EXTENSIONAL OVERPRINTS IN THE LOWER CRUSTAL ARCHITECTURE, INSIGHTS FROM GRAVITY MODELLING OF THE ROMANIAN SHELF

Bogdan ALEXANDRESCU[1,2], Ioan MUNTEANU[2], Radu DIMITRIU[1]

[1]National Institute of Marine Geology and Geo-Ecology (GeoEcoMar), 23-25 Dimitrie Onciul St., 024053 Bucharest, Romania
e-mail: alexandrescu.bogdan@geoecomar.ro
[2]University of Bucharest, Faculty of Geology and Geophysics, 6 Traian Vuia Street, 020956 Bucharest, Romania

Abstract. The structure of the Romanian Western Black Sea shelf has been studied for the last 50 years. This paper aims to give a new interpretation, highlight a new vision regarding the lower crust architecture by combining the known local data with new measurements. In 2005, a new set of gravimetric data was collected by the Romanian National Institute of Marine Geology and Geo-ecology (GeoEcoMar), in the project Marine Geohazard, financed by the EU, which summed up to thousands of gravimetric profiles on the Romanian and Bulgarian offshore. By combining the new data with the known geological setting, a new vision emerged regarding the understanding of the complex structural dynamics of the deep shelf area and the geomorphology of the deep geological structure. For this investigation, a set of 3 profiles have been constructed as a starting point for the geological structure. In the process of inserting data, we had to take into consideration all the implicit information available from the local wells that are considered a secure source of upper-structure information. Once the model obtained, the image showed different areas where the Western Black Sea back-arc opening of the basin showed its marks, by presenting an unexpectedly complex architecture, considering all the constraints and local limitations.

Key words: Western Black Sea; deep structure; gravimetry; lower crust

1. INTRODUCTION

The Northwestern Black Sea shelf has been the subject of extensive investigations during the last 50 years (Dinu *et al.*, 2018; Dinu *et al.*, 2005; Nikishin *et al.*, 2015; Ţambrea, 2007). Because of the economic interest in the area, this article aims to help decipher the ongoing geophysical research in the area, by presenting a new in-depth model of the Romanian shelf architecture, extending also in the northern edge of the Bulgarian shelf.

The model herein presented has been created by the integration of the previous geological cross-sections in the area, on top of which we add the newest gravimetric data gathered from the National Institute of Research and Development (NIRD) GeoEcoMar, acquired during the Marine Geohazard European Project. In frame of this project, developed from December 2010 up to May 2013, four research institutes from Romania (including GeoEcoMar) and Bulgaria performed complex geophysical data, among them gravimetric profiles, which cover an area of around 65,000 km^2 (Dimitriu *et al.*, 2016).

All the models obtained so far agree that the Black Sea basin has went through multiple and complex tectonic phases, which have shaped the crustal architecture; their effects could be seen today, especially for the youngest created major structures inherited from the Cretaceous, associated with the opening of the Black Sea Basin and the Late Eocene-Miocene inversion (Munteanu *et al.*, 2011). These events generated a major uplift represented today by the Balkanides-Pontides in the South and Crimea-Caucasus in the North (Fig. 1).

The main studied profiles (by using the latest gravity data available) cover the Balkanides in the south and continues over the Moesian Platform, Histria Depression and ends in the Scythian Platform in the North, aiming to represent the crustal architecture of the Western Black Sea margin, along a profile extended on 372 km, located exclusively on the shelf area. The other two regional transects are designed to cover the continental to deep water area of the Western Black Sea Basin, from continental to oceanic type crust (Fig. 1); connecting two distinct areas, one being a relatively stable zone (onshore Dobrogea) and one which experienced the rifting and subsequent shortening (offshore).

2. GEOLOGICAL SETTING

The Western Black Sea-Dobrogea area suffered major changes over time having numerous deformations during tectonic phases. The most recent two phases that had a major impact were: the Cretaceous opening of the Black Sea basin and the subsequent inversion during the Eocene - Miocene times (Moroșanu, 2012; Munteanu *et al.*, 2011), a phenomenon observed even today in the upper layers, encountered in most cases, following geodesic and geophysical investigations. In this direction a very important and "palpable" witness are the results obtained from a high number of drillings in the area, detailed and well-documented in many papers.

The age of Western Black Sea basin opening is still debated in the scientific community, however on the Romanian shelf a Barremian age was proposed for initial opening, followed by continental rifting during the Aptian and an oceanic phase in the Albian (Görür, 1988; Țambrea, 2007; Munteanu *et al.*, 2011). The Western Black Sea basin rifting and expansion persisted within Late Cretaceous times; an oceanic crust already formed in the center of the basin, while the passive margin of the previously extended areas spread (Nikishin *et al.*, 2015 and references included). Afterwards, the extensional phase continued up to the Middle Eocene interval (Munteanu *et al.*, 2011).

The Scythian Platform is part of the Pre-Dobrogean Depression basement and consists mainly of Proterozoic granitoids and Neoproterozoic-Permian sedimentary foundations. The sedimentary cover has formed over several sedimentary cycles, such as: Paleozoic, Lower Triassic, Middle-Upper Triassic, Jurassic, Lower Cretaceous and Upper Miocene (Sarmatian), separated by important gaps in sedimentation. The southern limit of the Scythian Platform is conventionally established along the Sfântu-Gheorghe Fault, which continues eastward on the shelf, where it joins the northwest Crimea region (Dinu *et al.*, 2005).

The North Dobrogea Orogen represents a segment of the Hercynian Orogeny that has been reshaped during the Late Palaeozoic-Early Jurassic extension and subsequently inverted in the Alpine tectonic deformation (Dinu *et al.*, 2005; Seghedi, 2001). Its southern limit is given by the Peceneaga-Camena Fault, which separates it from the Moesian Platform, while its northern boundary is usually considered to be the Saint George Fault (Fig. 1), separating it from Scythian Platform (Visarion *et al.*, 1990). More recent studies (Stephenson *et al.*, 2004) suggest a more southern limit of Scythian Platform, on the Lebăda-Heraclea Fault, which will include the former Tulcea Unit of the North Dobrogea Orogen (Săndulescu, 1984). The exposed basement consists of several metamorphic successions that are Precambrian and Cambrian age, with an important number of magmatic intrusions of Palaeozoic origin at different depths (Săndulescu and Visarion 2000; Seghedi *et al.*, 2005). The offshore continuation of North Dobrogea structures can be found under the Paleogene deposits of the Histria Depression (Dinu *et al.*, 2005; Țambrea *et al.*, 2002).

The Moesian Platform is located in the western sector of the Black Sea, being delimited to the north by the Peceneaga-Camena Fault, the major structural element of the North Dobrogean Orogen (Fig. 1), and to the south, in the Kamchian Foredeep (Finetti *et al.*, 1988) through the pre-Balkan line, by the Balkan Orogen (Fig. 2). To the east, the Moesian Platform continues in the offshore domain at least up to the point of the continental slope (Fig. 2).

The Balkan Orogen (Balkanides) represents the southernmost limit of the studied area (Fig. 1). This major tectonic unit is divided into three main tectonic zones: Balkan, Srednogorie and Morava-Rhodope (Georgiev, 2012). The external part of Balkanides geometry exposed the Late Eocene-Pliocene compressional overprint, which affected the entire Western Black Sea shelf (Munteanu *et al.*, 2011).

3. METHODOLOGY AND MODELLING STRATEGY

The studied profile was built based on important references from published papers, which have been revised and represented by using the Oasis Montaj software. The main difficulty in realizing the profile overlapping to obtain the evolution model was to achieve a realistic interpretation, because the ones advanced so far differ from one author to another, for the same geophysically investigated area. Therefore, we have observed some discrepancies when the profiles presented in various papers were merged into each other, by using the aforementioned software.

Assuming that all studied profiles are correct, the conclusion was that the overlapping was not perfect, so a correction was made, by realizing also a network of profiles from the land to the shelf area. The result was that most of the errors were corrected and the main model has been built according to the geological features of the studied area. The method used to represent the structural blocks was "point-by-point" representation, meaning that all the limits between the neighbouring blocks were drawn by hand using multiple limit points.

The profile presented in this paper has a relative SW-NE orientation and intersects major faults and tectonic structures. It starts from the Balkanides, at the southern limit of the Moesian Platform and crosses its northern boundary, extending up to the North Dobrogea Orogen.

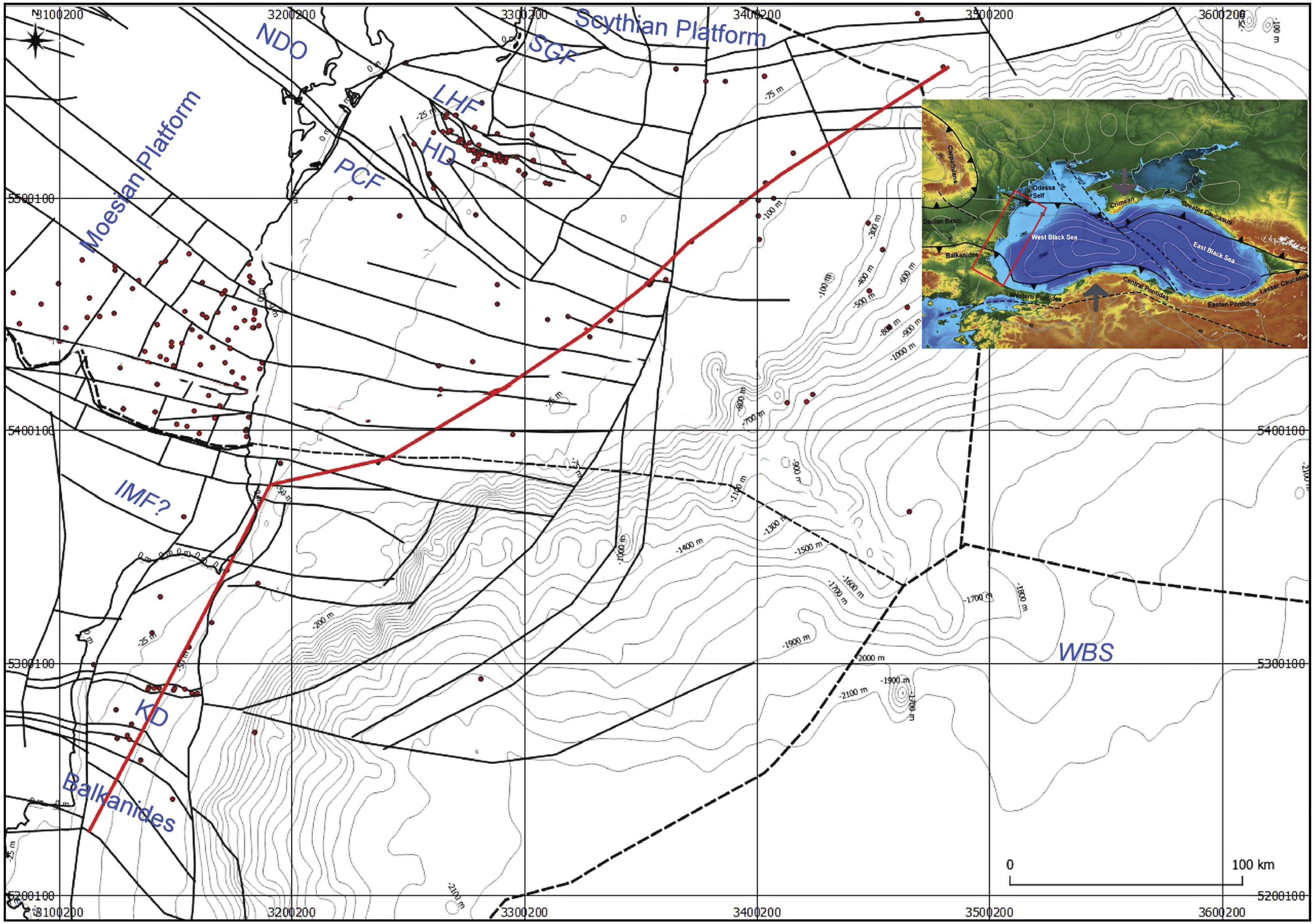

Fig. 1. Tectonic map of the Western Black Sea shelf, illustrating the complex tectonic setting of this area (compiled after Dinu *et al.*, 2005; Georgiev, 2012; Munteanu *et al.*, 2011). Inset map is illustrating the Western Black Sea settings according to Munteanu, 2012. Red lines indicate the modeled cross-sections and red dots the boreholes. HD – Histria Depression, KD – Kamchya Depression, LHF – Lebăda-Heraclea Fault, IMF – Intra Moesian Fault, PCF – Peceneaga-Camena Fault, SGF – Saint George Fault, WBS – Western Black Sea Basin.

The regional geological cross-section is made of many other existing profiles, interpreted by Georgiev (2012), Sava *et al.* (2000) and Munteanu *et al.* (2011).

For this study, aiming to realize an accurate representation, three sections have been chosen, each of them being described by different authors. The total length of the three sections of the profile extends on 372 km. The depth measured for the Moho discontinuity, in 3 points, at equal intervals (near the beginning-middle-near the end), is: 39km/34km/39km.

- Section 1 – Georgiev, 2012 – 36 km (distance from the starting point);
- Section 2 – Sava *et al.*, 2000 – 96 km (distance from the starting point);
- Section 3 – Munteanu *et al.*, 2011 – 288 km (distance from the starting point).

After the profile has been drawn (the in-depth structure being built), the data from a complex gravity map was added to the model, importing a new set of density values to all the corresponding units. In some cases, the in-depth data were insufficient, so the main goal was to represent the missing units (blocks) by using the known general frame and the available gravity data.

4. CRUSTAL STRUCTURE, INSIGHTS FROM GRAVIMETRIC MODELLING

At the upper crustal level, starting from South to North, the first noticeable structure appears at km 13, where the internal part of Balkanides are overthrusted on top of the external units. Here, the fold and thrust belt, including Neogene, Oligocene, Middle and Upper Eocene, Lower Eocene to Upper Paleocene and Upper Cretaceous sediments (Fig. 2), developed mainly at the top of the Triassic-Jurassic rift related basins, that contain Lower to Middle Jurassic, Middle Triassic and Lower Triassic depositional intervals (Fig. 2). The structure is a wrinkled, sinusoidal one, with a crooked geometry, due to the presence of thrust and normal faults. This succession is narrowed at km 42 due to a uplifting phenomenon, linked to the existence of a narrow block bordered by two faults. The greatest thicknesses are those belonging to the Cretaceous and Triassic depositional intervals, being approximately 3 km each (Fig. 2).

At km 64, in the E offshore of the Varna city, a major fault with a significant throw is present; another feature is the presence of older, Paleozoic deposits brought in a shallower position in the fault footwall. The sedimentary succession comprises the following intervals (from young to old): Oligocene, Middle and Upper Eocene, Upper Cretaceous, Lower Cretaceous - Upper Jurassic, Lower and Middle Jurassic, Lower Triassic and Paleozoic, Upper Carboniferous, Lower Carboniferous and Devonian.

Going towards N, the next important feature can be found at km 135, where one can notice the presence of another Triassic-Jurassic basin, with the depositional increase of Middle and Upper Triassic thicknesses, limited by a fault system associated with the Intra-Moesian Fault (Fig. 2). In the hanging wall of the fault, a thinning of the Triassic-Jurassic deposits is observed, coeval with the uplift of the Palaeozoic, possible Silurian, sediments (Fig. 2).

From the aforementioned point onward starts the development of the Histria Depression, with a pronounced deepening (the depocenter) at km 280. This structure consists of Pliocene, Miocene (Badenian-Sarmatian), Oligocene, Eocene, Upper Cretaceous, and locally Jurassic deposits (Fig. 2).

The biggest sediment thicknesses, up to 4 km, are found on the top of the Jurassic, following the 280 km mark. Significant thicknesses belong to the following intervals (in stratigraphic order): Miocene 3 km, Oligocene 3.59 km and Upper Cretaceous - Eocene 1.18 km.

At a deep crustal level, the modelling results suggest a complex topography of the lower/upper crust limit, the so-called Conrad discontinuity (Fig. 1). The topography is given by the thinning of thickening of the upper crust, which is compensated by the lower crust resulting a graben and horst structure (Fig. 2). Significant upper crustal thinning areas are to be found below the Balkanides and nearby Southern Moesian Platform border and northward below the Histria Depression/North Dobrogea Orogen (Fig. 2).

Below the former extensional related basins, either Triassic-Jurassic or Cretaceous-Paleogene in age, as Histria Depression of W Black Sea, the lower crust is situated in the most uplifted position, compensating the thinning of Palaeozoic and older rocks. In contrast, the Central and Southern Dobrogea have the thicker upper crust (Fig. 2).

5. CONCLUSIONS

The gravimetric modelling herein presented brought new insights in the crustal architecture of the Western Black Sea Margin, and in particular the lower crustal structure, which should reflect the polyphase evolution of this area. Since the upper layers geometry and properties are well constrained by numerous data, such as wells and seismic lines, we have concluded that the rest of the anomalies must come from deeper level, *e.g.* from upper to lower crust boundary. Therefore, the resulted model manages to illustrate the graben and horst look alike geometry of this boundary.

Since there is a good corelation between upper crust extensional grabens and thickening of the lower crust, we suggest that the observed geometry has to be related with extensional Triassic-Jurassic and Cretaceous-Paleogene stages of the Western Black Sea, when upper crustal streaking and thinning is compensated by lower crust flow and uplift.

The lower crustal uplift must have been taking place on regional detachments, which might explain some of the sharper geometries at the Conrad surface. We assume that some of the shallower faults might be rooted deeper at lower crust level, similar with the system described by Munteanu

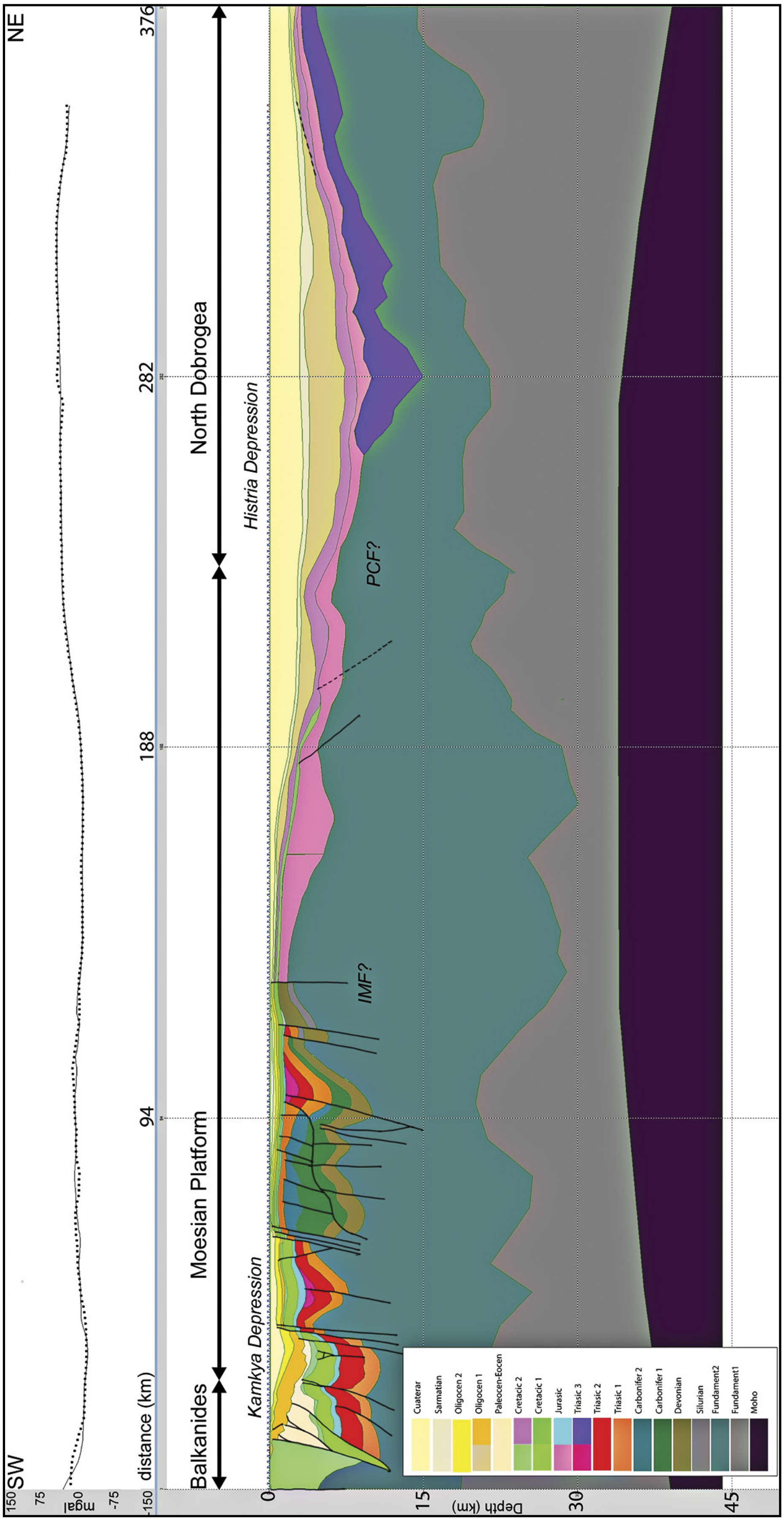

Fig. 2. Regional cross-section after the model. The location is that shown in Fig.1.

et al., 2011 and Moroșanu, 2012. By contrast, the thinner and deeper lower crust is observed below the Southern and Central Dobrogea Sectors of the Moesian Platform, where Palaeozoic and green schist basement rocks are in the most uplifted position, and possible unaffected by the Cretaceous-Paleogene extension.

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