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GEONOMY

STANDARD SOURCE ROCKS in THE ROMANIAN PETROLEUM SYSTEMS – AN OVERVIEW

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Accepted June 29, 2016

The discussed types of source rocks were classified through their properties (thickness, types, mineral composition, depositional system, organofacies) in a time interval between the Cambrian-Ordovician and the Sarmatian.
The quality of these rocks (formations) is different as a result of the original organic matter content of the depositional systems in which they accumulated, but also as a result of the historic process through which the primary sediments were buried.
The values of the analyzed parameters express also the different geotectonic position (in orogenic units, in the Carpathian foreland and/or in their back arc) in which such formations occur.
Overall, the hydrocarbon generating potential of the source rocks appears The source rocks of a given petroleum system are the key element in assessing the hydrocarbons potential of a petroleum structure.
The organogenic properties defining the source rocks' quality and maturity were reassessed through new RockEval analyses (TOC, Ro, Tmax, kerogen) and through the interpretation of earlier analyses.
We have studied the geological formations from the folded belt of the Eastern Carpathians (the Flysch Basin), the Carpathian foreland (the Moesia, Scythia basins), and the back arc units (the Transylvanian Basin, the Pannonian Basin).
favourable and higher in the deep sectors of the Carpathian orogen and at the Paleozoic level in the foreland area.

Keywords: petroleum system, source rocks, orogen, foreland, Carpathians.

INTRODUCTION

The geological evolution of the sedimentary basins within the Carpathian-Danubian-Pontic area during the Phanerozoic created the circumstances necessary for the accumulation of hydrocarbon generating organic substances, their maturation, through successive burial, their migration towards clastic and carbonate **reservoirs** capable to trap the oil and natural gas under impermeable **screens**. The regular tectonic movements completed the sequences' architecture and the relationship between formations generating the **traps** necessary for the creation of an exploitable petroleum structure.

The petroleum systems thus generated, having different characteristics depending on the respective geological ages, are located in a single geostructural unit, *i.e. the folded orogen*, *the Carpathian foreland*, or *the back arc areas*, but sometimes they may traverse different units (from the Flysch Basin into the Getic Basin, or from the Molassic Basin into the Getic Basin, or from Easterm Moesia into Western Moesia, etc.)[27].

The primary basins in which generating muds – the future source rocks – built up had an euxinic character and were dominated by a negative redox potential. The progressive burial under the covering pile of sediments created the conditions for the diagenesis of the accumulated organic substances (*biopolymers* like proteins, carbohydrates, lipids, and lignin) and their transformation into *biomonomers* (peptids, aminoacids, sugars, phenols) which, by condensation and polymerization, turn into *geopolymers* (hydrocarbons, kerogen).

The geological formations having such evolution display sedimentary sequences with characteristics specific to the hydrocarbon *source* (mother) *rocks*.

THE GEOTECTONIC AND DEPOSITIONAL FRAMEWORK

The geotectonic re-systematization attempts of the Carpathian-Danubian-Pontic area led to the separation of three megaunits: the orogenic folded belts (*Foldbelt Units*), the platform units at the front of the folded belts (*Foreland Units*), and the units at the back of some magmatic arcs (*Tertiary Back-Arc Units*)[27,19] (Fig. 1).

Within ***the folded belts***, with thrust sheets, the accumulation and maturation conditions of hydrocarbons were met in the Eastern Carpathians (Moldavides) and in the Cretaceous Flysch Province, the Paleogeneous Flysch Province and the Trans-Carpathian Province, respectively[23,34]. Deep-sea depositional systems, with turbidite, slope and abyssal plain subsystems, were laid down in all the basins within the mentioned provinces.

In the ***Carpathian foreland***, the Moldavian, Scythian (Bârlad), Northern-Dobruja and Moesian (Moesia) Provinces can be separated and delimited by the Carpathian foredeep, the Eastern European Platform and the Balkans. The sedimentary basins within such provinces evolved from the Paleozoic into the Sarmatian with depositional systems, from basinal depocenters to slope sectors, delta fronts, and delta plains.

The occurrence of a posttectonic regime starting from the Middle-Late Sarmatian entailed the activation of sedimentation at the back of the magmatic arcs, in the ***Tertiary Back-Arc Basins***, where the Transylvania, Pannonia, and Maramureş Provinces can be individualized.

Outside the Carpathian arc and also under a posttectonic regime the Dacian, Focşani and Hystria Provinces to the west of the Black Sea were formed. Within the petroleum basins hosted by such provinces, the depositional systems varied from shallow water, delta, even river-delta, and lake ones (Table 1).

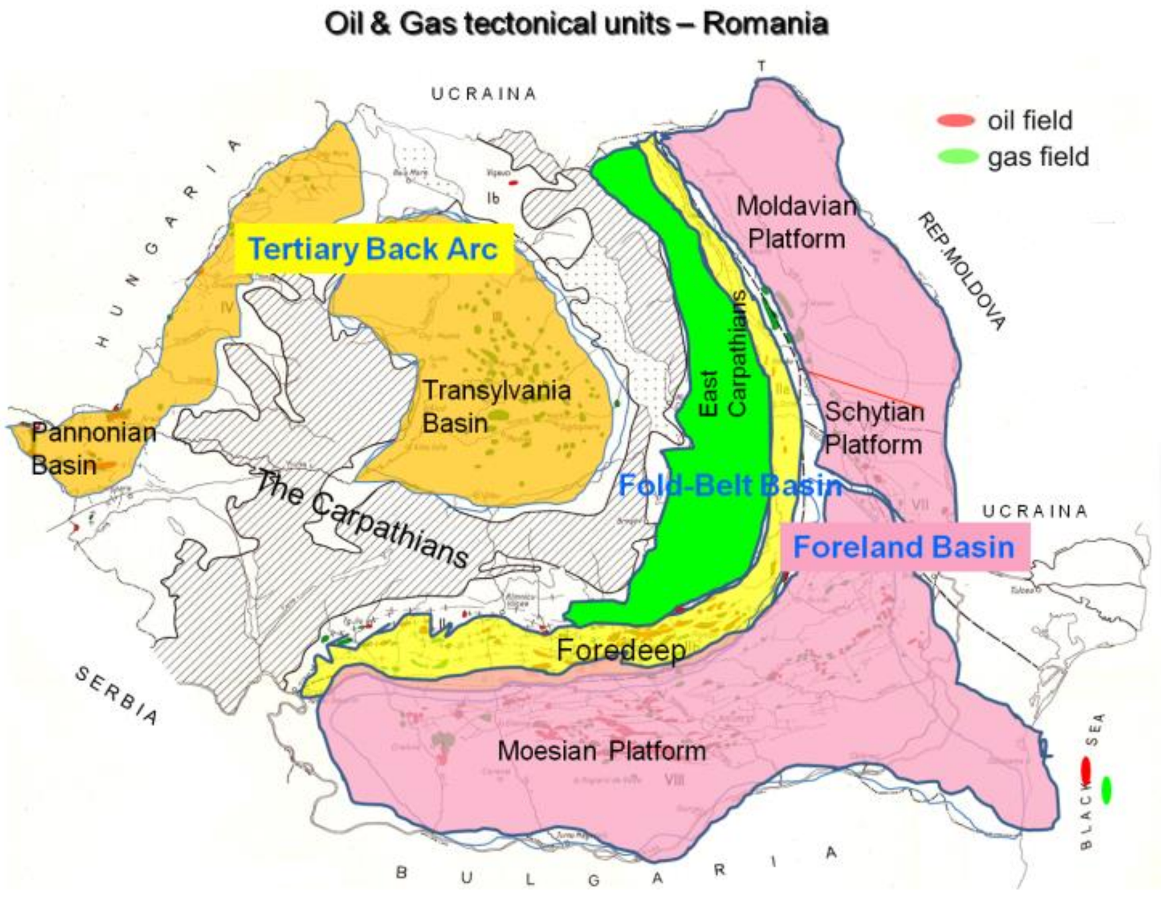

Fig. 1. Major tectonic units within the Carpathian-Danubian area.
(Adapted from[24, 27]; Paraschiv, 1975; Popescu, 1995).

Table 1

Petroleum provinces in the Romanian geotectonic units; age and thickness of the source rock formations

		Foldbelt Unit	Foreland Units				Tertiary Back Arc Units	
Provinces →		**East Carpathians**	**Moldavia**	**Scythia**	**Moesia**	**Getica**	**Transylvania**	**Pannonia**
Period	**mil. y.**							
Pliocene	5							
Miocene	23						**1200**	**250**
Oligocene	33	**200**				**180**	**60**	
Eocene	55					**150**		
Paleocene	65							
Cretaceous	145	**600**						
Jurassic	199			**1500**				
Triassic	251							
Permian	299							
Carboniferous	359				**800**			
Devonian	416			**60**	**2500**			
Silurian	439		**1200**	**100**				
Ordovician	488				**1200**			
Cambrian	542		**130**					
Ptz	2500							

SPECIFIC ROCK TYPES – REFERENCE SYSTEMS

The distinguishing characteristics of the source rocks – as a distinctive part of a petroleum system – *i.e.* the clast grain size, mineralogical, petrographic, microstructural and geochemical (organofacies) properties defining them display very close values for these parameters.

From the *clast grain size* standpoint, they correspond to lutites and silts (clasts smaller than 0.063 mm), being fine rocks.

Their mineralogical composition is dominated by the abundance of clay minerals (hydromica, smectite, candite – in varying proportions), chlorite, sericite, quartzite (or opal and chalcedony), of feldspar, pyrite, and calcite as main minerals.

The *petrography* of the source rocks is defined by the mineralogical composition and is apparent from the percentage variations of the clay minerals against silica and carbonates. According to the *Scolari*, *Lille* diagram (Fig. 2), the main specific rock types are: the shale, the marl, the silicolithe, the carbonate micrite and the corresponding transitional terms, *i.e.* the calcareous shale, the clay–limestone, the siliceous clay, the clay silicolithe. If the clay's and marl's diagenesis level is advanced, the rocks crumble easily and tend to foliate and turn into *argillite* (*slate*). Even if frequently used, terms such as *black shale*, *black schist*, or *dysodile* do not fit into the international petrographic nomenclature; they convey no information on the systematic position, composition, etc.

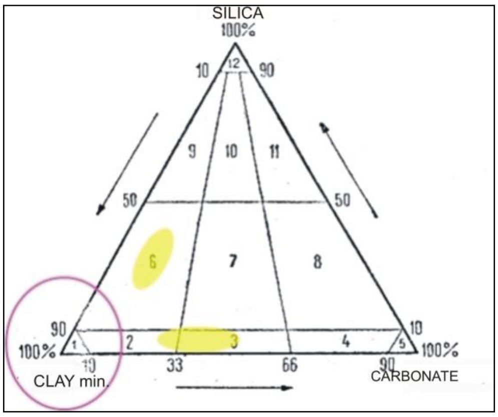

Fig. 2. The nomenclature of the hybrid rocks from the *silica-clay-carbonates* triad:
1. clay; 2. calcareous clay; 3. marl; 4. clay limestone; 5. limestone; 6. siliceous clay; 7. siliceous marl; 8. siliceous limestone; 9. clay silica; 10. marly silica; 11. calcareous silica; 12. Silica rocks (adapted from [35]; Scolari, Lille, 1973).

The *microstructure* of the source rocks can be massive, unorganized, if the original sediments were mud flows, or, most frequently, there can be a parallel, rhythmic micro stratification, generated by the sequence of the lutite-silt, clay-marl, clay-silicolithe, silicolithe-marl micro-couples. They always signify a microcyclical sedimentation.

They are rocks with a variable, sometimes high, porosity, but with a very low permeability.

Colours grey and black of these rocks are most of the times due to the presence or abundance of organic matter in various stages of evolution. Colours yellow and/or red are often postdepositional and reflect the degree of oxidation that affected these rocks.

The *organofacies* of the source rocks – with a high bituminous character – or the geochemical parameters that explain the hydrocarbon generating potential of these rocks are: the organic matter (%), the type of bitumen (A, B), Total Organic Carbon-TOC %, Ro (%) – vitrinite reflectance, HI – hydrogen index, OI – oxygen index, – the thermal maturity, the type of kerogen, the thermal alteration index (TAI), the conodont color (CAI).

THE CARPATHIAN FLYSCH PROVINCE – FORMATIONS AND AGES

The petroleum systems of the folded belts (**Foldbelt Units**), separated in the *Flysch Province*, include source rocks from the Cretaceuos (from the internal Moldavids– in the Teleajen nappe – Hauterivian-Barremian, and the Audia nappe – Valanginian-Albian) and from the Paleogene (from the external Moldavides – in the Tarcău nappe and the Marginal folds nappe – of Vrancea (Latorfian-Rupelian).

SOURCE ROCKS FROM THE CRETACEOUS, THE INTERNAL FLYSCH BASIN

Within the Teleajen nappe, the Plaegi and Toroclej were separated – Hauterivian-Barremian-Apţian, with shale and sandy shale in the basinal facies[38, 21, 27.]

Within the Audia Formation (equivalent of the Black schist area or the Audia layers), having a longitudinal extension of over 300 km between Covasna and Romania's northern border, and a variable thickness (600–700 m), the source rocks belong to the Median Member, with *lidiens* [6,11] and are identified with the black schists – bituminous argillite, microlayered silicolithe, and bituminous micrite with a strong lithification.

The depositional facies are variable and alternative, from basinal facies with pelagic depositions (suspensions) to turbiditic facies (lobe fringe type) from low density currents[19, 20,32].

SOURCE ROCKS FROM THE PALEOGENE, THE EXTERNAL FLYSCH BASIN

At the Oligocene level, the bituminous clastic sequences with source rock properties correspond to the inferior Menilite Formations (20–40 m thick), Bituminous (brown) marl (40–60 m thick), and to the inferior Dysodile Formation (250–300 m thick) . These formations stretch along the basin from the Prahova Valley–Teleajen to the north of the Moldova Valley. The specific rock types are: the bituminous silicolithe (menilite), marl and clay limestone, black argillite, siltite, bituminous argillite (dysodile), sideritic limestone[22, 24].

Mineralogy: clay minerals (illite, kaolinite – 33–48%), feldspar (2–6%), carbonate (0.0–17%), chlorite (0.0–16%), pyrite (0.0–10%)[14,15].

The depositional system: mixed turbidite system (clay-sandy, the *Richards and Reading* terminology, 1996) – architectural element levee or basinal plain (Fig. 3)[2, 30].

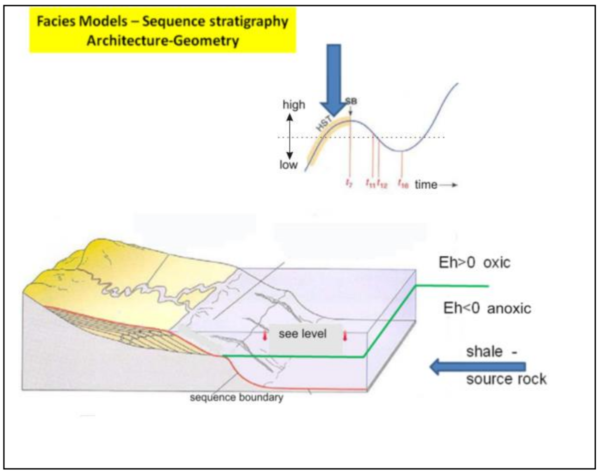

Fig. 3. The facies model for the Flysch Province.

The organogenic potential of the source rocks from the Flysch Province – the Cretaceous-Paleogene petroleum system.

In the Cretaceous petroleum system, the main organogenic parameters of the source rocks are:

Organic matter (C_{org}): 0.30 – 0.84% [6]
Bitumen A: 0.10 – 0.16% [6]

TOC (%): 0.25%; 1.23 – 1.31% [3, 1, 4]
Vitrinite reflectance (Ro%): 0.98 – 1.14 % [3]
Tmax: 425^{o}C Kerogen: I – II, mature in the oil window

At the Paleogene level, two petroleum sub-systems were identified (Moineşti and Târgovişte)[27], in which the source rock formations have identical characteristics, even if their toponyms are different, that is: Aluniş bituminous argillites (which have to be equated to the inferior menilite, the bituminous marl and the inferior dysodile) and the Pucioasa shale (equated to the inferior dysodile).

The organogenic parameters of the bituminous marl are:

Organic matter: 3.54 – 10.04 % [14]
Bitumen A: 0.25 – 0.40% [6,7]
TOC (%): 2.92 – 4.73[3]
Tmax: 425 – 427^{o}C [3]
Vitrinite reflectance (Ro%): 0.47 – 0.65 % [3, 4]
Kerogen: I, marginally mature [3]

For the inferior dysodile:

Organic matter: 2.00 – 30.76% [14]
(C_{org}): 0.35 – 2.5%, [6,7]
Bitumen A: 0.16 – 1.96% [14]
TOC (%): 0.8 – 4.1%; 2.03 – 10.90% [3]
Tmax: 407 – 422^{o}C
Vitrinite reflectance (Ro%): 1.10 – 1.15 %; 0.57% [3, 4]
Kerogen: I – II (oil prone)

From the standpoint of the content in **organic matter**, the maximum values of the Audia Formation and Dysodile Formation (including both the inferior dysodile and the superior one) render them have an oil- and gas-generating potential. The large difference between the maximum and the minimum in the case of the Audia Formation must be explained through the dillution of some samples, generated by the small thickness of the laminae concomitantly with an increase in the frequency of some microarenitic and clastic lithones rich in silicate.

The values of the **Total Organic Carbon** (TOC) are situated beyond the interest limit in relation to the classic standards of the argillite only in the case of the Menilitic Formation (TOC = 6.64), of the bituminous marl formations (TOC = 12.69), and of the dysodile formations (where TOC reaches the significant value of 17.62%)[6,7]. The large differences, in the case of the dysodile, between a minimum (0.82) and a maximum (17.62), suggest the lack of homogeneity of the sequences and the diversity of the rhytms which make up the formation in its entirety. These differences will render more difficult the evaluation of the oil- and gas-generating potential and, implicitly, a possible calculation of the reserves (Fig. 4).

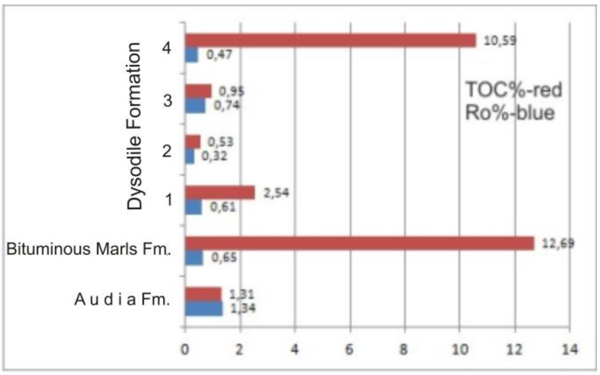

Fig. 4. The TOC (%) and Ro (%) values for the source rock formations from the Flysch Province, the Eastern Carpathians.

The condition for the **maturation of the organic substances** and the entry of the sediments in the dry-gas window is given by temperatures higher than 420–430 ^{o}C. In the Eastern Carpathians these temperatures were reached by the Audia, Podu Secu, menilite, brown marl and dysodile formations. The degree of maturity in all these cases varies from under-mature to mature (Fig. 5).

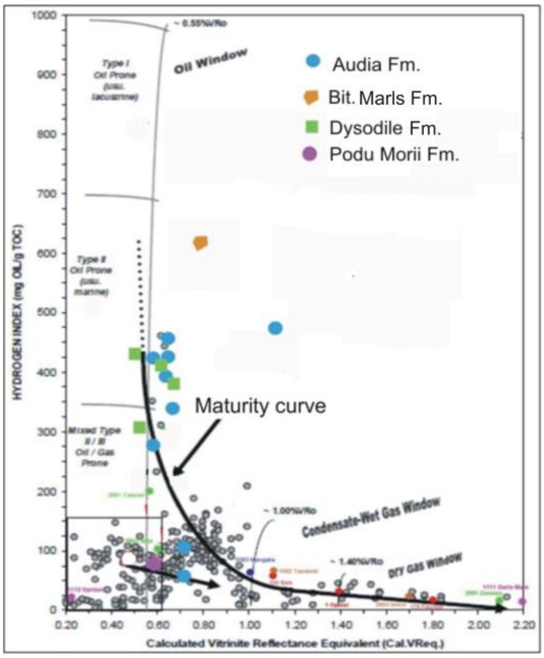

Fig. 5. Projection of the IH/Ro values for the source rocks from the Flysch Province in relation to the Barnett standards (the grey points) (source of the RockEval data[3, 4]: Anastasiu *et al*., 2011).

THE TRANSCARPATHIAN BASIN

The Transcarpathian Basin or the Maramureş Basin is surrounded by the internal Dacides (Internide–Apusenide, part of the pre-Apulian continental block) and the Tethysian Suture (MTS) to the west, and by the median Dacides (the crystalline Mesozoic area of the Eastern Carpathians or the Central-Eastern Carpathian Unit) to the east (Fig. 6).

The petroleum system associated with this basin includes source rocks from the ***Valea Carelor Formation*** (with the inferior bituminous series and *Valea Vinului – Beca marl series*, 1983) ***Valea Morii Formation*** (Oligocene-Rupelian), both in a marly-bituminous facies (Ileanda Mare type), which outcrops on both sides of the Bogdan Vodă Fault. They may be considered hydrocarbon **source rocks**, in spite of the massive structofacies which often has a slump character[5,8].

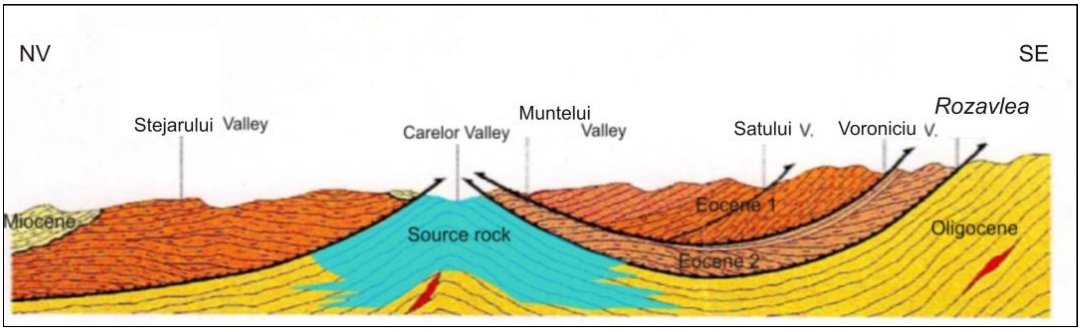

Fig. 6. Cross-section through the Pienides Area, the Transcarpathian province.
(Adapted from[5]; Aroldi, 2001).

Along with the marly facies sporadically and in disarray appear dysodile, ankerite and evaporitic facies, suggesting an anoxic, euxinic and/or lagunar environment (?). These sequences are sometimes described as the *Inferior Bituminous Series*[8]. The specific rock types from the final terms of the Borşa Formation have a bituminous character (bituminous marl) and could themselves generate hydrocarbons.

The depositional facies are basinal, of the shallow water type, with an anoxic towards euxinic regime, accumulated in the neritic zone (the external shelf)[5].

The source rocks are found in the oil windows at depths < 3 km.

There are big chances for wells to encounter several source rock layers more than 100 m thick[18].

The main basins from the Carpathian **foreland** are the Moldavian Basin (Moldavia), the Scythian Basin (Scythia), the Northern Dobruja Basin (associated with the Northern Dobruja Promontory), and the Moesian Basin (Moesia).

THE MOLDAVIAN BASIN

In the westernmost end of the Eastern European Platform, the Moldavian Basin evolved from the west of the Dniester to the Eastern Carpathian foredeep, which is part of the Moldavian Platform geotectonic unit.

The sedimentary cycles which define the Moldavian Basin filling has a total thickness ranging from 2,500 m towards the east and 6,100 m towards the west. In the area of the Moldavian Platform, the basin appears like a western extension of the Dniester Basin, overlapping the continental edge of the Eastern European Platform (Fig. 7). Hence it was also named the Moldavia Slope [9,27].

The petroleum systems are supplied with cycle I source rocks, from the Lower Vendian, the Kalius-Dniester Formation (40–55 m), of the Lower Cambrian – the Naslavcea Formation, and from the Middle-Upper Silurian – the Rădăuţi Formation (argillite with graptolite). On the basis of thermal analyses, the mineral composition of the argillite is the following: montmorillonite (20–30%), hydromica (40–50%), chlorite (15–25%), quartz (10–15%), calcite (3–7%), dolomite (3–5%), feldspar (1–5%)[13]. At the Vendian level, the bituminous argillite reaches a 300-meter thickness. The Naslavcea Formation outcropping in the Dniester Valley belongs to the Cambrian, comprises black argillite, and is 130-meter thick in the Bătrâneşti drilling. The last sequence of source rock quality corresponds to the Rădăuţi Formation from the Middle-Upper Silurian level[13].

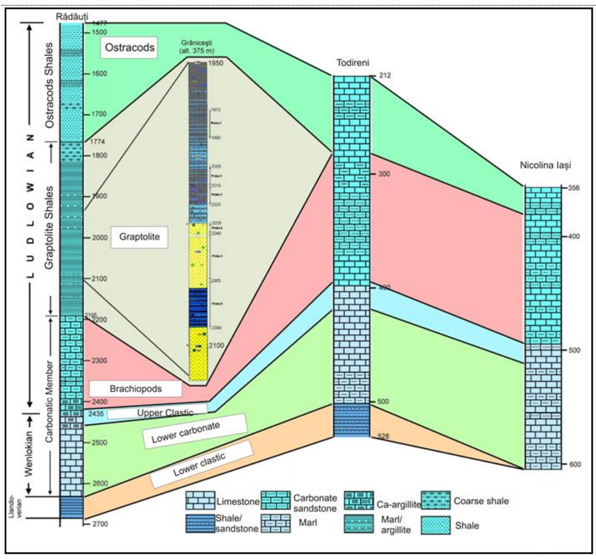

Fig. 7. Cross-section and lithologic columns on the Nicolina-Todireni-Rădăuţi alignment, Moldavia (adapted from[9,10]; Brânzilă, 1999, Cirimpei, 2009).

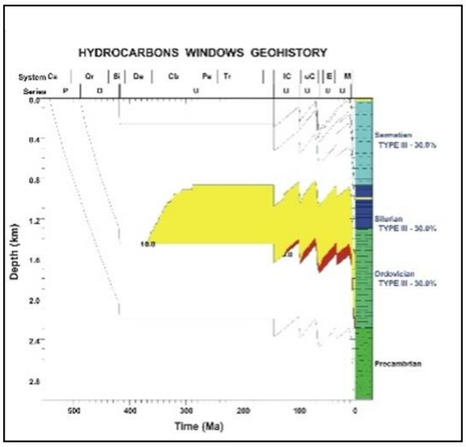

Fig. 8. History of the burial of the hydrocarbons source rocks in the Moldavian Platform, the Moldavian Basin (adapted from[13]; Francovschi, 2014).

The organogenic parameters are (Fig. 8):

Organic matter (C_{org}): 0.5 – 1.2%
TOC (%): 1 – 2% (0.24 – 0.68 % [27, 4]
Tmax: 438°C
IH: < 200
Vitrinite reflectance (Ro%): 0.7 – 2.8% [40, 4]
Kerogen: II – III

THE SCYTHIAN BASIN (BÂRLAD) AND THE NORTHERN DOBRUJA PROMONTORY

The Scythian Basin (Scythia) is bordered to the north by the Moldavian Basin through Falia Fălciu – Ivăneşti – Plopana (the Vaslui Fault) and to the south by the buried Northern Dobruja Promontory, separately by the Sf. Gheorghe – Oancea – Adjud Fault. On its turn, this promontory extends to the south down to the Peceneaga – Camena Fault and to its continuation towards the Trans-European Suture Zone (TESZ) (Fig. 9).

The sedimentary cover of the basin accumulated throughout four depositional cycles: Silurian–Devonian; Permian–Triassic; Jurassic–Cretaceous–Eocene; Badenian–Quaternary[9,10].

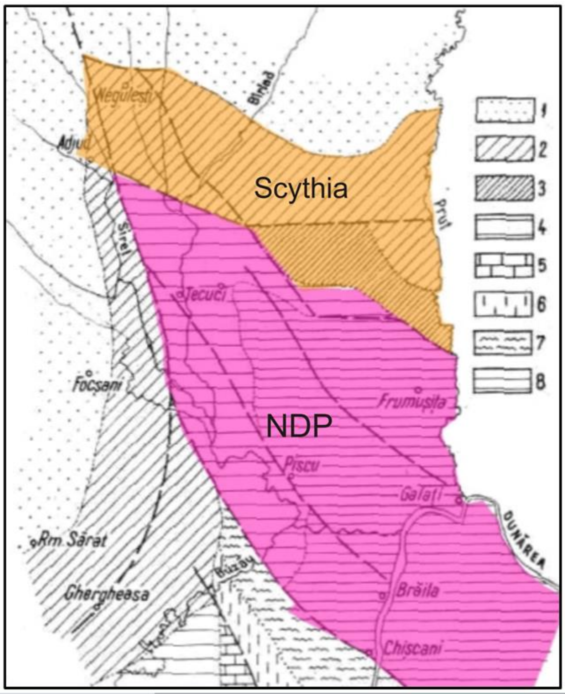

Fig. 9. The distribution of the pre-Neogene formations in the Northern Dobruja Promontory (NDP) and Scythia: 1. Cretaceous; 2. Jurassic; 3. Triassic; 4. Carboniferous; 5. Devonian; 6. Silurian; 7. green schists; 8. metamorphosed foundation.

The source rocks of the identified **petroleum systems** are the Largorin Formation (100 m thick) and the Crasna Formation (60 m thick) from the cycle I level, as well as the Mândrişca Formation (1,500 m thick) (equivalent of the Layers with *Posidonia*, the Bositra – Dogger facies) from the cycle III level. The clastic and carbonatic facies are specific to a shallow water environment, from shelf to subcontinental, lagunar [9,10].

The main rock types are siliciclastic (quartz sandstone, lithic sandstone, calcareous sandstone, red sandstone, siltite) and, more rarely, carbonatic (calcirudite, black micrite, dolomite), accumulated in subcontinental, lagunar systems.

The organogenic parameters are:

Organic matter (C_{org}): 4.25%
TOC (%): 1.0 – 2.4 [3]
Vitrinite reflectance (Ro%): 0.58 – 3.6 % [3]
Kerogen: II – III

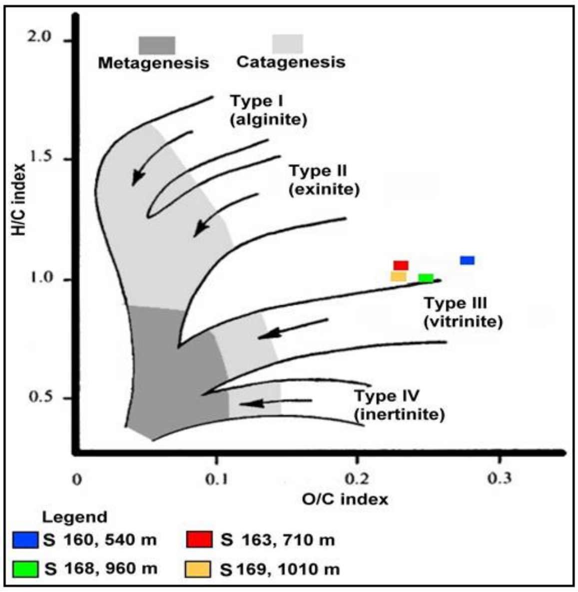

Fig. 10. The H/C – O/C chart-index of the distribution of the samples collected from the 540–1,010 m interval (drillings 160–169) in relation to the kerogen type (from *Ţabără*, 2012, in fide[3,4]; Anastasiu, 2013).

THE MOESIAN BASIN

The Moesian Platform, separated from the Carpathian units to the north by the Peri-Carpathian Fault, comes into contact with the foredeep. To the north-east, it borders the North Dobruja Promontory along the Peceneaga-Camena tectonic line, while to the east it borders the Central Dobruja Massif (Fig. 11).

The sedimentation of the Moesian Platform cover took place throughout four large cycles: Upper Cambrian-Westphalian, Permian-Triassic, Toarcian-Senonian, and Eocene. Starting from the Upper Sarmatian, the lithologic sequences were accumulated in a post-tectonic moment and belong to the Dacian Basin [3,36, 39].

The conditions that led to the formation of the source rocks that supplied the clastic and carbonatic reservoirs of the petroleum systems from the Moesian Basin were met in the I, III, and IV cycles [8,25,27]. Thus:

In **Western Moesia**, in the north-western sector, where the Râmeşti-Făureşti petroleum system[27] can be separated, the source rocks are black shales from the Dogger level; such rocks have a variable thickness, between 10 and 400 m.

The Teleorman-Dâmboviţa petroleum system, from the central-eastern end of Western Moesia is supplied from formations belonging to three depositional cycles:

At Cycle I level, there can be identified in the Cambrian-Silurian the black Hăbeşti type shale, the black argillite, and the green siltite with chlorite, with a thickness ranging from 30 to 1,200 m, in the euxinic basinal facies.

In the Devonian and Carboniferous periods, the Călăraşi Formations with dolomites and bituminous limestones reached thicknesses ranging from 800 to 2,500 meters and covered a facies with carbonatic platform with shallow waters.

In the Namurian–Westphallian interval, the Vlaşin Formation includes source rocks of the bituminous dolomite type, the thickness of which ranged from 700 to 800 m, in a shallow water, lacustrine facies.

At Cycle II level, with a low potential, the Balş Formation (Jurassic-Bajocian) includes *bituminous shale* 80 to 600 meter thick.

In Cycle IV, Eocene – Sarmatian, the Pucioasa Formation (Oligocene) from the Getic Basin is dominated by dysodile shale which is also a source rock for the Teleorman – Dâmboviţa system.

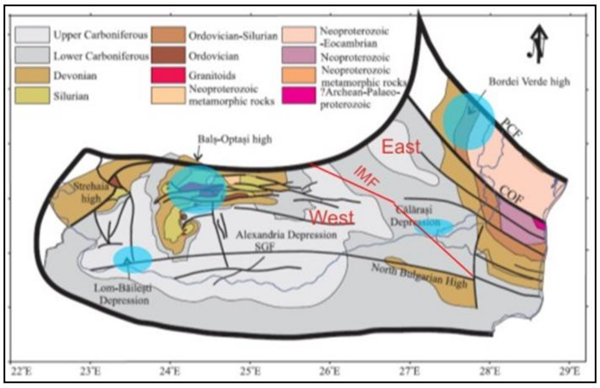

Fig. 11. Distribution of the depression areas (minibasins) and raised platforms in the Moesia space (adapted from[36]; Seghedi, 2005).

The organogenic parameters are (Fig. 12):

Organic matter: 20 – 30%
Bitumen A: 0.011 – 0.47%
C_{org}: 0.35%
TOC (%): 4.48%, 2.33%, 6.77% [3]
Vitrinite reflectance (Ro%): 1.30 – 2.75%[3]
Kerogen: I – II

In **Eastern Moesia**, to the east of the Intramoesian Fault (IMF), the source rocks of the Buzău-Ialomiţa and Călăraşi-Mangalia petroleum systems are the Ţăndărei Formation, *i.e.* argillite with graptolite (Ordovician–Silurian) (30–1,200 m thick), the Călăraşi Formation, *i.e.* bituminous limestone and marl (Upper Devonian–Upper Carbonifereous) (800–2,500 m thick), and the Balş Formation with bituminous shales (80–600 m thick)[13].

The organogenic parameters are:

C_{org}: 0.24 – 1.24%, [24]
TOC (%): 4.48% [3]
Vitrinite reflectance (Ro%): 1.2 – 2.05% [3]
Kerogen: II – III

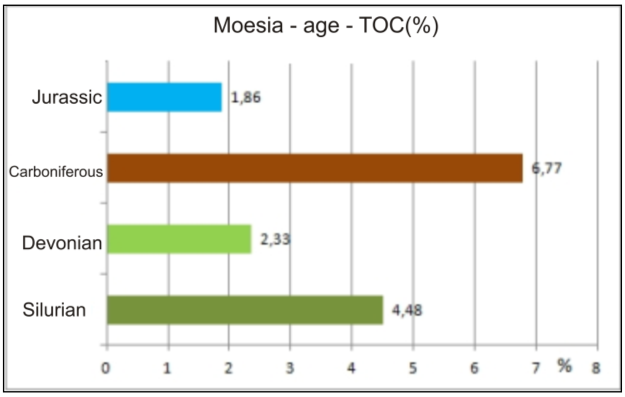

Fig. 12. TOC (%) values for the source rocks of the Silurian, Devonian, Carbonifereous and Jurassic (Dogger).

THE DACIAN BASIN

The Dacian Basin in its current meaning [16] occupies an area between the folded zones of the Southern Carpathians and the curvature of the Eastern Carpathians, to the north and north-west, and the Danube, to the south (Fig. 13). This basin can be considered a part of the Paratethys. The formations accumulated in the basin are dated from the Upper-Terminal Sarmatian (Volhinian–Kersonian) to the Romanian. Its depositions cover discordantly older formations of the Moesian Platform, of the North Dobruja Orogen, of the Scythian Platform, and of the Moldavian Platform.

The basin evolved gradually from seaside facies, with shallow waters, to lacustrine and fluvio-deltaic facies, and from brackish water to fresh water [16].

The petroleum system of the Dacian Basin includes hydrocarbon reservoirs at the Sarmatian, Meotian, and Dacian levels, and the following *source rocks*: shales and marls, bituminous siltite at the Middle and Upper Sarmatian and Pontian levels.

The occurrence of a posttectonic regime starting from the Middle-Terminal Sarmatian entailed the activation of sedimentation behind the magmatic arcs, in Tertiary Back-Arc Basins, in the Transylvania Basin, in the Pannonic Basin, and in the Maramureş Basin.

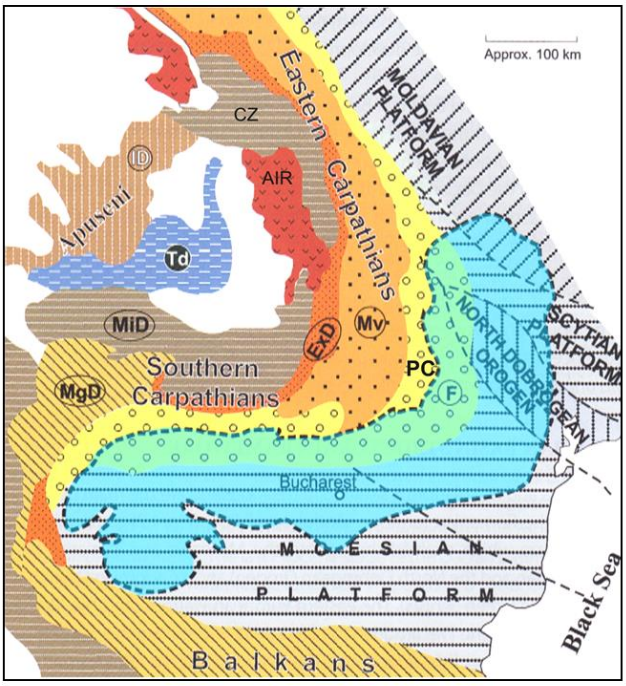

Fig. 13. Projection of the Dacian Basin (in bleu fill) in relation to Moesia, OND, Schytia and Moldavia (adapted from[16]; Jipa and Olariu, 2009); ID–Internal Dacides, TD–Transivanids, MiD–Middle Dacides, MgD–Marginal Dacides, ExD–Outer Dacides, Mv–Moldavides, F–Foredeep, AIR–Alpine igneous rocks, CZ–Crystalline Zone, PC – Peri-Carpathian Unit.

THE TRANSYLVANIA BASIN

The Transylvania Basin occupies an intra-Carpathian depression in which the sediment pile's thickness reached thousands of meters. This basin evolved as a post-Cenomanian sedimentary basin localized behind the volcano arc (*Back-Arc Basin*), considered at a certain moment in time an intra-Carpathian basin[33], and more recently[17,12], a post-evaporitic (the salty layer) molassic basin which shows similitudes with the Carpathian foreland (Fig. 14). The identified petroleum systems – biogenic and thermogenic – were separated in the Mesosic, the Upper Cretaceous-Oligocene cycle and the Badenian-Upper Miocene cycle (post-evaporitic)[17,11].

Throughout the **Paleogene**, the depression functioned as a flexural foreland basin, in which very different facies (alluvial, fluvial, deltaic, lagunar, seaside coastal fans) deposited especially towards its western and north-western ends, in the Gilău, Meseş and Preluca sectors. The source rocks are found in the Mortănuşa Formation (Bartonian – 80 m thick), the Brebi Formation (Upper Priabonian – 60 m thick), and the Ileanda Formation (Rupelian – 60 m thick) [8, 12, 24, 17].

Throughout the **Neogene**, redox negative depositional episodes with organic matter enrichment are encountered at the level of the Hida sandstone (molasse) – 1,200 m thick (Aquitanian–Burdigalian) and of the Pietroasa Formation – 1,000 m thick (Badenian)[11,12].

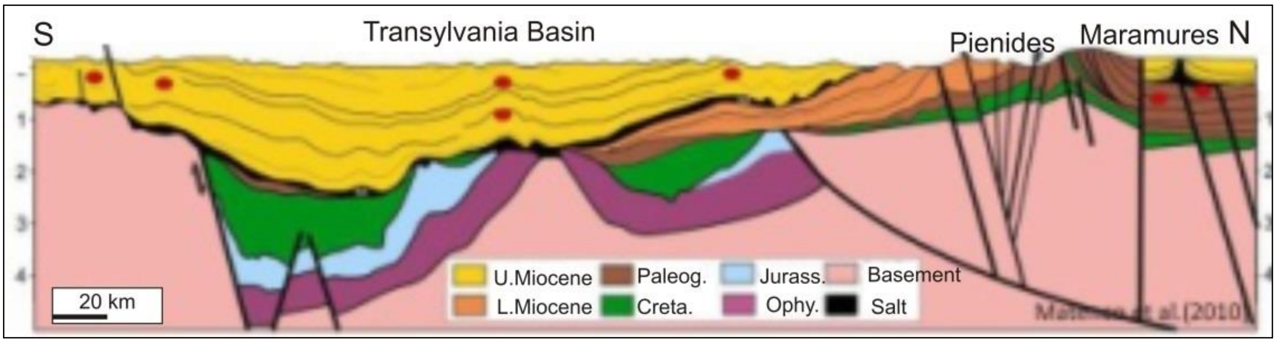

Fig. 14. Cross-section through the Transylvanian Basin; Ophy-ophyolites, Creta-Cretaceous, Paleog-Paleogene (adapted from[19]; Maţenco *et al*., 2010).

For the biogenic system, the source rocks from the Badenian–Pannonian (Pliocene) interval have the following parameters:

C_{org}: 0.5%[24]
TOC: 1 – 2%
T_{max} : 423 – 436°C
Kerogen: II and III, with thermally immature shales [27, 17]

For the thermogenic systems from the Gilău-Maramureş-Jibou Basin, the bituminous shales, marl and siltite from the Ileanda Mare Formation have the following parameters:

C_{org} : 0.2 – 4.5%[24]
TOC: 1 – 2%,
Ro: 0.4 – 1%
T_{max}: 420°C
Kerogen: I and II

THE PANNONIAN BASIN

The main sedimentary basins from the eastern end of the Pannonian Depression, with formations the thickness of which increases towards the west (Romanian-Hungarian border) are the Carei, Abrămuţ, Socodor, and Tomnatec basins (Fig. 15)[28].

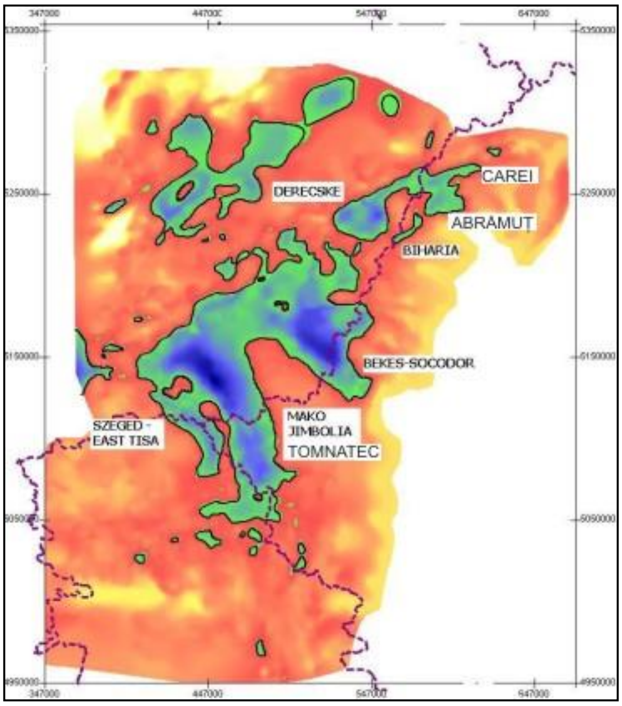

Fig. 15. The main petroleum basins from Pannonia. (Adapted from[27]; Popescu, 1995).

The source rocks of the *petroleum systems are:* shales from the Lower Cretaceous and marls and bituminous shales from the Miocene (Table 2).

The Miocene shales enter the oil window between 2,200 and 2,800 m and mature at greater depths.

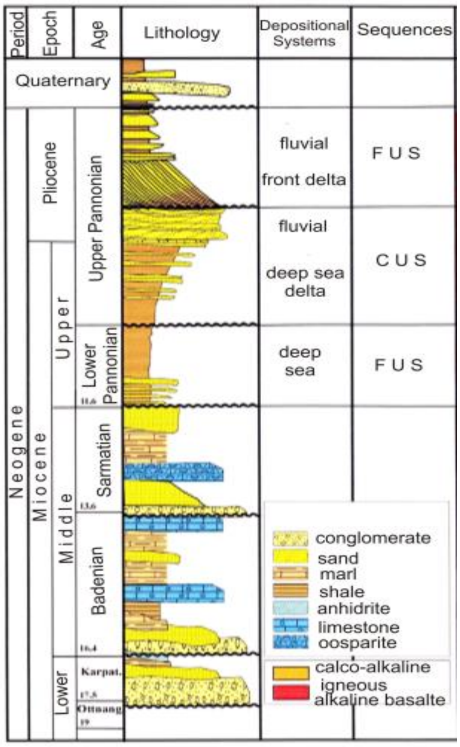

Fig. 16. The lithological column an shales d the depositional environments for the depositional sequences from Pannonia. (Adapted from[28]; Annamaria Răbăgia (2009).

Table 2

Thickness of the source rock formations from Pannonia and their organogenic parameters

Ages	Formaţiuni	Thickness (m)	TOC (%)	Tmax °C	Kerogen
Pannonian-Pontian		3000 ?? in Hungary:	TOC = 1%	Tmax = 434°C	Kerogen II–III
Ng1-Langhian	Sînnicolau de Munte Formation	600	TOC = 0.54% – – 2.26%	Tmax = 434°C – – 444°C	Kerogen II–III
Cretaceous	Căbeşti Layers	100			

THE GETIC BASIN

The petroleum basin from the southern part of the Southern Carpathians overlaps the **Getic Province** and, respectively, the deformed part of the basin which includes formations aged between Cretaceous and Sarmatian.

The boundaries of the Getic Province are the following: to the *north*, the line left by the Upper Cretaceous-Tertiary, where the sin- and postdeformational sediments cover the orogenic structures of the Southern Carpathians; to the *south*, “the Peri-Carpathian line”; to the *east*, the Intra-Moesian Fault separating this zone from the folded depositions of the Eastern Carpathians, and to the *west*, the system of loosened faults from the Jiu area (Fig. 17).

The Upper Cretaceous-Tertiary sedimentary sequences are approximately 6,000 m thick and were built up under a polyphase tectonic regime[29]. The respective basin functioned originally as a foredeep generated by compressional movements and by the relationships established between the Moesian plate and the South Carpathisn Orogene. In the Paleogene and, later, in the Miocene and the Pliocene, the basin may be considered of a *pull apart* type under a transtensional regime.

Formations with a source rock character: Oligocene

Location: outcrops on the northern frame of the Getic Province, overlapping the Orogenic–Middle Dacides nappes, between rivers Otăsău and Râul Doamnei. They were also found in drillings, in the southern area.

*Their **age*** is Eocene-Lower Burdigalian (Fig. 18).

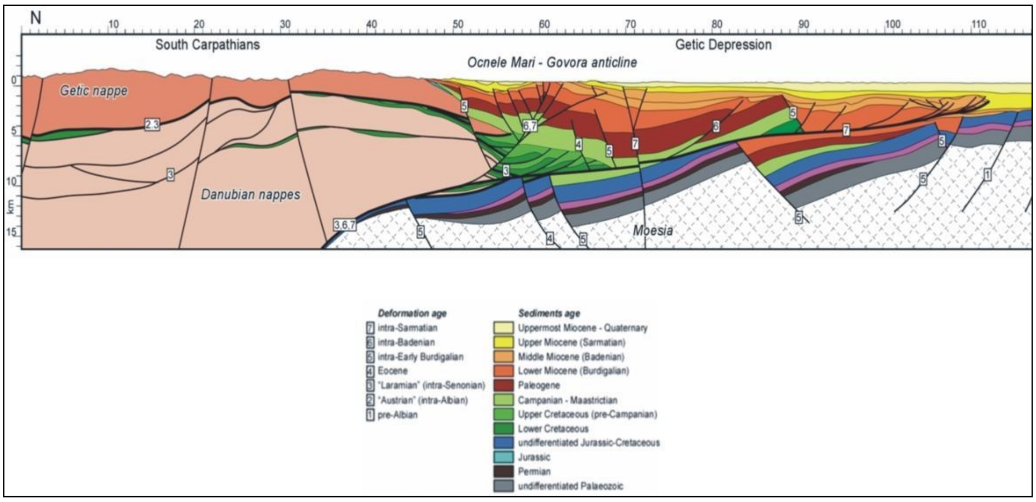

Fig. 17. Cross-section through the Getic Province. (Adapted from[19]; Mațenco *et al*., 2010).

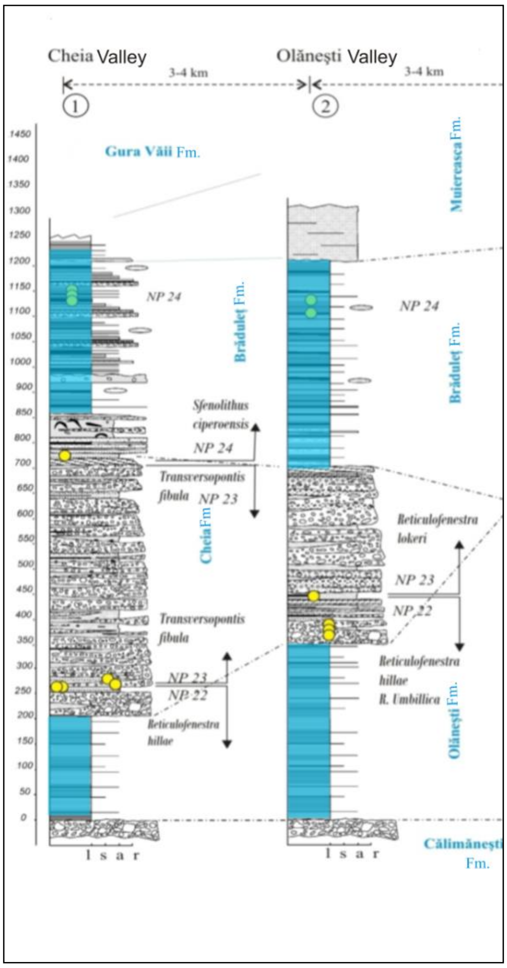

Fig. 18. The lithostratigraphy of the Brăduleț Formation (Fm.) and Olănești Formation (Fm.) from the Getic Province. (Adapted from[31]; Roban, 2008).

Oil generating potential: the shales facies of the Oligocene formations are known as hydrocarbon source rocks.

The thickness of such formations ranges from 200 to 600 m (Table 3).

Lithofacies: *The Olăneşti Formations* comprises two members: the inferior member with a maximum thickness of 40 m and containing shale with gravel and boulders with conglomeratic intercalations.

The superior member contains 70% *grey shale and silt*, 25% under lithic sandstone, and 5% microconglomeratic facies.

Depositional systems: LST: slope depositions made up of prodeltaic deposits/basinal plain with intercalations of thin turbidite lobes (arenitic nappes and predominantly arenitic nappes)[31].

Possibly TST and HST: distal shelf depositions.

The Brădulet Formation shows significant facies variations from the west to the east. The western zone has a higher content of ruditic rocks. In the eastern part, *i.e*. Doamnei–Vâlsan rivers, the formation is 80% constituted of *bituminous shale*, similarly to the Pucioasa facies in the Eastern Carpathians, 15% of under lithic sandstone, and 5% of marl, siderite and micro-conglomerates.

Depositional systems: turbidite cones (*slope fan*) accumulated in LSST and preserved in the distal zone, followed by hemipelagite (in HSST)[31].

The shale minerals are of the following types: smectite (predominantly), illite, kaolinite, vermiculite. Also there were identified fragments of plagioclase feldspar, quartz, and gypsum.

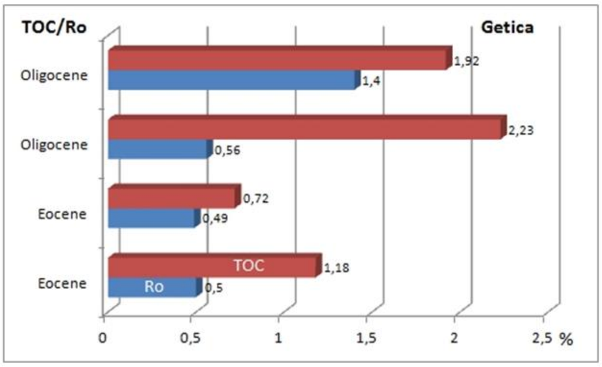

Fig. 19. The TOC/Ro values of the Eocene (Olăneşti Formation) and Oligocene (Brădulet Formation) source rocks.

Generating potential: weak-good in the east of the GB and very good in the west of the GB.

Table 3

Thickness and organogenic parameters of the rock source formations from the Getic Basin (GB) (see also Fig. 19)

Age	Formation	Thickness (m)	TOC (%)	Thermal maturity (T_{max})	Ro (%)	Kerogen
Miocene (Aquitanian)	Muiereasca Formation: 10% bituminous shale	50–100				
Oligocene Chattian)	Brădulet Formation 80% bituminous shales and marl, polymictic shale-siltite couples	1,000	1,92	434–441	1.33–1.50	II–III
Eocene (Lutetian-Priabonian)	Olăneşti Formation: 70% grey shales and silt	200	1.18		0.49	

CONCLUSIONS

The sedimentary formations with hydrocarbon source rocks that supplied the petroleum systems from the Carpathian-Danubian-Pontic area are found in all the depositional cycles of the Phanerozoic, starting from the Early Paleozoic and ending with the Late Cenozoic.

The thickness of these formations varies from several tens of meters to hundreds (thousands) of meters (Fig. 20), and the sequences making up the formations are accompanied by lutite and fine siltite or arenite. The proportion of such grain-size facies is variable: 20–70%/ 10–20%/ 5–10%.

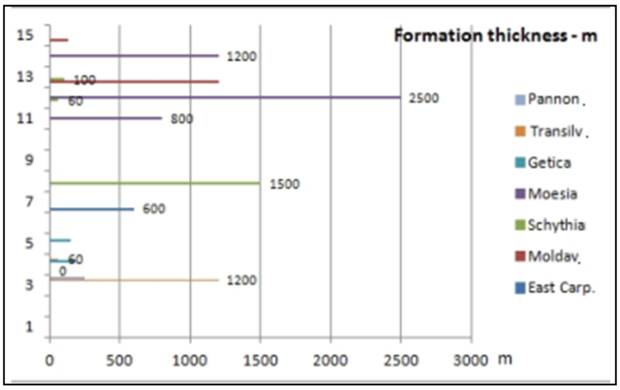

Fig. 20. The thickness of source rocks carrying formations found in the Carpathian-Danubian-Pannonic area.

The lutite and siltite rock types constantly fit into the ternary terms clay–silica–limestone affected by diagenesis in the meta- and catagenesis phases. The petrographic categories correspond to shale, bituminous shale, argillite (dysodile ss), marl, shale limestone, and bituminous dolomite, bituminous silicolite (menilite ss), bituminous siltite.

The mineralogical composition of these rock types is dominated by clay minerals (illite, candite), chlorite, sericite/quartz, chalcedony and opal/ calcite, and dolomite, in association with pyrite and marcasite.

The depositional systems in which primary muds accumulated were controlled by an anoxic and euxinic-type environment, with a negative redox potential, regardless of the basin's depth and the depocenter's position [21, 26].

The water salinity varied from saline-marine facies to brackish facies.

The organogenic parameters of the source rocks obtained from outcrop samples or boring samples showed variable values, sometimes displaying large ranges, depending on a multitude of factors. Their significance for the oleogenic and gasogenic potential of the respective formations depends also on the geotectonic context in which the source rocks evolved, the alterations they sustained during the selective burial, or the repeated emergence events.

The source rocks reached their maturity level when they entered the oil and/or gas window and at deeper burials they attained an supermaturity level, thus losing their generating potential. Submitted to tectonic movements, when the formations bearing such rocks were raised (and over-raised), the organic substance degraded or was entirely removed.

Taking into account the position of the petroleum systems in the provinces (basins) that we have described, we demonstrated the role of overthrust (in FBB) and subsidence and raisings (in FB or TBAB) for the hydrocarbon generating potential of the source rocks, up to a certain moment in time. The outlook of the source rock formations depend on how such potential is preserved.

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