SARMATIAN FACIES ASSOCIATIONS AND EVOLUTION OF THE WESTERN FLANK OF FOCȘANI BASIN, ROMANIA

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Abstract. This paper presents sedimentological data that point out the evolution of the western flank of the Focșani Basin, during the Sarmatian stage. The facies and their associations are indicative of (fan)delta, shallow- and deep marine palaeoenvironments. Their evolution, in time and space, shows similarities between Putna, Milcov and Râmnicul Sărat areas.

Key words: Focșani Basin; Sarmatian; facies associations; deltaic, shallow water, deep marine palaeoenvironments

1. INTRODUCTION

The Focșani Basin represents a foreland basin (*sensu* DeCelles and Giles, 1996) where four depocenters are identifiable as: wedge top, foredeep, forebulge and back-bulge. The study area is part of the Focșani Basin and it is spatially placed in the central part of the Eastern Carpathians (Fig. 1).

In this region, the Sarmatian deposits have been studied by several authors. Most of these studies involved regional approach such as geotectonic and structural data (Mațenco, 1997, Tărăpoanca, 2004, Leever, 2007), palaeontologic aspects (Olteanu and Jipa, 2006) and palaeogeographic evolution of the Dacian Basin (Jipa, 2006), without giving details of their depositional environments.

Therefore, this study focusing on Sarmatian deposits and has as main purpose the reconstruction of the palaeoenvironment, palaeogeography and the evolution that characterized this basin, by using the analysis of sedimentary facies and depositional sequence as a consequence of dynamic interplay between sediment supply and accommodation.

Nevertheless, because the western flank features spectacular outcrops, sedimentological information can be further correlated directly with other existing geological data (seismic and wireline logs) from the entire basin.

2. MATERIAL AND METHODS

The field analyses have been carried out in the proximity of Valea Sării, Reghiu and Jitia localities (Fig. 1). From north to south, three outcrops over 1 km each, have been detached by the superimposed erosion of Putna, Milcov and Râmnicul Sărat rivers. The deposits have been divided into 21 siliciclastic types of sedimentary facies, which have been grouped further into three facies associations (Table 1). The descriptive terminology of Miall (1977) and Ghibaudo (1992) have been followed. Facies are considered to represent different modes of sediment deposition, whereas facies associations represent different depositional environments.

Our investigation is based on the building of sedimentological logs at different scales (1:10, 1:100 and 1:1000) which allow us to identified various aspects, such as lithology, grainsize and sedimentary structures of the analysed succesions (Plate 1, 2, 3).

These data have been integrated into the sequence stratigraphic framework and sequence boundary has been used for lateral correlation across the basin in order to decipher the evolution of the basin (Plate 6).

Tabel 1. Depositional environments and their associated facies. Annotations: U – upper part of sarmatian sedimentary succession, M – middle part of Sarmatian sedimentary succession, L – lower part of Sarmatian sedimentary succession, P – Putna valley, Mi – Milcov valley, RS – Râmnicul Sărat valley.

	Lithofacies	Description	Interpretation	Valley
(FAN)DELTA	Conglomerate and sandstone	Decimetres to meter thicknesses, erosional lower boundaries, centimeters-scale pebble to cobble size clast, matrix to clast support conglomerate with medium to coarse sand matrix. Poor sorting, angular and sub-rounded clast morphology; predominantly metamorphic and sedimentary gravels; massive or stratified; in some situation fitoclasts have been recorded.	High density flow, debris falls, possible deposited on fandelta low angle-foresets, channels	*Upper P, Mi, RS*
	Sandstone	Decimetres to metres thicknesses, fine to medium sandstone, massive, graded, horizontal laminated, trough and cross-strified.	Sand dunes and bars, low energy or tractive currents	
	Mud	Centimetres to decimetres-scale massive to laminated dark gray fine sediments (mud and silt).	Overbank fine.	
SHALLOW WATER	Conglomerate	Decimetres-scale strata pebbly size clasts, erosional lower boundaries, poor sorted; metamorphic, volcanic and chert clasts; massive to graded.	Distributary channels incised in the upper shorface to inner shelf.	*Middle P, Mi, RS*
	Sandstone	Decimetres to metres-scale beds medium to coarse grained, well sorted, horizontal lamination, graded and cross-stratification; injection structures have been observed.	Upper to lower shorface sandy dunes and bars	
	Sandstone with bioclasts	Centimetre to metres-scale coarse to medium grained sand with bioclasts, both matrix and (bio)clast supported alternating with centimeters thick shale; the lower sandstone boundaries are sharp; majority of bioclast are disjointed and chaotic or horizontal stratified.	Shoreline, upper and lower shorface sandy dunes; storm deposits; fall-out shale.	
	Sandstone with mud	Decimetre-scale fine to medium grained sandstone interbedded with centimeter-scale mud; massive to graded and laminated; no erosional lower boundaries; ripple marks on top of sandstone.	Upper to lower shorface sandy dunes; suspension fall-out mud.	
	Mud with sandstone	Centimetre-scale mud interbedded with minor sandstone; horizontal lamination; no visible erosional lower boundaries.	Inner to outer shelf below the storm-wave base.	
DEEP WATER	Sandstone with mud	Decimetre to metres-scale Bouma-type (Tabcd, Tbcd, Tbc) sandy turbidities associated with mud. Non-erosional boundaries. Flute cast, mud clasts or shale rip-ups.	High-density turbidites, low density turbidites, suspension fall-out; submarine channels or submarine fan lobe and hemipelagites.	*Lower P, Mi, RS, LP*
	Mud and sandstone	Metres scale massive or laminated mud interbedded with minor fine to medium grained sandy turbidites (Bouma-type Tac, Tcd,). Non-erosional lower boundaries. No channels or rip-ups.	Fall-out and low-density turbidites; submarine fan levee or outer lobe fringe.	
	Mud	Tens of metres massive or laminated mud and marls, scarcity but present of deep-water microfauna.	Suspension fall-out; pelagites on upper slope or basin plain.	

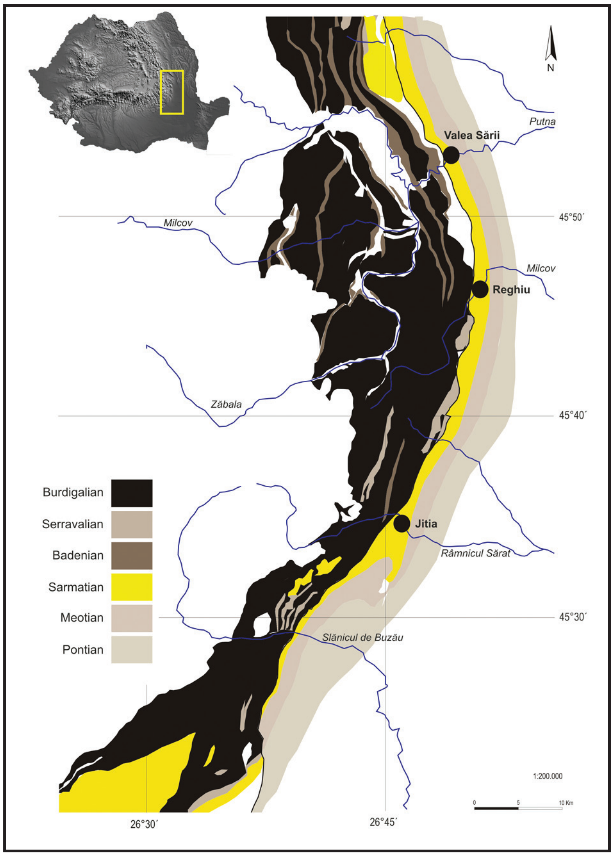


Fig 1 Focşani Basin location (yellow rectangle) and Miocen deposits from Outer Carpathians, which crop out on Putna, Milcov and Râmnicul Sărat rivers. Background map simplified from the geological map of Romania, scale 1:100,0000, made by the Geological Institute of Romania, Covasna sheet (1968).

3. SEDIMENTARY FACIES AND THEIR ASSOCIATIONS

The main characterisics of the 21 facies recognized in the Sarmatian sedimentary succesions are shown in Table 1. These sediments are conglomerates, sandstones, mixed deposits (i.e. sandstones with bivalves) and fine sediments (silt and mud) (Plate 5). The facies associations and their successions are as follows (from bottom to top):

3.1. Facies association I – deep marine system

Their succesions are grouped as follows:

Fine (mud and silt). Mud (hemipelagic) is characterized by dark homogeneous and heavily bioturbated grey muds. Sulphate spots are present (Plate 5, C5). *Silty-clay and clayey-silt turbidite beds* consist of alternating millimetres to centimetre-thick silty and muddy laminae that display massive, planar lamination (Plate 5, C4) or, rarely, cross-lamination (F m, F l, FS l, F *flaser* like). The cross-lamination (F *flaser* like) facies distinguish itself by high percent of mica. This mineral could be the explanation for very small-scale internal trough cross-lamination, but also an indicator of fluctuations in quality of sediment input or hydrodynamic regime. Non-erosional parallel boundaries are visible. At some places, diagenetic processes lead to alteration, re-mobilization and re-precipitation of the iron component. The result is a succession of centimetres to sub-centimetre and parallel stripes of oxides between bedding planes. Also, under compaction process the mixed clay-rich composition developed a visible fissile lamination/fissility (Stow and Atkin, 1987). These facies typically result from over spilling of the upper part of channelized gravity flows (turbidity currents or surges).

Mud with sandstone beds are composed of centimetre thin sand and fine (mud and silt) layers (Plate 5, C3). These sequences reveal a similar general morphology as Bouma sequence but with different sandy turbidites incomplete sequence (Tac, Tcde). Sand units show no evidence of erosional boundaries. The entire unit suggest roughly tabular non-channelized bodies (middle to distal lobes).

Sandstone and mud beds consist of decimetres to several metres-scale Bouma type (Tab, Tabc, Tabcd…) sandy turbidites interbedded with decimetre thick marls (SF mg/fl, SF mg, SF m; Plate 5, C1, C2). These facies are characterized by a sharp or erosive base, vertically massive to graded, and in some situation is visible a centimetre-scale planar and/or cross lamination. Another diagnostic for turbidite flow is the presence of erosional features. Flute casts, tool marks, and mudclasts at the base of some beds are considered to be genetically linked with the depositional event, but in a down current position (Mutti and Davoli, 1992). Similar beds are observed typically to infill submarine channels or occur with lobe sequences (Normark *et al.*, 1997).

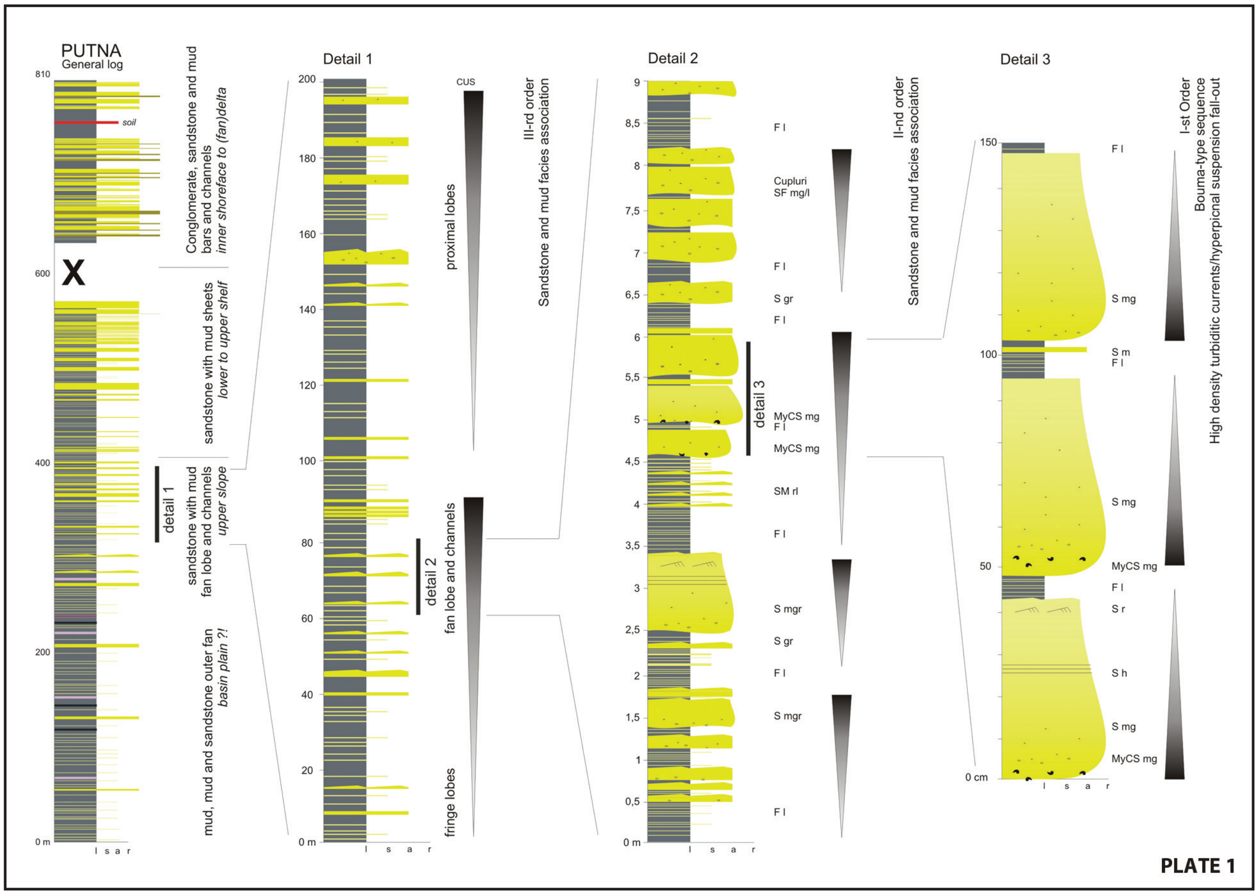
3.2. Facies associations II – shallow water system

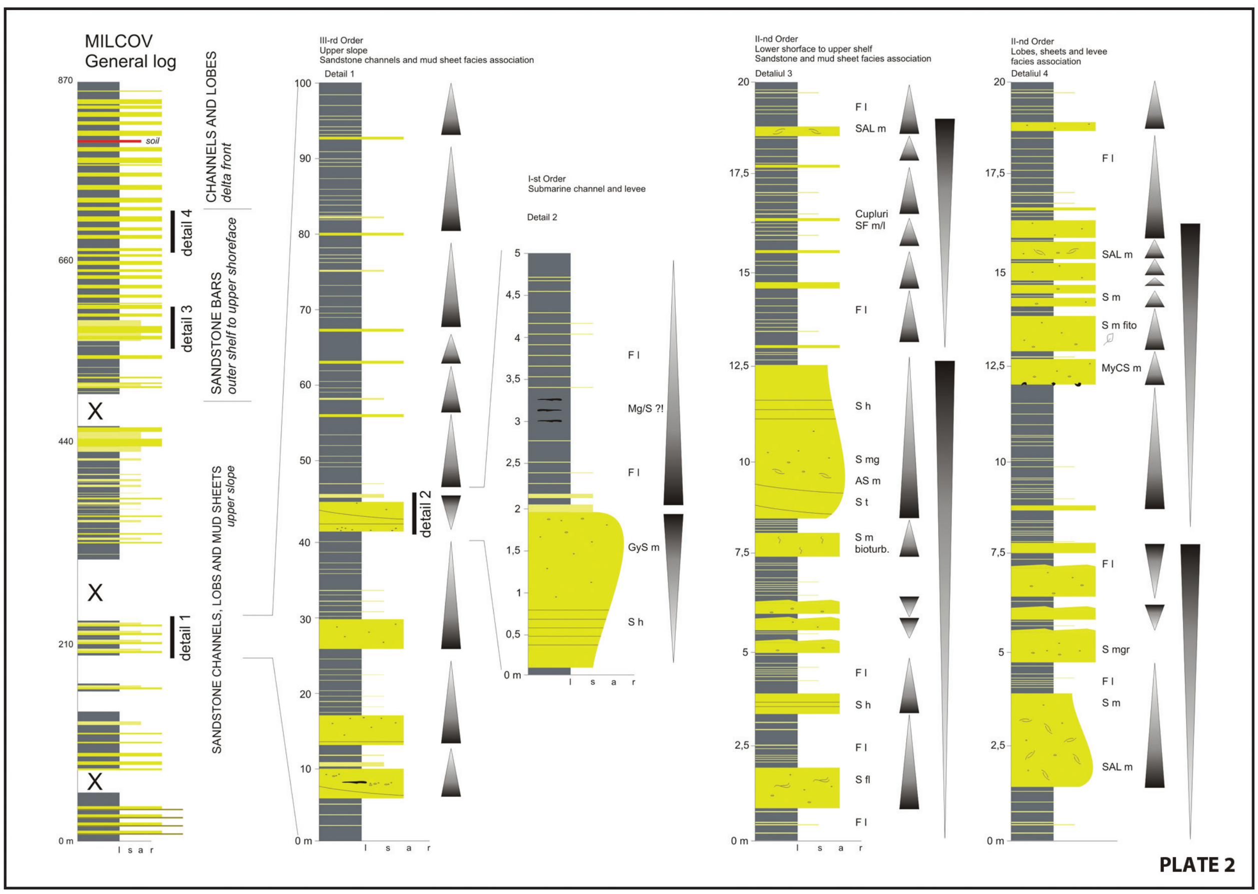
This facies association represents an alternation of fine (mud and silt), sandstones, sandstone with bioclasts (Plate 5, B8) and conglomerate deposits.

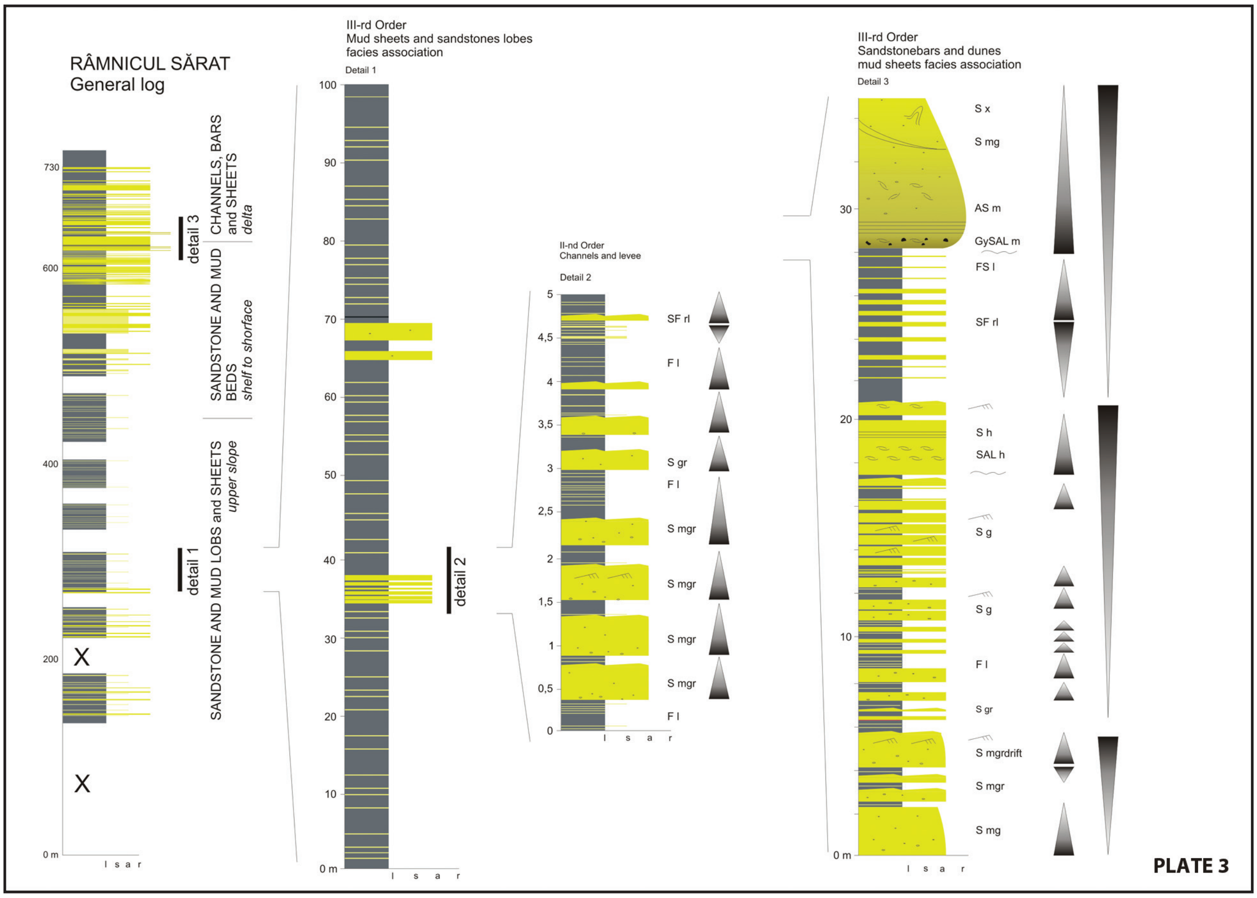
Laminated dark grey *mud* alternate with thin massive *sandstone* units that grades upwards into ripples.

Sandstone with mud. Decimetre-scale fine- to medium-grained sandstone, interbedded with centimetre-scale mud. This units show no erosional lower boundaries and some of them preserved ripple marks on top. The internal structures vary from massive (Sm), graded (Sg) to trough cross-lamination (St) and planar or low-angle cross-lamination (Sr) (Plate 5, B1, B2, B5 and B6). The fine sediments (F l, F m), as part of couples and their succession, indicate, probably, hemipelagic deposits that settled after each storm event during fair weather conditions.

Sandstone. Decimetre to metre-scale medium- to fine-sand with current lineation on parting planes underline sand depositional unit, with low-angle hummocky cross-stratified (HCS) depositional units (Plate 5, B4). This typical internal sedimentary structure is the result of the stress imparted by both flow component (oscillating water and geostrophic currents) and associated with storms. Succession of massive, graded (S mg) to parallel stratification sand (Sl) beds, were amalgamated by successive storms. Some beds present post-depositional (deformation) structures, such as *water escape*


PUTNA
General log
Conglomerate, sandstone and mud bars and channels
inner shoreface to (fan)delta
sandstone with mud sheets
lower to upper shelf
sandstone with mud fan lobe and channels
upper slope
mud, mud and sandstone outer fan
basin plain ?!
Detail 1
proximal lobes
fan lobe and channels
fringe lobes
III-rd order
Sandstone and mud facies association
Detail 2
II-nd order
Sandstone and mud facies association
Detail 3
I-st Order
Bouma-type sequence
High density turbiditic currents/hyperpicnal suspension fall-out
PLATE 1


MILCOV
General log
CHANNELS AND LOBES
delta front
SANDSTONE BARS
outer shelf to upper shoreface
SANDSTONE CHANNELS, LOBS AND MUD SHEETS
upper slope
III-rd Order
Upper slope
Sandstone channels and mud sheet facies association
I-st Order
Submarine channel and levee
II-nd Order
Lower shorface to upper shelf
Sandstone and mud sheet facies association
II-nd Order
Lobes, sheets and levee facies association
PLATE 2



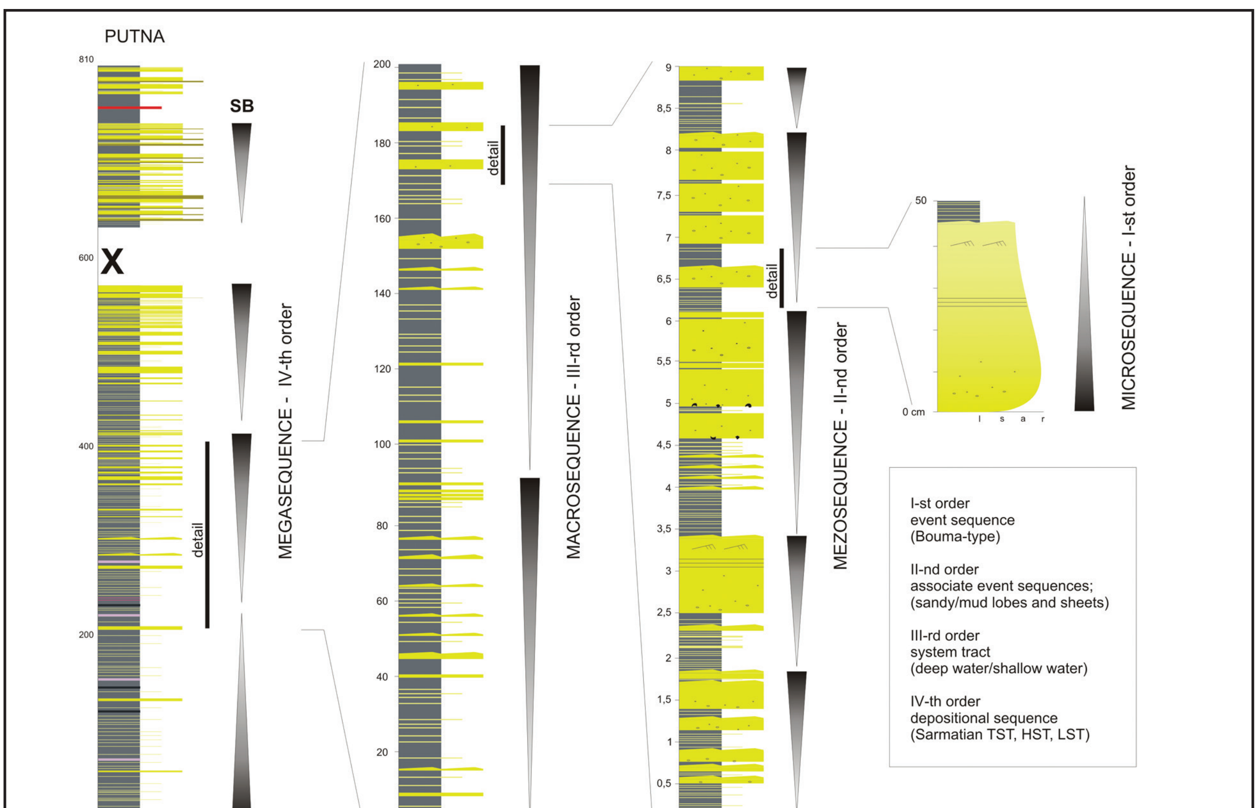


PLATE 4

Hierarchy of facies associations
Putna valley


S m
GyS mt
GyS mh
GyS mg
GyS m
B1
S m
B2
S x
S x
B3
S h
GyAS m
GyS m
B4
S h
S x
B5
S x
B6
S h
B7
S fl
B8
SAL m
B9
Ripple marks
B10
S x
C1
1m
C2
1m
C3
C4
F l
C5

◂◂ **Plate 5** Deltaic (A1-3), shallow marine (B1-10) and deep marine (C1-4) facies associations. (A1) Gravelly-sand basal lag formed by horizontall and cross-stratified unit, separated by massive sand units; A2) amalgamated fluvial channels (GyS mg); A3) lower erosional base of a channel and basal lag. (B1) Bioturbated massive sand, (B2) low angle cross stratification (foreshore)(B 3) massive conglomerate with few bioclasts that grade upwards, into horizontally stratified sandstones (upper shoreface); (B4, 6) low-angle cross-stratification followed by horizontal lamination (shoreface); (B5) climbing ripple; (B7) flaser-like internal structure; B8) articulated and disarticulated bivalves interbedded with massive sand represented by storm deposits; (B9, 10) wave ripples top and wave migration internal structure; Proximal (C1, 2) and distal (C3) fan deposits consist of meters of Bouma-type sequences. The lower base is non-erosional and some sandstone units contain mud clasts. The lateral extend is considerable. C4) hemipelagite and C5) sulphate nodules. The abbreviation of lithofacies areas is the following: G – gravel, S – sand, F – fines (shale, marls), h – horizontally laminated, r – ripple-laminated, t – trough cross-bedded, h – horizontal, l –low-angle cross-bedded, m – massive, g – graded, and l – fine laminated. According to Ghibaudo (1992) and Miall (1996) nomenclatures.

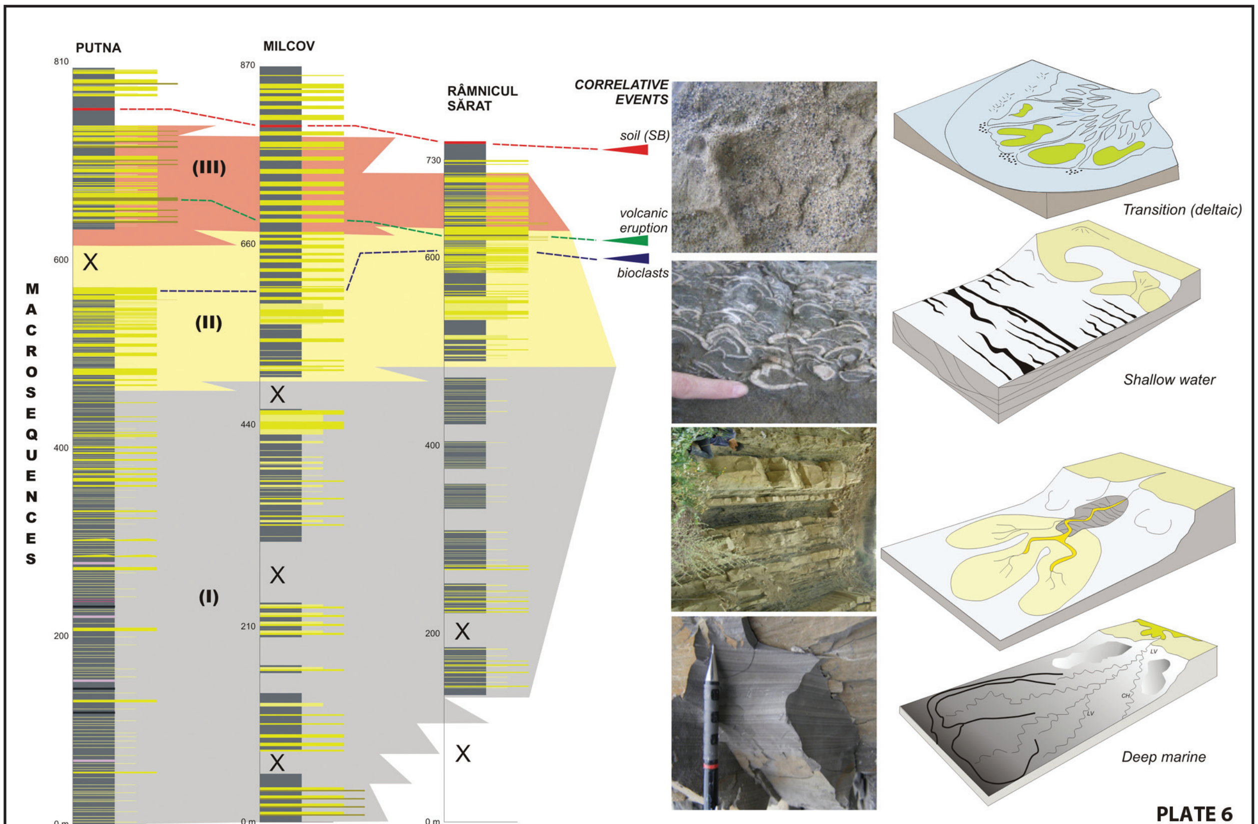


PLATE 6
SEDIMENTARY EVOLUTION OF THE BASIN
The colors emphasize the macrosequence I (grey), macrosequence II (yellow) and macrosequence III (red).

or *dewatering structures* – high rate of accumulation and instability generated by shocks, storms or earthquake (probably also very frequent in the past of the Vrancea seismic area, where the study is located).

Sandstone with bioclasts. Decimetre-scale sandstone with bivalves (allochem limestone) massive to horizontal (Plate 6) or trough cross-stratified (SAL mh, SAL mt) with very high degree of crashing of shells. These could be consider storms product which frequently eroded shells of bottom-dwelling faunas, accumulating them landward to the normal beach, barrier zone, or in the vicinity of shoreface environment.

Conglomerate. Decimetres-scale massive and coarse-grained sandstone with conglomerate frequently graded upwards into medium horizontal laminated sandstone (Plate 5, B3). This unit shows lower erosional boundaries. Few bioclasts highly disarticulated and randomly distributed within the unit. The lateral migration of the channel is visible and cut the underneath mud unit.

3.3. Facies associations III – transition (deltaic) system

Consist of conglomerates which are the most common, sandstone and mud.

Conglomerates are bipartite clast- and matrix-supported, poorly sorted with erosional lower boundaries. Internal structures reveal different variations from massive (GyS mg) (Plate 5, A1, A2, A3) where pebbles are randomly distributed and incorporated into sandy matrix to cross-lamination (GyS mt). These units are underlined by horizontally laminated or massive coarse to medium-grained *sandstone* that are finning upwards. Vaguely pebbly imbrication has been recorded at the base of massive sandstones. Occasionally, mud rip-ups can occur. The petrography of gravels clasts indicate metamorphic, sedimentary and seldom volcanic sources (Anastasiu *et al.*, 2009). Their morphology varies from subangular to subrounded.

The massive conglomerates of massive to laminated sandstone units are considered to be the product of hyperconcentraded flows that were followed by tractive currents progressively decelerating (Bouma, 1962). The presence of the fine laminated or massive fine sediments (mud and silt) are considered to be the results of decelerating currents and overbank accumulation.

4. MODEL OF EVOLUTION

The facies model suggests that, in the lower part of the Sarmatian succession (*Macrosequence I*, Plate 6) fine deposits have been accumulated. This kind of deposition is propably linked to a deep sea (deeper than 200 m) palaeoenvironment, indicative of a constant increasing of the relative sea level, followed by a transgression when a transgressive system track (TST) took place. This the moment when fine and bipartite sand-mud deposits have been accumulated as a result of suspension fall-out in a quiet environment, occasionally perturbed by thin sand units in response to the turbiditic flows. These deposits have been interpreted as distal lobes specific to a mud-rich system.

The further changes in the sand-mud ratio triggered by an increasing in the sediment supply; a source area reactivation or a normal regression induced the thickening of the sandstone strata (aggradational stage). The presence of erosional features such as flute cast and sole marks at the base of sand-mud first order sequences allow to allocate them the attribute of Bouma-type (complete or not) as a turbiditic flow accumulation in proximal lobes.

The middle succession (*Macrosequence II*) is characterized by a gradually thicker and coarser sand deposits that tend to accumulate as a continuous, but slow decreasing of the sea level (normal regression). The general trend is coarsening-upwards progradational pattern, consisting of facies ranging from distal shelf to foreshore. The presence of a high amount of bivalves, >90 % of them being broken and randomly amalgamated with siliciclastics (sand and conglomerates) have been interpreted as autochthonous storm deposits accumulated under high regime flow in the proximity of shoreline. Their preservation *in situ* occurred due to rapid burial.

The climax is reached in the upper part of the succession (*Macrosequence III*), when facies changes dramatically their physiognomy and become more and more coarser (conglomerates) and thicker with the same progradational stacking pattern. Finally, their exhumation lead to subaerial alteration and development of soils interpreted as sequence boundary that marks the regressive stage (RST).

5. CONCLUSIONS

In all, 21 facies have been described and interpreted by using sequential analysis.

Facies analysis leads to separate gravel (conglomerate), sand, couples of sand-mud and mud-sand, respectively, mud lithofacies with various internal structure. Their association pattern allowed the reconstruction of the geometries of the sedimentary body and the architectural model that was ranked into *micro-*, *meso-*, *macro-* and *megasequences*.

The overall successions are composed, form the base towards the top, by three macrosequences: (i) The Lower Sequence (*Macrosequence I*) represented by fine siliciclastic deposits made by mesosequences of lobes and channels; (ii) The Middle Sequence (*Macrosequence II*) characterized, mainly, by sand bars and dunes, with high amount of chaotic/desarticulated bioclast deposits and, (iii) The Upper Sequence (*Macrosequence III*), predominantly made by conglomerates, represents a depositional sequence (*Megasequence*) considered to be the Sarmatian megasequence.

The association of these three macrosequences indicates an evolution from an initial transgresive stage, when deep marine environments prevailed, followed by a short moment of highstand with shallow water into a final regressive stage with deltaic deposits. The Sarmatian megasequence has been deposited in response to the changes of the ratio between accomodation space and sediment supply which became progressively high. The base of the megasequence corresponds to an aggradational (para)sequences, while the upper, to a progradational one, conditionated by an transgressive-regressive cycle with a mixed, i.e., tectonic and eustatic, control.

6. ACKNOWLEDGEMENTS

I would like to express thanks to Mihaela C. Melinte-Dobrinescu for providing constructive comments that improved the quality of the manuscript.

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