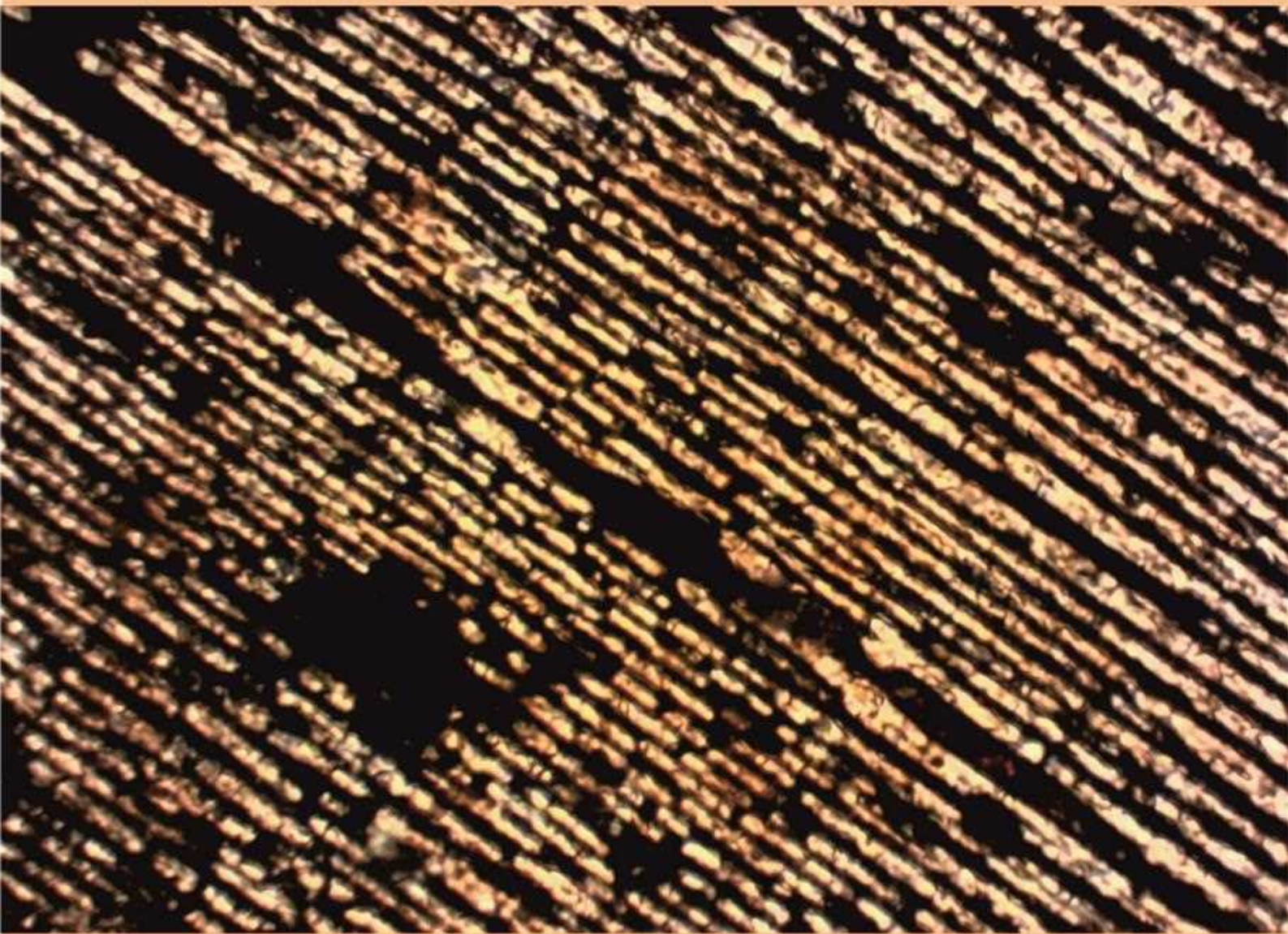


Volume 86, issue 2

December 2012

ISSN 2248-2563

Romanian Journal of Earth Sciences



GEOLOGICAL INSTITUTE OF ROMANIA

GEOLOGICAL INSTITUTE OF ROMANIA

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Editorial Office: Romanian Journal of Earth Sciences, Geological Institute of Romania, 1 Caransebeș St, room 505, 012271 Bucharest, Romania. Phone: +40213060400/+40213060491. fax: +40213181326.

The ideas expressed in the articles are the responsibility of the authors and do not involve any scientific position of the journal or of the Geological Institute of Romania

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ISSN 2248 – 2563

Cover illustration: Detailed view of a barred olivine chondrule in Gresia meteorite. The base of the microphotograph is 0.6 mm. Picture taken by Ion Stelea.



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New petrified woods from the Curvature Carpathians

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Abstract: A new collection of petrified wood coming from the Curvature Carpathians, Romania, is studied. Some samples have been found in the Oligocene "Kliwa Sandstones Formation" and some others are reworked within the so-called "Salt Breccia" (=Cosmina breccia). Previously, in this area, some pieces of Oligocene petrified wood were described and identified as morphospecies of *Sequoioxylon*, *Laurinoxylon* and *Icacinoxylon*. Also, by the analysis of pollen grains preserved in "the Kliwa Sandstones" from the Colți area, conifers and angiosperms were identified, indicating for the Oligocene a Mixed Mesophytic forest type. The new petrified woods found have been studied and identified as morphotaxa belonging to Conifers and Angiosperms: *Cupressinoxylon* sp. aff. *Thujoxydon* sp., *Sequoioxylon gypsaceum* (Goepp.) Greguss, *Quercoxydon* sp., *Ulmoxylon* sp. cf. *Ulmus carpinifolia* Gled.

Keywords: petrified wood, amber, Oligocene, Curvature Carpathians.

1 Introduction

A new collection of 10 specimens of Oligocene petrified wood found in the Curvature Carpathians, kept in the collection of the "University of Petroleum and Gas Ploiești" ("UPG Collection Ploiești") is taken in study now, defining new areas of petrified wood occurrence in Romania. Some other specimens, one from Colți area, other two from the "salt breccia" of Lopătari area (both in Buzău county), were added to this study (Figs. 1, 4).

Due to the previous correlation between the Oligocene and Miocene lithostratigraphic units of the Outer Moldavides for the Curvature Carpathians area (Săndulescu et al., 1995), which has been modified by some new researches (Frunzescu and Brănoiu, 2004; Frunzescu et al., 2012), it seems that the Kliwa Sandstone Formation represents the late Oligocene (Figs. 2, 3).

Thus, we have to correct the probable lower Oligocene age given by Petrescu et al. (1989) to the studied assemblage of petrified wood presented in his paper. He identified there some petrified woods found around the Colți locality, in the Fața Budei brook and in the Aluniș brook, as *Sequoioxylon gypsaceum* (Goepp.) Greguss (7 specimens), *Laurinoxylon murgoci* Petrescu (1 specimen) and *Icacinoxylon* sp. (1 specimen), all of them quasi-tropical trees. By palynologic analysis, Coniferous pollen grains (30-40%) preserved in the Oligocene sediments as well as in amber: *Podocarpus*(?), *Cupressus*, *Taxodium*, *Sciadopitys*, *Picea*, *Abies*, *Tsuga* and Angiospermous pollen (42-55%): *Myrica*, *Engelhardtia*, *Quercus*, *Ulmus*, *Alnus*, *Nyssa*, *Carya*, Compositae, Sapotaceae, Palmae) were identified (Petrescu et al., 1989, p. 191), all of them indicating a Mixed Mesophytic Forest – otherwise typical for the Oligocene vegetation within the Carpathian and Transylvanian areas.

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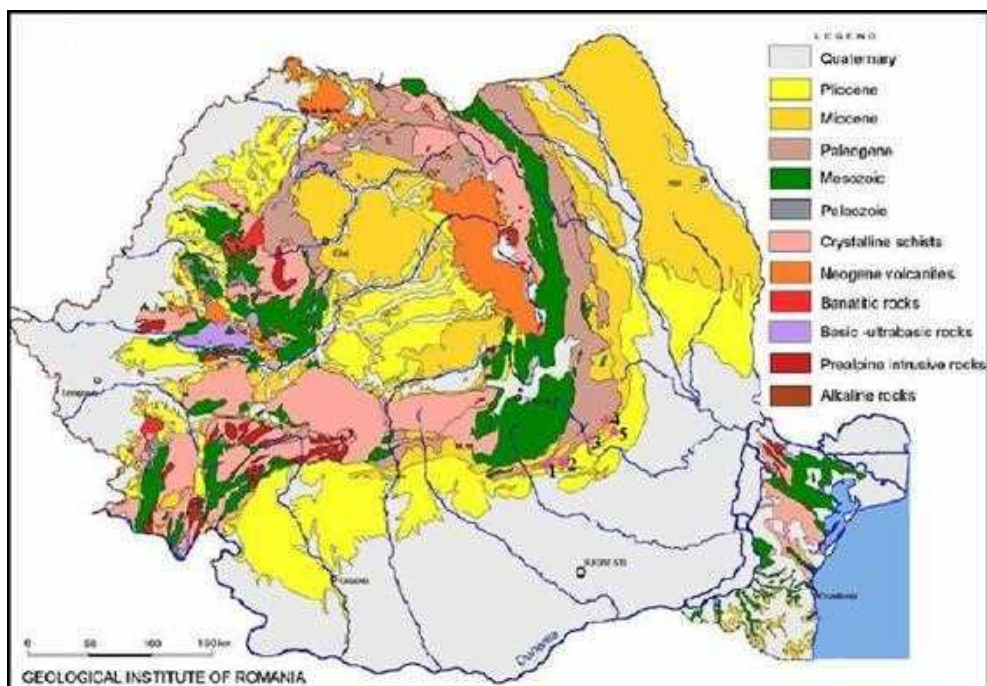


Fig. 1. Localization of samples (*) within the Curvature Carpathians: 1-2 – Zâmbroaia-Slavu-Vâlcănești, 3 – Colți, 4 – Lopătari, 5 – Beceni. (Romania's geological map sketch by GIR).

Tarcău Nappe	Marginal Folds' Nappe	Subcarpathian Nappe	Age
		Conglomerates, sandstones	VOLHINIAN
Telega Formation		Telega fm. / Halos fm.	KOSSOVIAN
Cosmina Breccia (Evaporitic fm.)		Cosmina Breccia (Evaporitic fm.)	LANGHIAN
Câmpinița fm. / Slănic tuff		Câmpinița fm. / Răchitașu fm. Slănic tuff	
Doftana Formation	Grey Schlier Formation		BURDIGALIAN
	Perchiu Gypsum	Tescani Formation	
Brebu Conglomerates	Hârja Formation	Măgurești Formation Pietricica's Conglomerates	
Cornu Formation		Condor Sandstone	
Sărata Formation (Lower Gypsum)		Sărata Formation (salt fm.)	
Starchiojd Formation		Goru-Meșina Formation (Terminal menilites)	AQUITANIAN
(Upper Disodilic and menilites)		Starchiojd Formation (Upper menilites)	
Vinețușu Formation	Băstenași Formation Podu Morii Formation Topile Formation	Upper disodilic schists	
Fusaru Sandstone Formation		Kliwa Sandstone Formation	OLIGOCENE
		Lower disodilic shales	
"Claysh Horizon"		Lower menilites	
		Fierăstrău Sandstone + slates	PRIABONIAN
		Marls with Globigerines + Lucăcești Sandstone	

Fig. 2. Corellation of the Oligocene and Miocene Lithostratigraphic Units of Outer Moldavides within the Curvature Carpathians. (Săndulescu et al., 1995, modified by Frunzescu and Brănoiu, 2004). * - Fossil woods.

PUCIOASA – FUSARU LITHOFACIES		BITUMINOUS KLIWA LITHOFACIES		Nanno-zones
Early Miocene	Burdigalian	SARATA FORMATION (= LOWER GYPSUMS FORMATION)		NN3
		STARCHIOJD FORMATION (UPPER DISODILES FORMATION) BĂTRÂNI TUFF	STARCHIOJD FORMATION (UPPER MENILITES + DISODILIC SHALES FORMATION)	
		STARCHIOJD FORMATION (UPPER DISODILES FORMATION)	STARCHIOJD FORMATION (UPPER DISODILES FORMATION)	NN2 a, b.
	Aquitanian	MLACILE TUFF – VALENI TUFF	MLACILE TUFF – VALENI TUFF	NN1
Oligocene	Chattian	VINETIȘU TUFF – GURA VITTOAREI BENTHONITES	STARCHIOJD FORMATION	
		PUCIOASA FORMATION WITH FUSARU SANDSTONES	KLIWA SANDSTONE FORMATION	NP25 a, b.
			LIMESTONES OF JASLO TYPE	NP24
	Rupelian	LOWER DISODILES FORMATION	LOWER MENILITES FORMATION	NP23
			VALEA TIGVEI TUFF	NP22

Fig. 3. Corellation of the Oligocene and Miocene Lithofacieses from the Curvature Carpathians (after Frunzescu et al., 2012).

The new found petrified woods were collected from a large area within Carpathians bend from the Oligocene Kliwa Sandstone Formation, to which some reworked samples found within the Miocene so called “Salt breccia” (= Cosmina breccia), which belong to the Evaporitic Formation (Frunzescu and Brănoiu, 2004) were added. These wood pieces definitely could be considered of Oligocene origin, since the “Salt breccia” does not offer any condition for petrifying the wood, and, beside this, the Oligocene blocks are frequently present in it (Fig. 4).

By paleoxylotomical study, the following morphotaxa were identified: *Cupressinoxylon* sp. aff. *Thujoxydon* sp. (6 specimens), *Sequoioxylon gypsaceum* (Goepp.) Greguss 1967 (4 specimens), *Quercoxylon* sp. (1 specimen), *Ulmoxylon* sp. cf. *Ulmus carpinifolia* Gled. (1 specimen), which again, perfectly agree with the typical Oligocene Carpathian vegetation, suggested by Petrescu et al. (1989).

2 Systematics and discussions

Gymnospermae

Phylum **PINOPHYTA** Cronquist (Takht. and Zimmerm., ex Reveal)

Family **CUPRESSACEAE** Rich. (ex Bartling)

Genus ***Cupressinoxylon*** GOEPPERT 1850

Cupressinoxylon sp. aff. *Thujoxydon* sp.

Plate I, figs. 1-9, Plate II, figs. 1-9.

Origin of samples and macroscopic description:

Six decimetric or centimetric silicified wood samples, collected from the Curvature Carpathians area were sampled and submitted to a palaeoxylotomical study. These petrified woods, representing pieces from the trunk or thick branch fragments, have brownish to dark-brown color and have fibrous texture, and regular growth rings – suggesting a probable conifer structure. The studied material was sampled from bigger fragments of petrified wood which were found as follows:

1. Sample 2203-3, comes from a small silicified wood fragment, of 9/4/4 cm, locally having coalified furrows, found in the Kliwa Sandstone Formation, in Zâmbroaia area - Prahova county, kept now in the “UPG Collection, Ploiești” under the number 3.

2. Sample 2207-9 comes from a silicified wood fragment, light brown on surface, sized of 30/12/8 cm, found in the “Salt breccia” (= Cosmina breccia), in Matia valley, Zâmbroaia area - Prahova county, kept now in the “UPG Collection Ploiești” under the number 9.

3. Sample 2208-8 comes from a silicified wood fragment, brown, 85/13/7 cm in size, found in the “Salt breccia” (= Cosmina breccia), in Matia valley, Zâmbroaia area, Prahova county, kept now in the “UPG Collection, Ploiești” under the number 8.

4. Sample 2209-10 comes from a dark silicified wood fragment, brown, 20/14/6 cm in size, found in the “Slavu breccia” (= Cosmina breccia), in Păcureți-Slavu area - Prahova county, most probably reworked from the late Oligocene), kept in the “UPG Collection Ploiești” under the number 6.

5. Sample 2206-7 comes from a small calcified wood fragment with ceramic aspect on the surface, of brick color, 18/6/5 cm in size, found in the “Salt breccia” (= Cosmina breccia, closest related to the Evaporitic Formation), in Budureasa area - Prahova county, most probably reworked from the Kliwa Sandstone Formation, kept now in the “UPG Collection, Ploiești” under the number 7.

6. Sample 2202-1, comes from a small silicified wood fragment, 13/5/8 cm in size, found in the “Salt breccia” (= Cosmina breccia), in Vâlcănești area, Prahova county, kept now in the “UPG Collection, Ploiești” under the number 1.

Microscopic description In the cross section, the growth rings are distinct, the early wood having big quadrangular tracheids, or deformed by compression, and relatively thick-walled (4-6 μm the double wall), progressively thicker to the well developed latewood. The cells lumina have polygonal to rounded corners, the radial/ tangential diameters of 25-60/30-50 μm , in the transitional wood gradually diminishing to smaller, quadrangular, radially flattened (the



Fig.4. Studied petrified woods collection of “UPG Collection, Ploiești”, Colți specimen excluded. Sample 2202-1, (13/5/8 cm), Vâlcănești; Sample 2201-2, (36/14/22 cm), Zâmbroaia; Sample 2203-3, (9/4/4 cm), Zâmbroaia; Sample 2200-4, (18/13/20 cm), Matia valley, Zâmbroaia; Sample 2205-5, (two pieces: 14/4/4 and 17/8/5 cm), Beceni; Sample 2204-6, (18/6/5 cm), Matia valley, Zâmbroaia; Sample 2206-7, (18/6/5 cm), Budureasa; Sample 2208-8, (85/13/7 cm), Matia valley, Zâmbroaia; Sample 2207-9, Matia valley, Zâmbroaia; Sample 2209-10, (20/14/6 cm), Păcureți-Slavu; Sample 2211, (26/8/6 cm), Colți

radial/tangential diameters = 10-20/15-30 μm) and with very thick walled cells (7-10 μm the double wall) in the late wood. The structure is devoid of any resin canal and has 1-13 rows of tracheids between two rays. Tracheidal pitting on the radial walls is especially present, abietinean, usually uniseriate, spaced, rarely contiguous, sometimes with crassulae. The spaced bordered pits are relatively small (10-12 μm), sometimes larger (14-19 μm), with visible

round aperture (3-6 μm). The tracheids usually lean their slightly tapered and terminally rounded ends, changing direction, intersecting the structure close or after ray meeting, generating a very specific aspect.

The axial parenchyma seems to be absent in cross section, but it is thick walled and is difficult to be observed amongst the tracheids. However, rather rarely, it appears in tangential view, having short elements, separated by horizontal or/and inclined transversal walls, fine and smooth or slightly knotted. Also, longitudinally, the cells present glomerules or plugs of resin.

The uniseriate medullary rays, linear in cross sections, are not very tall, having 1-3-8(-13) cells, rarely more. Radially, the rays seem to be homogeneous and are constituted of cells 12-14 μm tall, the marginals slightly taller and with the external wall weakly undulated. The tangential walls are rounded or inclined, and probably knotted. No indentures have been observed, maybe because of the bad preservation. In their cupressoid cross fields, 1-2-4(-6) small cupressoid pits are present, often in vertical pairs, small, rounded, 5-6 μm in diameter and with inclined to vertical lens-like apertures.

Affinities and discussions All these xylotomical observations made on the studied specimens suggest a coniferous, more specific with cupressaceous structure but, unfortunately, due to the relatively badly preserved material, it gave insufficient details to choose between the extant *Juniperus* or *Thuja* or *Chamaecyparis* or other type of structure (Greguss, 1955; Schweingruber, 1991; InsideWood, 2004 - onwards). However, analyzing all these features, it seems that we face a fossil cupressaceous structure closer to *Thujoxylon* genus, but still difficult to identify as a species.

Vaudois and Privé (1971), in their identification key, present these structures of *Thuja* type having “zones d’acroissement distinctes, tracheides a ponctuations radiales abietineennes uniseriées, parenchyme absent ou rare, a parois transversales noduleuses ou

ponctuées, rayons généralement peu élevés, uniseriées, parfois biseriées sur un faible hauteur; champs de croisement contenant 1-4 ponctuations taxodioides, parfois cupressoides, indentures présentes”.

Chamaecyparis, a close genus, have instead, a lot of parenchyma, and *Juniperus* have specific “juniperoid nodules” on their inclined tangential walls of ray cells, which are unclear or absent in our specimens, probably due to the bad preservation of the studied material too; hence, our material presents features closer to *Thujoxylon* genus.

Taking into account the revised diagnoses of Kräusel (1949), and the studies of Zalewska (1953), Greguss (1967, 1969), Dupéron-Laudouéneix (1979), it is very difficult to identify our relatively badly preserved specimens at species level. We prefer to attribute our studied material to *Cupressinoxylon* sp. aff. *Thujoxylon* sp., because there it is no identity between the few xylotomical characters observed on our specimens and other already described taxa and, surely, insufficient to describe a new species. Otherwise, due to the bad preservation, the microscopical study on the samples 2206-7 and 2202-1 did not give enough taxonomic details and they could be considered both coniferous wood, most probably, of the same cupressaceous type.

Genus *Sequoioxylon* Torrey 1923

Sequoioxylon gypsaceum (Goepp.) Greguss 1967
Plate III, figs. 1-9; Plate IV, figs. 1-9; Plate V,
figs. 1-9.

Origin of samples and macroscopic description: four fragments of petrified wood as fragments of trunks or thick branches, having decimetric to centimetric size and brownish to dark-brown color were submitted to palaeoxylotomical study. Macroscopically, all these wood samples are silicified, have fibrous texture and regular growth rings – suggesting a conifer structure and were collected from the Carpathian Curvature area, as follows:

1. Sample 2200-4, was taken from a wood fragment sized of 18/13/20 cm, found in the Kliwa Sandstone Formation (Upper Kliwa Sandstone) of "Văleni Spur", in Matia valley, Zâmbroaia area - Prahova county, kept now in the "UPG Collection Ploiești" under the number 4.
2. Sample 2201-2, comes from a wood fragment sized of 36/14/22 cm, found in the Kliwa Sandstone Formation of "Văleni Spur", on Zâmbroaia hill - Prahova county, kept now in the "UPG Collection Ploiești" under the number 2.
3. Sample 2211, comes from a black colored trunk fragment of 26/8/6 cm, found in the Kliwa Sandstone Formation, within the Colți area (Buzău county), kept now in "Colți Museums Collection".
4. Sample 2204-6, comes from a wood fragment sized of 18/6/5 cm, found in the "Salt breccia" (= Cosmina breccia, closest related to the Badenian Evaporitic Formation), in the Matia valley, Zâmbroaia area - Prahova county, and kept now in the "UPG Collection Ploiești" under the number 6.

Microscopic description In cross section, the growth rings are obviously distinctly present, rather unequal, and marked in the late wood by thick-walled cells, by contrast to the early-wood thin-walled cells. The transition is gradual and no resin duct is present. The tracheids are polygonal in cross section and have their lumina radial/tangential diameters of 30-60(80)/20-60(70) μm , smaller in the late wood, and the walls are of 3-6 μm the double wall to 7-10 μm in the late wood. There are 1-15 radial regular rows between two successive rays. Tangentially few, uniseriate and spaced abietineous pits appear, smaller than in radial view. No helical thickenings can be seen on the tracheids. The radial pitting, typical abietineous, 12-16-19 μm in diameter, with round apertures of 4-6 μm , smaller in the late wood, spaced, arranged in 1-2-3 vertical rows, usually separated by crassulae sometimes presenting small irregularities in the arrangement.

The axial parenchyma – not too visible in cross section, appear in vertical views as rectangular thin-walled cells, with thin horizontal walls rugose or slightly nodular, and with the large balls, dark remains, or plugs or dark resin inside.

Rays usually uniseriate, sometimes with local biseriations, have 1-3-15 or more cells high. The thin-walled ray cells are homogeneous, of 14-18 μm tall, the marginals slightly taller and without indentures. The cross fields have 1-3(4) taxodioid pitting in horizontal rows, pairs slightly diagonal. In the marginal cross fields 1-6 pitting in 1-2 horizontal rows. Pit apertures are elliptical, oblique to horizontal.

Affinities and discussions The xylotomical details of these specimens are typical for the cupressaceous woods, especially of taxodiaceous type, by the presence of radial opposite pitting on 1-3 vertical rows, with obvious crassulae and typical taxodioid pitting in the cross fields (Greguss, 1955; InsideWood, 2004 - onwards). Compared with fossil taxodiaceous genera (Greguss, 1967) we found great similitude with *Sequoioxylon* Torrey and also with *Taxodioxylon* (Hartig) Gothan, presenting many similarities with the extant species *Sequoia sempervirens* L. The distinction between those two genera is problematic enough, since some of the paleoxylologists contest the validity of the genus *Sequoioxylon* Torrey, considering that the diagnosis of *Taxodioxylon* genus is sufficiently comprehensive and the establishment of new competency domains can complicate the fossil wood identifications.

Historically, it must be stressed that the genus *Sequoioxylon* was created by Torrey (1923) on a traumatic fossil wood structure (with traumatic resin ducts) and, for this reason, Kräusel (1949) rejected it. However Greguss (1967) sustained the use of this genus for all the structures related to the extant genus *Sequoia*, characterized by: horizontal walls of the axial parenchyma perfectly smooth, rarely slightly thickened or rugose or very weakly nodular, radial pitting 1-3-seriate with conspicuous crassulae and cross-fields with 1-3 taxodioid

pitting (or slightly podocarpoid, or circular), in a horizontal row, rarely in vertical pairs, more numerous in the marginal fields and in two rows, rarely alternate or slightly irregular. He attributed to this genus the species *gypsaceum*, *medullare*, *podocarpoides*, *germanicum*, and other numerous forms described only as *Sequoioxylon* sp.

Roy and Stewart (1971) have described a *S. gypsaceum* from Cypress Hills Formation (Oligocene, Saskatchewan - Canada), and renamed the *Taxodioxyton gypsaceum* described by Ramanujam and Stewart (1969) from Edmonton Formation (Upper Cretaceous, Alberta - Canada), as *Sequoioxylon gypsaceum*.

The genus name was also used by Petrescu and Popa (1971), and Petrescu (1978) for similar structures described in Romania, with the species *gypsaceum* and *giganteoides*, the last renaming the taxon described by Huard (1966) - equivalent to the extant species *Sequoia gigantea* Decaisne, and also by us (Iamandei and Iamandei, 2000; Iamandei et al., 2001, 2008).

The same kind of wood has been described too, as fossil, under the name *Taxodioxyton gypsaceum* (Goepp.) Kräusel 1949 [= *T. sequoianum* (Mercklin) Gothan 1906]. Huard (1966) showed that this taxon, *Taxodioxyton gypsaceum*, is grouping many diverse forms, all of them equivalent to the extant *Sequoia sempervirens* Endl., and that it was broadly distributed in the Northern Hemisphere (Eurasia and North America) during the Cenozoic.

Similar wood was described as *Taxodioxyton gypsaceum*: by Nagy (1969) - for a specimen found in Northwestern Romania, at Clit, in an Oligocene Formation; by Privé-Gill (1977, 1990) for material coming from the Oligocene of Limagne and Razet (Allier, France); by Bugnicuort et al. (1988) for fossil woods found in an Upper Miocene lignite deposit of Capvern, Hautes Pyrénées; by Gottwald (1992) for fossil woods coming from the Eocene of Helmstedt (Germany), and by many others.

Greguss (1967) considered that the name *Taxodioxyton* should remain reserved only to the structures characterized by the presence of

numerous nodular thickenings on the horizontal walls of the axial parenchyma, very typical features to the extant genus *Taxodium*. Privé-Gill (1977), quoting Bailey and Faull, warned again about the great variability of the ray characters in the extant *Sequoia*.

However, this taxon is, morphologically and ecologically, different from *Taxodium*. Now, the Cupressaceae family s.l. comprises also the taxa of the former Taxodiaceae genera with both extant and fossil forms (Gadek et al., 2000; Farjon, 2005), included in the next subfamilies:

- Taxodioideae Endl. ex K.Koch, with *Taxodium*, *Glyptostrobus*, and *Cryptomeria* genera;
- Sequoioideae (Lueress.) Quinn, with *Sequoia*, *Sequoiadendron* and *Metasequoia* genera;
- Athrotaxidoideae Quinn, with *Athrotaxis*;
- Cunninghamioideae (Sieb. and Zucc.) Quinn, with *Cunninghamia*;
- Taiwanioideae (Hayata) Quinn, with *Taiwania*.

Since *Taxodioxyton* became a “pocket genus” for already all the taxodiaceous woods, eventually difficult to distinguish from each other, the proposal of Greguss (1967) was followed by many palaeoxylogists. Personally, we stress that the use of the genus *Sequoioxylon* Torrey is correct, legitimate and it represents the fossil correspondent of extant important genus *Sequoia*, since its diagnosis, established by Torrey (1923), was emended by Greguss (1967) who did not consider the presence of the traumatic structures as taxonomic details, as also Ramanujam and Stewart (1969, p. 117) emphasized.

The here studied specimens, devoid of resin ducts, sometimes with local resin tissue – most probably of traumatic origin, with tracheidal abietineous 1-3-seriate pitting, with conspicuous *crassulae*, with axial parenchyma relatively abundant, having resin balls and plugs and horizontal walls usually smooth and thin, with uniseriate rays frequently having biseriate stories and typical taxodioid cross-fields, are very similar to extant *Sequoia* structure, and, after these considerations, we have attributed these

four studied specimens to *Sequoioxylon gypsaceum* (Goepp.) Greguss 1967.

Angiospermae – Dicotyledonatae

Phylum **MAGNOLIOPHYTA** Cronquist,

Takht. and Zimerm. ex Reveal

Family **FAGACEAE** Dum.

Genus *Quercoxylon* (Kräusel) Gros 1988

Quercoxylon sp.

Plate VI, fig. 1-9.

Origin of samples and macroscopic description: a fragment of petrified (silicified) wood numbered with the field number 2150, having 7/3/5 cm in size, brownish color, fibrous texture and regular growth rings – suggesting, by the presence of visible large vessels, a dicot. It was collected from the Carpathian Curvature area, in Lopătari (Buzău county), from the so called “Salt breccia” (= Cosmina breccia, closest related to the Evaporitic Formation), most probably reworked from the late Oligocene formation, kept in the GIR Collection – National Museum of Geology, Bucharest, under the number 27.226.

Microscopic description The growth rings are distinct in cross section, defining typical ring porous structure marked by very large vessels in the early wood, round to radial oval, exclusively solitary, in radial rows arranged (or slightly “in flame”), with gradual diminishing, giving a half-ring-porous aspect. The large solitary vessels have the lumina size of 150-350/150-250 µm the radial/tangential diameter, to 70-200/70-130 µm in the late wood, and with 8-16 µm the simple wall thickness. In longitudinal views, the vessels have simple perforations and bordered numerous, spaced, pitted, opposite, subopposite to alternate, surrounded by pitted vasicentric tracheids. Inside the vessels no tyloses have been seen.

The axial wood parenchyma is visible as short tangential uniseriate rows in cross section, is of diffuse or of apotracheal type and scanty paratracheal too, scattered among the libriform or fibrotracheids. In longitudinal sections can be seen as rows of rectangular cells with crystals or

grains of tannin or full of dark tannin amongst the elements of ground mass.

The rays of two sizes are present: the uniseriates numerous, medium tall and the multiseriates of aggregate type (up to 22 cells or more) taller than 1 mm usually, dissected by libriform fibers giving typical aspect of aggregate ray. In cross fields with vessels they are obviously homocellular showing cells all procumbent, but pits are not visible, because the ray cells are full of tannin. The ray-cells frequently contain crystals, sometimes with slightly rounded corners.

The mixed ground mass constituted from parenchyma, tracheids and libriform often difficult to identify each other. The libriform fibers with polygonal cross section have unpitted vertical walls and are unsepted. The vascular tracheids are frequent, bordered pitted on the vertical walls.

Affinities and discussions In cross section, the studied material shows affinities with fagaceous wood structure of oak type by its ring-porosity and two-sized rays beside the typical aspect and distribution of the vessels and of the ground tissue. We have seen this, consulting the atlas of Schweingrüber (1991), InsideWood, (2004-onwards), Wheeler (2011), but for a correct generic identification other keys of identification were consulted, as well:

1. Hadziev and Mädel (1962) have separated four structural types of oak wood:

- Type "Weisseichen" (white oaks), comprising most of the species of section *Lepidobalanus* – having ring porous structure and small, polygonal, thin-walled vessels in the late wood;
- Type "Roteichen" (red oaks), comprising the species of the section *Eritrobalanus* and some species of *Lepidobalanoideae* – having ring porous structure and relatively large, round, thick-walled vessels in the late wood;

2. Privé (1975), in accord with Hadziev and Mädel (1962) shows that the oak wood is characterized by vessels in radial rows more or less dendritically distributed and showing simple

perforations. She emphasized that two-sized rays (multiseriate very broad and finer, 1-2-seriate) are present in *Quercus* L. and in *Lithocarpus* BL. (= *Pasania* Oerst.) with some tens of species from temperate to warm regions of north hemisphere, islander also and that the diffuse pore distribution characterizes the evergreen species, the ring-porous one is typical to the deciduous species of *Quercus* and the most septentrional species of *Lithocarpus*. In the root wood, the deciduous species often tend to lose the ring-porousness and become porous, similar to the evergreen species, and the broad rays become divided in false rays (aggregate rays).

3. Petrescu (1976) made a good systematization of the xylotomical details of fagaceous wood types, useful as a key of identification for the fossil wood too, presented as follows (Table 1).

4. Suzuki and Ohba (1991) used a comparative synthesis of the essential xylotomical characters of the extant fagaceous taxa, based on the anatomic studies and the phylogenetic relations between the genera of Fagaceae made by Shimanji, which also can be used as a key of genera identification.

Using all those keys we observed that having large vessels, gradually diminishing to latewood, giving an aspect of half ring porous structure, round thick walled vessels in latewood, simple perforations and twosized rays (uniseriate and

aggregate thick rays) and crystalliferous ray parenchyma. These structures are similar to extant *Quercus* L. of sempervirent type or *Lithocarpus* Blume, respectively to fossil form-genera *Quercoxylon* (Kräusel) Gros 1988 or *Lithocarpoxyton* Petrescu 1978.

The observed details seem to be insufficient in order to define a morphospecies, while the genus identification is problematic, and we took into account a part of the numerous studies on extant or fossil oaks consulted: Müller-Stoll and Mädel (1957), Brett (1960), Greguss (1969), Nagy and Petrescu (1969), Kramer (1974), Hadziev and Mädel (1962), Huard (1966), Privé-Gill (1975, 1984, 1990), Privé and Brousse (1976); Petrescu (1971, 1976, 1978), Petrescu et al. (1969, 1972, 1974), Starostin and Trelea (1969, 1984), Lupu (1984), Selmeier (1971, 1997), Suzuki and Ohba (1991), Gottwald (1992), Iamandei et al. (2000, 2008a,b,c, 2011, 2012).

We retained the observation of Privé (1975), that the extant genus *Quercus* L. shows a great interspecific anatomic homogeneity, therefore, it is very difficult to delimitate a fossil species, even if it has only a descriptive value, as form-species. In these circumstances we name our studied specimen as *Quercoxylon* sp., as a correspondent of the extant sempervirent type of *Quercus* L. or, possibly to *Lithocarpus* Blume.

Table 1. Key of identification for the Fagaceous fossil wood (after Petrescu, 1976)

Type A	Structures with solitary vessels or grouped (2-3 or more), with simple and scalariform perforations on vessels.	Fine rays (1-3-seriate) and compact multiseriate.	<i>Fagoxylon</i> <i>Nothofagoxylon</i>
Type B	Structures with solitary vessels, having simple perforations, sometimes some scalariform, with few bars.	Exclusively uniseriate rays.	<i>Castanoxylon</i>
		Uniseriate and compact pluriseriate, sometimes compact-composed or partially aggregate rays.	<i>Quercoxylon</i>
		Uniseriate and pluriseriate aggregate rays.	<i>Lithocarpoxyton</i>

Family **ULMACEAE** Mirb.
 Genus ***Ulmoxylon*** Hofmann 1939
Ulmoxylon sp. cf. *Ulmus carpinifolia* Gled.
 Plate VII, fig. 1-9.

Origin of samples and macroscopic description: A reworked petrified wood broken in two pieces (14/4/4 cm and respectively 17/8/5 cm) was found in the alluvial material (pebbles) of Slănic river, in Beceni locality (Buzău county), coming, most probably, from the Badenian “salt breccia” (= Cosmina Breccia), from the Lopătari area. For study, small samples were taken, numbered with 2205-5. The silicified wood probably represents fragments of trunk or of thick branches. It has a regular fibrous texture and obvious annual rings with large vessels in the early wood and broad rays visible by naked eyes, suggesting a dicotyledonate structure. The samples are kept in the “UPG Collection, Ploiești” under the number 5.

Microscopic description The growth rings in cross section are distinct, since the typical ring-porous structure is marked by very large vessels round to slightly oval in the early-wood (150 - 200/60 - 150µm the radial/ tangential diameters), exclusively solitary and thick walled (of 3-6.5 µm the simple wall). To the latewood, the relatively thick-walled vessels (6-8 µm the double wall) rounded vessels of 20-30 µm appear in tangentially grouped as “ulmiform” bands, of 3-5 cells thick giving a typical “ulmoid structure”. In longitudinal views, the vessels have simple perforations and small bordered pitting, opposite, subopposite to alternate, spaced, numerous, with elliptic horizontal apertures. The strongly deformed structure offers few other taxonomic details.

The axial parenchyma – of apotracheal type, appear diffuse, scattered between the other ground tissue elements.

The rays seem to be two-sized: 1-3-seriate, medium tall, and multiseriate (of 4-12 cells wide, or more), taller, usually compact. In the cross fields with vessels numerous small bordered pitting is present. The ray cells seem crystalliferous.

The libriform fibers have polygonal cross section, rounded-shaped lumina, 10–20 µm in diameter, have moderately thick walls of 3-5 µm the double wall, are unpitted and unsepted.

The vascular tracheids are frequent, pitted on the vertical walls with round to elliptic bordered pits.

Affinities and discussions From the cross section, the “ulmiform” distribution of the vessels defining a typical ring-porous structure with two-sized classes of vessels can be recognized, so it is clear that we had in study a member of Ulmaceae family, unfortunately badly preserved. Studying a Miocene ulmaceous wood from Gleichenberg (Steiermark, Austria) as *Ulmoxylon*, Kaiser (1879) reviewed the species *Cottaites lapidariorum* described by Unger some decades ago, and, probably considering it as type for the genus, he did not design a genus type, fact which now is not accepted (see ING Database: type non designatus). A correct and legitimate taxon name of *Ulmoxylon* was described by Hofmann (1939), almost identical with the wood of *Ulmus* described by Linnaeus two hundred years ago.

Consulting the atlas of Schweingruber (1991), the paper of Greguss (1969), Sweitzer (1971), Wheeler et al. (1989), Zhong et al. (1992), the site InsideWood (2004-onwards), and Wheeler (2011) – we have found a great similarity of the structure of our specimen with the group of the extant *Ulmus carpinifolia* (Soft elm), *U. glabra* (Scotch elm or Wych elm) or *U. laevis* (European white elm or Russian elm), which include themselves several synonyms. However, we found few fossil correspondents already described till now, and we used them for comparison with our here described specimen:

- Hofmann (1939), described from the Tertiary of Hungary a fossil wood structure of *Ulmus campestris* L. type (synonymized now with *U. carpinifolia* Gled.);
- Watari (1952), described from Miocene of Japan an *Ulmus crystallophora* (Watari) Watari;

- Andreášky (1953) shortly described an *Ulmus* sp. also from the Cenozoic of Hungary, similar to *Celtis* or to the fossil form *Ulmus plurinervia* Unger.
 - Sacchi Vialli (1958) described from Fontana di Anibale, Casteggio, Italy an “*Ulmoxylon*” (p. 121, figs. 1-10), a wood structure compared with *Ulmus campestris* L.
 - Prakash and Barghoorn (1961) described *Ulmus miocenica* and *U. baileyana* from the Miocene of the USA, which seems to have the nearest affinities with the modern *U. americana* L. type and also *U. pacifica* which shows structural resemblance with the modern *Ulmus mexicana* (Liebm.) Planch., as nearest relative species of *Ulmus*.
 - Greguss (1969) described *Ulmoxylon* sp. cf. *Ulmus carpinifolia* Gled., and an *Ulmoxylon scabroides* and even if the figures are slightly unclear, the description corresponds and the extant equivalent is *Ulmus scabra* which is a synonym of *U. glabra*.
 - Starostin and Trelea (1969) described from the Miocene of Moldavia *Ulmoxylon kersonianum*.
 - Petrescu and Dragastan (1971) described from Southern Sub-Carpathians *Ulmoxylon* cf. *Ulmus americana* L.
 - Biondi (1981) described from Sibillini Mts. (Central Appennins) *Ulmoxylon marchesonii*, having similar structure with *U. carpinifolia* Gled.
 - Lupu et al. (1984) described two sub-fossil woods of *Ulmus* as *U. minor* (Mill.) and *U. laevis* Pall.
 - The species described by Sakala (2002) on some fossil wood from Czech Republic as *Ulmoxylon marchesonii* Biondi 1981 has structural details which put it close to the extant species *Ulmus macrocarpa* Hance from North America, to *U. parvifolia* Jacq. from China and to the European common elm *U. carpinifolia* Gled.
- Otherwise, Sakala (2002) consider for comparison five fossil forms which show rather similar wood pattern: *Ulmus crystallophora* (Watari) Watari 1952, from the Miocene of Japan, *Ulmus baileyana* Prakash and Barghoorn 1961 from the Miocene of USA, *Ulmoxylon kersonianum* Starostin and Trelea 1969 from the Miocene of Moldavia, and *Ulmoxylon* cf. *Ulmus carpinifolia* Gled. from the Mio-Pliocene of Hungary described by Greguss (1969).
- The new species described by Wheeler and Manchester (2007), as *Ulmus woodii* Wheeler and Manchester - similar to the Chinese *Trichoptelea* type and *Ulmus danielii* Wheeler and Manchester - similar to the American *Ulmus lanceifolia* Roxb. ex Wall.
 - Privé-Gill et al. (2008) described an *Ulmoxylon lapidarium* (Unger) Felix 1883, considered to be closer to the extant species *Ulmus campestris* L., having similar structure, and gathered under this umbrella several other already described fossil species: *Ulmoxylon* aff. *lapidarium* (Unger) Felix, of Privé et Brousse, 1969, *U. khersonianum* of Starostin and Trelea, 1969, the species of Sacchi Viali (1958), and others.
- Since our studied material, even if is badly preserved, presents a ring-porous structure, two-sized vessels, 1-2 rows of big vessels in the early-wood, simple perforations and alternate pitting on vessels, apotracheal and paratracheal chambered parenchyma and with crystals, broad rays up to 7 cells wide and medium tall, homocellular and with typical pitting in “the cross fields” of rays with vessels, similar details meet at *Ulmus carpinifolia* to which we can confine our specimen and we name it *Ulmoxylon* sp. cf. *Ulmus carpinifolia* Gled.

3 Conclusions

The new collection of Oligocene petrified wood coming from the Carpathian curvature

Table 2. List of Oligocene flora identified within the Curvature Carpathians

No.	Taxon name	Type of fossil	Extant equivalent	Obs.
1	<i>Taxodium</i>	Pollen	Bald cypress	Petrescu et al. (1989)
2	<i>Sciadopitys</i>	Pollen	Japanese umbrella-pine	Petrescu et al. (1989)
3	<i>Picea</i>	Pollen	Spruce	Petrescu et al. (1989)
4	<i>Abies</i> ,	Pollen	Fir	Petrescu et al. (1989)
5	<i>Tsuga</i>	Pollen	Hemlock	Petrescu et al. (1989)
6	<i>Cupressus</i>	Pollen	Cypress	Petrescu et al. (1989)
7	<i>Podocarpus</i> (?)	Pollen	Fern pine	Petrescu et al. (1989)
8	<i>Myrica</i> ,	Pollen	Bayberry	Petrescu et al. (1989)
9	<i>Engelhardia</i>	Pollen	Tropical tree	Petrescu et al. (1989)
10	<i>Quercus</i>	Pollen	Oak	Petrescu et al. (1989)
11	<i>Ulmus</i>	Pollen	Elm	Petrescu et al. (1989)
12	<i>Alnus</i>	Pollen	Alder	Petrescu et al. (1989)
13	<i>Nyssa</i>	Pollen	Black tupelo	Petrescu et al. (1989)
14	<i>Carya</i>	Pollen	Hickory	Petrescu et al. (1989)
15	Compositae	Pollen	Aster, daisy	Petrescu et al. (1989)
16	Sapotaceae	Pollen	Tropical trees	Petrescu et al. (1989)
17	Palmae	Pollen	Palms	Petrescu et al. (1989)
21	<i>Cupressinoxylon</i> sp. aff. <i>Thujoxylo</i> sp.	Petrified wood	Cypress	Iamandei et al., present paper
22	<i>Sequoioxylon gypsaceum</i> (Goepp.) Greguss	Petrified wood	Redwood	Petrescu et al. (1989) and Iamandei et al., present paper
19	<i>Laurinoxylon murgoci</i> Petrescu	Petrified wood	Cinnamon	Petrescu et al. (1989)
20	<i>Icacinoxylon</i> sp.	Petrified wood	Tropical tree	Petrescu et al. (1989)
23	<i>Quercoxylon</i> sp.	Petrified wood	Oak	Iamandei et al., present paper
24	<i>Ulmoxylon</i> sp. cf. <i>Ulmus carpinifolia</i> Gled.	Petrified wood	Elm	Iamandei et al., present paper

define new areas for petrified wood occurrence, which deserves a special interest because its age and its novelty for Romania.

Our study increases the inventory of fossil taxa given by Petrescu et al. (1989) for the Mixed Mesophytic Forest discovered in the Oligocene deposits of the Carpathian Curvature area, identified by palaeopalynological and palaeoxylotomical studies (Table 2).

The presence of *Taxodium*, *Cupressus*, *Podocarpus*, *Sequoioxylon*, *Laurinoxylon*, *Icacinoxylon*, *Nyssa*, *Carya*, Sapotaceae div. and even Palms, within the list of taxa from the Oligocene Mixed Mesophytic Forests from the Carpathians suggest a warm palaeoclimate of probably of subtropical type. Beside this, it is a

region where the Romanian amber (Rumanit, Romanit) appears within a formation of similar age and a relation is to be searched, since a clear connection of amber and amber-generating trees has never been found, even if some suggestions have been made by Murgoci (1903), Petrescu et al. (1989) and Teodor (2010).

The new collection of petrified woods found in a large area within Curvature Carpathians has been studied and the following morphotaxa were identified: *Cupressinoxylon* sp. aff. *Thujoxylo* sp., 6 specimens), *Sequoioxylon gypsaceum* (Goepp.) Greguss 1967. (4 specimens), *Quercoxylon* sp. (1 specimen), and *Ulmoxylon* sp. cf. *Ulmus carpinifolia* Gled. (1 specimen) which perfectly fit within the typical Oligocene

Carpathian vegetation considered a Mixed Mesophytic Forest of warm temperate climate in an island area within the Paratethys Sea.

Acknowledgements

The research was supported by the National University Research Council (CNCSIS) through the project ID_441 - contract no. 336/2007 and ID_584 - contract no. 1074/2009, and also by the project "Romanit", sponsored by the National Center of Programmes Management (CNMP) through the contract no. 91-019/2007. This research was presented at the Congress of the Carpathian-Balkan Geological Association, in Thessaloniki, Greece (Iamandei et al., 2010). The manuscript benefited from the comments made by Daniel Țabără ("Alexandru Ioan Cuza" University of Iași) and Valentin Paraschiv (Geological Institute of Romania).

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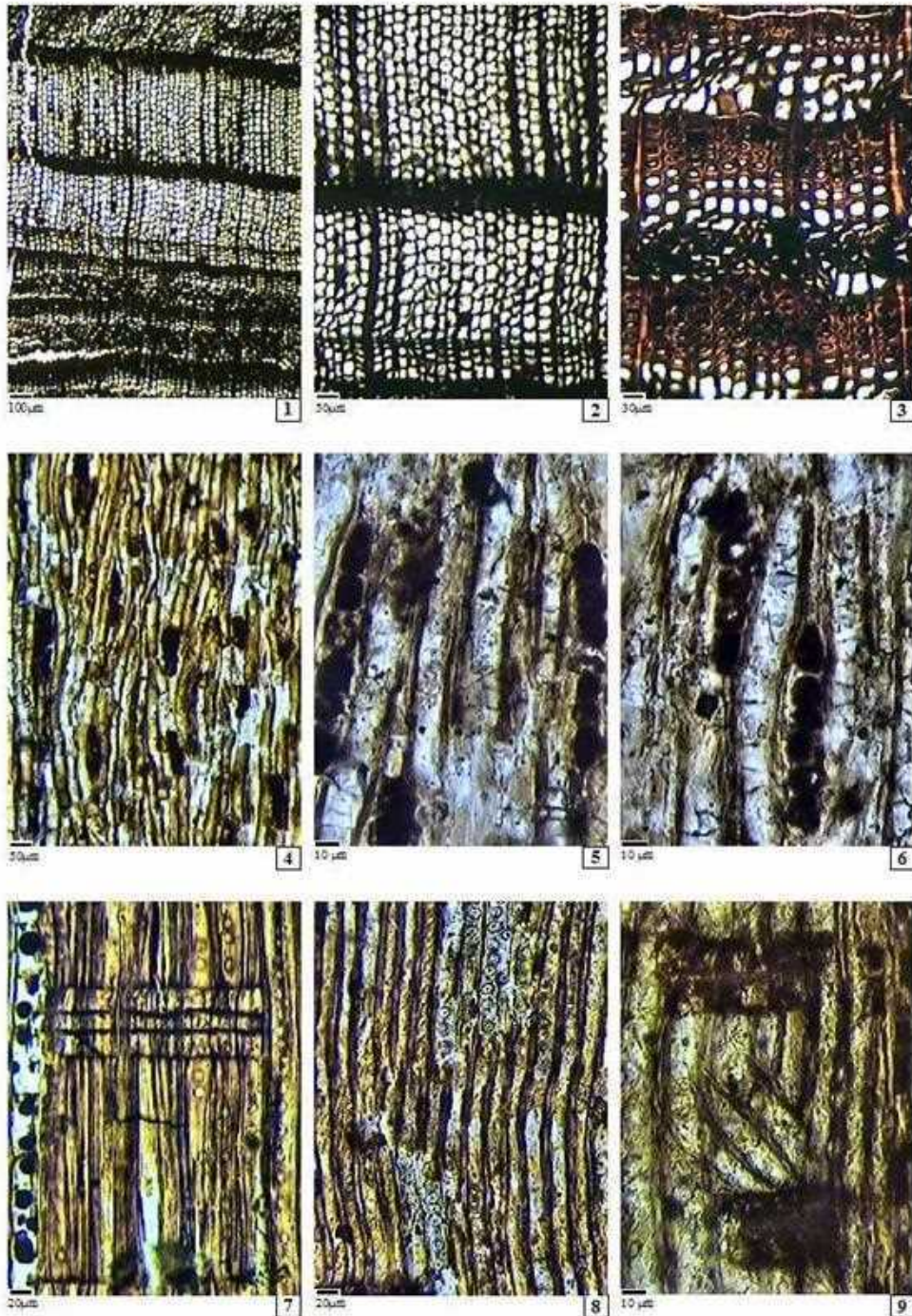
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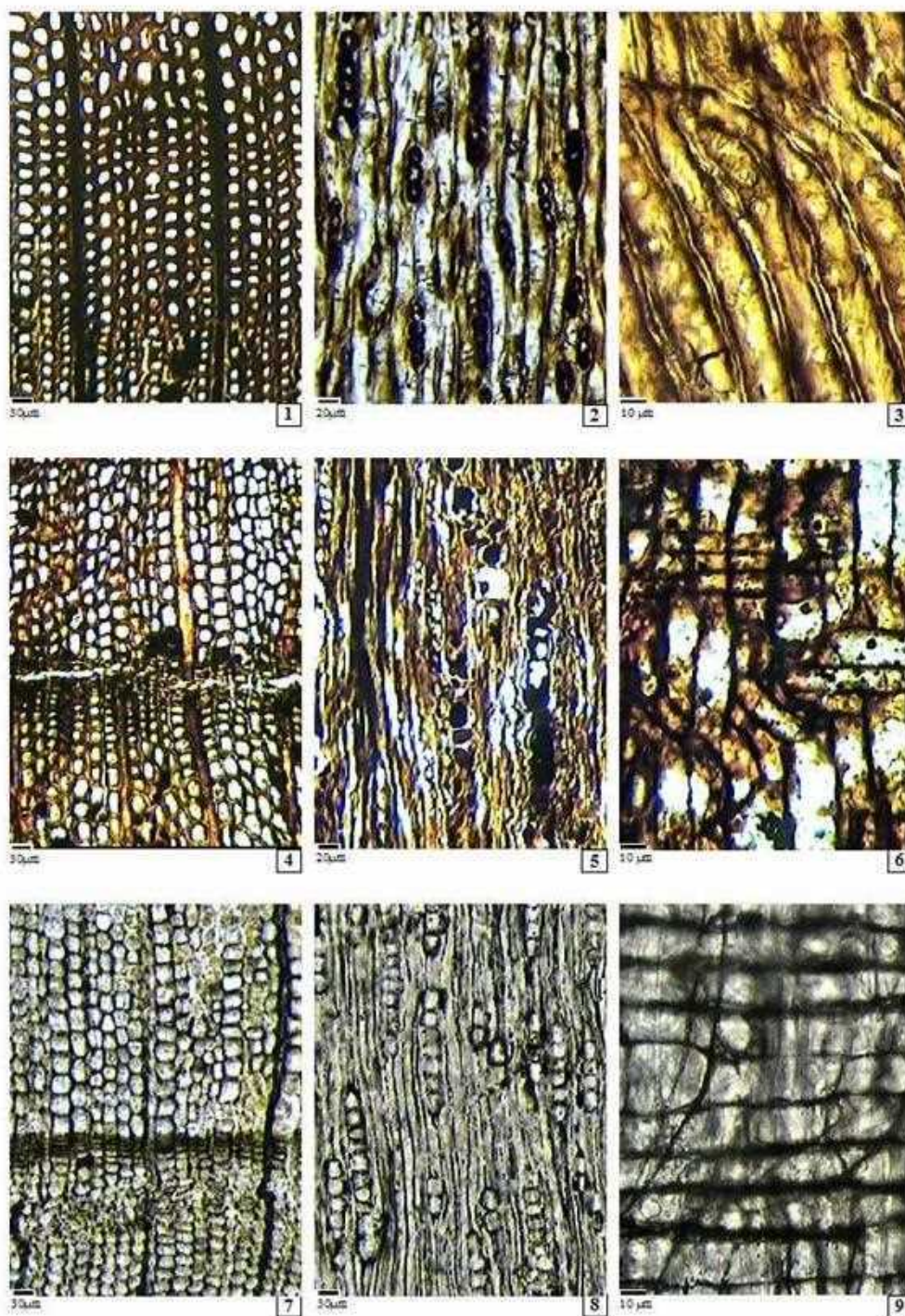
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PLATE I



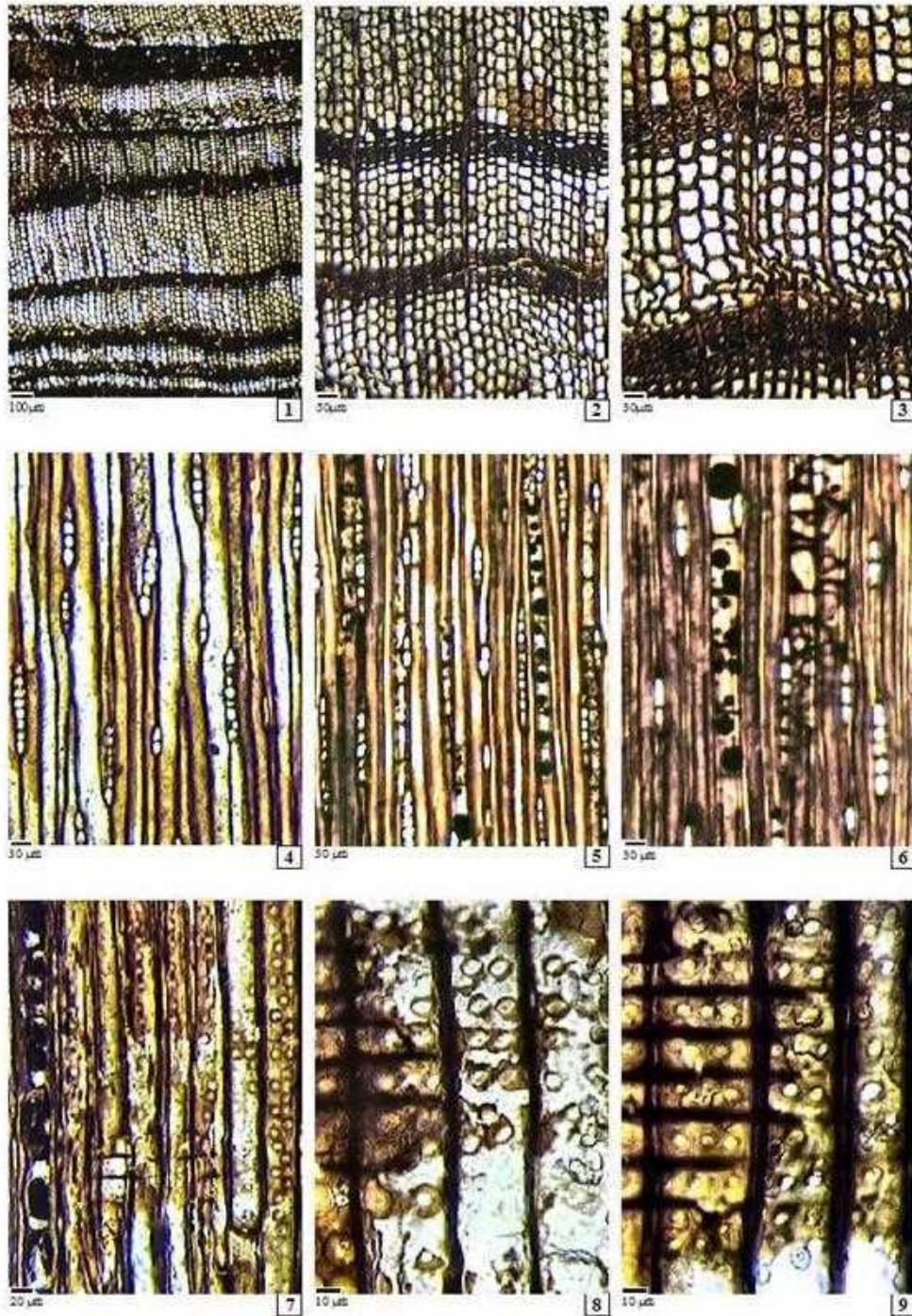
Cupressinoxylon sp. aff. *Thujoxylon* sp., fossil wood from Zâmbroaia (Ph.) - no. 3 in "UPG Collection, Ploiești". Figs. 1-3. Cross section. Growth rings marked by late-wood thickened tracheids. Few parenchyma cells. Figs. 4-6. Tangential section. Uniseriate short rays. Figs. 7-9. Radial section. Uniseriate radial pitting, cupressoid cross fields, parenchyma with resin balls, leaning tracheidal endings.

PLATE II



Cupressinoxylon sp. aff. *Thujoxylon* sp., fossil wood from Zâmbroaia (Ph.) - nos. 9, 10 and from Păcureți-Slavu (Ph.) - nr. 8 in "UPG Collection, Ploiești". Figs. 1, 4, 7. Cross section. Growth rings with relatively thick walled tracheids more thickened in the late-wood. Figs. 2, 5, 8. Tangential section. Uniseriate short rays. Fig. 3, 6, 9. Radial section. Uniseriate radial pitting, leaning tracheidal endings. Badly preserved uniseriate radial pitting and cupressoid cross fields, leaning tracheidal endings.

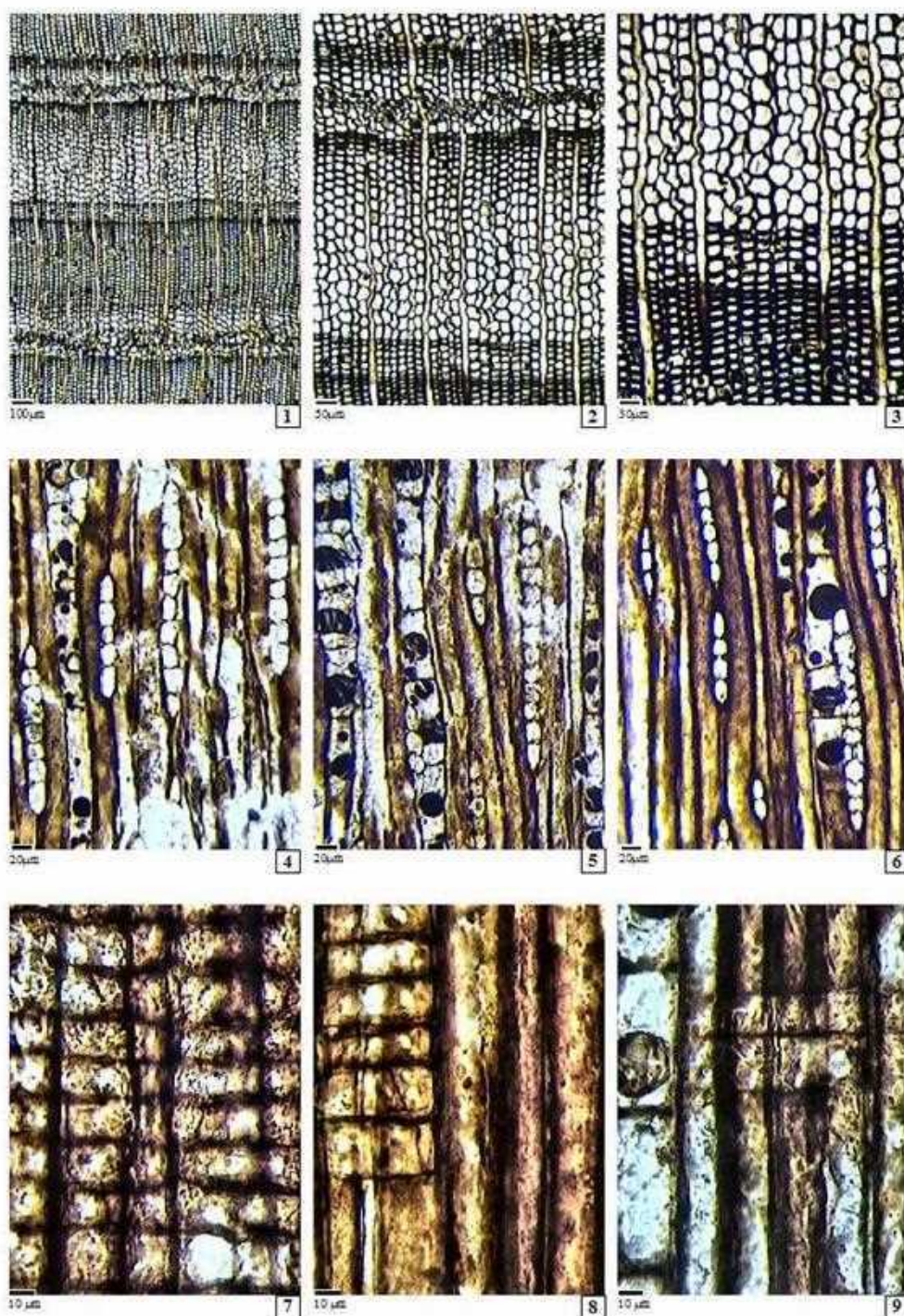
PLATE III



Sequoioxylon gypsaceum, fossil wood from Zâmbroaia (Ph.) - nr. 1 in "UPG Collection, Ploiești"

Figs. 1-3. Cross section. Distribution of tracheids, parenchyma and rays. Growth rings marked by late wood thickened cells. Figs. 4-6. Tangential section. Uniseriate rays with biseriate storeys, and parenchyma with smooth horizontal walls and resin balls. Figs. 7-9. Radial section. 1-2-3 radial pitting, taxodioid cross fields pitting, axial parenchyma.

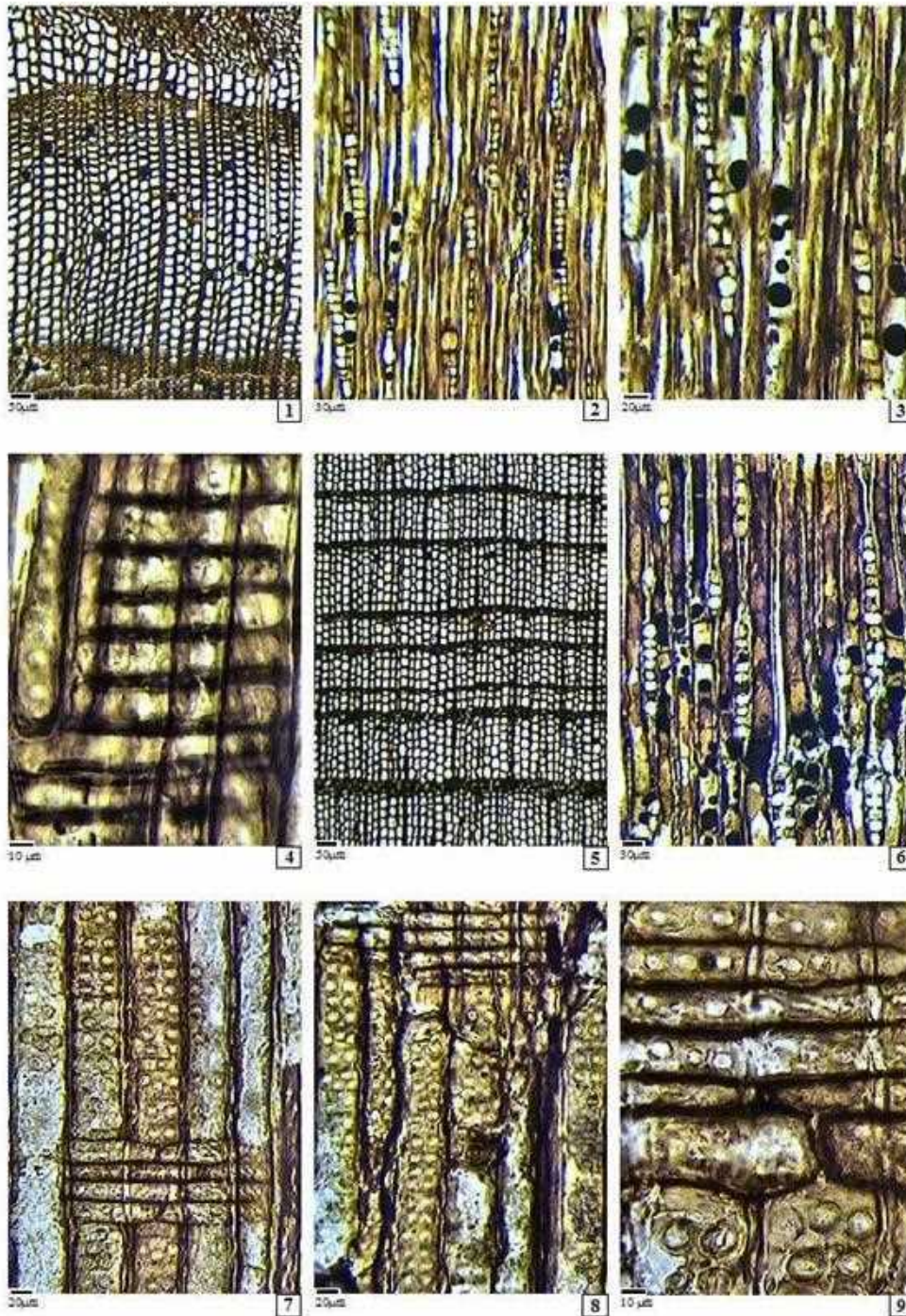
PLATE IV



Sequoioxylon gypsaceum, fossil wood from Colți (Bz.) - nr. 1 in "Colți Museums's Collection".

Figs. 1-3. Cross section. Thinwalled polygonal tracheids in early wood, parenchyma and rays in growth rings which are marked by late wood thickened cells. Figs. 4-6. Tangential section. Medium tall uniseriate rays with biseriate storeys; parenchyma cells with smooth horizontal walls and resin balls. Figs. 7-9. Radial section. Typical taxodioid cross fields pitting, axial parenchyma.

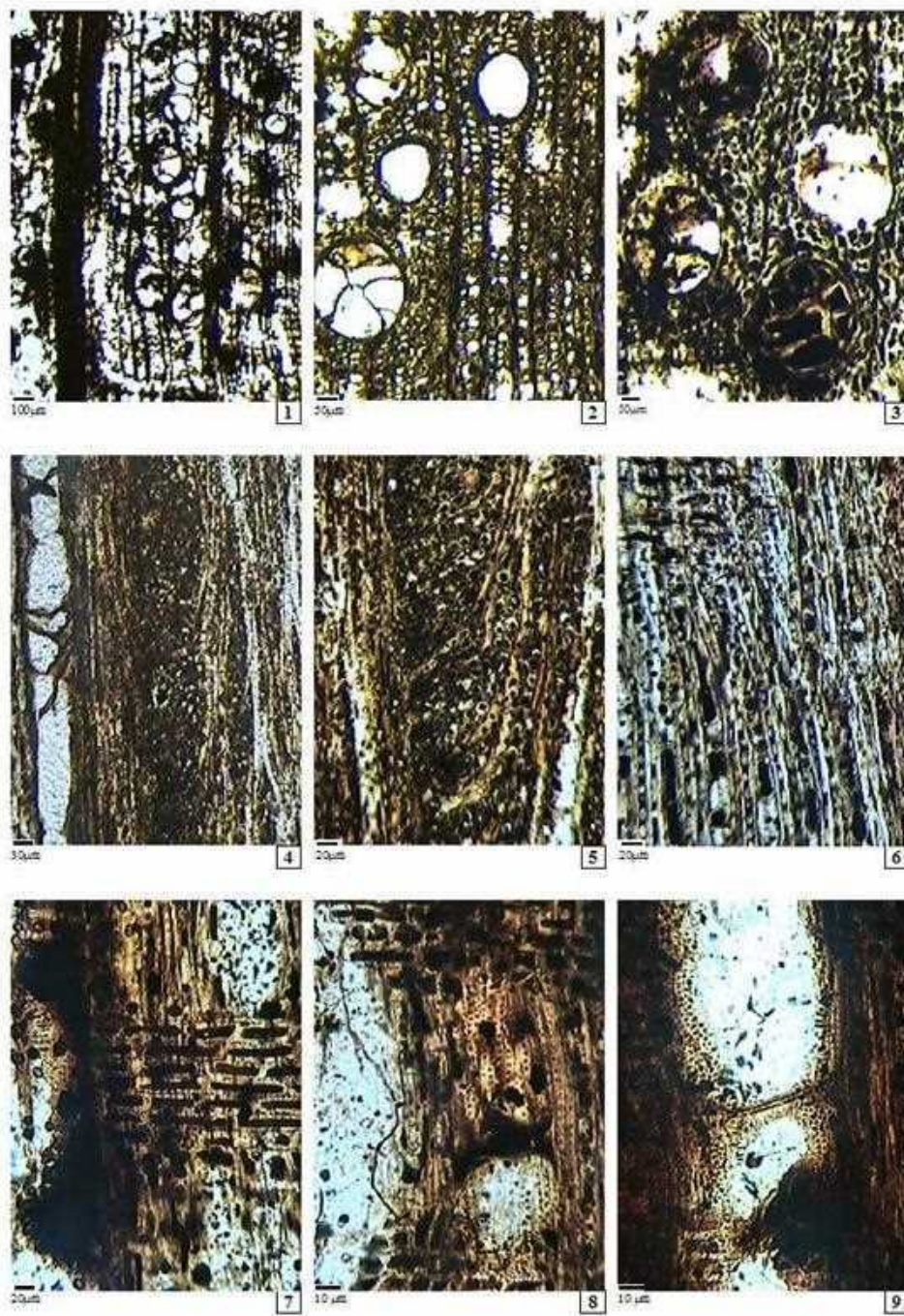
PLATE V



Sequoioxylon gypsaceum, fossil wood from Zâmbroaia (Ph.) - nos. 4, 6 in "UPG Collection, Ploieşti".

Figs. 1, 5. Cross section. Polygonal tracheids in growth rings which are marked by late wood thickened cells. Figs. 2, 3, 6. Tangential section. Tall uniseriate rays with biseriate storeys; parenchyma cells with smooth horizontal walls and resin balls. Figs. 4, 7-9. Radial section. 1-2-3 radial pitting, crassulae, taxodioid cross fields pitting, axial parenchyma.

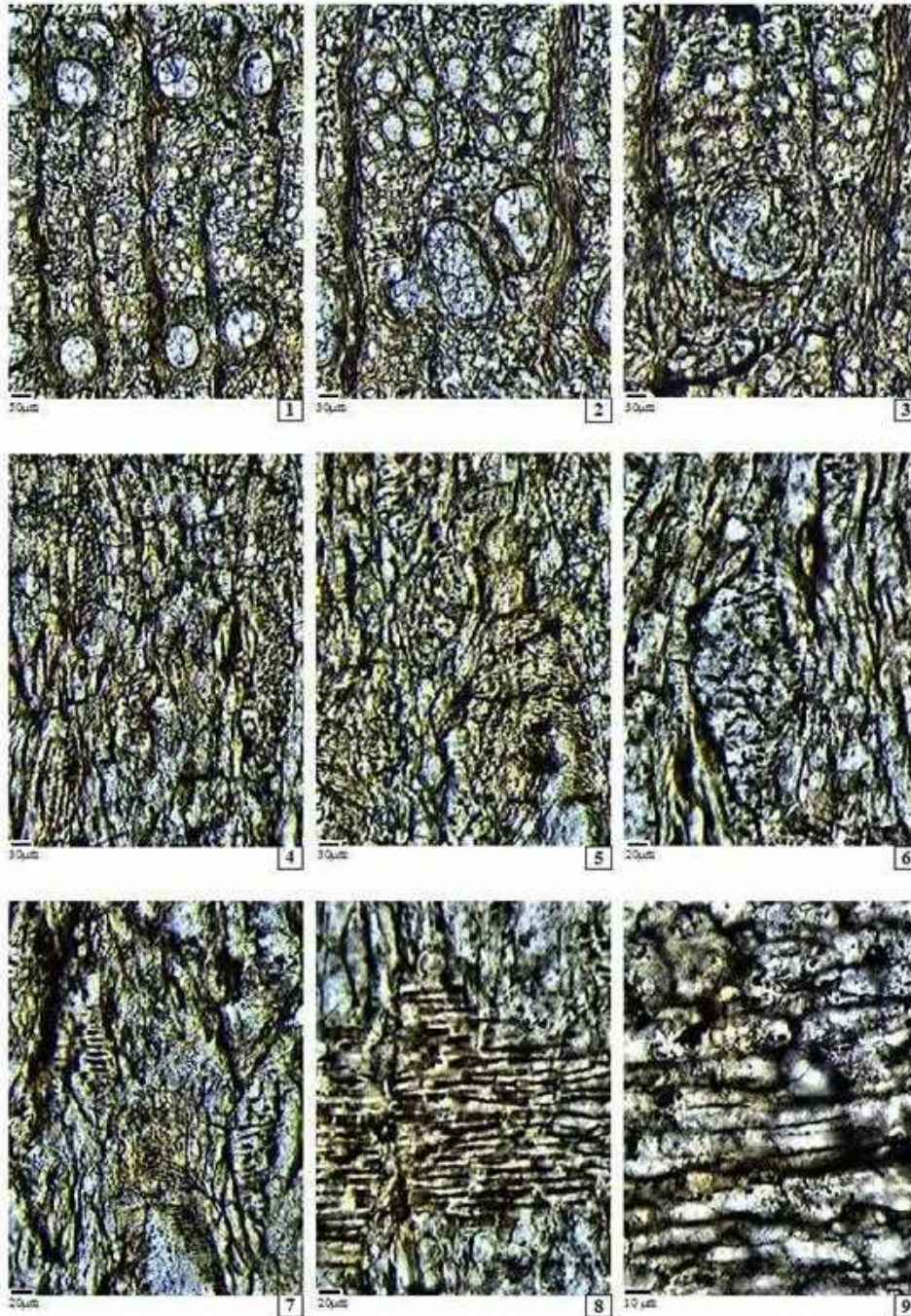
PLATE VI



Quercoxylon sp., reworked fossil wood from Lopătari (Bz.) - inv. no. 27.226, in the IGR Collection – National Museum of Geology, Bucharest.

Figs. 1-3. Cross section. Round thick-walled vessels radially arranged, fibers, fibrotracheids, parenchyma and uniseriate and broad rays. Figs. 4-6. Tangential section. Uniseriate and aggregate multiseriate rays, vessels and parenchyma filled with tannin. Figs. 7-9. Radial section. Radial pitting, unclear cross fields blurred by tannin, pitting on vessel, pitting on paratracheal parenchyma.

PLATE VII



Ulmoxydon sp. cf. *Ulmus carpinifolia* Gled., reworked fossil wood from Beceni (Bz.) - no. 5 in "UPG Collection, Ploiești".

Figs. 1-3. Cross section. Distribution of two-sized vessels: 1-2 rows of big, solitary round to oval vessels, and ulmiiform bands of small round vessels, and ground tissue of fibers, parenchyma and broad rays. Growth rings marked by late wood thickened cells. Figs. 4-6. Tangential section. Broad rays, vessels and parenchyma rather unclear, in a crushed structure. Figs. 7-9. Radial section. Pitting on vessels, cross fields blurred by tannin.

The hydrocarbon potential of the Romanian Black Sea continental plateau

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Abstract: The article deals with the petroleum systems in the North-Western Black Sea Basin covering Ukrainian, Romanian and Bulgarian shelves, with a focus on the traps, reservoirs and source rocks from the Romanian Shelf. A large variety of traps have been evidenced in the study area: fault anticlines in syn-extensional formations, not-faulted anticlines, pinch-outs, drape anticlines on older relief, traps in prograding formations at shelf margin, depositional fans, gravitational slide etc. The most important reservoirs are developed in the Albion, Upper Cretaceous (Turonian, Coniacian-Santonian) and Eocene successions of clastic (sandy) and carbonate types. Beside the Oligocene, older source rocks (Jurassic, Neocomian, Paleozoic?) are considered. Several petroleum systems are presented, with the specification of the traps, nature of the accumulated hydrocarbon, source rocks and reservoirs.

Keywords: oil field, trap, reservoir, source rock, petroleum systems

1. Introduction

The western part of the Black Sea Basin is one of the most promising hydrocarbon-bearing areas in the SE Europe. Its hydrocarbon potential has been proved by the oil and gas fields discovered on the Romanian shelf (Fig. 1). The most recent (2012) discovery is a huge gas field in deep water (Domino), estimated to 40-80 Bcf. The Romanian Continental Plateau of the Black Sea comprises the following geotectonic units, from the north to the south (Figs. 2 and 3):

- Krilov-Karkinit Depression (Moroșanu, 2004);
- Scythian Block (Moroșanu, 2002);
- North Dobrogea-Histria Depression;
- Greenschist Block-Midia Crest;
- Southern Dobrogea (Moesian Platform).

So far, Histria Depression is the most important by its hydrocarbon potential. Although the exploration for hydrocarbon accumulations in the Romanian Black Sea shelf started at the

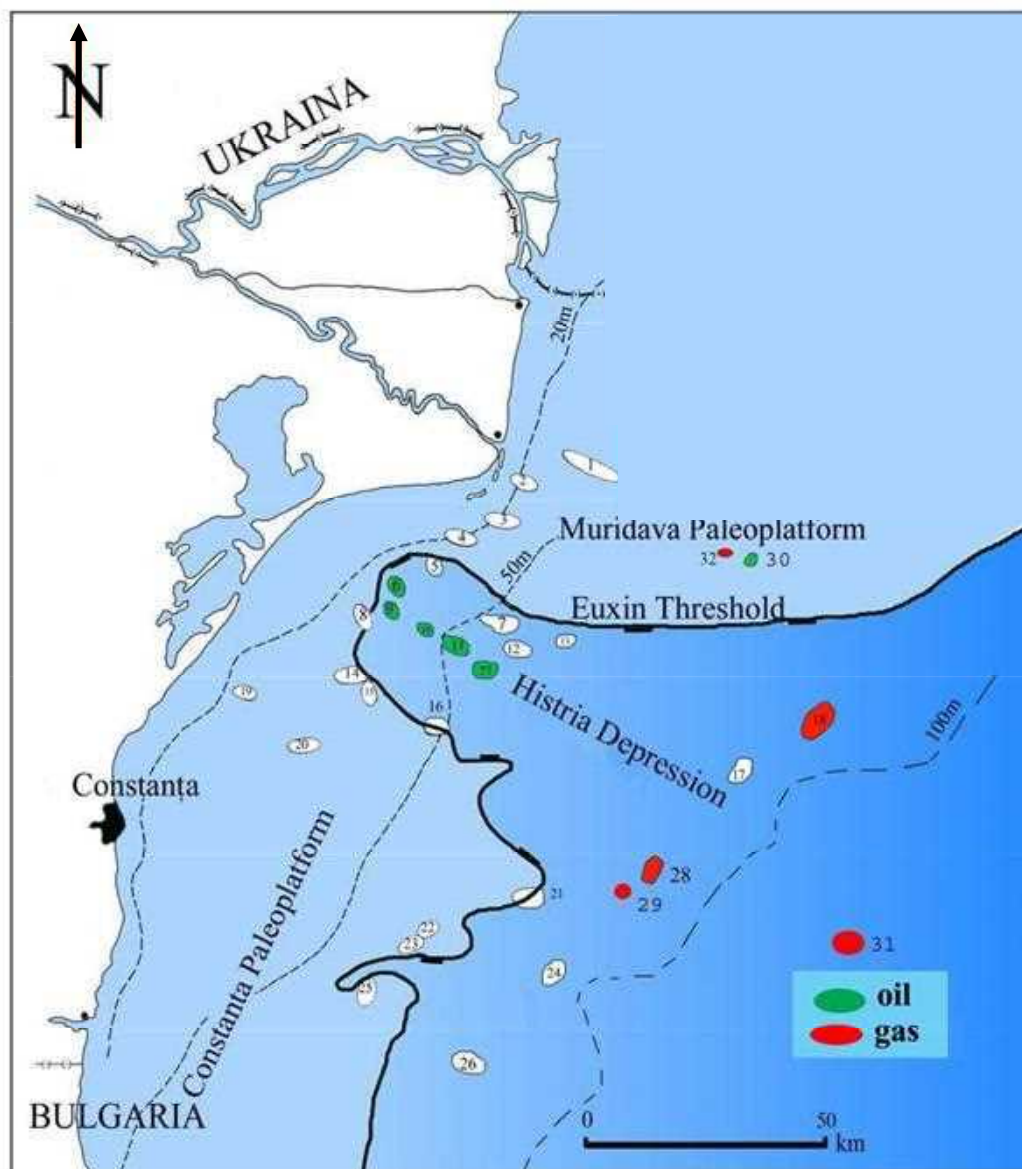
beginning of the 1970s, the number of investigated oil fields is still reduced. This fact is due to the structural complexities and to the concentration of the exploration works mainly on the northern flank of the Histria Depression, where the first oil accumulations were discovered. In the other areas, corresponding to the Moesian Platform and Scythian Block, the drilling exploration is deficitary.

The paper has been carried out using the seismic acquisition, gravimetry-magnetometry and wells data, in addition data from the published papers related to Ukrainian and Bulgarian offshore were used.

Until now, the following oil fields were evidenced:

- Pescăruș, with oil in Albion;
- East Lebăda with oil in Albion and Upper Cretaceous, and gas in Eocene;
- West Lebăda with oil in Albion, Upper Cretaceous and Eocene;

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1-Sf.Gheorghe 2-Pelican 3-Sacalin 4-Sturion 5-Egreta 6-Portita 7-Heracleea 8-Venus 9-Sinoe
 10-Lebada-W 11-Lebada-E 12-Minerva 13-Albatros 14-Iris 15-Lotus 16-Tomis 17-Ovidiu
 18-Cobalcescu 19-Vadu 20-Corbu 21-Midia 22-Meduză 23-Neptun 24-Neptun-E 25-Delfin
 26-Jupiter 27-Pescarus 28-Doina 29-Ana 30-Muridava(Olimpyska) 31-Domino 32-Eugenia

Fig. 1 - Location map of the Romanian Black Sea Shelf showing the Euxin Threshold, Histria Depression and the main plays and leads.

- Sinoe with oil in Eocene;
 - Portița with oil in Upper Cretaceous and Oligocene.
 - Muridava (Olimpyska) with oil in Eocene.
 - Eugenia with gas in Cretaceous and Eocene
- All these fields are situated on the northern flank of Histria Depression, except Muridava and

Eugenia, which are situated on the Scythian Block. Gas shows or commercial accumulations were frequently signalled, especially in the Lower Pontian and Dacian, practically in all the wells drilled, the most important of them being Doina and Doina Sister, Ana, Cobălcescu and Domino fields (Fig. 1).

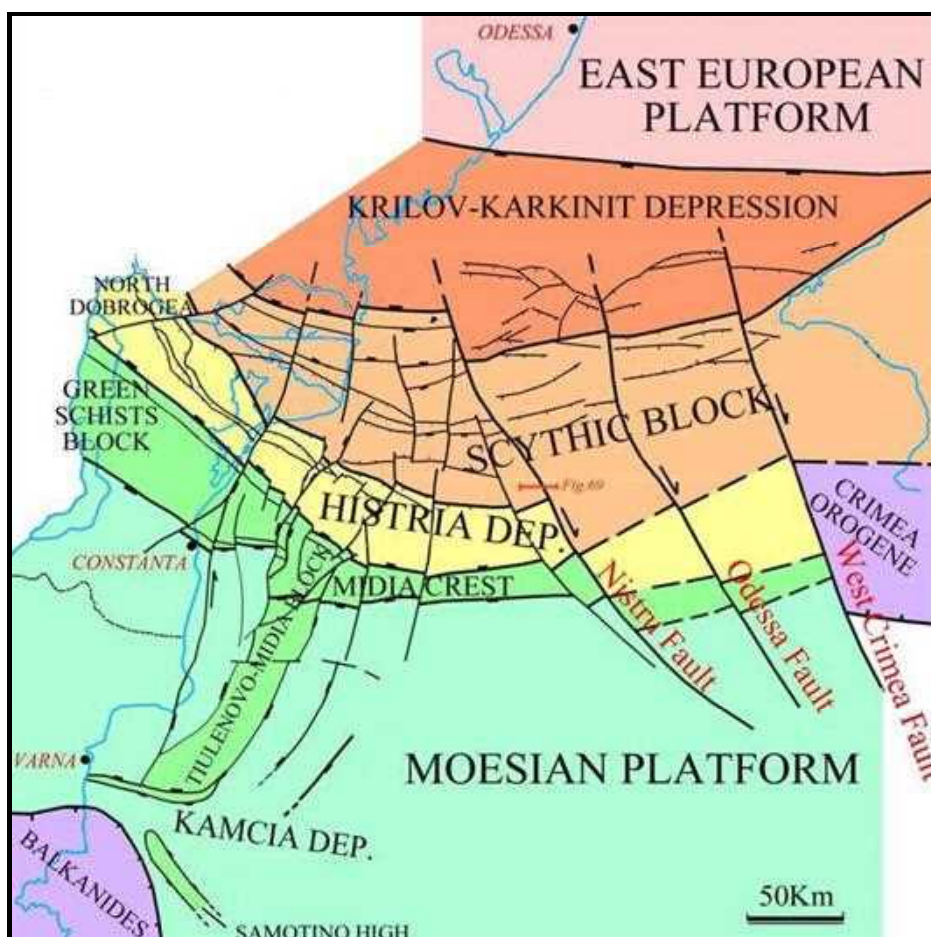


Fig. 2. Tectonic map of the Western Black Sea Shelf

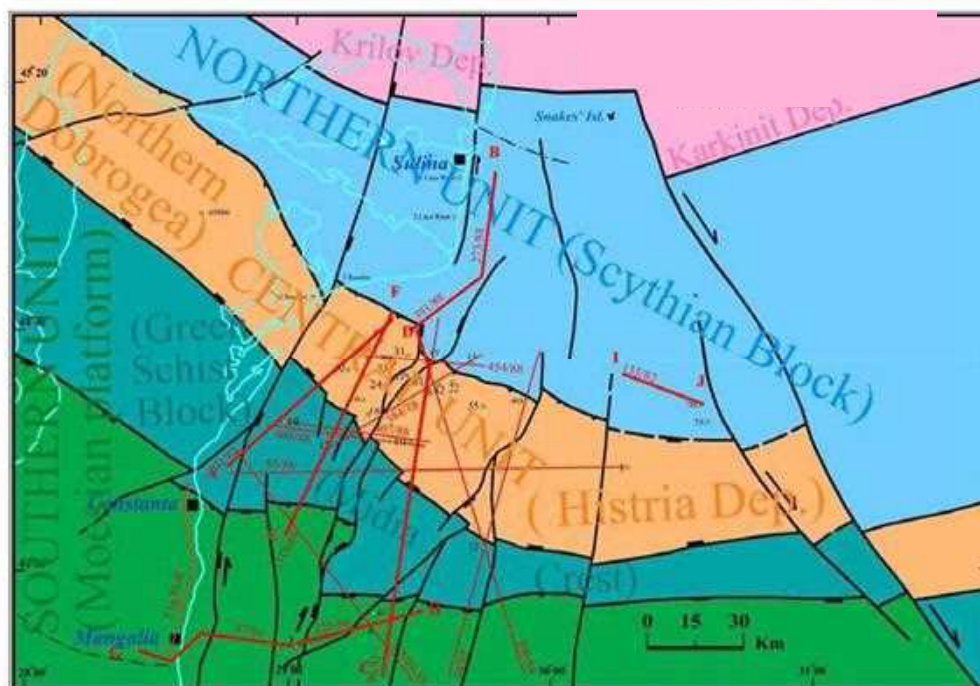


Fig. 3. Tectonic units of the Romanian Black Sea Shelf showing the location of the cross-sections and wells.

These data prove with certitude the favourable perspectives for the Romanian continental plateau but, in the same time, they show that there does not exist a unique law regarding the distribution of hydrocarbon traps, this fact being influenced, not only by the structural complexity, but also by the source rocks (the existence of one or several levels of source rocks, their burial conditions, etc.) but also by the migration paths and existence of the carrier rocks of hydrocarbon.

This paper presents the regional image of the hydrocarbon systems of the West Black Sea Basin correlated with the main tectonic features from this area. Although a large volume of data has been obtained from wells and seismic prospections, the petroleum systems have not been drawn and correlated with these data up to now. The purpose of this paper is to describe the petroleum systems from Western Black Sea Basin, focusing on the traps, reservoirs and source rocks from the Romanian Shelf.

2. Main structural and lithologic features

The existence of the oil and gas fields on the Romanian continental plateau as well as in its vicinity, at the south, in Bulgaria and at the north, in Ukraine, lead to the conclusion of the existence within the West-Black Sea basin of the entire chain of hydrocarbon genesis, migration and accumulation. In this manner, the deciphering of all elements that condition this chain becomes necessary exactly for the discovery of the hydrocarbon accumulations in a short period of time and with small costs.

2.1 Traps

Due to the depositional and structural complexity, a multitude of types of structures were formed on the Romanian continental plateau; some of these already proved to be traps for hydrocarbon, while others are considered as potential traps.

In general, in the Pre-Oligocene formations, the compressive structures predominate, caused by the inversion tectonics (Moroşanu, 1990; 1994a,b; 1996a,b; 1997; 1999; 2000; 2002;

2007). This tectonics causes fault anticlines in syn-extensional formations and anticlines, usually non-faulted, in the post-extensional formations. This type of structure occurs on the northern flank of Histria Depression, being represented by the Egreta, Lebăda-Portița and Sinoe trends as well as by the group of structures Pelican-Sacalin, belonging to the Scythian block (Figs. 4, 5 and 6). In the Moesian Platform there are a few structures of this type, among which the most important are East Neptun and Delfin (Fig. 7). In the areas that were not affected by the inversional tectonics or were affected in an insignificant manner, the traps are of stratigraphic type, represented by pinch-outs, drape anticlines on older relief or traps in prograding formations at the shelf margin. These types are mainly characteristic to the southern flank of the Histria Depression.

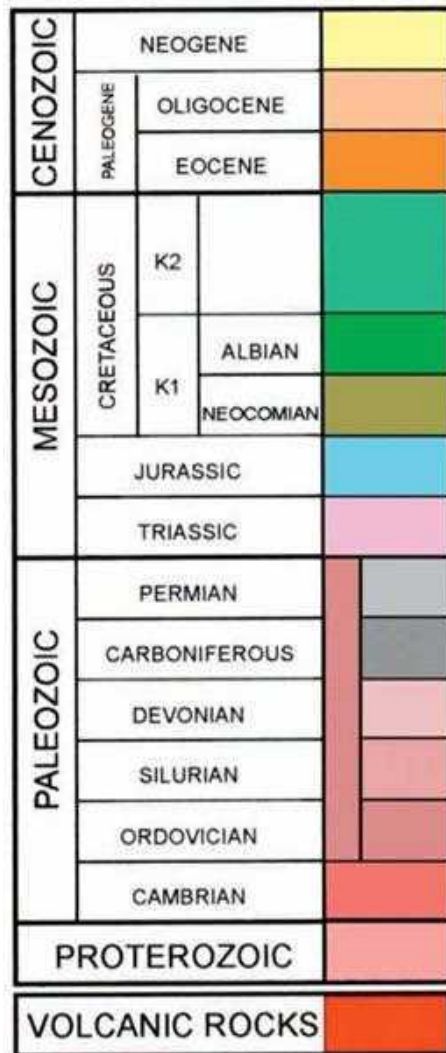
In the Oligocene formations traps can be found especially at the lower part, being of pinch-out type. In the post-Oligocene formations, the traps are of stratigraphic type, represented by depositional fans, especially in the Sarmatian formations, anticlines of differential setting, specific to the Pontian formations, spread on wide areas and being affected by gravity faults and growth faults.

A last type of structures, some of which became traps, are those caused by gravitational slide such as those from the Cobălcescu area (Fig. 8), where the roll-over anticlines, horsts, overthrusts from the front of the sliding blocks can become favourable traps for hydrocarbon (Moroşanu, 1994).

2.2 Reservoirs

The wells drilled on the Romanian continental plateau, especially on the Lebăda-Portița trend, showed that the most important reservoirs are developed in Albian, Upper Cretaceous (Turonian, Coniacian-Santonian) and Eocene (Ionescu, 2002). In Portița area, a reservoir has been outlined at the base of Oligocene (Ionescu, 2002). From the lithologic point of view, the reservoirs are represented by clastic rocks (especially sandy) and carbonate rocks.

Hydrocarbon potential of the Romanian Black Sea continental plateau



Legend of Figs. 4, 5, 6 and 7

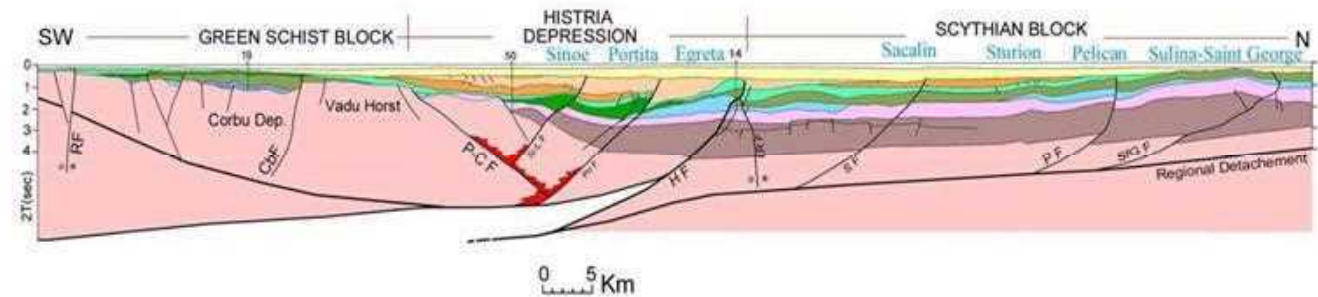


Fig. 4. Seismo-geologic cross-section A-B (see Fig. 3) showing the tectonic units of the Romanian Black Sea Shelf. CbF = Corbu Fault; HF = Heracleea Fault; LR F = Lacu Roșu Fault; P-C F = Peceneaga-Camena Fault; PF = Pelican Fault; Po F = Portița Fault; SF = Sacalin Fault; Si-L = Sinoe-Lebăda Fault; RF = Razelm fault; SfG F = Saint George Fault.

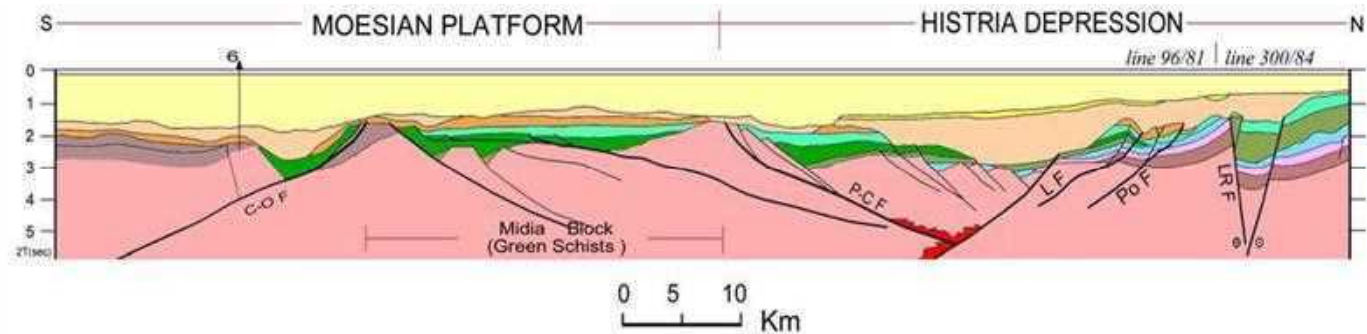


Fig. 5. Seismo-geologic cross-section C-D (see Fig. 3) showing the predominant extensional style of the Romanian Black Sea Shelf. C-O F = Capidava-Ovidiu Fault; LF = Lebăda Fault; LR F = Lacu Roșu Fault; P-C F = Peceneaga-Camena Fault; Po F = Portița Fault;.

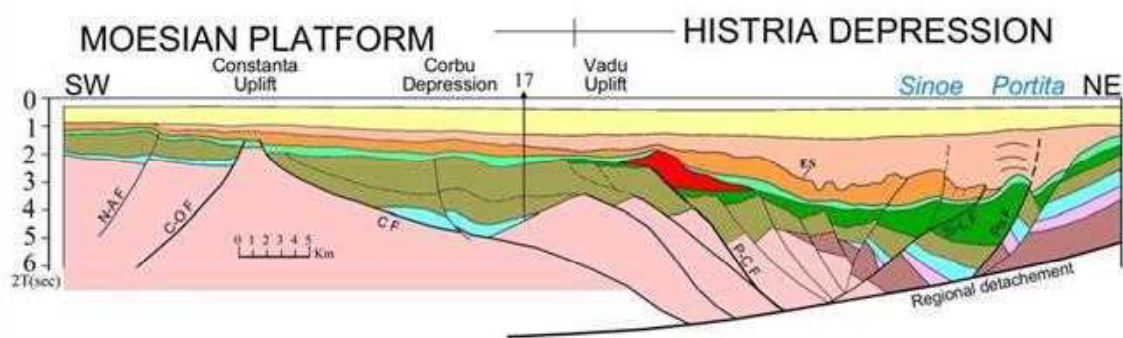


Fig. 6. Seismo-geologic cross-section E-F (see Fig. 3) showing the extensional and reverse features of the Histria Depression (for Legend, see Figs. 4 and 5). C-O F = Capidava-Ovidiu Fault; CF = Constanța Fault; NA F = North-Agigea Fault; P-C F = Peceneaga-Camena Fault; Po F = Portița Fault; Si-L = Sinoe-Lebăda Fault. ES = Erosional surface at the top of the Eocene.

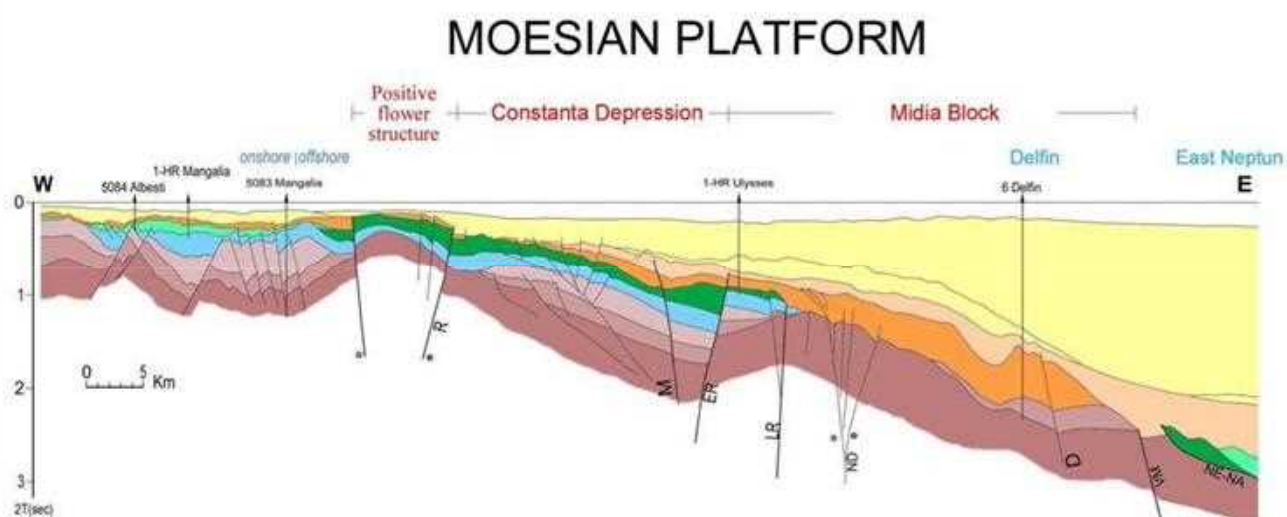


Fig. 7. East-west seismo-geologic cross-section G-H (see Fig. 3) showing a positive flower structure to east of the Mangalia town (for Legend, see Figs. 4 and 5). D = Delfin Fault; EN-NA = East Neptun – North Agigea Fault; ER = East Razelm Fault; LR = Lacu Roșu Fault; M = Mangalia Fault; ND = North Delfin Fault; R = Razelm Fault; VM = West Midia Fault.

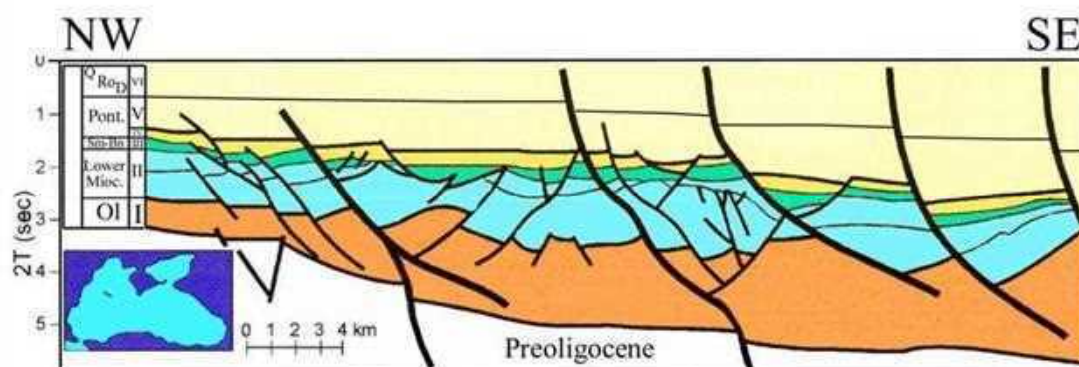


Fig. 8. Seismo-geologic cross-section I-J (see Fig. 3) showing the gravitational tectonics in Cobălcescu area.

The Albian reservoir is the most important for the accumulations of oil discovered until now. Lithologically it is composed of quartz sandstone with carbonate cement, lithic sandstone, micro-conglomerate and sandy limestone. The depositional geometries of wedge type and the variations of the thickness (maximum until 790 m in 13 Heraclea well), as well as its lithology, prove that this reservoir was formed under structural control, being formed concomitantly with extensional motions, that led to the opening of Histria Depression.

The Albian reservoir is characterised by the presence of an alternation between porous-permeable zones with compact zones. The values of porosity vary between 3 and 30% and the permeability between 1 and 200 mD (Ionescu, 2002).

The Upper Cretaceous reservoir is formed of micritic limestone, sandy limestone and chalky limestone with thin intercalations of sandstone, microconglomerate, marl and shale. The thickness of the reservoir varies between 30 m and 190 m. The porosity, average of 17%, is mixed, micro-fissural, vacuolar and intergranular, with a non-uniform distribution. The average permeability is of 0.48 Md.

The Eocene reservoir is of carbonate facies: shaly limestone, sandy limestone, microcrystalline limestone and marl. The total thickness exceeds 350 m. The porosity is mixed, intergranular, fissural and vacuolar having an average of 21%. The permeability is of 2 Md. In the western part of the West Lebăda field, the Eocene is represented by clastic rocks: sandstone, microconglomerate and conglomerate. These have an average porosity of 15% and an average permeability of 170 Md.

The Oligocene reservoir is less studied. It was reported only from the Portița field. This reservoir is formed of coarse quartz sandstone passing to microconglomerate. In 11 Portița well, this reservoir is placed at the lower part of the Oligocene black shale. Due to this reason, part of the geologists placed it at the top of the Upper Cretaceous that is developed immediately below. The 11 Portița well intercepted another layer, 5-10 m thick, of the same type, situated at

the lower part of the Oligocene shales but shallower, which places it undoubtedly in the Oligocene.

2.3 Source rocks

The study of the Black Sea began much later than in the surrounding areas. Therefore, the first phase of interpretation was that the onshore structure was continued in the offshore (Figs. 2 and 3). In this manner, knowing from the southeastern area (Georgia) that the Oligocene is represented by the Maikop schists (resembling with dysodilic facies from the Eastern Carpathians) it was considered that this formation represents also the Oligocene of the Black Sea. Also, that here being developed on wider areas and having better conditions for generation, this will produce oil that will be found in the adjacent areas.

On the Romanian continental plateau the seismic study and later drilling wells in the Histria Depression lead to the discovery of the oil accumulations on the north-eastern flank of this depression. These discoveries have in common two important features: first – the structures that appear on this flank are of the same type (fault anticline at the northern flank, which took birth during the inversion process and belong to pre-Oligocene formations) (Figs. 4 and 5) and the second – the Oligocene formations enter successively in contact through onlap (pinch-outs) with each of the older formations, beginning from the axle of the depression towards its flanks. This placement led to the conclusion that the Oligocene is the only source rock responsible for the existent deposits.

The existence of rocks older than the Oligocene (such as the Dogger) as source rocks has been considered (Baltes, 1988, 1989, 1991) but subsequent research, including geochemical analyses (Șaramet et al., 2005; 2008; 2010; Cranganu et al., 2009; 2011), certified the Oligocene as generator, at least for the accumulations discovered until now in Histria basin; the origin of the oil and gas from Olimpyska (Muridava) and Eugenia, situated on the Scythian Block remains yet unclear.

Passing at the research with wells in other areas (especially the southwestern flank of the Histria Depression) with the same structural-stratigraphic characteristics, the results obtained were negative. This fact gives us to think at the “oneness” of Oligocene as source rock.

After 1990, the companies that operated on the Romanian Black Sea shelf (*Petrom, Enterprise, Paladin, Hemco, Elf, Sterling, Exxon*) made also some geochemical studies in order to determine the source rocks and their parameters. The results obtained are quite contradictory and could not lead to a clear conclusion, allowing the possibility that source rocks older than the Oligocene produced the oil.

3. Discussions

3.1 Problems related to source rocks

3.1.1 Oligocene as source rock

For these formations there were analysed over 30 tests taken from the Albatros, Minerva, East Lebăda, West Lebăda, Sinoe, Portița, Midia, Ovidiu and Cobălcescu fields. The results of the analyses are presented in Table 1 (Ionescu et al., 2002) and they only test if the Oligocene is or not the source responsible for the oil discovered until now.

Our interpretation of the results led to the following conclusions:

- **TOC** is uniformly distributed, with frequent values over 1. Hence, the possibility of the Oligocene to be a source rock is good.
- **EOM** – all values (except for two) go over 500 ppm, in the Ovidiu-Minerva-Cobălcescu area the values being the biggest. Therefore, the Oligocene can be considered as a source rock.
- **HC** – in the Histria Depression area, the predominant values are under 300 ppm with few exceptions. In Ovidiu-Minerva-Cobălcescu area, the values frequently go over 500 ppm, reaching even over 1000 ppm. So the potential of generation is moderated towards small, only in the last mentioned area (Cobălcescu), the potential is good towards really good.

- **EOM/TOC** – 2/3 of the tests are within 3-10%, being considered immature or weakly matured, 1/3 have percentages of 10-15% and only 2 tests pass 15%. This means a medium or low maturity degree and implicitly a low generation degree.

- **HC/EOM** – in the area of Histria Depression is frequently under 50%. In Ovidiu-Minerva-Cobălcescu area most values are over 50% and the smallest are close to 50%.

- **HE/TOC** – more than 3/4 of the tests produced values below 5%, while ca. ¼ of them are between 5% and 8% (4 of them being very close to 5%). Therefore, from the organic matter point of view, Oligocene has a quite low oil generation potential (in this area).

Hence, we can say that Oligocene can be considered as source rock, but its potential of hydrocarbon generation becomes obvious only in the Ovidiu-Cobălcescu area (and probably gets developed southeastward, in the area of the deeper basin). Similar conclusions appear in other reports (Geochem, 1993, 1994): the investigated Oligocene sediments are immature or very close to the maturity limit, but are not in the oil window. For the Cobălcescu area, there are greater possibilities that the Oligocene is a source rock that might have generated oil.

Nevertheless, the research published by Șaramet (2004), Șaramet et al. (2005), Cranganu and Șaramet (2011), based on isotopic and molecular analyses of the oils and bitumen extracted from the source rocks, indicated the Oligocene pelites as the source rocks of the hydrocarbon accumulations from the north-eastern flank of the Histria depression.

3.1.2 Pre-Oligocene formations as source rocks

Because the analyses on the tests from the well 13 Heraclea (3874 m – Middle Jurassic and 4100 m – Lower Jurassic) and 12 Midia well (3257-3884 m – Neocomian) are few, we do not believe that they can be taken as fully representative for these formations but the results can be integrated within a valid general frame. So, the results of the analyses for the well 13 Heraclea show that

Table 1 Source rock parameters (Ionescu et al., 2002)

	Location	Well	Depth (m)	TOC (%)	EOM (ppm)	HC (ppm)	HC/EOM (%)	EOM/TOC (%)	HC/TOC (%)
1	Albatros	40	3017-3019	0.42	530	323	60.94	12.62	7.69
2			3083-3084	0.87	1025	441	43.02	11.78	5.07
3	Minerva	22	1852.5-1853.5	1.19	1281	333	25.99	10.76	2.8
4	East Lebăda	8	1162-1164	1.53	885	329	37.17	5.78	2.15
5			1300-1303	1.78	936	296	31.62	5.26	1.66
6			1380-1381	1.65	568	130	22.89	3.34	0.78
7		82	1442-2445	1.5	1312	356	27.13	8.75	2.37
8		83	1675-1676.5	0.6	649	201	30.97	10.81	3.35
9		85	1753-1755	1.88	1210	372	30.74	6.43	1.97
10		89	1855-1859	3.12	984	504	51.22	3.15	1.61
11	West Lebăda	25	1816-1821	1.04	497	230	46.28	4.78	2.21
12			1936-1941	1.3	427	251	58.78	3.28	1.93
13		817	1908-1912	1.37	1003	328	32.7	7.32	2.39
14		818	2144-2147.5	1.03	1196	558	46.65	11.61	5.41
15			2322-2328.5	0.68	1385	713	51.48	20.36	10.48
16			2328.5-2338	1.12	1289	626	48.56	11.5	5.58
17	Sinoe	33	1939.3-1939.4	0.62	312	84			
18	Portița	11	1384.1-1384.8	0.61	730	227	31.09	11.96	3.72
19	Midia	12	2574-2575.5	1.37	589	161	27.33	4.29	1.17
20			2817.5	0.58	580	204	35.17	10	3.51
21	Ovidiu	1	3941-3946	0.98	1224	242	19.77	12.49	2.46
22		K28 L-1	4406-4410.5	1.49	1380	740	53.62	9.26	4.97
23		K28 L-2		1.31	1374	648	54.43	10	4.94
24		K30 L-1	4562-4567	1.83	1818	918	50.49	10	5.02
25		K30 L-2		2.39	1756	880	50.1	7.34	3.64
26		K31 X	4820-4824.5	2.34	1536	626	40.79	6.56	2.67
27		K31 Y		1.12	2098	902	42.99	18.73	8.05
28			5001-5006	1.95	1664	822	49.39	8.53	4.21
29									
29	Cobălcescu	75	3496.2-3496.4	1.92	2147	1917	89.29	11.18	9.89
30			3597.4-3597.6	0.91	488	236	48.36	5.36	2.59
31			3601.7-3601.8	1.49	3070	2308	17.18	20.6	15.48
32			3714-3714.6	0.93	326	176	53.98	3.5	1.89
33			3996.7-3997	1.91	1812	684	37.75	9.49	3.58

the Jurassic formations are mature, but still not in the oil window, while the tests from the well 12 Midia prove that the Neocomian formations are weak producers of gas.

While analysing 4 oil tests (one from Sinoe, another from Portița and two from West Lebăda), Geochem (1994) reached the following conclusions:

- the oils are quite similar and seem to have the same type of source rock and maturity;
- all tested oils are unaffected by bacterial alteration and were not washed by water;

- it is possible that oils were generated by Tertiary sources or Upper Cretaceous ones, rich in algal organic matter deposited in an anoxic environment;

- the generation of oils appears at the upper limit of the oil window;

- the similarities between the distribution of biomarkers from these oils suggest that none of these oils migrated long distances;

- the small differences of the ratio between biomarkers and carbon isotopes suggest that the oil from the Eocene reservoirs (test from Sinoe

and from West Lebăda) is a little less mature than those from the Albian (West Lebăda) and Oligocene (Portița) reservoirs.

Hence, according to the data given above, a paradoxical situation appears: clearly established oil accumulations exist, but the Oligocene does not seem to have generated all of them because its source rocks are quite poor and also the generation conditions are not reached. It has to be mentioned that for the formations older than the Oligocene, there are no data published until now. Therefore, the problems of the rocks that generated the hydrocarbon and the processes of hydrocarbon accumulation are not entirely solved.

3.2 Petroleum systems

If we consider that the oil did not migrate a long distance, according to one of the conclusions mentioned above, this would mean that the Oligocene could not be the source of all deposits but older formations, belonging to Neocomian, Jurassic or even Paleozoic have to be investigated as source rocks. If we consider that Oligocene is the source rock, then we have to accept also a migration on a longer distance, from the deeper parts of the basin. Chișcan et al. (1998), referring to the structures Portița (e.g. Portița 11 well), Sinoe and Lebăda, presumed that hydrocarbon migration from the deep zones to the shallower traps took place along porous channels from the base of the Oligocene formations. However, it is of note that the discovered oil accumulations are preferentially located on the northeastern flank of the Histria Depression and that a migration of the oil from east to west can be inferred, as an upward trend towards west, as well as the successive filling, towards the west, of progressively younger reservoirs, reaching the Oligocene in the Portița field. This fact might reinforce the idea of source rocks older than Oligocene.

In this sense, there can be noticed that the structures with oil are placed on an area with Neocomian formations (black shale) and Middle Jurassic formations that are also argillaceous-limy. These were deposited syn-extensional, in

long and narrow troughs spread on the northwest-southeast direction and which, through permanent subsidence during the extensional period, followed by the cover of post-extensional formations, could have reached the oil window. Moreover, after the inversion period that has lifted them up together with the entire structure, part of these formations are still in the oil window, in the conditions of a thermal flux with a medium value of 60mW/m^2 (Veliciu, 2002). The same situation could have existed on the southwestern flank of Histria Depression, where the thermal conditions were similar. The gas shows from 18 Lotus and 10 Tomis wells plead for further investigation of this flank. The oil generation from a Middle Neocomian-Jurassic local system might very well explain the distribution (until now) of the structures with commercial oil accumulations only on the northeastern flank of the Histria Depression. Another commercial oil accumulation was discovered in 2001 – Muridava (Olimpiska) field to the north of Histria Depression, in the Scythian Block. The oil and gas are trapped in fractured and cavernous limestone of Middle Eocene. In our opinion, the source rocks belong to the Lower Cretaceous, developed below, especially to the Barremian, with black shales. If this is the case, the Muridava (Olimpiska) field can be considered to belong to the same system as the northeastern flank of the Histria Depression. Similar conditions could be met by the Neocomian and even the Paleozoic formations (Silurian) situated in the Corbu-Constanța depression. Taking this into account and also the different maturity of the oil from several structures, there is clearly outlined the idea that at least part of the oil was generated by rocks older than Oligocene, from the Eocene to Paleozoic, that could locally generate in conditions of high heat flow.

The heat flow could bring some clarifications on the condition under which the hydrocarbon accumulations have formed. In the Black Sea, more than 500 determinations of heat flow have been made (Veliciu, 2002). Although the number is impressive, it is not satisfying, if we take into consideration that most of these

measurements are concentrated on areas with exploration wells for hydrocarbon. The map resulted from the measurements presents two areas with relatively high heat flow, around 72mW/m^2 . One is northeast of the Romanian

shelf and continues to the area in front of the Danube Delta, covering the Karkinit Depression; another one is in the southwestern extremity of the Romanian shelf, partially placed onshore, partially offshore, in the Mangalia area (Fig. 9).

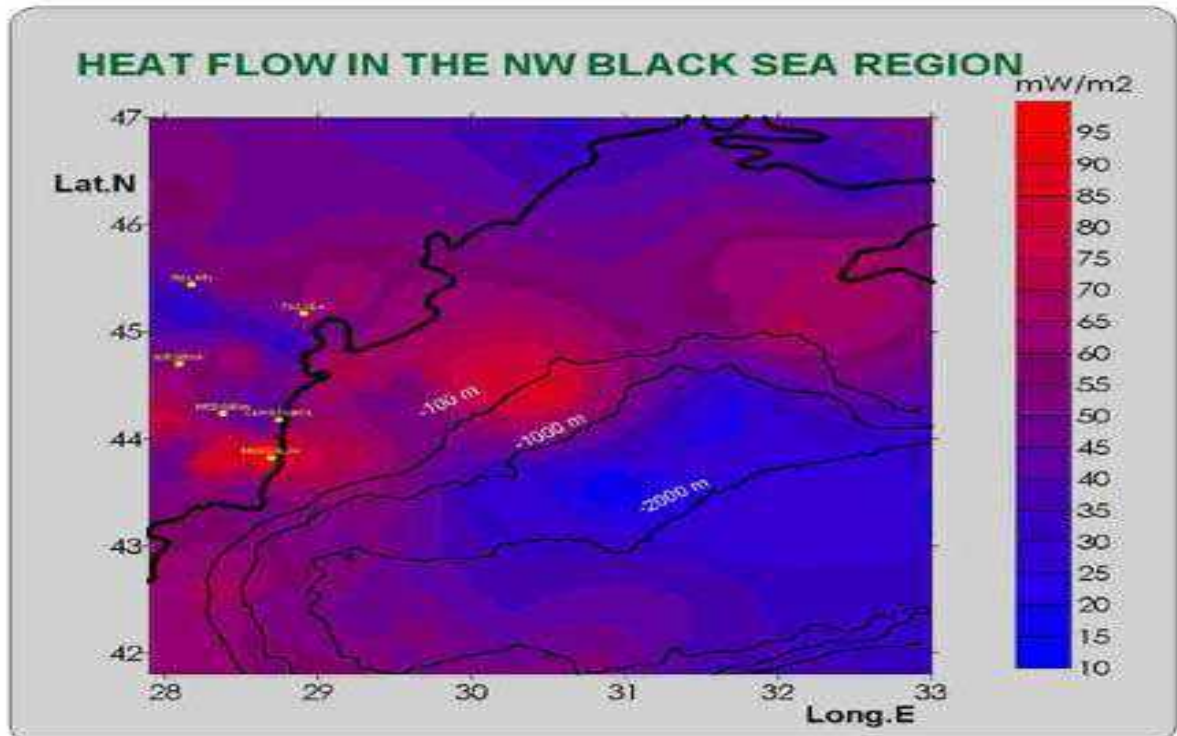


Fig. 9. Heat flow map on the north-western shelf of the Black Sea (Veliciu, 2002).

Between these areas, a lower heat flow ($32\text{--}46\text{ mW/m}^2$) is superposed on the central area, respectively Histria Depression-North Dobrogea, fact which is quite curious if we consider that Histria Depression has a riftogene character and only in this area there are oil fields. We also have to mention that this is the present heat flow. We do not have yet values of paleoheatflow that are really interesting for the pre-Oligocene period. However, it is possible that the present values were somehow higher in the two extreme areas of the Romanian shelf, reaching almost 90 mW/m^2 if we apply the corrections for the reduction of thermal gradient as a result of

sedimentation ratio and of thermal refraction (Veliciu, 2000). The heat flow values presented above for the Romanian shelf are quite low. This fact, correlated with depths until 3500 m where is included a part of the formations which are possible source rocks, from the Oligocene to the Middle Jurassic, leads to the conclusion that they did not beneficiate of optimum conditions of generation. An exception is represented by the Ovidiu area, where the Oligocene is developed from 3992 m downwards and where it might generate oil and gas condensate, which is confirmed also by the burial and maturation history diagram from this area (Figs. 10 and 11).

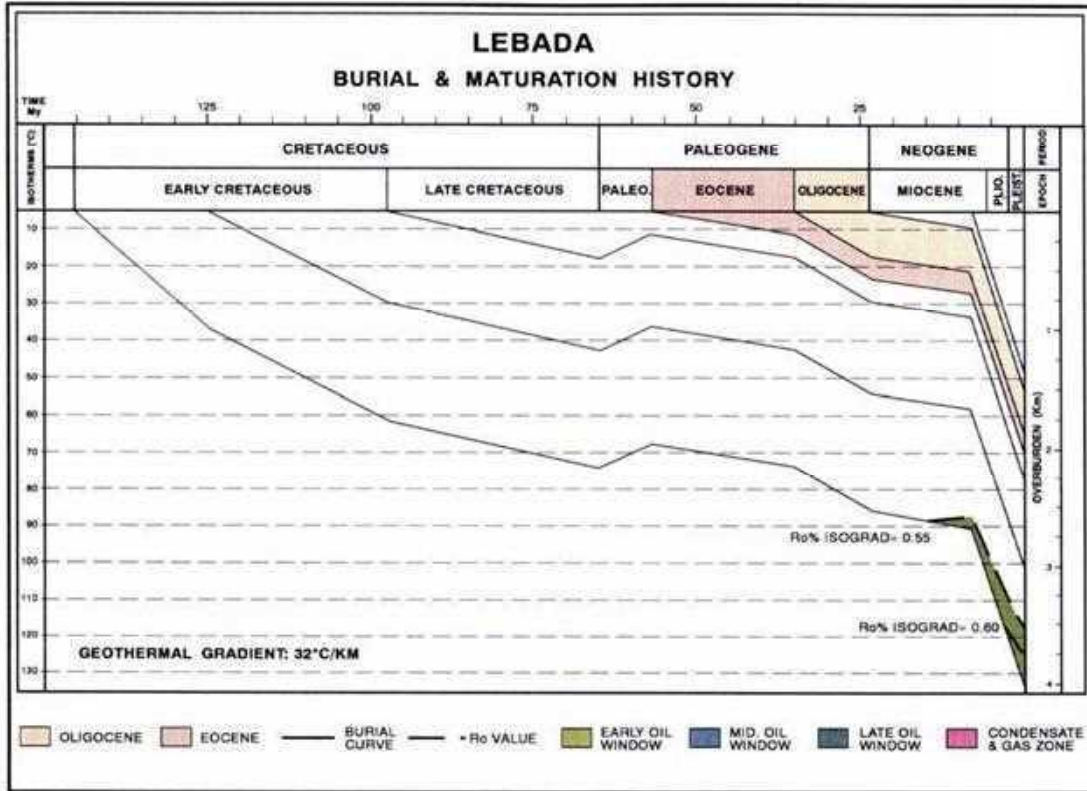


Fig. 10 - Burial and maturation history in Lebăda area.

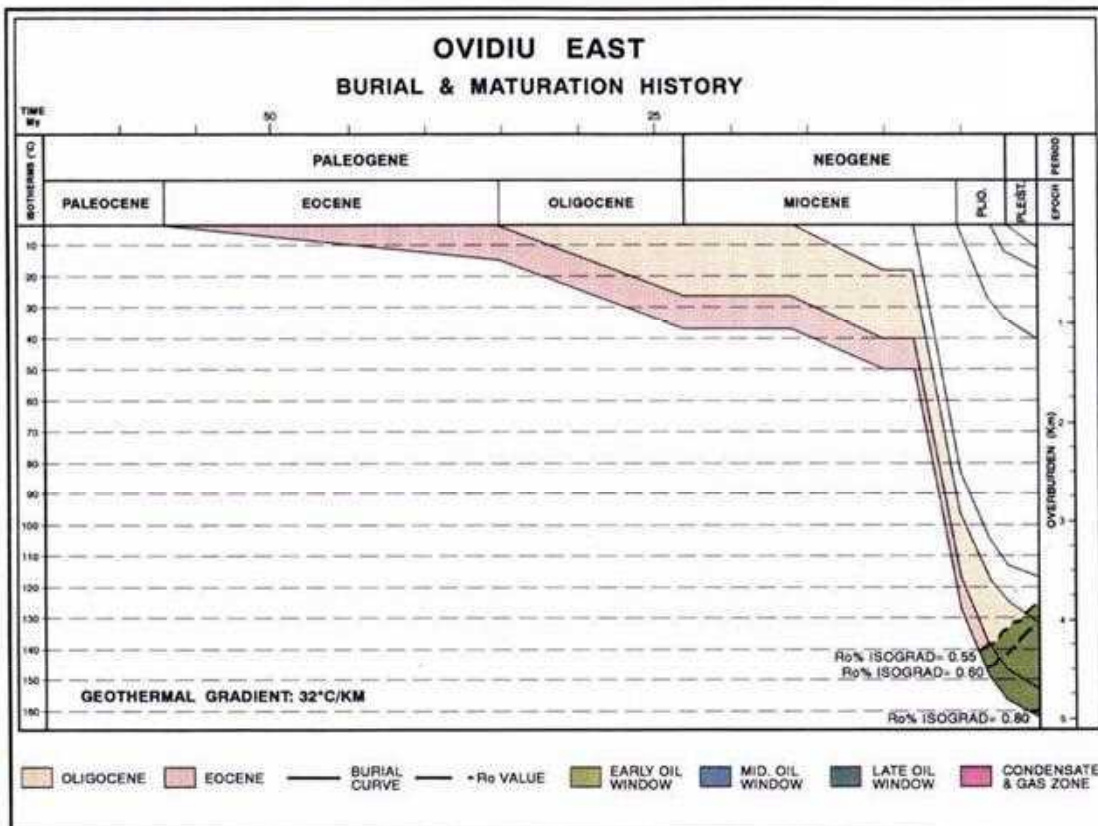


Fig. 11 - Burial and maturation history in Ovidiu area.

According to the data from these diagrams, the Oligocene together with the Eocene and, partially, Miocene would have entered in the upper part of the oil window, the generation beginning from the Pliocene. Also, in the area of the well 12 Midia, the Neocomian black shale and the Jurassic limestone might generate oil and gas condensate. For the source rocks from Paleozoic, in the absence of thermal paleoflux data, we cannot make any remarks but related to their burial depth, which, during their evolution, at least for part of them, crossed the oil window, these being able to generate hydrocarbon.

The problem of the source rocks is put actually for the entire western shelf of the Black Sea. The hydrocarbon discoveries from this part are presented in Table 2.

In Ukraine – area of the Odessa Gulf and surrounding onshore – around 40 leads with possible hydrocarbon accumulations were identified, 20 of them being localised in the Karkinit Depression, part of these proving to have gas accumulations (Fig. 12). The leads contain from one to four reservoirs included in the depth interval 500-2190 m. Eleven of these belong to Maikop formation (Oligocene), 4 to the Lower Paleocene, 1 to the Eocene and 1 to the Miocene. Within the shelf structures, only gas accumulations were discovered, excepting the Golitiin field, with gas condensate. On the onshore, oil was discovered even in older rocks. In Crimea, in reservoirs belonging to the Lower Cretaceous, there was discovered oil (Oktiabriskoe West), oil and gas (Oktiabriskoe) and gas-condensate (Tatyanivka).

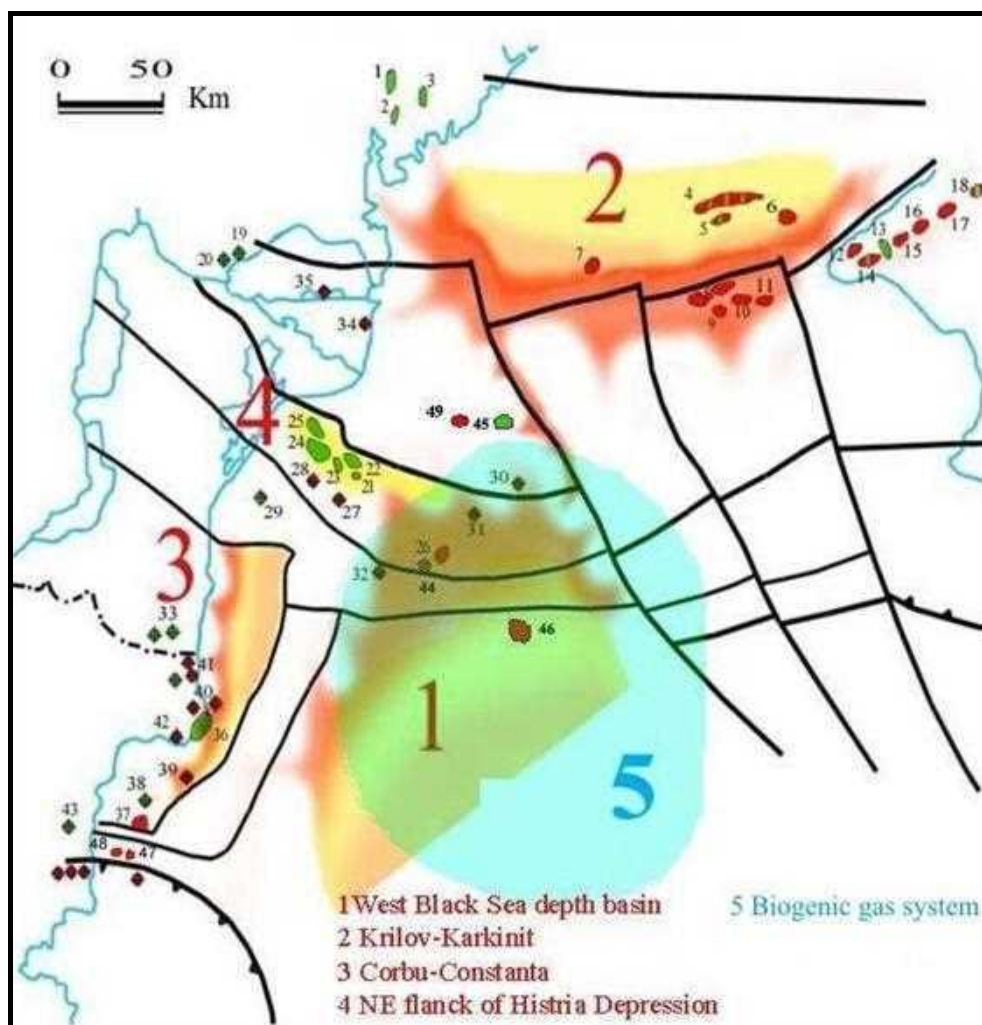


Fig. 12. The petroleum systems and directions of hydrocarbon migration (from lighter shades to darker ones) on the northwestern shelf of the Black Sea (see Table 2). Red = gas, green = oil. Circles = hydrocarbon accumulations identified but not outlined, yet.

Table 2 Oil and gas fields and shows in the West Black Sea Basin and surrounding areas. Numbers correspond to those from Fig. 12.

No	Field	Hydrocarbon	Age of reservoir
UKRAINE			
1	Sărata	oil	Devonian 2-3
2	Belolesii	oil	Devonian 2-3
3	Jeltii Yar	oil	Devonian 2-3
4	Golitin	gas-condensate	Paleocene
		gas	Oligocene-Miocene
5	South Golitin	gas	Oligocene
6	Shmidt	gas	Oligocene
		gas-condensate	Upper Cretaceous-Paleocene
7	Odessa	gas	Eocene-Lower Paleocene
8	Stormova	gas	Lower Paleocene
9	Arhanghelski	gas	Lower Paleocene-Oligocene-Tortonian-Sarmatian
10	Stileva	gas	Oligocene
11	Crimea	gas	Oligocene-Miocene
12	Olenev	gas	Paleocene
13	Oktiabrsk	oil	Neocomian-Aptian
		gas	Cenomanian
14	W-Oktiabrsk	gas-condensate	Middle Albion
15	Glebovkoe	gas	Lower Paleocene
16	Krasnopolev	gas	Paleocene
17	Tatianivka	gas-condensate	Middle Albion
18	Zadorneno	gas-condensate	Lower Paleocene
19	Izmail	oil shows	Jurassic
20	Matroz	oil shows	Jurassic
ROMANIA			
21	Pescăruş	oil	Albian
22	East Lebăda	oil	Albian, Upper Cretaceous
		gas	Eocene
23	West Lebăda	oil	Albian, Upper Cretaceous
			Eocene
24	Sinoe	oil	Eocene
25	Portiţa	oil	Oligocene
26	Doina	gas	Pontian
27	Tomis	gas shows	Neocomian

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28	Lotus	gas shows	Neocomian
29	Vadu	gas shows	Neocomian
30	Cobălcescu	gas	Pontian
31	Ovidiu	gas shows	Pontian
32	Midia	gas shows	Pontian
33	Comana	oil shows	Middle-Upper Devonian
34	Lacu Roșu	gas shows	Middle Jurassic
35	Obretin	gas shows	Middle Jurassic
44	Ana	gas	Pontian
45	Olimpiska (Muridava)	oil	Eocene
46	Domino	gas	Pliocene
49	Eugenia	gas	Cretaceous, Eocene

BULGARIA

36	Tiulenovo	oil & gas	Valanginian
37	Galata	gas	Upper Cretaceous-Paleocene
38	Epsilon	oil shows	Lower Cretaceous
39	Elisabetino	gas shows	Cretaceous
40	North Sabla	gas shows	Eocene
41	Krapez	gas & oil shows	Oligocene
42	Bulgarevo	gas shows	Paleocene
43	Blyznatzy	gas shows	Paleocene
47	Samotino More	gas condensate	Middle Eocene
48	LA-1	gas condensate	Valanginian

These fields, like those from the shelf, are in their majority of fault anticlines, the faults being reversed. On the western shore, in Devonian formations, 3 fields with oil were identified: East Sărata, Belolesii and Jeltii Yar. In the same area, oil shows also appear in Jurassic formations (Izmail, Matroz) (Fig. 12).

The pelitic sequences of the Upper Eocene could be considered as possible source rocks of many gas fields from the shelf. Nevertheless, the presence of gas condensate (Golîţin) diminishes this possibility because the Eocene is not mature enough even to produce oil (Robinson et al., 1997). Also, the Aptian-Albian pelitic rocks might represent source rocks. They contain small quantities of carbon and kerogen of III type, favourable to the production of dry gas and might generate hydrocarbon if there were

deposited in deep zones of the extensional basins (Robinson et al., 1997).

The discovery of oil accumulations in Devonian formations, on the west shore of the Odessa Gulf (Table-2) might suggest also the presence of the Paleozoic source rocks.

At the south, on the Bulgarian shelf, the single one oil field discovered is at Tiulenovo and contains oil and gas in the fissured carbonates of Valanginian. Also in the Galata field there was evidenced gas in calcareous sand of Paleocene, in Samotino More field gas condensate in Mid Eocene and in LA-1 gas condensate in Valanginian (Georgiev, 2012). Gas shows were identified in few small structures from the onshore, at the border between Romania and Bulgaria. In this southern area, as well, the source rock is not known but

only supposed. For the Tiulenovo field, Bottomley et al. (1998), consider, based on the analysis of the biomarkers, that the source has to be Tertiary and localised at a distance of no less than 50 km south-east of the field, in the Kamcia Depression because in its vicinity these sediments are immature. Nevertheless, in the Kamcia Depression, from the burial depths point of view (Sinclair et al., 1997), only partially the Lower Cretaceous and partially the Jurassic might be considered as potential generating source rocks. In this case, the position of the Tiulenovo field is correlative with the position of the source rock from the Kamcia Depression.

Georgiev (2012), according with data from Rock-Eval analyses, log records and biomarker correlations on the Galata-1 well, drilled in 1993, consider that the primary source rocks in East Varna Trough are Lower-Middle Jurassic argillaceous sequences: Provadia and Etropole formations. For Samotino More and LA-1 fields, the author considers possible source rocks belonging to the Eocene and Paleocene-Upper Cretaceous. The latter two fields are situated in Kamcia Depression (Fig. 12). Hence, it can be stated that the most difficult problem for the hydrocarbon investigation in the western part of the Black Sea is the identification of the source rock.

Regarding the Romanian shelf, the hydrocarbon potential seems to be distributed to four termogenic petroleum systems and one biogenic gas system (Fig. 12):

Krîlov-Karkinit system presents a high heat flow favourable to the transformations of the organic matter. The active source rocks might be placed in the interval Eocene-Jurassic and possibly Paleozoic. The migration paths could be on the Nistru fault southward, in this manner the hydrocarbon being able to enter in contact mainly with the Scythian Block and the northeastern flank of the Histria Depression. This direction would be confirmed also by the position of the oil fields discovered until now, Eugenia and Muridava (Olimpyska) (Fig. 12). The Paleozoic could have encountered the burial-generation conditions, especially that on the

onshore, immediately west of Olimpyska and Eugenia fields, there are a few oil fields and numerous oil shows in this type of formations (Fig. 12). The hydrocarbon in these discoveries, considering their location at depth, cannot come but from Paleozoic source rocks.

The West Black Sea deep basin system, which, even if does not present a high heat flow, might gather favourable burial-generation conditions for the formations of the basal Oligocene situated at more than 3000 m depth. The most probable migration path could be represented by the unconformity Oligocene/Pre-Oligocene. The role of the Oligocene formations in this system might be especially of seal. The area favourable for the accumulation within this system, is represented by the eastern flank of Midia-Tiulenovo Block situated in the immediate vicinity, west of the generation area (Figs. 3 and 12). The hydrocarbon migration from the West Black Sea deep basin system to the traps of the Histria Depression would have covered quite a long distance (100-150 km), which is unlikely.

Corbu-Constanța depression system is placed between the Razelm and Lacu Roşu faults and is continued southward, in Bulgaria with Varna Trough, the Tiulenovo field being tributary to this system (Fig. 12). Here, the burial depths and the proximity to the area of higher heat flow from Mangalia, creates good conditions of generation, especially for the Paleozoic (Silurian) and Neocomian formations. The plans with northern vergence and east-west direction of the normal or reverse faults can represent good paths of migration towards traps of fault anticline type. The degraded oil put into evidence in the Devonian formations from 1 Comana well, on onshore, 10 km west of the shore line, pleads for this migration. Also, the complex of Razelm and Lacu Roşu faults might represent paths migration. Moreover, along these faults, there might exist different traps represented by uplifted blocks of “positive flower” structure type; this seem to be the case of the Tiulenovo field and of the structure from

the front of Mangalia town, towards offshore, the latter being shown in Fig. 7.

The north-eastern flank of the Histria Depression system is a system more or less local, developed on semi-grabens created through extensional and then reversed dynamics where the Neocomian formations represent the main generating source rock. These formations had good generation conditions by burial and presently they are not uplifted, through inversion, to more than 3000 m depth. From the correlation of the seismic lines with the well data, it results that these formations, together with those from the Middle Jurassic, which have possibilities of generating hydrocarbon, are quite well developed on this flank.

The coincidence of the development of some Neocomian-Middle Jurassic source rocks, in favourable conditions of burial-generation, beginning from the extensional period and until

the present, with the existence here of the East Lebăda – Portița and West Lebăda – Sinoe fields, with oil and gas accumulations, make us believe that we are in presence of a hydrocarbon system.

The migration paths towards traps can be represented by the reverse faults with northwest-southeast direction as probably is the case of the Lacu Roșu fault that seems to divide the system in two areas: an eastern area, with Albatros, East Lebăda and West Lebăda fields, and a western area, with Sinoe and Portița fields.

The situation could be repeated for the opposite flank of the depression, where it also might exist a petroleum system that only needs to be put into evidence. Anyway, we do not exclude the possibility that the Oligocene sedimentary was a source rock, with the active source rock being situated in the deep basin. The migration path could have been the erosional surface from the base of the Oligocene.

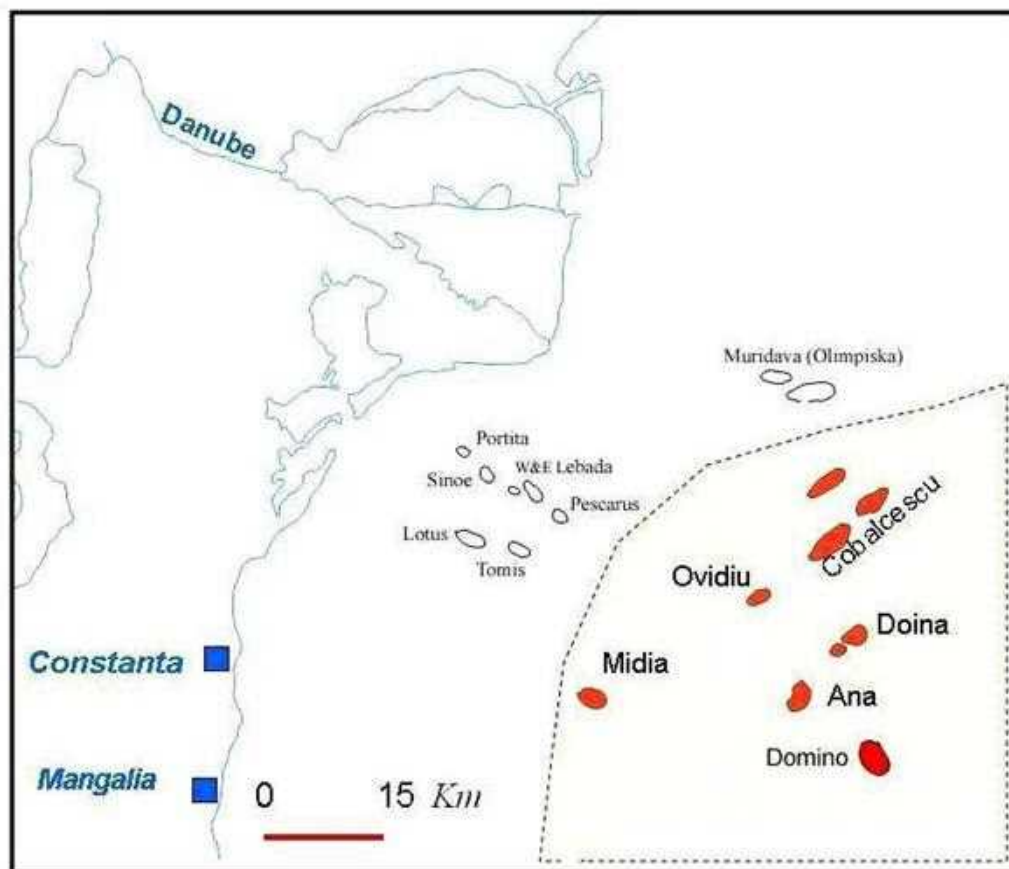


Fig. 13 - The biogenic gas system (red) on the Romanian Continental Plateau

The biogenic gas system is placed on the Western Black Sea depth basin being represented by Midia, Ovidiu, Cobălcescu, Doina and Doina Sister, Ana and Domino gas fields (Figs. 12 and 13). The gas is trapped in Lower Pontian-Dacian sandstones and the source rock is considered to be the pelitic formations from the Lower Pontian (and Sarmatian?). Seals can be all pelitic sequences from the Pliocene. The type of traps are represented by large drape anticline (Ovidiu, Midia), roll-over anticline or horsts and monocline beds affected by lystric faults (Cobălcescu –Fig. 8). Also, there are many stratigraphic types of traps (pinch-out, depositional fans, etc) not drilled until now. Gas migration can be considered on vertical direction or along lystric faults. This system could be extended towards west north-west and north, numerous gas shows being reported from the Lower Pontian in all wells drilled on the Romanian shelf.

4 Conclusions

The continental plateau of the western Black Sea is characterised by a variety of traps and reservoirs. So far, the north-eastern part of Histria depression comprises most hydrocarbon accumulations on the western Black Sea shelf. Beside the Oligocene, proved as source rock for the petroleum system in the north-eastern flank of Histria depression, older rocks could have generated hydrocarbon, as well.

In our opinion, on the Romanian Continental Plateau, only a small part of the hydrocarbon reserves have been discovered, huge reserves being undiscovered yet.

Acknowledgements

The author benefited from the constructive remarks made by Mihai Şaramet (University "Alexandru Ioan Cuza" Iaşi) and by an anonymous reviewer on an earlier version of the manuscript.

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A new assessment of the Kısacık gold mineralization (Ayvacık-Çanakkale, NW Anatolia)

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Abstract The Kısacık gold deposit is situated within the Ayvacık-Karabiga tectonic zone of the Biga Peninsula (Western Turkey). There are indications that both fault-related control and lithological control were important for the genesis of the mineralization. Gold mineralization at Kısacık is of two types. The first one is relatively high grade gold ore associated with quartz-sulphide veins located within the units rich in pumice. The second one occurs in thick layers of pyroclastic rocks, with gold grain size ranging from 10 µm to 100 µm. The gold grains occur within quartz, as well as along fractures and in the wall rocks.

Key words: ignimbrite, gold deposits, Kısacık-Çanakkale, Biga Peninsula, Anatolia, Turkey

1. Introduction

The registered owner of Kısacık Area is Mehmet Sedat YALINKAYA, chief executive officer of Goldaş Holdings A.S. (Golaş) and president of Pregold. The Kısacık Property is accessible by paved road from Çanakkale, a city with a population of approximately 150,000, to the village of Kısacık, and then by gravel road. Historical mining on the Kısacık Property is indicated by the presence of several old adits, whose portals are partly collapsed. During the 2008 exploration program, the General Directorate of Mineral Research and Exploration of Turkey (MTA) discovered two old adits and at least four small pits, which are suspected to represent gold mining operations. One of them is situated close to the road to Ayvaçık, where gold is reported to have been produced by gravity concentration (Fig. 1). All these old mining works are situated within ignimbrites. An old adit at Mağaradere is 28 m long and is driven in north-easterly direction.

Another adit, at Sudöndü Dere, is 70 m long, with similar orientation (Kılıç et al., 2009, Özpınar et.al. 2009, Agnerian, 2010). At the present time, there are no clear indications on the age of these old workings.



Fig. 1. Gold grains after panning.

The purpose of this paper is to inform about the studies related to Kısacık gold deposit as well as on some mineralogical and chemical aspects, to discuss on the alteration, deposits type and origin of gold mineralization.

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2. Geological background

The Kısacık area is situated within the Ayvacık-Karabiga Zone on the Biga Peninsula (Western Turkey). The Biga Peninsula comprises three main northeast-trending tectonic zones. From northwest

to southeast, these are known as the Ezine, Ayvacık-Karabiga, and Sakarya zones (Fig. 2). The study area is underlain by basement rocks of the Paleozoic Kazdağ Metamorphic Group (KMG), which have been thrust and unconformably overlain by younger Upper Cretaceous

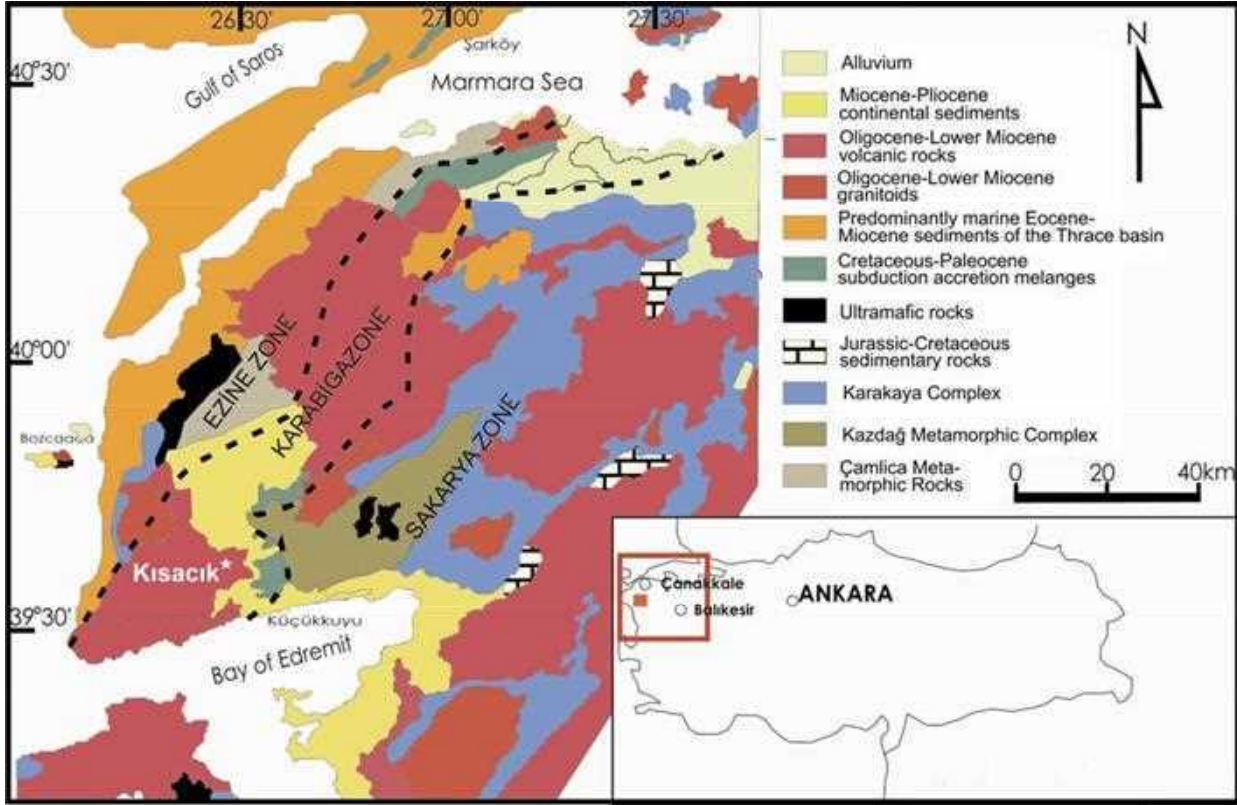


Fig. 2. Location map of study area and geotectonic map of NW Anatolia (Okay and Satır, 2000).

Çetmi Ophiolitic Mélange (ÇOM), Mid-Miocene Hüseyinfakı volcanic rocks including ignimbrites, rhyolite, rhyolitic tuffs and lapilli tuffs, and clastic rocks of the İlyasbaşı Formation, with lateral, vertical transitions, volcanic intercalations, and angular disconformity over pre-Tertiary basement rocks. The Pliocene conglomerates, sandstones, and siltstones of the Bayramiç Formation unconformably overlie older rocks in the area.

3. Geology of the study area

The lithostratigraphic composition of the Kısacık Property includes several formations.

İlyasbaşı Formation (İb): Within the Kısacık area, the İlyasbaşı Formation comprises reddish brown to yellowish beige siltstone, sandstone, claystone, gravel, tuff and sandy limestone (Fig. 3), deposited in lacustrine environment (Kılıç et al., 2009).

Hüseyinfakı Formation (Kf): Hüseyinfakı Formation is represented by volcanic rocks and includes greenish-grey to purplish-grey basaltic, trachy-andesitic lavas, and pyroclastic rocks.

Ignimbrite (Ig): Ignimbrite is the most common rock type on the Kısacık area. Commonly, it contains disseminations and stringers of pyrite, quartz and hematite veinlets.

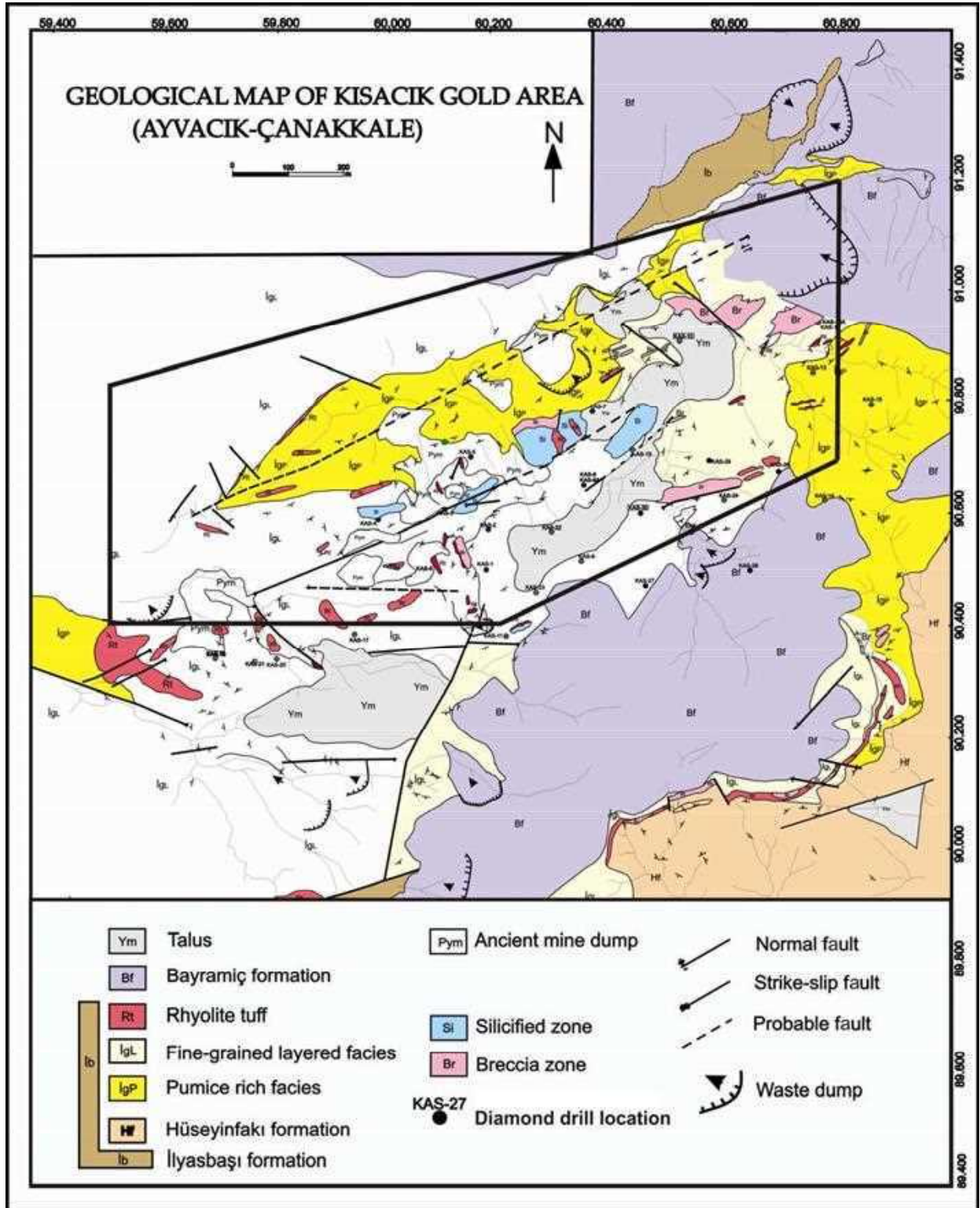


Fig. 3. Geological map of the Kısacık (Ayvacık-Çanakkale) gold district. The area inside the polygon is represented in Fig. 4.

Rhyolite and rhyolite tuff (Rt): Rhyolite and rhyolitic tuff comprise pink or grey, fine-grained rocks with porphyritic texture, and micro-crystalline quartz as matrix material. The tuff variety includes fresh biotite, sanidine phenocrysts and volcanic glass.

Bayramıç Formation (Bf): Bayramıç Formation rocks overlie all other rocks on the Biga Peninsula. They comprise poorly-consolidated Pliocene gravel, conglomerate, siltstone, and minor limestone, interpreted to have been deposited in a lacustrine environment

Alluvium: Alluvium comprises Quaternary unconsolidated material deposited in areas of depression due to faulting or other talus slope material

4. Investigation methods

This investigation has begun in 2002 and still continues (Kılıç et al., 2004, 2007, 2008 and 2009, Özpınar et.al, 2009). The detailed knowledge related to investigation is given below.

In the first stage, in 2002, in the area of 80 km², detailed geological mapping (at 1:10,000 scale) was carried out and pre-geochemical study was made and then alteration area at the

Kırantepe location of Kısacık village was determined.

In the second stage study, during the years 2003-2004, detailed geological mapping (1:2,000 scale) and detailed geochemical studies were made. According to these studies, Au-Sb-As anomalies were determined for Kısacık area. It was revealed for the first time that Au-Sb-As anomalies were caused by the gold mineralization that have been mined during the ancient periods.

From 2004 to 2006, MTA carried out systematic mineralogical and petrographic studies on diamond drill core as part of the exploration program at Kısacık. In total, 2,920 samples were analyzed by Atomic Absorption Spectroscopy (AAS) method. Some samples were also assayed by the fire assay method, while 239 samples were studied under the microscope, 92 determinations were carried out by X-ray Diffraction (XRD) method, and 42 fluid inclusion studies were carried out on samples of drill core. Afterwards, according to mineralogical data, the alteration map (Fig. 4) and geological revisions were carried out by Özpınar et. al. (2009).

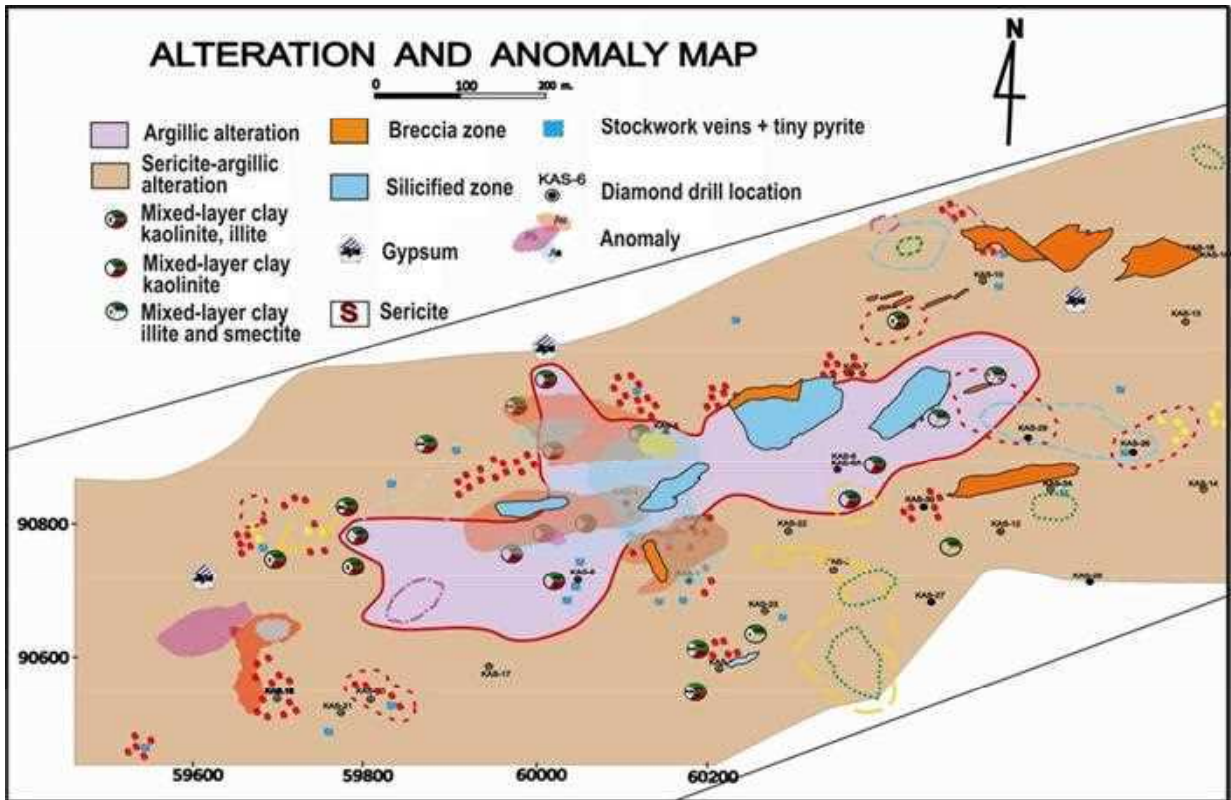


Fig. 4. Alteration map of the Kısacık (Ayvacık-Çanakkale) gold district.

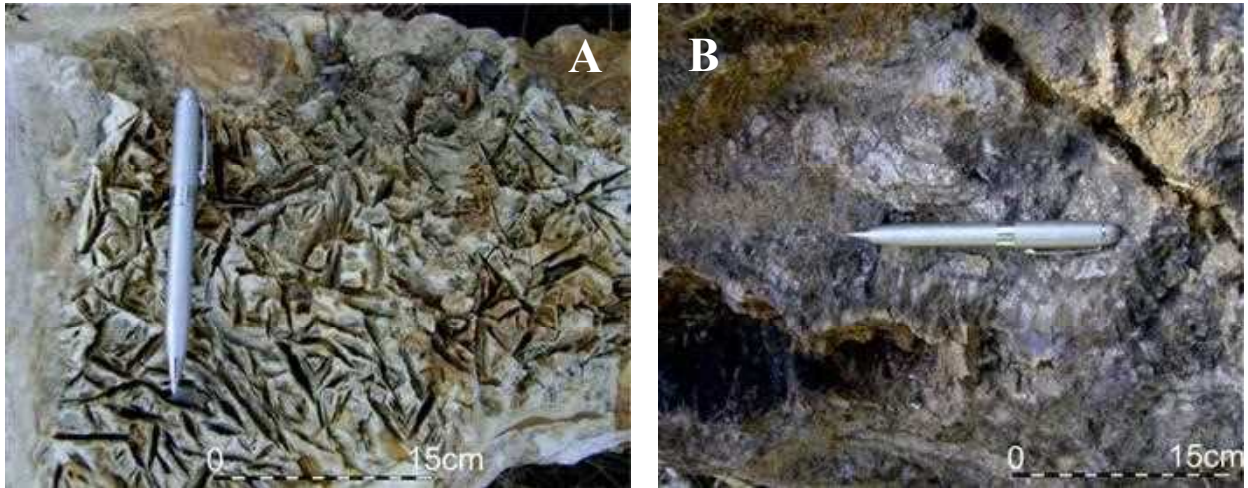


Fig. 5. Examples of quartz textures in the Kısacık area. A. Jagged quartz texture. B. Symmetric quartz texture.

5. Results and discussions

In the Kısacık area, argillic and sericitic-argillic alteration types have been identified. The results of 145 thin section specimens and 25 XRD investigations have been used to make the alteration map. The alteration zones of the study area consist of an argillic alteration zone located in the central part of the study area and sericitic-argillic alteration located around the argillic alteration (Fig. 4). Quartz is the most common mineral, since it is resistant to alteration, sometimes forming symmetric or jagged textures (Fig. 5A,B). In places, quartz mobilization has resulted in small scarps comprising of jasper. The original feldspars have been completely altered to kaolinite and illite. Occasional calcite veins are also present, and limonitic pseudomorphs of pyrite occur along fracture planes. Mineralogical studies (thin sections and polished sections) indicate that the gold mineralization at Kısacık is associated with intense silicification, sericitization and carbonate alteration.

The combined study of the alteration map and ore anomalies indicate an intense silicification located in the central part of the study area, related to a fault zone with NE-SW direction.

Gold mineralization in the Kısacık (Ayvaçık-Çanakkale) gold district is typical of high-sulphidation, quartz-clay mineral assemblage, epithermal systems, formed at relatively shallow depth, from just below the surface to a little over one kilometre deep, from acid-pH hydrothermal

fluids with temperatures ranging from less than 150°C to 300°C.

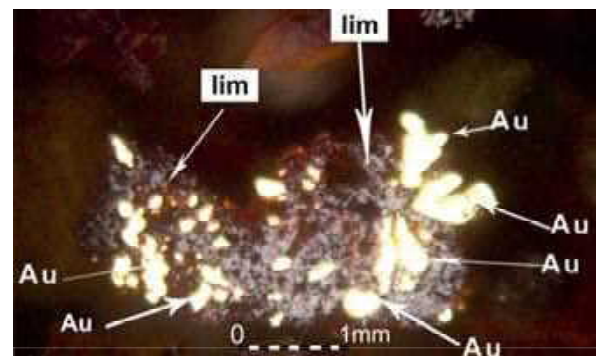


Fig. 6. Gold grains included in limonite (goethite) pseudomorphs on pyrite. Reflected light. Au = native gold, lim = limonite.

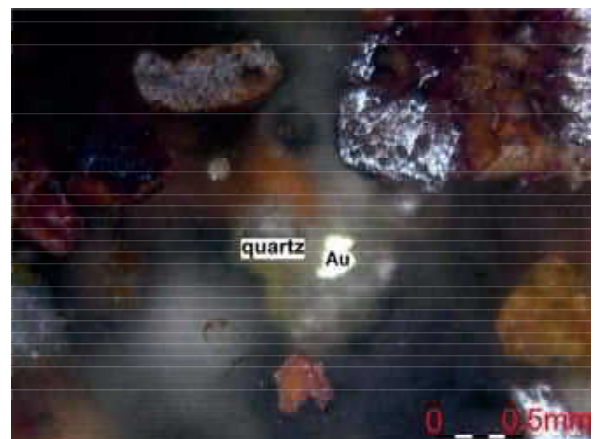


Fig 7. Grain of native gold (Au) included in quartz crystal. Reflected light.

Based on core investigation of 5965.05 m diamond drilling carried out by MTA from 2004 to 2006, a resource volume of 56,537,693 ton (proved + probable + possible) were calculated, with an average grade of 546 ppb (0.55g/t) Au.

All elemental anomalies were located at the margin of the argillic alteration zone and in the areas with scarce silicification, and also in the sericitic-argillic alteration zones.

According to microscope investigations, gold mineralization was developed within quartz veinlets (Figs. 6 and 7) located in the sericitic-argillic alteration zones.

6. Conclusions

In the Kısacık area, argillic and sericite-argillic alterations have been determined. All ore anomalies are located at the border zone of argillic alteration, in the areas with scarce silicification, and in the sericitic-argillic alteration zones. Gold mineralization has lithological and tectonic (fault) controls. Gold mineralization was developed within quartz veinlets located within the units rich in pumice. The style of mineralization is similar to high-sulphidation epithermal gold deposits, such as Ağı Dağı on the Biga Peninsula, and other deposits in Central and South America (Agnerian, 2010).

Acknowledgements

The manuscript benefited from the constructive remarks of two anonymous reviewers.

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The meteorite of Gresia - Teleorman County (Romania)

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Abstract: This preliminary paper gives the first petrographic description of the meteorite of Gresia, southern Romania. We identified it as chondritic meteorite in October 2012, based on the petrographic analysis of a small sample under the optical microscope. The meteorite was preserved almost entirely, being one of the biggest fallen in Romania. There is no information about its fall. The medium to advanced degree of weathering suggests a terrestrial age of a few hundred years, even more.

Keywords: meteorite, chondrules, petrography, Gresia, Romania

1 Introduction

Thirty years ago, a peasant digging a hole in the garden of his house in Gresia village, on the right bank of the Vedea River, found a large, hard, egg-shaped boulder at a depth of more than one meter. He drew it out and put it in the back of his house, where the boulder remained until the discoverer's son presumed that it could be a meteorite and brought a very small sample of it to the Geological Institute of Romania. We confirmed his supposition by microscopic examination of a few thin sections and polished sections and we identified the boulder as a lithic meteorite of chondritic type. The owner asked for an identification certificate, which the Geological Institute of Romania issued under our signatures.

2 Macroscopic description

The meteorite of Gresia (Fig. 1) has the shape of a triaxial ellipsoide, with the long axis of 39 cm, the medium axis of 29 cm and the short one of 18 cm. It weights 26,9 kg, being the second heaviest in Romania, after the one fallen

in 1882 near Mociu, Cluj County, which weighted 35 kg. The meteorite surface is smooth and impregnated with Fe-hydroxides so that its general colour is reddish-brown, with diffuse spots of its original dark brown colour. Three fragments of the meteorite are missing, representing about 1/3 of its volume. They were probably detached at the impact or shortly before that. The broken zones have irregular surfaces of reddish colour due to a more advanced weathering.

If the Gresia meteorite should have been preserved entirely, it would have weighted about 37-38 kg. Its location at more than one meter in depth was probably due to both the impact and subsequent deposition of recent sediments.

3 Petrographic analysis

The microscopic analysis of the meteorite revealed a breccious structure, in which the constituents are granules, fragments of crystals and crystals of olivine and orthopyroxene, chondrules and fragments of chondrules and glass, in a matrix of microcrystalline material, iddingsite and Fe-hydroxides (goethite and

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lepidocrocite) with relics of pyrrhotite and pentlandite. The Fe-Mg silicates and sulfides are primary minerals, of extraterrestrial origin, while the goethite, lepidocrocite and iddingsite are secondary minerals, formed by weathering in terrestrial conditions. The presence of iron and nickel sulfides confers magnetic properties to the meteorite.

Small-sized crystals and granules of olivine and orthopyroxene usually form mono- or biminerall aggregates of irregular shape. The monomineral aggregates are olivinic and frequently show porphyritic internal textures, with rare granules in a glassy matrix (Fig. 2 c, e). The more compact aggregates are of olivine granule $\pm$ pyrrhotite inclusions, on the margins, and packs of olivine laths, in the central area (Fig. 2 f, g). The biminerall aggregates (lithic fragments?) have polygonal contours and are formed of olivine thin laths and euhedral or fibrous crystals of orthopyroxene (Fig. 2 d).

The larger crystals are either isolated or grouped in monomineral aggregates of orthopyroxene, with intergranular glass, and polymineral aggregates (lithic fragments?) of olivine and orthopyroxene in pyrrhotite matrix or olivine in fibrous pyroxene matrix. The isolated crystals of orthopyroxene are frequently deformed (microfractures, undulatory extinction).

The chondrules are spherical polycrystalline formations characteristic for chondritic meteorites. The chondrules in the Gresia meteorite have submillimetric dimensions, rarely 1-2 mm, and show very varied internal textures. The most frequent, these correspond to the main textural types described by Wasson (1974): fibroradiating, barred, porphyritic and glassy. The chondrules with fibrous textures (Fig. 2 c, e, g) are made of fibrous pyroxene, optically undeterminable. Many of them are fibroradiating, with curved fibres diverging from a single point situated on the circumference so that these ones resemble a shell (Fig. 2 g). Sometimes, the fibroradiating chondrules include small crystals (clasts?) of olivine. Others fibrous chondrules contain many fasciculi of right fibres, converging in the central area (Fig.

2 g). The contours of some fibrous chondrules show concavities without deformation traces.

The barred chondrules (Fig. 2 d, e, f) are formed of olivine laths with glass or rare laths of orthopyroxene between them. The olivine laths, sometimes intergrown with pyrrhotite, are parallel or divergent, with the divergence point on the chondrule circumference. Sometimes, the laths are grouped in packs convergent in the central area of the chondrule. The shape of the chondrules with parallel laths approaches to that of a hexagon (Fig. 2 d). Frequently, the circumference of barred chondrules is outlined by a inner ring of olivine grains (Fig. 2 f).

The porphyritic chondrules (Fig. 2 b, c, h) consist of olivine and glass, rarely of orthopyroxene and glass. The olivinic chondrules often have one or two subhedral crystals (clasts?) in the central area, surrounded by smaller roundish grains (Fig. 2 c). The porphyritic chondrules can also be of irregular to quasicircular shapes, like a light bulb for example (Fig. 2 b). These ones can be considered porphyritic aggregates rather than chondrules.

The glassy (microcrystalline) chondrules, sometimes with imperfect circular shapes, contain devitrified glass and usually show homogenous textures (Fig. 2 g). Rarely, in the glassy chondrules we recognized some feathery olivine crystals.

Other textural types of chondrules observed can be defined as equigranular, composed of small rounded olivine grains, and holocrystalline, composed of one or more euhedral crystals of orthopyroxene with olivine inclusions (Fig. 2 c). It is possible that these textural types represent in fact mineral aggregates with rounded contour.

4 Weathering processes

The weathering processes in terrestrial conditions affected most of the sulfides and, to a lesser extent, the silicates. The secondary minerals resulted by weathering form a matrix composed of iddingsite, goethite and lepidocrocite (Fig. 2 g, h).



Fig.1. Photographs of the Gresia meteorite. The inferred places of the three missing fragments can be seen, one in (a) and two in (b). The place from which the studied sample was cut can be seen in (b, left side).

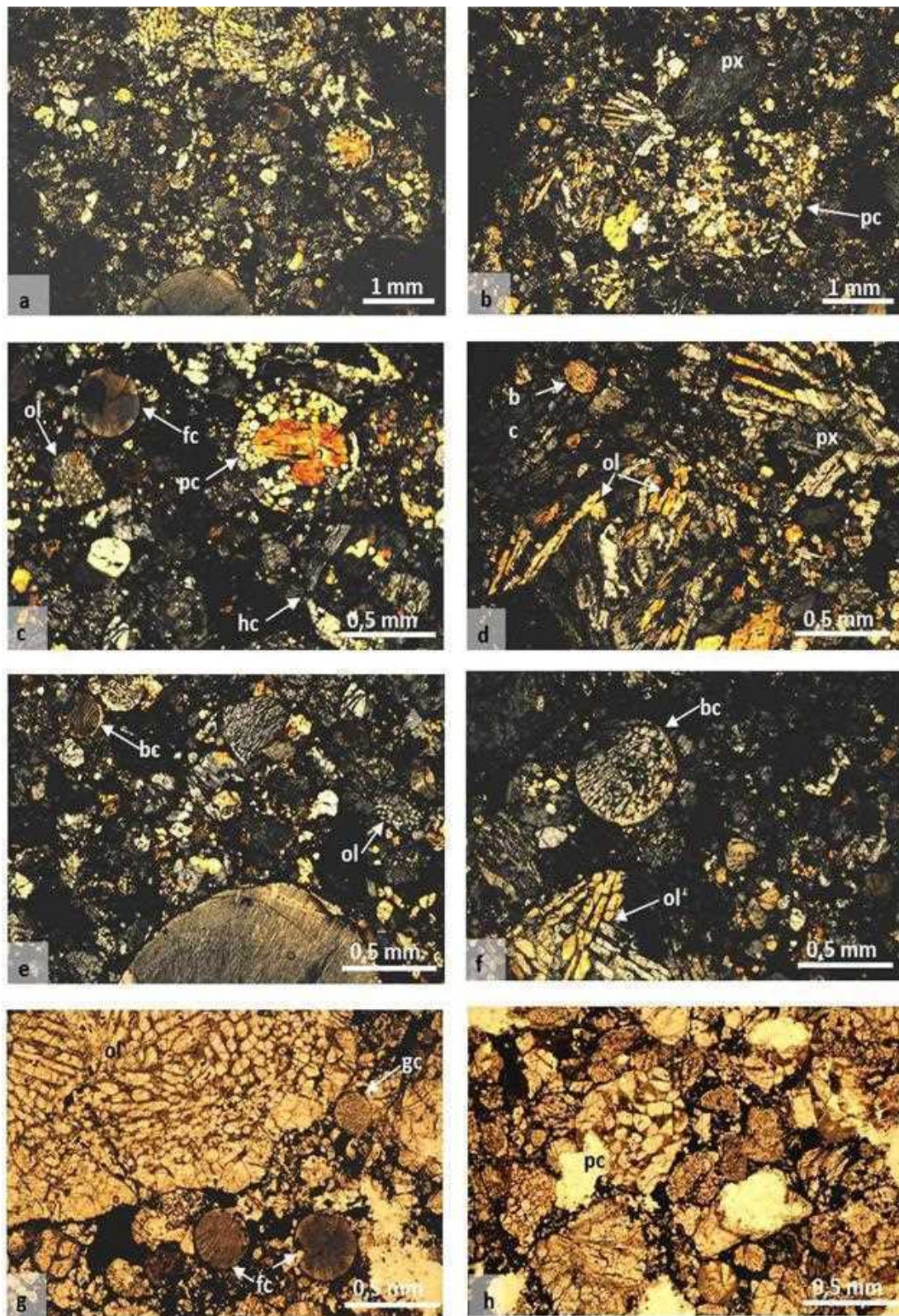


Fig. 2. Photomicrographs in transmitted light of the Gresia meteorite, with crossed (a-f) and parallel nicols (g, h); (a, b) - general images (30x) showing the breccious structure; (c-h) - detailed images (100x) showing olivine (ol) and orthopyroxene (px) aggregates and different types of chondrules: fibrous (fc), barred (bc), porphyritic (pc), glassy (gc) and holocrystalline (hc). Detailed explanations in the text.

The goethite, associated with the lepidocrocite, is formed on the pyrrhotite and pentlandite, minerals which are preserved as relics with highly corroded contours. The pyrrhotite also appears as rims on the olivinic chondrules or as small drops in the olivine. The iddingsite appears as compact aggregates on the olivine, as filling of the fissures and as thin rims on the olivinic chondrules.

From a quantitative point of view, the present mineralogical composition of the meteorite consists of 60-65% Fe-Mg silicates, about 5% sulfides and 30-35% secondary minerals. Taking into consideration the weathering degree, we estimate an initial composition of 85-90% Fe-Mg silicates and 10-15% Fe-Ni sulfides.

5 Speculations regarding the terrestrial age of the meteorite

Taking into account the quite advanced degree of weathering, we appreciate, before any other speculations, that the Gresia meteorite has a terrestrial age of at least 200 years.

The Gresia village appears on the statistic map of southern Romania since 1835, counting 37 houses (Giurescu, 1957), which means that it existed even at the end of the 18th century. Since we could not find information regarding the fall of a meteorite in this village, though such reports exist for other localities in Romania, even from more ancient times, we may presume that the phenomenon took place before 1800. In 1786, in the evening of September the 8th, a fall of meteorites took place in the Făgăraș Mountains region, described by eye witnesses from Curtea de Argeș and Oradea (Corfus, 1975). One of these meteorites could have fallen at Gresia.

The terrestrial age of 200 years represents enough time for the meteorite to be covered by recent sediments, in the case it fell exactly in the place where it was found. According to the topographic and geological maps, the Gresia village lay on Upper Holocen fluvial deposits (Ghenea et al., 1971). Since the fluvial deposits do not have constant sedimentation rate, we cannot make an estimation of the period of the meteorite burial. Moreover, the possibility arises that it has been brought from upstream of the Vedea River by catastrophic floods, the violent water transport causing its breaking. After 1786, such catastrophic floods are reported on Vedea River in 1814 and 1837 (Corfus, 1975). It is possible that the meteorite arrived in Gresia by that time.

Acknowledgements

We benefited from the constructive comments made by Gheorghe Ilinca (University of Bucharest) and Mihai Tatu (Institute of Geodynamics of the Romanian Academy) on an earlier version of the manuscript.

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