UNCOVERING THE PRE-MIOCENE "HERITAGE" THE CARPATHIANS OBLITERATED IN THEIR RISE

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Abstract. Foreland basins are dependent on two key parts, a „moving part" (the fold and thrust belt) and a relatively „stationary part" (the pre-existing basins). Throughout the study area multiple wells drilled the pre-Miocene stratigraphy from multiple basins (East European Platform, Bârlad Depression, North Dobrogea Promontory, East Moesian Platform) and each basin had a different response for the E-ward advancing Carpathians. The older and colder the plates, the more rigidly they responded to the advancement of the nappes and a new pre-foreland setup was established through creation of multiple depocenters across the basin. The pre-existing topography played an important role for foreland geometry and fill. Main findings show that the Northern foreland didn't advance too far away as the East European Platform broke apart on long N-S fault zones rather than flexing and creating too much accommodation space for the Miocene fill. Further to the South we observe that the nappes had more space to advance, and this seems to be related to the response of the Bârlad Depression, as weaker plate flexing easily under the load and generating a rapid subsiding foreland basin. This area shows the highest subsidence rate for the Sarmatian section (Bacau area). Further to the South as the Carpathians hit the toughest block, the Nord Dobrogea Promontory (made up of Palaeozoic sediments and metamorphic basement rocks), the advancement of the thrust belt found advancing to the East as difficult as it can possibly be, thus the weakest link in the area (East Moesia), started flexing and creating large accommodation space starting with Sarmatian and through time until Romanian-Quaternary times.

Key words: subcrop, PreNeogene unconformity, Moesia, Bârlad Depression, North Dobrogea Orogen

1. INTRODUCTION

The pre-Neogene unconformity (PNU) represents the boundary between Neogene sediments and pre-existing stratigraphy across the Eastern and Southern edge of the Eastern Carpathians. Within the Neogene sequence we observe that the fill of the basin begins in the Middle Miocene (Badenian Paratethyan age), between 14.9-12.7 Ma (Piller *et al.*, 2005; Jipa & Olariu, 2009); hence, systematically the basin was filled, covering any pre-existing paleotopography. The Mio-Pliocene foreland fill is highly dependent on pre-existing topography as accommodation space was created following the interaction between the Carpathians rise and movement and pre-existing basins. Although, an important factor for sediment distribution and later on hydrocarbon migration, the unconformity has been usually evaluated, with poor seismic resolution. Main morphological features (promontories or paleovalleys) are related with large topographic relief, which has been created along strike in front of the advancing fold and thrust belt. It is assumed that the timespan of the pre-Neogene unconformity covers around 50 Ma, including the Paleogene-Early Miocene interval. Several features, without detailed data, have been published on this topic, by Paraschiv (1979a, 1979b, 1997) and Paraschiv *et al.*, (1983a, 1983b), focused on two main high relief promontories (Bordei Verde and North Dobrogea) and two large depressions (Movila Miresei and Bârlad), without going into too much detail.

The objective of this paper is to present the relationships which the rise of the Carpathians had with the pre-existing geological provinces and what were the main effects considering sediment distribution and structural setting. The surface in discussion is considered to have played an important role in hydrocarbon migration, as it's been related to 175 fields (Paraschiv, 1997) in all nearby basins, *i.e.*, Conţeşti - Indepedenţa trend and Târgu Fierbinţi - Oprişeneşti trend.

2. MATERIAL AND METHODS

The research area of this study is located in the Eastern part of Romania, from its border with Ukraine and Republic of Moldova in the N-NE and up to the Danube River, in the S (Fig. 1). We focus on the E Miocene-Pliocene foreland basin of Romania and the associated tectonic units (East European Platform, Bârlad Depression, North Dobrogea Promontory, East Moesian Platform).

Research was carried out by interpreting well and seismic data, both 2D and 3D, with the integration of gravimetry-magnetic data obtained from global datasets. Geological maps and published material were used to support the proposed model. Regional and local cross-sections were revised for areas without data or with very few ones.

3. GEOLOGICAL SETTING

The study area, extended on 44 000 km², comprises multiple old basins superimposed by younger ones (Fig. 2). The basins formed early on in the Paleozoic, some on older basement (Precambrian) and some younger basement (Late Neoproterozoic), such as the Ediacaran turbidites of the Histria Formation (Oaie *et al.*, 2005, Żelaźniewicz *et al.*, 2009), initially defined and for long time known as„Green Schists"(Săndulescu, 1984). Due to the limited dataset available, some boundaries between basins remain unknown and only inferred.

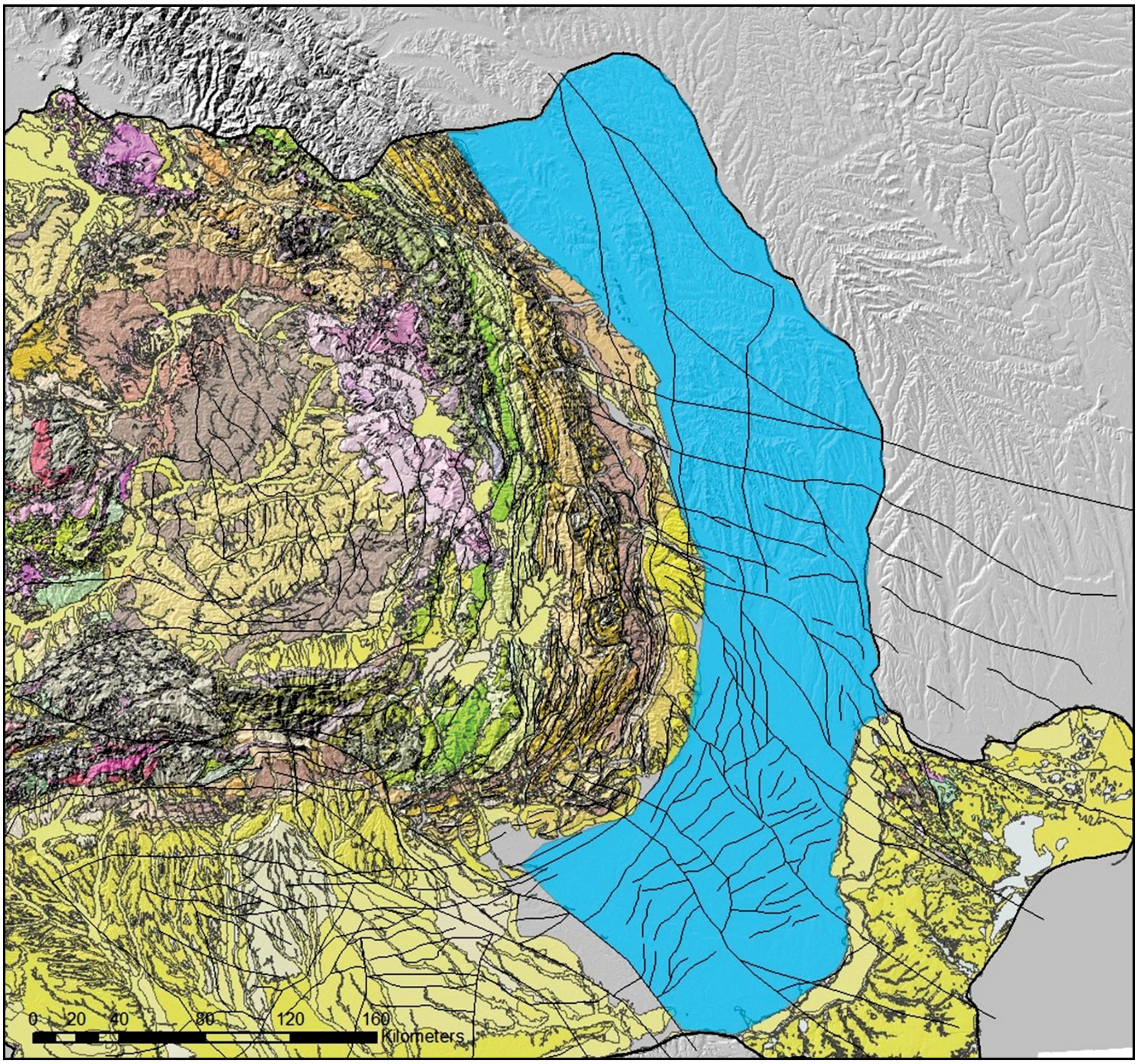

Fig. 1. The investigated area (shown in blue colour), figured on the geological map of Romania (modified after Săndulescu *et al.*, 1978).

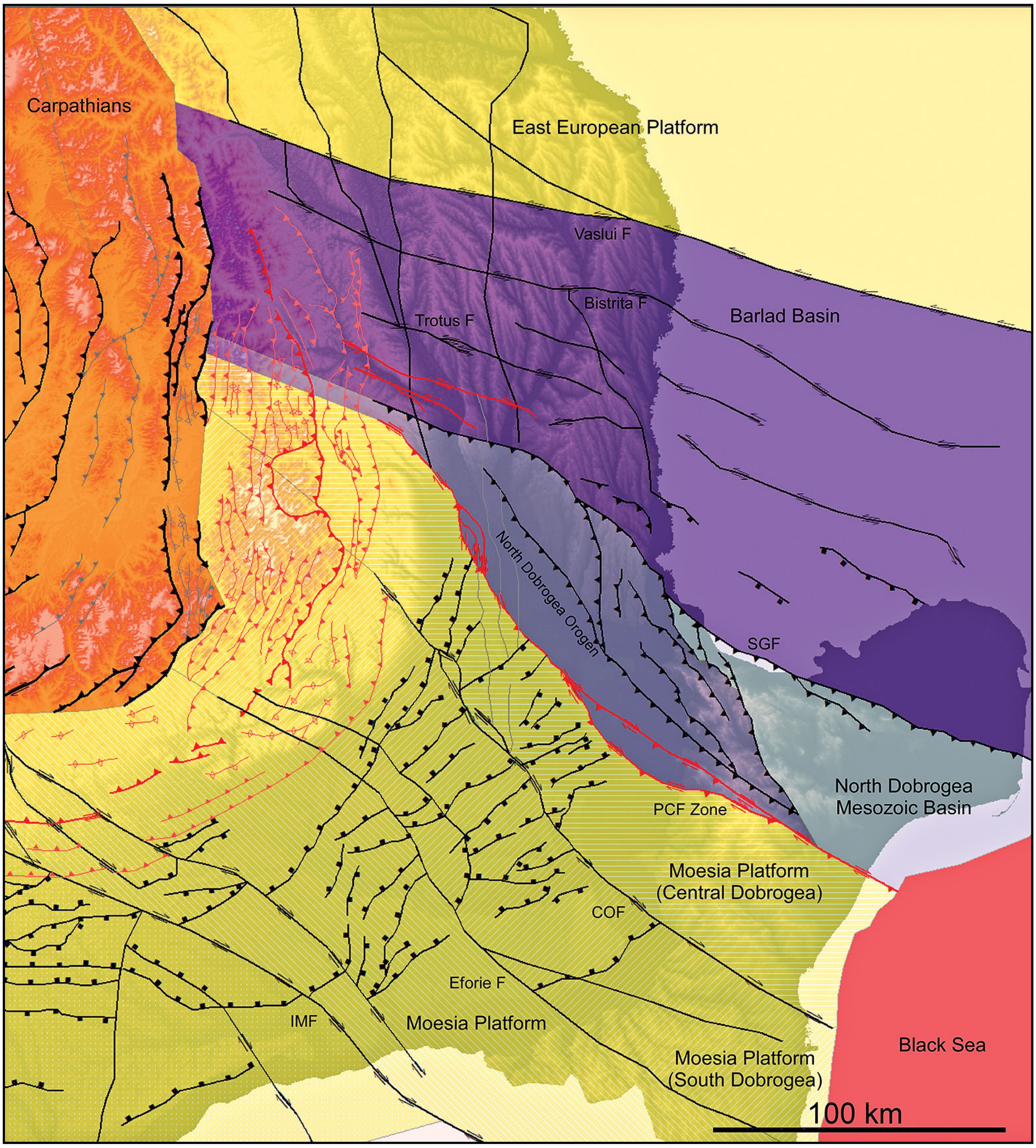

Fig. 2. Tectonic Map of Eastern Romania, compiled based on published material (Săndulescu, 1984; Getech unpublished study) (IMF – Intramoesian Fault, COF – Capidava-Ovidiu Fault, PCF – Peceneaga-Camena Fault, SGF- Sf Gheorghe Fault).

Structural lineaments are derived from published literature (Săndulescu, 1984, Săndulescu and Visarion, 2000) but modified based on gravimetric and magnetometric maps at a regional scale. The lineaments do not reflect details which can be seen on seismic data.

The Romanian part of the East European Platform namely the Moldavian Platform in Romanian literature, is delimited towards the South by the Bistrița Fault, according to Airinei *et al.* (1966) and Săndulescu and Visarion (2000). The Precambrian basement, mainly made by gneisses and migmatites, is delimited to the South by Paleozoic, Mesozoic and Cenozoic sediments. Westward, the Moldavian Platform continues under the Paleogene-Miocene fold and thrust belt of the Eastern Carpathians, falling stepwise along NNW-SSE oriented regional faults.

Săndulescu (1984, 1994) believed that the Scythian Platform is delimited the South by the Sfantul Gheorghe Fault, being separated from the North Dobrogea by the Sulina-Tarkhankut Fault. The basement of the Scythian Platform is considered to possibly be made up by Precambrian granitoids and Neoproterozoic to Silurian sediments (Neaga and Moroz, 1987; Vaida and Seghedi, 1997). Further, the sedimentary succession comprises Paleozoic, Triassic, Jurassic, Lower Cretaceous and Middle Miocene (Sarmatian-Pliocene) deposits, separated by important sedimentary gaps (Mutihac, 1990; Mutihac *et al.*, 2004).

In the Scythian Platform, enclosing the Bârlad basin studied herein, with a possible Precambrian-Vendian basement, the sedimentation started later than in the East European Platform (including its Romanian part, the Moldovian Platform), probably since Lower Devonian. The basin was affected by transtension and by extension during the opening of the Paleotethys Ocean. The sedimentation continued with a Devonian-Upper Carboniferous carbonate platform, the later interfingering with deltaic clastics (coal measures) since the upper part of Visean (Seghedi *et al.*, 2003; Seghedi, 2012). Starting with the Early Permian (Paleotethys closure?), the Scythian platform was affected by active rifting, with accumulation of red clastics and evaporites, accompanied a bimodal alkaline volcanism (hawaiites and trachytes) and syenite intrusions. Multiple extensional and compressional events affected the basin during the Jurassic, (Sinemurian-early Aalenian weak rifting, Late Aalenian-early Bathonian subsidence, Callovian-mid Berriasian new rift phase) and in the Cretaceous (such as Berriasian folding, rifting during Aptian-Albian and regional post-Albian subsidence until end of Cretaceous exposure to surface) (Nikishin *et al.*, 1998, 2014b).

For the North Dobrogea Promontory (Gavăt *et al.*, 1967), considered a concealed W-NW extension of the North Dobrogea Orogen, many data are available, as at least 150 wells have been drilled in the region. Several authors consider the subsurface geology in the area similar with what is known from exposures, in North Dobrogea *i.e.*, variously metamorphosed (Precambrian) and folded Paleozoic and Triassic deposits. The stratigraphic successions encountered were assigned to metamorphic rocks of the Orliga, Megina and Boclugea Series, the Țepu Formation (possible Silurian), Măxineni Formation (Devonian), Carapelit Formation (possible Carboniferous-Permian), and Triassic, along with magmatic rocks (Paraschiv *et al.*, 1983a). The North Dobrogea Orogen represents a narrow zone with NW-SE orientation, superimposed on a Hercynian deformed basment and deformed during the Cimmerian Orogeny (Murgoci, 1914; Săndulescu, 1984; Seghedi, 2001). The orogen is made up of Late Proterozoic and Paleozoic formations deformed in the Hercynian events (Mirăuță and Mirăuță, 1962, 1964; Seghedi, 2012; Balintoni and Balica, 2016), Triassic and Jurassic carbonates and turbidites, associated with Triassic bimodal volcanics (Săndulescu, 1984; Grădinaru, 1984, 1988; Baltres, 1993; Seghedi and Szakács, 1994; Seghedi, 2001).

The East Moesia terrane is characterized by an Ediacaran basement (Histria Formation turbidites) concealed in the subsurface of the Romanian Plain, but similar with what is exposed in Central Dobrogea (Pătruț *et al.*, 1961; Mirauță, 1966; Săndulescu, 1984); in the subsurface of South Dobrogea, Archaen gneisses are covered by Lower Proterozoic metamorphic series (sensu Seghedi, 2012). The Paleozoic Moesian cover is composed of Cambrian-Ordovician siliceous sandstones (ortho-quartzites) with pelitic interbeds, followed by Ordovician-Silurian clastic series with graptolites, followed by dark shales and limestones towards the uppermost part of Silurian and Lower Devonian (Eifelian) (Iordan and Rickards, 1971; Iordan, 1972, 1981). Above, continental-deltaic sediments (quartzitic sandstone, lithic sandstone with bioclasts, or siltic graywacke with shelly limestone interbedds) covered the basin, during Lower-Middle Devonian (Emsian-Eifelian), similar to the Old Red Sandstone type facies (Iordan, 1984). According to various auhors (Iordan, 1981; Paraschiv *et al.*, 1983a, 1983b; Iordan *et al.*, 1987; Pană, 1997; Seghedi *et al.*, 2005), a long-lived carbonate platform developed during Devonian-Carboniferous (Givetian, Frasnian and Visean), followed by sandstones interbedded with coals and carbonates in the Upper Carboniferous (Visean-Moscovian). Within the carbonate platform, the Fammenian and Tournasian are sporadically missing (Paraschiv *et al.*, 1975; Iordan, 1981). During Permo-Triassic, NNW-SSE oriented half grabens have formed, followed by bimodal volcanism (basalts and rhyolites) (Paraschiv, 1986c). The german-type Triassic facies encountered (ferruginous feldspathic sandstone, graywacke, ferruginous, mottled clay, calcareous clay, marl and gritty limestone) suggests a strong similarity with Western Europe (Paraschiv *et al.*, 1983b). Similarly with the Moesian Platform, in the North Dobrogea and Scythian Platform, the half grabens were inverted during Late Triassic (Tari *et al.*, 1997). The extension continued during the Neotethys opening (Early-Middle Jurassic). Mostly post-rift sediments are encountered in wells, dated as Middle Jurassic. A carbonate platform developed during the Late Jurassic-Lower Cretaceous (Oxfordian-Barremian) (Neagu and Dragastan, 1984). This deposition was interrupted by the opening of the Black Sea (in the Aptian-Albian interval), when the platform was exposed (Okay *et al.*, 1994). Later, clastic sediments accumulated during Aptian-Turonian interval (Ion *et al.*, 1995). A deeper water carbonate platform developed during the uppermost Cretaceous (Paraschiv, 1985).

The Mio-Pliocene foreland basin sedimentation started in the Badenian, with clastic to carbonate mixed deposits, filling up a paleotopography created by the long-term exhumation of the terranes surrounding the Carpathians (Tarapoanca, 2004; Leveer, 2007; Jipa & Olariu, 2009, 2013). The water depth of the basin decreases through time, with a deep-marine paleosetting encountered during the Badenian and a shallow marine to fresh-water one in the Sarmatian, and lacustrine one from since the uppermost Miocene (Macaleț *et al.*, 2016). The top of the Badenian is marked by a biotic extinction event (Melinte-Dobrinescu and Stoica, 2014; Palcu *et al.*, 2015) that facilitated the transition from a marine basin to a brackish one.

Aiming to illustrate the similarities and differences between the depositional regime of the studied basins, a chronostratigraphic chart was built (Fig. 3), based on various published data (Mutihac, 1990; Mutihac *et al.*, 2004; Paraschiv *et al.*, 1983a, 1983b; Vinogradov *et al.*, 1997; Świdrowska *et al.*, 2005), and on the framework of what the Romanian Geological Institute (IGR) published in 1973, in its Lithofacial Atlas.

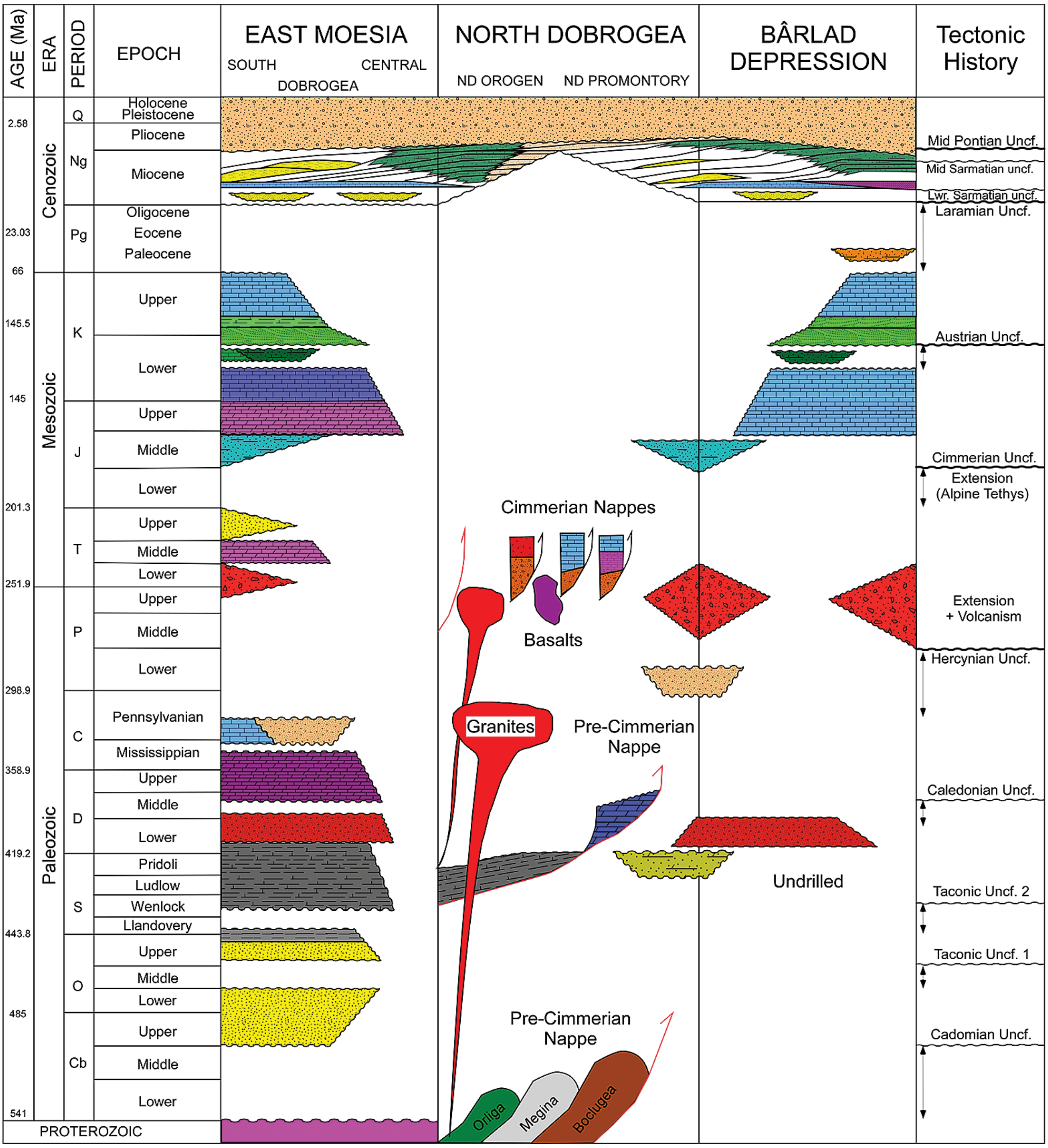

Fig. 3. Chronostratigraphic chart illustrating the differences and similarities among the three juxtaposed basins (East Moesia, North Dobrogea Orogen and Bârlad Depression), (Săndulescu, 1984, Vinogradov *et al.*, 1997, Mutihac *et al.*, 2004, Seghedi, 2012). Chronostratigraphic scale after IGR Lithofacial Atlas; Uncf.: unconformity.

In terms of what we can find under the PNU, we observe that there is a large central feature, the concealed North Dobrogea Orogen, which creates a significant high between two depocenters since its inception. The East Moesia and Bârlad Depression have a similar geohistory, with the main differences being related to the amount of erosion each basin suffered through time, with Bârlad Depression being more affected by subaerial exposure or non-deposition.

4. RESULTS AND DISCUSSION

The studied area has been analyzed intensively in the last century by numerous geoscientists, considering the existing outcrops exposed in North Dobrogea, extending into the subsurface (between 1934-1941) by using gravity-magnetic and magneto-telluric data (Burlacu *et al.*, 1991). Later, in the last decades, when exploration for hydrocarbons had its peak, seismic acquisition and drilling increased (between 1970-1990) (Burlacu *et al.*, 1991). There have been a few hundred wells that were drilled below the Tertiary cover throughout the studied area, with little penetration into the pre-Neogene. However, the seismic data have been acquired predominantly in the 70's and 80's; as the purpose of the drilling was not the pre-Tertiary stratigraphy, along with the limited technology of that time, it is extremely difficult to recognize geological features below the pre-Neogene unconformity. Therefore, due the limited quality of the subsurface data, the deposition below the Miocene-Pliocene foreland is not well known.

The seismic data from the Bârlad basin were acquired during the 80's. During this period a proper image was obtained, which enabled the definition of important seismic markers such as the presence of the Middle Miocene (Badenian) Anhydrite, along with the base of the Neogene and the base of Jurassic (Cimmerian unconformity) (Burlacu *et al.*, 1991). The seismic character below the pre-Neogene unconformity is complicated and very limited, being very dependent on the offset, energy used and lithological succession. In the proximity of the unconformity, some truncated reflectors have been pointed out (Roşca *et al.*, 1995).

Large scale features, such as basin delineation, have been established in the past through field observations, gravimetric and magnetometric interpretations but very little seismic interpretation. Regional projects such as Transmed (Papanikolaou *et al.*, 2004), have allowed the integration of geological data across borders and offered common observations in multiple basins. Unfortunately, data availability is limiting proper observations on some key features, with major boundaries remaining inferred rather than properly imaged by data.

The boundary between the Moldavian Platform and the Scythian Platform (Bârlad basin) is defined by the E-W regional Bistrița Fault (Săndulescu, 1984), considered a basement suture fault, which did not affect the sedimentary cover. However, although a grav-mag response might imply a contact in the area, on the seismic sections there is no any visible boundary, as the two basins acted together as a single depocenter for a long period of time. Roşca *et al.*, (1995) considered that the aforementioned boundary is marked by the Vaslui Fault, with a similar background as the Bistrița Fault representing a basement contact between two terranes further to the S (Fig. 2).

According to Mutihac *et al.*, (2010), in the Moldavian Platform, the stratigraphic succession begins with a Cambrian-Ordovician series, composed of sandstones and conglomerates with shales in the upper part, encountered in the Bătrâneşti, Iaşi and Popeşti wells. The succession continues with a Silurian sequence with limestones, interbedded with marls, calcareous sandstones, shales and tuffs, showing a variable thickness (120-300m), found in Todireni, Bătrâneşti and Popeşti wells. A long period of erosion and non-deposition follows as the Cretaceous section can be found overlaying the Silurian in most of the platform. At Rădăuți-Hudeşti, Lower Devonian deposits have been found betwen the Silurian and Cretaceous dark limestones, dated on fauna (Ionesi, 1989). Lower Cretaceous (up to 350m thickness) algal limestones, marls and dolomites, with anhydrites are present in the NW sector (Rădăuți and Suceava area) (Ionesi, 1989; Mutihac *et al.* 2010); The Cenomanian-Senonian is made up of glauconitic sandstones and argillaceous and chalky limestones with silex concretions, thickening westward (Saulea *et al.*, 1966). Part of the Cretaceous is also present in the W but it might be that it belongs to the extension of the Bârlad Depression rather than the Moldavian Platform.

The pre-Neogene truncations are visibile on a W-E correlation section from the Bacău to Ivăneşti wells (Fig. 4). We assume that this feature may be extrapolated throughout the whole part of the East European Craton extending in Romania (*i.e.*, the Moldavian Platform), where the Paleocene is only found in patches and the Cretaceous was more and more truncated eastwards.

The Bârlad Depression, considered also as part of Scythian Platform, seems to have had a long and complicated history, with similar basement like Greater Caucasus and Moesia (Saintot *et al.*, 2006). As there is no penetration to basement, it is extremely difficult to identify the basement nature or contact. It can either be Nord Dobrogea-related or East European Craton related. The begining of the Bârlad depression remains unknown considering the few wells that penetrated pre-Permian stratigraphy. During the Permo-Triassic and Middle Jurassic, the basin underwent a long period of extensional tectonics. The oldest Palaeozoic deposits would be the shallow marine Lower Devonian clastics. Several wells have encountered a red continental formation, ascribed to the Permian-(possibly also Lower Triassic) age, by comparison with similar deposits from Pre-Dobrogea Depression in the SE (Paraschiv, 1986). Deposition of marine clastics began in the Middle Jurassic. The Liasic is only present East of the river Prut (Vinogradov *et al.*, 1997).

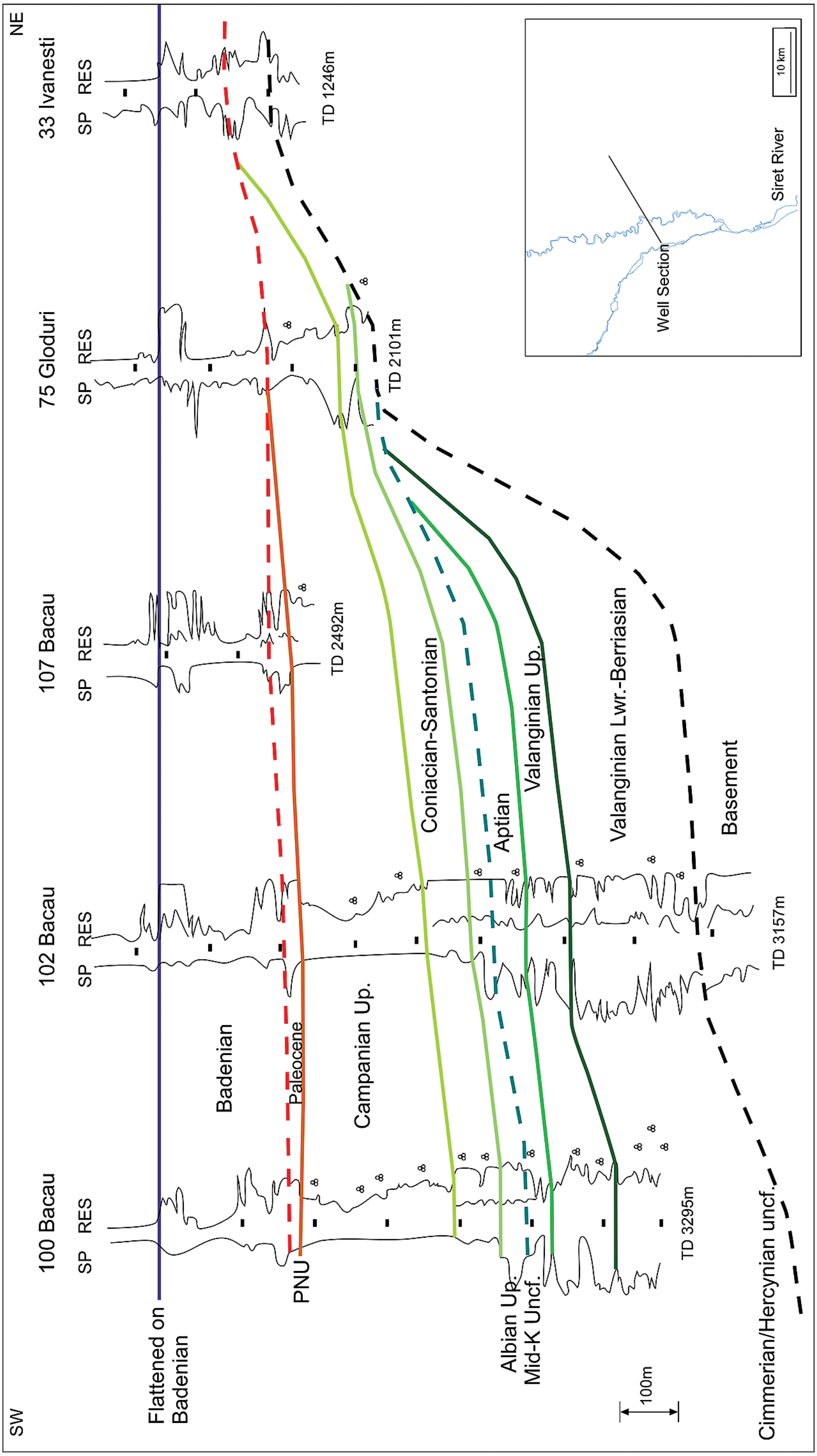

Fig. 4. Well Correlation section (sketch) showing Pre-Neogene stratigraphy in Moldova (East European Platform), redrawn after Zaharescu, 1979.

It's succession consists of a thick sandstone at the base, followed by marly limestone, with thick shales and rare sandstones at the top (Dogger). The Malm includes detritic limestones and dolomites with anhydrite (Oxfordian-Lower Kimmeridgian), followed by micritic limestone with interbeds of fossiliferous and pseudo-oolitic limestones and marly limestones (Kimmeridgian Upper-Tithonian) (Pătruţ *et al.*, 1983). The age was determined based on Saccocomide, similar with Moesia (Vinogradov *et al.*, 1997). The Cretaceous shows a similar facies like the Upper Malm, with micritic limestones interbedded with pseudoolitic and fossiliferous limestones, as well as with anhydrite interbeds, deposited in a lagoonal environment. The Aptian consists of siliceous sandstones, sands, calcareous sandstones, dolomites and limestones, and marls with shales. Limestones and dolomites seem to have a red colour due to oxidation. The Albian is local and made up of marls and marly limestones. The Cenomanian is made of siliceous sandstones and sandy fossiliferous limestones. The Campanian shows a limestone facies, sandy and fossiliferous, marly (Coman *et al.*, 1977). The PNU subcrop map (Fig. 5) illustrates an increased erosion southwards, where the Permo-Triassic can be found directly beneath the unconformity. This implies that the North Dobrogea Promontory might have been uplifted during post-Cretaceous times. It is extremely difficult to define the nature of the contact between the pre-Tertiary sediments and the pre-existing relief, as seismics doesn't offer the proper resolution. Thus, a tectonic contact has been drawn in figure 5, to imply lateral changes between the promontory and the adjacent basin.

In the North Dobrogea Promontory, the Ţepu Fm. is a clastic succesion present in 20 wells and described as siliceous sandstones and phylitic shales interbedded with limestone and marls with thin shales interbeds; such successions were ascribed to the Silurian by correlation with the Llandovery?-Ludlow sequences from the Moldavian Platform (Beju, 1971; Paraschiv *et al.*, 1983a). The Măxineni Fm, found in Măxineni wells and including limestones, dolomitic limestones with interbeds of shaly schists, was assigned to the Lower Devonian, by correlation to the Bujoare Formation from North Dobrogea (Paraschiv, 1981). Several wells intercepted clastic which were ascribed to the Carboniferous-Permian, by correlation with the upper Paleozoic Carapelit Formation, well exposed in North Dobrogea (Paraschiv *et al.*,1983a). At outcrop, the Carapelit Formation consists of grey and red continental clastics (Mrazec and Pascu, 1896; Seghedi and Oaie, 1986; Oaie, 1986), associated locally with thick volcano-sedimentary successions (rhyolitic ignimbrites, air fall tuffs, epiclastic rocks) (Seghedi *et al.*, 1987). As the fossils seem to be lacking in the Paleozoic successions of the Promontory, correlation with the exposed Paleozoic successions from North Dobrogea have been done based on petrographic and lithological features.

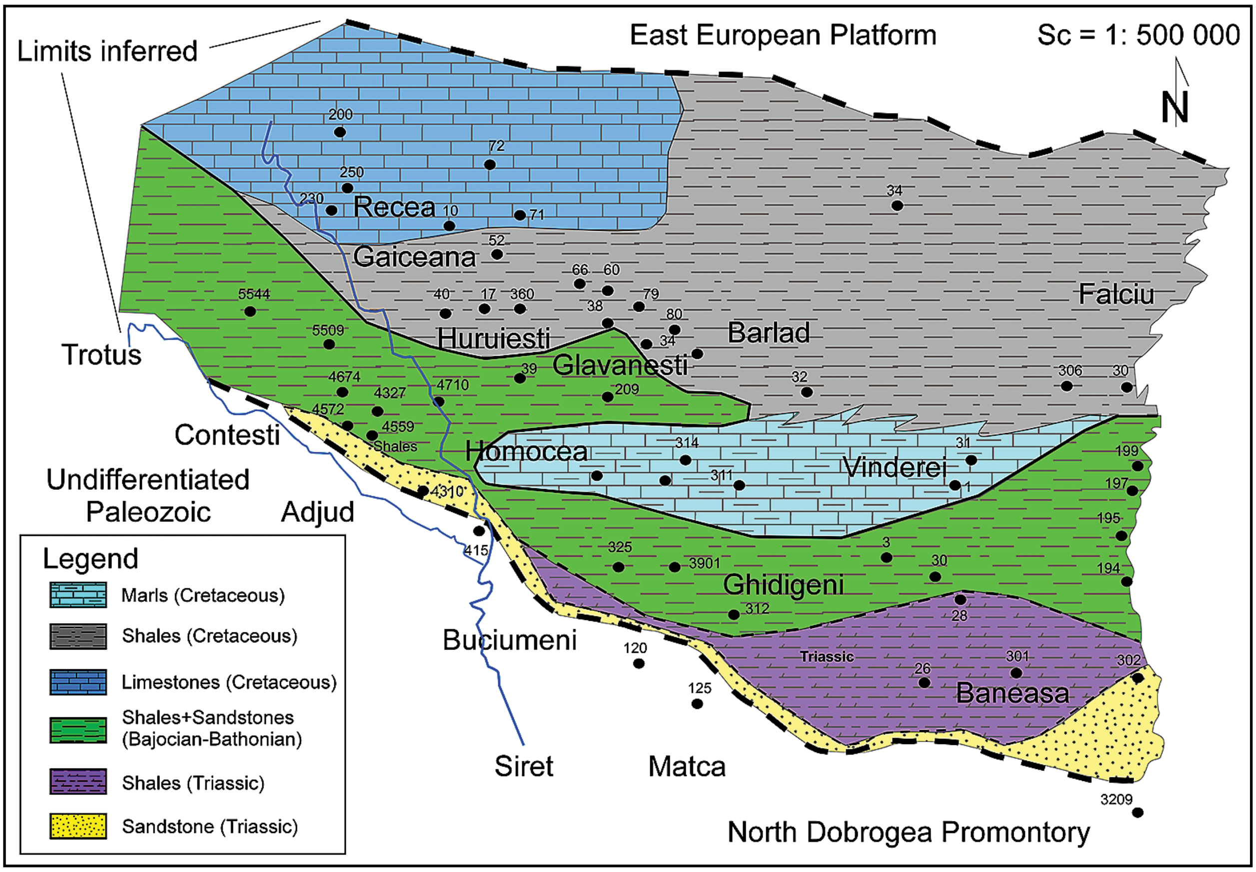

Fig. 5. Pre-Neogene subcrop map of the Bârlad Depression (revised after Burlacu *et al.*, 1991).

The constitution of the concealed north-western part of the orogen (the North Dobrogea Promontory) and distribution of the pre-Neogene formations according to Paraschiv (1981) is shown in figure 6, along with the mostly inferred tectonic contacts. The problem is that it is based very little on biostratigraphic constraints and more on lithological similarities from well data with the Nord Dobrogea Orogen outcrops. Based on seismic data and on older well logs (Spontaneous Potential+Resistivity), is very difficult to make assumptions on lithology. Considering that most of the seismic surveys were acquired post-1985, the map compiled by Paraschiv *et al.*, (1985), lacks significant control on contacts and lithological extent.

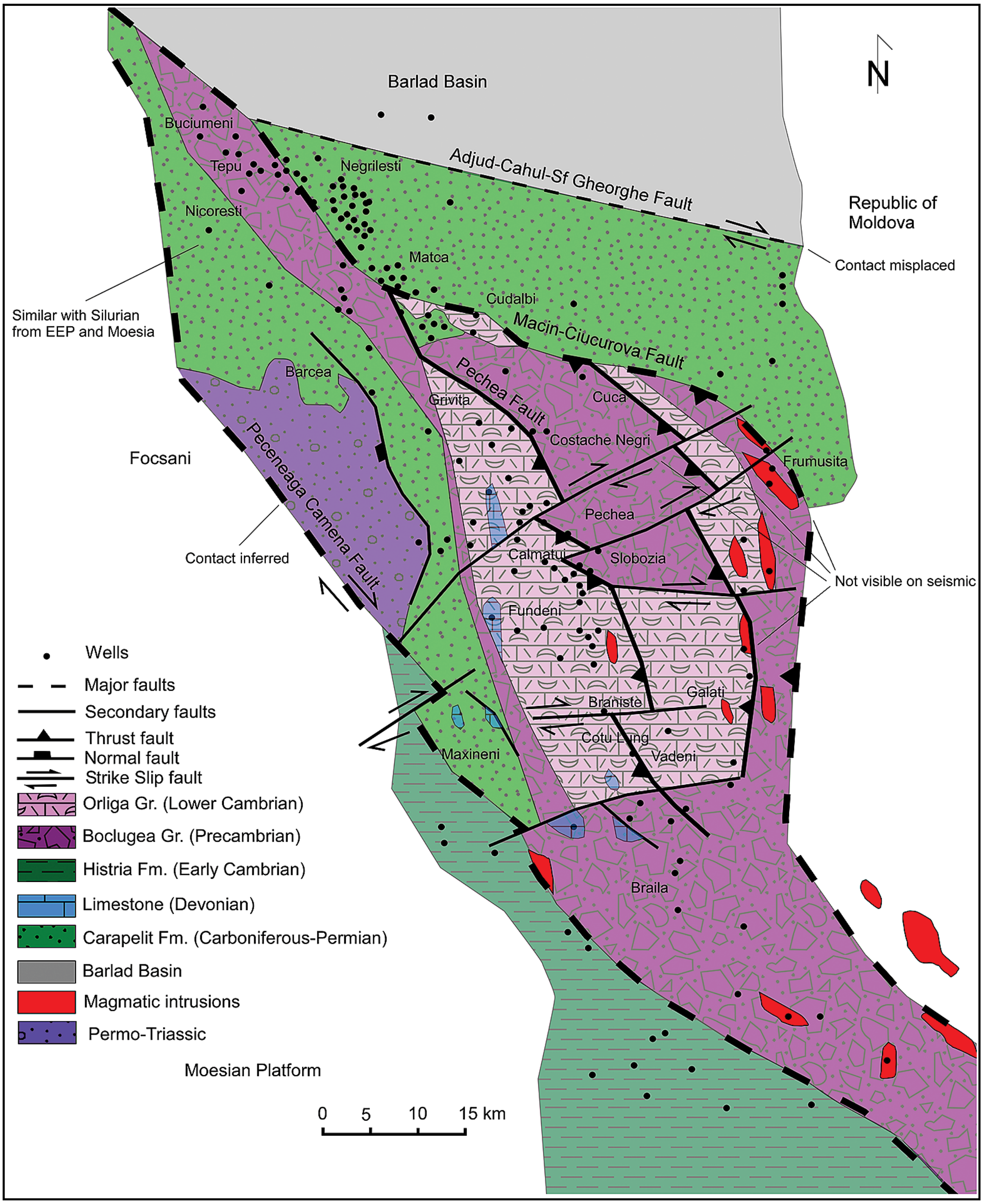

Fig. 6. Pre-Neogene subcrop map in the North Dobrogea Promontory (revised after Paraschiv *et al.*, 1985).

The poor faunal recovery from multiple wells suggests that most lithologies that have been found in the promontory are probably high energy in nature (sandstones and conglomerates – possible fluvial and alluvial depositional environments) with poor faunal preservation. It's also worth mentioning that more than 700 wells were drilled in the study area since 1985.

According to Mutihac (1990) and Mutihac *et al.* (2004), the following succession of Paleozoic and Mesozoic deposits occurs in the Moesian Platform. The Cambro-Ordovician depositional interval is characterized by a succession of more than 600m thick siliceous sandstones and microconglomerates, underlying a shaly unit with interbedded limestones (graptolite shale facies), dated as Silurian (Iordan, 1981, 1984). The Devonian contains a lower clastic succession 200-300 m thick, followed by a 2000-3000 m sequence of dolomites, limestones and evaporites, Middle Devonian to Early Carboniferous age (Paraschiv, 1974, 1975; Iordan, 1981; Vinogradov and Popescu, 1984). A Lower-Upper Carboniferous clastic unit is present sporadically, with coal layers and rare interbedded carbonates. The Triassic contains feldspar sandstones, shales, sandy shales, limestones, at least 100 m thick (Paraschiv *et al.*, 1983). The Jurassic, at least 400 m thick, encloses in general micritic limestone, stromatolitic with algal reefs, oncolythic and breccia facies (Pătruţ *et al.*, 1983b). The youngest sediments, Middle Jurassic (Dogger) in age, are made of 6-8 m thick conglomerates and sandstones overlying the basement.

In the Moesian Platform, the pre-Neogene unconformity, as defined by Paraschiv, (1997), describes the boundary at a larger scale between the Neogene and pre-Neogene deposits, which can be considered to have lasted at least 30 Ma and up to 50 Ma. Due to the tectonic movements in the Mio-Pliocene, it is hard to advance a scenario of what the unconformity looked like prior to these movements, being distorted. The main structural features observed in the studied area, are Bârlad Depression, North Dobrogea Promontory, Movila Miresei Depression, Bordei Verde Promontory. In the NE part of the study area, NE-SW paleovalleys are visible.

In figure 7, (a 2D seismic line acquired in 2012), the most visible boundary is represented by the large contrast associated with the pre-Neogene unconformity. Possibly, the overlying Badenian and Lower Sarmatian mixed carbonate-clastics are unconformably lying over either reddish clastics Permo-Triassic in age in the nearby wells on the most western edge or onto old indurated Paleozoic clastics, poorly dated (Roşca *et al.*, 1995)

The structural pattern presented herein is inferred considering outcrop descriptions and geological maps, joint together with limited seismic reflection, considered to represent a fault discontinuity. During the Permo-Triassic, a NW-SE fault orientation is possible with remanants of half graben fill. Taking into account field observations, we assume that thrust faults oriented westernward are present in the Paleozoic. Possibly, the Moesian Platform basement thrusted over Silurian-Lower Devonian clastics.

The most recent deformations associated with the Cimmerian unconformity and later with the mid-Cretaceous unconformity, suggest a trend north-eastward thrust. Probably, the Paleozoic sediments, along with the basement, were thrusted over the Mesozoic Bârlad basin.

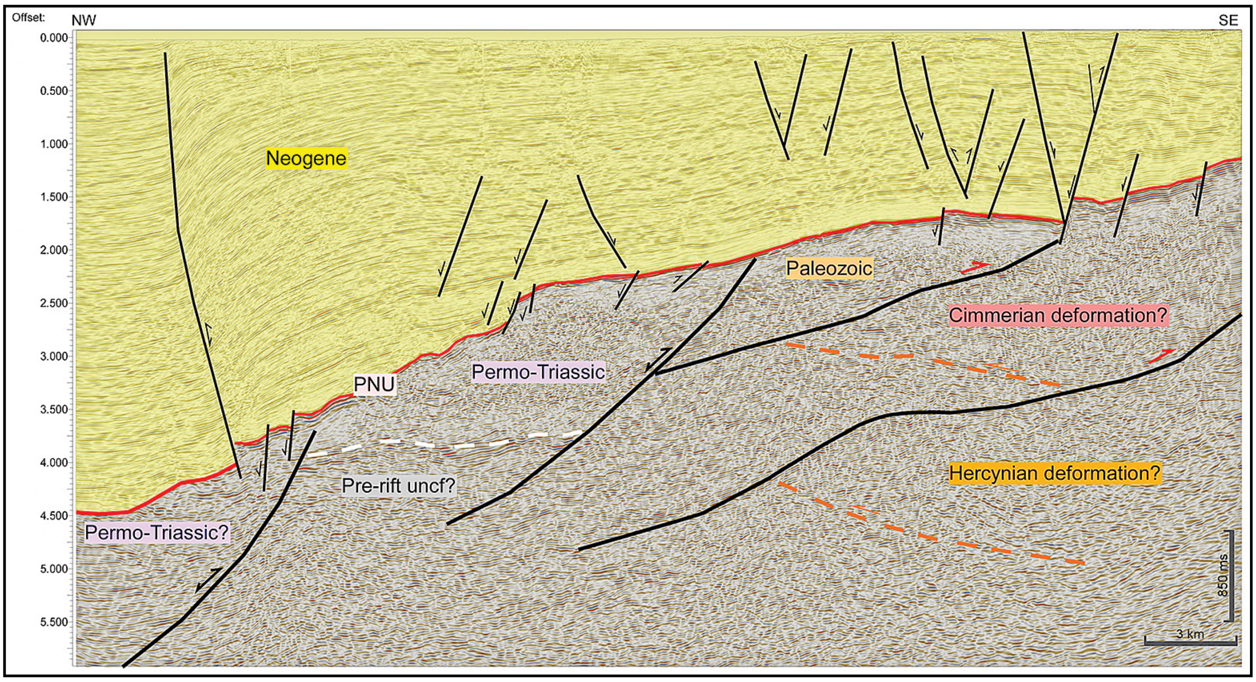

Fig. 7. 2D seismic line acquired and processed in 2012 by OMVP and Hunt Oil, illustrating the poor-quality seismic character visible below the PNU, and a possible interpretation based on Nord Dobrogea Orogen outcrops observations.

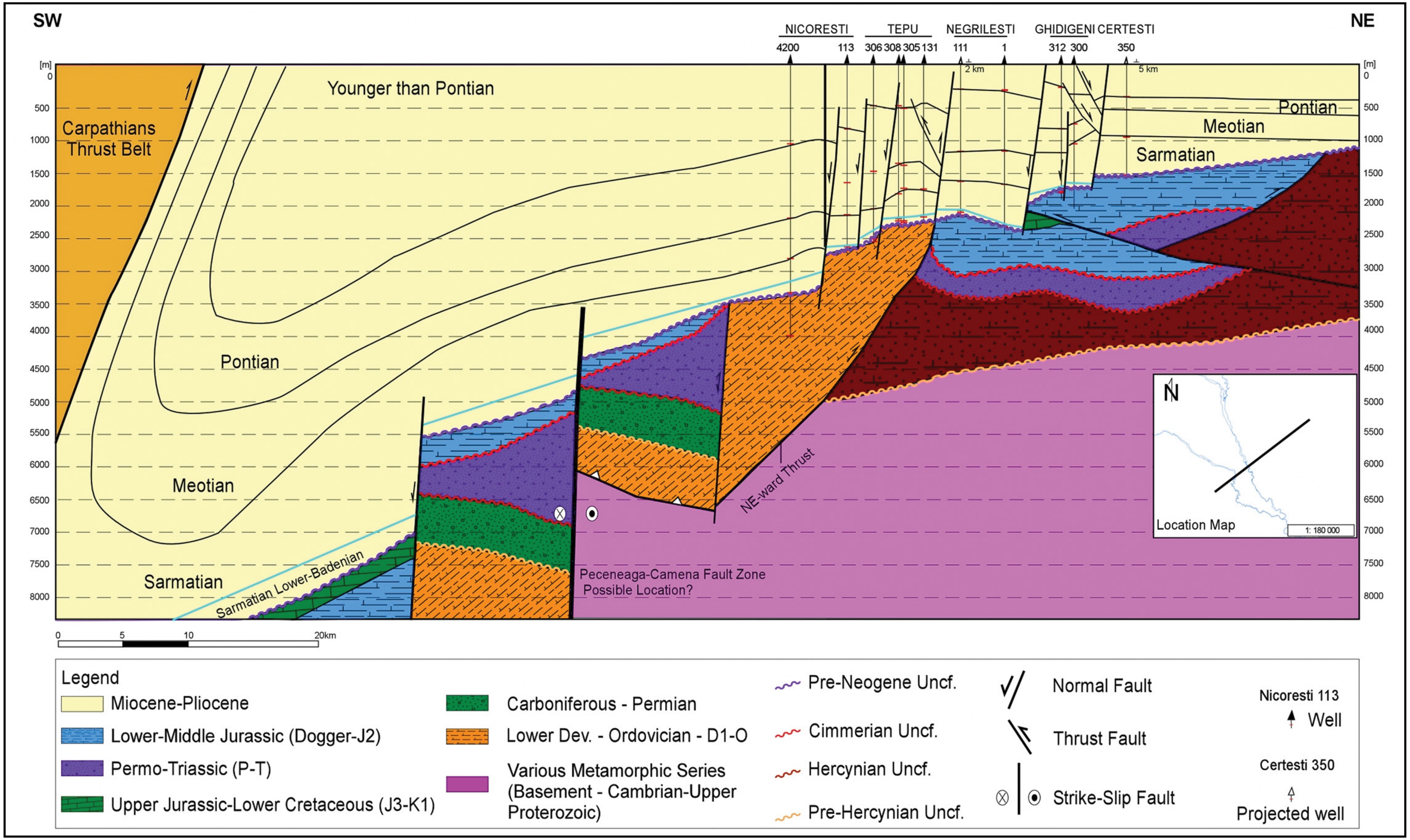

Fig. 8. SW-NE geological cross-section in the ND Promontory using well data and seismic observations. Poorly constrained geology below the PNU.

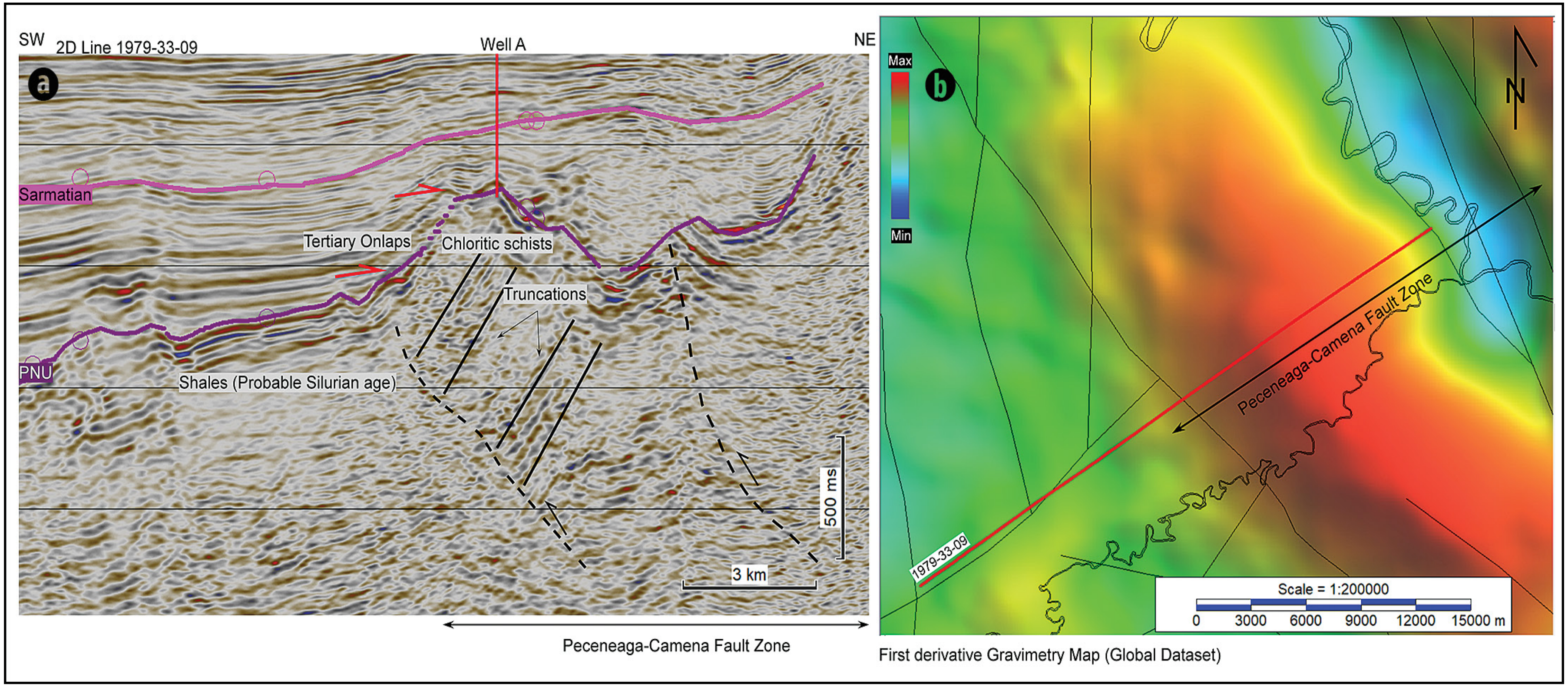

Fig. 9. Subsurface image of Peceneaga-Camena Fault Zone. (**a**) 2D seismic line acquired in 1979; (**b**) location of the section on the gravity map (global dataset).

A slightly different geological model can be inffered by using mostly the well data (Fig. 8), suggesting only one thrust fault going north-eastward. The contact between the orogen and the Bârlad basin is considered to have been the Sf. Gheorghe Fault (in this case a thrust fault, Cimmerian in age, NE orientation). Probably the tectonic scenario shown in figures 7 and 8 might be improved, if more drilling and sesimics data will be acquired.

In the North Dobrogea Promontory, the pre-Neogene subcrop map shows the Permo-Triassic intercepted in several wells (*i.e.*, Fundeni and Drăgăneşti), comprising microconglomerates and siliceous sandstones, dipping 20-30 degrees. The clastic lithology was ascribed to the Carapelit Formation; its age was variously interpreted as Carboniferous (Paraschiv *et al.*, 1983a, 1983b), or Upper Carboniferous-Lower Permian (Seghedi & Oaie, 1984, 1996; Roşca *et al.*, 1995). Considering the lithologies encountered in Suraia wells, drilled in the 1980s, iron-stained calcareous sandstones and arkosic sandstones, deposited in a possible fluvio-deltaic environment, the area might have been part of the Permo-Triassic extension which affected the Moesian area and Bârlad Depression, rather than being part of the Carapelit Formation.

The Peceneaga-Camena Fault is considered the boundary which separated the East Moesia from the North Dobrogea Orogen and is considered to have played an important role in setting up the paleo-topography for the pre-Neogene. The fault has been identified in outcrop (Grădinaru, 1988), but very little evidence exists for it in the subsurface. It is difficult to point out if the Tornquist-Teyssere Suture Zone is this fault zone or not, as it considered to have had a larger impact between two Lower Paleozoic terranes (Avalonia and Baltica), implying a displacement of 500 km (Winchester *et al.*, 2006, Oczlon *et al.*, 2010). The location of the fault in the study area has not been identified on seismics.

In the study area, the zone which reflects the projection of the Peceneaga-Camena fault in the northwest, represented by a positive anomaly on the gravity map, on seismic only some possible thrust faults can be inferred based on seismic character and few well penetrations, covered by the regional pre-Tertiary unconformity.

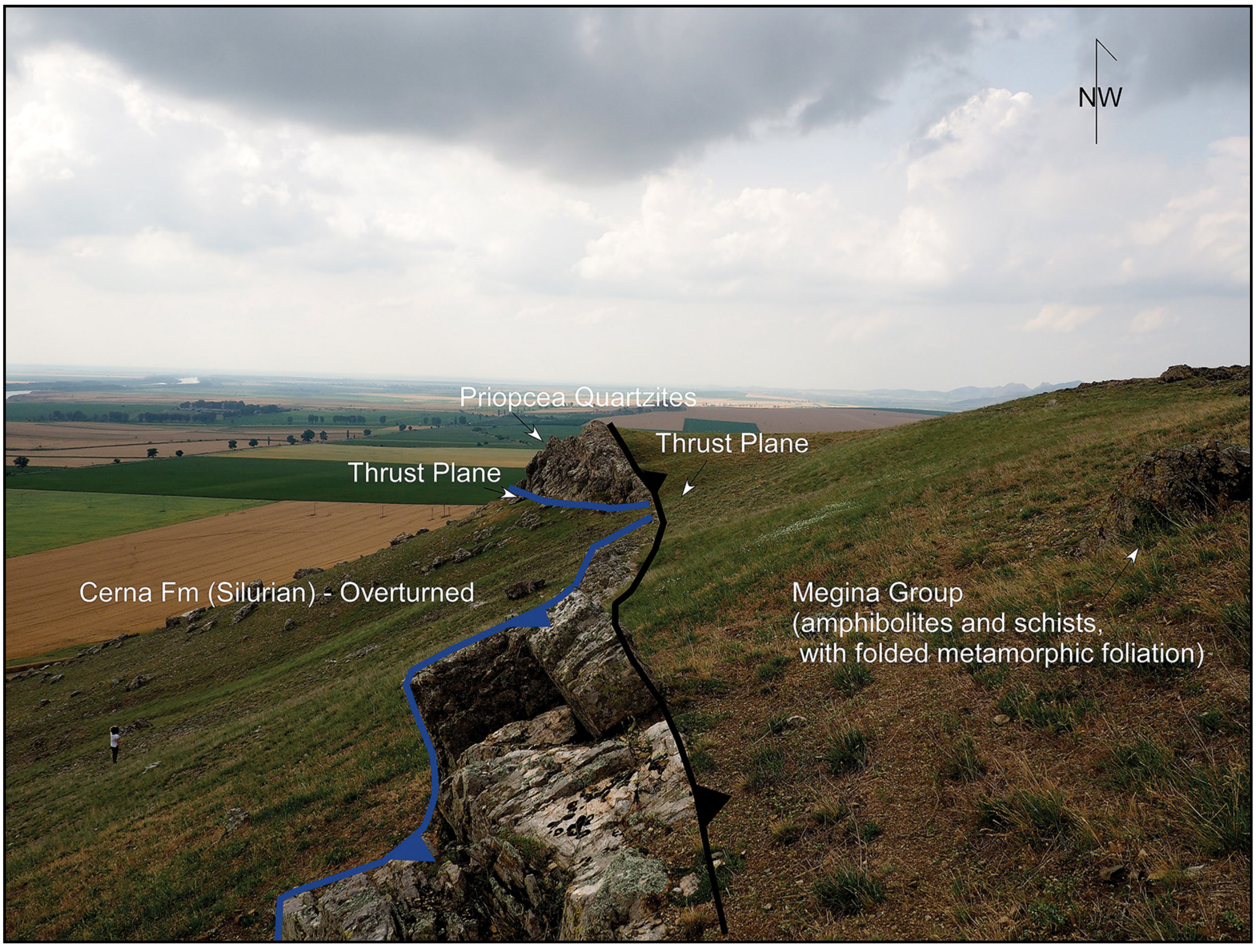

Fig. 10. Overturned Silurian beds in Priopcea Hill, overthrusted by Priopcea Quartzites and Megina amphibolites and schists, Nord Dobrogea Orogen.

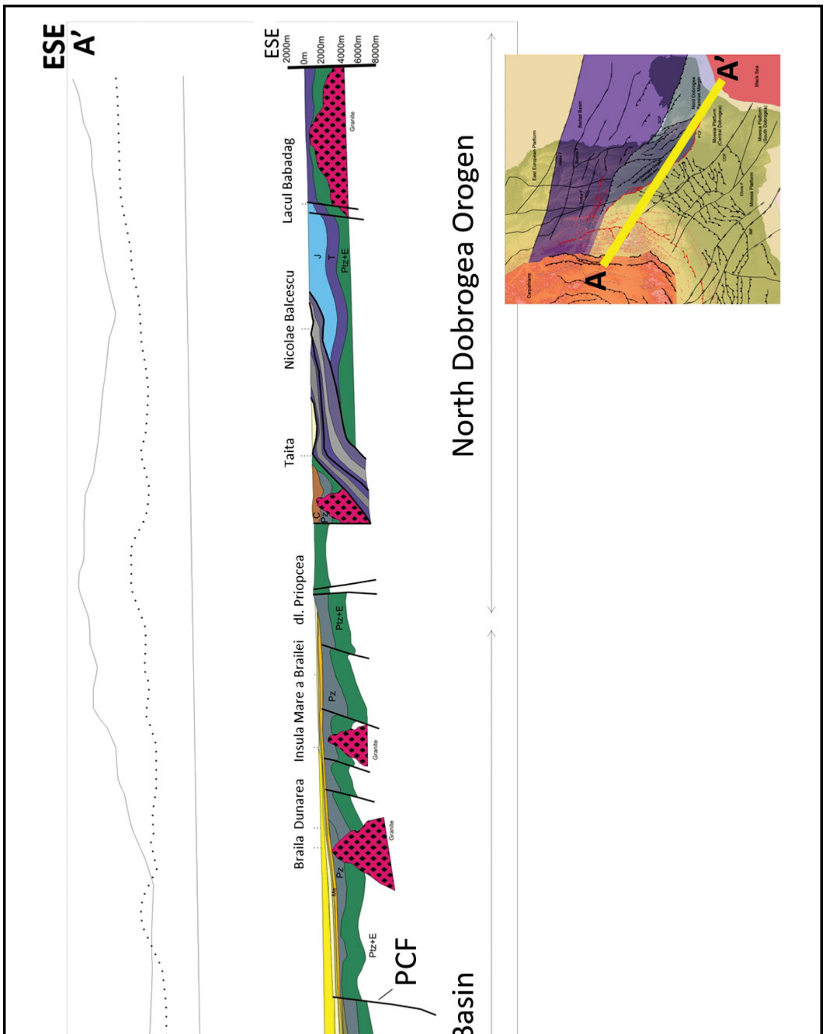

Fig. 11. Geological cross-section in the Carpathian Foreland modified after Stefanescu *et al.*, 1986. *Abbreviations*: Ptz+E, Proterozoic-Early Paleozoic; Pz, Paleozoic; C, Carboniferous; T, Triassic; J, Jurassic; J3, Upper Jurassic; K, Cretaceous, Bd, Badenian; Sm, Sarmatian; Me, Meotian; Po, Pontian; Da, Dacian; Ro, Romanian.

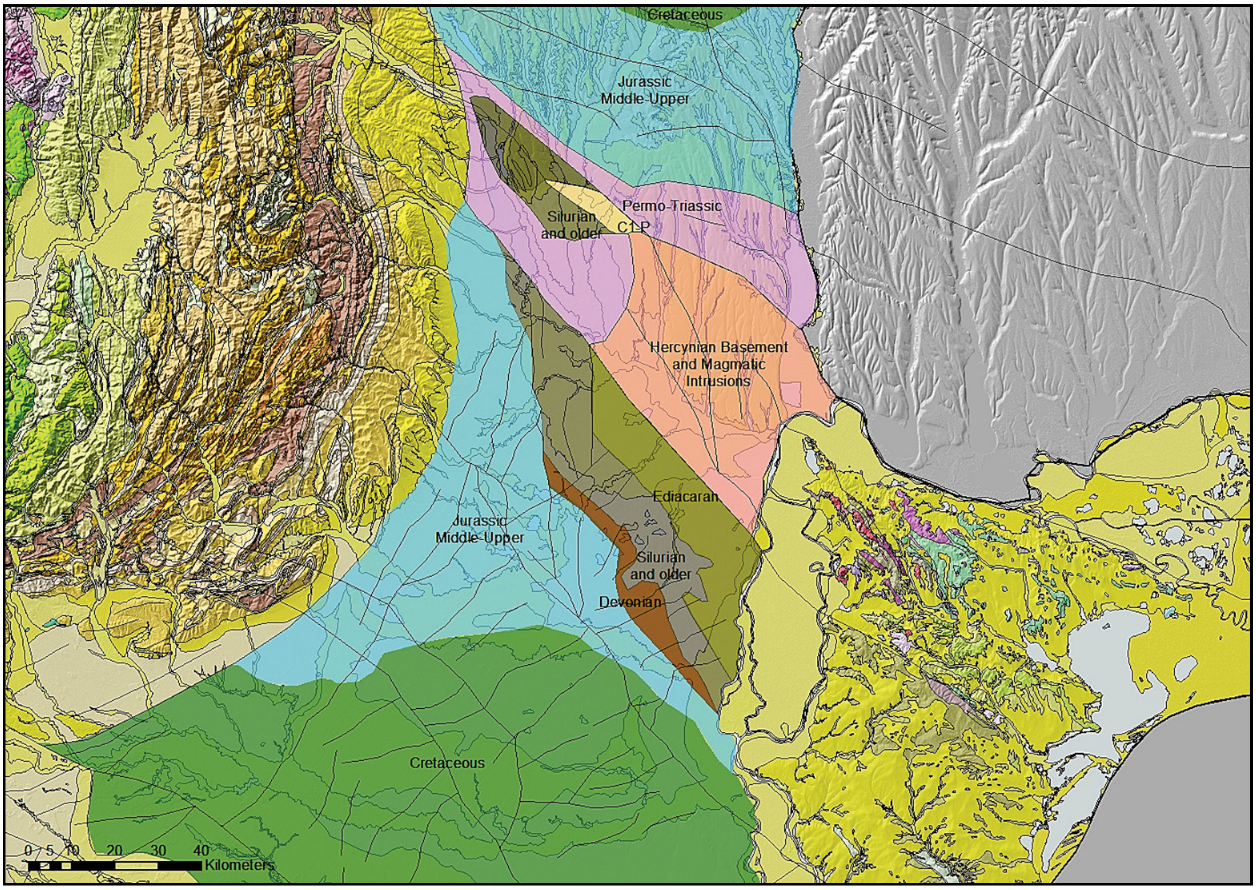

Fig. 12. Pre-Tertiary subcrop map of the geological units situated in the E-SE and S of the Eastern Carpathians, only for the studied area; continued with surface geology (Săndulescu *et al.*, 1978).

Similar thrusts are visible at outcrop in Priopcea hill (Fig. 10), where the Pre-Silurian metamorphic basement is overthrusted over the Silurian (Cerna Fm), considered to be overturned (Mirăuță *et al.*, 1962). There is decent outcrop exposure available in Măcin Mountains, where the relationship can be measured, and the two units are available for sampling.

Based on drilling data, Ştefănescu and Polonic (1988) published a set of geological cross sections on the Romanian territory, crossing the orogen and platform structures. One of these cross-sections traversed, at its SE end, the Focşani Basin, the North Dobrogea orogen and the Babadag basin. The geological features in the cross section from figure 11 are considerably simplified, highlighting only major features, such as folded Paleozoic successions or granite intrusions, with undifferentiated basement.

Within the study area, the main conclusion would be that what is subcropping under the pre-Neogene unconformity would be inline with what we have identified in our dataset and in other publications, although at a different resolution. For instance, the North Dobrogea Orogen seems to have acted act as a large high relief feature with long periods of non-deposition both in outcrops and in the promontory. Granites (pre-Permian and Permian) play an important role in thermally metamorphosing the Lower and Upper Paleozoic successions in outcrops, but we did not observed the same effect in the promontory, suggesting either less magmatism to the north-west, or not enough data.

By using all available data, we have generated a large scale subcrop map for the pre-Neogene unconformity, which at this scale shows that most of the erosion associated with the unconformity is lying in the central part of the foreland, where the Cimmerian orogen lies. The latest deformation of the orogen is considered to be Late Triassic-Lower Jurassic in age, on a north-eastward direction. Prior to this deformation, possibly the „orogen" behaved as a horst during the Permo-Triassic extension.

5. CONCLUSIONS

In the studied area, the long-term exhumation has led to the erosion of a significant pile of sediments, covering at least 35 Ma, since the Carpathians orogen has begun weighting on the nearby pre-existing basins. The area has been exposed for long intervals of time and has suffered significant erosion or non-deposition at the end of the Paleozoic (Variscan Orogeny) and/or end of the Triassic through Early Jurassic (Cimmerian Orogeny). Our data indicate that the Cretaceous deposits have been preserved throughout the area, being truncated towards the East, additionally, towards W, the Paleocene sediments are preserved as well.

In the Scythian Platform (the Bârlad Depression), the Cretaceous sedimentation dominates the northern part, suggesting a decreased exposure to surface in comparison with the rest of the basin, where Jurassic and Triassic strata are directly truncated by the pre-Neogene unconformity.

This feature is linked to the presence of the North Dobrogea Promontory and its younger deformations during Jurassic and Cretaceous which led to local uplifting. The Triassic sedimentation seems to be present on the flanks of the promontory, which possibly acted as a horst during the Permo-Triassic extension, bounded by normal faults, which later were reversed, as younger compression affected the area. The NE oriented thrust faults, which can be seen in both outcrop and subsurface seismics, might be assigned to a „Cimmerian" age or even younger.

In the southern extremity of the studied area, our data indicate that during post-Cretaceous times the Moesian Platform shows a significant response in relationship with the eastward migrating orogen. We assume that the Moesian Platform was exposed significantly during the Paleogene, considering the lack of sediments during this time; hence, the pre-Neogene unconformity cuts a significant pile of sediments, getting down to the Ediacaran basement in its eastermost part (Movila Miresei Depression).

Moreover, we identified large paleo-valleys that seem to have formed during the subaerial exposure, which started possibly at the end of the Cretaceous. The data acquired from some wells show a basement at the eastern edge of the platform, and a younger deposition towards W, in a step like manner. The rise of the area seems to be similar with what we observe in the North Dobrogea Promontory, where most of Mesozoic and Paleozoic deposits have been eroded; consequently, the Neogene sediments are directly overlying the basement.

During the latest Miocene to earliest Pliocene (Meotian-Pontian) times, the Moesian Platform began to be structurally affected by the loading of the orogen, and large normal faults broke apart the platform in a step like manner. Most of the younger faults reactivated weak zones, which pre-existed even since the Paleozoic. The largest intensity of the tectonics was probably produced during the Late Neogene.

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