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PROVENANCE CHANGES AND SEDIMENTOLOGY OF THE EOCENE–OLIGOCENE "*MOLDOVIȚA LITHOFACIES*" OF THE TARCĂU NAPPE (EASTERN CARPATHIANS, ROMANIA)

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Abstract: Lithostratigraphic, sedimentological and petrographic data collected from the lower portion (Eocene–Oligocene) of the "*Moldovița Lithofacies*" (near the stratigraphic boundary with the underlying successions of the Tazlău "*Lithofacies*") show evidence of a turbidite system characterized by two different sedimentary supplies. Quartzarenite and litharenite sandstones, in fact, characterize the analysed stratigraphic succession, measured along the Ovăzu River, near the Ciumârna village (Bucovina region), thus testifying to the existence of two different provenances, linked to sediment sources tentatively identified with external cratonic areas and with inner crystalline belts together with their sedimentary cover, respectively. Moreover, the depositional trend, inferred by the facies analysis, shows an arenaceous interval interpreted as part of an active system (lobe or channel) included in thin and fine-grained facies probably belonging to fringe or marginal areas. Fine-grained lithofacies with menilite beds, typical of basin plain, are well represented in the upper part of the succession. Similar turbiditic deposits, but Oligocene–Miocene aged, are well known along the Betic-Maghrebian Chain ("Mixed Successions" *auctorum*), where they represent the stratigraphic interference of two opposite depositional systems closely linked to the starting of the tectogenesis preluding the closure of the Maghrebian Flysch Basin. Nevertheless, the analysed succession, very similar in composition and in textural characters to the Betic-Maghrebian "Mixed Successions", cannot assume the same significance. In this case, in fact, we suppose that the studied succession could be linked to a peculiar paleogeographical morphology of the sedimentary basin, excluding that tectonic events could have been the main control factors of the interaction of the two recognized different depositional systems, owing to the Eocene–Oligocene age of the lower portion of the "*Moldovița Lithofacies*", here analysed.

Key words: Eocene–Oligocene, Eastern Carpathians, Romania, "*Moldovița Lithofacies*", paleogeography, petrography, sedimentology.

Introduction and objectives

The lithostratigraphy, sedimentology and mineralogical-petrographic characters of the "*Moldovița Lithofacies*"[1] (Tarcău Nappe, Eastern Carpathians) show evidence of different sedimentary supplies.

This particular sedimentation, occurred in the outer flysch of the Eastern Carpathians (Săndulescu et al. 1995), emphasizes some important paleogeographical implications. The different petrofacies characterizing some stratigraphic intervals of the Tarcău Nappe, in fact, suggest a differentiated sedimentary supply by different sources since Eocene times linked to the different deposits belonging to the following groups of stratigraphic successions: Tarcău, Tazlău and Doamna "*Lithofacies*", from west to east (see Table 1 and references therein, after Grasu et al. 1988).

This differentiated sedimentation also continued during Oligocene times with the deposition of three different successions, cropping out in the northern part of Romanian Eastern Carpathians (north of the Trotuş Fault) and known as Fusaru and Kliwa "*Lithofacies*" and "*Moldovița Lithofacies*", from west to east, respectively (Table 1). The "*Moldovița Lithofacies*" (Ionesi 1971) represents a sedimentary succession very diversified in lithology, which continues upwards the sedimentation of the underlying formations belonging to the Tazlău "*Lithofacies*".

This peculiar character could be related to different provenances, which must be detected in order to define a more exact paleogeographical scenario.

Similar turbiditic successions, well characterized by different composition and provenance (quartzarenites and lithic arkoses up to litharenites, fed from external cratonic areas

[1]The "lithofacies" term is here adopted according to the Romanian geological literature (*sensu* Ionesi 1971). It re-groups together more geological formations on the basis of their petrographic similarities and not in observance to the international stratigraphic criteria. In this work we maintain this terminology waiting for to attain a stratigraphic revision of the Tarcău Nappe.

Table 1: Cretaceous–Tertiary lithostratigraphic successions of the Tarcău Nappe and their eastward lateral variations (toward right in the scheme, after Grasu et al. 1988, modified).

TARCĂU NAPPE						
Lower Miocene	**Fusaru** *"Lithofacies"*	Vinețișu Formation	*"Moldovița Lithofacies"*	Vinețișu Formation	**Kliwa** *"Lithofacies"*	Kliwa Sandstones
Oligocene		Fusaru Sandstones		Kliwa Sandstones + Fusaru Sandstones		Kliwa Sandstones
		Lower dysodilic shales		Lower dysodilic shales		Lower dysodilic shales
		Brownish bituminous marls		Brownish bituminous marls		Brownish bituminous marls
		Lower Menilites: Compact Menilites		Lower Menilites: Compact Menilites		Lower Menilites: Compact Menilites
		Lower Menilites: Tărcuța Sandstones		Lower Menilites: Lingureşti Member		Lower Menilites: Lingureşti Member
Eocene	**Tarcău** *"Lithofacies"*	Ardeluța Formation	**Tazlău** *"Lithofacies"*	Lupoaia Formation	Lucaceşti Sandstones	
		Podu Secu Formation		Plopu Formation	**Doamna** *"Lithofacies"*	Bisericani Formation
		Tarcău Sandstones		Tazlău Formation		Doamna Limestones
						Sucevița Formation
Paleocene		Tarcău Sandstones	Straja Formation			
		Horgazu Formation	Izvor Formation			
Cretaceous		Horgazu Formation	Hangu Formation			
	Cîrnu – Şiclău Formation					
	Audia Formation					

The "lithofacies" term is derived from the Romanian geological literature, where it is used not in observance to the international stratigraphic criteria, but for re-grouping more geological formations with similar petrographic characters.

and from inner crystalline belts with their sedimentary cover, respectively), are known along the Betic-Maghrebian Chains as "Mixed Successions", thus testifying a system source area-sedimentary basin strongly affected by the initial phase of the tectogenesis (Grasso et al. 1987; Carmisciano et al. 1987).

In particular, the identification of the different provenances characterizing both the Tazlău and "*Moldovița Lithofacies*" successions in the Carpathian Chain might provide useful paleogeographical information about the Eocene–Oligocene evolution of source areas and depositional systems in the Eastern Carpathians (outer Flysch Zone Domain), so representing a key-element for the reconstruction of the geodynamic evolution of the orogen and for regional correlations.

Thus, this paper aims (i) to provide new interdisciplinary stratigraphic, sedimentological and petrographic data from the Eocene-Oligocene "*Moldovița Lithofacies*"[2], (ii) to detect the paleogeographical context of this succession and (iii) to evaluate the possibility of correlation of the studied deposits with other similar "Mixed Successions" recognized in the Betic-Maghrebian Chain, thus pointing out the real significance in the framework of the geodynamic evolution of a convergent orogenic system.

Geological setting

The Romanian Carpathians, about 700-km long fold-thrust belt with a striking arc structure formed during the Cretaceous and Cenozoic tectogenesis, are subdivided into inner and outer sectors (Fig. 1).

[2] C. Grasu and C. Miclăuş suggested the location of the studied log, D. Puglisi together with C. Grasu and C. Miclăuş are responsible for the geological chapters and for the conclusions. Petrographic analyses have been carried out by D. Puglisi, L.G. Gigliuto and G. Raffaelli and sedimentological data were collected by F. Loiacono, C. Miclăuş and E. Moretti.

The first ones, made up by crystalline basement nappes and by their Mesozoic sedimentary cover (Dacide Units, *sensu* Dumitrescu et al. 1962), predominantly deformed during Cretaceous times, comprise several continental blocks (i.e. the North Pannonian and Tisza-Dacia blocks, this last including the Apuseni Mts and other basements of the Eastern and Southern Carpathians; Balla 1984, 1986; Csontos 1995).

The Outer Eastern Carpathians (Moldavide nappe complex, Săndulescu 1975, 1980, 1984; Debelmas et al. 1980), instead, characterized by mainly Tertiary deformations and consisting mainly of Cretaceous to Tertiary flysch and molasse nappes, form a continuous, curved belt, convex towards the foreland. The Moldavide nappe complex also shows an outward structural vergence and an outward propagation of the deformations and of the facies migration through time, already recognized many times by Romanian authors.

In the Eastern Carpathians, the tectonic units of these different sectors (Internal Dacide and Moldavide Units) are separated by several tectonic units, mainly represented by the flysch deposits belonging to the Outer Dacide Units (Ceahlău Nappe, Black Flysch, Baraolt and Bobu Nappes), which underwent mainly Cretaceous deformation (Săndulescu 1975, 1984; Săndulescu et al. 1995).

The successions of the Moldavide Units, originally deposited in the same basin of the successions of the Outer Dacide nappe complex, represent the tectonic-sedimentary result of a deposition on a basin floored by oceanic or strongly thinned continental crust, affected by Late Cretaceous to Tertiary subduction under the Tisza-Dacia block, preluding the collision of this block with the European craton during Miocene times and the consequent closure of the Carpathian flysch basin (Rădulescu & Săndulescu 1973; Royden 1993).

The Moldavide nappe complex includes sediments progressively younger towards structurally lower positions. Thus, the innermost units, the Teleajen Nappe (Curbicortical Nappe or Convolute Flysch Nappe, in the older literature), as well as the Macla and the Audia Nappes mainly consist of Cretaceous flysch, whereas the outermost ones, Tarcău and Vrancea Nappes (this last also known as Marginal Fold Nappe, in the older literature) together with the Pericarpathian Nappe (Folded Molasse or Inner Molasse) and with the deformed foreland, are formed mainly by Tertiary to Recent flysch and molasses.

The foreland of the Eastern Carpathians is represented by several platforms of different age (East European Platform, known as Moldavian Platform on the Romania territory, and Scythian Platform). In the Black Sea sector it includes the pe-

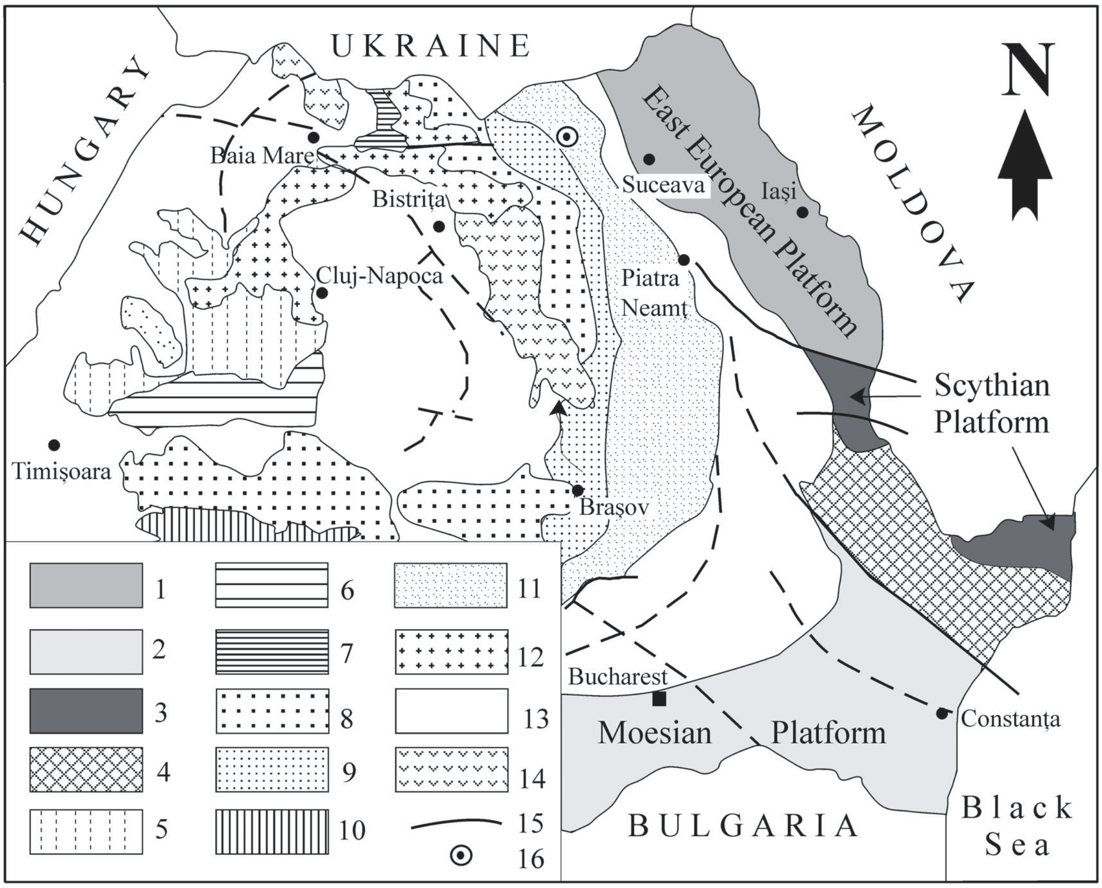

Fig. 1. Geological sketch map of Romania (after Dumitrescu & Săndulescu 1968, simplified and modified). **1** — East European Platform; **2** — and **3** — Moesian and Scythian Platforms; **4** — North Dobrogea Orogen; **5** — Internal Dacides; **6** — Transylvanides; **7** — Pienide Units; **8** — Median 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.

culiar intracratonic chain of the North Dobrogea Orogen, a folded belt made up by deformed Paleozoic crystalline rocks and by Triassic and Jurassic sedimentary successions together with magmatic rocks.

Nevertheless, Grasu et al. (2002) point to the existence of a new foreland basin system located in front of the Eastern Carpathians, strongly controlled by the Volhynian tectonic, thus admitting that the Romanian area of the East European Platform did not act as a real platform because it was reactivated during the intra Badenian (?) and intra Volhynian tectogenesis.

The Tarcău Nappe of the Moldavide nappe complex is the object of this study. This nappe, in fact, includes the Tazlău successions and the "*Moldoviţa Lithofacies*" (Eocene and Oligocene in age, respectively[3]) which could be comparable, as regards the paleotectonic implications, to those defined and described in the Maghrebian Chain by Grasso et al. (1987) and by Carmisciano et al. (1987). The stratigraphic succession sampled and measured along the Ovăzu River, near the Ciumârna village (exactly at the confluence of the Ovăzu and Ciumârna Rivers; latitude 47°43′13″, longitude 25°36′48″ and altitude ~780 m a.s.l.) where the succession here described is well exposed, could correspond to the Tazlău-"*Moldoviţa Lithofacies*" boundary (i.e. to the Lupoaia-Lower Menilites boundary, Stoica 1944; Ionesi 1965; Ionesi & Grasu 1987, see Table 1).

Sedimentology of the "*Moldoviţa Lithofacies*" section

The stratigraphic section of the "*Moldoviţa Lithofacies*", measured in the above-mentioned locality, allows us to recognize the facies characters and the vertical stacking pattern of an up to 130 m thick succession, representing the uppermost part of the Plopu Formation (Atanasiu 1943), the Lupoaia Formation, up to the Lingureşti Member and the overlying Compact Menilites, both representing the so-called Lower Menilites (Stoica 1944).

The section is mainly composed of thin-bedded and fine-grained deposits, characterized by appreciable variations in the lithological character as well as in the sandstone : mudstone ratio and in sedimentary structures (Fig. 2).

Four stratigraphic intervals, corresponding to depositional elements or members of a deep sea system, are distinguished from the base:

1. **Lower shale-rich interval** (0–29 m). In this stratigraphic interval, almost equivalent to the uppermost part of the Plopu Formation, the sandstone : mudstone ratio is very low (less or much less than 1). The sandstone beds are thin or very thin (2–8 cm), rarely thicker than 10 cm. Two types of sandstones are distinguished on the basis of their structural characteristics and petrographic composition. The litharenitic type, fine or very fine-grained, thinly laminated, has a transitional contact with the overlying mudstone and is interpreted as the product of mud-rich turbidity current (facies $C_{2.2}$ of Pickering et al. 1989). The more quartzose type, coarse-grained (1 mm) at the base, clearly graded, laminated at the top (Bouma sequences type Tab), split from the upper mudstone, is referred to denser turbidity currents. The sharp contact between sandy and muddy portions may be related to different mechanism or to different source. Further analyses might reveal some mixing of the suspended load. Waning flows may be responsible of most deposition of silty-shale beds, thick or very thick.

2. **Arenaceous interval** (29–70 m). This interval, equivalent to the Lupoaia Formation, is characterized by (1) a sharp contact with the underlying mudstone member, (2) a sandstone : mudstone ratio close to 1 and (3) thicker sandstone beds (up to 80 cm). The more common structures of these beds are: flat lower contact, sole markings (current and load), rip-up clasts or scattered pebbles, Bouma divisions (Tad, Tbd, Tce sequences). At the scale of outcrops the small-medium scale geometries of the sandstone beds refer to amalgamated bodies through wavy surfaces, even low-angle embricated (Fig. 3a), or with deformation structures as thick convolute divisions (Fig. 3b). In many cases the sandstone beds have wavy or truncated upper surfaces (small scale ripple laminations) in transition to thinly laminated muds (Fig. 3c). The former turbidite beds, in many cases made up by lithic and micaceous sandstones, indicate depositional processes during the waning stage of initial highly concentrated mud-rich turbidity currents; the latter, truncated ones, quartzose type, probably suggest topping process (erosional effect) during by-passing of high energy currents. These facies are related to different types ($C_{2.2}$, $C_{2.3}$ and $C_{2.4}$) of C_2 group (Pickering et al. 1989). Some thinning- or thickening-upward sequences are recognized in a few meters thick packages, probably linked to autocyclic processes (e.g. compensation cycles, Mutti & Sonnino 1981). An amalgamated sandstone bed, 3 m thick, shows multiple graded intervals (grain size up to 1 mm) and cross laminations at the top. The recurrent tractive structures as horizontal to wavy parallel laminations (Fig. 3a,b), climbing and convolute cross laminations (Fig. 3c) suggest a by-passing process in the transport of clastic material. The deposits of this interval are referred to a more proximal area and higher energy than the underlying interval.

3. **Upper shale-rich interval** (70–92 m). This interval, equivalent to the Lingureşti Member, is composed of thin (up to 5 cm) sandstone beds, showing lens-shape and base cut-out Bouma sequences (Tbe, Tce) related to facies $C_{2.3}$ of Pickering et al. (1989). The dominant facies is represented by black mudstones or shales. The sandstone : mudstone ratio is <1, rarely >1. This interval shows a gradual decrease of sandy supply and energy of the flows. The facies relationships with the underlying interval allow us to connect these deposits with the switching of an active depositional or feeding system (lobe or channel).

4. **Mudstone interval with siliceous beds** (95–127 m). Very thin fine-grained silty beds (2–7 cm), interbedded to thicker mud intervals are the main lithologies of this interval

[3]Preliminary analyses on calcareous nannofossils observed in few samples suggest that the studied section is not older than Late Eocene in age, Zone NP19 (Martini 1971), on the basis of the occurrence of *Isthmolithus recurvus,* and seems to extend up to the Oligocene (Zone NP21).

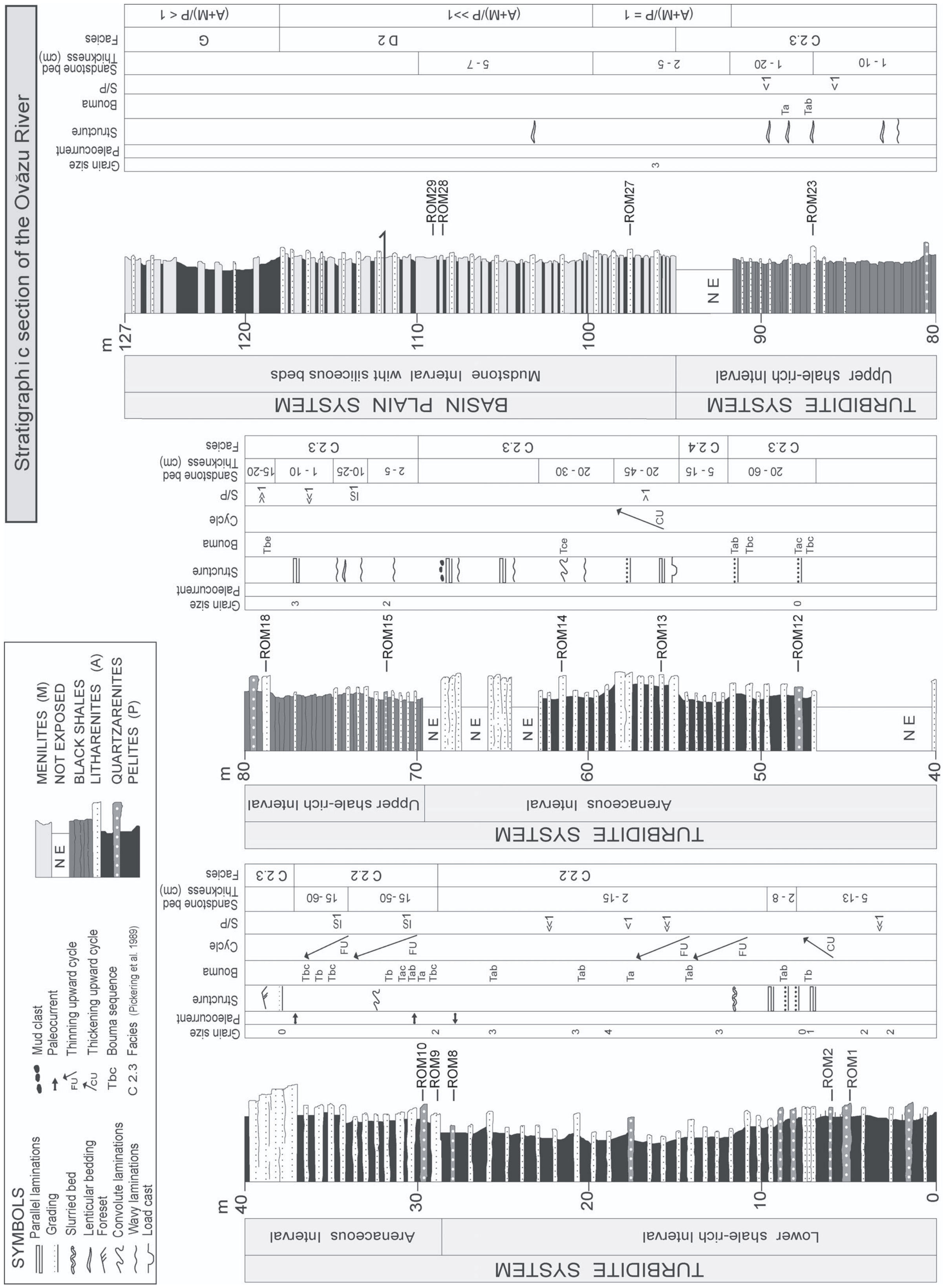

Fig. 2. Sedimentological log of the Ovăzu river section.

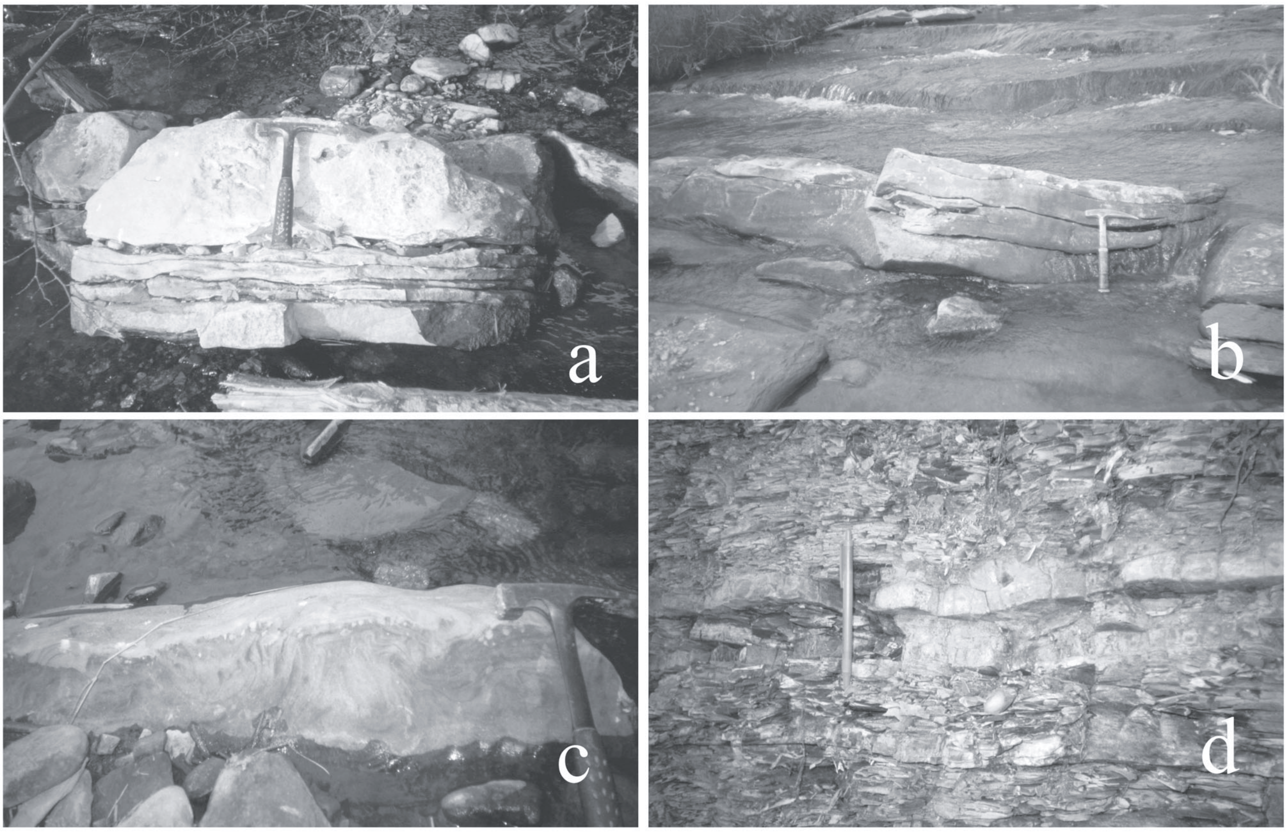

Fig. 3. a — A bedset type of thin amalgamated or separated beds from wavy surfaces or very thin mudstones. In the lower part irregular geometries are visible on a small scale, suggesting weak effect of shearing. In the upper part the thick bed is a bioturbated massive fine sandstone. **b** — Thick amalgamated sandstone bed, internally wavy laminated and partially embricated. **c** — Bouma sequence of C_2 facies showing a thick convolute interval. An upper sharp contact with a thin small scale ripple interval and the uppermost thick laminated mudstone bed reveals the surge character of tractive and traction plus fallout process. **d** — Facies characteristics of the uppermost interval of the studied section. In the middle part of the photo two well cemented beds are visible interbedded to thick marls: the lower one is a siliceous bed (menilite facies), the upper one is a quartzose sandstone passing upward to emipelagic mudstones (facies G).

(Fig. 3d). These sediments are devoid of primary current-formed structures. Only the thin silty beds can show faint laminations (facies D_2 of Pickering et al. 1989).

The main sedimentological characteristics are:

a. upward increase of chert with bedded cherts,

b. rhythmically interbedded thick mudstone, thin sandstones and menilite beds,

c. the ratio between the various type of lithologies shows an upward increase of the menilite facies and a decrease of the sandstones.

The stratification is homogeneous: the beds are 2–7 cm thick.

This interval shows a drastic decrease of terrigenous supply and a depositional area typical of open basin where the pelitic component is dominant (facies G of Pickering et al. 1989).

An attempt at interpretation

A preliminary interpretation of the stratigraphic section referred to the Tarcău Nappe of the Moldavide domain can be based on sedimentary features and petrographic compositions. A more complete reconstruction of the depositional system could be advanced from further studies extended to the whole Tarcău Nappe.

Bed thickness, grain size and sedimentary structures observed in the previously described intervals give some indication on the depositional mechanisms and paleoenvironments.

The lower part of the section (first interval) is composed of stacked fine-grained facies (mudstones) and very thin, locally well graded and coarse-grained sandstone beds, with a sandstone : mudstone ratio < 1. These characteristics suggest dilute turbidity currents depositing in a marginal area of a turbidite system (Mutti 1977) not well specifiable (lobe fringe or outer fan?).

The second interval shows thicker and coarser sandstone beds, in some cases amalgamated, referred to relatively more frequent and denser turbidity currents.

The abundant erosional and tractive structures may be connected with a more active approaching source area (lobe or channel system). In fact, sole marks, scattered pebbles and rip-up clasts are discovered in both amalgamated and medium-thin beds.

Tractive structures (parallel, cross and wavy laminations) as well as convolute and small slices or thin embricated beds (Fig. 2) can indicate down-current deformation processes and large sedimentary shear structures connected with a highly concentrated bedload at the base of high-density turbidity currents. The range of the structures observed in the beds of this interval of the "*Moldoviţa Lithofacies*" section may be relatively common in the process of flow transformation associated to high-density turbidity currents, as shown in the classification scheme of turbidite facies by Mutti (1992) and observed in the Grès d'Annot (Clark & Stanbrook 2001). In a preliminary interpretation, the depositional area of these turbidites may be related to the peripheral zone of a depositional lobe or a channel-levee system.

The third and fourth interval may indicate the recessional trend of a turbidite system and the evolution to a basin plain system characterized by an ever decreasing terrigenous input and consequent increase in pelagic deposition.

Petrographic characteristics of the sandstones of the "*Moldoviţa Lithofacies*"

Modal point counting in thin section (Table 2) has been carried out in order to detect the composition, the petrographic characters and the main textural features of the sandstones of the "*Moldoviţa Lithofacies*". The gross composition has also been checked by means of qualitative mineral phase analyses obtained with diffractometric methodologies (Table 3).

Table 2 lists the gross composition of the sandstones characterizing the "*Moldoviţa Lithofacies*". The samples have mainly been collected from the first three stratigraphic intervals excluding the fourth one because of the abundance of menilite facies in spite of the sandstone levels.

Nevertheless, some samples of the menilite facies observed in thin section show abundant dull-greyish to brownish varieties of opal as well as, locally, cryptocrystalline and fibrous varieties of quartz as chert and chalcedony, respectively. Other samples of this menilite facies appear to be almost completely formed by chert, made up by cryptocrystalline to, rarely, fine-grained microcrystalline aggregate of quartz. Finally, other rocks of this facies (sample ROM 29), consisting of a mixture of clay or silty clay and a large but variable proportion of opaline silica, show a finely laminated structure and an abnormally high content in quartz and could be related to the family of the "siliceous shales" (*sensu* Pettijhon 1975).

The mean values of the detrital modes known in literature for the Fusaru and Kliwa Sandstones (Vinogradov et al. 1983; Grasu et al. 1988), which can be related to the analysed rocks, are shown in Table 2 and/or in Fig. 4, where they are compared with the new petrographic data here obtained for the "*Moldoviţa Lithofacies*" terrigenous arenites. Table 2 also gives the compositional parameters adopted for the modal analysis; these have been performed according to the criteria suggested by Gazzi (1966), Dickinson (1970) and by Gazzi et al. (1973), in order to minimize the dependence of the rock composition on grain size. The $\mathbf{Q_m}$, $\mathbf{F}$ and $\mathbf{L_t}$ parameters are also included in this Table, as suggested by Graham et al. (1976) and by Dickinson & Suczek (1979) as a means of recognizing the provenance of the clastic supply ($\mathbf{QFL}$ and $\mathbf{Q_mFL_t}$ parameters, in fact, emphasize maturity and provenance of the sandstones, respectively).

The analysed rocks can be referred to the quartzarenite/sublitharenite and to the litharenite/feldspatic litharenite groups

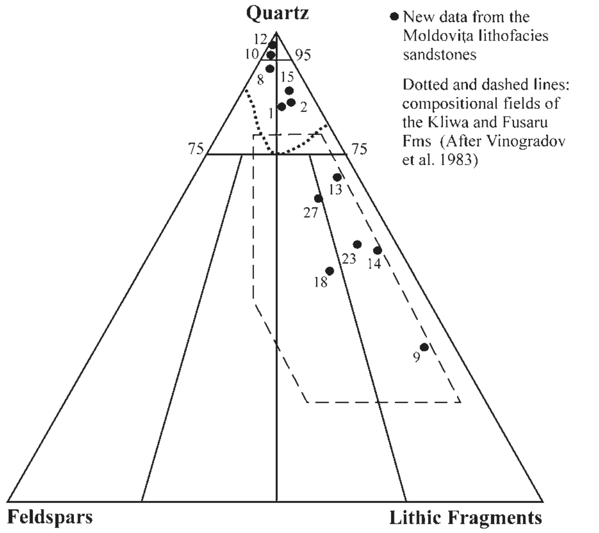

Fig. 4. Quartz-Feldspars-Lithic Fragments ternary plot showing the composition of the analysed sandstones ("*Moldoviţa Lithofacies*"), compared with the Kliwa and Fusaru Sandstone Formations.

(*sensu* Folk 1974). In the first case (samples ROM 1, ROM 2, ROM 8, ROM 10, ROM 12, ROM 15, Fig. 5a and 5b) the rocks show very high compositional maturity ($\mathbf{Q}_{91.8}\mathbf{F}_{3.7}\mathbf{L}_{4.5}$, $\mathbf{Qm}_{51.7}\mathbf{F}_{3.7}\mathbf{Lt}_{44.6}$) coupled with a poor sorting and with a moderate to high roundness of the detrital quartz grains. Other mineralogical components are rare; however, a few well rounded grains of K-feldspar and plagioclase occur in these rocks as well as smaller amounts of fine-grained rock fragments (mainly epimetamorphic clasts), together with moderate amounts of glauconite (max. 12.0 %), nearly always present, and with very low contents of micas and/or chlorites.

In contrast, the litharenite/feldspatic litharenite rocks ($\mathbf{Q}_{58.9}\mathbf{F}_{6.5}\mathbf{L}_{34.6}$, $\mathbf{Qm}_{39.9}\mathbf{F}_{6.5}\mathbf{Lt}_{53.6}$, samples ROM 9, ROM 13, ROM 14, ROM 18, ROM 23, ROM 27, Fig. 5c and 5d) are characterized by the prevalence of quartz grains and of lithic fragments, with a very low content of feldspars. The lithic fraction is mainly represented by carbonate rocks, fossils, epimetamorphic lithic clasts as phyllites and rare quartzites and few sedimentary rocks (quartzose siltstones, shales and rare metarenites). These sandstones usually show a low textural maturity (poor sorting, abundance of angular to subangular quartz grains, locally presence of a small amount of siliciclastic matrix, often pseudomatrix-like, *sensu* Dickinson 1970), which strongly points to very short transports.

The Quartz-Feldspars-Lithic Fragments ternary plot (Fig. 4) shows the gross composition of the "*Moldoviţa Lithofacies*" sandstones together with the bulk of the compositional data of the Fusaru and Kliwa Sandstones (Vinogradov et al. 1983), probably corresponding respectively to the litharenite and quartzarenite sandstones analysed.

Quartz is by far the most abundant mineral in both the sandstone families recognized. The great variability of textures displayed suggested the possibility of collecting further petrographic data during the point-counting of the modal analyses, useful for detect the provenance of the sandstones. So, accord-

Table 2: Modal point counts of the "*Moldoviţa Lithofacies*" sandstones compared with the Kliwa Formation.

	ROM 1	ROM 2	ROM 8	ROM 9	ROM 10	ROM 12	ROM 13	ROM 14	ROM 15	ROM 18	ROM 23	ROM 27	x	σ	x'	σ'	Kliwa Sandstones*
Q_m'	10.3	9.9	9.5	8.1	7.8	16.5	15.5	5.2	7.1	8.3	9.8	10.6	10.3	3.04	9.6	3.14	
Q_m''	27.7	22.9	25.9	13.6	25.1	40.2	27.6	22.4	37.9	15.2	16.6	28.1	30.0	6.62	20.5	5.81	
Q_p'	7.0	8.5	11.9	2.6	20.6	11.8	6.4	3.3	12.6	4.9	5.5	6.5	12.1	4.31	4.9	1.47	**Q** 80–90
Q_p''	10.7	14.8	24.9	3.2	25.9	17.3	10.1	9.8	21.6	11.5	9.6	10.1	19.3	5.45	9.1	2.69	
Qr	–	–	0.8	0.5	–	–	0.8	–	–	–	–	–	0.1	0.30	0.2	0.32	
Ch	1.1	3.5	–	–	–	–	0.4	0.3	–	3.6	2.6	0.7	0.8	1.29	1.3	1.34	
Ps	2.7	2.7	1.1	1.4	1.6	0.5	1.1	2.1	1.7	5.7	3.3	5.2	1.7	0.80	3.1	1.78	
Pr	–	–	0.3	–	–	–	–	–	–	0.5	–	0.8	0.1	0.11	0.2	0.32	**F** 5–10
Ks	2.1	0.9	1.4	1.1	0.8	0.7	0.9	1.2	1.4	4.1	1.3	1.0	1.2	0.48	1.6	1.12	
Kr	–	–	–	0.5	–	–	0.2	–	–	–	–	–	–		0.1	0.19	
Lv	1.3	1.2	–	–	–	–	0.4	–	–	1.6	5.2	5.1	0.4	0.59	2.1	2.26	
Lc	1.5	1.9	–	23.1	–	–	6.8	10.8	0.8	5.3	1.1	–	0.7	0.77	7.9	7.70	
Ls	–	–	–	–	–	–	1.7	2.4	–	–	–	2.2	–		1.1	1.07	**L** –
Lm	1.8	1.2	1.8	3.2	1.2	0.4	7.9	9.4	0.8	15.1	11.6	10.8	1.2	0.50	9.6	3.64	
Fo	0.8	1.7	–	17.1	–	–	5.7	10.5	5.3	0.9	7.0	–	1.3	1.89	6.9	5.80	
Ms	6.7	9.2	6.9	8.4	6.5	2.2	4.2	7.8	2.9	6.3	6.2	5.5	5.8	2.43	6.4	1.39	**Gl** 3–10
Mr	–	–	–	–	–	–	0.8	1.7	–	1.6	1.1	–	–		0.9	0.68	
Gl	11.3	12.0	8.2	2.2	6.1	3.3	0.2	0.3	3.6	–	7.2	5.2	7.5	3.41	2.5	2.76	
Op	0.9	–	–	1.1	–	–	–	2.0	0.9	1.8	–	–	0.3	0.42	0.8	0.86	**M + Al** sp
Al	1.1	–	0.6	–	1.6	0.4	–	–	–	1.2	–	–	0.6	0.58	0.2	0.45	
Mt	8.9	5.7	5.1	3.4	0.7	4.4	3.1	1.6	2.7	2.5	1.3	8.2	3.2	1.96	3.3	2.29	* Mean framework modes from Grasu et al. (1988).
Cm	4.1	3.9	1.6	9.9	2.1	2.3	6.4	9.2	0.7	9.9	10.6	–	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	84.7	86.2	94.2	38.1	95.7	98.1	71.1	58.8	88.8	56.7	59.9	69.1	91.8	4.99	58.9	10.73	
F	7.2	5.2	3.6	4.0	2.9	1.4	2.6	3.7	3.5	13.4	6.3	8.6	3.7	1.83	6.5	3.68	**x** and **σ** = average and standard deviation of quartzarenites.
L	8.1	8.6	2.2	57.9	1.4	0.5	26.3	37.5	7.7	29.9	33.8	22.3	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	50.7	47.4	46.8	30.4	39.7	64.7	51.2	43.6	50.4	30.7	35.8	47.7	51.7	7.52	39.9	5.54	
F	7.2	5.2	3.6	4.0	2.9	1.4	2.6	3.7	3.5	13.4	6.3	8.6	3.7	1.83	6.5	3.68	**x'** and **σ'** = average and standard deviation of litharenites.
L_t	36.1	47.4	49.6	65.6	57.4	33.9	46.2	52.7	46.1	55.9	57.9	43.7	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.

ing to the Basu's (1985) criteria, modified by Basu et al. (1975), two different types of detrital quartz have been distinguished: monocrystalline and polycrystalline quartz grains. Each of these has been subdivided into two populations: the monocrystalline quartz grains have been separated into varieties of low and high undulosity (i.e. ≤5° or >5° apparent angle of extinction, determined using a flat-stage) and the polycrystalline quartz grains have been subdivided by the number of crystal units contained within each grain (with few or many subgrains, ≤4 or >4).

The data concerning the undulatory extinction and the polycrystallinity of the detrital quartz grains should be collected only from the medium sand-size fraction (0.2–0.5 mm) because of the well known relationship between grain size and

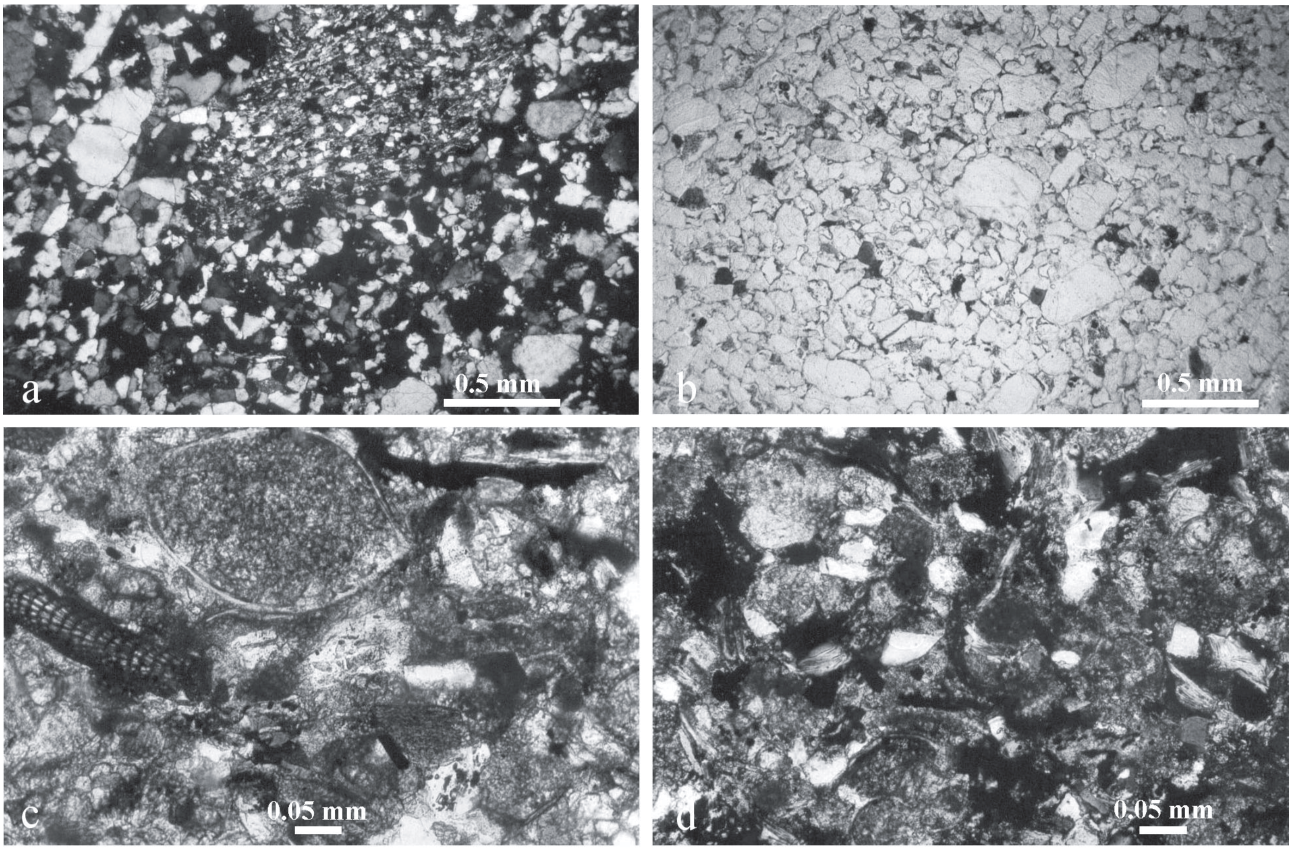

Fig. 5. a — Quartzarenite (sample ROM 12) showing a big lithic fragment with schistose texture (N X); **b** — Very poorly sorted quartzarenite (sample ROM 10) with well rounded detrital quartz grains (N ||); **c** — Litharenite (sample ROM 9) showing abundant micritic limestone and fossil fragments (N ||); **d** — Subangular quartz grains, micas, carbonate rock fragments and fossils within a litharenite sample (ROM 14; N X).

Table 3: Main mineral phases recognized by X-ray diffraction in the analysed sandstones.

Sample	**Qz**	**Pl**	**Kf**	**I/M**	**Chl**	**Ca**	**Do**	**Py**	**S**
ROM 1	XXXX	X	±	±	tr	±			
ROM 2	XXXX	X	±	±		±		±	
ROM 8	XXXX	±	±	±	±	±	tr	tr	±
ROM 9	XX	±	tr	±	tr	XXX	tr		
ROM 10	XXXX	±	±	±	±	±	tr		
ROM 12	XXXX	±	±	tr	±	±			tr
ROM 13	XXX	±	±	±	±	X	tr		
ROM 14	XXX	±	±	X	±	X	tr	±	
ROM 15	XXXX	±	±	tr				±	tr
ROM 18	XXX	±	tr	±	±	±	X	±	
ROM 20	XXX	X	±	X	±	±	±	±	tr
ROM 23	XXX	±	tr	±	tr	X	X	±	
ROM 27	XXXX	X	X	±	±	tr	tr	±	

Abbreviations and symbols: Qz — Quartz, **Pl** — Plagioclase, **Kf** — K-feldspar, **I/M** — Illite/Mica Group, **Chl** — Chlorite, **Ca** — Calcite, **Do** — Dolomite, **Py** — Pyrite, **S** — Sulphates; **XXXX** — very abundant, **XXX** — abundant, **XX** — less abundant, **X** — discrete, **±** — minor, **tr** — trace.

amount of polycrystalline and undulatory quartz (Connolly 1965; Basu et al. 1975; Young 1976). These varieties of quartz, in fact, strongly point to selective destruction by mechanical agencies during prolonged transports as well as during successive sedimentary cycles (Blatt & Christie 1963; Basu 1985). Thus, as the results of the modal analyses of this study regard all the possible grain sizes of the quartz grains present within the sandstones and occurred during the point-counting and since the analysed sandstones are usually medium- to fine-grained, we can quite suppose that the above mentioned criteria have been respected.

In both the recognized clans of sandstones it is important to underline that the monocrystalline quartz grains with high undulosity and polycrystalline grains with many crystal units per grain are more abundant than the varieties with low undulosity and with few subgrains, thus suggesting a predominant provenance from low grade metamorphic sources.

This result is well supported for the litharenite/feldspatic litharenite sandstones by the occurrence of abundant fine-grained lithic fragments of semischists, chlorite-schists, quartzites, locally mixed with micritic limestone and abundant fossils[4]. In addition, the scarce content of feldspars in spite of the abundance of quartz and lithic fragments excludes a conspicuous contribution from plutonic and/or high grade metamorphic sources.

In contrast, the provenance of the quartzarenites is more difficult to hypothesize. In fact, the occurrence of very few epimetamorphic rock fragments is not sufficient to justify a sediment supply from low grade metamorphic rocks as suggested by the study of the polycrystallinity and undulatory ex-

[4] Small amounts of very altered volcanic rocks, mainly represented by fragments of oligohyaline fine-grained groundmass, are also present.

tinction of the detrital quartz grains. Furthermore, the high compositional maturity together with the moderate to high roundness of the quartz grains seems to suggest prolonged transports of the detritus or, more probably, a polycyclic origin, as strongly emphasized by Suttner et al. (1981) for the bulk of ancient quartzarenites. In this case, the abundance of polycrystalline and undulatory quartz grains could acquire an important significance; in fact, taking into account the lower stability of these varieties of quartz and assuming these rocks as affected by more sedimentary cycles, we would quite suppose the sediment sources must have been enriched in these types of quartz and thus they may have been represented also by low grade metamorphic rocks.

Thus, the difference from the other type of sandstone with litharenite/feldspatic litharenite composition does not consist only of a larger amount of fine-grained rock fragments characterizing these last rocks (carbonate, epimetamorphic lithic fragments and, locally, abundant fossils), but it is also related to different modalities of sedimentary transport as well as to a different geological history including different sources, together, probably, with a polycyclicity of the detritus responsible for the enrichment of quartz.

Conclusions

The results of this paper concerning the study of a stratigraphic interval, not more than 130 m thick and located at the boundary between the Tazlău and the "*Moldoviţa Lithofacies*" successions (Late Eocene–Early Oligocene), mark the evidence of a turbiditic deposition, related to the peripheral zone of a depositional lobe or a channel-levee system and linked to different sedimentary supplies.

The vertical evolution of the analysed stratigraphic succession may indicate a recessional trend of the turbidite system evolving to a basin plain system (interval four, menilite facies with "siliceous shales"), with decrease in the terrigenous input and consequent increase in pelitic deposition. The other stratigraphic intervals, instead, are always characterized by turbidite sandstones strongly different in composition.

Mainly quartzarenite and litharenite compositions, in fact, characterize these sandstones suggesting the existence of two different provenances, testified by the presence of abundant detrital quartz grains with moderate to high roundness in the first type, and of abundant lithic fragments (carbonate rocks, quartzose siltstones, shales and epimetamorphic lithic clasts) together with moderate contents of angular to subangular quartz grains in the second type. These provenances must be related to different sediment sources, which could be tentatively identified with external cratonic areas in the first case and with inner crystalline belts together with their sedimentary cover in the second.

This particular interference of two opposite depositional systems has already been observed in different sectors of the Betic-Maghrebian Chain (Oligocene-Miocene "Mixed Successions", *sensu* Grasso et al. 1987; Carmisciano et al. 1987) with the significance of a sedimentation related to the beginning of the tectogenesis, aged to Upper Oligocene–Lower Miocene, antecedent to the Maghrebian Flysch Basin closure.

The older age of the study succession (Eocene–Oligocene) can quite exclude the previous tectonic interpretation because the deposition of the "*Moldoviţa Lithofacies*" is continuous up to the Oligocene-Miocene boundary. Thus, we suppose that only peculiar paleogeographical scenarios with not very large basins, where interference between two different depositional systems with different provenance was possible, could permit the deposition of the analysed succession.

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