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Research paper

Eastern Mediterranean: Combined geological–geophysical zonation and paleogeodynamics of the Mesozoic and Cenozoic structural-sedimentation stages

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ABSTRACT

The eastern Mediterranean, in the Neo-Tethyan collision zone, consists mainly of the Mesozoic terrane belt and the adjoining oceanic crust complex of the northern part of the Sinai plate. The recent discovery of large hydrocarbon deposits has attracted considerable attention to this region. Combined analysis of gravity, magnetic, paleomagnetic, tectonic, structural and paleogeographical data sheds light on the tectonic evolution of this region. The Kiama paleomagnetic zone of inverse polarity, discovered in the oceanic crust of the eastern Mediterranean suggests transport along transform faults from the eastern part of the Tethys Ocean. The discrepancy between the terrane belt and the Nubian–Arabian foreland, oceanic crust, and terrane belt testify to the allochthonous nature of the eastern Mediterranean. For the first time, formation-paleogeographical maps of structural stages from the Triassic to the Neogene –Quaternary have been compiled. The integrated tectono-geophysical and paleogeographical specifics of deep zonation call for a reevaluation of regional criteria for oil and gas exploration.

1. Introduction

The eastern Mediterranean (Fig. 1) is part of the Afro-Eurasian collision zone (Fig. 2) (e.g., Ben-Avraham, 1978; Khain, 1984; Garfunkel, 1998), which contains both oceanic rift systems and terrane belts (Stampfli et al., 2013). Despite years of investigation, the geological and geophysical structure of the eastern Mediterranean remains unclear. The formation of its modern structure has been related to the evolution of the Neotethys Ocean and its margins (e.g., Ben-Avraham and Ginzburg, 1990; Robertson et al., 1991; Ben-Avraham et al., 2002). The eastern Mediterranean originated during the initial phase of the Neotethys, in the Early and Late Permian (Golonka and Ford, 2000; Khain, 2001; Stampfli and Borel, 2002; Muttoni et al., 2003). Herein we focus on the combined geological and geophysical zonation of initial stages and structures of the Neotethyan system including oceanic crust, terranes and the Nubian–Arabian foreland.

The eastern Mediterranean region has attracted increasing attention because of recent hydrocarbon discoveries (e.g., Khain and Polyakova, 2004; Noble, 2010; Montadert et al., 2010, 2014; Schenk et al., 2010; Eppelbaum et al., 2012; Hodgson, 2012). For example, Schenk et al. (2010) estimated that more than 4 trillion m^3 of recoverable gas is available in the Levant Basin in the central part of the eastern Mediterranean. Currently, seismic prospecting is the main exploration tool. However, even sophisticated seismic data analysis (e.g., Hall et al., 2005; Roberts and Peace, 2007; Gardosh et al., 2010; Marlow et al., 2011; Lazar et al., 2012; Montadert et al., 2014), has failed to identify the complete structural and tectonic mosaic of this region and, more importantly, has been unable to clarify different aspects of its tectonic evolution. This highlights the need for integrating geophysical data and paleogeographic reconstructions to yield deep paleotectonic criteria for oil and gas discovery.

Extensive geological and geophysical investigations have been carried out (e.g., Garfunkel, 1998; Ben-Avraham et al., 2002, 2006a; Robertson and Mountrakis, 2006; Gardosh et al., 2010; Homberg et al., 2010; Elgabry et al., 2013; Montadert et al., 2014), and a significant number of deep boreholes have been drilled. However integrated estimation of the deep structure of the hydrocarbon hosts and their evolution in terms of modern geodynamics (Ben-Avraham and Ginzburg, 1990; Robertson, 1998; Ben-Avraham

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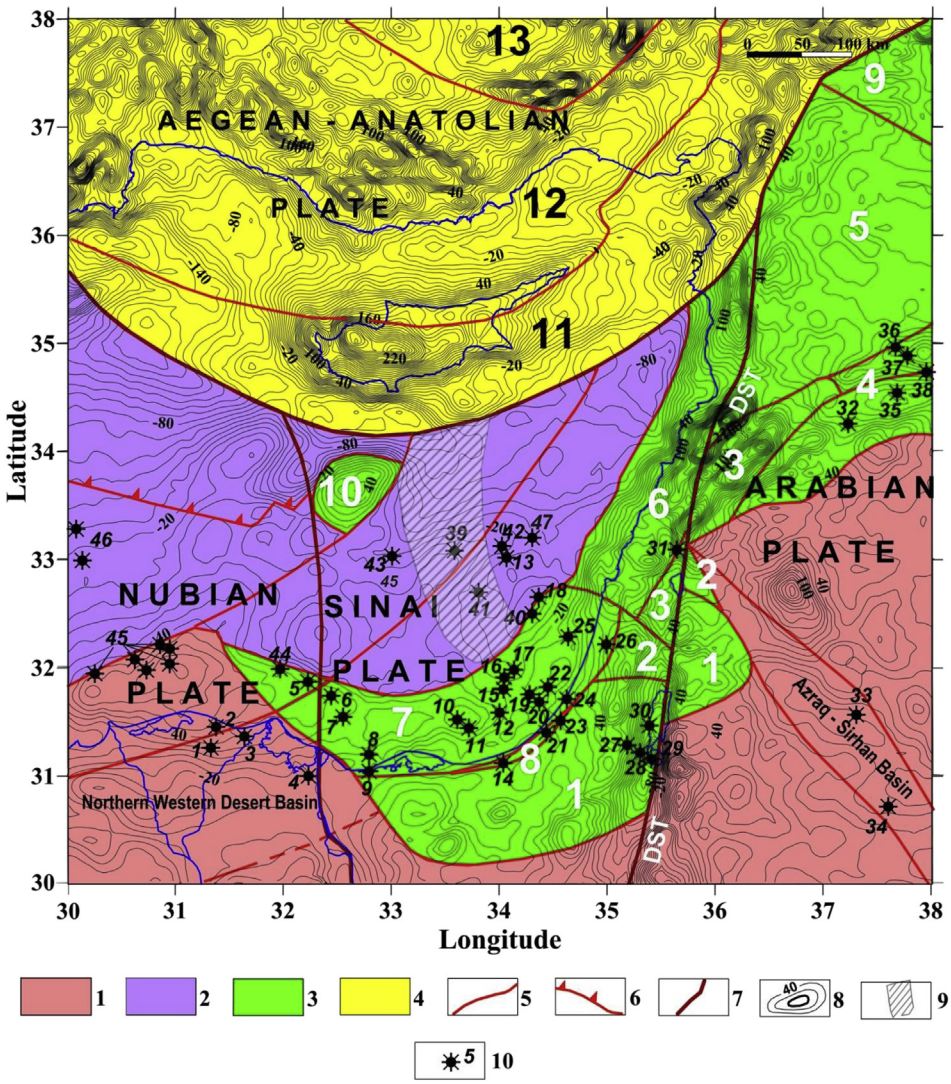

Figure 1. Tectonic and gravity map of the Eastern Mediterranean with location of boreholes that discovered hydrocarbon reserves (extended and modified after Eppelbaum and Katz, 2012b). (1) Precambrian plates with continental crust, (2) oceanic crust, (3) Mesozoic terranes, (4) Alpine tectonic belt, (5) intraplate faults, (6) southern boundary of the Mediterranean accretionary belt, (7) main faults, (8) gravity field isolines, at 20 mGal intervals, (9) contour of the Kiama paleomagnetic zone, (10) boreholes: 1 – Khelala-1, 2 – El-Qara-1, 3 – Wastani-1, 4 – Qnantara-1, 5 – Temsah-1, 6 – Kersh-1, 7 – Port Fouad-1, 8 – Tineh-1, 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 Deep 1A, 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, 47 – Karish. Terranes denoted by large white and black 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 Taurids, 12 – Taurus, and 13 – Anatolides

et al., 2002, 2006a; Le Pichon and Kreemer, 2010; Roure et al., 2012), are relatively recent (Eppelbaum and Katz, 2011; Eppelbaum et al., 2012; Eppelbaum and Katz, 2014a, 2015).

The aim of this study is to present the key tectonic and geodynamic features of the eastern Mediterranean deep structure and construct new maps of Mesozoic and Cenozoic structural stages, by integrating regional analysis of geophysical (magnetic, paleomagnetic, gravity, seismological, and thermal) and geologic (distribution and thickness of sedimentary facies, magmatic units, structural, paleontologic, and geochronologic) data. We examine structural stages in the following tectonic–geophysical zones: (1) regions of continental crust in the Nubian, Arabian and Sinai plates, (2) oceanic crust of the eastern Mediterranean, and (3) thinned continental crust of the Mesozoic terrane belt. We construct a series of new gravity and magnetic maps (and their transformations) that use satellite and airborne data and are accompanied by newly developed tectonic schemes. These new maps help gain a better understanding of the dynamics of hydrocarbon basins in the continental and shelf depressions, as well as the deep depressions of the eastern Mediterranean where gas deposits in zones of oceanic crust have only recently (OE Digital, April 2013) been exploited. Our paleomagnetic map constructed for the eastern Mediterranean region indicates that the tectonic evolution of the region needs to be reconsidered.

2. Geophysical and geological zonation

2.1. Geophysical data analysis

The satellite gravity data for this study were obtained from the World Gravity DB as retracked from Geosat and ERS-1 altimetry (Sandwell and Smith, 2009). These observations were made with regular global 1-min grids, and the error of gravity data computation was estimated at 1.5–2 mGals. The gravity map (Fig. 1) shows