Israel – Petroleum Geology and Prospective Provinces*

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Introduction

The recent discovery of large offshore gas deposits, as well as gigantic reserves of oil shale, has attracted the attention of many researchers to Israel. The latest U.S. Geological Survey estimates, using conventional assessment methodology, suggest that there are in the order of 1.7 billion barrels of recoverable oil and more than 4 trillion m^3 of recoverable gas in the Levant Basin (Schenk et al., 2010).

Short Review of Available Hydrocarbon Deposits in Israel

Heletz Oil Deposit

The Heletz oil deposit is located several km SW of Ashqelon and was the first oil field discovered in the eastern Mediterranean. It was originally identified as an oil-gas prospect based on gravity data. Oil pools exist mainly in the Lower Cretaceous sandstones, and to a lesser extent in dolomites, at depths of 1.5 to 2.0 km. Oil sources are believed to be Lower Cretaceous shales of the Gevar-Am formations or the Middle Jurassic small-grained carbonates of the Barnea Formation. The Heletz reserves are estimated at 40 million barrels, and the field has been in operation for more than 50 years now. The results of recent integrated seismic-gravity analysis (Berkovich et al., 2005) and structural reconstructions (Eppelbaum and Katz, 2011) indicate that deep horizons there may host significant additional hydrocarbons.

The Dead Sea Area

Exploration for economic hydrocarbon deposits in the Dead Sea from both the Israeli and Jordanian sides have so far failed, despite the presence of sedimentary deposits of many kilometer thickness, the presence of salt (Ben- Avraham et al., 2008), as well as favorable heat flows (Eppelbaum et al., 2006). Obviously active tectonic processes inside and outside the DST (Dead Sea Transform fault zone) prevent the accumulation of hydrocarbon pools of commercial value. The Israeli Oil Company exploits the Zuk-Tamrur deposit near the SW coastline of the Dead Sea. The daily output is about 200 barrels of high-quality oil. The latest company reports mention the discovery of a new oil pool with reserves of about 10 million barrels. A small gas deposit at Zohar (about 1.9 billion m^3 of gas condensate) was discovered in 1961 at the western boundary of the Dead Sea in a Jurassic limestone anticline at a depth of 500-700 m. These reserves are sufficient to meet the consumption needs of the city of Arad.

Oil-Bearing Shales

Israeli shale oil (Late Cretaceous bituminous marls) contains up to 12-25 % organic fertilizer. After heating to 500ºC it decomposes into oil, gas and other ingredients. This method yields large volumes of vapor and energy. Alternatively, shale oil can produce such valuable chemical byproducts as lubricants, phenols, solvents, etc. The shale oil deposits are mainly concentrated in central Israel (Shfela area) and the Negev, with thicknesses ranging from 35 to 80 m. However, the cost of a barrel of oil from shale currently exceeds the cost from a conventional oil deposit. Nevertheless, the total reserves of oil-bearing shales in the Shfela district are estimated at 350 billion barrels of extractable oil (these reserves rank third in the world after the USA and China). Israel Energy Initiatives (IEI) has already invested “tens of millions of dollars” in preparing a pilot project and announced that they have a technology that can heat the oil shales to the required temperature without any mining. Besides this, this technology produces gas emissions less than half that from conventional oil wells and does not consume water. Some international experts have suggested that these shales will be no less important for Israel economically than the large hydrocarbon reserves discovered recently off the coast of the country.

Offshore Hydrocarbons

Several gas deposits occurring in the southern offshore zone (Noah, Mango, Nir, Mari-B, etc.) are almost exhausted, despite the repeatedly reported discoveries of satellite fields. In the deeper offshore, according to the latest data (October 2012) the total gas reserves of the Tamar (300 billion m^3), Leviathan (470 billion m^3), Pelagik (190 billion m^3), and few other smaller deposits consist of more than 1 trillion m^3. Below the Leviathan gas deposit (at a depth of 5.8 km) apparently occurs an oil deposit containing about 3 billion barrels. The discovered gas deposits lie in the vicinity of deep, almost vertical paleofaults, intersecting all stratigraphic sequences, from Mesozoic, crossing Cenozoic (including Messinian salt), Pliocene, and Pleistocene. Close to the faults are active seepages of hydrocarbons detected at the sea bottom.

The preparations for the development of the hydrocarbons are in full swing. Obviously, the reserves of the deeper offshore of Israel are significantly larger than all the other above mentioned ones.

Results of Integrated Tectono-Geophysical Zonation

The eastern Mediterranean region (including Israel) represents a classic area for the emergence of plate tectonics (Ben-Avraham, 1978; Ben-Avraham and Ginzburg, 1990; Ben-Avraham et al., 2002). Recent discoveries of significant hydrocarbon deposits in offshore Israel (e.g., Tamar, 2009; Noble, 2010; Eastern, 2010) have increased the need for a robust tectonostructural model to assist in hydrocarbon exploration.

Integrated geophysical data on crust thicknesses (Ben-Avraham et al., 2002, 2006; Eppelbaum and Katz, 2011) indicate that several terranes occur in Israel and its vicinity (Galilee-Lebanon, Judea-Samaria, Negev, Pleshet, Heletz and Antilebanon) (Figure 1). Previously, the terranes have been divided based on comprehensive analyses of seismic, gravity, and magnetic data (e.g., Ben-Avraham et al., 2002, 2006). Already the first map of the Curie discontinuity of Israel (Eppelbaum and Pilchin, 2006) correlates to the position of these terranes (e.g., Ben-Avraham et al., 2006). The sources of the two most significant gravity-magnetic anomalies in Israel – Hebron and Carmel – were assigned to tectonically weakened zones between the terranes.

Isopach maps of the Middle-Upper Jurassic and Lower Cretaceous were constructed on the basis of numerous, detailed well sections and the most significant outcrops (Eppelbaum and Katz, 2011). A thorough analysis of these maps indicates that practically all the aforementioned terranes are reflected in the Middle-Upper Jurassic and Lower Cretaceous deposits. Thus, the data on the sedimentary-thickness distribution provide an unambiguous confirmation of the terrane model of the evolution of the eastern Mediterranean derived from the regional geophysical data analysis (Ben-Avraham et al., 2002).

The analysis of the regional gravity field (constructed on the basis of data obtained from the World Gravity DB as retracked from Geosat and ERS-1 altimetry (Sandwell and Smith, 2009)) and an integrated examination of the magnetic and thermal field analysis, the Moho discontinuity map of the eastern Mediterranean and the Curie discontinuity map of Israel, maps of earthquake epicenters, and seismic data analyses were all combined to construct a modified tectonic map of the eastern Mediterranean (Figure 1) (supplemented after Eppelbaum and Katz, 2012). This map depicts the main plate tectonic structures of this region: the African, Arabian, Sinai and Aegean-Anatolian plates with the latter being part of the Alpine mobile belt. Precambrian continental crust, oceanic crust, and Mesozoic accretional complexes compose the African, Arabian, and Sinai plates.

Terranes create some tectonic belts separating thinned oceanic and thickened continental types of crusts. In the eastern Mediterranean, Alpine terranes are clearly detected at the northern side of the Tethys (South Taurides, Taurus and Anatolides) and Mesozoic terranes at the southern side of the Tethys (Negev, Judea-Samaria, Antilebanon, Palmyride, Aleppo, Galilee-Lebanon, Pleshet, Heletz, Abdelaziz, and Eratosthenes). The southern margin of the Alpine terranes is disrupted in the subduction zone (Ben-Avraham, 1978). In the zone of the joining of the two mentioned terrane belts ophiolite associations developed.

Several hundred deep wells were drilled in the study area and more than 50 of them have discovered hydrocarbon reserves (Figure 1). The performed tectono-geophysical zonation of the area indicates that accumulation of commercial hydrocarbon deposits in the eastern Mediterranean appears in the vicinity of the boundary between the continental and oceanic crustal types. The explanation for the phenomena that wells drilled in the continental part of the region do not contain significant accumulations of hydrocarbons is explained below.

Hydrocarbon Provinces

Based on a geoscientific integrated approach, geodynamic stages and the tectonic evolution were identified, and this methodology only ensures a reliable estimate of the overall hydrocarbon potential in the eastern Mediterranean. The subsequent geotectonic zonation established three hydrocarbon provinces for exploration purposes:

(1) a province located on the ancient Nubian-Arabian Precambrian platform,
(2) a province of a terrane belt with thinned Precambrian crust,
(3) a province of basins with oceanic crust.

The hydrocarbon basins of the first province are narrow, intraplate marginal graben-like troughs. Their formation was initiated in the Late Cretaceous. However, the main stage of their development and hydrocarbon migration are associated with Neotectonic epochs (30 Ma. – to present) and connected to the Red Sea system riftogenesis. There are known oil deposits (October and other oil fields in the Suez Basin (outside Israel)), ozocerites (Dead Sea Basin) and small gas deposits (Hula Basin). The prospects for oil and gas exploration are associated with the presence of a thick series of the lower Messinian salt.

In the second province, three structural levels have developed in the sedimentary cover:

(a) Late Precambrian molasses,
(b) the pre-accretional carbonate platform of the Late Permian–Early Mesozoic,
(c) the post-accretional Late Mesozoic-Cenozoic, predominantly terrigenous sediments.

Oil and gas deposits were found in (b) and (c). The carbonate platform (b) reaches thicknesses of up to 5-6 km and hydrocarbon exploration is focusing on the build-ups, including bioherms. Prospects of this type can be targeted by an exploration strategy that is based on a combined historical-geodynamical and paleogeographical examination. Taking into account that the thick Mesozoic carbonate series were formed in terranes of the peripheral zones of the Tethys Ocean, the presence of organogenic complexes in this region is obvious. A predominantly terrigenous sequence (c) mostly developed in the coastal plain of the eastern Mediterranean, as well as directly in the shelf zone (its thickness reaches 4-5 km), targets potential reservoirs of Late Cenozoic age associated with the upper Messinian salt. The Early Cretaceous erosional channel complexes are of special interest. The long-known Heletz oil deposit (central Israel) belongs to just this type. The recently generated Early Cretaceous paleogeographical map reveals for the first time a complex system of ancient erosional channels. The presence of the majority of the hydrocarbon deposits and the geotectonic link in the Pleshet terrane is noted. In this terrane occur predominantly terrigenous-carbonate rocks, a facial type known from many oil and gas provinces worldwide.

The third province consists of many basins, but our analysis focuses solely on the largest Levant basin. The tectono-geophysical analysis was applied to define the basin boundaries with respect to the zone of terrane belt and other eastern Mediterranean basins of this province. The western part of this basin is bounded by the Leviathan high (on which the well Leviathan-1 was drilled – see Figure 1), and the eastern part, by the continent-ocean transition zone. Note that in the central part of the Levant basin a Moho discontinuity lowering was detected (see Figure 2A). The lower Mesozoic-Cenozoic facies characteristics of the sedimentary cover are similar to the corresponding one of the Pleshet terrane.

The available data indicate that structural zones of oceanic type, as found in the Gulf of Mexico, the Pricaspian basin and the Southern Caspian basin, have developed here. Ben-Avraham's (1978) claims that intensive geodynamic movements at the boundary of the Sinai and Aegean-Anatolian plates allow us to suggest that in the Levant basin numerous prospective local structures and swells may occur. Hence, it is likely that the high-potential hydrocarbon deposits in Tamar-1 and Leviathan (Figure 1) discovered recently in this region are not isolated features.

Conclusion

Latest analyses indicate that Israeli territory is highly perspective for discovering various hydrocarbon deposits. The discovered gas deposits offshore Israel (with total reserves more than 1 trillion m^3) occur mainly in regions with oceanic crust, and oil deposits (small for today) are distributed in general in shelf and coastal plain areas. Oil shale deposits (with total reserves of 350 billion barrels) occur in the areas of the terrane belt province.

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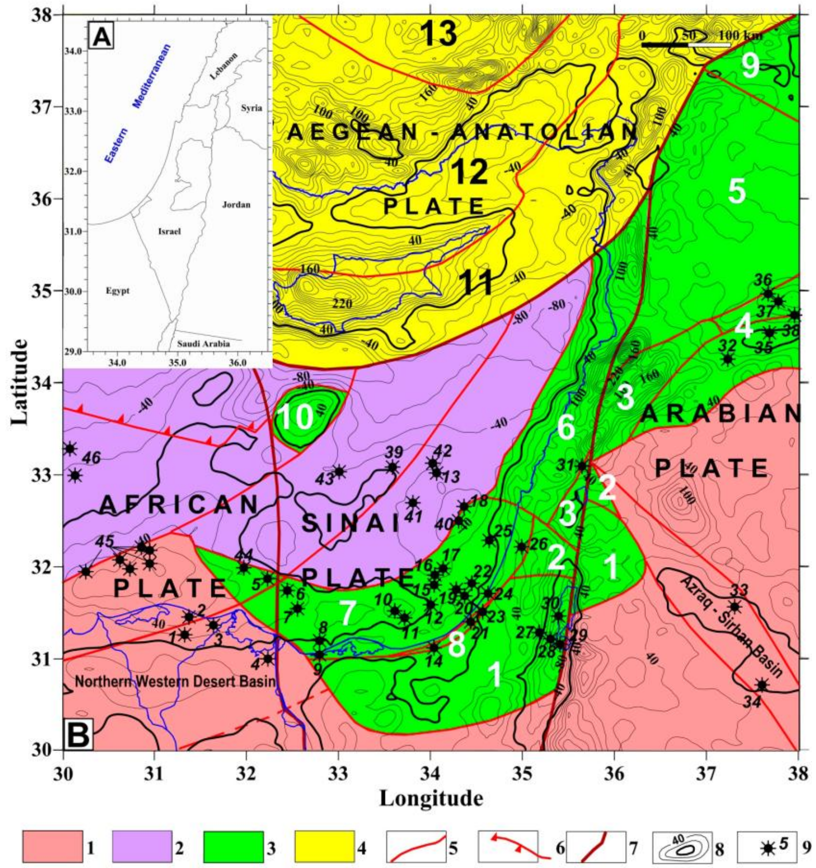

Figure 1. A. Areal map of the investigated region. B. Tectonic geophysical zonation of the eastern Mediterranean with location of wells discovered hydrocarbon deposits (overlaid on the smoothed gravity map) (after Eppelbaum and Katz, 2011, 2012, revised and supplemented)

(1) Precambrian plates with continental crust, (2) oceanic crust, (3) Mesozoic terranes, (4) Alpine tectonic belt, (5) main tectonic faults, (6) southern boundary of the Mediterranean Ridge, (7) intraplate tectonic faults, (8) gravity isolines, mGal, (9) boreholes with discovered hydrocarbon reserves (black italic numbers):

1 Khelala-1, 2 El-Qara-1, 3 Wastani-1, 4 Qnantara-1, 5 Temsah1, 6 Kersh-1, 7 Port Fouad-1, 8 Tineh1, 9 Bougaz-1, 10 Mango-1, 11 Mango-2, 12 Gaza Marine, 13 Tamar-1, 14 Sadot-1, 15 Noa South-1, 16 Noa-1, 17 Or-1, 18 Dalit-1, 19 Mari-1,2, 20 Nir-1,2, 21 Shiqma-1, 22 Yam-2, 23 Heletz, 24 Ashdod, 25 Yam-Yafo-1, 26 Meged-2, 27 Zahar-8, 28 Gurim-1, 29 Zuk-Tamrur-4, 30 Emunah-1, 31 Hula, 32 Qaruateine-1, 33 Hamza, 34 Wadi Sirhan-4, 35 Cheriffe-1, 36 & 37 boreholes with unknown names, 38 Al Shaier-1, 39 Leviathan-1, 40 Sarah-Myra, 41 Dolphin, 42 Tanin, 43 Afrodite, 44 Ras el-Barr, 45 West Delta Deep Marine, 46 Northern Border of Nile Delta.

Terrane position (large numbers): 1 Negev, 2 Judea-Samaria, 3 Antilebanon, 4 Palmyride, 5 Aleppo, 6 Galilee-Lebanon, 7 Pleshet, 8 Heletz, 9 Abdelaziz, 10 Eratosthenes, 11 South Taurides, 12 Taurus, and 13 Anatolides.

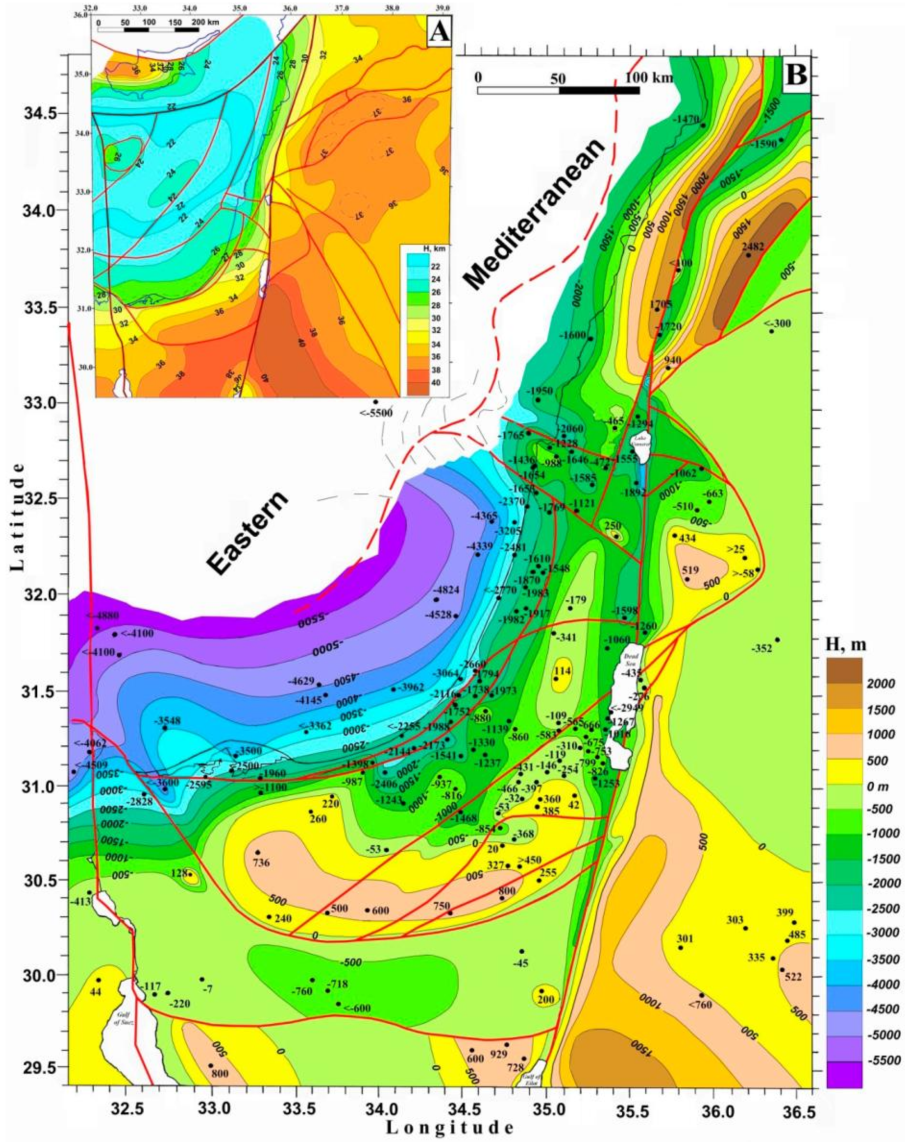

Figure 2. A. Moho discontinuity map of the Eastern Mediterranean (significantly modified after Eppelbaum and Pilchin, 2006). B. Structural map of the base of the newest (post-Jurassic sediments) tectonic complex. Color column shows deformation of the post-Jurassic erosion surface. Solid points on the map designate utilized deep boreholes and distinctive outcrops. Numbers next to solid black dots designate estimates of the base of the post-Jurassic (in m) derived from well sections and outcrops (initial sources are noted in Eppelbaum and Katz, 2011).