



Sarmatian (Middle Miocene) Coastal Deposits in the Wedge-Top Depozone of the Eastern Carpathian Foreland Basin System. A Case Study

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Abstract

The deposits studied crop out in the Piemontan Hills south of the Vicovu de Jos village (Suceava County). For the first time, the sedimentological characteristics of these deposits (mainly sands with minor interlayers of gravel and mud), belonging to the undeformed sedimentary cover unconformably resting on the folded Pericarpathian Nappe, are described based on a sedimentary facies analysis. The sedimentary succession was accumulated in the wedge-top depozone of the Eastern Carpathian foreland basin system after the Moldavian tectogenesis (Early Sarmatian, i. e. Middle Miocene) and can be an important tool to constrain the timing of this last tectonic event. Twelve sedimentary facies were identified and grouped into three facies associations interpreted as lower, middle and upper shoreface depositional sub-environments of a prograding fair-weather wave-dominated coastal environment with periodic storms. The stratigraphic organization of the facies associations reveals that this sedimentary succession consists of at least five shallowing upward parasequences, three of which are detailed in the present paper. The parasequences are bound by flooding surfaces, the lowest one possibly being a sequence boundary reworked by a maximum flooding surface. The general trend of the parasequence set is a progradational one, characteristic for high-stand system tracts.

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Keywords: coastal depositional system, shallowing upward parasequences, wedge-top depozone, Carpathian foreland basin system, Sarmatian.

Introduction

The present study focuses on the Early Sarmatian (Volhynian) deposits belonging to the wedge-top depozone (*sensu* DeCelles and Giles, 1996 terminology) of the Eastern Carpathian

foreland basin system. For the first time, the data, acquired as a result of detailed lithological logging, have been assessed in order to establish the depositional environment by using the sedimentary facies analysis method (Walker, 1984, 1992; Reading, 2001; Reading and Levell, 1996).

The sedimentological results were used in a high-resolution sequence stratigraphic analysis of the sedimentary succession, which allowed us to describe the behavior of the ancient depositional environment inferred for the short Early Volhynian time span. The concepts of sequence stratigraphy remain the same, regardless of the spatial or temporal scale which the deposits studied involve (Cătuneanu, 2006), therefore they can be used on a whole range of scales, from basin analysis to the local description of small-scale outcrops such are those in the studied area.

On the outcrop scale, a parasequence (Van Wagoner et al., 1990) rather than a sequence can be used as working stratigraphic unit. A parasequence is recognizable in the outcrop based on its facies architecture and the peculiar upward shallowing upward motif, reflecting a filling episode of the accommodation space. In the outcrops studied, at least five parasequences with a progradational trend are documented and considered of high-stand system tract.

Geological setting

The foreland basin system of the Eastern Carpathians is part of the largest sedimentary basin in Central Europe, developed after the Miocene tectogeneses of the Carpathians. Its deposits were previously ascribed to the third sedimentation megacycle of the Moldavian Platform (Ionesi, 1994 and references within). The symmetric wedge shape, the subsidence history, the facies architecture and the structural relationships of the Sarmatian deposits with the fold-thrust Carpathian chain indicate, however, a foreland basin system, as redefined by DeCelles and Giles (1996).

Thus, according to the model of the above-mentioned authors, Grasu et al. (2002) recognized the four basic depozones of this foreland basin system (wedge-top, foredeep, forebulge and backbulge).

The basin was covered by the epicontinental Miocene Paratethys Sea, whose level rose after the "Middle Badenian" salinity crisis, during which thick evaporites accumulated, and flooded even the orogenic wedge (Kovac et al., 2007; Artyushkov et al., 1996) developed during the Old Styrian (intra-Burdigalian), New Styrian (intra-Badenian) and Moldavian (intra-Sarmatian) tectogeneses (Săndulescu, 1984, 1988).

The deposits studied crop out along the Remezău and Voitinel creeks, south of the Vicovul de Jos village (Suceava County), where Buglowian (Earliest Sarmatian) folded gray mudstone is unconformably covered by around 50–60m of undeformed Volhynian (Early Sarmatian) sands slightly tilted toward the hinterland (Fig. 1).

These deposits were first signaled by Joja (1955), Macarovici (1964) and Barbu et al. (1966), who dated them as Volhynian. The latter authors consider that the deposits belong to the so-called "lower clayey-sand complex," which supports the "upper fluvio-deltaic complex". A more precise dating ascribed them to the Biozone with *Ervillea* and *Tapes* (Ionesi, 1969), and the Biozone with *Elphidium rugosum*, respectively (Ionesi, 1968). Thus, they were believed to represent an Early Volhynian age without its basal part. According to more recent biozonations (Ionesi, 2006; Țibuleac, 2009), the concurrent range zone with *Abra reflexa* and *Obsoletiforma lithopodolica* (Early Volhynian) or the assemblage zone with *Inaequicostata pia* and *I. gleichenbergense* would in fact define the undeformed tilted sands studied (Fig. 2).

Based on data from wells, Băncilă and Hristescu (1963) mentioned Sarmatian deposits

underneath the Pericarpathian Nappe at about 3 kilometers west of the Pericarpathian thrust line on the Valea Putnei-Suceava transect, which could explain the lack of the Volhynian basal part on the wedge top. Maţenco and Bertotti (2000) believe that the age of the deposits sealing the frontal sole thrust (e.g., their profile 1 probably equivalent to Valea Putnei-Suceava) is Uppermost Sarmatian to Lowermost Meotian, which would support the hypothesis of a tectogenetic event during the Late Sarmatian. Nevertheless, after 130 years of research on Sarmatian deposits, it is now accepted that, north of the Târgu Neamţ-Paşcani-Iaşi line, deposits younger than Volhynian are rarely preserved. When preservation does occur, it is mainly on interfluves or topfills.

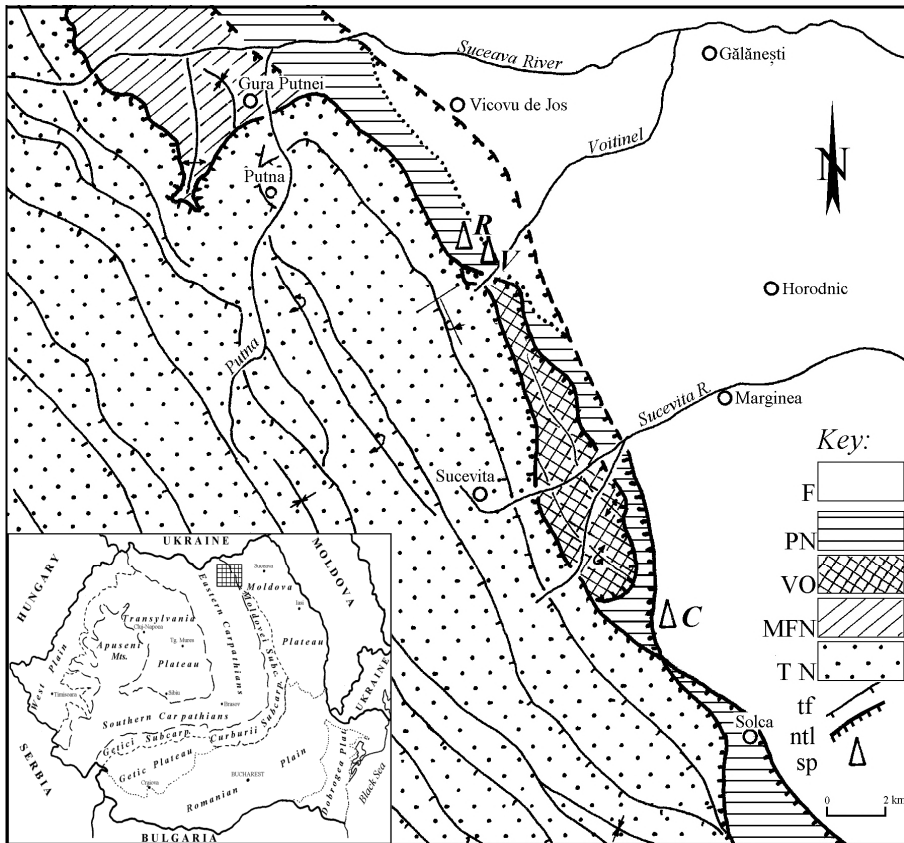


Fig. 1 The position of studied outcrops on the geological sketch map (based on Joja et al., 1969): TN–Tarcău Nappe; MFN–Marginal Folds Nappe (or Vrancea Nappe); VO–Voievodeasa outlier; PN–Pericarpathian Nappe; F–foreland basin system; tf–thrust faults; ntl–nappe’s thrust lines; sp–studied or mentioned points (C–Clit; V–Voitinel; R–Remezău).

The deposits discussed in the present paper are well-exposed along the Remezău and Voitinel creeks (Fig. 1), tributaries of the Suceava River, where the facies analysis was performed. These outcrops represent an almost unique example, as Early Sarmatian deposits can be seen atop the Carpathian orogenic wedge. Relict deposits of the same age and with similar positions onto the orogenic wedge toe occur in the Clit area, along the Clit creek, some

kilometers south of the studied area (Fig. 1), and in the Viișoara-Brătești area, near the Târگو Trotuș locality (Bacău County). Martiniuc (1948) considered them only patches of a former continuous sedimentary cover that once draped the entire Pericarpathian Nappe, in which the rivers incised and cut their valleys. Artyushkov et al. (1996) describes Sarmatian shallow-water deposits atop the Skiba, Boryslav-Pokutya and Sambir Units in the Ukraine Carpathians, equivalent to the Tarcău, Vrancea and Pericarpathian Nappes, which means that the wedge-top depozone was much larger.

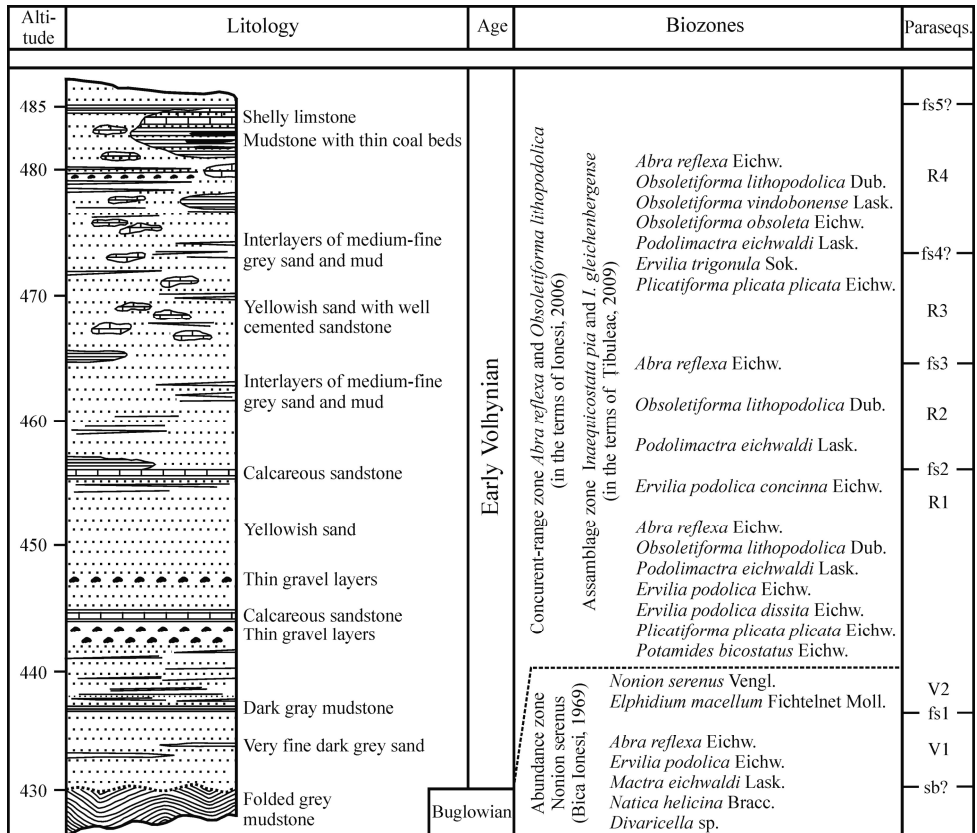


Fig. 2 Lithological Lithological column and biostratigraphy of the Sarmatian deposits in the area of the Voitinel-Remezău creeks (Suceava County): sb–sequence boundary; fs–flooding surface; V–parasequence on Voitinel Creek; R–parasequence on Remezău Creek.

The deposits in the Viișoara-Brătești area are Buglowian-Volhynian in age (Ionesi and Ionesi, 1972), while those in the Clit area were dated, based on their position, as Volhynian (Ionesi et al., 1971), since only reworked fossils were described (Ionesi, 1968). In both locations, they unconformably overlie the folded deposits of the Pericarpathian Nappe (Preda, 1917; Săndulescu, 1962; Ionesi, 1968) and are, in turn, tilted or slightly folded during the post-Moldavian tectogeneses.

In the Viișoara-Brătești area, the deposits consist of Buglowian mudstone, sharply overlain mainly by Volhynian gravity-flow deposits (un-cohesive gravelly debris flows, sandy debris

flows) and, subordinately, by tractive current and hemipelagic deposits (Grasu et al., 2002). According to these authors, the deposits were accumulated in a small and shallow piggy-back basin developed during the shortening of the Carpathian Nappes, corresponding to the Moldavian tectogenesis. The compressive regime seems to be proven by the small-scale thrust faults which characterize the lower part of the column.

In the Clit area, the Volhynian deposits are around 180m thick and were interpreted by Barbu et al. (1966) and Ionesi et al. (1971) as a “fluvio-deltaic facies”. Based on sedimentary facies analysis, Miclăuș (2001, in Grasu et al., 2002) interpreted them as wet alluvial fan. The author recognized three “fluvial sequences” separated by two unconformity surfaces tilted 10–15°W, which were accumulated in a nascent piggy-back basin, corresponding to the same shortening event (Moldavian tectogenesis).

Facies analysis of the Volhynian deposits in the area of the Remezău and Voitinel creeks

Sedimentary facies

In the logged columns from the Remezău and Voitinel creeks (around 50m), 12 sedimentary facies have been defined based on their lithology, internal sedimentary structure and geometry. Their descriptive characteristics and interpretations in terms of sedimentary processes are presented in Table 1. The deposits consist mainly of sand and, subordinately, of mud and gravels. Plant and shell debris is also visible in the sands.

Facies associations

The above-mentioned sedimentary facies have been grouped into three facies associations (Fig. 3), described and interpreted in the present section, associations which represent sub-environments of a coastal depositional system. The vertical stacking of the facies associations allows the recognition of two parasequences in the outcrops studied. However, the entire sedimentary column in the Remezău-Voitinel area can be subdivided into at least five parasequences.

Facies association A: upper shoreface

Description. This facies association consists mostly of clean yellowish sands and rare gravel interlayers. The most representative sedimentary facies is *Spp* (Tab. 1, fine-to-medium parallel stratified sands) and *Stcs* (medium-to-coarse sands) with interlayers of *Gpp*, *Gtcs* and *Gpsc*. Solitary sets of coarse sand (*Spcs*) can also be recognized.

The gravel clasts, 4–16cm in diameter and well-rounded, consist of menilite, bituminous marls and Kliwa-type sandstones, suggesting a Carpathian source area. The layers of gravel also contain broken shells of gastropods and bivalves.

In the sands of this facies association, well-cemented sandstone occurs as a discontinuous bed with a thickness of 0.3 up to 1m (Fig. 14). The sedimentary structure in this sandstone is one of swaley cross-stratification. No trace fossils were observed.

Interpretation. This facies association consists mainly of medium-coarse sands and gravels, which indicate an environment characterized by high energy. The lack of mud interlayers also indicates a permanent winnowing of sediments by waves, interrupted by storm events proven by structures such as the swaley cross-stratification (SCS) and the low-angle cross-stratification (Leckie and Walker, 1982; Dumas and Arnott, 2006). The SCS is considered a proximal equivalent of the hummocky cross-stratification (HCS) discussed below, whose convex laminae are selectively eroded (Dumas and Arnott, 2006).

The sets of sands with TCS (best-exposed on the Putredu tributary of the Voitinel creek) indicate the migration of dunes, probably driven by longshore and/or rip currents on a barred sea floor, as is possibly the case with many prograding coasts, although their preservation potential is reduced (Clifton, 2006).

Tab. 1 The sedimentary facies of the Volhynian succession on Remežau and Voitinel Creeks

Facies code	Facies name and description	Genetic interpretation
Gpcs (Fig. 4)	Gravel with planar cross stratification – granule to fine pebbles in solitary sets up to 15cm (paleocurrent 40°E)	tractive deposition on 2D dune by wave generated currents (Clifton, 1976, 2006) possible rip currents
Gtcs (Fig. 5)	Gravel with trough cross stratification – granule to fine pebbles in solitary sets up to 20cm grading upward in coarse sands (paleotrough direction roughly N–S)	tractive deposition on 3D dunes by wave generated currents, possible longshore currents as indicate paleotrough direction
Gpp (Fig. 6)	Gravel with planar parallel stratification – very fine to fine gravels in coarse sands with shell hashes. Planar parallel (PP) strata form sets of 10–15cm with sharp bases.	tractive deposition of gravels by relative strong currents on planar seafloor or selectively erosion of finer (storm lags)
Spes (Fig. 7)	Sand with planar cross stratification – solitary sets of coarse to very coarse sands with planar cross stratification dipping up to 25° toward SW	tractive deposition on 2D dunes by wave currents possible longshore currents (Clifton, 1976, 2006)
Stcs (Fig. 8)	Sand with trough cross stratification – grouped sets medium to coarse size sand with trough cross stratification; the tangential foreset laminae roughly dip both to S and to N more or less parallel with paleoshoreline	tractive deposition on 3D dunes with opposite migration direction driven by possible longshore currents (Clifton, 1976, 2006)
Shcs (Fig. 11)	Sand with hummocky cross stratification – fine to medium size yellowish sand or sandstone with convex (hummocky – HCS) and concave (swaley – SCS) cross stratification either in solitary sets with sharp lower boundary	storm induced oscillatory flow with high velocity at the bed, combined with sand deposition from suspension (Harms et al., 1975; Harms 1979) or waning storm deposits on 3D large vortex ripple (Cheel and Leckie, 1993; Duke et al., 1991) at high rate of aggradation (Dumas and Arnott, 2006)
Scs (Fig. 10)	Sand with swaley cross stratification – fine to medium yellowish clean sand with submetric-metric scale concave upward stratification (SCS) cutting each other at low angles; the texture of sand is more similar with sands above described	storm-dominated processes hydrodynamically similar with those of hummocky cross stratification development able to remove and rework fair weather deposits (Leckie and Walker, 1982; Dott and Bourgeois, 1982) but at lower aggradation rate (Dumas and Arnott, 2006)
Swrc1 (Fig. 11)	Sand with ripple cross lamination – grey dirty fine to medium sand with concave upward laminae showing opposed dip directions but prevalently toward the supposed paleoshoreline; the cross laminated sands are organized in sets up to 5cm high bounded by thick laminae of grey mud.	deposits of 2D to 3D vortex ripples driven by pure oscillatory to combined flow induced by shoaling waves (Harms et al., 1975; Harms, 1979; Clifton, 1976; Clifton and Dingler, 1984; Collinson and Thompson, 1989; Hardisty, 1994)
Slacs	Sand with low angle cross stratification – fine sands with low angle cross stratification (<10°)	storm dominated processes hydrodynamically similar with those responsible of the HCS and SCS development
Spp (Fig. 9)	Sand with planar parallel stratification – fine sands with plan parallel stratification in sets of 0.3–0.6m thick, amalgamated after erosive flare or slightly concave upward surfaces enhanced by coarse lags	either deposition from strong unidirectional flow, or from strong oscillatory flow (Walker et al., 1983); as result of deposition from waning storm related combined flows (Arnott, 1993) or of high shear stresses which can shape a planar sea floor in the swash and breaker zones (Clifton, 1976) during fairweather conditions
Scs (Fig. 12)	Sand with convolute stratification – fine sands with contorted stratification where sharp antiformal and rounded larger sinformal can be recognized	soft sediment deformation reflecting both internal foundering in underlying layer and preferred routes of pore water upward escape (Collinson, 1994)
MI (Fig. 11)	Mudstone with thick laminae – grey mudstone interlayered with sand with wave ripple cross lamination	fallout from suspension in quiet-water (Collinson and Thompson, 1989)

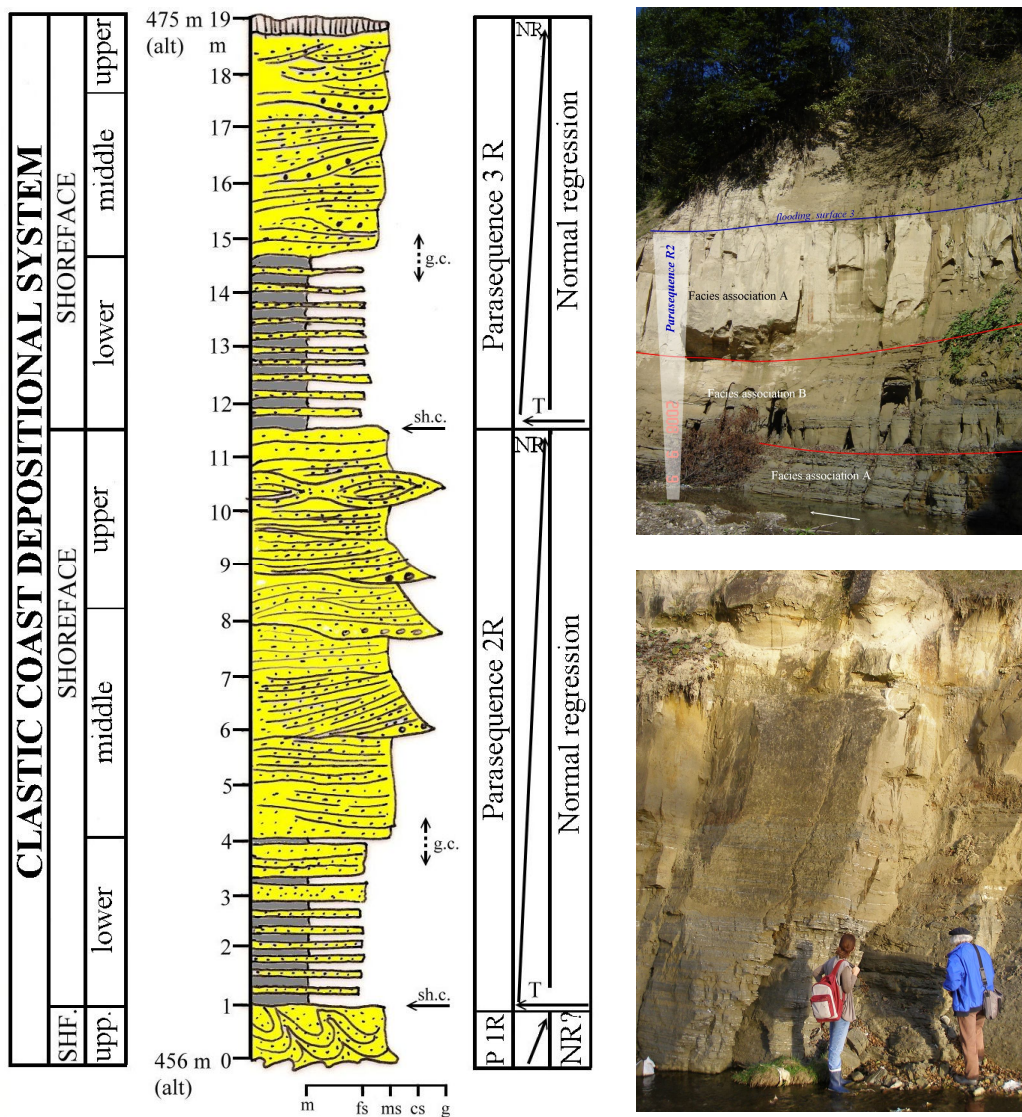


Fig. 3 (Left) The facies associations of the upper, middle, and lower shoreface of a clastic coastal depositional system recognized in the Early Sarmatian deposits found in the area of the Voitinel-Remezău creeks. (Right) The R2 parasequence from the Remezău creek, with the three facies associations defined capped by flooding surface 3 (top) and the gradational contact surfaces (red lines) between the grey heterolithics of facies association C, which go upward into the yellowish sand of facies associations B and A (base). Note the tilting to the right (roughly to the W) of the deposits: T–transgression; NR–normal regression; sh.c.–sharp contact (flooding surface); g.c.–gradational contact of facies association C (lower shoreface) with facies association B (middle shoreface); m–mudstone; fs–fine sand; ms–medium sand; cs–coarse sand; g–gravel.

The gravel was probably derived from a contemporaneous beach zone and shaped as 2D and 3D dune trains. Such a beach is possible, since, in the Clit area, Miclăuş (2001, in Grasu et al., 2002) describes a gravel-bed fluvial system which could supply a gravelly beach.

Such processes shaping seabed into plane bed, 2D and 3D dunes migrating parallel or orthogonal to the shoreline are characteristic to the upper shoreface.



Fig. 4 Gravel with planar cross stratification (*Gpcs*).



Fig. 5 Gravel with trough cross stratification (*Gtcs*).

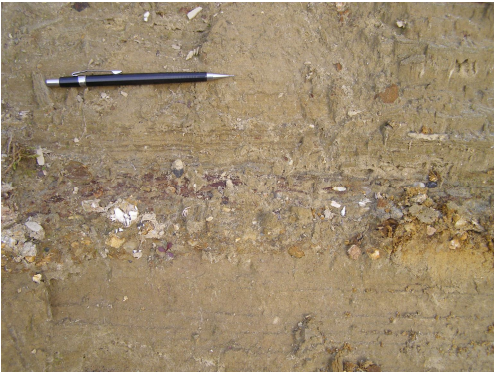


Fig. 6 Gravel with plan parallel stratification (*Gpp*) – storm lag covered by sand with plan parallel stratification.



Fig. 7 Sand with planar cross stratification (*Spcs*).



Fig. 8 Sand with trough cross stratification (*Stcs*). The sets are enhanced by the well cemented sand layers.



Fig. 9 Sand with plan parallel stratification (*Spp*) with bounding surfaces associated with very coarse material.



Fig. 10 Sand with swaley cross stratification (*Sscs*).

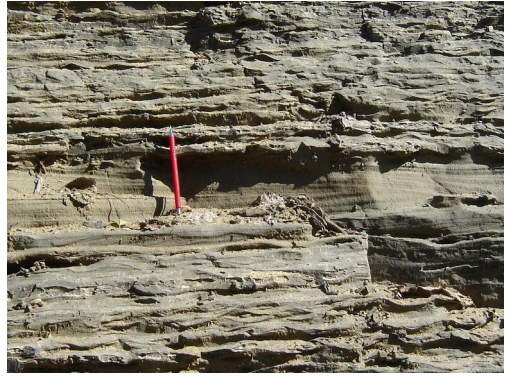


Fig. 11 Bed of yellowish sand with scour and drape hummocky cross stratification (*Shcs*) in between grey sands with wave ripples (*Swrcr*) draped by mud (*MI*).



Fig. 12 Sand with convolute stratification (*Scs*) sharply covered by heterolithics (*Swrcr+MI*).



Fig. 13 Facies association C – lower shoreface.



Fig. 14 Facies association A – upper shoreface.



Fig. 15 Facies association B – middle shoreface.

Facies association B: middle shoreface

Description. The sand with swaley cross-stratification (*Sscs*) is the most peculiar facies of this association (Fig. 15), although the most frequent one is the sand with plan-parallel (*Spp*) and

low-angle cross-stratification (*Slacs*). Subordinately, centimeter-thick sets of sands with wave ripple cross-lamination (*Swrc1*) separate decimeter-thick sets of sands with SCS or PP and LACS. Minor interlayers of mud draping trains of asymmetric wave ripples can also be noticed (Fig. 3).

Interpretation. This facies association, dominated by *Spp*, indicates a high-energy oscillatory flow able to shape a plane seabed (Walker et al., 1983). Deposition on such a seabed is driven by strong movement to and fro, which inhibits any bedform development, but creates the conditions for the deposition of laminae between reversing currents (Bridge and Demico, 2008). When unidirectional currents (such as the geostrophic current) are superposed onto the oscillatory flow, it is difficult to establish which one is responsible for shaping the plane seabed. The plan-parallel stratification may also occur during fair weather in the breaker zone (Clifton, 1976) or onto the beachface (Harms, 1979).

Some plane erosive bounding surfaces associated with gravel lags indicate processes of sand winnowing during storm climax, followed by bed aggradation, possibly driven by combined flow. Such an interpretation is also supported by the occurrence of *Sscs*, which is considered a storm deposit (Leckie and Walker, 1982; Dott and Bourgeois, 1982; Dumas and Arnott, 2006).

The arguments above suggest to relate this facies association by a middle shoreface subenvironment, where high-energy processes are characteristic both during fair-weather and storm conditions.

Facies association C: lower shoreface

Description. This facies association is a heterolithic one and it consists mainly of dirty grey sands with wave ripple cross-lamination (*Swrc1*) and up-to-2cm-thick grey mud layers draping the ripples (Fig. 13). The sets of such sands are up-to-5cm thick. Their cross laminae indicate mainly asymmetric ripples, but also symmetric ripples with rounded crests and large troughs. The grey sands with plan-parallel stratification containing laminae of coaly debris underlie some sets of sand with WRCL.

The grey mud occur as thick (1–2cm) undulating continuous laminae draping sand ripples as wavy bedding, but also as thin lenticular (few mm) laminae isolated in some ripple troughs as flaser stratification. Few solitary interlayers of sand (decimeter-thick) with convex and concave large-scale undulations (HCS–SCS) are enhanced by their clean texture and yellowish color on the grey background.

Upward in the column, toward facies association B, the mud laminae become thinner and thinner, while the sand becomes cleaner and cleaner and its structure changes from wave cross-lamination to plan-parallel stratification.

The fossil assemblage was mainly collected from this heterolithic unit, although, given their poor preservation, the genus or species of very few shells could be determined. The valves use to rest in a convex-upward position. Plant detritus can also be seen, in association with dirty sands.

Interpretation. The dominance of sands with wave ripple cross-lamination indicates a permanent action of waves, with sporadic storm intervention proven by sands with HCS–SCS structures of the scour-and-drape type (Cheel and Leckie, 1993). The problem of hummocky cross-stratification has been a matter of debate for decades, since it was defined by Harms et al. (1975) as a result of strong wave orbital motions. Other authors suggested a flow with two components: a dominant oscillatory flow induced by storm waves, and a unidirectional current (Duke et al., 1991). According to the original model proposed, the seabed is shaped as hummocks and swales, and the sand is temporarily lifted into suspension from where it is deposited as draping convex-concave laminae. According to the other model, the bed is eroded by unidirectional currents during the storm climax. Over the eroded bed the sand transported as bedload or suspended load is rapidly accumulated as storm waning. The sand is then shaped by strong oscillatory flow into large 3D ripples on the active aggrading background. The control of

the aggradation rate has been proven by wave-tunnel experiments (Dumas and Arnott, 2006). After the lowering of storm waves, the seabed is shaped into vortex ripples.

The heterolithic background with asymmetric-to-symmetric wave ripples draped by thick continuous to thin lenticular mud laminae, resembling flaser-to-wavy bedding, suggests alternating processes of sand transport and sedimentation with mud sedimentation processes possibly related to the seasonal lowering and rising of the fair-weather (winter-summer) wave base. We consider such an explanation more appropriate than the widely-accepted hypothesis of tide-influenced deposit (Reineck and Singh, 1975), as there is not enough time for such thick laminae to accumulate during a tidal cycle.

The occurrence of *Shcs* as discrete beds on this heterolithic background indicates sporadic storm incidences when the clean sand from the forebeach-upper shoreface was eroded and resedimented as storm beds in the lower shoreface.

The shoreface environment

The clastic shoreline is one of the most studied and well-understood depositional systems, different facies models being available since 1970s (Harms et al., 1975; Davis and Hayes, 1984; Walker, 1984; Elliott, 1986; Walker and Plint, 1992; Reading and Collinson, 1996; Clifton, 2006).

The coarsening and shallowing-up motifs from the offshore mud to the beach sand of the prograding clastic shorelines are the most striking features of all the models listed. In clastic shoreline models, the shoreface is a fundamental element, although there is a continuous debate regarding the proper way in which it should be defined, based on sediment texture, sedimentary structures, fair-weather wave base, bioturbation, combined criteria (for a detailed discussion see Clifton, 2003). The most proximal facies (the foreshore and the back-beach) have a low preservation potential due to the erosive processes associated with transgressions.

Most of the models mentioned above recognize the fact that wave-generated currents are responsible for transport and sedimentation in the upper shoreface, where parallel bars and troughs could be developed, and the peculiar sedimentary structure is the trough cross-stratification. In the Voitinél log (Putredu tributary), this structure is well-exposed (Fig. 8), while in the Remezău log it is less characteristic. On contemporary open coasts, the bar-trough systems are common, as they were probably common in ancient systems. However, their preservation potential is low, being obliterated by high-energy features (Clifton, 2006).

We have separated a middle shoreface based on the high frequency of sand with swaley cross-stratification, although this sub-environment is not generally seen in the above-mentioned facies models. Usually, the sand with SCS is described in the columns above the sand with HCS (Leckie and Walker, 1982; Dott and Bourgeois, 1982), but it is not to be confused with the amalgamated HCS (Cheel and Leckie, 1993).

The lower shoreface, with its interlayers of sand with wave ripple cross-lamination and mud, supporting storm beds (with HCS), indicates an alternation of periods when the seabed is shaped by wave processes with periods when the seabed is draped by fine sediments.

Since Reineck and Singh (1975) stated that the seaward limit of the shoreface is located at the fair-weather wave base, this criterion was adopted in most of the facies models proposed (Walker, 1984; Elliott, 1986; Walker and Plint, 1992; Reading and Collinson, 1996), although in stratigraphic records it can only be inferred based on different characteristics (lithologic contrast, sedimentary structures, bioturbation degree, mud presence). It is usually believed that mud sedimentation is incompatible with wave action, but, in facies association C, the symmetric-to-asymmetric ripples indicating deposition above the fair-weather wave base are draped by centimeter-thick laminae of mud which cannot be interpreted as tidal slack. The lack of bioturbation in all three of the facies associations might also indicate continuous wave processes shaping the seabed.

Clifton (2003, 2006) considers that the link between the fair-weather wave base and the seaward limit of the shoreface is a mere coincidence, therefore its importance in establishing the seaward limit of the shoreface must not be considered a dogma.

The sedimentary record in the area delineated by the Voitinel and Remezău creeks indicates a fair-weather coastal depositional system with storm processes acting periodically. The fair-weather wave base fluctuated, possibly seasonally, and is registered by the heterolithics of facies association C. In the back-beach sub-environment, there were conditions for coal formation. In the studied area, there are neither more proximal, nor more distal deposits, compared to the shoreface. Barbu et al. (1966) suggest that some coarse gravel preserved on the surrounding hilltops might be interpreted as a fluvio-deltaic environment, yet no sedimentological study has been carried out in this respect up to the present moment. Such a hypothesis is to be taken into consideration, however, since, in the Clit area (C on Fig. 1), a humid alluvial fan going distally in a braided fluvial system has been reconstituted (Miclăuș, 2001; in Grasu et al., 2002).

Sequence stratigraphy

The current definition of “parasequence” involves an asymmetric succession of shallowing upward facies associations bounded by flooding surfaces both at the base and at the top (Posamentier et al., 1988; Van Wagoner et al., 1990). In this case, the episode of water deepening, which is a proxy for the generation of accommodation space, is only marked by sharp contacts between shallow-water facies and the overlying deeper-water facies, sometimes associated with minor erosion enhanced by coarse materials (gravels, bioclasts, mudclasts) or with times of non-deposition (Van Wagoner et al., 1990). Based on the above-mentioned definition, it seems that a parasequence can only develop during the normal regression between two episodes of transgression, one generating the accommodation space, one interrupting the progradation of shoreline by shifting it again landward. Arnott (1995) pointed out certain situations when active sedimentation can be registered also during transgression.

The definition of parasequence seems to be coincident with the facies model of the coast, which is a shallowing and coarsening upward succession, as well, for which reason shallow-water recordings are recognized (Cătuneanu, 2006). An episode of accommodation space generation and filling is recorded.

In the studied area, on the Remezău creek, there are two sharp contact surfaces which can be interpreted as flooding surfaces. The lower one caps yellowish sand with a convolute stratification and underlies deeper-water heterolithics (Fig. 12). The convolute stratification of the shallow-water sand suggests liquefaction processes probably triggered by an external shock that either an earthquake or a storm wave induces (Allen, 2001). The upper one caps the yellowish sand of the upper shoreface and underlies the heterolithics of the lower shoreface (Fig. 3). In-between these two flooding surfaces, the best-exposed parasequence (R2) consists of all three facies associations presented above (Fig. 3).

On the Voitinel Creek, a flooding surface can be inferred between the Buglowian folded mudstone and the undeformed Volhynian sands. This surface is not exposed, but, considering the fact that it is a surface which brings into contact deposits belonging to different basins (the Moldavide basin and the foreland basin system), its significance may be greater, converting it into a potential candidate for a sequence boundary reworked by a maximum flooding surface. However, since the surface is not exposed, this diagnostic cannot be seen as unequivocal.

The deepest deposits recorded in the sedimentary succession are the heterolithics of the lower shoreface. The lower shoreface deposits coarsen and clean gradationally upward through the sand of the middle shoreface to the sand with TCS supporting gravel interlayers of the upper shoreface (Fig. 3). This parasequence (R2), with sharp bounding surfaces interpreted as flooding surfaces

(fs2 and fs3), is the best-exposed. The most proximal deposits consist of mudstone with coal interlayers of R4.

The prograding events can be unequivocally interpreted based on their shallowing upward trends, recognized in the deposits of the Voitinel-Remezău area (Figs. 2, 3). From the lowermost parasequence (V1), which overlies the possible sequence boundary, only the yellowish sand of the middle-upper shoreface is exposed. The parasequence (R4) which ends with mudstone containing thin (centimeter-thick) coal layers indicates the progradational trend of the parasequence set. This trend is characteristic to the high-stand system tract (HST), a component of the depositional sequence, bounded by a maximum flooding surface at the base, and by the sequence boundary at the top (Van Wagoner et al., 1988, 1990).

Considering the orogenic thrust load consequent to the Moldavian tectogenesis, the accommodation space was created most likely under tectonic control, although the eustatic control as background is necessary for the explanation of the reestablishment of marine sedimentation after the sea-level drop corresponding to the Badenian/Sarmatian boundary (Harzhauser and Piller, 2007; Piller et al., 2007), which is defined in the case of the East-Carpathian foreland as unconformity (Ionesi, 1994). The transgression followed by the deduced highstand may be linked to the reconnection between the Eastern Mediterranean and the Paratethyan basins from the Early Sarmatian (Steininger and Wessely, 2000). Krécszek and Filipescu (2005) also describe a HST (HST5) in the Transylvanian basin during the Early Sarmatian, HST which may correspond to the HST registered in the deposits described in the present paper, although the paleontological constraint of our deposits is not as accurate.

The average thickness of a parasequence is 10m, with a maximum of around 20m (parasequence V2R1), and a minimum of 8m (parasequence V1). These extreme thickness values are due either to the lack of distal facies association (V1) or to poor exposure, which hides the relationships between facies associations inside the V2–R1 parasequence. Usually, the parasequence thickness in open-coast depositional systems is considered more or less equivalent to the depth of the water, most of the similar units described having thicknesses of 10–15m (numerous references in Clifton, 2003, 2006).

Conclusions

The entire column studied is Early Volhynian in age, as indicated by the concurrent range zone with *Abra reflexa* and *Obsoletiforma lithopodolica*, spanning a narrow time range (a few hundred thousand years).

The sedimentary record in the studied area is fully marine, with the exception of the mudstone with coal interlayers recognized in the 4R parasequence and related to a back-beach facies.

The deposits are mainly represented by clean yellowish and dirty grey sands, with interlayers of gravels, mud and well-cemented yellowish sandstones. They were sedimented in the wedge-top depozone of the Eastern Carpathian foreland basin system, as testified by the angular unconformity which marks the contact between the grey folded Buglowian mudstone and the undeformed, but slightly tilted, Early Volhynian deposits, possibly in an incipient piggy-back-like basin, as that recognized in the Clit area and described by Miclăuş (2001, in Grasu et al., 2002).

The analysis of the sedimentary facies allowed us to recognize lower, middle and upper shoreface sub-environments of a fair-weather coastal depositional system with storm processes acting periodically.

The positions of the facies association within the column allowed us to define five parasequences bounded by flooding surfaces. Some flooding surfaces (fs2, fs3) are exposed (Figs. 3, 12), others are inferred. The basal flooding surface may be a sequence boundary

reworked by a maximum flooding surface, since it brings into contact deposits belonging to different sedimentary basins (the Moldavide Basin and the foreland basin system). This surface also corresponds to the angular unconformity mentioned above. The subaerial erosion usually invoked as defining the sequence boundary is not exposed or was not preserved. The general trend of the parasequence set is a progradational one, typical for an open-coast depositional system and characteristic of a high-stand depositional system tract.

Deposits as these studied can be used to constrain the Moldavian tectogenetic event because they seal the frontal sole thrust.

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