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Stratigraphy, petrography and palaeogeographic significance of the Early Oligocene "menilite facies" of the Tarcău Nappe (Eastern Carpathians, Romania)

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ABSTRACT:

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The analyzed "menilite facies" (Early Oligocene Lower Menilites of the Tarcău Nappe, Romanian Carpathians, formed by "bedded cherts" and black shale-like deposits), document the upward evolution of a mainly turbiditic sequence. The stratigraphical relationships with the underlying turbidites are marked by a sudden and sharp transition to a predominantly pelitic menilite-bearing succession, probably as a consequence of a drastic decrease in the terrigenous supply. This type of sedimentation ceased at the Rupelian-Chattian boundary, when new turbiditic flows occurred. The multi-source provenance characterizing the basal turbidites (quartzarenite and litharenite sandstones which were probably derived from external cratonic areas and from inner crystalline belts respectively), is here interpreted as closely linked to tectonically induced palaeogeographic modifications. This hypothesis is in agreement with literature data, which relate these "menilite facies" to an Eocene-Oligocene widespread anoxic event that occurred in the western and central Paratethys, linked to drastic palaeogeographical modifications and to a global climatic deterioration. These palaeogeographical modifications may have corresponded to the Paleogene microplate reorganization and progressive exhumation of the Alpine-Dinaric-Balkan fold-thrust belt, which was responsible for the increasing isolation of the Paratethian basin from the World Ocean. Early Oligocene cooling events, consequent stratification of different salinity water layers and/or upwelling currents, could have produced anoxic conditions at the bottom of the flysch basin and the deposition of the "menilite facies".

Key words: Romania, Eastern Carpathians, Menilite Facies, Eocene-Oligocene transition, Sedimentology, Petrography, Palaeogeography.

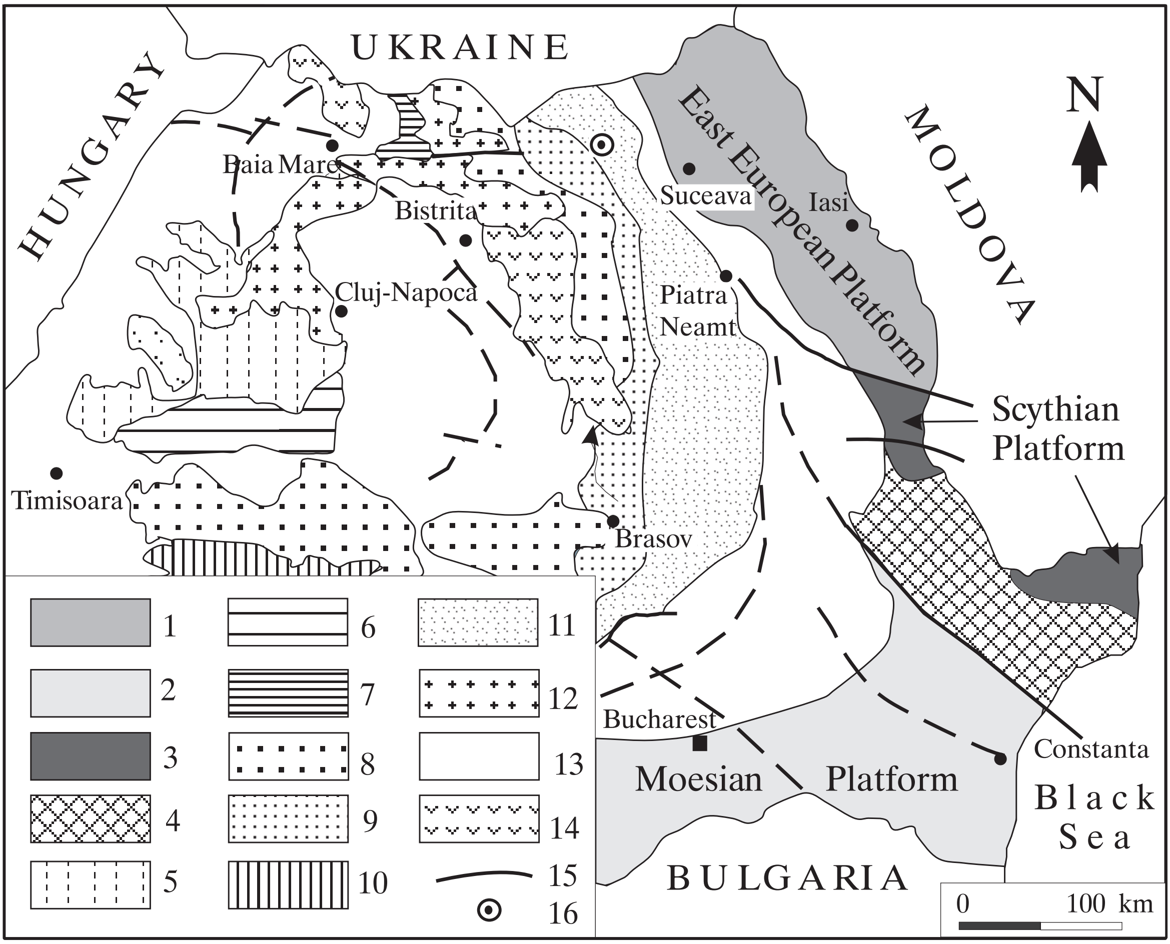

Fig. 1. Geological sketch map of Romania (after DUMITRESCU & SĂNDULESCU 1968, SĂNDULESCU 1994, simplified and modified). 1 – East-European Platform; 2 – and 3 – Moesian and Scythian Platforms; 4 – North Dobrogea Orogen; 5 – Internal Dacides; 6 – Transylvanides; 7 – Pienide Units; 8 – Median Dacides; 9 – External Dacide Units; 10-Marginal Dacides; 11 – Moldavide Nappe Complex; 12 – Post-orogenic covers; 13 – Neogene molasse depression and foredeep; 14 – Neogene Magmatic arcs; 15 – faults, 16 – location of the study section

GEOLOGICAL SETTING

The Carpathian Orogen extends from the Czech Republic (Vienna Basin) through Slovakia, Poland, Ukraine to Romania, and represents a segment of the Tethyan Chain joining the Alps with the Balkan and Rhodopean Chains (to west and south respectively). It includes remnants of the Tethyan oceanic crust and of its continental margins, both strongly deformed by the Cretaceous and Miocene orogenic events (SĂNDULESCU 1994, MATENCO & BERTOTTI 2000).

The Romanian Carpathians (Text-fig. 1) are usually subdivided into inner (crystalline basement nappes and Mesozoic sedimentary cover, i. e. Median Dacide Units, *sensu* DUMITRESCU & *al*. 1962, deformed mainly during the Cretaceous shortening, SĂNDULESCU 1975, BALLA 1986) and outer sectors (flysch zone, i. e. External Dacides and Moldavide Nappe Complex).

The External Dacides and the Moldavides consist mainly of Cretaceous to Tertiary flysch and molasse nappes (SĂNDULESCU 1975, 1980, 1984, DEBELMAS & *al*. 1980, BADESCU 1997) that were affected by Lower and Upper Cretaceous (External Dacides) and Tertiary (Moldavides) deformations, the latter linked to the Miocene collision of the Tisza–Dacia block with the European craton and to the consequent closure of the Carpathian flysch basin (RĂDULESCU & SĂNDULESCU 1973, ROYDEN 1993).

Thus, in the Eastern Carpathians, the Median Dacides, formed mainly by pre-Mesozoic basement and Mesozoic sedimentary cover (i.e. Bucovinian, sub-Bucovinian and infra-Bucovinian nappes), are covered tectonically by the Pienides Units and, in turn, are separated from the underlying Moldavide Units by several tectonic units, represented mainly by flysch deposits belonging to the External Dacides (Black Flysch, Baraolt, Ceahlău and Bobu Nappes; Text-fig. 2). The Median and External Dacides underwent mainly Cretaceous deformations (Săndulescu 1975, 1984, Săndulescu & *al*. 1995, Badescu 1998a, 1998b).

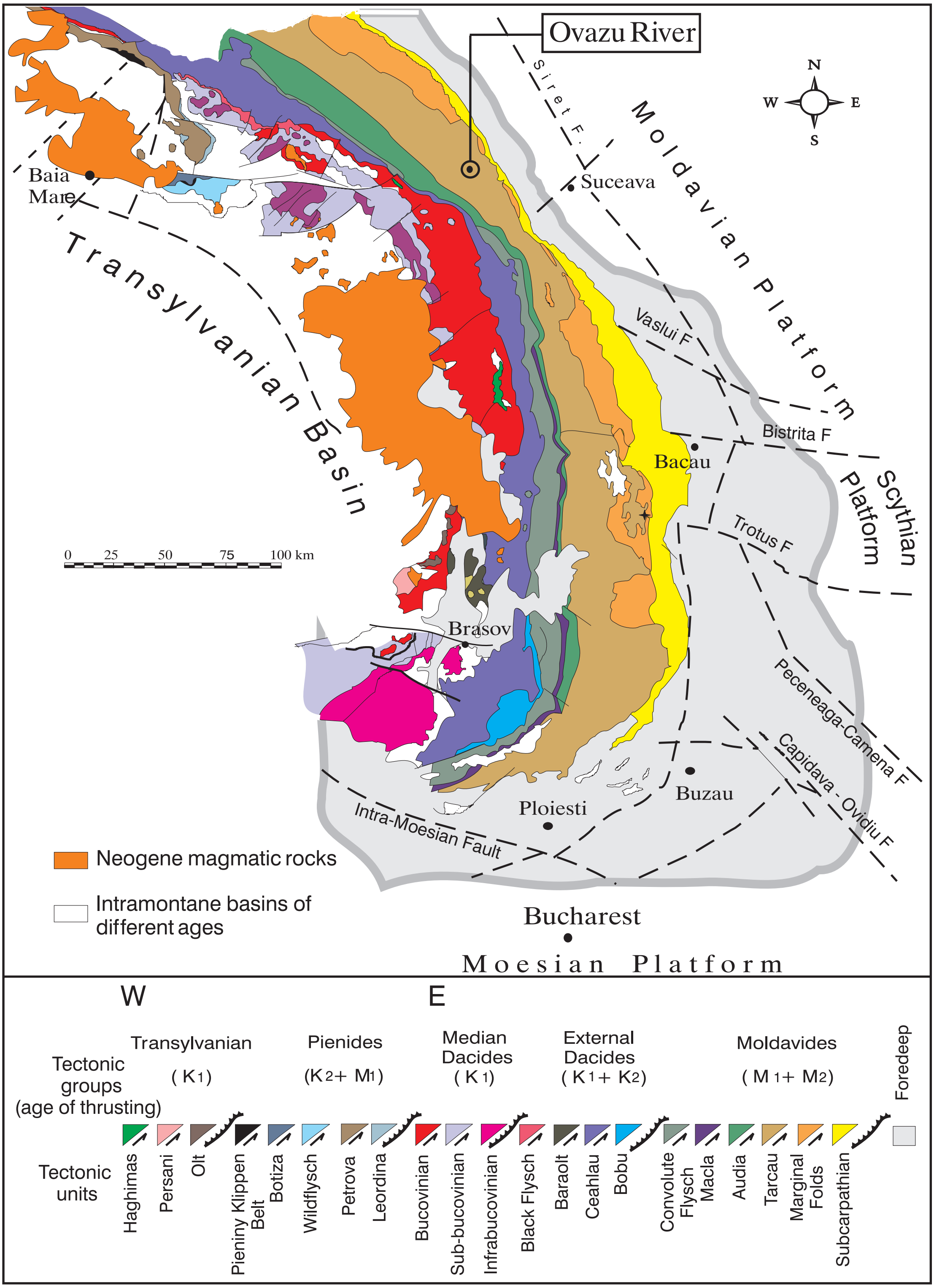

Fig. 2. Geological sketch map of the Eastern Carpathians (after Badescu 1998a, 1998c)

In Text-fig. 2, the Pienides, a group of tectonic units representing the Alpine Tethyan Suture (SĂNDULESCU 1994, SCHMID & FÜGENSCHUH 2003), also include the Poiana Botizi Klippens, in contrast to the interpretation of BOMBITA & *al.* (1992).

The Moldavides, characterized instead by Tertiary deformations, are formed by the innermost tectonic units (Teleajen or Convolute Flysch, Macla and Audia Nappes; SĂNDULESCU 1975) consisting mainly of Cretaceous flysch and by the outermost units, Tarcău, Vrancea (or Marginal Folds) and Subcarpathian Nappes (Text-fig. 2) which, together with the deformed foreland, comprise predominantly Tertiary to Recent flysch and molasse successions (SĂNDULESCU 1975, 1984; SĂNDULESCU *& al.* 1995; BADESCU 1998a, 1998b).

Finally, several platforms of different ages such as the East-European (i. e. Moldavian Platform on the territory of Romania), the Scythian (i. e. Central-European Platform) and the Moesian Platforms represent the foreland areas of the Eastern Carpathians.

The middle to upper part of the Tarcău Nappe is the object of this study. This nappe, at the Eocene–Oligocene boundary, shows the transition from a mainly arenaceous to a mainly pelitic succession, this last grading upward into the deposits known as Lower Menilites and Dysodilic Shales in the Romanian geological literature (IONESI 1971, IONESI & GRASU 1987, BADESCU 1997).

Along the entire Carpathian Flysch Basin, the menilites are usually concentrated in two horizons (Lower and Upper Menilites, of Early Oligocene and Early Miocene age respectively), ranging in thickness from a few to some tens of metres.

The stratigraphical succession sampled and logged along the Ovăzu River, near the village of Ciumârna (Bucovina Region), shows the middle to upper portions of the sedimentary succession of the Tarcău Nappe, where the transition to the Lower Menilites is well exposed. In this region the Lower Menilites also characterize the base of the so-called Fusaru, Moldoviţa and Kliwa Lithofacies, which represent different Oligocene sedimentary successions from west to east (STOICA 1944, IONESI 1965, IONESI 1971, IONESI & GRASU 1987).

The succession investigated belongs to the so-called *“Moldoviţa Lithofacies”* (IONESI 1971, GRASU & *al.* 1988 and references therein), representing a lateral variation of the Tarcău Nappe lithostratigraphical succession that is lithologically highly diversified because it is characterized by different sources of detrital material.

Above these “menilite facies”, the section shows a mainly pelitic interval (here named “upper black shale-rich interval” in Text-fig. 3), which could correspond to the classic Lower Dysodilic Shales, these last grading upward rapidly into the Kliwa Sandstones (AUCT.).

The petrographical and sedimentological characters of this succession have recently been studied (GIGLIUTO & *al.* 2004) in order to determine the palaeogeographical context of the deposition of the arenaceous turbidites that grade upward into the Early Oligocene Lower Menilites. However, no data have been collected with respect to the “menilite facies” and the other closely associated rocks in order to characterize the highest horizons of the succession.

The aim of this paper is to collect new interdisciplinary stratigraphical and petrographical data in order (1) to characterize the transition between the arenaceous turbidites and the overlying “menilite facies”, (2) to establish a hypothetical palaeogeographical scenario and the geodynamic context related to this transition and (3) the origin of this deposit.

STRATIGRAPHICAL SETTING AND SEDIMENTOLOGY

The stratigraphical succession analysed crops out along the Ovăzu River, at the confluence with the Ciumârna River, near to the village of that name (latitude 47°43’13”, longitude 25°36’48” and altitude ~ 780 m a. s. l.).

In this section (up to 200 m thick) the stratigraphical analysis allowed to recognize the vertical distribution of the facies, defined by lithologies, paleocurrents, geometries of sedimentary bodies, boundaries, internal sedimentary structures, grain size and sand/pelite ratio. The facies associations recognized and their vertical assemblage permit to distinguish three deep-sea depositional systems: two turbidite systems separated by an intermediate basin plain system (Text-fig. 3).

Lower Turbidite System (LTS)

This system consists mainly of an arenaceous interval (~ 40 m thick) intercalated between two shale-rich intervals (29 m and 20 m thick, at the bottom and top respectively).

The shale-rich interval at the base of the LTS, composed of mudstones and thin-bedded sandstones, has been referred to the distal part of a turbidite system (GIGLIUTO *& al.* 2004). The sandstones, thin- or very thin-bedded, massive and without any palaeoflow structures, are litharenitic or quartzarenitic in composition and show a gradational contact with the overlying mudstones.

This interval should also include the "sub-menilite globigerina marls" (AUCT.), a well known thin but regionally persistent marker horizon, occurring in the outer sectors of the western and eastern Carpathians (Slovak Republic, south-eastern Poland and Romania, southern Ukraine), underlying the Lower Menilites and recording the Eocene-Oligocene boundary (VAN COUVERING *& al*. 1981).

In the whole study section, there is no evidence of any thin interval whose characteristics could perfectly correspond to those of the "sub-menilite globigerina marls", described by VAN COUVERING *& al*. (1981) ("massive, heavily bioturbated, greenish-buff and pale-colored organic calcareous shales, distinctly standing out from the strongly stratified beds above and below").

Nevertheless, even if it is impossible to recognize a "sub-menilite globigerina marls"-like horizon within the Lower Turbidite System of the section analyzed, we suppose that a hypothetical correlation could be made with the basal shale-rich interval; this hypothesis is supported by new and unpublished biostratigraphical data which place the Eocene-Oligocene boundary a few metres above the base of the arenaceous interval.

This result (COCCIONI *& al.* in prep.), based on analyses by R. COCCIONI (University of Urbino) and R. CATANZARITI (C. N. R., Istituto di Geoscienze e Georisorse, Pisa) of planktonic foraminiferids and calcareous nannofossils from many samples collected from the Ovăzu River Section and other outcrops of the Tarcău Nappe, indicates that the Eocene-Oligocene transition is located within the Lower Turbidite System, very near to the base of the arenaceous interval (Text-fig. 3).

The arenaceous interval (up to 40 m thick, located in the middle portion of the LTS, Text-fig. 3) is characterized by sedimentary structures revealing the following processes: waning flows with weak erosive power (groove casts), predominant traction and shearing (convolute and truncated laminae), by-passing of residual flows. Some thick amalgamated beds show active deposition from waning pulse currents (GIGLIUTO *& al.* 2004). The palaeocurrents, based on groove casts, ripples and convolute laminations, indicate eastward palaeoflows for the litharenite beds and westward palaeoflows for the quartzarenite beds (Text-figs 3, 4). The facies characters of the arenaceous interval suggest a likely awarding at depositional lobe or interlobe of a turbidite system (*sensu* MUTTI 1977). A linked channeled system, inferred on the basis of the sedimentological characters of the arenaceous turbidites (erosional, tractive and shear structures, GIGLIUTO *& al*. 2004), may be a hypothesis acceptable, even if speculative.

Finally, black shales, with subordinate thin- to medium-bedded and lenticular shaped turbidites with litharenitic and/or quartzarenitic composition, characterize the top of the LTS (black shales-rich interval, 70-92 m, Text-fig. 3). The litharenite beds, well graded and parallel or wavy laminated, show an upward transition to mudstones and paleoflows toward east or northeast. The quartzarenites beds, on the contrary, are ungraded and show a sharp upper surface. Deformed foresets in rare convolute intervals reveal palaeocurrents from the southeast (Text-fig. 4a).

Basin Plain System (BPS)

The transition to a BPS in the middle part of the section is very rapid: in fact, the BPS (95–162 m, Text-fig. 3) is represented by a mudstone interval containing the "menilite facies" (about 35 m thick) and an upper black shale-rich interval (up to 35 m thick), corresponding to the Lower Dysodilic Shales (AUCT.).

The basin plain facies (Text-fig. 3) include very thin, fine-grained silty beds (2–7 cm thick), interbedded with thicker mud intervals and siliceous deposits containing the well known Early Oligocene Lower Menilites (AUCT.). In the upper part, the basin plain system is represented mainly by black shales.

Four lithofacies have been distinguished (Plate 1):

1 – thin-bedded silty or fine-grained sandstone beds, massive or crude laminated; these beds are referred to low concentration turbidity currents or to weak bottom currents;

2 – thick mudstone beds from suspension;

3 – thin-bedded and structureless "menilite facies" separated by thin pelitic horizons. The origin of this facies is still the subject of debate (see next sections). The sedimentological characters of the menilite strata are very similar to those of the so-called "bedded cherts"; the lateral and vertical uniformity of layering, the rhythmical character of the stratification (usually thin beds separated by very thin horizons of siliceous shales) are, in fact, the main diagnostic characters of the "bedded cherts" that are also recognized within the Early Oligocene Lower Menilites (AUCT.);

4 – black shales, abundant in the upper interval (140–162 m), indicate a sharp increase in organic input and anoxic conditions.

On the whole, these facies are referred to the facies D_2 of PICKERING & *al.* (1989). The drastic decrease in terrigenous supply and the dominant pelitic component suggest a depositional area typical of a basin plain.

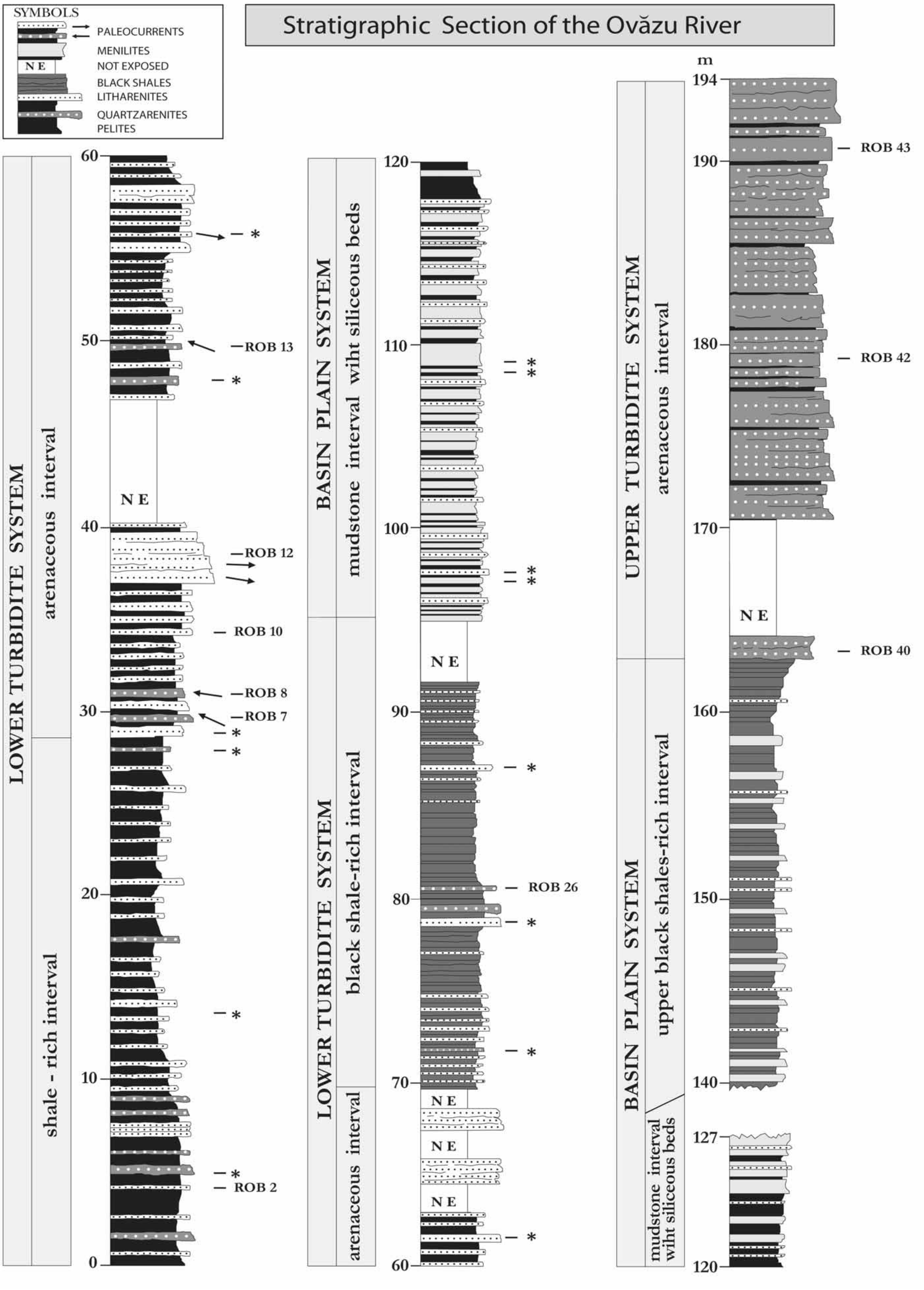

Fig. 3. Sedimentological log of the Ovăzu River Section. Asterisks: location of sandstone samples already analyzed by GIGLIUTO & *al*. (2004)

Plate 1. “Menilite facies” and their associated rocks: a, b = menilite horizons; c= upper black shale-rich interval; d, e= top of the arenaceous interval at the transition with the black shale-rich interval, f = arenaceous interval showing sandstone beds with different provenance (Lt: litharenites, Qz: quartzarenites); g = arenaceous interval, h= shale-rich interval, base of the section.

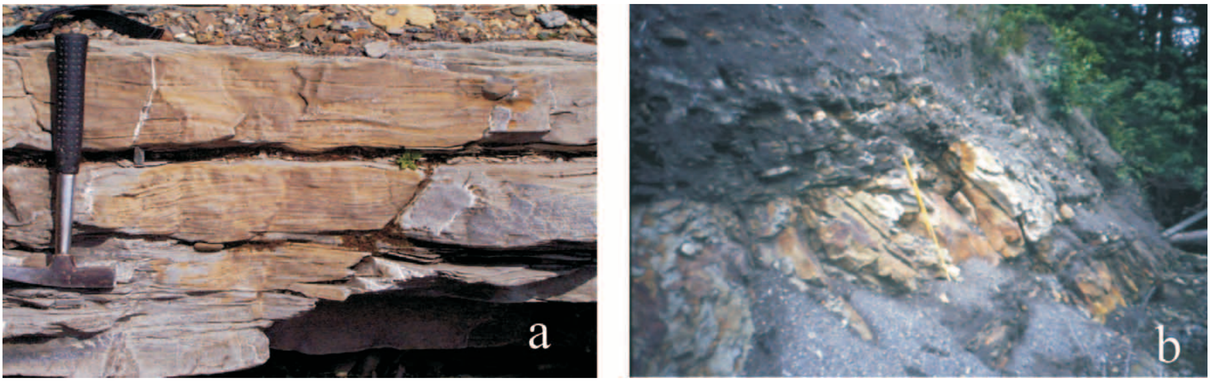

Fig. 4. **a**. Tractive structures in a multiple bed of the arenaceous interval of the Lower Turbidite System: a basal massive and thin horizon is overlaid by thick irregular ripples locally climbing and connected by sinusoidal laminae. **b**. Thick-bedded, lens-shaped and erosional based quartzarenites are locally intercalated in the upper part of the Basin Plain System

Upper Turbidite System (UTS)

The upper part of the section (162-194 m) indicates a sharp restarting of the turbidite sedimentation, recorded by an increase in the quartzose input.

The lowermost beds of this turbidite system, fine- or medium-grained, are organized in a rapidly thickening upward sequence (Text-fig. 4b). The lower surfaces of the quartzarenite beds are generally erosional, irregularly deformed by load casts, and characterized by big bounce casts, groove casts and scours indicating NW-SE palaeocurrent directions. Internally, the thick or very thick amalgamated beds contain large concentrated mud clasts or rip-up clasts scattered near the amalgamation surfaces. These sedimentological characters reveal a rapidly growing, sand-rich turbidite system.

The petrographic and textural characters of these sandstones (high compositional maturity with moderate to high roundness of detrital quartz grains, poor sorting and high content of glauconite grains) are well comparable with those of the Kliwa Sandstones (VINOGRADOV & *al*. 1983, GRASU & *al.* 1988).

The sharp boundary between the BPS and UTS and the facies characters of the quartzarenitic beds could indicate an allocyclic control factor (tectonics) as responsible for the facies relationships and for the rapid progradation of the depositional system

PROVENANCE CHANGES WITHIN THE SANDSTONES ASSOCIATED WITH THE “MENILITE FACIES”

Arenaceous turbidites characterize the analyzed section below and above the stratigraphical interval containing the “menilite facies” (Plate 1).

Their petrographical characters (Table 1, Text-fig. 5) show that the different types of sandstones received their detrital supplies from distinctly different sources.

Modal point counting in thin section, performed according to the criteria suggested by GAZZI (1966), DICKINSON (1970) and GAZZI & *al*. (1973) show the following average compositions characterizing two different groups of sandstones related to the quartzarenite and litharenite clans: $Q_{93.1}F_{5.4}L_{1.5}$-$Qm_{59.5}F_{5.4}Lt_{35.1}$ and $Q_{59.3}F_{6.4}L_{35.3}$-$Qm_{36.0}F_{6.4}Lt_{57.6}$[3].

These data confirm the original hypothesis of GIGLIUTO & *al*. (2004), suggesting the coexistence of two distinct depositional systems, related to different sediment sources: (1) the quartzarenites, characterized by abundant detrital quartz grains with moderate to high roundness; these were probably derived from the erosion of external cratonic areas and (2) the litharen-

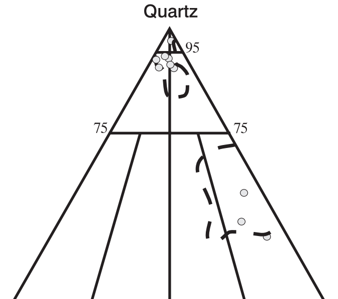

Fig. 5. Quartz-Feldspars-Lithic fragments ternary plot showing the composition of the sandstones associated to the “menilite facies”. Dashed areas represent the compositional fields obtained for the litharenite and quartzarenite sandstones by GIGLIUTO & *al*. (2004)

	ROB 2	**ROB 7**	**ROB 8**	**ROB 10**	**ROB 12**	**ROB 13**	**ROB 26**	**ROB 40**	**ROB42**	**ROB43**	**x**	**σ**	**x_1**	**σ_1**	**x_2**	**σ_2**	**x_3**	**σ_3**
Q_m’	7.7	18.9	15.6	8.8	13.8	22.7	10.7	17.1	26.2	24.1	19.3	5.40	10.0	3.25	10.3	3.04	9.6	3.14
Q_m”	15.3	26.7	24.2	18.4	20.4	30.3	23.9	28.8	27.0	29.2	27.2	2.46	17.9	2.57	30.0	6.62	20.5	5.81
Q_p’	6.1	8.5	10.7	3.8	6.0	12.6	10.0	10.0	12.4	10.9	10.7	1.43	5.2	1.30	12.1	4..31	4.9	1.47
Q_p”	12.2	12.7	14.3	7.8	12.0	15.3	13.8	14.3	12.6	15.9	14.1	1.23	10.6	2.48	19.3	5.45	9.1	2.69
Qr	-	-	-	-	-	-	-	-	-	-	-		-		0.1	0.30	0.2	0.32
Ch	1.2	1.6	0.7	1.6	0.5	0.4	1.3	0.5	1.1	1.6	1.0	0.50	1.1	0.56	0.8	1.29	1.3	1.34
Ps	3.7	3.5	3.1	4.6	4.2	0.9	2.9	4.0	3.6	3.5	3.1	1.02	4.2	0.45	1.7	0.80	3.1	1.78
Pr	-	0.6	0.3	-	-	-	-	0.9	-	0.4	0.3	0.35	-		0.1	0.11	0.2	0.32
Ks	0.4	1.7	0.4	1.6	0.7	0.4	0.9	0.9	0.6	0.4	0.8	0.47	0.9	0.62	1.2	0.48	1.6	1.12
Kr	-	-	-	-	-	-	-	-	-	-	-		-		-		0.1	0.19
Lv	-	-	-	-	-	-	-	-	-	-	-		-		0.4	0.59	2.1	2.26
Lc	13.9	-	-	14.2	12.7	-	-	-	-	-	-		13.5	0.79	0.7	0.77	7.9	7.70
Ls	-	-	-	3.4	0.7	0.4	1.1	0.5	1.3	0.8	0.6	0.51	2.4	2.05	-		1.1	1.07
Lm	1.2	-	-	1.9	0.9	-	0.4	0.5	2.8	0.6	0.6	0.99	1.3	0.51	1.2	0.50	9.6	3.64
Fo	14.1	-	-	7.3	13.1	-	-	-	-	-	-		11.4	3.67	1.3	1.89	6.9	5.80
Ms	7.3	4.3	3.0	6.0	5.4	0.6	1.4	2.6	0.4	0.4	1.8	1.52	6.1	0.97	5.8	2.43	6.4	1.39
Mr	-	-	-	-	-	-	-	-	-	-	-		-		-		0.9	0.68
Gl	3.3	16.2	18.4	10.6	4.9	3.4	21.9	10.2	3.0	4.1	11.0	7.85	6.1	3.84	7.5	3.41	2.5	2.76
Op	1.2	0.6	0.5	1.0	-	0.4	0.9	1.8	1.5	2.2	1.1	0.71	0.7	0.64	0.3	0.42	0.8	0.86
Al	0.9	0.4	0.5	1.4	0.7	0.4	0.5	1.6	1.5	1.8	1.0	0.64	1.0	0.36	0.6	0.58	0.2	0.45
Mt	7.8	3.1	1.2	3.0	3.1	0.8	0.9	6.3	6.0	4.1	3.2	2.36	4.5	2.74	3.2	196	3.3	2.29
Cm	3.7	1.2	7.1	4.6	0.9	11.8	9.4	-	-	-	4.2	5.08	3.1	1.93	2.4	1.21	7.7	3.68
	100.0	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**		**100.0**		**100.0**		**100.0**	
Q	56.1	92.2	94.5	58.0	63.9	97.9	91.9	91.2	90.6	93.5	93.1	2.49	59.3	4.07	91.8	4.99	58.9	10.73
F	5.4	7.8	5.5	8.5	5.3	1.6	5.8	7.5	4.8	4.9	5.4	2.06	6.4	1.82	3.7	1.83	6.5	3.68
L	38.5	-	-	36.5	30.8	0.5	2.3	1.3	4.6	1.6	1.5	1.62	35.3	3.99	4.5	3.32	34.6	11.50
	100.0	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**		**100.0**		**100.0**		**100.0**	
Q_m	30.4	61.5	57.4	37.0	40.7	63.7	53.3	59.2	60.7	61.0	59.5	3.37	36.0	5.22	51.7	7.52	39.9	5.54
F	5.4	7.8	5.5	8.5	5.3	1.6	5.8	7.5	4.8	4.9	5.4	2.06	6.4	1.82	3.7	1.83	6.5	3.68
L_t	64.2	30.7	37.1	54.5	54.0	34.7	40.9	33.3	34.5	34.1	35.1	3.21	57.6	5.75	44.6	8.00	53.6	7.32
	100.0	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**		**100.0**		**100.0**		**100.0**	

Symbols of the parameters adopted for the modal analysis

Q = Q_m + Q_p, where: **Q** = total quartzose grains including **Q_m**= monocrystalline quartzose grains subdivided into **Q_m’**= of low undulosity (< 5°) and **Q_m”**= of high undulosity (> 5°) and **Q_r**= quartz in coarse-grained rock fragments (i. e. > 0.06 mm), **Q_p**= polycrystalline quartzose grains (including **Ch**= chert) subdivided into **Q_p’**= with few subgrains (> 4 crystalline units per grain) and **Q_p”** = with many subgrains (> 4 crystalline units per grain);

F = P + K, where: **F** = total feldspar grains, **P** and **K**= plagioclase and potassium feldspar single grains (**Ps** and **Ks**) or in coarse-grained rock fragments (**Pr** and **Kr**);

L = Lv + Lc + Lm, where: **L** = unstable fine-grained rock fragments (< 0.06 mm, including: **Lv**= volcanic, **Ls**= sedimentary, **Lc**= carbonate, **Lm**= epimetamorphic lithic fragments and **Fo**= fossils);

Lt = L + Q_p, where: **Lt**= total lithic fragments (both unstable and quartzose);

M = micas and/or chlorites, in single grains (**Ms**) or in coarse-grained rock fragments (**Mr**);

Gl = glauconite grains, **Al**= other mineral grains, **Mt**= siliciclastic matrix; **Cm**= carbonate cement. **Sp**= sporadic occurrence.

x, σ and **x_1**, **σ_1**= average and standard deviation of quartzarenites and litharenites, respectively; **x_2**, **σ_2** and **x_3**, **σ_3**= ibidem by GIGLIUTO et al. (2004)

Table 1. Modal point counts of the sandstones associated with the “menilite facies”.

ites, with abundant fragments of carbonate rocks, quartzose siltstones, shales and minor amounts of epimetamorphic rocks (i. e. slightly schistose micaceous lithic fragments), together with moderate contents of fossils and of angular to subangular quartz grains; these were probably linked to the erosion of inner crystalline belts with their sedimentary covers and to the External Dacides.

Both of these two different detrital sources are represented in the succession up to the first occurrence of the "menilite facies", whereas an overwhelming supply from cratonic areas (quartzarenite sandstones) seems to characterize the overlying levels (Text-fig. 3).

This bimodality of provenance undoubtedly represents the stratigraphical interference of two opposite turbidite systems linked to two different sediment sources. Thus, tectonic events could have occasionally acted as the main factors controlling the interaction of these two different depositional systems, while the scarcity of sandstones within the "menilite facies" horizons seems to point to a decrease in the sedimentary input related to a short period of quiescence within a stepped tectonic evolution.

PETROGRAPHY OF THE "MENILITE FACIES"

The "menilite facies" analysed are composed mainly of dark and black, mostly laminated, carbonate-free shales with intercalated "bedded chert" horizons (menilites s. s., AUCT.).

The shales show a finely laminated structure and macroscopic characters that are very similar to those of black shale-like deposits. In thin section, the shales are represented mainly by (1) a mixture of clay or silty clay, (2) a large but variable proportion of colourless to yellowish very fine-grained quartz crystal groundmass with small amounts of opaline silica and (3) an abnormally high quartz content. They could therefore be assigned to the "siliceous shales" family (*sensu* PETTIJHON 1975).

The "bedded cherts", the most common lithotype of the "menilite facies" studied, are usually represented by brownish, thin-bedded strata with a conchoidal fracture.

The siliceous components, in thin section, are represented by crystalline silica-phases such as chalcedony up to crypto- and/or microcrystalline quartz of non-detrital origin, probably representing different progressive stages of crystallization. Microcrystalline quartz (1 to 30 μm in diameter), the most abundant type of silica-phase in cherts (FOLK & WEAVER 1952, PETTIJHON 1975), is commonly considered as a re-crystallization product of metastable opaline-like silica-phases (MEYERS & JAMES 1978, WISE *& al*. 1972).

Other samples of these "bedded cherts" appear to be formed almost completely of chert composed of a crypto-crystalline to, rarely, a fine-grained microcrystalline aggregate of quartz and, sporadically, also of very low contents of dull greyish to brownish varieties of amorphous silica.

X-ray diffractograms of these samples always show the occurrence of quartz, coupled locally with a very small, sharp peak at about 4.04Å, related to the presence of well ordered opal-CT and/or length-fast chalcedony, and an X-ray reflection at 4.48Å, representing the whole-rock clay fraction. Traces of hematite and small amounts of probable montmorillonite are also present.

According to LASCHET's (1984) classification scheme of non-detrital siliceous rocks, these menilites could be referred partly to the "cristobalitic chert" and mainly to the "chert s. s." groups on the basis of the very high quartz/opal ratio, which strongly reflects the progressive disappearance of the immature (metastable) silica-phases.

The relative scarcity of metastable silica-phases, such as opal varieties, seems to be in contrast with the Early Oligocene age known in literature for all the succession containing similar "menilite facies" belonging to the tectonic units cropping out in the outer Western (i. e. Slovakian and Polish) and Eastern Carpathians (Romania and Ukraine).

The quartz/opal ratio, in fact, seems to reach higher values with increasing geological age, due to the increase in crystallinity linked to diagenetic evolution (LASCHET 1984). Thus, the abundance of stable silica-phases with higher maturity (i. e. micro- and megaquartz, length-fast and length-slow chalcedony) has been considered exceptional in Eocene-Oligocene rocks (VON RAD & RÖSCH 1972, LASCHET 1984) and interpreted as the product of unusual diagenetic conditions (RIECH & VON RAD 1979).

These anomalously high contents of stable silica-phases allow us to infer that the "menilite facies" analysed could have suffered an intensive diagenesis, probably as a consequence of a rapid and thick burial. Diagenesis, in fact, could be responsible for a progressive increase in the maturity of the silica-phases, for their re-crystallization and also for the probable destruction of the fossils.

In thin sections, these rocks show no presence of fossils (siliceous or not), thus confirming FILIPESCU's (1936) observations, which distinguished within the Early Oligocene Carpathian "menilite facies" two types of siliceous rocks: the organic siliceous rocks with a high fossil content (diatoms, sponges and rare radiolaria) and the chemical siliceous rocks ("menilites" s. s.) which are virtually or totally devoid of fossils. The chemical siliceous rocks tend to predominate in the northern outcrops of the Eastern Carpathians, whereas the "menilite facies" of the southern sectors are formed mainly by organic siliceous rocks with rare interbedded chemical siliceous rocks (FILIPESCU 1936).

Finally, the chemical composition of the "bedded cherts" show a high SiO_2 content (about 93.0 % and 94.8 %; FILIPESCU 1936 and GRASU *& al*. 1988 respectively) together with very low contents of Al_2O_3, Fe_2O_3 and CaO, thus testifying to an extremely reduced content, or even total lack, of detrital clay materials. In contrast, the chemical data available for the organic siliceous rocks (FILIPESCU 1936) show lower contents of SiO_2 (84.9 %) and higher percentages of Al_2O_3 and Fe_2O_3 tot (9.5 and 3.4 % respectively).

Comparison of these data with other chemical analyses from the literature (GARRELS & MACKENZIE 1971, BLATT *& al*. 1972, PETTIJHON 1975) emphasizes the difference between the "bedded cherts" here analyzed (menilite beds *sensu* FILIPESCU 1936) and other types of siliceous rocks rich in fossils (mainly diatomaceous and radiolarian cherts), which are characterized by lower contents of silica. This difference seems also to be strongly supported by the lack of fossils in the menilite beds analysed.

Furthermore, it should be emphasized that diatomites and/or diatomaceous shales also occur within the Lower Menilites belonging to tectonic units of the western Carpathians in SE Poland (GUCWA & ŚLĄCZKA 1972, HACZEWSKI 1989, KOTLARCZYK & LEŚNIAK 1990) and within coeval flysch deposits of southern Moravia (Czech Republic, KRHOVSKÝ *& al*. 1991, KRHOVSKÝ 1995), and that organic molecular fossils derived from diatoms are present within the same Lower Oligocene menilite horizons from the Outer Polish Carpathians (ROSPONDEK *& al.* 2000).

These results seem to indicate a substantial contribution of diatoms to the origin of these "menilite facies", thus suggesting that the absence of siliceous fossils in the rocks examined could be related to an intensive diagenetic history, which locally could have caused their destruction. This could also explain FILIPESCU's (1936) observations of two different types of siliceous rocks within the Early Oligocene Carpathian "menilite facies": an organic siliceous type and a chemical type, the latter totally devoid of fossils.

PALAEOGEOGRAPHIC CONTEXT OF THE "MENILITE FACIES" AND THEIR ASSOCIATED SANDSTONE SUITES

The deposition of "menilite facies" is commonly referred to the Eocene-Oligocene birth of the Paratethys Sea, an intercontinental and isolated basin whose formation (BÁLDI 1980, RUSU 1988) is the consequence of strong tectonic activities which changed the Eurasian configuration (counterclockwise rotation of Africa, collision of the Indian and Asia continents and an increase of the European continent; RÖGL 1999, SOTÁK & KOVÁČ 2002, SOTÁK *& al*. 2002).

Paratethys, extending from the western Alpine Molasse Basin (Switzerland) and the Rhone Basin (France) to the Aral Sea (Uzbekistan), is commonly subdivided into Western, Central and Eastern Paratethys. Central Paratethys, extending from Bavaria to the Carpathian Chain, is represented mainly by the Pannonian Basin System, surrounded by the Alps, Carpathians and Dinarides (CSONTOS & NAGYMAROSY 1998, OSZCZYPKO 1999, PAVELIÇ 2002), thus including those sectors of the Alpine Chain known in the more recent literature as AlCaPa (Al= Alps, Ca= Carpathians, Pa= Pannonian) and PanCarDi (Pan= Pannonian, Car= Carpathian, Di= Dinarides) regions.

The "menilite facies" form an Early Oligocene marker succession, belonging to different tectonic units, that is of widespread occurrence along the outer sectors of the western Carpathians (Magura, Dukla, Silesian and Skole Units in northern Slovak Republic and in south-eastern Poland) and of the eastern Carpathians (Tarcău and Vrancea Nappes in north-eastern Romania and Stebnik Unit in southern Ukraine and in Poland). Deposits widely correlated with the "menilite facies" are also present within the successions of the Buda-type Palaeogene (Hungary, Slovenia and Croatia) and Transylvanian Basins (Romania), all belonging to the Pannonian Basin System which represents the largest part of Central Paratethys.

Furthermore, these successions represent the main source rocks of oil reservoirs in the entire Carpathian region and their economic importance has recently been emphasized by numerous studies carried out in south-eastern Poland (KRUGE *& al*. 1996, BESSEREAU *& al*. 1997) and in Ukraine (KOLTUN 1992, KOLTUN *& al*. 1998).

These menilites have recently been ascribed to one of the main Assessment Units characterizing the North Carpathian Basin Geological Province by the U.S.G.S.: the "Deformed Belt" Assessment Unit (PAWLEWICZ 2000).

The literature on the "menilite facies" always describes the presence of rare thin-bedded (up to a few dm), structureless fine-grained sandstones, interpreted as distal turbidites of deep sea fans, intercalated within the "menilite facies" of the tectonic units of the Polish Outer Carpathians (LESZCZYŃSKI 1996, 1997, KÖSTER *& al*. 1998a, 1998b). Similar sandstones also occur in some successions of the Pannonian (calcareous tur-

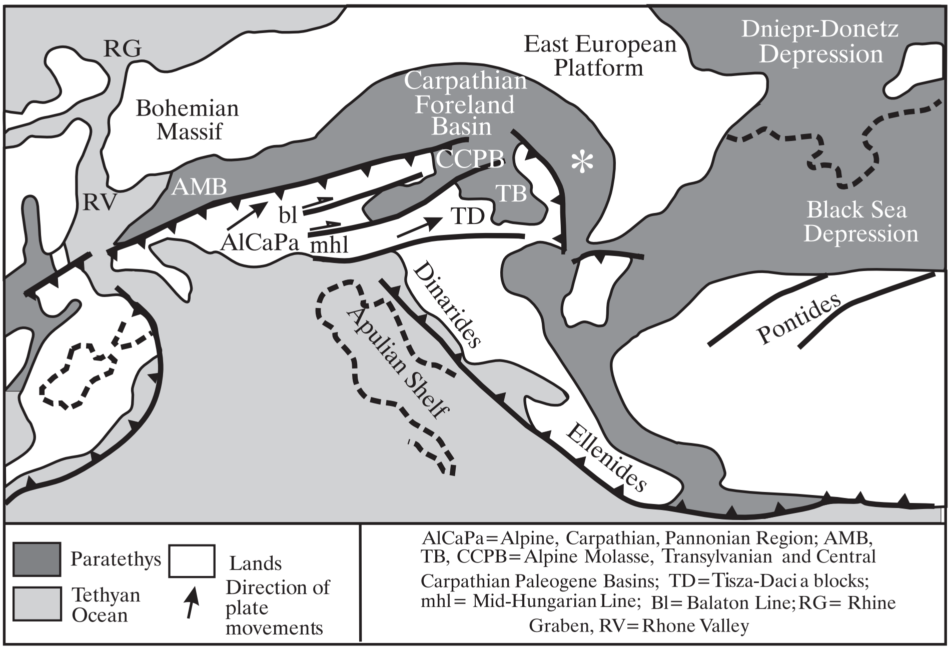

Fig. 6. Palaeogeographic map of the Central Europe showing the Early Oligocene Paratethys (modified after CSONTOS & *al*. 1992, NAGYMAROSY & BALDI-BEKE 1993, SOTÁK & KOVÁĂ 2002, MEULENKAMP & SISSINGH 2003). Asterisk marks the probable deposition area of the Tarcău Nappe “menilite facies”

bidites within the Buda Marls and Tard Clays; BÁLDI 1984, NAGYMAROSY 2000) and Transylvanian Basins (Ileanda Clays; IVA & RUSU 1982).

The interbedded sandstones comprising the arenaceous turbidites below, within and above the “menilite facies” show different petrographical and sedimentological characters:

– the sandstones below the “menilite facies” show two distinct provenances related to very different sediment sources,

– clastic supply decreases upwards and the rare, structureless and very thin-bedded sandstones occurring within the “menilite facies” show mainly a litharenitic composition,

– the thick-bedded and amalgamated sandstones that overlie the “menilite facies” show mainly a quartzarenitic composition.

Thus, there is evidence that only the turbiditic system related to the inner crystalline belts and to the External Dacides was slightly active during the deposition of the “menilite facies”, supplying minor amounts of arenaceous products. The other system seemed to remain quiescent during this time, following which it restarted to feed the basin with mainly quartzose turbiditic flows.

These alternating provenances could be interpreted by inferring that the predominant supply was always linked to external cratonic areas (i. e. foreland sources, identified with the Moesian Platform and partially with the Scythian Platform; GRASU & *al*. 1999, 2002) and that the turbidites with inner provenance (litharenite sandstones) represented only a temporary sedimentary response to the Early Oligocene tectonic movements responsible for the increasing of continentalization and for the isolation of the Paratethys (Text-fig. 6).

CONCLUDING REMARKS

The Early Oligocene “menilite facies” of the sections analyzed (Eastern Carpathians, Bucovina Region, Romania) are represented mainly by “bedded chert”-like deposits, whose origin is still an unresolved problem, particularly in respect of the sources of the silica necessary for the formation of primary and/or secondary cherts.

Volcanic sources of the silica have been invoked for the petrogenesis of the “menilite facies” because they are associated locally with bentonitic tuffs and an organic origin has also been suggested on the basis of the occurrence of siliceous fossils (GRASU & *al*. 1988, and bibliography therein).

In contrast, our data show evidence of a nearly total absence of fossils and volcanic products within the “menilite facies”. Thus, different sources of silica could tentatively be related to a provenance from wide continental areas strongly affected by an extensive global palaeoclimate with ferrallitic weathering (LASCHET

1984). This hypothesis would be in agreement with the increasing continentalization during the deposition of the “menilite facies” (AlCaPa region, Auct.) and with the consequent isolation of the Paratethys, but it cannot readily be substantiated owing to the scarcity of data. Finally, the lack of fossils could be attributed to destruction by re-crystallization processes during an intensive diagenesis.

Furthermore, stratigraphical and petrographical data collected from the outer fan-related turbiditic sandstones associated with the “menilite facies” display very marked vertical changes indicative of (i) sedimentation during the deepening of the basin, (ii) a rapid decrease in terrigenous supply and oxygenation, resulting in total anoxia at the bottom of the basin and (iii) a sedimentary evolution typical of a tectonically-controlled foreland basin, with recession of the internal turbiditic system and a progressive increase in the supply of mature quartzose detritus from external cratonic areas.

A sharp contact, in fact, seems to characterize the transition between the multisource provenance basal turbiditic flows and the overlying black shale-like deposits, which are suddenly replaced upward by the “menilite facies”, thus testifying to the rapid evolution of a turbidite system into a basin plain system, coupled with the rapid and progressive attainment of totally anoxic conditions.

Bottom anoxia in the Carpathian Flysch Basin seems to be linked to an upwelling origin (Vetŏ 1987) as well as to a water-mass stratification in layers with different salinity and temperature (Báldi 1984) and also to the influx of continental runoff (Soták & *al*. 2002). All these mechanisms acted under a stepwise cooling culminating in the “Terminal Eocene Event”, corresponding to the global cooling (Pomerol & Premoli-Silva 1986).

This evolution also shows that, in this area, the predominant detrital supply was linked increasingly to foreland sources (quartzarenite sandstones); we consider that the litharenitic sandstones resulted from the erosion of a new, progressively uplifting landmass barrier (Alpine-Dinaric-Balkan Internides) that started to separate the Paratethys from the rest of the Tethys (Báldi 1984, Rögl 1999, Soták. & Kováč 2002).

In the area studied, the sedimentary evolution of the highest levels of the Tarcău Nappe succession overlying the “menilite facies” shows mainly an upper black shale-rich interval (=Lower Dysodilic Shales Auct.), rapidly evolving upward to foreland-related high density turbiditic flows (quartzarenites of the Kliwa Sandstones, Text-fig. 3).

The Lower Dysodilic Shales/Kliwa Sandstones contact, already described in other sectors of the Eastern Carpathians as a gradual transition (Băncilă 1958, Stefanescu & *al*. 1979), cannot be well defined in the study area because about 10 m of the section are not exposed. In any case, even if gradual, this transition appears have taken place within a maximum 15 m (Text-fig. 3).

In conclusion, on the basis of the results obtained, it can be inferred that the tectonic event responsible for the deposition of the turbidite succession including the menilite horizons corresponds to the “orogenic stage” recently defined by Golonka & *al*. (2003) in the geodynamic evolution of the Outer Carpathians. The beginning of this stage was characterized by a global climate cooling connected with the first glaciation of Antarctica (Golonka 2000).

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