Geophysical Research Abstracts
Vol. 19, EGU2017-2908-1, 2017
EGU General Assembly 2017

Satellite Gravity Transforms Unmask Tectonic Pattern of Arabian-African Region

Lev Eppelbaum (1) and Youri Katz (2)

(1) Tel Aviv University, Faculty of Exact Sciences, Geosciences, Tel Aviv, Israel (levap@post.tau.ac.il), (2) Tel Aviv University, Faculty of Life Sciences, Steinhardt Museum of Natural History & National Research Center

Satellite derived geophysical gravity data are the modern powerful tool of regional tectono-geophysical examination of the Earth's crust and upper mantle. It is well known that regional long-term seismological prognosis, strategy of searching economic deposits and many other important geological-geophysical problems are based mainly on constructions derived from the combined tectono-geophysical zonation. Some authors' experience of the tectono-geophysical zonation in the Eastern Mediterranean (both sea and land) with satellite derived gravity field (Eppelbaum and Katz, 2015a, 2015b) indicates a high effectiveness of the data employment for delineation of different tectono-structural units. Therefore, on the basis of the previous successive application, satellite derived gravity field analysis was applied for a giant (covering > 10 mln. km2) and complex Arabian-African region (including Zagros Mts.). The gravity field retracked from the Geosat and ERS-1 altimetry (e.g., Sandwell and Smith, 2009) was processed by the use of different mathematical apparatus employment enabling to underline these or those tectonic (geodynamic) features of the region under study.

The main goals of present investigation are following: (1) employment of a new powerful regional geophysical tool – satellite derived gravity data and its transforms for unmasking some buried tectonic and geodynamic peculiarities of the study area, (2) finding definite relationships between the novel tectonic map and the gravity field transformations, (3) development of a novel tectonic map of this area (on the basis of careful examination of and generalization of available geological and geophysical (mostly satellite gravity) data).

The compiled gravity map (for the map compiling more than 4 mln. observations were utilized) with the main tectonic features shows the intricate gravity pattern of the investigated area. An initial analysis of the gravity field behavior enabled to separate two main types of tectonic structures: (1) stable zones of continental and oceanic crust, and (2) mobile geotectonic belts. First type is characterized by homogeneous character of gravity field pattern (for instance, East Arabian Craton), whereas second type is characterized by mosaic and variable behavior of gravity field (especially, active rift zones).

It should be noted that 'youngest' mobile structure (Alpine-Himalayan orogenic belt and active rift systems of the Red Sea – East Africa) significantly differs in the gravity field pattern from the Mesozoic terrane belt and Neoproterozoic belt.

In this investigation six satellite gravity transforms (*SGT*) are described: multidimensional statistical analysis (MSA) by the use of sliding window, low-pass filtering, informational approach, gradient operator, entropy processing by sliding window of adaptive form, and 3D inverse methods.

Application of the MSA enabled not only to delineate geodynamical parameters of the studied region (collision zone at the boundary between the Arabian and Eurasian Plates, and active rift zones between the Arabian, Nubian and Somalian Plates, etc.), but also to estimate generalized properties of the Earth's crust. Results of MSA employment clearly show zone of development of the oceanic crust of the Easternmost Mediterranean and zone of oceanic crust of the Gulf of Aden and eastern (oceanic) part of the Somalian Plate. Besides this, in this map the Arabian and East African active rift zones and collision zone between the Arabian and Eurasian Plates are visibly traced.

Applied low-pass gravity field filtering enabled to recognize the most contrast crust-mantle structures. For example, the Afar triangle zone is clearly detected. Zones of the Neotethys closing Eastern Mediterranean, Persian Gulf, Zagros Fault Zone and South Caspian Basin can be easily identified. Subduction zones associated with the plate boundaries are reflected by elongated gradient pattern. These nonstable zones are conjugated with large mobile belts: Alpine-Himalayan belt and Mesozoic terrane belt. The zone of active rifting of the Red Sea, Gulf of Aden and complex structure of Afar triangle as well as East African rift system are noticeably fixed. The boundary between the continental and crust in the SE part of the region (where occurs a transfer zone between the Gulf of

Aden and Arabian Sea) is visibly detected.

Application of informational approach (Eppelbaum and Khesin, 2012) enabled to reliably fix both continental and oceanic cratons and all belts. To south-east of the Horn of Africa the Arabian Sea Basin with oceanic crust is clearly distinguished. The East Arabian Craton (platform) as well as its framing are noticeably detected.

Computation of entropy map from the satellite derived gravity field was earlier successfully tested by the authors in the Eastern Mediterranean (Eppelbaum and Katz, 2015a). Application of the adaptive form sliding window enables to receive the most reliable entropy estimations in conditions of complex field caused by superimposed influence of targets of different order. Obviously, computation of an entropial map by the same method for the region under study reproduces mainly deep tectonic units (elements) of the region. Complex pattern of entropial field in the SE part of the region reflects transfer from the Somalian Plate to Indian Plate (this area is characterized by the most mosaic pattern). This map nicely indicates position of the Mesozoic terrane belt and transition zone between the Victorian and Tanzanian plates.

On the basis of advanced inverse method employment, the map indicating the most density contrast surface (discontinuity) in the upper mantle was developed. This map presents an intricate density-tectonic depth pattern of the region. Here such important tectonic features as the Afar Triple Junction and collision zone between the Arabian and Eurasian lithospheric plates are noticeably recognized. Besides this, we can note increasing of lithospheric thickness in central parts of the Arabian and Somalian plates. Both these plates are countered by low-thickness lithospheric zones corresponding to the active rift zones. As it is indicated in the map, the thick lithospheric zones are associated with collisional zones at boundaries between the cratons and mobile belts. We suggest that the lowered values in the northern boundaries of the Arabian Plate correspond to subduction zones. The zones of lowered values in the middle of western part of the region correspond to the Neoproterozoic belt where ophiolitic and back-arc complexes with a thinned crust (e.g., Stern et al., 2004) are developed.

Compiled satellite derived gravity field and a set of *SGT* were utilized for development of a novel tectono-geophysical zonation map of the Arabian-African region. Structurally- geodynamically this region is one of the key Earth's megastructures where are closely disposed remain elements of the Tethys Ocean crust (Ben-Avraham et al., 2002; Robertson, 2004), most ancient Early Permian reversly magnetized Kiama zone (Eppelbaum and Katz, 2012b; Eppelbaum et al., 2014), and the youngest modern oceanic crust of the Afar triangle developed among the continental lumps (Yirgu et al., 2006; Bastow et al., 2011).

The tectonic zonation was carried out with application of three main principles of tectonic analysis:
(1) classic basis of space-temporary reflection of structural complexes,
(2) modern structural-geodynamic approach derived from the plate tectonic reconstructions where essential role plays analysis of rift, tectonic transform and collision forms of Earth's development,
(3) revealing of intricate correlation between the mapped tectono-structural elements and lithospheric-mantle complexes delineated by using both conventional geophysical methods (seismic, seismological, thermal data, etc.) and comprehensive analysis of satellite derived gravity data.

Compiled tectonic map of the region ($0^0 - 35.6^0$ north, and $30^0 - 57^0$ east) indicates that Precambrian basement and Mesozoic-Cenozoic structures play dominating structural- geodynamic role in this region. Precambrian generations include two main structural elements: (1) Archean platforms (Eastern Arabian, Tanzanian and Eastern Saharan cratons), and (2) Neoproterozoic belt. In the Neoproterozoic belt we distinguish: (a) final Proterozoic back-arc belts with ophiolites, and (b) more ancient Early/Middle Proterozoic massifs (detected both in some previous works of various authors and recognized by the authors of the present investigation using a set of geological-geophysical indicators).

In the areas of development of sedimentary Phanerozoic cover in the northern part of Arabian and African (Nubian) Plates, boundaries of Early/Middle Proterozoic massifs (Tabuk, Haif-Rutfah, Widyan and Nile Cone) and Neoproterozoic belts (Azraq-Sirhan, Ga'ara and Northern Western Desert) were delineated by analysis of: (1) land and airborne geophysical data, and (2) satellite derived gravity data.

Meso-Cenozoic structures of the region contain two tectonic complexes of its forming. 1*st* complex (from Permian to present) is associated with the Neotethys Ocean evolution. 2*nd* complex (from Oligocene to present) is associated with initial phases of spreading in the Arabian-African segment of Earth's crust.

1*st* complex structurally and geodynamically is a multiple generation since the Neotethys Ocean evolution was accompanied by processes of spreading, movements of some giant blocks along tectonic transforms, and collisions. These processes have formed structures of three types: (1) Mesozoic terrane belt, (2) Cenozoic orogenic belt, and (3) remain depressions of the Neotethys with oceanic crust.

Western (Levantine) part of the Mesozoic terrane belt is characterized by more ancient (Hauterive) age of consolidation comparing with the eastern part of the belt (Persian-Oman). Its terranes (from Zagros to Makran) and ophiolites were joined to Arabian platform in the Middle Cretaceous (Senomanian-Turonian). Many authors note an important role of Zagros terrane in the region under study and within the Caucasian-Arabian Sintaxis (e.g., Reilinger et al., 2006; Bordenave, 2008; Agard et al., 2011; Verges et al., 2011; Sharkov et al., 2015; Tunini et al., 2015). We propose that present study will unmask some tectono-geodynamic peculiarities of this complex tectonic unit.

The Mesozoic terrane belt was delineated in the Eastern Mediterranean by the use of variety of geological and geophysical methods (multilevel gravity and magnetic data examination, thermal data analysis, seismic and seismological data) application (Ben- Avraham et al., 2002; Eppelbaum et al., 2012; Eppelbaum, 2015; Eppelbaum and Katz, 2015a, 2015b, 2016). At the same time, eastern Zagros-Makran part of the Mesozoic terrane belt never was analyzed as a separately developing structural part (unit) of the Arabian craton. In all known paleogeographical reconstructions the Zagros-Makran structure is shown as a part of its northern periphery. However, analysis of facial, sedimentary and structural data (presented in Bordenave, 2008) indicates that there is a sharp discordant joining between the Arabian craton and Zagros belt. Axes of anticline structures of the Arabian craton have a meridional strike, while axes of the Zagros anticline structures are disposed discordantly to them at SW $35-50^0$. Besides this, paleogeological maps of Paleozoic (Bordenave, 2008) indicate that Devonian and Carboniferous deposits widely developed within the Arabian craton, do not presented in the Zagros belt. It testifies an uplift of Zagros structure and its isolated evaluation in the post-Carboniferous time when the Tethys Ocean began to form. Geological factors of Zagros structure isolation indicate that it was possibly a part of terrane belt in the southern part of the Neothetys Ocean forming.

It is necessary to take into account that Zagros structure most likely occupied different tectonic positions at different periods of geological time: (1) up to Carboniferous period Zagros was a part of the Eastern Arabian Craton, (2) in the interval between Permian and Middle Cretaceous it was a part of the terrane belt within Neotethys, (3) at present it is a marginal part of the Arabian lithospheric plate. All three aforementioned items find a direct reflection in the compiled gravity and *SGT* maps:
(1) Common structural-geophysical properties of Zagros structure and Arabian craton can be recognized in informational and gradient gravity field transformations;
(2) Examination of initial gravity map, entropial transformation map and deep structure map testify that Zagros is an independent structural unit within the Mesozoic terrane belt. Presence of thick Cenozoic sediments in the eastern part of Arabian Plate essentially limits application of conventional geological methods; therefore, contouring of boundaries between the Mesozoic terrane belt and Precambrian platform is possible mainly by regional geophysical data analysis. Sharp changing of gravity pattern in all three afore- mentioned maps enables to utilize this property as criterion for delineation of southern boundary of the Mesozoic terrane belt;
(3) Examination of the MSA map unambiguously indicates that Zagros suture is a marginal part of the Arabian lithospheric plate.

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