively for tectono-geological mapping (Eppelbaum and Katz, 2011). The satellite gravity data were obtained from the World Gravity Data Base as retracked from the Geosat satellite and ERS-1 altimetry (Sandwell and Smith, 2009). It should be noted that these observations were made with regular global 1-minute grids (Sandwell and Smith, 2009) and the gravity data computation error was estimated at 2-3 mGals. The gravity map compiled in Figure 1 shows the intricate gravity pattern of this area (the isoline interval is 5 mGal; “zero” isoline is dashed and bolded).

This figure demonstrates how worthwhile it is in some specific cases (for instance, for tectonic-structural or geodynamical mapping) to display the gravity field map without any reduction (Eppelbaum and Khesin, 2012). The positive and negative gravity anomalies (Figure 1) clearly reflect the majority of the structural-geotectonical units of the region. The map depicts both the main structural elements (e.g., Eastern Mediterranean basin), and the smaller depressions and highs of the neotectonic relief of the Nubean-Arabian and Anatolian plates.

Brief geological setting

According to modern geological-geophysical analyses, the Eastern Mediterranean region covers four geotectonic plates: the African, Sinai, Arabian and Aegean-Anatolian (Figure 2). The first two plates consist of heterogeneous blocks of continental and oceanic crust and each of these plates is circumscribed by deep faults. According to Robertson et al. (1991), the oceanic crust of the eastern Mediterranean is a remnant of the Neotethys. The Sinai plate (McKenzie et al., 1970) is bounded from the west and the east by a system of deep Late Cenozoic faults (Malovitskiy et al., 1975; Ben-Avraham, 1978). The eastern part of the eastern Mediterranean is formed by the Dead Sea Fault System (Figure 2) along which about 100 km of left-lateral strike-slip motion has developed (Dubertret, 1932). Within this fault system numerous horsts and grabens have emerged. These grabens usually represent pull-apart basins (Cloetingh et al., 1996) filled by terrigenous evaporite molasses and basal rocks.

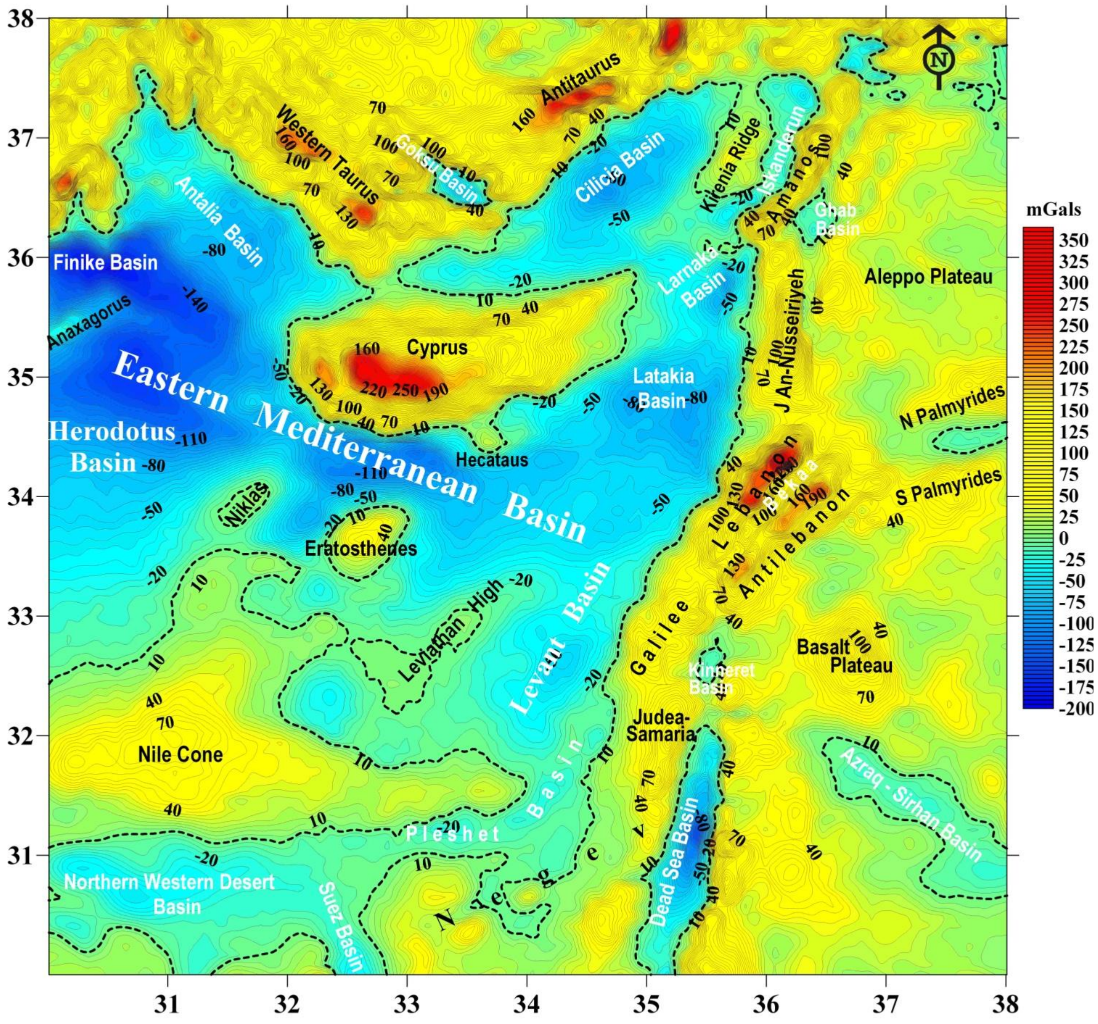

Figure 1. Map of key satellite derived gravity anomalies of the Eastern Mediterranean

Between the oceanic and continental crust is the Syrian fold belt (Syrian arc) (e.g., Garfunkel, 1998). This belt is the eastern part of the larger Alpine-Mediterranean fold belt and basin system (Khain, 1984; Bosworth et al., 2008). The structural inhomogeneity of the Syrian arc was revealed by analysis of subsurface Paleogene – Upper Cretaceous sediments (Flexer, 1971; Sneh et al., 1998). However, the tectonic characteristics of the deeper structural stages have been studied to a lesser extent. Geophysically it was shown (Ben-Avraham and Ginzburg, 1990) that a thinned continental crust composes the Syrian arc structure. Tectonically, this belt is made up of a sequence of extensional independent crystal units (Ben-Avraham et al., 2006).

Precambrian, Paleozoic, Mesozoic and Cenozoic associations form the geological section of the African and Arabian platforms within the eastern Mediterranean. The Precambrian is known to contain metamorphic and igneous rocks, and in the upper part of the Precambrian there is molassa which passes to the Cambrian base. Cambrian rocks are extensive in the Sinai, but are not found in the borehole sections of the Negev desert. In the Negev the Permian deposits overlie the Precambrian arkosic sandstone. In the Heletz block there is no molasses and the Permian deposits are in direct contact with the crystalline schist.

More completely than in the Sinai, Lower Paleozoic sequences are present to the east of the Eastern Mediterranean coast in Syria, Jordan and Iran. Analysis of geophysical data testifies to the absence of Lower Paleozoic strata in the Levant Basin and in the Pleshet terrane (Gardosh et al., 2008, 2010; Mechie et al., 2009). Devonian and Carbon deposits have not been detected in the borehole sections of Israel. The Carbon and Permian continental associations were studied in the Sinai (Druckman et al., 1983). Deep boreholes drilled in the Negev, the coastal plain of Israel, the Judean mountains and western Jordan, have revealed marine Permian deposits (Andrews, 1992; Hall et al., 2005). Thus, the Precambrian and Paleozoic associations of the Arabian plate and southern Sinai differ significantly from the folded zone of the Syrian arc.

The Mesozoic and Paleogene associations make up the carbonate platform of the Eastern Mediterranean (including reefs and other organogenic constructions). These carbonate associations also include small terrigenous complexes and traps. The Miocene and Quaternary associations are represented by terrigenous molassa with Early Messinian evaporates, sometimes generating salt domes and diapirs. These associations have developed mainly in the pull-apart basins within the Dead Sea transform zone and Levant Basin (Ben-Avraham, 1992). Besides sedimentary deposits, the Mesozoic and Late Cenozoic magmatic rocks are widely developed in the Eastern Mediterranean (Garfunkel, 1989; Sneh et al., 1998; Segev et al., 2000).

Integrated geophysical-geological data analysis

Heat flow measurements in the Eastern Mediterranean have yielded low values averaging 31 mW/m^2 (Erickson et al., 1977; Morgan, 1979; Čermak, 1980). After applying a correction for sedimentation rate, this value becomes 43 mW/m^2 (Verzhbitsky, 1996), which is similar to the average geothermal flow of 40 mW/m^2 calculated for deep oceanic basins (Sclater et al., 1980). Theoretical calculations by Verzhbitsky (1996) suggest that the average age of the Levant Basin crust is $\approx$ 125 Ma, which is consistent with the time of terranes accretion in the Early Cretaceous during the Levantine phase (~ 132 Ma) (Katz and Eppelbaum, 1999a).

Integrated analysis of geophysical materials integrates deep seismic sounding data (Malovitskiy et al., 1975; Ben-Avraham et al., 2002, 2006; Hall et al., 2005; Mechie et al., 2009; Gardosh et al., 2010), magnetic surveys (Folkman and Yuval, 1976; Rybakov et al., 1997; Ben-Avraham et al., 2002), gravity data (Ginzburg et al., 1993; Rybakov et al., 1997; Hall et al., 2005; Sandwell and Smith, 2009), thermal data (Levitte and Olshina, 1985; Eppelbaum et al., 1996; Verzhbitsky, 1996; Pilchin and Eppelbaum, 1997; Eppelbaum and Pilchin, 2006) and seismological parameters (Seismological Data Base of the GII; Shapira, 1992; Punar and Türkelli, 1997; Salamon, 2003,2010; El-Hefnawy et al., 2006).

The main interpretation method involves a deep tectonic-geophysical analysis combining (partially employing principles presented in Eppelbaum et al., 2003) the geophysical quantitative data and qualitative patterns with available deep borehole sections, geological data, tectonic and paleomagnetic reconstructions. For example, our recent analysis specifically designates that the zones of inverse magnetization unambiguously revealed in the Levant Basin of the Eastern Mediterranean (Ben-Avraham et al., 2002) relate to the Kiama hyperzone. It enables us to suppose that the Earth's crust within the Levant Basin can be composed by Permian-Triassic rocks.

Combined analysis of the aforementioned data (parts of this analysis are reported in Ginzburg and Eppelbaum, 1993, 1994; Eppelbaum, 1996; Ben-Avraham et al., 2002; Eppelbaum et al., 1998, 2004, 2005, 2006a, 2006b, 2007; Eppelbaum and Katz, 2011, 2012) enabled us to develop a map of the deep tectonic-geodynamic regioning (Figure 3) (modified after Eppelbaum and Katz, 2011), a revised and supplemented map of the Moho discontinuity depth (Figure 4), a hypsometric map of the base of the newest (Post-Jurassic) tectonic complex (Figure 5), and a seismotectonical map (Figure 6).

First directional derivatives map (e.g., Tuma, 1979) of the satellite derived gravity field in the direction south-north is shown in Figure 2A, and the same map with the tectonic elements is presented in Figure 2B. The direction south-north was selected because the majority of geological structures within the Alpine Mediterranean belt area was characterized by a latitude extension (Khain, 1984). Figure 2B indicates that the derivatives clearly trace main tectonic and geophysical peculiarities of the region, especially a boundary between continental and oceanic crust is visibly traced (Ben-Avraham et al., 2002).

Figure 3 modified after Eppelbaum and Katz (2011) to incorporate recent publications by Moix et al. (2011) and Bulut et al. (2012) shows the most important regional tectonic features revealed by integrated analysis of geophysical and geological data which is overlaid on the smoothed gravity map (with an isoline interval of 20 mGal). This map depicts the main tectonic structures of this region; i.e., the African, Arabian, Sinai and Aegean-Anatolian plates. The latter plate is part of the Alpine-Mediterranean fold belt (Khain, 1984). Associations of the Precambrian continental crust, oceanic crust and Mesozoic accretional complexes compose the African, Arabian and Sinai plates.

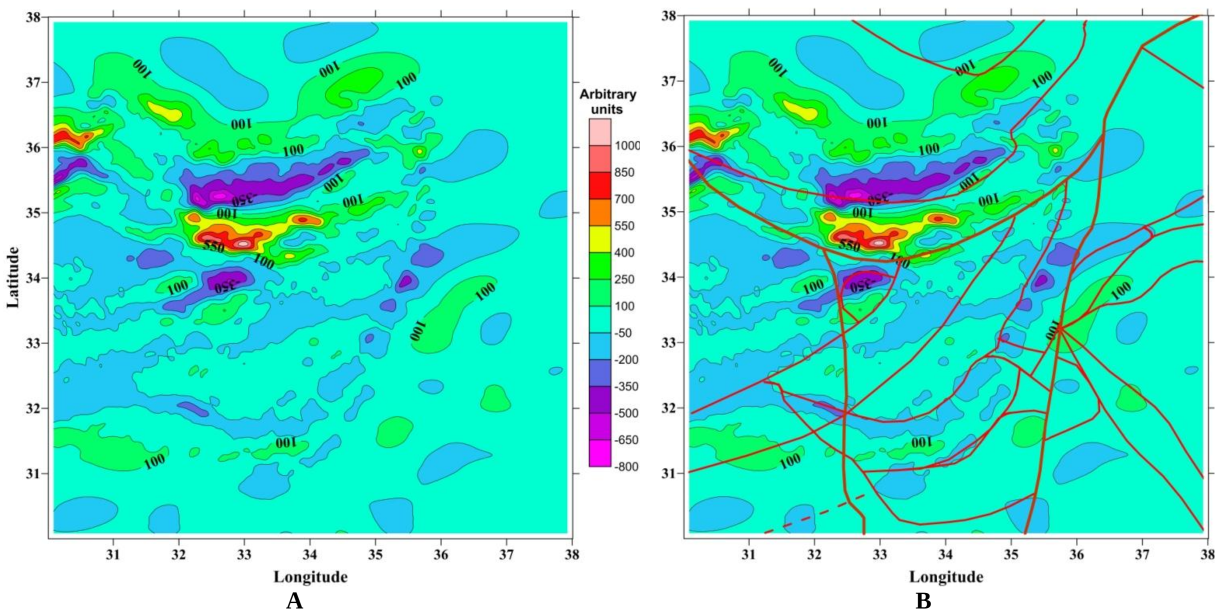

Figure 2. Map of the first directional derivatives (south-north) of satellite derived gravity field smoothed 4 x 4 (**A**), and the same map with drawn tectonic elements (**B**)

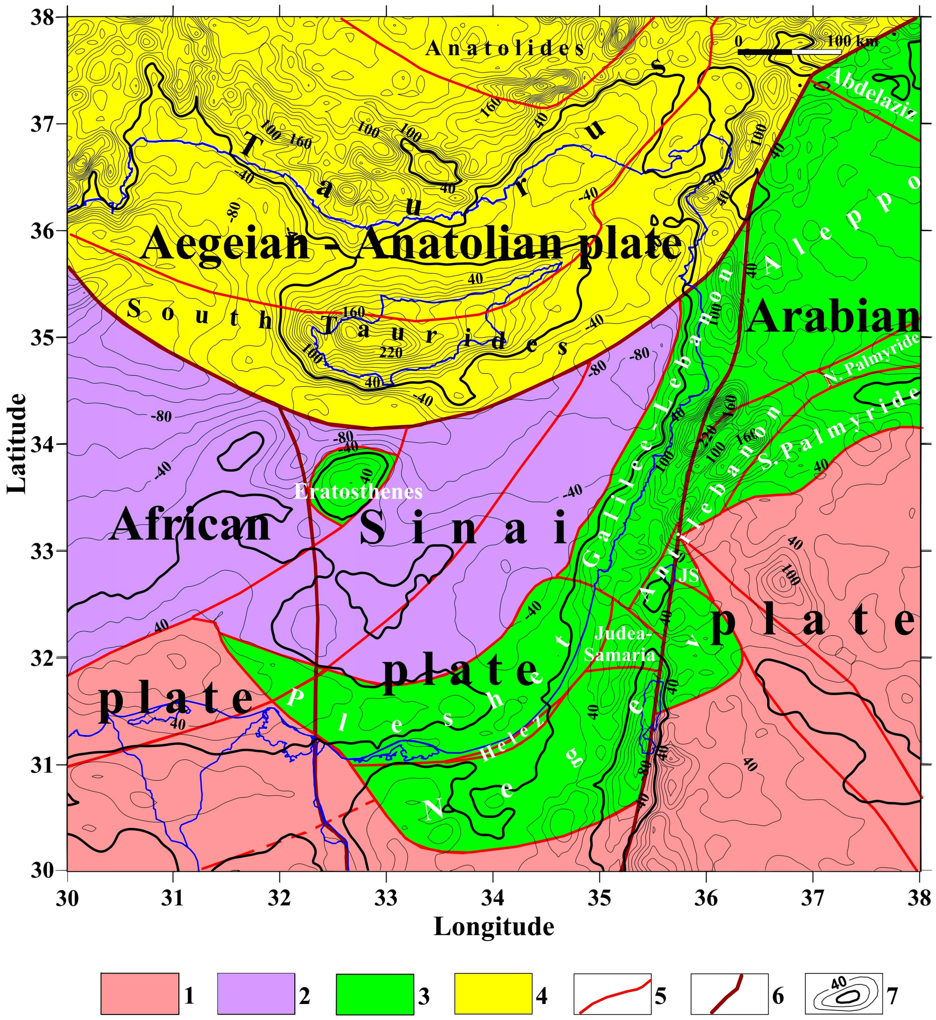

Figure 3. Tectonic zonation chart of the Eastern Mediterranean overlaid on the smoothed gravity map (1) Precambrian plates with continental crust, (2) oceanic crust, (3) Mesozoic terranes, (4) Alpine tectonic belt, (5) main tectonic faults, (6) intraplate tectonic faults, (7) gravity isolines, mGal

To analyze contemporary geodynamics, the Moho discontinuity map (Figure 4) was utilized. Initially this map was constructed by the correlation method on the basis of integrated processing of seismic data and maps of the Bouguer gravity for Israel and the Eastern Mediterranean (Eppelbaum and Pilchin, 2006). The map shown here (Figure 4) was modified to include recently published data (Gardosh et al., 2010; Marlow et al., 2011; Tawardos, 2011), as well as our latest developments (Eppelbaum and Katz, 2011) on regional structural and deep geological-geophysical zonation. As depicted in this map, the Eastern Mediterranean Basin is composed of a thinned crust with a thickness of 22-28 km, properly developed oceanic crust (22-24 km) probably presenting a residual crust of the Tethys Ocean (Robertson et al., 1991; Robertson, 1998) and a crust of marginal terranes. The most crust thickness (> 40 km) corresponds to the western part of the Arabian plate. As a whole, the Earth's crust of the ancient Gondwana in the Eastern Mediterranean consists of 32-40 km. The thickness of the terranes crust ranges between 32 to 36-37 km (S. Palmirides, Negev, Aleppo and Anti-Lebanon), and between 24 to 30 km (Heletz, Judea-Samaria, Galilee-Lebanon and Eratosthenes). The thickness decreases towards the grabens of Suez and Aqaba (Eilat). The initial variant of the Moho discontinuity map was utilized to develop the first map of the Curie discontinuity of Israel (Eppelbaum and Pilchin, 2006). It revealed that the depth of the Curie discontinuity computed by thermal data analysis (which is more reliable) exceeds as a rule the depth of the lower edges of magnetized bodies obtained by magnetic data interpretation.

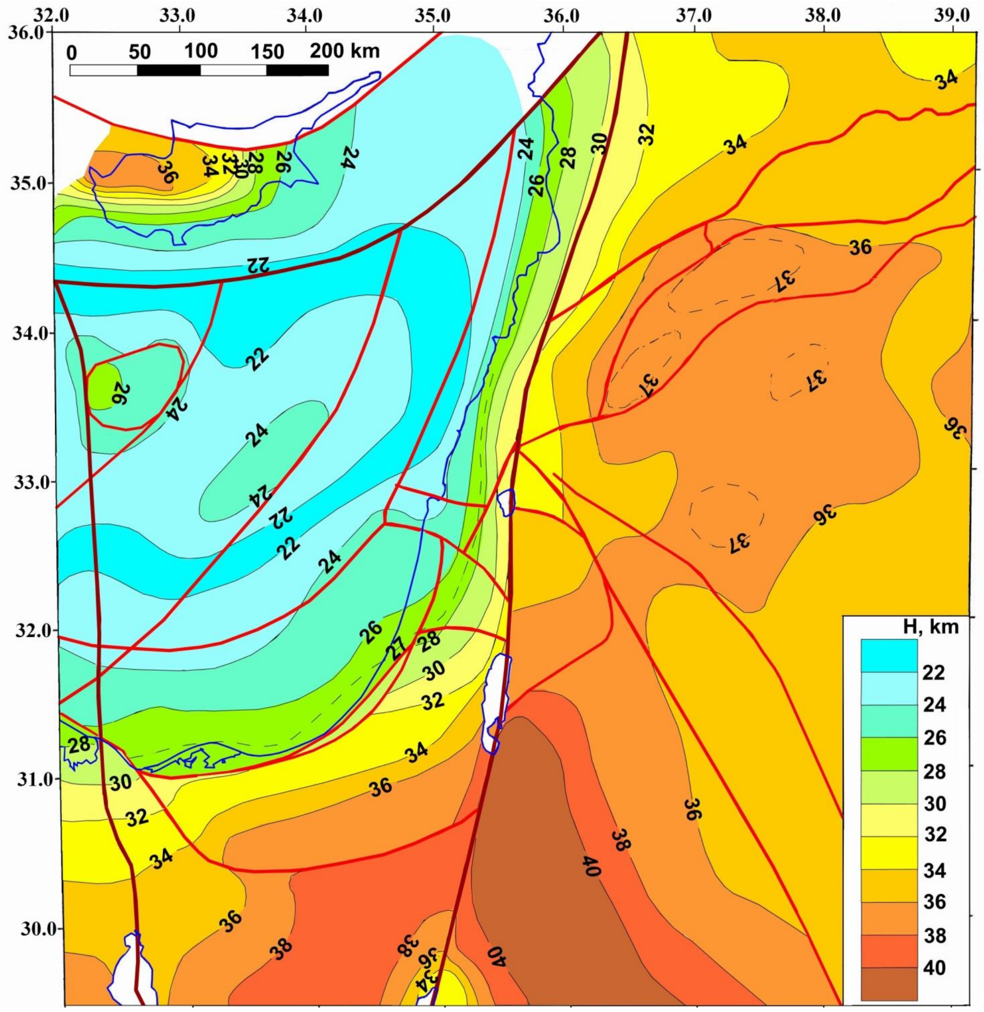

Figure 4. Map of the Moho discontinuity of the Eastern Mediterranean (in km)

The map of deformation of the Post-Jurassic surface leveling (Figure 5) reflects the modern evolution of the tectonic stage of the Eastern Mediterranean. The map of the base of the newest (Post-Jurassic) tectonic complex (Figure 5) has an obvious correlation with the Moho discontinuity map (Figure 4). Accretion of terranes played a role in the Early Cretaceous, mainly in the middle of the Hauterivian during the Levantine phase (~ 132 Ma) (Katz and Eppelbaum, 1999a). In the basal part of the post-accretional complex a transgressive terrigenous carbonate formation has developed at a thickness up to 1400 m in the zone of erosion canyons. The trap formation of the Lower Cretaceous at a thickness up to 300 m has developed mainly in zone of the Levantine Fault System (Katz and Eppelbaum, 1999b; Eppelbaum and Katz, 2012). In the middle part of the post-accretional complex there is a carbonate formation of the Upper Cretaceous-Palaeogene measuring roughly 1000-2000 m in thickness, and in the Azraq-Sirhan graben it reaches up to 3500 m. The Neogene-Quaternary upper transgressive terrigenous formation and traps compose the roof of the post-accretional neotectonic complex. The thickness of the terrigenous associations in the coastal plain reaches 1000-1600 m, in the Eastern Mediterranean mainly measures 2000-2600 m, and in the pull-apart basins is calculated at more than 3000 m. The thickness of traps is usually 100-200 m, and in the erosion-tectonic depressions it can attain 1000 m.

A structural map of the Post-Jurassic leveling surface (Figure 5) testifies to the difference between the neotectonic movements within the (1) Precambrian platforms, (2) terranes, and (3) Levant Basin. The terrane belt (also termed the Syrian arc) in its contemporary modern stage consists of geological structures with very intensively expressed highs and depressions. Between the Negev terrane and Sinai plate a compensation depression has developed that separates the uplift of the southern Negev from the highs of the northern Sinai (Bartov et al., 1980). The rift zones of Suez and Aqaba were formed in the longitudinal part of uplifts that corresponded to the area under study for high hypsometric values of the leveling surface (up to 800-1500 m). Along the Dead Sea Transform (DST) there are alternate zones of uplifts and depressions of this surface reaching or exceeding the absolute values of 4-8 km. This map (Figure 5) may be used not only for various tectono-geological reconstructions, searches for hydrocarbons and projection of their exploitation, but also for planning the new infrastructure and transport systems in Israel.

The seismotectonic map (Figure 6) presents a synthesis of the materials on a deep regional geophysical-geological level (Eppelbaum and Katz, 2011) and seismicity data for the period between 1900 and April 2012. The seismicity data were obtained from the Seismological Data Base compiled by the Geophysical Institute of Israel (GII). In addition the data collected by Salomon et al. (2003,2010), Arieh and Rabinowitz (1989), Punar and Türkelli (1997), Vannucci et al. (2004), El-Hefnawy et al. (2006), Wdowinsky et al. (2006), Tan et al. (2008) and Kalyoncuoglu et al. (2011) were incorporated.

An analysis of the map (Figure 6) reveals a number of key features.

Simple visual analysis indicates that most geodynamic activity in the region is confined to the greatest gradients of gravity field: the largest positive gravity anomaly in the Cyprus area and the highly negative gravity anomaly along the DST. Thus, the gravity data retracked from the satellite observations can be employed for surface mapping the areas of dangerous geodynamic events at a depth.

The boundaries of the African, Sinai, Arabian and Aegean-Anatolian techtonic plates appear to be zones of higher activity. The Aegean-Anatolian plate of the Alpine-Himalayan convergence zone is younger (Cenozoic) and characterized by more frequent and high-magnitude seismicity. The zones of the Mesozoic consolidation are seismically less active. However, the DST area, as was noted elsewhere (e.g., Arieh and Rabinowitz, 1989; Ben-Avraham, 1992) exhibits very active seismicity.

The boundaries between the smaller tectonic-geophysical zones are identifiable but are less visible than the inter-plate boundaries. In particular, the boundaries of the Mesozoic terrane belt in contact with the thinned oceanic crust and the continental crust of Gondwana are fairly distinct, but not in all extensions. They developed mainly to west and east of the DST.

The Pelusium Megashear System (Neev, 1977; Neev et al., 1982; Hall et al., 2005) is highly important for studying geodynamic activity in this region. Two systems of shears (marked as bold red lines) are shown in Figure 6 from SW to NE. The shears were marked seismically (Shapira, 1992; Punar and Türkelli, 1997), and magnetically (Meshref, 1990). However, our data indicate that in fact the Pelusium shear (some 60 km off the coast of Israel) has no independent structural-seismotectonic status. The line in the northern part mainly coincides with the boundary between the oceanic crust and the Galilee-Lebanon terrane. Thus, the Pelusium shear cannot be a marker of the northern part of the Sinai plate. However, it is consistent with the conceptual model proposed by Ben-Avraham (1978) where the northern boundary of the Sinai plate collides with the Aegean-Anatolian (Turkish) plate.

Perpendicular to the Pelusium Megashear System there are a series of faults, the most typical of which are the Carmel and Azraq-Sirhan. These fault zones were identified geophysically by magnetic and gravity anomalies (Ginzburg and Eppelbaum, 1993; Ben-Gai and Ben-Avraham, 1995; Al-Zoubi and Ben-Avraham, 2002). These directions geodynamically are of great importance since they are indicators of lines of high seismicity both to SE and NW of the Carmel and Azraq-Sirhan faults. The same direction can be traced in the Isparta Angle (SW Turkey) by seismological data and geomorphological features (Kalyoncuoglu et al., 2011) and in the Cyprian region (Makris et al., 2000; Zverev, 2000). The present investigation enabled to recognize that a similar direction has a projection of the delineated Kiama hyperzone to the earth’s surface. It is likely that these directions may correspond to the lines of planetary fracturing (e.g., Florinsky, 2012). These diagonal zones demand a further investigation. Thus, analysis of the data indicates that seismological effects in the Eastern Mediterranean are produced by different tectonic-geophysical sources.

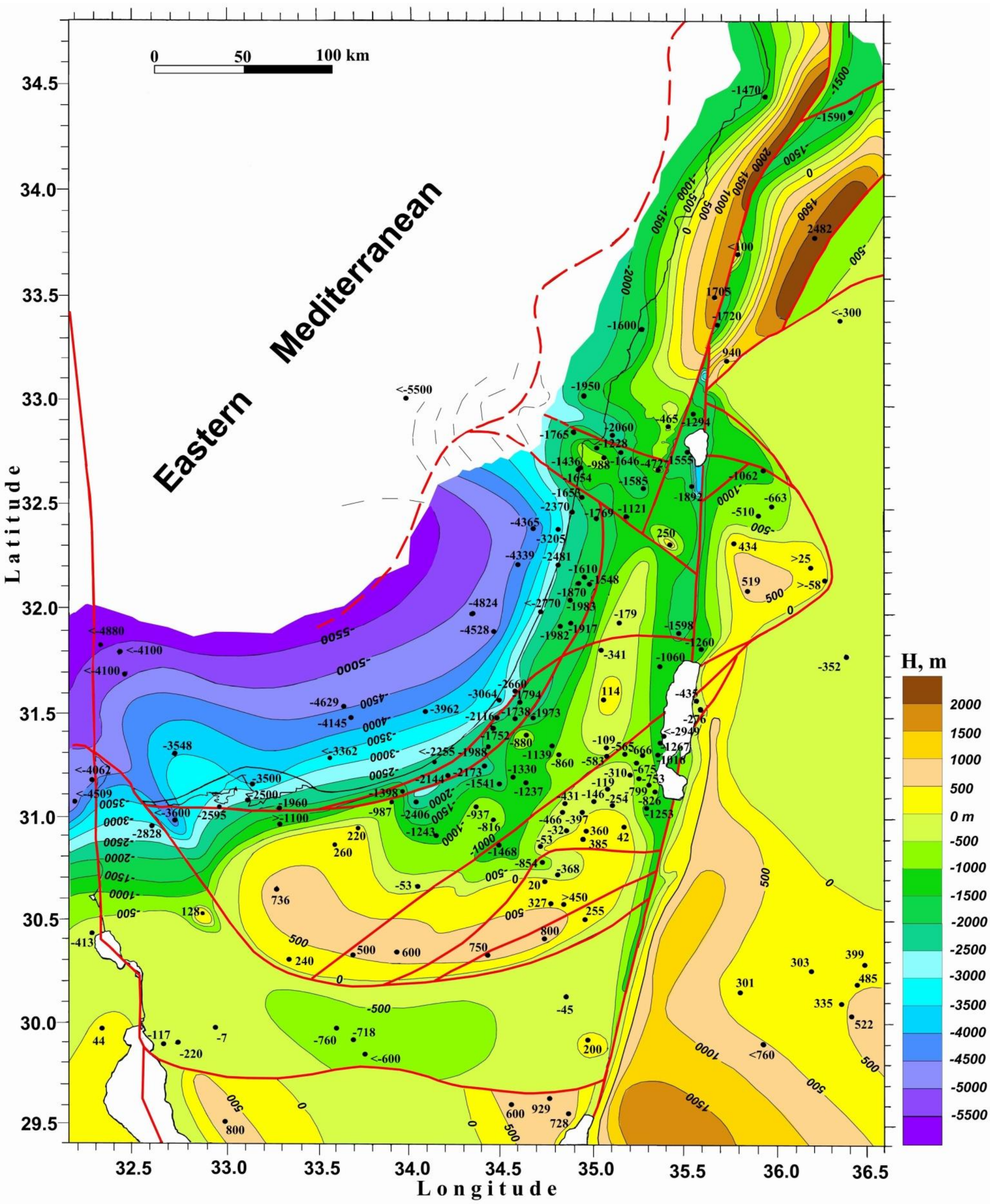

Figure 5. Hypsometric map of the base of the newest (Post-Jurassic) tectonic complex. Color column shows deformation of the Post-Jurassic erosion surface. Solid points on the map show utilized deep boreholes and distinctive outcroppings. Numbers next to solid black dots show estimates of the base of the Post-Jurassic (in m) derived from borehole sections and outcrops, initial sources can be found in Eppelbaum and Katz (2011)

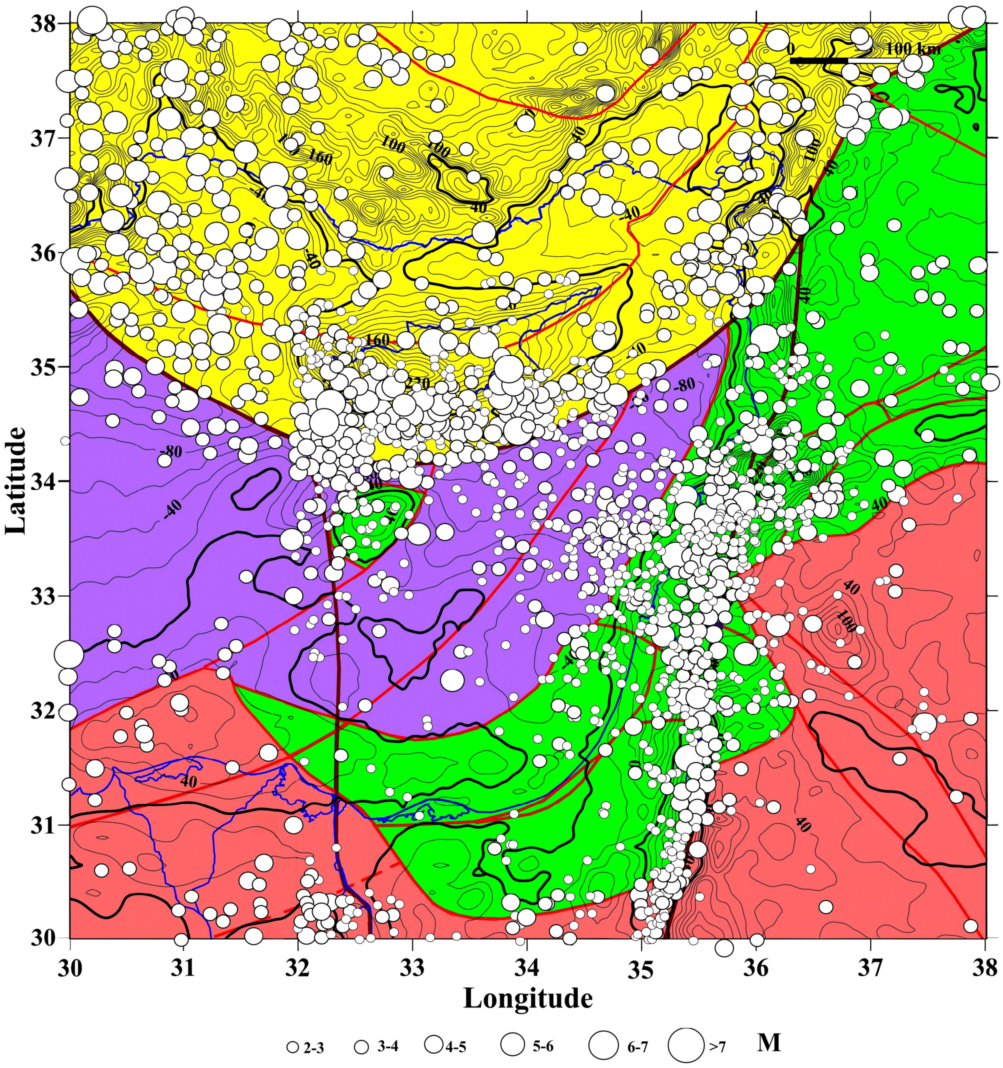

Figure 6. Eastern Mediterranean seismicity map for the period between 1900 and 2012 overlaid on the smoothed gravity map with indicators of tectonic zonation. White circles show earthquake magnitudes on the Richter scale

Changes in the thickness of the Earth's crust in many cases are sufficiently seismically expressed (for instance, within the Arabian and African plates). The most significant seismic events in the region are associated with the northern part of the Gulf of Aqaba, but it is located south of the investigation area and demands special analysis.

Obviously, the further investigations will include analysis of ancient geodynamic events (until 1900), and the area under study will be extended for about 200 km to the south.

These seismological features should be taken into account not only for regional tectono-geophysical mapping of the Eastern Mediterranean, but also for hydrocarbon searches and in particular for potential exploitation of hydrocarbon deposits in the region.

Summary

The map of directional derivatives of satellite derived gravity field clearly indicates the many tectonic features of the region. The modified Moho discontinuity map constructed on the basis of integrated processing of seismic data and the Bouguer gravity maps for Israel and the Eastern Mediterranean shows an intricate pattern of the Moho depth distribution in the region and enabling to recognize continental and oceanic types of the Earth's crust. The hypsometric map of the base of the newest (Post-Jurassic) tectonic complex is at least partially correlated with the Moho discontinuity map. Combined analysis of seismicity (for the period between 1900 and 2012) and the data of geological-geophysical zonation were used here to pinpoint some key neotectonic features of the Eastern Mediterranean. These maps are crucial not only for current knowledge of the Eastern Mediterranean tectonic patterns, but also for infrastructure development in this region.

Acknowledgements

The authors thank the Geophysical Institute of Israel (GII) for permission to use the Seismological Database of Israel and the Eastern Mediterranean compiled by the GII. This study received funding from the European Community's Seventh Framework Program (FP7/2007-2013) under Grant Agreement No. 225663.

REFERENCES

AL-ZOUBI, A., BEN-AVRAHAM, Z. 2002. Structure of the earth's crust in Jordan from potential field data. *Tectonophysics*, 346, 45-59.

ANDREWS, I.J. 1992. Permian, Triassic and Jurassic lithostratigraphy of the subsurface of Jordan. *Subsurface Geology Bull*., 4, 1-60.

ARIEH, E. RABINOWITZ, N., 1989. Probabilistic assessment of earthquake hazard in Israel. *Tectonophysics*, 167, 223-233.

BARTOV, Y., LEWY, Z., STEINITZ, G., ZAK, I. 1980. Mesozoic and Tertiary stratigraphy, paleogeography and structural history of the Gebel Areif en Naqa area, Eastern Sinai. *Israel Journal of Earth Sciences*, 29, 114-139.

BEN-AVRAHAM, *Z.* 1978. The structure and tectonic setting of the Levant continental margin, Eastern Mediterranean. *Tectonophysics*, 46, 313-331.

BEN-AVRAHAM, Z. 1992. Development of asymmetric basins along continental transform faults. *Tectonophysics*, 215, 209-220.

BEN-AVRAHAM, Z., GINZBURG, A. 1990. Displaced terranes and crustal evolution of the Levant and the eastern Mediterranean. *Tectonics*, 9, 613-622.

BEN-AVRAHAM, Z., GINZBURG, A., MAKRIS, J., EPPELBAUM, L. 2002. Crustal structure of the Levant basin, Eastern Mediterranean. *Tectonophysics,* 346, 23-43.

BEN-AVRAHAM, Z., SCHATTNER, U., LAZAR, M., HALL, J.K., BEN-GAI, Y., NEEV, D., RESHEF, M. 2006. Segmentation of the Levant continental margin, eastern Mediterranean. *Tectonics*, 25, TC5002, 1-17.

BEN-GAI, Y., BEN-AVRAHAM, Z. 1995. Tectonic processes in offshore northern Israel and the evolution of the Carmel structure. *Marine and Petroleum Geology*, 12, 5, 533-548.

BOSWORTH, W., EL-HAWAT, A.S., HELGELSON, D.E., BURKE, K. 2008. Cyrenacian "shock absorber" and associated inversion strain shadow in the collision zone of northeast Africa. *Geology*, 36, 9, 695-698.

BULUT, F., BOHNHOFF, M., EKEN, T., JANSSEN, C., KILIÇ, T., DRESEN, G. 2012. The East Anatolian Fault Zone: Seismotectonic setting and spatiotemporal characteristics of seismicity based on precise earthquake locations. *Journal of Geophysical Research*, 117, B07304, doi: 10.1029/2011JB008966.

ČERMAK, V. 1980. Heat flow in the Eastern Mediterranean and the Black Sea. *EGS Program and Abstracts,* Budapest, 121.

CLOETINGH, S., BEN-AVRAHAM, Z., SASSI, W., HORVATH, F. 1996. Dynamics of basin formation and strike-slip tectonics. *Tectonophysics,* 449, 1-4, 1-10.

DRUCKMAN, Y., WEISSBROD, T., GOLDBERG, M., BOEHM, S. 1983. Lithological and stratigraphic data on the Precambrian, Paleozoic, Triassic and Jurassic subsurface sequences penetrated in the Negev and Northern Sinai. *Geol. Survey of Israel, Mapping, stratigraphy and oil division*, S/6/83.

DUBERTRET, L. 1932. Les formes structurales de la Syrie et de la Palestine. *C. r. Acad. Sci*., Paris, 195, 66-68.

EL-HEFNAWY, M., DEIF, A., EL-HEMAMY, S.T., GOMAA, N.M. 2006. Probabilistic assessment of earthquake hazard in Sinai in relation to the seismicity in the eastern Mediterranean. *Bull. Eng. Geol. Env.,* 65, 309-319.

EPPELBAUM, L.V. 1996. Combined interpretation of gravity and magnetic fields over the Rosh-Ha'Ayin structure, Israel. *Trans. of the Conf. of the Geol. Soc. of America, North-Central section,* Iowa, USA, 28, 6, 38.

EPPELBAUM, L., BEN-AVRAHAM, Z. KATZ, Y. 2004. Integrated analysis of magnetic, paleomagnetic and K-Ar data in a tectonic complex region: an example from the Sea of Galilee. *Geophysical Research Letters*, 31, 19, doi:10.1029/2004GL021298, L19602, 1-4.

EPPELBAUM, L., BEN-AVRAHAM, Z., KATZ, Y. 2005. Does mantle diapir produce Hebron magnetic anomaly? *Trans. of the Conf. of the Israel Geol. Soc. Ann. Meet., Moshabim Country Logging (Negev),* Israel, 26.

EPPELBAUM, L.V., BEN-AVRAHAM, Z., KATZ, Y.I. 2007. Structure of the Sea of Galilee and Kinarot Valley derived from combined geological-geophysical analysis. First Break, 25, 1, 21-28.

EPPELBAUM, L., EPPELBAUM, V., BEN-AVRAHAM, Z. 2003. Formalization and estimation of integrated geological investigations: Informational approach. *Geoinformatics*, 14, 3, 233-240.

EPPELBAUM, L.V., KATZ, Y.I. 2011. Tectonic-Geophysical Mapping of Israel and Eastern Mediterranean: Implication for Hydrocarbon Prospecting. *Positioning,* 2, 1, 36-54.

EPPELBAUM, L.V., KATZ, Y.I. 2012. Mineral deposits in Israel: A contemporary view, In: *Israel: Social, Economic and Political Developments*, Nova Science Publishers, N.Y., USA, 1-41.

EPPELBAUM, L., KATZ, Y., BEN-AVRAHAM, Z. 2006a. Mt. Carmel structure as a plate tectonics phenomenon. *Trans. of the Conf. of the Israel Geol. Soc. Ann. Meet.*, Beit-Shean, Israel, 31.

EPPELBAUM, L.V., KHESIN, B.E. 2012. Geophysical Studies in the Caucasus. Springer. 411 p.

EPPELBAUM, L.V., LIVSHITS, YA., FLEXER, A., BEN-AVRAHAM, Z. 1998. Integrated geological-geophysical analysis of Ring Structures phenomenon in the Eastern Mediterranean. *Trans. of the Conf. of the Israel Geol. Soc. Ann. Meet.*, Mizpe-Ramon, Israel, 25.

EPPELBAUM, L.V., MODELEVSKY, M.M., PILCHIN, A.N. 1996. Thermal investigation in petroleum geology: the experience of implication in the Dead Sea Rift zone, Israel. *Journal of Petroleum Geology*, 19, 4, 425-444.

EPPELBAUM, L.V., PILCHIN, A.N. 2006. Methodology of Curie discontinuity map development for regions with low thermal characteristics: an example from Israel. *Earth and Planetary Sciences Letters*, 243, 3-4, 536-551.

EPPELBAUM, L.V., VAKSMAN, V.L., KOUZNETSOV, S.V., SAZONOVA, L.M., SMIRNOV, S.A., SURKOV, A.V., BEZLEPKIN, B., KATZ Y., KOROTAEVA, N.N., BELOVITSKAYA, G. 2006b. Discovering of microdiamonds and minerals-satellites in Canyon Makhtesh Ramon (Negev desert, Israel). *Doklady Earth Sciences* (Springer), 407, 2, 202-204.

FLORINSKY, I.V. 2012. Digital Terrain Analysis in Soil Science and Geology. Academic Press. Boston. 432 p.

FOLKMAN, Y., YUVAL, Z. 1976. Aeromagnetic Map of Israel, 1:250,000. Israel Institute for Petroleum Research and Geophysics. Holon. Israel.

ERICKSON, A.J., SIMMONS, G., RYAN, W.B.F. 1977. Review of heat flow data from the Mediterranean and Aegean Seas. In: *Intern. Symp. on the Struct. Hist. of the Mediter. Basins, 25th Geological Conference*, Technip, Splite, 263-280.

FLEXER, A. 1971. Late Cretaceous palaeogeography of northern Israel and its significance for the Levant geology. *Palaeogeography, Palaeoclimatology, Palaeoecology*, 10, 293-316.

GARDOSH, M.A., DRUCKMAN, Y., BUCHBINDER, B., RYBAKOV, M. 2008. The Levant Basin offshore Israel: Stratigraphy, structure, tectonic evolution and implications for hydrocarbon exploration. GII 429/328/08, Geological Inst. of Israel, 1-118.

GARDOSH, M.A., GARFUNKEL Z., DRUCKMAN, Y., BUCHBINDER, *B.* 2010. Tethyan rifting in the Levant Region and its role in Early Mesozoic crustal evolution. *Geological Society*, London, 341, 9-36.

GARFUNKEL, Z. 1989. Tectonic setting of Phanerozoic magmatism in Israel. *Israel Journal of Earth Sciences*, 38, 2-4, 51-74.

GARFUNKEL, Z. 1998. Constrains on the origin and history of the Eastern Mediterranean basin. *Tectonophysics*, 298, 1-3, 5-35.

GINZBURG, A., EPPELBAUM, L. 1993. A combined 3-D interpretation of the Carmel gravity and magnetic anomalies. Report prepared on behalf of Oilfields Ltd., Israel, 1-42.

GINZBURG, A., EPPELBAUM, *L.* 1994. A 3-D reinterpretation of the Ma'anit gravity anomaly. Report prepared on behalf of Oilfields Ltd., Israel, 1-39.

GINZBURG, A., FOLKMAN, Y., RYBAKOV, M., ROTSTEIN, Y., ASSAEL, Y., YUVAL, Z. 1993. Israel: Bouguer Gravity Map. Scale 1:250,000. Survey of Israel. Jerusalem.

HALL, J.K., KRASHENINNIKOV, V.A., HIRSCH, F., BENJAMINI, C., FLEXER, A. (eds.). 2005. Geological framework of the Levant, Volume II: The Levantine Basin and Israel. Jerusalem, 826 p.

KATZ, Y.I., EPPELBAUM, L.V. 1999a. Levantine phase of tectonic-thermal activity in the Eastern Mediterranean. *Trans. of the Ann. Meet. of Geol. Soc. of Amer., Sect: Planetary Geology*, 31, 7, A119.

KATZ, Y., EPPELBAUM, L.V. 1999b. Preliminary results of basin mapping of the Lower Cretaceous traps in northern Israel. *Trans. of the Conf. of the Israel Geological Society. Annual Meeting*, Dead Sea, Israel, 40.

KALYONCUOGLU, Ü.Y., ELITOK, Ö., DOLMAZ, M.N., ANADOLU, N.C. 2011. Geophysical and geological imprints of southern Neotethyan subduction between Cyprus and the Isparta Angle, SW Turkey. *Journal of Geodynamics*, 52, 70-82.

KHAIN, V.E. 1984. Regional geodynamics. Alpine Mediterranean Belt. Nedra. Moscow (in Russian), 344 p.

Le PICHON, X., KREEMER, C. 2010. The Miocene-to-present kinematic evolution of the Eastern Mediterranean and Middle East and its implications for Dynamics. *Annu. Rev. Earth Planet. Sci.*, 38, 323-351.

LEVITTE, D., OLSHINA, A. 1985. Isotherm and Geothermal Gradient Maps of Israel. Geological Survey of Israel. Report GSI/60/85.

MAKRIS, J., STACKER, J., KRAMVIS, S. 2000, Microseismic studies and tectonic implications of Cyprus. In: *Proceed. of the 3rd Intern. Conf. on the Geology of the Eastern Mediterranean*, Geol. Survey Dept., Republic of Cyprus, 137-145.

MALOVITSKIY, YA.P., EMELYANOV, E.M., KAZAKOV, O.V., MOSKALENKO, V.N., OSIPOV, G.V., SHIMKUS, K.M., CHUMAKOV, I.S. 1975. Geological structure of the Mediterranean Sea floor (based on geological-geophysical data). *Marine Geology*, 18, 231-261.

MARLOW, L., KORNPIHL, K., KENDALL, C.G.St.C. 2011. 2-D basin modeling study of petroleum systems in the Levantine Basin, Eastern Mediterranean. *Geoarabia*, 16, 2, 17-42.

McKENZIE, D.P., DAVIES, D., MOLNAR, P. 1970. Plate tectonics of the Red Sea and East Africa. *Nature*, 226, 243-248.

MECHIE, J., ABU-AYYASH, K., BEN-AVRAHAM, Z., EL-KELANI, R., QABBANI, I., WEBER, M. 2009. Crustal structure of the southern Dead Sea basin derived from project DESIRE wide-angle seismic data. *Geophysical Journal International*, 178, 1, 457-478.

MOIX, P., BECCALETTO, L., MASSET, O., KOZUR, H.W., DUMITRICA, P., VACHARD, D., MARTINI, R., STAMPFLI, G.M. 2011. Geology and correlation of the Mersin mélanges, southern Turkey. *Turkish Journal of Earth Sciences*, 20, 57-98.

MONTADERT, L., LIE, O., SEMB, P.H., KASSNIS, S. 2010. New seismic may put offshore Cyprus hydrocarbon prospects in the spotlight. *First Break*, 28, 4, 91-101.

MESHREF, W.M. 1990. Tectonic framework. In: *Geology of Egypt.* A.A. Balkema, Rotterdam, 113-156.

MORGAN, P. 1979. Cyprus heat flow with comments on the thermal regime of the eastern Mediterranean. In: *Terrestrial Heat Flow in Europe*. Springer-Verlag, Berlin, 144-151.

NEEV, D. 1977. The Pelusium Line – a major transcontinental shear. *Tectonophysics*, 38, 3-4, 114-123.

NEEV, D., HALL, J.K., SAUL, J.M. 1982. The Pelusium Megasher System across Africa and associated lineament swarms. *Journal of Geophysical Research*, 87, B2, 1015-1030.

NOBLE IDENTIFIES giant prospect offshore Israel. 2010. *Offshore*, 70, 5, June 04, http://www.offshore-mag.com/index/article-display/6855731723/articles/ offshore/field-development/middleeast/2010/06/noble-identifies_giant.html

PILCHIN, A.N., EPPELBAUM, L.V., 1997. Determination of magnetized bodies lower edges by using geothermal data. *Geophysical Journal International*, 128, 1, 167-174.

PUNAR, A., TÜRKELLI, N., 1997. Source inversion of the 1993 and 1995 Gulf of Aqaba earthquakes. *Tectonophysics,* 283, 279-288.

ROBERTSON, A.H.F. 1998. Mesozoic–Tertiary tectonic evolution of the easternmost Mediterranean area: integration of marine and land evidence. In: *Proceeding of the Ocean Drilling Program, Scientific Results,* 160, 723-782.

ROBERTSON, A.H.F., CLIFT, P.D., DEGNAN, P.J., JONES, G. 1991. Palaeogeographic and palaeotectonic evolution of the Eastern Mediterranean Neotethys. *Palaeogeography, Palaeoclimatology, Palaeoecology,* 87, 289-343.

ROBERTSON, A.H.F., DIXON, J.E. 1984. Introduction: aspects of the geological evolution of the Eastern Mediterranean. In: *The Geological Evolution of the Eastern Mediterranean, Geological Society Special Publ*., 17, 1-74.

RYBAKOV, M., GOLDSHMIDT, V., ROTSTEIN, Y. 1997. New compilation of the gravity and magnetic maps of the Levant. *Geophysical Research Letters,* 24, 33-36.

SALAMON, A., HOFSTETTER, A., GARFUNKEL, Z., RON, H. 2003. Seismotectonics of the Sinai subplate – the eastern Mediterranean region. *Journal Geophysical International*, 155, 149-173.

SALAMON, A., KATZ, O., CROUVI, O. 2010. Zones of required investigation for earthquake-related hazards in Jerusalem. *Natural Hazards*, 53, 375-406.

SANDWELL, D.T., SMITH, W.H.F. 2009. Global marine gravity from retracked Geosat and ERS-1 altimetry: Ridge Segmentation versus spreading rate. *Journal of Geophysical Research*, 114, B01411, doi: 10.1029/ 2008JB006008, 1-18.

SCLATER, J.G., JAUPART, C., GALSON, D. 1980. The heat flow through oceanic and continental crust and the heat loss of the Earth. *Rev. Geophys. Space Phys*., 18, 1, 269-311.

SCHENK, C.J., KIRSCHBAUM, M.A., CHARPENTIER, R.R., KLETT, T.R., BROWNFIELD, M.E., PITMAN, J.K., COOK T.A., TENNYSON M.E. 2010. Assessment of undiscovered oil and gas resources of the Levant Basin Province, Eastern Mediterranean. *U.S. Geological Survey Fact Sheet 2010-3014*, 1-4.

SEGEV, A. 2000. Synchronous magmatic cycles during the fragmentation of Gondwana: radiometric ages from the Levant and other provinces. *Tectonophysics,* 325, 3-4, 257-277.

SHAPIRA, A. 1992. Detectability of region seismic networks: Analysis of the Israel seismic networks. *Israel Journal of Earth Sciences*, 41, 21-25.

SNEH, A., BARTOV, Y., ROZENSAFT, M. 1998. Geological Map of Israel, Scale 1:200,000. Geol. Survey of Israel. Min. of Nation. Infrastructure. Jerusalem.

TAN, O., TAPIRDAMAZ, M.C., YÖRÜK, A. 2008. The earthquake catalogues for Turkey. *Turkish Journal of Earth Sciences*, 17, 405-418.

TAWARDOS, E. 2011. Geology of North Africa. CRC Press. 952 p.

TUMA, J.J. 1979. Engineering Mathematics Handbook. 2nd ed. McGraw-Hill Co. NY. 394 p.

VANNUCCI, G., PONDRELLI, S., ARGNANI, A., MORELI, A., GASPERINI, P., BOSCHI, E. 2004. An atlas of Mediterranean seismicity. *Annals of Geophysics, Suppl*. , 47, 1, 247-306.

VERZHBITSKY, E.V. 1996. The Geothermal Regime and Seafloor Tectonics of Marine Basins along the Alpine–Himalayan belt. Nauka. Moscow (in Russian). 130 p.

WDOWINSKY, S., BEN-AVRAHAM, Z., ARVIDSSON, R., EKSTRÖM, *G.* 2006. Seismotectonics of the Cyprian arc. *Geophysical Journal International*, 164, 176-181.

ZVEREV, S.M. 2008. Internal structure of active fault zones based on deep seismic sounding data: Evidence from the Cyprian and Kuril-Kamchatka arcs. *Doklady Earth Sciences (Springer*), 420, 4, 644-648.

Reviewer: Corresponding member of ANAS F.S.Akhmedbeyli