GEOLOGICA CARPATHICA, DECEMBER 2012, 63, 6, 463–479 doi: 10.2478/v10096-012-0036-0

Tectonic control on the sedimentary record of the central Moldavidian Basin (Eastern Carpathians, Romania)

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(Manuscript received November 9, 2011; accepted in revised form June 13, 2012)

Abstract: The sedimentary record of the Tarcău and Vrancea Nappes, belonging to the flysch accretionary zone of the Eastern Carpathians (Eastern Carpathian Outer Flysch), registered Cretaceous-Miocene events during the evolution of the Moldavidian Basin. Our biostratigraphic data indicate that the deposits studied are younger than previously reported. The comparison of sedimentary record studied with the Late Cretaceous–Early Miocene global eustatic curve indicates that eustatic factor played a secondary role, after the tectonic one. Four main stages of different processes influenced by tectonics are recognized in the sedimentary record: (1) Campanian–Maastrichtian–earliest Paleocene; (2) latest Ypresian–Lutetian; (3) late Chattian–earliest Aquitanian, and (4) late Aquitanian-early Burdigalian. The late Chattian–earliest Aquitanian and late Aquitanian-early Burdigalian records indicate a high tectonic influence. The first event was related to the foredeep stage of the sedimentary domain studied, and the second one to the deformation stage of the same domain. The sedimentary records of tectonic influence recognized during these stages are useful tools for geodynamic reconstructions. The stratigraphic correlation of Tarcău and Vrancea sedimentary records are used to propose some constraints in the timing of the deformation for the central Moldavidian Basin and close domains.

Key words: Cretaceous-Miocene stratigraphy, central Moldavidian Basin, Tarcău and Vrancea Nappes (Romanian Eastern Carpathians), paleogeography, geodynamic constraints, tectono-sedimentary processes, calcareous nannoplankton, planktonic foraminifera.

Introduction

This research seeks to characterize the Vrancea (or Marginal Folds Nappe) and Tarcău Nappes, representing the external tectonic units of the Outer Moldavidian domain of the Romanian Carpathians. The Tarcău Nappe crops out in the Piatra Neamţ area in an internal tectonic position in comparison with the Vrancea Nappe. In the same area the latter crops out in tectonic half-window named Bistriţa (Băncilă 1958), the second one of the four half-windows — Putna, Bistriţa, Oituz, and Vrancea, from the north to the south — where the Vrancea Nappe is exposed along the Eastern Carpathian front (Maţenco & Bertotti 2000; Belayouni et al. 2007, *among others*). Our study of Vrancea Nappe was conducted in the Bistriţa half-window, in the Piatra Neamţ-Bacău area, while the study of Tarcău Nappe both in the Piatra Neamţ area and in the Gura Humorului area in the northern part of Eastern Carpathians (Belayouni et al. 2007). According to previous literature (Dumitrescu 1952; Băncilă 1958; Ionesi 1971; Săndulescu 1984, 1988; Grasu et al. 1988, *among others*) the Tarcău and Vrancea Nappe's successions range from the Early Cretaceous to the Early Miocene, the deposits showing a marked vertical and lateral lithofacies variability. The successions register four main stages of different tectonic activities proved by stratigraphic evidence of great interest for the knowledge of the Moldavidian Basin evolution. We use the term Moldavidian Basin to designate the basin where the Cretaceous-Early Miocene sedimentary succession was deposited, then deformed, detached and thrusted over the foreland as the thin-skinned (NW-SE oriented and NE faced) Moldavide Nappes (Teleajen or Convolute Flysch, Macla, Audia, Tarcău, Vrancea or Marginal Folds, and Pericarpathian Nappes, from the internal to external ones).

Therefore, the aim of the present study is to provide new litho- and bio-stratigraphic data in order to better define the Late Cretaceous-Early Miocene periods with large terrigenous supply in the Moldavidian Basin. The lithostratigraphic study of the sedimentary successions and the better dating of the large terrigenous supply events give information on when the source rocks were unroofed in response to tectonics of rising areas by folding and nappe piling. Finally, this stratigraphic approach can advance the understanding of the geodynamic evolution of the central Moldavidian Basin.

The successions analysed from Vrancea and Tarcău Nappes in the central part of the former Moldavidian Basin (Fig. 1) have broadened our perspective of the entire basin. Our study includes: (a) field lithostratigraphic analysis and correlations, and sampling of the units involved; (b) integrated (foraminifers and nannoplankton) biostratigraphic dating; (c) statement and interpretation of tectono-sedimentary processes; (d) constraints on the timing of the deformation in the central Moldavidian Basin.

Geological background

The Romanian Carpathians constitute a double-looped orogenic belt (Fig. 1) formed in response to the Alpine evolution of several continental blocks (Apulia, Adria, ALCAPA, Tisza, Dacia, as well as the European-Scythian-Moesian Platforms and the Anatolia block) separated by Tethysian oceanic branches. According to recent papers on tectonics, exhumation, and volcanism (Morley 1996; Bădescu 1997; Mason et al. 1998; Hippolyte et al. 1999; Sanders et al. 1999; Maţenco & Bertotti 2000; Gibson 2001; Seghedi et al. 2004; Golonka et al. 2006; Gröger et al. 2008; Schmid et al. 2008; Maţenco et al. 2010; Merten et al. 2010; Márton et al. 2011) these blocks have drifted and collided since the Cretaceous, with a progressive reorientation of convergence directions (Mann 1997).

The suggested evolution can be described as follows: (1) Cretaceous to Paleogene northward convergence affected the Apulia, Adria, ALCAPA, and North European plates (giving NW-SE orientation of tectonic lineaments) with the docking of tectonic deformation against the European plate; (2) Paleogene to Early Miocene northeastward to eastward tectonic escape of the Tisza-Dacia block (Tisia) with a progressive clockwise migration and rotation into the Carpathian embayment (reaching the perpendicular to NW-SE orienta-

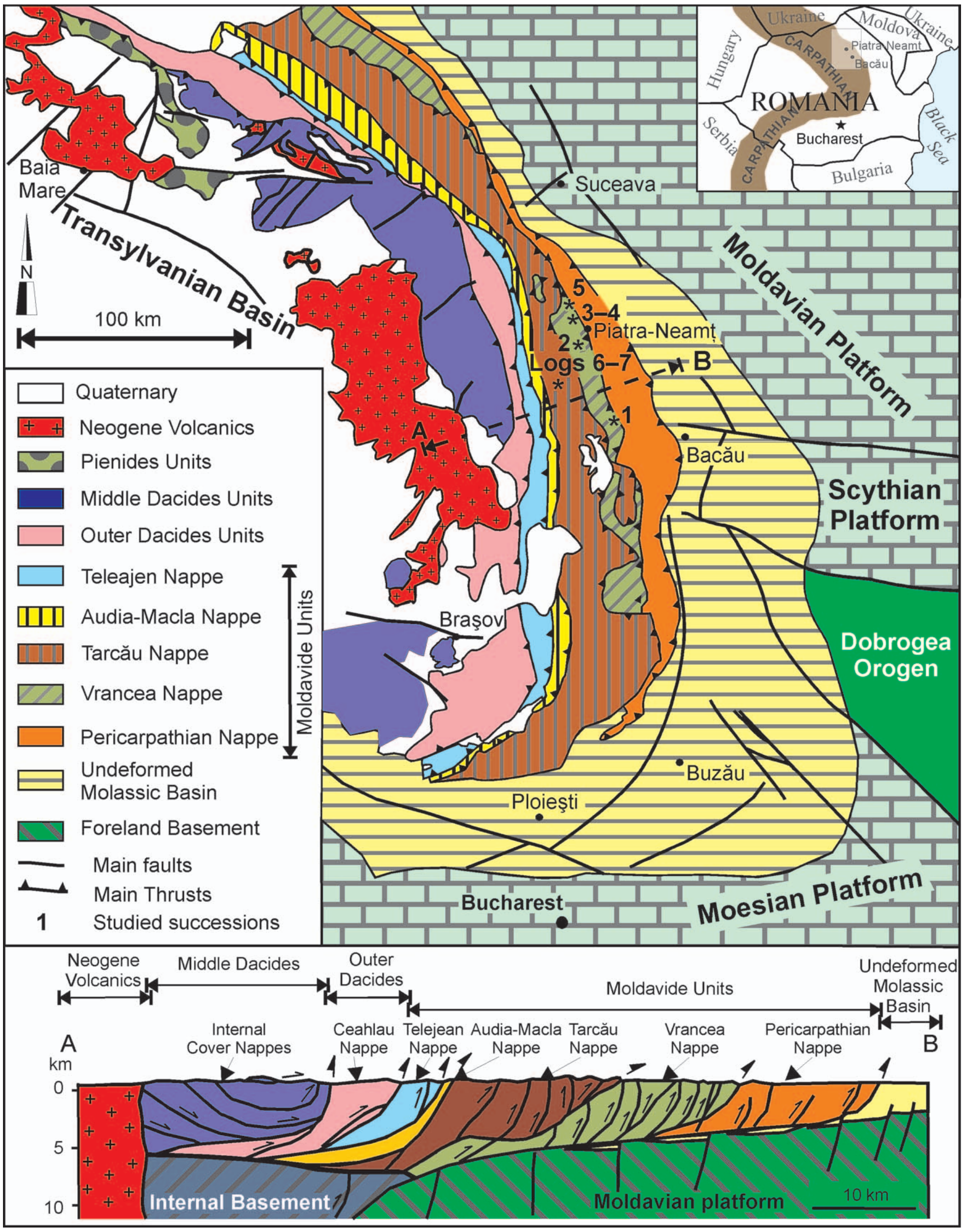

Fig. 1. Geological, structural sketch, and schematic cross-section of the Eastern Carpathian Chain (after Maţenco & Bertotti 2000; modified). The locations of the seven stratigraphic sections (logs) studied are also shown.

tions of the tectonic lineaments with a NE facing); (3) remnant embayment to the southeast after Tisia collided against the Eastern European plate-Moesian platform involving the larger part of the Moldavidian Basin; (4) new docking and clockwise rotation reaching a southeastward convergence from the Middle Miocene onward, contemporaneous with the westward movement and pushing of Anatolia block which caused the double-arched shape of the southern loop of the Carpathian Belt (Mann 1997).

As a consequence of the above-exposed geodynamic evolution, from Late Cretaceous onward, the Moldavidian Basin developed as a foreland basin. From the Early Miocene onward, the foredeep stage (*sensu* Guerrera et al. 1993) started in the Moldavidian Basin, whose deposits were structured in several overthrusted units: the Moldavide units.

The evolution of the Moldavide units stacking is considered well documented (Săndulescu 1984, 1988; Roure et al. 1993; Ellouz & Roca 1994; Maţenco & Bertotti 2000). According to the afore-mentioned authors, the Moldavidian Basin underwent three compressional episodes during the Early, Middle, and Late Miocene (early Styrian, late Styrian, and Moldavian tectonic episodes, respectively). The Pericarpathian Nappe was also locally folded in the Pleistocene (Wallachian tectonic event in Carpathian Bend Area; Săndulescu 1988).

Stratigraphy of the central Moldavidian Basin

Lithostratigraphy

In this section, we present the most important lithostratigraphic successions reconstructed in the field. The Vrancea Nappe was studied in five stratigraphic sections (logs 1 to 5) while the succession from the Tarcău Nappe was studied in two stratigraphic sections (logs 6 and 7) cropping out in the Piatra Neamţ-Bacău area (Fig. 1). It is important to mention that, in this area, only the internal "lithofacies" of the Tarcău Nappe is preserved, the mixed and external ones have been eroded. The mixed and external "lithofacies" were studied in the Gura Humorului area situated toward the north (Belayouni et al. 2007). The terminology for stratigraphic units, main lithofacies, thickness, samples, and stratigraphic sections of the Vrancea and Tarcău Nappes are summarized in Tables 1 and 2, respectively, while detailed lithostratigraphy is reported in Figure 2.

Log 1: this is exposed along the Tazlău River (UTM coordinates: 5174128/35458011, 5174358/35458861; samples: 1–69). The exposed stratigraphic succession (680 m thick) spans from the Bisericani Formation *p.p.* to the Gura Şoimului Formation. The succession is deformed, ending in tectonic contact with the "salted breccia and gypsum formation", belonging to the Pericarpathian Nappe.

Log 2: the succession, 440 m thick, crops out near Piatra Şoimului village, along the Calu River (UTM coordinates: 5187169/35454002; samples: 70–91) and along the Dracului tributary; (5187315/35452061; samples 92–108). The stratigraphic succession consists of deposits from the uppermost part of the Piatra Uscată Formation up to "upper dysodilic shales member".

Log 3: the succession, 30 m thick, crops out along the Cuejdi River (Cuejdi Village area near the town of Piatra Neamţ; UTM coordinates: 5204359/35445725; samples: 109–115). In this outcrop, only the lower member of the Sărata Formation is exposed.

Log 4: the succession, 889 m thick, was studied along the Cuejdi (Cuejdi Village area) and Runcu Rivers (UTM coordinates: 5204774/35445217; sample: 116; 5204562/3544100, sample: 134). In this outcrop the succession from the middle member of Sărata Formation to the top of the Bisericani Formation is exposed.

Log 5: the succession, 20 m thick, crops out along the Runcu River (UTM coordinates: 5204774/35445217; sample: 135; 5204485/3544034, sample: 144). In this stratigraphic section, the "Globigerina marls member" and Lingureşti Brown Marls of the "lower menilites member" are exposed.

Log 6: the succession, 1280 m thick, crops out along the Tărcuţa Creek (UTM coordinates: 5174538/441207; samples: T-1 to T-72) a tributary of the Tarcău River. In this stratigraphic section, the Tarcău Sandstone Fm, Unit A (Podu Secu and Ardeluţa Mbs), Unit B ("lower menilites", "bituminous marls" and "lower dysodilic shales mbs"), and the Fusaru Fm are exposed.

Log 7: the succession, 230 m thick, crops out along the Răchitiş Creek, a tributary of the Tărcuţa Creek (UTM coordinates: 5171958/425994; samples: T-73 to T-76). In this stratigraphic section, only the Vineţişu Fm is exposed.

On the basis of the main characteristics of the persistent lithofacies, we reconstructed the vertical stratigraphy of the central Moldavidian Basin (Tarcău and Vrancea sedimentary domains: Fig. 3), as described below.

The oldest deposits cropping out in the Bistriţa half-window, Late Cretaceous in age according to our data (see below), belong to the Sărata and Lepşa Fms (stratigraphic sections 3, 4). This stratigraphic interval begins with black and silicified shale and black chert beds (5–10 cm thick) deposited in pelagic sedimentary realms followed by well-stratified calcarenites (locally coarse and dolomitized), probably deposited on an external platform. Upward, coarse deposits occur, consisting of polygenic breccias/conglomerates (5–30 cm thick; with limestone and green-schist clasts), turbiditic sandstone (2–20 cm thick) and slump deposits (up to 15 m thick). This interval ends with another slumped body (20 m thick), involving black shale from the Sărata Fm middle member, probably deposited on a slope.

The succession continues with Putna Fm (stratigraphic section 4), which consists of dark-greyish clays, turbiditic calcarenites (rare), limestones (4–5 m thick), silty shale and arenites with green-schist microrudites and algae fragments (Melobesiae) and some polygenic breccias (with green-schist clasts up to 2 cm in diameter). The Putna Fm could have been deposited in a deeper pelagic sedimentary realm. The Putna Fm is followed in column by the Piatra Uscată Fm, the contact being of gradational type. The latter consists of greyish-green pelites with calcarenite interlayers and some thin arenite beds (with green-schist clasts; stratigraphic section 2). The Piatra Uscată Fm was sedimented in the same realm as the Putna Fm. The succession continues with the Jgheabu Mare Fm, of bluish spongolitic limestones (5–50 cm thick) and thin (2–5 cm) interstratified bluish clays. Over the spongolitic limestones, a slump deposit 30 m thick occurs (stratigraphic section 2). The spongolitic limestones and as well as the slump deposit were probably deposited on a slope. Upwardly, greyish limestones, calcarenites, and marls of Doamna Limestone Fm occur. This formation was deposited on an outer platform.

Overlying the Doamna Limestone Fm, the Bisericani Fm occurs. The lower part of this formation ("green and red shale member") is not exposed in logged sections, the middle part ("greenish-grey mudstone member") consisting of micaceous greenish to reddish clay-silty/mudstones (with no carbonate), greenish to blackish mudstones with thin laminated sandy

Table 1: Stratigraphic nomenclature, main lithofacies, samples, thickness, and estimated age of the Vrancea Nappe succession (Moldavidian Basin, External Carpathian Chain) reconstructed by five measured logs.

V R A N C E A N A P P E						
Stratigraphic nomenclature			**Lithofacies and their main characteristics**	**Sample**	**Log**	**Estimated ages**
SALTED BRECCIAS Fm (Pericarpathian Nappe)			breccias with gypsum	---	1	
GURA ȘOIMULUI Fm (220 m)			chaotic polygenic breccias with metamorphic clasts (up to 1.5 m): garnet schists, gneiss, white and blackish quartzites, phyllites, amphibolites?; sedimentary clasts: fossiliferous, oolithic limestones, green-greyish arenites, black shales, limestone breccias, greyish pelites, lidites and clasts from dysodilic shales	49÷69	1	Aquitanian p.p.–Burdigalian
UNIT B (220 m)	Upper dysodilic shales mb (34–110 m)		laminated black shales, thin siltites, quartzarenites (2–30 cm thick), sub-arkoses, thin bentonitic clay beds (1–2 cm thick)	34÷48 106÷108	1 2	Aquitanian p.p.
	Transitional interval (5 m)		laminated black shales, thin quartzarenites (5–30 cm thick)	31÷33	1	Rupelian–Chattian (based on correlation with Tarcău Group
	Lower dysodilic shales mb with Kliwa Sst. (126–205 m)		black sandy-silt shales, thin quartzarenite beds of Kliwa type, (up to 25 m thick), greenish shales, disorganized polygenic conglomerates with green schist, arenitic and metamorphic clasts	15÷30 93÷105	1–2	
	Bituminous marls mb (28–66 m)		laminated bituminous marls, chert (beds and lens), thin quartzarenites (2–15 cm thick), marls with metamorphic clasts up to 30 cm in diameter	8÷14 92	1–2	
	Lower Menilites Mb (4/8–32 m)	Compact menilites (2–4 m)	silicified shales, black chert beds	6÷7	1	
		Lingurești Brown Marls (>8 m)	black shales, quartzarenites, brownish marls, black chert (frequent fish fragments)	143÷144	5–2	
LUCĂCEȘTI Fm and a part of Lingurești Brown Marls			not exposed in studied logs	---	1	
BISERICANI Fm (220–400 m)	Globigerina marls mb (12–20 m)		creamy marls, greyish marly clays, thin limestone beds	4–5 135÷142	1–5	early Rupelian
	Greenish-grey mudstone mb (50 m)		marls, micaceous greenish-grey mudstones, sideritic limestones in lens (5–20 cm), thin siltites (2–5 cm thick), limestones in lens up to 50–60 cm in diameter	83÷91 1÷3	2–1	
	Green and red shales mb (50–100 m ?)		not exposed in studied logs	---	2–4	?
DOAMNA LIMESTONE Fm (25–75 m)			whitish limestones, calcarenites, marls	80÷82	2–4	Lutetian *p.p.*
JGHEABU MARE Fm (40–125 m)			bluish spongolitic limestones (5–50 cm thick) thin (2–5 cm) bluish shales, slump up to 30 m thick	73÷79	2 4	latest Ypresian–Lutetian *p.p.*
PIATRA USCATĂ Fm (> 20 m)			greyish greenish silty shales, calcarenites, arenites with green schist clasts	70÷72	2	early Paleocene–latest Ypresian
PUTNA-PIATRA USCATĂ Fms (180 m)			greyish clays, rare calcarenites, limestones (4–5 m thick), arenites, polygenic breccias with green schist clasts up to 2 cm in diameter	129÷134	4	
LEPȘA Fm (70 m)			grey sandy marls, olistostrome of black shale with black chert up to 15 m thick at the top	122÷128	4	Early Cretaceous–Maastrichtian–Danian?
absent			absent in studied logs			
SĂRATA Fm (110–300 m)	Upper Mb (130 m)		sandy marls with green-schists clasts, marls, polygenic breccias with green schists and clasts up to 20 cm, calcarenites with green schists	120÷121	4	
	Middle Mb (> 110 m)		silicified black shales, black chert beds (5–10 cm thick), thin stratified calcarenites and breccias with limestones and green-schist clasts, slump up to 4 m thick	116÷119	4	
	Lower Mb p.p. (> 30 m)		black shales with turbiditic arenites (2–20 cm thick) and conglomerates (5–30 cm thick), slump up to 13 m thick	109÷115	3	

Table 2: Stratigraphic nomenclature, main lithofacies, samples, thickness, and estimated age of the internal Tarcău Nappe succession (Moldavidian Basin, External Carpathian Chain) reconstructed by two measured logs.

TARCĂU NAPPE						
Stratigraphic nomenclature			**Lithofacies and their main characteristics**	**Sample**	**Log**	**Estimated ages***
Tarcău Group	VINEȚIȘU Fm (> 230 m)		bituminous shales, siltstones, thin convolute sandstones (5÷20 cm thick) with some red shales (up to 10 cm) and two slumps (2 and 40 m); tectonized and reworked beds in the upper part of the succession	T73÷T76	7	Burdigalian p.p.
	FUSARU Fm (745 m)	Pelitic-arenitic mb (485 m)	micaceous pelites and litharenites, bituminous shales (in the lower part), marls and marly limestones	T61÷T72	6	Aquitanian p.p.
		Upper dysodilic shales mb (90 m)	well stratified thin brownish and bituminous shales (dysodilic type)	T56÷T60		
		Arenitic mb (170 m)	coarse micaceous litharenites, microconglomerates (up to 2–3 m thick) and rare pelites	T53÷T55		
	UNIT B (365 m)	Lower dysodilic shales mb (264 m) with Jaslo Lmst. marker-bed and arenites in the upper part	well-stratified and laminated thin brownish and bituminous shales (3÷15 cm thick) (dysodilic type) and litharenites in the upper part (Fusaru type)	T18÷T52		Not older than late Chattian
		Bituminous marls mb (20–25 m)	silicified lithofacies, laminated bituminous shales, marls, arenites, etc. (menilites s.s. type)	T15÷T17		
		Lower menilites mb (70–80 m)	silicified lithofacies, laminated bituminous shales (2÷6 cm thick); marls and micaceous litharenites (up to 1 m thick); (menilites s.s.)	T10÷T14		Not older than Late Rupelian
	UNIT A (170 m)	Ardeluța Mb (40 m)	blackish bituminous shales in the lower part; marls, marly limestone (rich in foraminifers), limestone, silicified arenites and micaceous laminated litharenites (up to 2 m thick)	T6÷T9		
		Podu Secu Mb (130 m)	bituminous, limonitic shales, micaceous pelites, micaceous laminated litharenites (0.2÷1 m thick)	T1÷T5		
	TARCĂU SANDSTONES Fm (> 50 m)		massive arenites (0.5÷2 m thick) with some conglomeratic beds	---		Eocene?

* after Belayouni et al. (2007).

turbiditic layers (2–5 cm thick), sideritic limestone in lenses (2–20 cm), rare carbonate clasts, up to 50–60 cm in diameter, and brownish marls (stratigraphic section 2). The upper member of the Bisericani Fm ("Globigerina marls mb") consists of marly clays, limestone and greyish marly pelites (stratigraphic section 5). The deposits of the Bisericani Fm could be related to a hemipelagic ramp to external platform realm. The Bisericani Fm of the Vrancea Nappe is correlatable with the Unit A (Podu Secu and Ardeluța Mbs) of the Tarcău Nappe (log 6).

Putna–Piatra Uscată, Jgheabu Mare, Doamna Limestone, and Bisericani Fms were deposited during the Paleocene to Early Oligocene (see below).

Overlying the Bisericani Fm, an episode of organic-matter-rich deposits was registered, during which the "lower menilites", "bituminous marls", and the "lower and upper dysodilic shales members" (stratigraphic sections 1, 2, 5) were accumulated in the external Moldavidic Basin. The above-mentioned lithostratigraphic units were grouped in a single informal unit (see Figs. 2 and 3) with rank of formation, consequently being considered members and not formations as they were previously (Grasu et al. 1988). Since this unit can be correlated with an analogous one defined by Belayouni et al. (2007) in the Tarcău Nappe, we will use the same informal name, Unit B. This unit (200–400 m thick from Fig. 2) is Late Oligocene to Early Miocene in age. The "lower menilites mb" (stratigraphic sections 1 and 5) is made up of black shale, quartzarenites, brownish marls, silicified black shale, and black chert with fish-fossil fragments (deposited in pelagic environments). This member is followed by the "bituminous marls mb" (stratigraphic sections 1, 2), consisting of bituminous marls, chert beds, silexites and quartzarenites. These lithofacies also point to a deposition in the pelagic-hemipelagic realm. The lower part of the "lower dysodilic shales mb" (stratigraphic sections 1, 2) is made up of sandy-silty black shale (with quartzarenitic dykes, also present in the "bituminous marls mb"), thin quartzarenites, greenish shale, disorganized polygenic conglomerates with "green clasts" and limestone clasts up to 1 m in diameter (log 2). The lithofacies mentioned seem to indicate a hemipelagic depositional environment. The upper part of the "lower dysodilic shales mb" consists of laminated black shale, thin (< 10 cm) siltstone beds and thin (2–30 cm) laminated turbiditic quartzarenites. A pebbly mudstone bed with some "green clasts" has also been recognized. Two upwardly thickening beds of white quartzarenites (up to 15–20 m thick), the Kliwa Sandstone, characterize this sub-unit, too. The "upper dysodilic shales mb" (stratigraphic sections 1, 2) consists of laminated black shale, quartzarenites, sub-arkoses and thin (1–2 cm thick) bentonitic beds. In the Tarcău Nappe, the equivalent succession (log 6) is made up of Unit B, consisting of "lower menilites", "bituminous marls", and "lower dysodilic shales mbs", as reported in Belayouni et al. (2007).

The Vrancea Nappe succession ends with Gura Șoimului Fm (log 1), Early Miocene (Aquitanian *p.p.*–Burdigalian *p.p.*) in age. The basal bounding surface of this formation is erosive. The Gura Șoimului Fm consists of a mega-olistostrome deposit made up of disorganized polygenic conglomerates with a matrix of green-greyish arenites and greyish pelites.

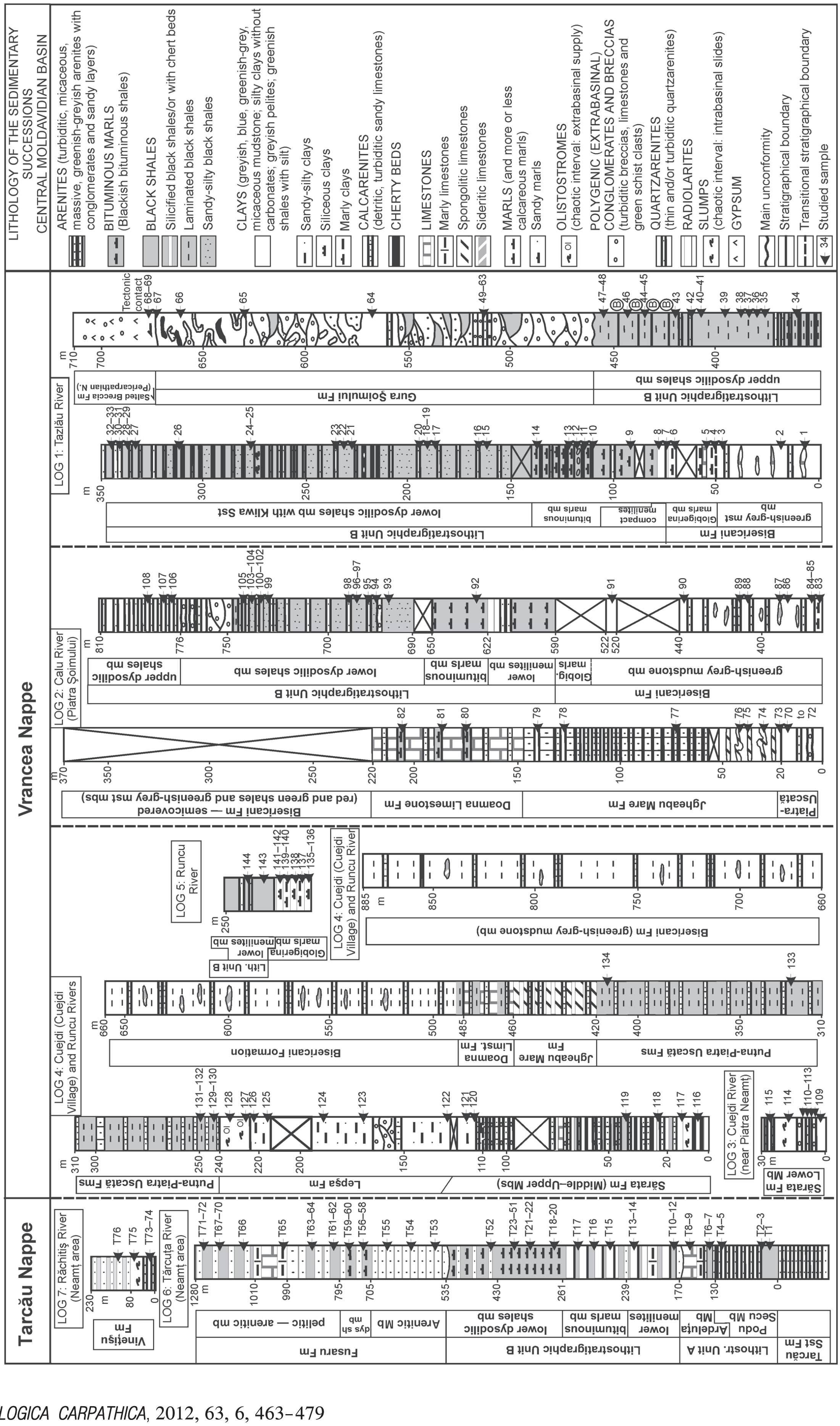

Fig. 2. Main lithological characters of the Tarcău and Vrancea Nappes successions reconstructed in the seven logs, and the stratigraphic position of the samples studied. The locations of the logs are shown in Fig. 1.

Most of the polygenic clasts are metamorphic (garnet schists, gneisses, white quartzites, blackish quartzites, phyllites and amphibolites?) but there are sedimentary clasts (fossiliferous limestones, oolithic limestones, greenish-greyish arenites, black shale, limestone breccias with Fe mineralization, greyish pelites, lidites, and polygenic breccias), also. Black-shale bodies are also included in the olistostrome. This mega-olistostrome deposit was probably sedimented in a slope realm. In the upper part of Gura Şoimului Fm, a thick (40–50 m) slumped deposit and olistostrome occur. The slumped body includes contorted beds of menilite and dysodilic shales with Kliwa-type sandstone interlayers as well as large blocks of white limestone and "green schists".

With the Gura Şoimului Formation, the succession of Vrancea Nappe in the Bistriţa half-window ends. The Vrancea Nappe is in tectonic contact with the "salted breccia and gypsum formation" of the Pericarpathian Nappe. In the Tarcău Nappe, the equivalent succession consists of the Fusaru Fm (log 6) and Vineţişu Fm (log 7), both correlatable with the Gura Şoimului Fm from the Vrancea Nappe.

Bio- and chronostratigraphy

The age of the former central Moldavidian Basin formations (of Tarcău and Vrancea sedimentary domains) have been determined by means of a biostratigraphic study based both on planktonic foraminifers and on calcareous nannoplankton (Ionesi 1957; Dumitrescu 1963; Mirăuţă & Mirăuţă 1964; Lebenzon 1973a,b; Ion et al. 1982; Micu & Gheţa 1986; Bombiţă 1986; Ionesi & Meszaros 1989; Juravle et al. 2008; Figs. 3, 4 and 5). The data listed below come from the 7 sections logged in the Vrancea Nappe (Sărata to Bisericani Formations) and Tarcău Nappe (Units A and B, Fusaru and Vineţişu Formations). The biostratigraphy based on the planktonic foraminifers was carried out using the zonation of Berggren & Pearson (2005) for the Paleogene and of Berggren et al. (1995) for the Aquitanian as reference. For the calcareous nannoplankton biostratigraphy, the standard zones of Martini (1971) and Okada & Bukry (1980) were used. These analyses gave the results presented in the next paragraphs and in Tables 1 and 2.

The oldest deposit in the study area is the Sărata Formation which has formerly been considered Early Cretaceous (Băncilă 1958; Mirăuţă & Mirăuţă 1964) and Valanginian–Albian (Melinte et al. 2007) in age. In the Cuejdi River section, the lower member of this formation (samples 109–115; log 3) yielded only some agglutinated foraminifers and echinoderm remains. In sample 109, three small conical foraminifers were identified as *Patellina* sp. This taxon appears in the Early Cretaceous but survives through younger ages. The siliceous black shales composing the middle member of the Sărata Formation (samples 116–119; log 4) are almost barren, except for some agglutinated foraminifers. Only in sample 119 was a very poorly preserved specimen found, probably belonging to *Globotruncana* sp., suggesting a Campanian-Maastrichtian age. The sandy marls of the upper member of the Sărata Formation (samples 120–121; log 4) contain a scarce and poorly preserved but typical Senonian planktonic foraminiferal assemblage. *Globotruncana ventricosa* (White) recognized in sample 120 indicates a Late Campanian-Early Maastrichtian age.

The marls and clays of the Lepşa Formation, previously dated Late Cretaceous–Paleocene (Dumitrescu 1963; Ion et al. 1982) (samples 122–128; log 4), include Senonian planktonic foraminiferal assemblages, too. In this formation, *Globotruncanita stuarti* (De Lapparent), *Abathomphalus mayaroensis* (Bolli), and *Racemiguembelina fructicosa* (Egger) appear (sample 124; Fig. 4.1–3), these being characteristic of the Late Maastrichtian (Caron 1985; Robaszynski et al. 2000). Moreover, Heterohelicidae predominate in most of the samples from the Lepşa Formation; this is a common event observed at the top of the Cretaceous (although it can also be interpreted as related to local paleo-environmental features). Regarding the calcareous nannoplankton, only some poorly preserved Late Cretaceous forms were found. In the uppermost sample (128) of this formation, no planktonic foraminifers or calcareous nannoplankton occur, and the microfauna consists only of scarce agglutinated foraminifers. These biotic features could be related to the Cretaceous-Paleocene transition (Danian), but no detailed biostratigraphic monitoring is possible, because the upper part of the Lepşa Formation (samples 127 and 128) is a mega-slump, according to field observations.

Above the Lepşa Formation, the dark grey to greenish-grey shale of the Putna–Piatra Uscată Formations occur (samples 129–134; log 4, Figs. 2 and 3). These formations, formerly dated as Middle–Late Paleocene (Ion et al. 1982), yielded microfauna made up mainly of agglutinated foraminifers (Astrorhizidae). Regarding the planktonic foraminifers, the lower levels (up to sample 132) contain only some earliest Paleocene small globigerinids such as *Subbotina cancellata* Blow. However, the presence of *Praemurica uncinata* (Bolli) in sample 133 (Fig. 4.4–6) characterizes Zone P2 of Berggren et al. (1995), dated as late Early Paleocene in age. In the Calu River (log 2) the green silty shale of the uppermost Piatra Uscată Formation contains mainly agglutinated foraminiferal microfauna (samples 70–72). In the rare and poorly preserved assemblages of planktonic foraminifers, *Morozovella aragonensis* (Nuttal), *Morozovella lensiformis* (Subbotina), *Subbotina linaperta* (Finlay), *S. inaequispira* (Subbotina), *Acarinina soldadoensis* (Brönnimann), *Acarinina angulosa* (Bolli), *A. pentacamerata* (Subbotina), and *A. pseudotopilensis* (Subbotina) have been identified (Fig. 4.7–10). These assemblages match with a biostratigraphic interval ranging between E5–E7 Zones of the late Ypresian. Some suppositions of such age were previously made by Ion et al. (1982) based on some benthonic foraminifers which evolved up to earliest Ypresian.

The shale interlayers in the overlying Jgheabu Mare Formation, considered latest Paleocene–Eocene (Grasu et al. 1988), are practically barren (samples 73–79; log 2, Figs. 2 and 3) except for very rare agglutinated foraminifers. However, the age of the overlying formation leads us to propose a latest Ypresian–Lutetian *p.p.* age.

A marly bed (sample 82) belonging to the overlying Doamna Limestone Formation, formerly considered Middle Eocene (Juravle et al. 2008 *and references within*), yielded some flattened and very poorly preserved planktonic foraminifers, most of them unidentifiable. However, *Acarinina* and *Morozovella* species, *Turborotalia* gr. *frontosa* (Subbotina)-*pomeroli* (Tourmakine & Bolli) and probably *Truncorotaloides* sp. and *Hantkenina* sp. were recognized, indicating

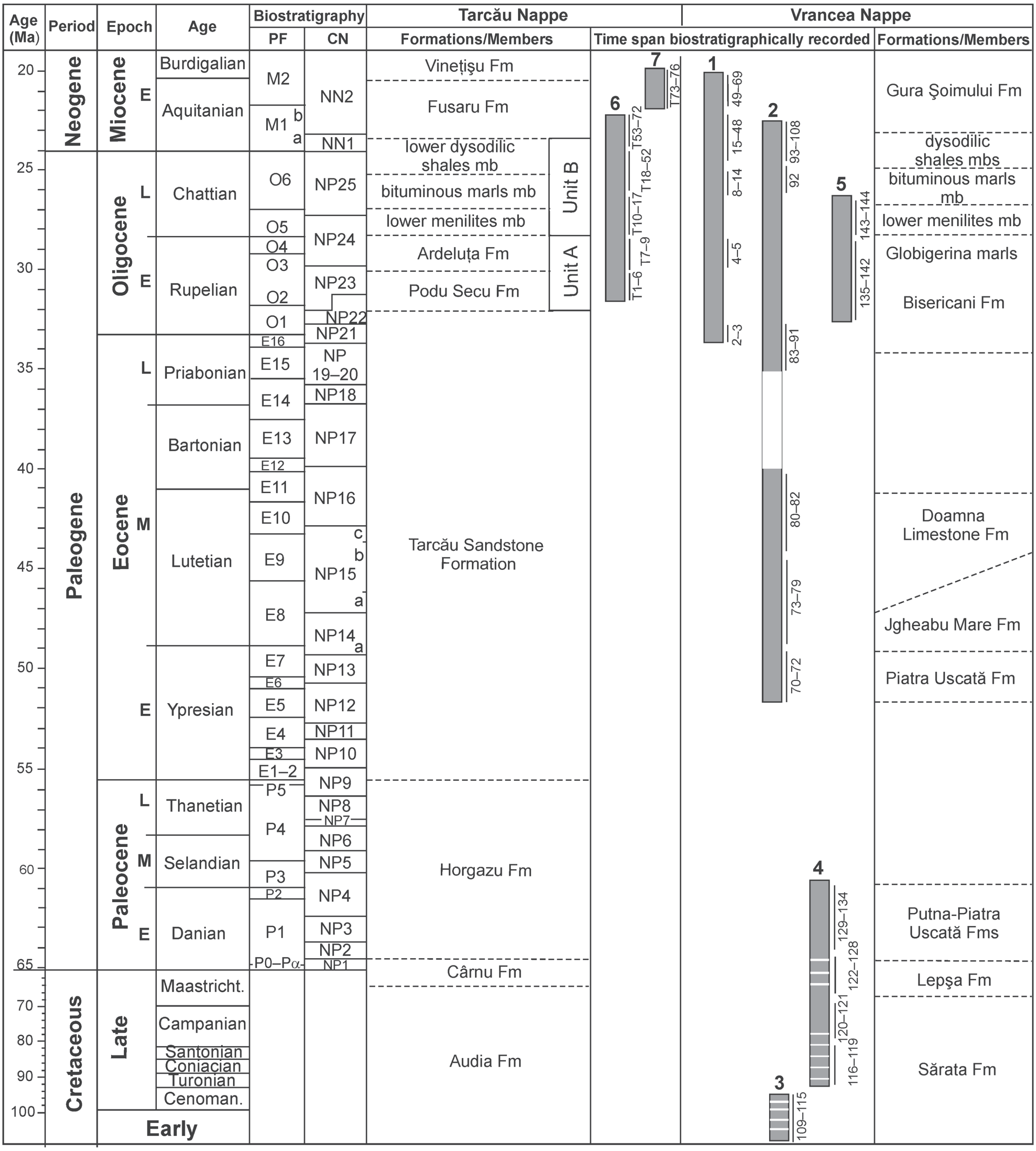

Fig. 3. Bio- and chronostratigraphy of the Tarcău and Vrancea successions studied (white spaces correspond to the chronostratigraphic intervals biostratigraphically unproven).

Fig. 4. Significant planktonic foraminifers and calcareous nannoplankton assemblages identified in some formations of the Vrancea Nappe. **Planktonic foraminifers.** Lepşa Fm: **1a,b,c** — *Globotruncanita stuarti* (De Lapparent), sample 127; **2a,b,c** — *Abathomphalus mayaroensis* (Bolli), sample 124; **3** — *Racemiguembelina fructicosa* (Egger), sample 124. Putna–Piatra Uscată Fms: **4a,b,c** — *Subbotina cancellata* Blow, sample 132; **5a,b,c** — *Parasubbotina pseudobulloides* (Plummer); **6b,c** — *Praemurica ucinata* (Bolli), sample 133. Piatra Uscată Fm: **7a,b,c** — *Morozovella aragonensis* (Nuttall), sample 72; **8a,b,c** — *Morozovella lensiformis* (Subbotina), sample 72; **9a,b,c** — *Acarinina soldadoensis* (Brönnimann), sample 72. Globigerina marls mb: **10a,b,c** — *Acarinina angulosa* (Bolli), sample 135;

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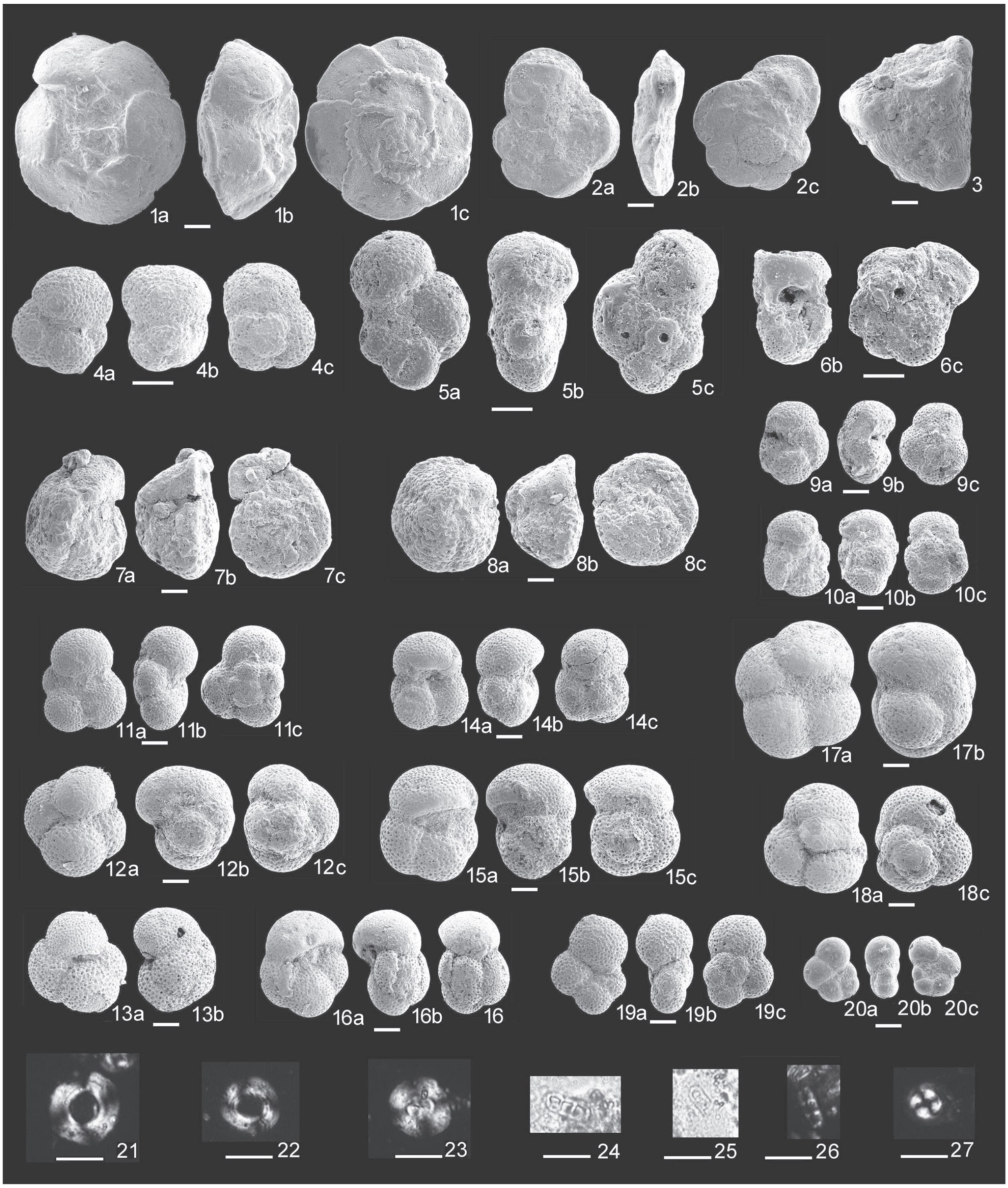

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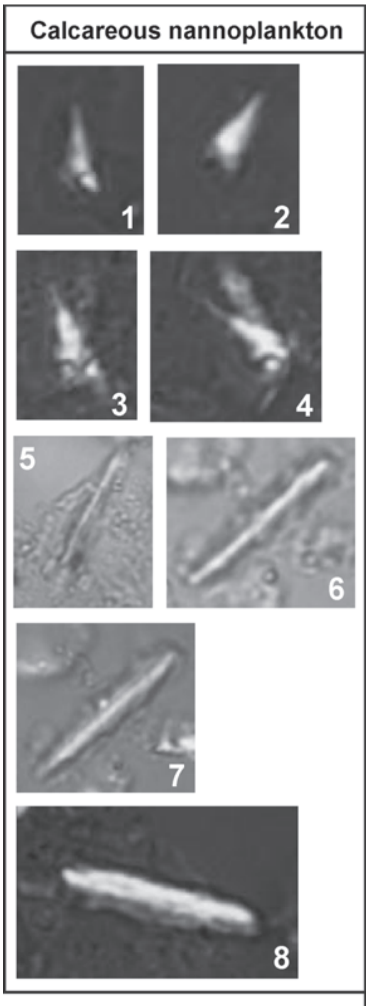
11a,b,c — *Globigerina eocaena* Guembel, sample 137; **12a,b,c** — *Globigerina corpulenta* Subbotina, sample 137; **13a,b** — *Globigerina angiporoides* Hornibrook, sample 142; **14a,b,c** — *Globigerina ampliapertura* Bolli, sample 138; **15a,b,c, 16a,b,c** — *Turborotalia increbescens* Bandy, sample 140. Lower menilites mb (Unit B): **17a,b** — *Paragloborotalia* cf. *opima* (Bolli), sample 141. Globigerina marls mb: **18a,c** — *Catapsydrax unicavus* Bolli, Loeblich & Tappan, sample 140; **19a,b,c** — *Globorotaloides suteri* Bolli, sample 137; **20a,b,c** — *Pseudohastigerina* cf. *micra* (Cole), sample 137. In all the cases, the scale bar represents 100 µm. **Calcareous nannoplankton.** Globigerina marls mb: **21, 22** — *Reticulofenestra umbilica* (Levin) (Martini & Ritzkowski 1968), sample 4. Greenish-grey mudstones mb (Bisericani Fm): **23** — *Reticulofenestra bisecta* (Hay et al. 1966; Roth 1970), sample 87; **24, 25, 26** — *Istmolithus recurvus* (Deflandre & Fert 1954), sample 83; **27** — *Ericsonia formosa* (Kamptner) (Haq 1971), sample 83. In all the cases, the scale bar attached represents 10 µm.

the Middle Eocene, so that the formation can be considered Lutetian *p.p.*

The Bisericani Formation, formerly dated as Late Eocene (Bombiţă 1986; Micu & Gheţa 1986 *and references within*), overlies the Doamna Limestone Formation. The lower member of this formation ("red and green shale member") is not exposed, a stratigraphic gap being possible between the two formations in the Middle–Late Eocene *p.p.* (Bartonian *p.p.*–Priabonian *p.p.*) time span. In the log 2 (samples 83–91), the middle member of the Bisericani Formation yielded very scarce microfauna composed of some agglutinated foraminifers and Nodosaridae (*Nodosaria* ssp., *Lenticulina* ssp.) while only two globigerinid specimens reminiscent of the Oligocene age were identified. Regarding the calcareous nannoplankton, despite its scarcity, *R. umbilica* (Fig. 4.21–22) *R. bisecta* (Fig. 4.23), *I. recurvus* (Fig. 4.24–26), and *E. formosa* (Fig. 4.27) were observed in the samples 83–85 (log 2). This assemblage characterizes interval NP19–NP22 of the standard calcareous nannoplankton zonation by Martini (1971), ranging between the latest Eocene and the early Rupelian. The absence of *Discoaster barbadiensis* Tan Sin Hok, and *Discoaster saipanensis* Bramlette & Riedel could restrict the age to the early Rupelian (Zone NP21). In the log 1, the middle member of the Bisericani Formation (samples 2–3) showed the presence of *I. recurvus* in combination with *Ericsonia formosa* (Kamptner) Haq, while *D. saipanensis* and *D. barbadiensis* are absent. According to this situation, these levels could plausibly be assigned to Zone NP21 of the early Rupelian.

The "Globigerina marls member" (upper member of the Bisericani Formation) was previously considered latest Eocene–earliest Rupelian (Micu & Gheţa 1986; Bombiţă



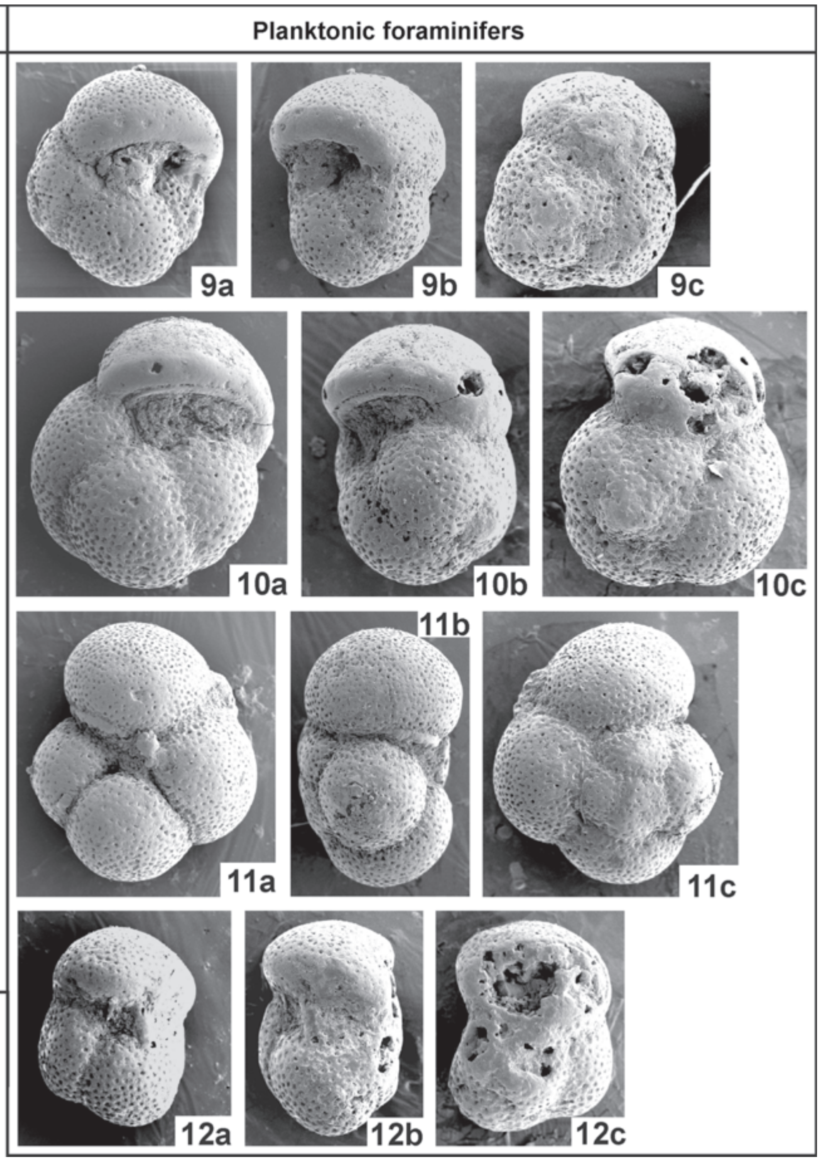


Fig. 5. Significant calcareous nannoplankton and planktonic foraminifers identified in some formations of the Tarcău Nappe. **Calcareous nannofossils** (all specimens ×2,500). Podu Secu Mb (Unit A; log 6): **1, 2, 3, 4** — *Sphenolithus distentus* (Martini), sample T2. Lower dysodilic shales mb (log 6): **5, 6, 7, 8** — *Triquetrorhabdulus carinatus* Martini, sample T52. **Planktonic foraminifers** (all specimens ×75). Ardeluța Mb (Unit A; log 6): **9a,b,c** — *Globigerina ampliapertura* Bolli, sample T9; **10a,b,c** — *Turborotalia increbescens* Bandy; **11a,b,c** — *Paragloborotalia opima* (Bolli), sample T9. Fusaru Sst. Fm (log 6): **12a,b,c** — *Globoquadrina dehiscens* (Chapman, Parr & Collins), sample T66.

1986). This unit is known throughout the former Carpathian Basin, its age being considered middle Late Eocene, latest Eocene, latest Eocene–Early Oligocene (Leszczynski 1997; Soták 2010, *and references within*). From the study area presented in this paper it yielded abundant planktonic foraminifers in the log 5 (samples 135–142), indicating a Rupelian age. The assemblage consists of *Globigerina galavisi* Bermúdez, *G. tripartita* Koch, *G. venezuelana* Hedberg, *G. eocaena* Gumbel (Fig. 4.11), *G. corpulenta* Subbotina (Fig. 4.12), *G. angiporoides* Hornibrook (Fig. 4.13), *G. ampliapertura* Bolli (Fig. 4.14), *T. increbescens* Bandy (Fig. 4.15–16), *C. unicavus* Bolli, Loeblich & Tappan (Fig. 4.18), *G. suteri* Bolli (Fig. 4.19), *G. ouachitaensis* Howe & Wallace, *G. ciperoensis* Bolli and *G. praebulloides* Blow. Moreover, sample 137 contains *Pseudohastigerina* cf. *micra* (Cole) (Fig. 4.20), which can restrict the interval corresponding to the samples 135–137 to the early Rupelian Zone O1 (Berggren & Pearson 2005). The presence of *Paragloborotalia* cf. *opima* (Bolli) (Fig. 4.17) in the sample 141 without *G. ampliapertura* or *T. increbescens* suggests that the deposition of the "Globigerina marls member" lasted until the late Rupelian. Calcareous nannoplankton assemblages from the same levels contain poorly preserved *E. formosa* (Fig. 4.21–27), *R. umbilica*, and *Helicosphaera compacta* Bramlette & Wilcoxon, whereas *I. recurvus*, *D. barbadiensis* and *D. saipanensis* were not recorded. These assemblages correspond to an early Rupelian age.

Unit A (Podu Secu and Ardeluţa Members) belonging to the internal part of the Tarcău Nappe, the equivalent of the Bisericani Formation of the Vrancea Nappe, was considered latest Eocene–earliest Rupelian (Ionesi 1957; Lebenzon 1973a,b). We dated Podu Secu Member (log 6) as not older than late Rupelian (NP23–24 Zones) by calcareous nannoplankton: *S. distentus* (sample T2; Fig. 5.1–3) and Ardeluţa Member (stratigraphic section 6) as the first part of the late Rupelian by planktonic foraminiferal assemblages with: *G. ampliapertura*, *T. increbescens*, *P.* cf. *opima* (sample T9; Fig. 5.17–19) together with *G. eocaena*, *G. corpulenta*, *G. tripartita*, *G. venezuelana*, *G. euapertura*, *G. ouachitaensis*, *G. praebulloides,* and *G. ciperoensis*.

Above the "Globigerina marls member", the deposits of the Vrancea Nappe rich in organic matter are devoid of fossils although three thin interlayers of white limestone (Tylawa, Jasło, and Zagórz) containing rich coccolith assemblages are used as regional markers (Hackzewski 1996, *and references within*; Švábenická et al. 2007). Ionesi (1986) recognized two of these in the Tarcău and Vrancea Nappes based only on lithological features, the Lower Jasło "Member" in the "lower dysodilic shales member" and the Upper Jasło "Member" in the Kliwa and Fusaru Sandstone. Melinte (2005) recognized and dated three of these, Tylawa (NP23) in the basal part of the "lower dysodilic shales member", Jasło and Zagórz (NP24) in the Fusaru and Kliwa Sandstones. The internal part of the overlying Tarcău Nappe, Unit B ("lower dysodilic shales member"), considered Early Oligocene (Băncilă 1958; Ionesi 1971; Săndulescu & Micu 1989), is dated here at the bottom (log 6) as not older than latest Chattian (NP25/CP19b Zone) by the presence of *H. recta* and *T. carinatus* (sample T52; Fig. 5.5–8). These data match the above-mentioned chronostratigraphic results and indicate an onset of the deposition of the "Cenozoic Black Shales" (comprising the "lower menilites", "bituminous marls", and "dysodilic shales members") towards the Rupelian/Chattian transition. Consequently, an Aquitanian *p.p.* age can be suggested for the "upper dysodilic shales member".

The Fusaru Formation of the internal Tarcău Nappe was dated for the first time (log 7) as not older than Aquitanian by the presence of *Globoquadrina dehiscens* (sample T66; Fig. 5.20).

The Vineţişu Formation, characterizing the internal and median part of the Tarcău Nappe, contains frequent radiolarian skeletons (sample T76). An early Burdigalian attribution may be consistent with its stratigraphic position. In addition, this peak of radiolarians appears to be consistent with the silexites marker-bed known in the Mediterranean region (Guerrera et al. 1992, *and references within*).

The Gura Şoimului Formation of the Vrancea Nappe, a lateral equivalent of the Fusaru–Vinetişu Formations of the Tarcău Nappe, was considered Burdigalian (NN2–NN3; Popescu 2005) and may be provisionally considered Aquitanian to early Burdigalian.

Discussion

Stratigraphic analysis of the tectono-sedimentary processes

The sedimentation in the central Moldavidian Basin was controlled mainly by tectonic processes and secondly by eustatic sea-level changes. In fact, the sedimentation occurred in a foreland basin (Moldavidian Basin) with tectonized realms (active margin of the Dacide and forebulge of the passive margin Moesian-Scythian-East European Platforms) representing the source areas of coarse sediment (Amadori et al. 2011, *and references within*). The successions studied (prevalently flysch-like deposits) do not allow the application of the conventional theoretical sequence-stratigraphy criteria. Therefore, the target of a sequential analysis of flysch-like successions should be to determine tectonic-activity markers. In fact, several indicators of continental erosion and tectonic instability processes (slumps, olistostromes, coarse sandy levels, upwardly thickening sequences) alternating with quiescent periods recorded as pelagic deposits (organic-siliceous, black shale, marly and clay beds, etc.) can be recognized. The ratio between the indicators of tectonic activity and tectonic quiescence can be used to define tectonic-influence intervals in the successions, contrasting with the system tracts of the classic sequence stratigraphy (Martín-Martín et al. 2001; Martín-Martín & Martín-Algarra 2002; Guerrera et al. 2006).

The sedimentary record studied can be divided into two main sedimentary cycles (SC-1 and SC-2) based on the significant amounts of terrigenous supply (Fig. 6):

SC-1 (Late Cretaceous to Early Oligocene), recording pelagic to hemipelagic conditions with sporadic development of external platform conditions, is related to prevalently tectonic quiescence. Based on surfaces interpreted as sequence boundaries and the recognized trends SC-1 can be divided into three stratigraphic units with the character of depositional

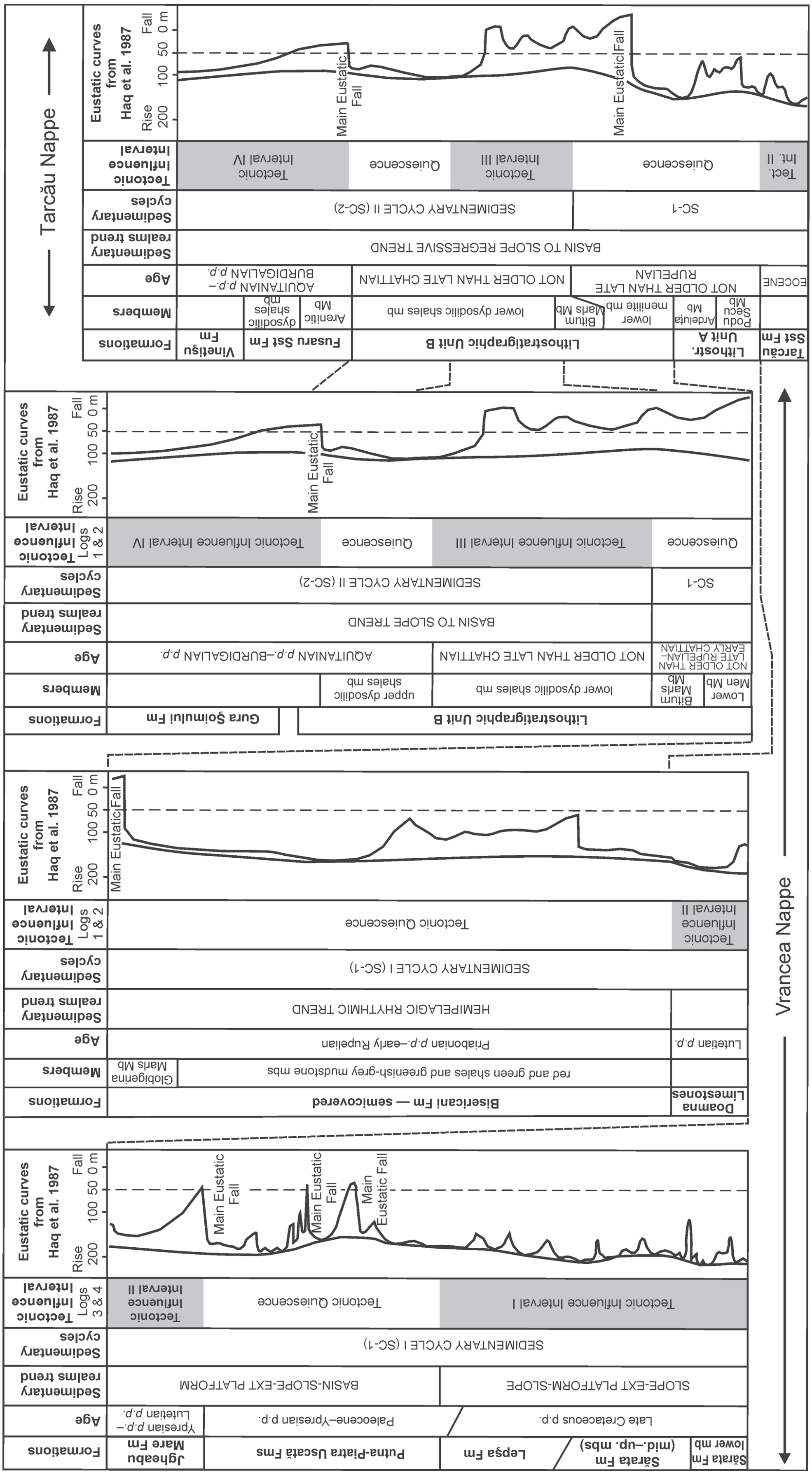


Fig. 6. Synthetic stratigraphy of the Vrancea and Tarcău Nappes (Late Cretaceous to Early Miocene) showing the formations, sedimentary domain trends, sedimentary cycles, tectonic-influenced intervals, and eustatic curves from Haq et al. (1987).

sequences. The first depositional sequence, Cretaceous to earliest Paleocene in age, consists of Sărata and Lepşa Formations which show a regressive-transgressive (progradational-retrogradational) trend. This trend reflects an evolution from pelagic (slope with slumps) to hemipelagic (external platform carbonates and marls) and again to pelagic (slope with slumps) sedimentary realms. The second depositional sequence, Paleocene *p.p.*–Middle Eocene in age, consists of the Putna, Piatra Uscată, Jgheabu Mare, and Doamna Limestone Formations, showing a regressive (progradational) trend. This sequence evolves from a pelagic basinal environment (Putna–Piatra Uscată Formations greyish to greenish shale with distal turbiditic sandstone) to slope (slumped siliceous facies at the base of the Jgheabu Mare Formation) and finally to external platform realms (the calcarenites and limestones of Jgheabu Mare and Doamna Limestone Formations). The relation of the second sequence to the third one is not clear due to lack of exposure between the Doamna and Bisericani Formations, a stratigraphic gap being possible. The third depositional sequence, Late Eocene–Early Oligocene in age, is made up of the Bisericani Formation recording hemipelagic rhythmic conditions (red and green shale, greenish-grey, sporadic dark shale with distal turbiditic sandstone and sideritic limestone intercalations) going upwards in the Early Oligocene "Globigerina marls member", which could indicate hemipelagic to external platform realms.

Only two stages indicate significant terrigenous supply and tectonic related instability processes: (1) Campanian–Maastrichtian–earliest Paleocene (sandstone, conglomerates, and slumped deposits during the sedimentation of Sărata-Lepşa Formations); (2) latest Ypresian-Lutetian (slumps and terrigenous supply during the sedimentation of the Jgheabu Mare-Doamna Limestone and Tarcău Sandstone Formation).

SC-2 (Late Oligocene to Early Miocene), deeper and with hemipelagic conditions in a regressive-like (progradational-like) trend, records a large terrigenous supply and a greater tectonic instability. SC-2 consists of several regressive (progradational) stratigraphic units with the character of a depositional sequence, including frequent tectofacies-levels related to compressional tectonic activity. Based on surfaces interpreted as sequence boundaries and the recognized trends, SC-2 can also be subdivided into three depositional sequences. The first, Rupelian in age, consists of the "lower menilites", "bituminous marls" and "lower dysodilic shales members", recording a regressive (progradational) trend from pelagic ("lower menilites" and "bituminous marls members" fine-grained lithofacies) to hemipelagic depositional environments ("lower dysodilic shales member" coarse lithofacies). The second, Aquitanian in age, consists of the "upper dysodilic shales member", recording a regressive (progradational) trend, also, with an evolution from pelagic (basal black shale) to hemipelagic environments (coarse facies in the upper part of the member). The third, Burdigalian in age, consists of Gura Şoimului Formation, made up of thick conglomerates with rounded clasts, and sandstone, followed by an olistostromic deposit involving deformed Late Oligocene-like deposits without trending recognized. The lower contact of this sequence is an unconformity related to a channelized area of a slope.

Two stages with high influence of tectono-sedimentary processes can be highlighted:

(1) late Chattian–earliest Aquitanian, which is marked by a large amount of turbiditic arenites, conglomerates, and slumps (Unit B);

(2) late Aquitanian–early Burdigalian characterized mainly by olistostromic polygenic conglomerates and sandstones from the Gura Şoimului Formation on the external margin of the basin and the Fusaru and Vinetişu Formations on the internal sedimentary domain of the Tarcău Nappe.

The correlation between sedimentary trends and eustatic curve (Haq et al. 1987) excludes the eustatic control (falls) on the terrigenous supplies (Fig. 6). In fact, the main eustatic falls (depth less than 50 m) occur both during the interpreted quiescence intervals and at the boundary between quiescence and tectonic-influence intervals. Moreover, the tectonic-influence intervals (see interval II, III and IV) are usually contemporary with eustatic rising periods.

Geodynamic constraints

The post-Cretaceous geodynamic evolution of the study area should be closely related to the post-Cretaceous Africa-Europe convergence, to the direction of transport of tectonic units (usually embayment or tectonic escapes with a progressive reorientation from NE-ward until reaching the SE-ward), and to the NW-SE orientation of the tectonic lineaments after the first eastward tectonic escape due to the Cretaceous docking in the northern part of the European plate (Morley 1996; Bădescu 1997; Mann 1997; Mason et al. 1998; Hippolyte et al. 1999; Sanders et al. 1999; Maţenco & Bertotti 2000; Gibson 2001; Seghedi et al. 2004; Golonka et al. 2006; Gröger et al. 2008; Schmid et al. 2008; Maţenco et al. 2010; Merten et al. 2010; Márton et al. 2011). The progressive reorientation of convergence and the NW-SE orientation of the tectonic lineaments should give a local geodynamic framework in the Moldavidian Basin, varying from transpressive dextral strike-slip to sinistral strike-slip passing through a purely compressive strike-slip as will be exposed in detail below by correlation with the tectonic-influence intervals detected in the sedimentary record (Fig. 7).

The four stages of significant tectonic activity indicated by the sedimentary record should be correlated with periods of tectonic rising and exhumation of source areas during the geodynamic evolution of the Moldavidian Basin, in particular, and the Eastern Carpathians, in general (Mann 1997; Maţenco & Bertotti 2000; Csontos & Vörös 2004). Miclăuş et al. (2009) consider that fragmentation of the forebulge, raised as a result of basin shortening, can explain the increasing supply of coarse sediment toward the Vrancea sedimentation area recorded at least in the Eocene–Oligocene time span.

In detail, the tectonic indicators are less pronounced in the two older stages and much more significant in the two recent ones. In these latter, the indicators consist of a high amount of coarse clastic material, probably related to the proximity of the exhumed areas and to the orientation of the tectonic transport of the tectonic units involved (Fig. 7). Thus, during the SC-1, the tectonic transport would have been oblique to the paleogeographic axis of the Moldavidian Basin, which underwent transpressive dextral strike-slip kinematics (NW-SE according to Zweigel et al. 1998; Linzer et al. 1998). As a result, tectonic areas, distantly located from the basin, must have gently risen. In the Late Oligocene (beginning of SC-2), tectonic transport could reach the NE orientation (perpendicular to the paleogeographic axis), leading to steeply rising tectonic areas situated near the basin (Mann 1997; Maţenco & Bertotti 2000; Csontos & Vörös 2004) in a purely compressive framework.

The tectonic phases that we defined and dated based on the estimated biostratigrafic ages could be integrated with those from the known geological literature. Gröger et al. (2008) hold that the Tisza and Dacia blocks collided during the Albian to create Tisia undergoing metamorphism (Austrian phase: Early Cretaceous), followed by cooling and exhumation at the beginning of the Late Cretaceous. Merten et al. (2010) propose a Laramian phase (Late Cretaceous) affecting

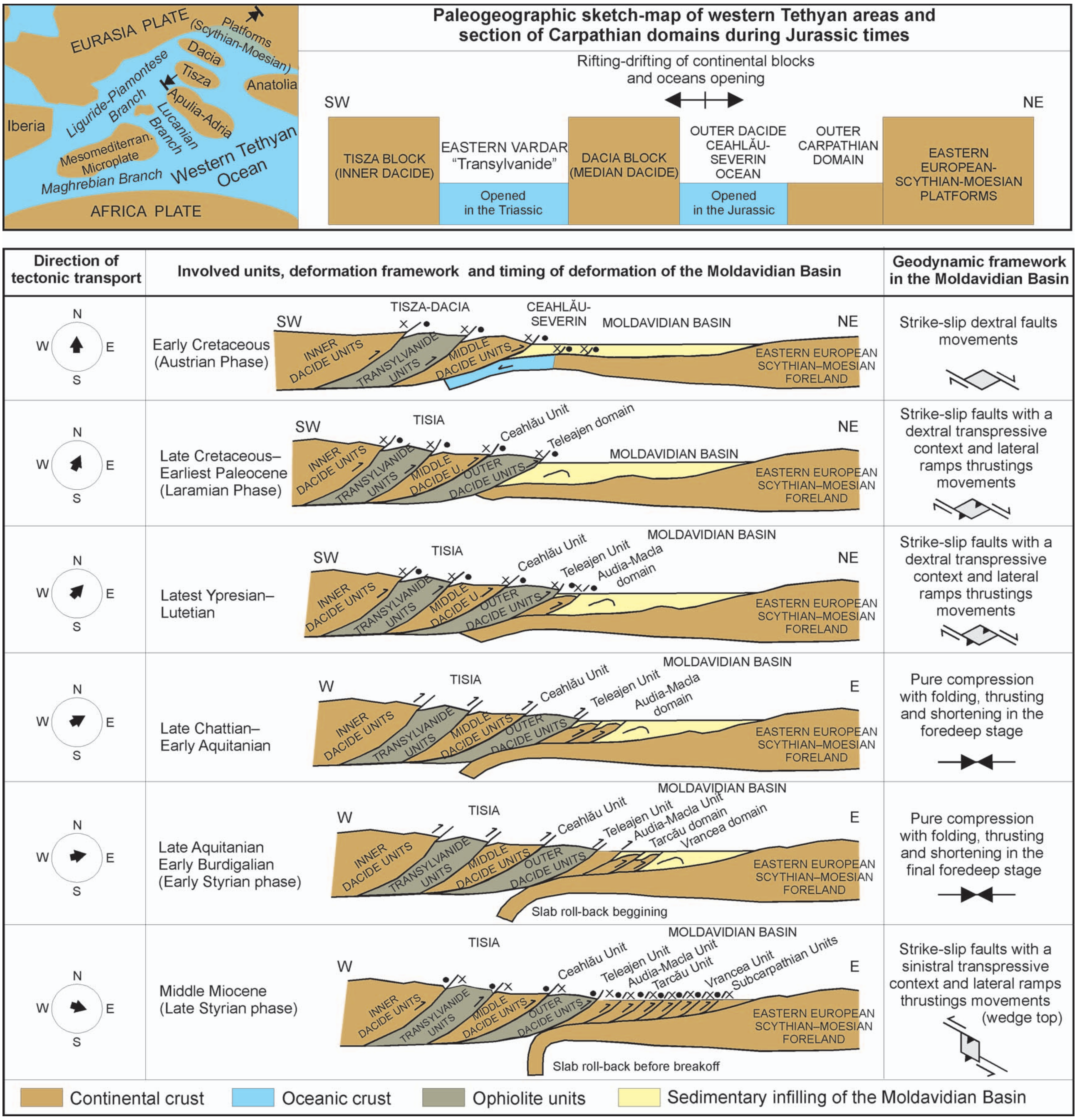


Fig. 7. Paleogeographic sketch map for western Tethyan areas and a cross-section of the Carpathian blocks and oceanic branches during the Jurassic (top figure). Cretaceous to Miocene paleogeographic and paleotectonic evolutionary model of the central Moldavidian Basin. Tectonic transport directions are indicated according to recent literature (Mann 1997; Zweigel et al. 1998; Linzer et al. 1998; Maţenco & Bertotti 2000; Csontos & Vörös 2004). The geodynamic framework (dextral or sinistral strike-slip or pure compression) in the Moldavidian Basin is deduced according to the tectonic transport directions and the orientation of main tectonic accidents.

the Ceahlău area (Outer Dacide) but also the internal part of the Moldavidian Basin (Teleajen sedimentary domain) with a northward tectonic transport. Our approach, based on lithostratigraphic and biostratigraphic data, seems to indicate that this phase can be correlated with the first tectonic-influence interval we defined in the sedimentary record, although slightly younger, reaching at least the earliest Paleocene (Fig. 7).

Another phase, at the late Ypresian, is cited by Maţenco et al. (2003) affecting the internal (mainly Teleajen, but also Audia-Macla sedimentary domains) which could correspond to the second tectonic-influence period proposed here, when the Moldavidian Basin evolved as a foreland basin. Consequently, according to our biostratigraphic data, this phase would also be younger, namely latest Ypresian–Lutetian in age (Fig. 7).

The late Chattian–early Aquitanian defined tectonic-influence interval is also mentioned by Linzer et al. (1998) and Maţenco et al. (2003) during the Oligocene. The large amount of terrigenous supply suggests that the Moldavidian Basin reached the foredeep stage (*sensu* Guerrera et al. 1993), affecting mainly the Audia-Macla but also the Tarcău domains (Fig. 7). Miclăuş et al. (2009) consider that Vrancea sedimentary area was on the partly emerged forebulge, supplying coarse material consisting of quartzose sand and “green schist” clasts.

The Aquitanian-Burdigalian boundary age deformative phase (early Styrian) in the central Moldavidian Basin of Maţenco & Bertotti (2000) and Maţenco et al. (2003) can be correlated with our latest Aquitanian–early Burdigalian tectonic-influence interval. This also coincides with the constructive wedge phase indicated by Sanders et al. (1999), as well as with the deformation of the Tarcău and Vrancea sedimentary domains and corresponding formation of nappes (Zweigel et al. 1998; Gibson 2001) during the end of the foredeep stage of the Moldavidian Basin (Fig. 7). The thick Gura Şoimului conglomerates with slumps are related to this event. Middle–late Miocene and younger deformation phases (late Styrian, Moldavian, Wallachian) are reported in the literature (Săndulescu 1988; Ellouz et al. 1996; Maţenco & Bertotti 2000; Maţenco et al. 2003; Merten et al. 2010, *among others*), progressively affecting more external and southward areas of the basin (Fig. 7).

Conclusions

This study of the sedimentary record of the central Moldavidian Basin (Romanian Outer Carpathian Domain) provides new data on lithostratigraphy, bio- and chronostratigraphy, and stratigraphic analysis of the tectono-sedimentary processes. Based on the analysis of tectono-sedimentary processes and on age results, the geodynamic evolution of the basin was better constrained. The main results and conclusions are summarized below.

(a) The sedimentary successions of the Tarcău and Vrancea Nappes were correlated based on the detailed lithostratigraphic study and, consequently, were used to reconstruct the stratigraphic architecture of their sedimentary domains in the central Moldavidian Basin (Fig. 2).

(b) The integrated biostratigraphic data (planktonic foraminifers and calcareous nannoplankton; Fig. 2; Tables 1, 2) indicate that all the formations studied are younger in age than previously reported in the literature, consequently all events during the basin evolution should be younger than considered. Two main time spans could not be confirmed by biostratigraphic analysis — Middle Paleocene *p.p.*–Early Eocene *p.p.*, and Late Eocene *p.p.* — a situation that might be explained either by non-deposition or as unrecorded (Fig. 3).

(c) The sedimentary indicators of tectonic-activity in the stratigraphic records studied were integrated in two synthetic columns, based on which two main sedimentary cycles, several minor sedimentary sequences and four main stages of tectonic influence were distinguished in the Moldavidian Basin (Fig. 6).

(d) After removing the eustatic interferences and considering the new established ages of deposits, the comparison of the four main stages of tectonic influence with the accepted geodynamic evolution of the Moldavidian Basin allowed better constraints of the main events (Fig. 7):

- The classic tectonic Laramian phase (Late Cretaceous in the literature) after which the Outer Dacide were structured, could be slightly younger, reaching at least the earliest Paleocene;
- The late Ypresian tectonic phase cited in literature, affecting the internal basin (mainly Teleajen but also Audia-Macla sedimentary domains), could correspond to the second tectonic stage proposed here since the Moldavidian Basin evolved as a foreland basin. According to our biostratigraphic data, this phase would be latest Ypresian–Lutetian in age;
- The Oligocene tectonic phase mentioned in literature could correspond to the third tectonic-influence interval defined in this paper (late Chattian to early Aquitanian), younger than previously reported, when a great amount of terrigenous material was supplied both on internal, and external domains studied in the Moldavidian Basin. We consider that Tarcău-Vrancea sedimentary domain reached the foredeep stage within this time span;
- The Aquitanian-Burdigalian boundary age deformation phase (early Styrian) in the central Moldavidian Basin from literature can be correlated with the latest Aquitanian–early Burdigalian tectonic-influence interval defined in this paper, also coinciding with the constructive wedge phase during the end of the foredeep stage.

Acknowledgments: The author wishes to thank to Ján Soták, András Nagymarosy, and Dušan Plašienka for their valuable comments which improved the earlier draft of the paper manuscript. Research supported by MIUR-Urbino University Grant (responsible F. Guerrera); CGL2009-09249, CGL2011-30153-CO2-02 and CGL2012-32169 Research Project (Spanish Ministry of Education and Science), Research Groups and Projects of the Generalitat Valenciana from Alicante University (CTMA-IGA) and Research Group 146 of the Junta de Andalucía. The geological and stratigraphic results are from F.G., M.M-M. and C.M.; the biostratigraphy from F.S. (foraminifers) and J.A.M-P. (nannofossils); F.G., M.M-M. I.M-R. and C.M. are responsible of the field data; the conclusions belong to all. David Nesbitt corrected the English version of the manuscript.

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