COARSENING UPWARD SEDIMENTATION IN THE MIDDLE PONTIAN DACIAN BASIN, PROGRADING SHORELINE OR DELTA FRONT?

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Abstract. The sedimentological study of a stacked succession of coarsening upward units, cropping out on Ialomița River (Central Dacian Basin), furnished data allowing the understanding of the dynamics of sedimentation and the analysis of the main governing factors. The association of the coarsening upward succession with the transgressive clayey sediments of the shallow water Dacian Basin led to the conclusion that the investigated sediments belong to a prograding shoreline system, not to an offshore delta complex. The occurrence of the coarsening upward sediments was not determined by a sea level drop. Changes affecting the source-area, possibly mostly of climatic nature, determined an increased influx of detrital material.

Key words: Dacian Basin, coarsening upward, prograding shoreline, delta, climate.

1. INTRODUCTION

It is common knowledge that the shoreline is the sedimentary environment developed at the margin of a water body. The highest shoreline detrital accumulation appears at the fluvial discharge areas. When the marine/lacustrine agents (waves, currents) are not able to disperse the sediment accumulated at the mouth of the fluvial channels, a delta is formed. The shoreline progrades through the advancement of this delta. Consequently, in a prograding shoreline the beach and delta concepts are intimately associated and difficult to distinguish.

The delta environment clearly differentiates *versus* the shoreline environment in the inner part of an epicontinental sea. Within such shallow water bodies the delta-type, coarsening upward sediment accumulations occur both in the shoreline and in the offshore areas. Small deltas develop on the prograding shoreface. Highly developed deltaic accumulation occurs in the offshore shallow marine zone, where the coarsening upward bodies may advance on large distance.

The Dacian Basin was a typical epicontinental sea, and the shallow water sedimentation developed on most of its area (Jipa and Olariu, 2009). The Middle Pontian deposits cropping out on the Ialomița River show sediment accumulations with evident coarsening upward features. The sedimentary paleoenvironment of these deposits is important for the understanding of the Dacian Basin evolution.

1.1. Objectives

The purpose of this paper is to describe and provide a genetic interpretation of the Pontian sedimentary succession with deltaic characteristics, visible on the Ialomița River channel, in the western neighborhood of the Pucioasa town (Dâmbovița County).

The main objective of our study was to document the sedimentary environment status of the Pontian coarsening upward deposits, cropping out on the Ialomita River area. The problem to be solved is the association of these delta-type sediments to the prograding onshore or to the deltaic offshore environments.

The second major aim of this paper is to provide evidence concerning the marine regressive or transgressive sedimentation regime of the investigated Pontian accumulation; stating the factors which determined the progradation, if this process developed during a marine transgression.

1.2. Methodology

In order to investigate the coarsening upward sedimentary succession, detailed sedimentogenetic observations have been performed on the outcrops along the Ialomița River, in the area close to Pucioasa town. The studies had in view to evidence the arrangement of the coarsening upward units within the Pontian series, and to record their sedimentary characteristics. The outcrop examinations provided data concerning the internal and external sedimentary structures and supplied information on the succession of the sedimentary facies. The azimuthal measurement of the current sedimentary structures offered information on the paleocurrent directions.

1.3. Study area

The sedimentological study area extended southwards from the Ialomița River bridge of the national highway DN 71 at the northern periphery of Pucioasa, up to the northern approach of the Ialomița and Bizdidel rivers confluence (Fig. 1).

Carried out in the autumn of the year 2011, the investigations used favorable outcrop conditions, due to the low level of the river water. Sediments were visible on the river banks, as well as in many parts of the river channel (Fig. 2).

1.4. Geological setting

Maeotian (8.60/8.2-6.0 Ma) to Pontian (6.0-4.9 Ma) is the stratigraphic interval which includes the sedimentary succession discussed in this paper. According to Vasiliev *et al*., (2004), Krjigsman *et al*. (2010) and the International Commission on Stratigraphy (2009), these two Eastern Paratethys stages correspond to the stratigraphic interval between Late Tortonian and the Early Zanclean.

The area investigated within the present study is located in the central part of the Dacian Basin, at its northern periphery (Jipa and Olariu, 2009).

The development of the Pontian sedimentary succession is stratigraphically complete in the study area. For the stratigraphic guidance of the carried out sedimentogenetic work, the following two sources have been used:

1. the geological map of Romania, scale 1:50,000, sheet 128-d (Ștefănescu *et al*., 1988) (Fig. 3A);
2. geological map of the Upper Neogene deposits between Dâmbovița and Prahova rivers (Damian, 2003) (Fig. 3B).

With small differences, the two geological information sources point out the presence of the three Pontian substages: Odessian, Portaferrian and Bosphorian. Lithologically, the Pontian deposits in the Pucioasa town area are dominantly clayey. In the upper part of the Bosphorian, the sedimentary succession becomes sandy (Fig. 4), a facies which continues in the overlying Getian (Lower Dacian) deposits. Mollusk shells are frequent at several levels of the Pontian deposits.

At the Maeotian/Dacian time boundary, a marine transgression started in the Dacian Basin (Marinescu, 1978; Papaianopol *et al*., 1995). Close to the Ialomița River area investigated, an Upper Maeotian-Lower Pontian section on Bizdidel River clearly presents the sedimentary changes inflicted by the transgressive sedimentary regime (Jipa and Olteanu, 2005). The study of this section shows that during the Maeotian time, sand in alternation with clay were accumulated, previously of shoreline, and subsequently of fluvial environment. Starting at the terminal Maeotian time and continuing during the Pontian, sedimentation turned entirely clayey. All over the Dacian Basin, the marine Pontian (shallow water) sediments were dominantly clayey. Krijgsman *et al*. (2010) pointed out the synchronous occurrence of the Pontian transgression, at 6.04 Ma, in the Dacian and the Euxinian basins.

2. PRESENTATION OF DATA

2.1. Succession of the coarsening upward units

Eleven coarsening upward, clayey-silty-sandy bodies, making a series of about 150 m thickness, have been evidenced in the studied Pucioasa town deposits. The lithologic column in the Figure 5 shows the succession of these deposits.

The investigated coarsening upward series is located in the middle part of the Pontian succession (Fig. 5). The available stratigraphic data offered by the used geological maps (Fig. 3) appear to indicate that the studied coarsening upward succession is Upper Portaferrian-Lower Bosphorian in age (Fig. 5). Detailed biostratigraphic data are necessary to confirm this dating.

2.2. Sedimentary features of the coarsening upward units

2.2.1. Facies characteristics

The earliest, basal silty-sandy facies deposits, occurring from the clayey Pontian series, are represented by two thin (10-20 cm) fine-grained sand beds (observation points Pt.1 and Pt. 2, in Fig. 5).

The first coarsening upward sedimentary body (D1, in Fig. 5) is dominantly silty at the upper part. The next two units (D2 and D3, in Fig. 5) become sandy at the upper part, where frequent shells occur. For the first time, coarse-grained sand appears at the top of the unit 3 (interval 'd' in Fig. 6), partly due to frequent shell fragments. Irregular surface, representing erosion micro-relief, is observed at the base of this coarse-grained interval.

On the Ialomița River, the unit no. 5 was observed in three dimensions, as it occurred on the two river banks, but also transversal on the channel (Fig. 8).

The structure of the units 6 and 7 is similar, in both cases, the upper coarse-grained sediment (d) being sharply delimited *versus* the underlying b interval (Figs. 9 and 10).

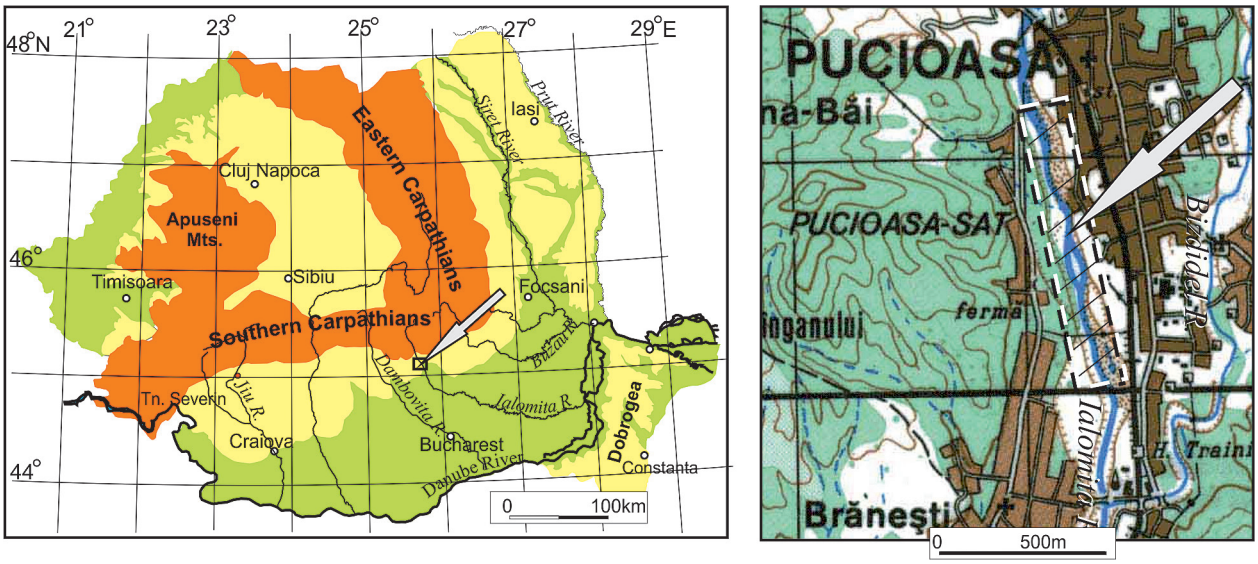


Fig. 1 Study area. The arrows point out study area location in Romania and in the Pucioasa town zone.

Fig. 2 Outcrops of Middle Pontian deposits on the Ialomița River.

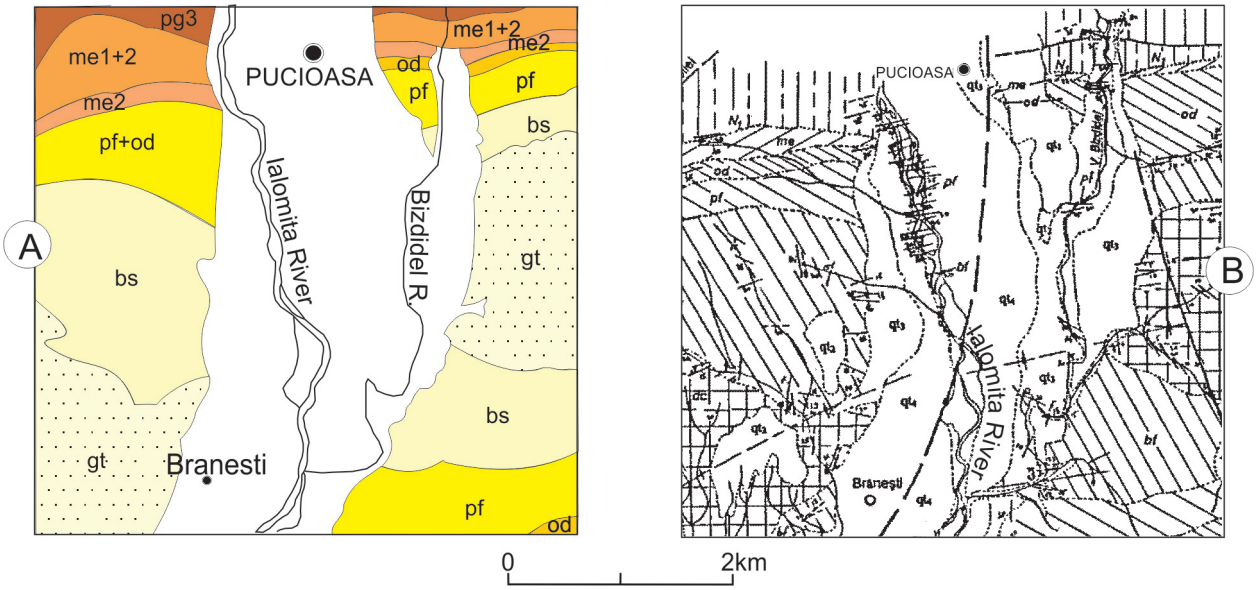


Fig. 3 Geological maps of the Late Neogene deposits from the Pucioasa-Brănești area. **A**. Simplified after Ștefănescu *et al*. (1988). *Legend*: Pg3 = Oligocene; me 1+2 = Early and Middle Miocene; me2 = Late Maeotian; od = Odessian; pf = Portaferrian; bs = Bosphorian; ge = Getian (Early Dacian); **B**. From Damian (1999). Legend: N1 = Miocene; me = Maeotian; od = Odessian; pf = Portaferrian; bs = Bosphorian; dc = Dacian.

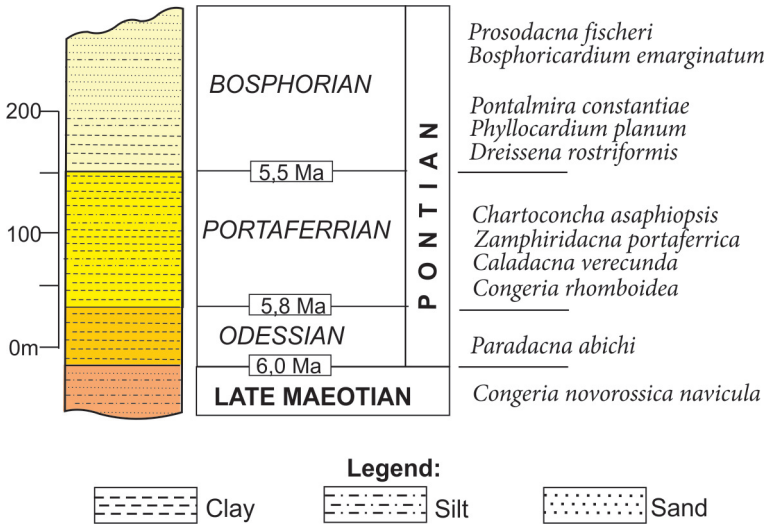


Fig. 4 Biostratigraphic column of the Late Neogene deposits cropping out on the Bizdidel River (Pucioasa western town limit). After Papaianopol (in Ștefănescu *et al.*, 2010), Cronostratigraphy after Krijgsman *et al.*, 2010.

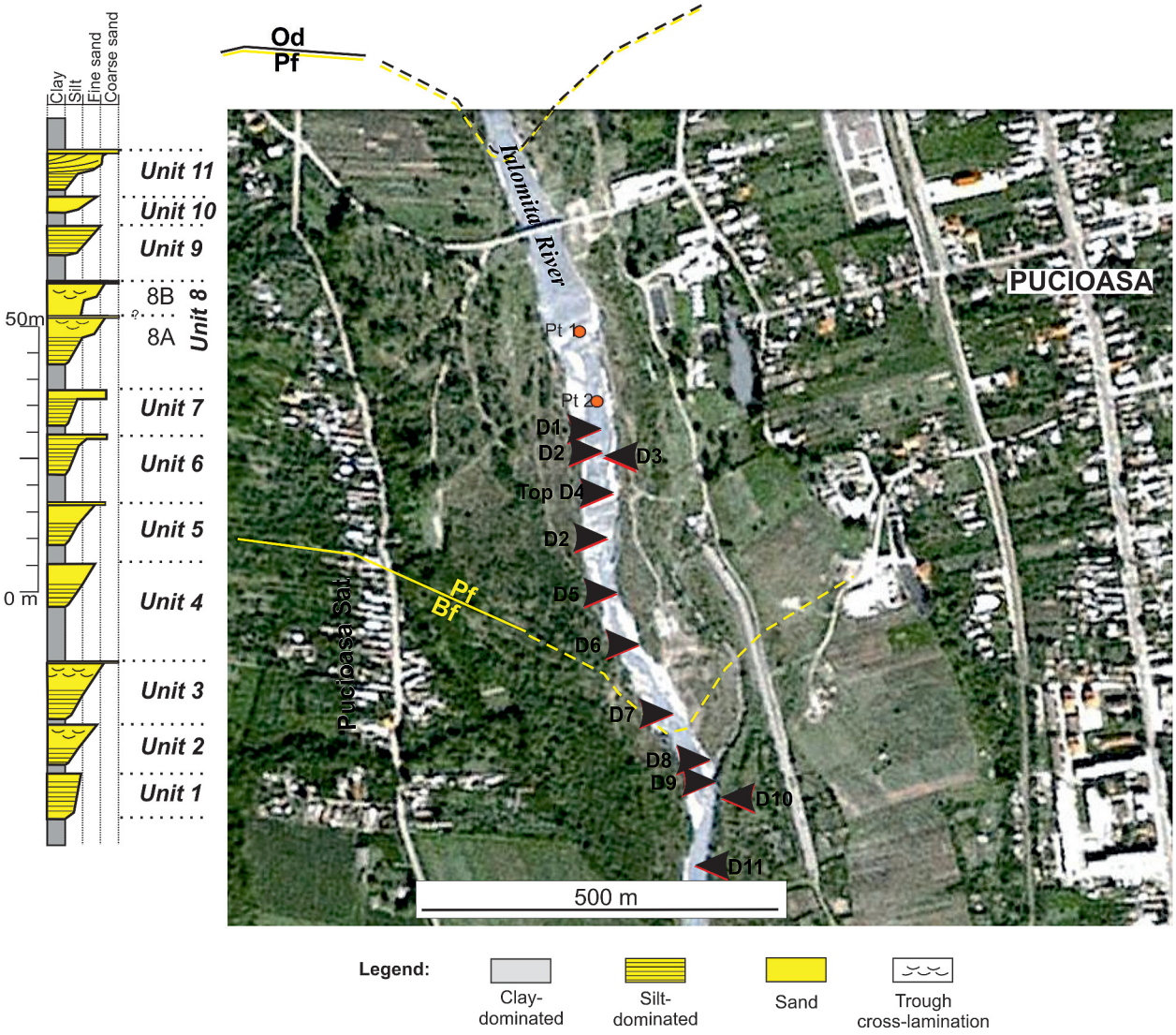
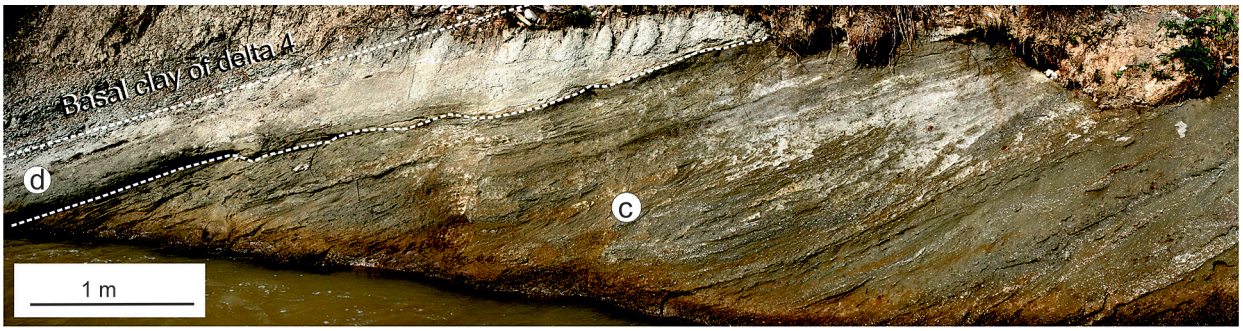
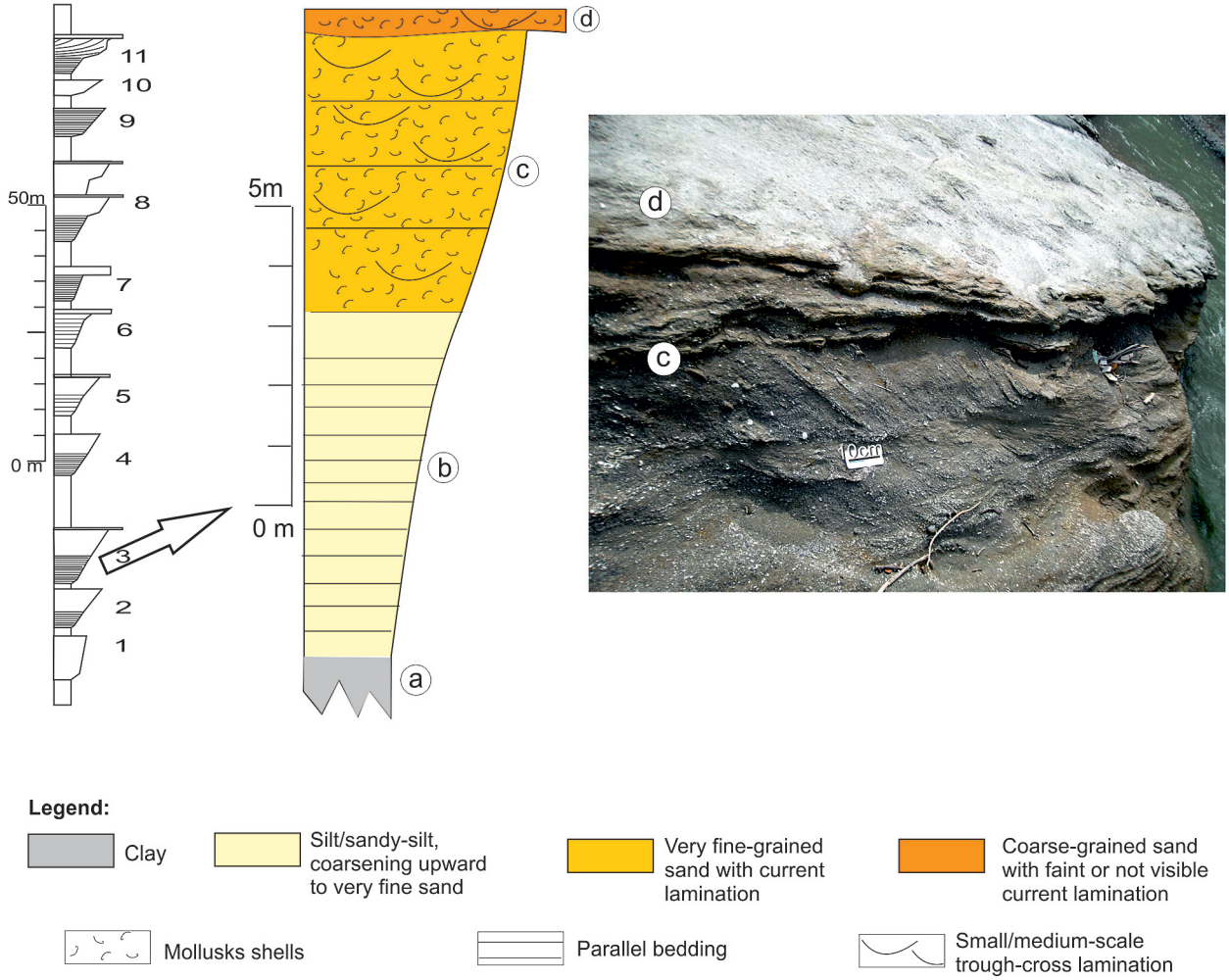


Fig. 5 Location of the observation points on Ialomița River channel, in the western neighborhood of Pucioasa town. The stratigraphic boundaries were transposed from the geological maps of Ștefănescu and Papaianopol (1988) and Damian (1999).





Legend:

Clay

Silt/sandy-silt, coarsening upward to very fine sand

Very fine-grained sand with current lamination

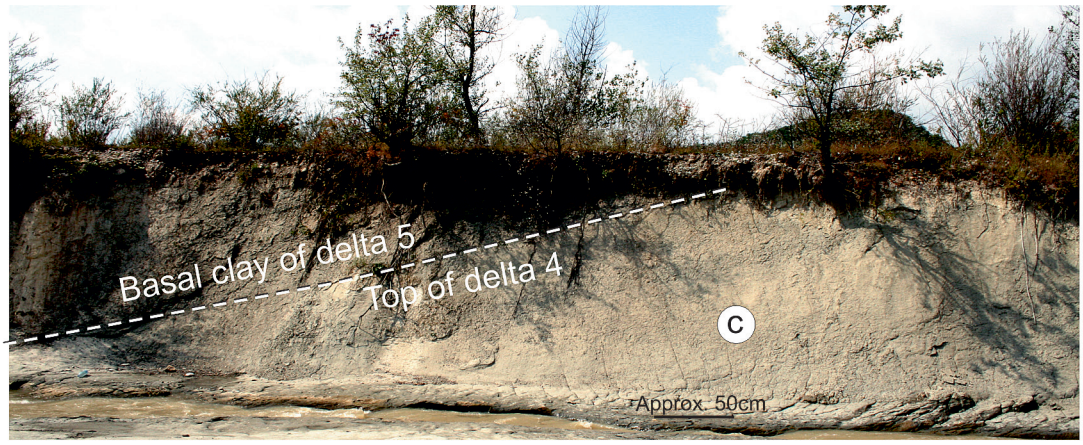
Coarse-grained sand with faint or not visible current lamination

Mollusks shells

Parallel bedding

Small/medium-scale trough-cross lamination

Fig. 6 Coarsening upward unit 3. The sandy intervals ('d' and especially 'c') show clear current structures. Not the erosional surface between 'c' and 'd'.



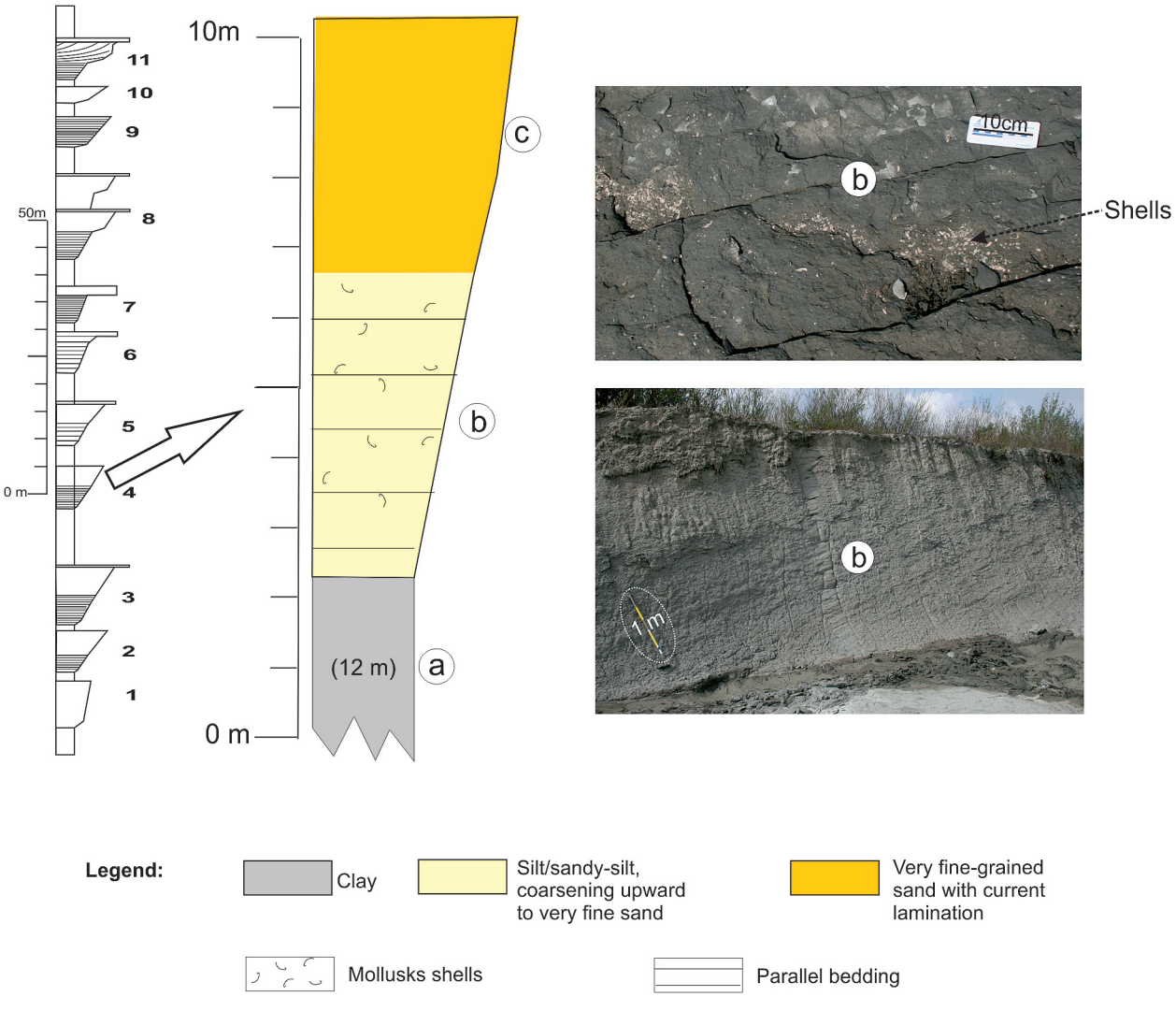


Fig. 7 Coarsening upward unit 4. The top, coarser-grained sand 'd' interval is absent.

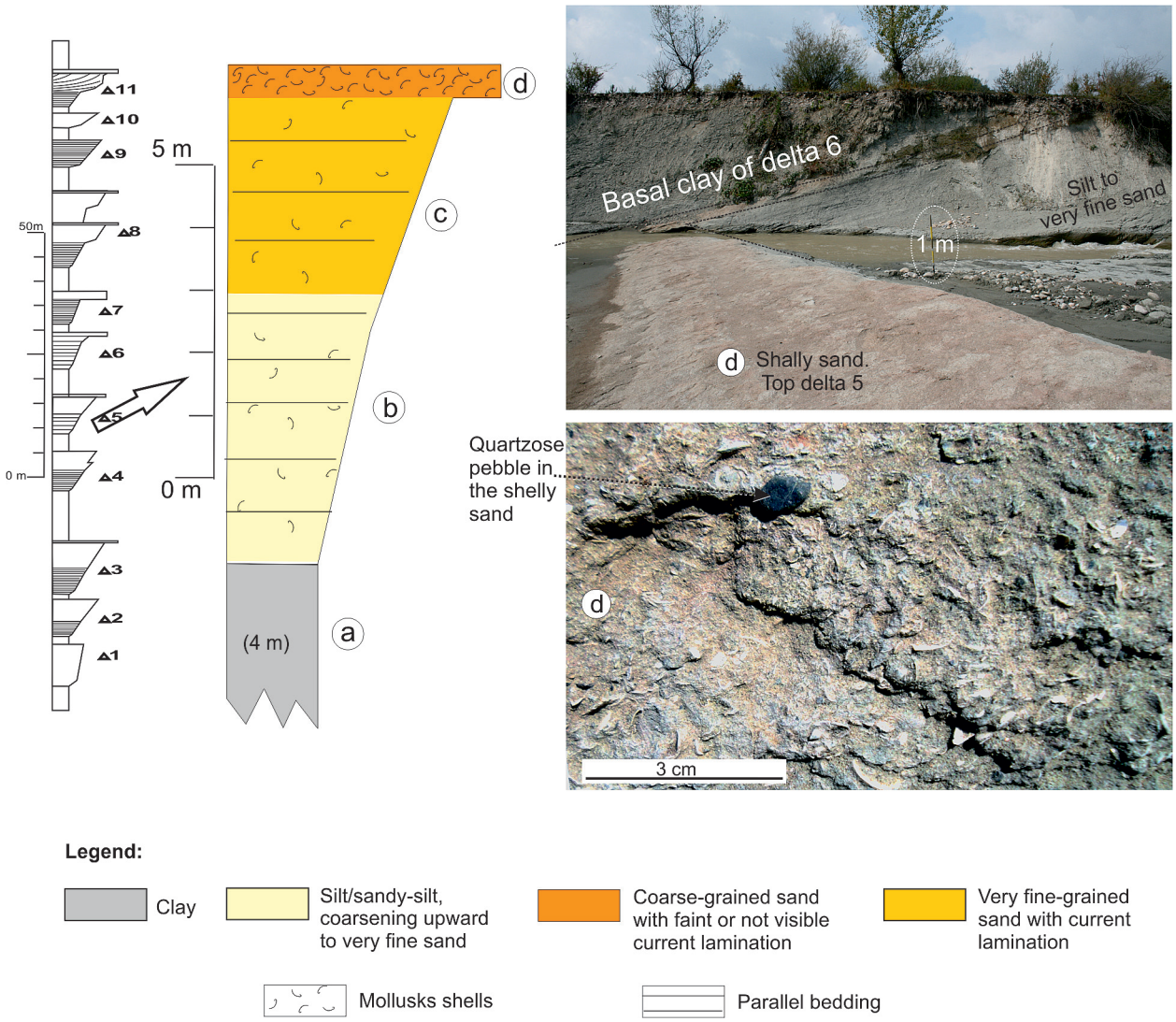


Fig. 8 Coarsening upward unit 4. The top coarser-grained sand (interval 'd') is visible in the vertical section and on the bedding plane surface.

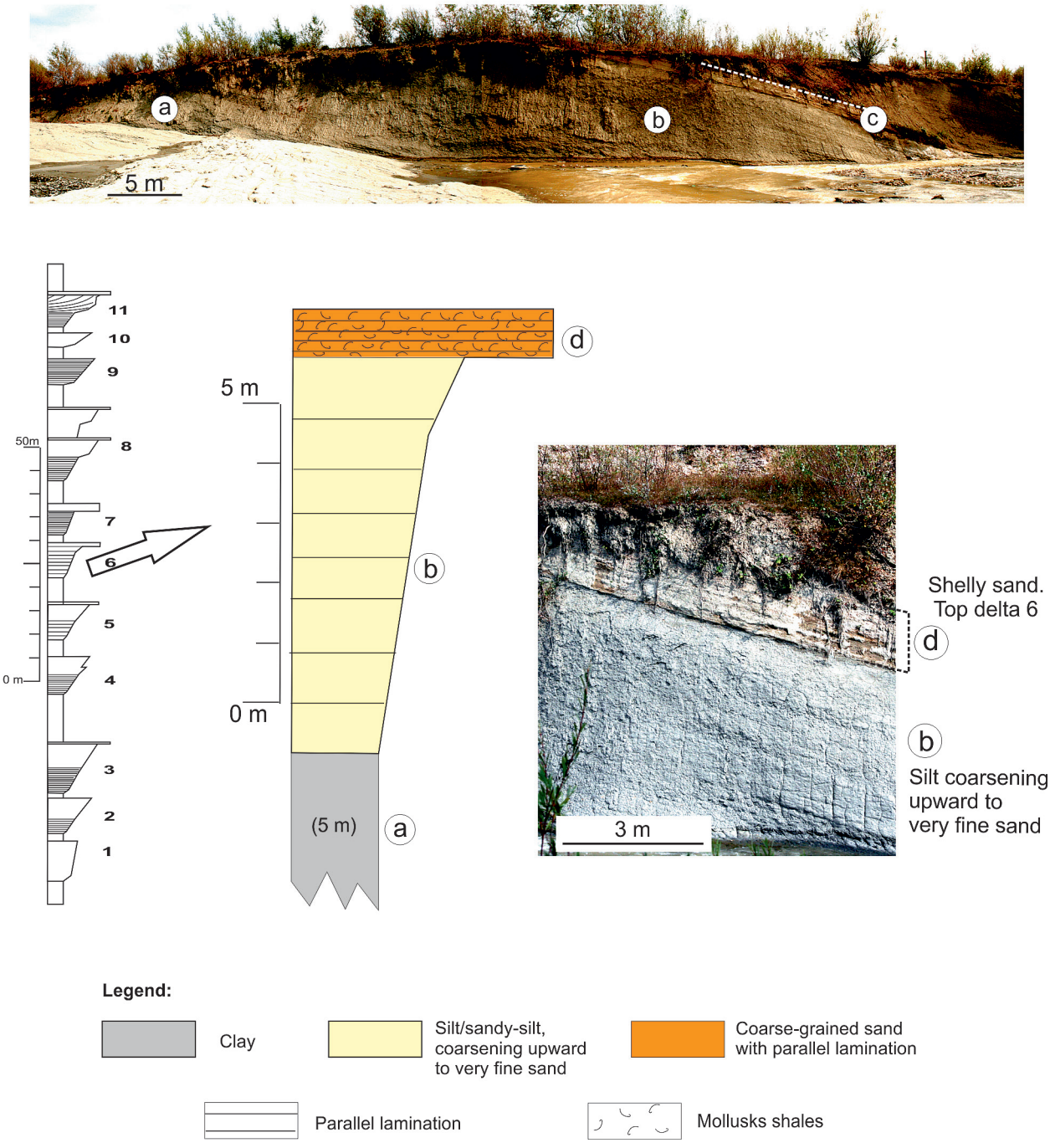


Fig. 9 Coarsening upward unit 6. The fine-grained sand interval is missing.

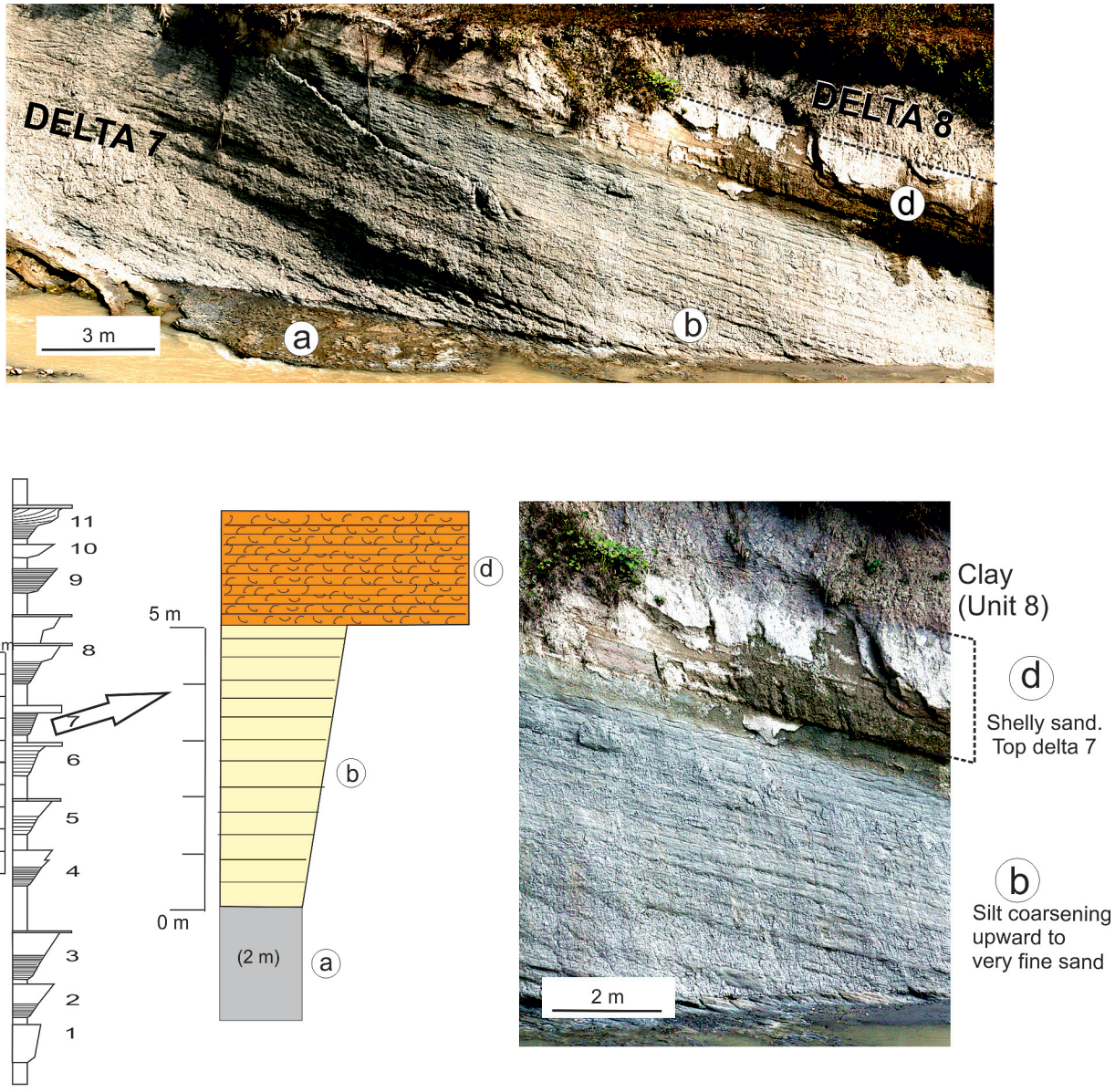


Fig. 10 Coarsening upward unit 7. The fine-grained sand interval ('c') is missing.

The bed no. 8 is the thickest unit in the coarsening upward succession observed in the Pucioasa area. This body shows a duplication of the 'c' sandy upper part (Fig. 11). It is also worth mentioning that the top interval ('d') is made of coarse-grained sand with quartzose and lithic small pebbles and also clay pebbles. The top part of the unit no. 9 (Fig. 12) consists of fine-grained sand, apparently not bedded, with quartzose micro-pebbles.

Although a thin one, the unit no. 10 (Fig. 13) shows a clear and complete coarsening upward trend.

2.2.2. Internal sedimentary structures

The silty term of the coarsening upward units cropping out in the Pucioasa area is characterized by the constant presence of the flat, parallel lamination. The sand intervals show flat (Fig. 9, 10 and 15A) and cross lamination. The later structures occur as current ripples, sometimes located at the upper part of a sand bed (Fig. 15 B, C, D and Fig. 16).

Current lamination structures also occur in the top coarse-grained sand (Fig. 6). At times, the coarse-grained sand is homogeneous, apparently not-bedded. The top interval of the coarsening upward unit no. 9 shows micro-pebbles embedded in a dominant fine-grained sand matrix (Fig. 12). We have already mentioned the erosional basal boundary of the coarse-grained sand term of the unit no. 3 (Fig. 6).

The uppermost unit of the investigated coarsening upward succession is conspicuous by the large scale cross-lamination of the upper sand term (Fig. 14).

It is to be pointed out that no wave or storm-generated sedimentary structures have been observed during the study of the coarsening upward deposits cropping out on the Ialomița River near Pucioasa town.

2.2.3. Paleocurrent directions

The transport direction of the Middle Pontian coarsening upward sediments was determined by measuring the orientation of the trough cross laminated units (Fig. 16). All these sedimentary structures were observed at the upper, coarser-grained division of the studied units, named in this paper the 'c' term sediments.

Although only a relatively small number of paleo-current directions were acquired (19 measurements), the total angular field is narrow enough to evidence the dominant paleo-current flow (Fig. 17). The individual paleo-flow directions vary from WNW-ESE to NNE-SSW. The dominant paleo-current direction is from NW to SE.

2.3. Lithofacies distribution in the shallow water Dacian Basin

Three main paleoenvironmental zones have been outlined in the Dacian Basin (Jipa and Olariu, 2009). While the northern end of the Dacian Basin is dominantly fluvial, in the western termination of the basin, there are characteristic deep water deposits (Fig. 20A). Shallow water sedimentation is the most representative for the Dacian Basin, covering its central part.

The borehole data show that, during the Maeotian time, the sandy facies was clearly dominant in the shallow water zone of the Dacian Basin (Fig. 20B). The coarsening upward trend is a frequent feature in this zone, which indicates the delta type development of the Maeotian sediment accumulation.

In contrast, in the same zone, the Pontian deposits are almost entirely clayey (Fig. 20C). The only Pontian sandy facies indications (including the Pucioasa coarsening upward units) come from the northern, sub-Carpathian periphery of the Dacian Basin (Fig. 20C). This sandy strip, of irregular lobate shape, is of maximum 15 to 25 km width, compared with the 130-140 km total width of the offshore clayey facies area.

3. DISCUSSION OF DATA

3.1. Conceptual model of the coarsening upward sedimentary successions

The coarsening upward trend is present in all silty-sandy bodies investigated in the Ialomița River area. This tendency is expressed by the following terms of the lithologic sequence (Fig. 18):

1. clayey deposits at the base of the coarsening upward succession;
2. silty sediments, sometimes with thin sand intercalations;
3. fine-grained sand, frequently with shelly intercalations;
4. coarse-grained sand, usually with shell fragments, but also with quartzose and lithic micro-pebbles.

This is the complete coarsening upward development, which makes up the main feature of the sedimentary model. The implicit characteristic is the grain-size transition between the succession terms, from the basal clay to the top coarse-grained sand. Along with the general grain-size variation the coarsening upward sequence also shows variation of the size of the cross-lamination structures and the frequency of the mollusks shell fragments (Fig. 18). The current lamination structures observed in the entire succession point out the genetic characteristic of the coarsening upward sediments.

Most of the units making up the investigated sediments from the Pucioasa area show the complete coarsening upward ('a' to 'd' intervals) succession (Fig. 19A). As revealed by the sedimentologic investigation, the upper coarse-grained sand interval of the coarsening upward units is occasionally missing (Fig. 19B). This probably indicates a lower level energy of the sediment accumulation process. In the case of units D 6 and D 7, the fine-grained sand interval 'c' is missing (or obscure) and the coarse-grained sand interval is overlaying the silty 'b' interval (Fig. 19C).

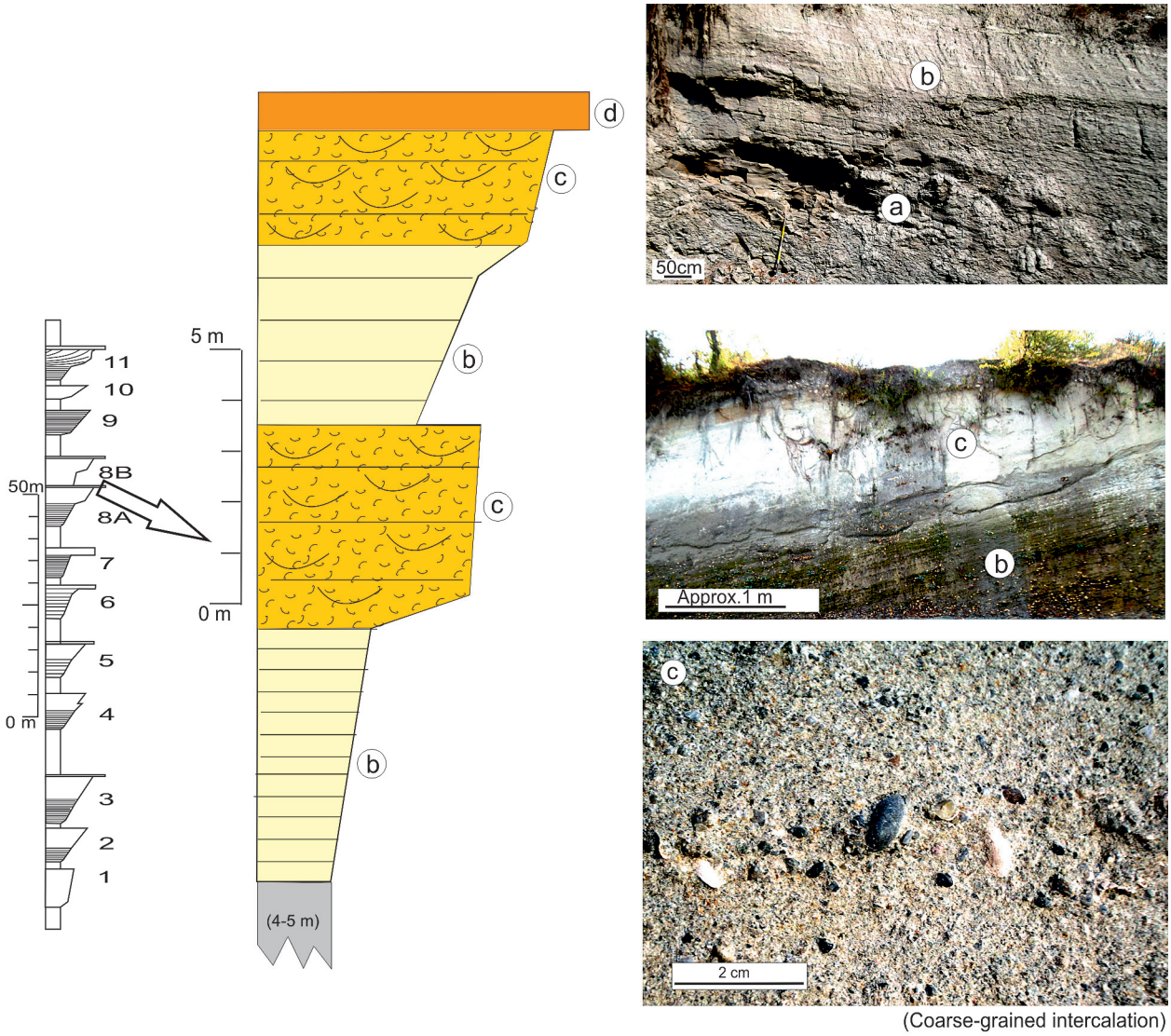


Fig. 11 Coarsening upward unit 8 (A and B).

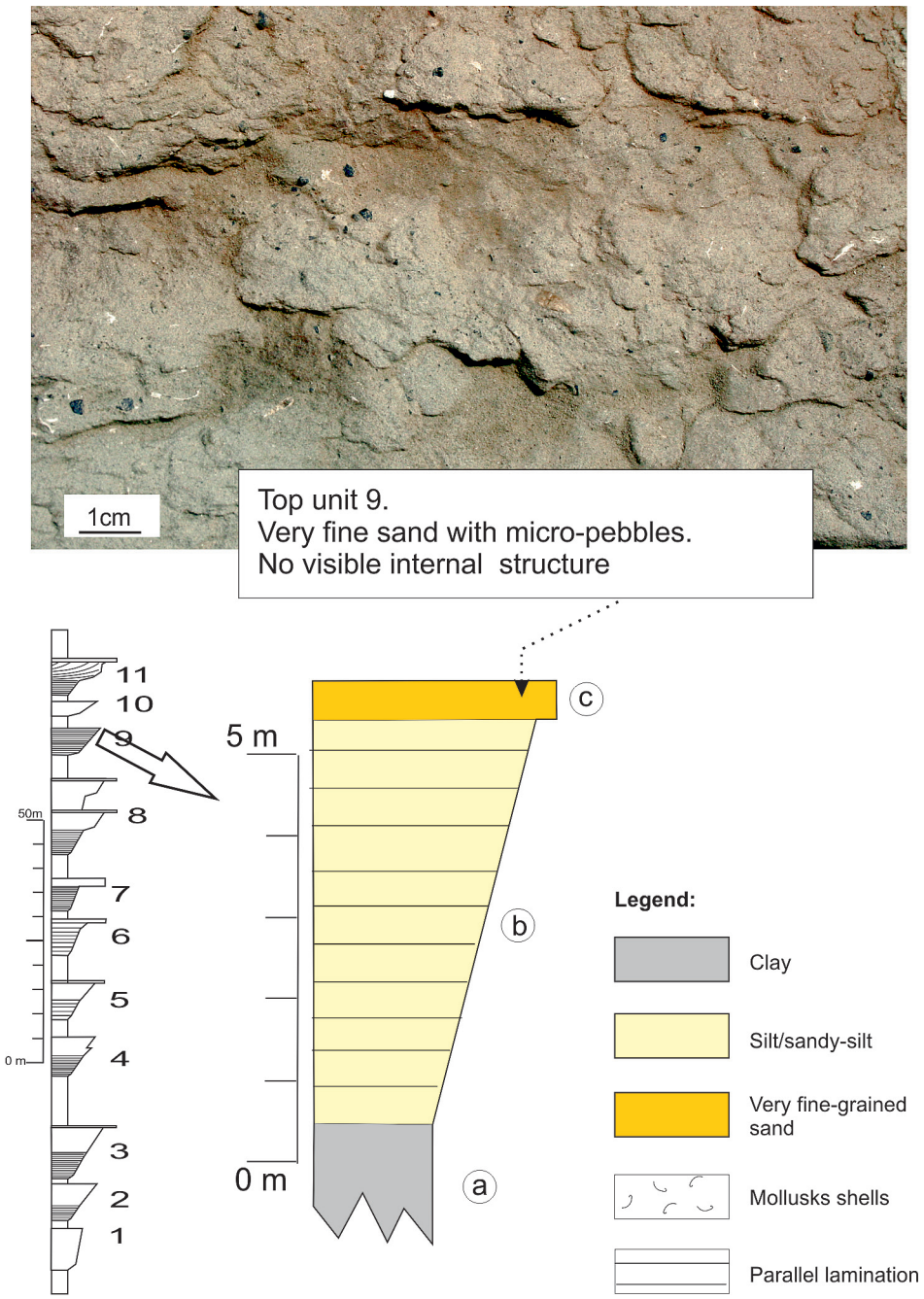


Fig. 12 Coarsening upward unit 9.

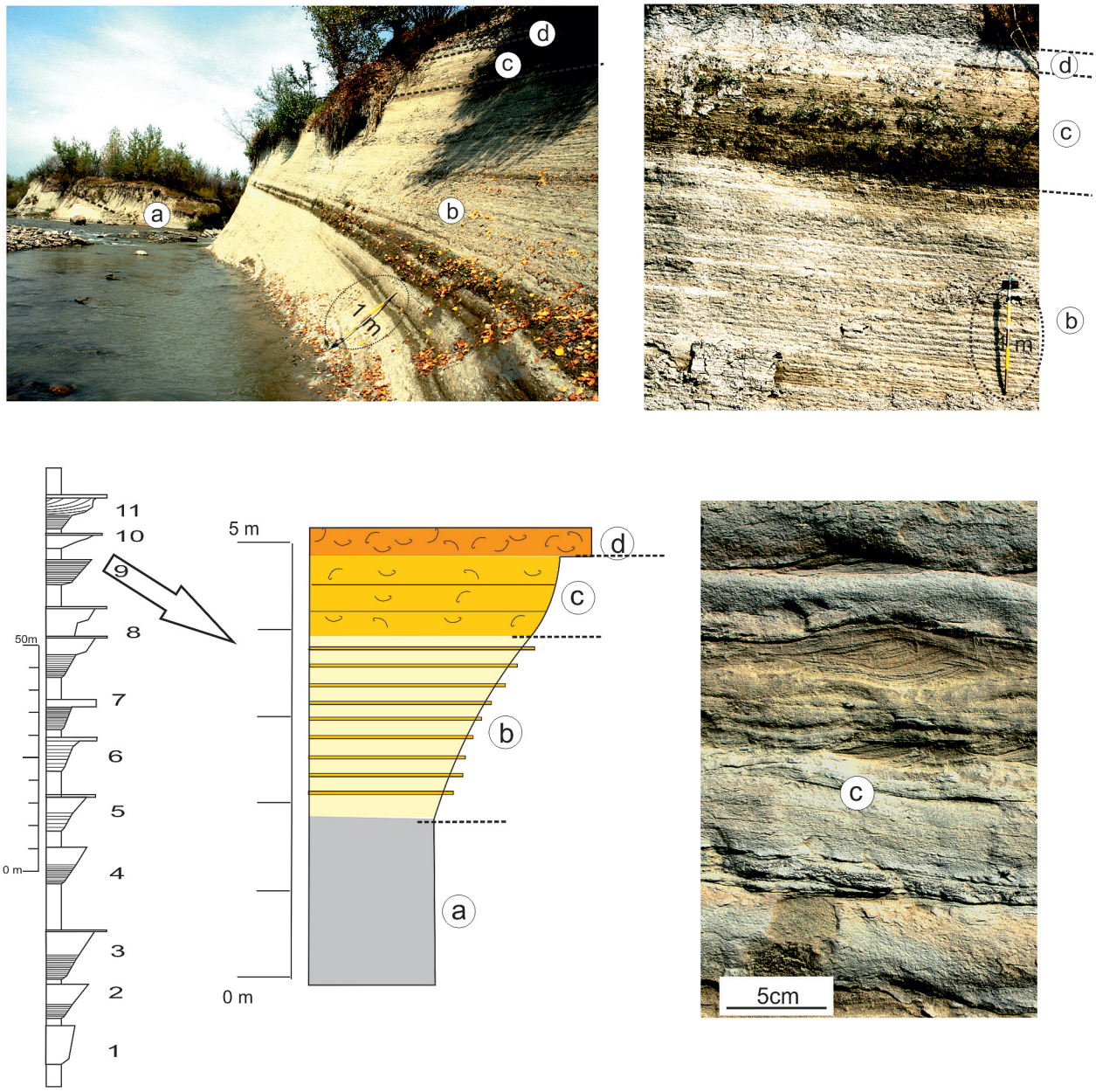
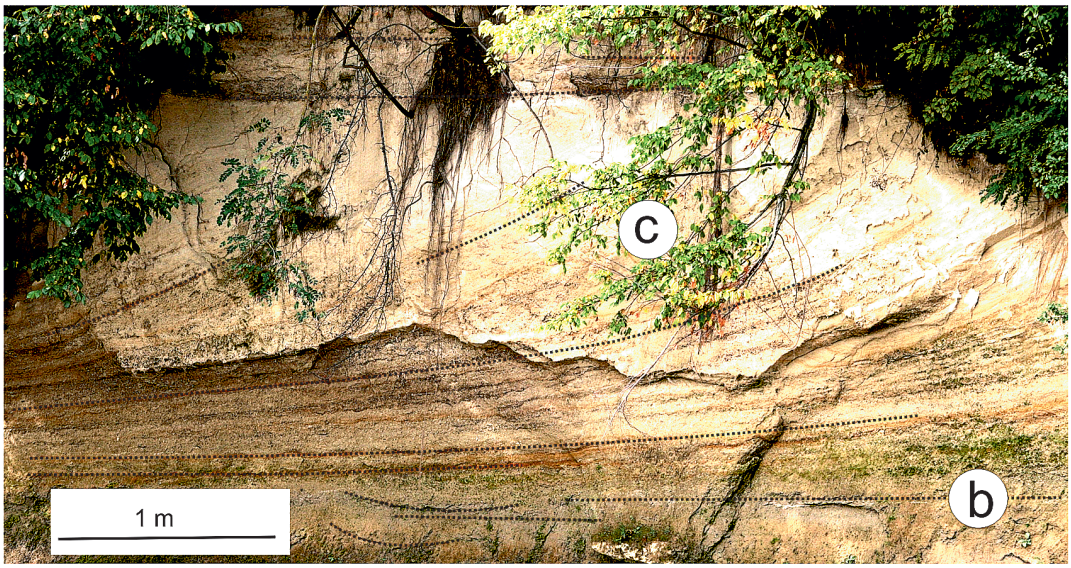
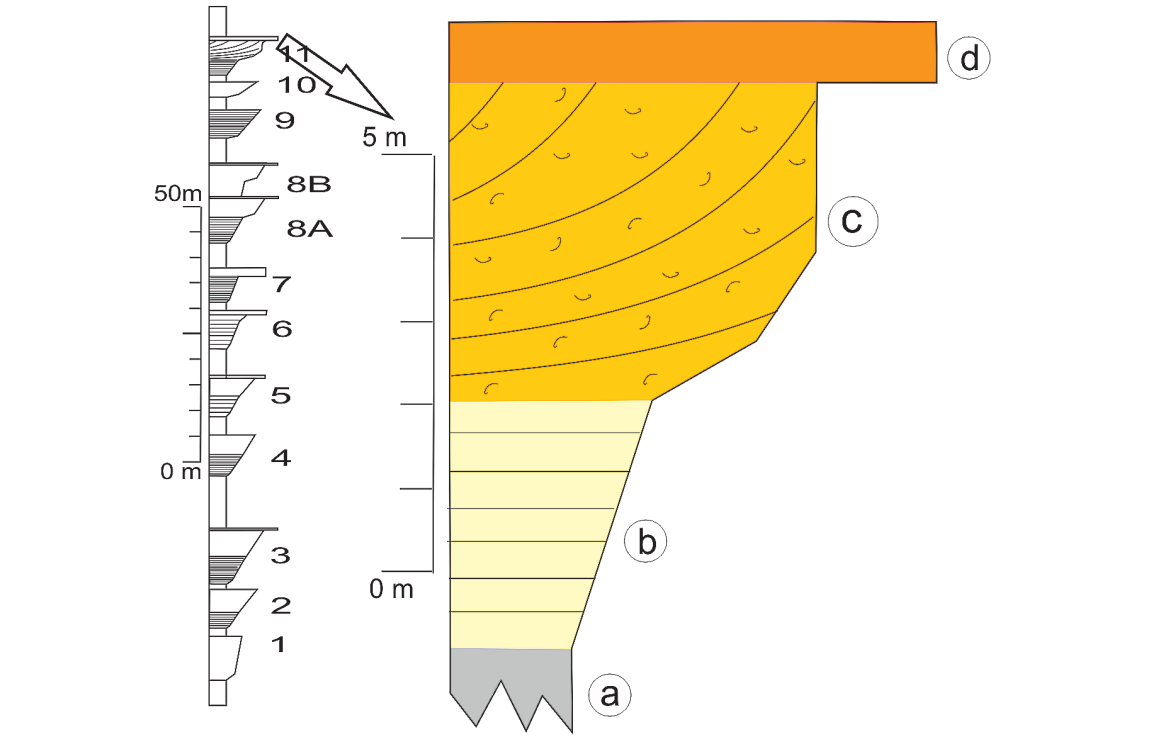


Fig. 13 Coarsening upward unit 10.





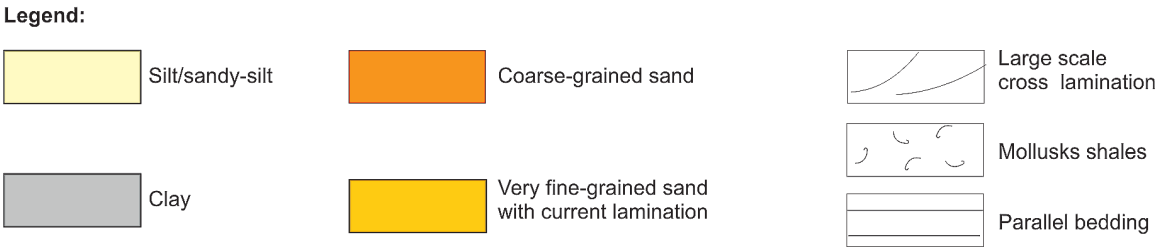


Fig. 14 Coarsening upward unit 11. The presence of large scale cross laminated interval 'c' is the special feature of this unit.

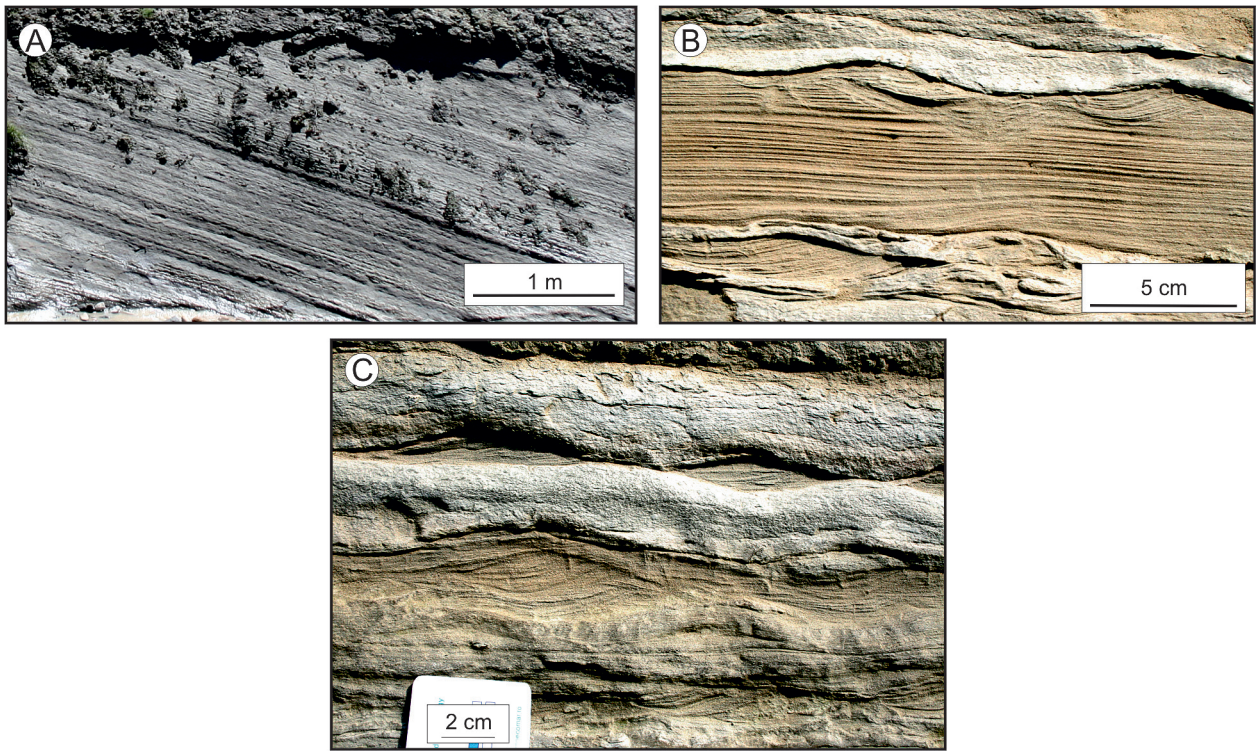


Fig. 15 Internal sedimentary structures in the deposits of the interval 'b'. Flat, parallel lamination is common in the sediments of this coarsening upward interval (**A**). Current ripples (**B**) occur in higher energy sedimentary accumulations. **C** = current ripples on top of a parallel laminated fine sand.

3.2. Coarsening upward sedimentation of the Middle Pontian Dacian Basin: prograding shoreline *vs* delta front.

The paleocurrent measurements pointed out that the Middle Pontian sandy sediments cropping out in the Ialomița River area, close to the town of Pucioasa, were transported dominantly from NNE toward SSW (Fig. 17). Consequently, the detrital material of the stacked coarsening upward units from the Pucioasa area is of Carpathian provenance.

The Middle Pontian sandy facies deposits did not extend offshore, but were restrained to the northern, onshore margin of the Dacian Basin (Fig. 20C). This feature indicates the Middle Pontian sandy units investigated by the present study, are part of a shoreline system. The coarsening upward trend, characteristic for the investigated Middle Pontian sedimentary succession, attests the prograding character of this shoreline zone.

The occurrence of sandy deposits in the middle part of the Pontian sedimentary succession is not limited to the coarsening upward sandy units investigated in the Pucioasa area. Similar deposits consisting of sand units alternating with clayey sediments crop out on Doftana River (south periphery of Câmpina town) and on Slănic de Buzău River (Sârbeşti locality) (Jipa and Olariu, 2009) (Fig. 20A). Comparable with the coarsening upward deposits from Pucioasa area, the sandy accumulations of Doftana and Slănic de Buzău are restricted to the northern, onshore zone of the Dacian Basin.

3.3. Factors governing the accumulation of the Middle Pontian coarsening upward sediments

The occurrence of the Middle Pontian sandy interval of the Pucioasa area represents an important modification of the Dacian Basin Pontian sedimentation style, which is dominated by clay accumulation. This implies a drastic change in the nature and the volume of the sediment supply. Such a change could have been generated by sea-level drop, tectonic uplift or climate variation.

The *sea-level drop* is the most frequently considered explanation for the appearance of a sandy facies as the Middle Pontian one. In case of the coarsening upward sedimentary succession from the Pucioasa area, there are strong arguments against such an interpretation. In the Dacian Basin shallow water area (Fig. 20A), the sediments accumulated during the Pontian are dominantly clayey (Fig. 20B), corresponding to the sea-level rise and marine transgression which marked this time period. In contrast, the regressive Upper Maeotian sediments are dominantly sandy (Fig. 20C). Being confined to the marginal, sub-Carpathian area of the Dacian Basin (Fig. 20B), the occurrence of the Pontian sandy sediments recorded by drilling, and also evidenced as the Middle Pontian cropping out sediments, is to be connected

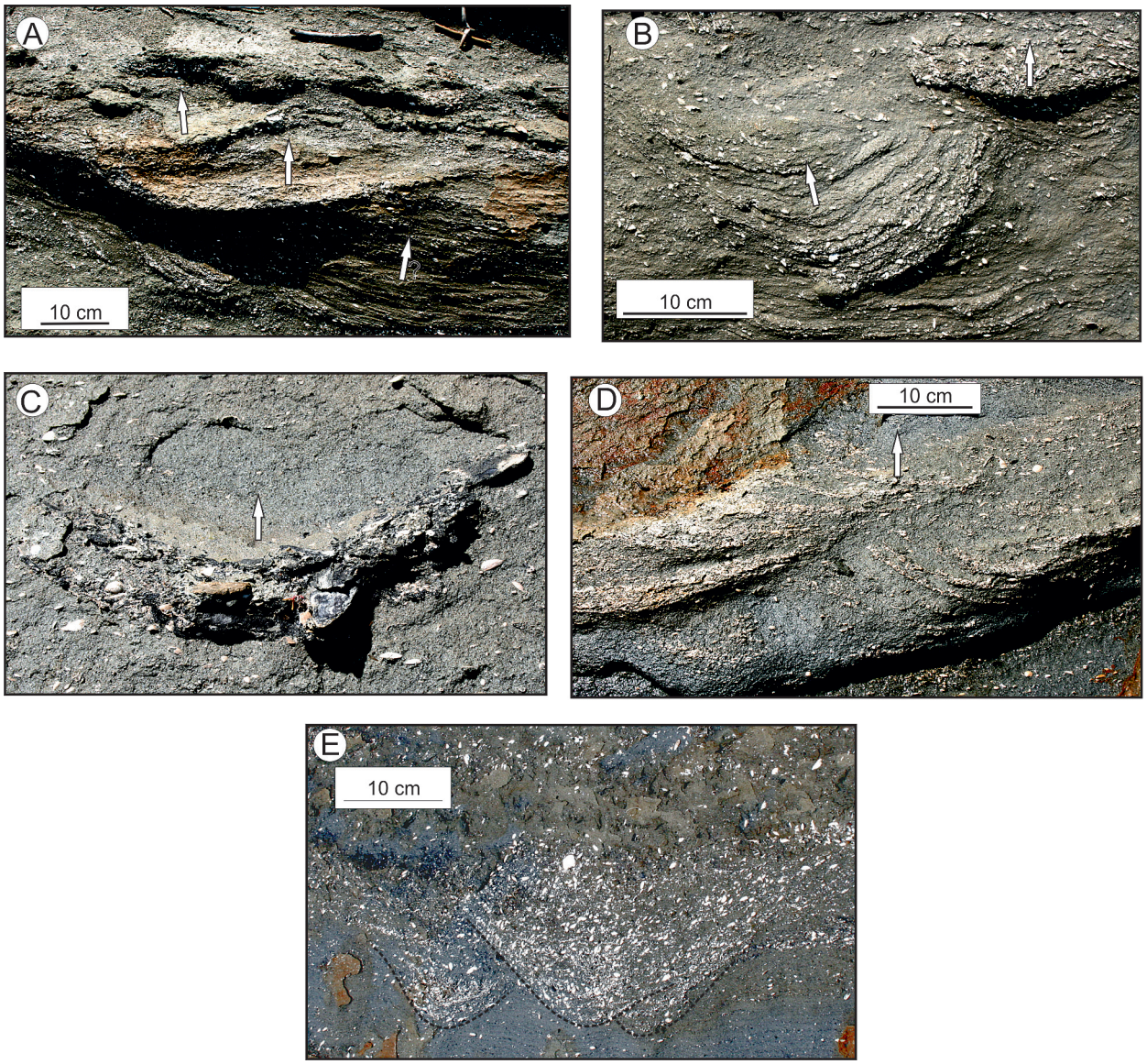


Fig. 16 Trough cross laminated units in deposits of the 'c' interval. **A** to **D** = Trough cross units observed on the bedding plane. The arrows indicate the paleocurrent flow direction. **E** = Trough cross lamination in vertical section.

to changes produced in the Carpathian source-area, not to the sea-level variation.

The Middle Pontian development of the prograding sandy sediments cropping out in the Ialomița River zone, was in contrast with the transgressive clayey sedimentation prevailing in the offshore, shallow water sector of the Dacian Basin. This was imposed by a high input of sandy detrital material coming from the Carpathian source-areas. A *tectonic uplift* could be the reason for the Middle Pontian sandy supply. This hypothesis is opposed by the thermochronology data of Sanders (1998), interpreted as indicating that after the Late Sarmatian the Carpathian uplift movement halted, and this state continued during the entire evolution of the Dacian Basin (also including the Pontian time).

The Sanders (1998) concept leads to the conclusion that *climate changes* (like increased rainy activity) could have been the main control factor that determined the appearance of the Middle Pontian sandy, coarsening upward facies.

4. CONCLUSION

A stacked succession of Middle Pontian coarsening upward units was investigated in the Pucioasa town area (Ialomița River, central Dacian Basin). The grain-size of the sedimentary units evolves from basal clay (interval 'a'), through silty sediments (interval 'b') and fine-grained sand (interval 'c'), to coarse-grained sand (interval 'd') on top. Current lamination structures were observed in the investigated sediments. Measured paleocurrent flow directions point out to a dominant sediment transport from NW toward SE.

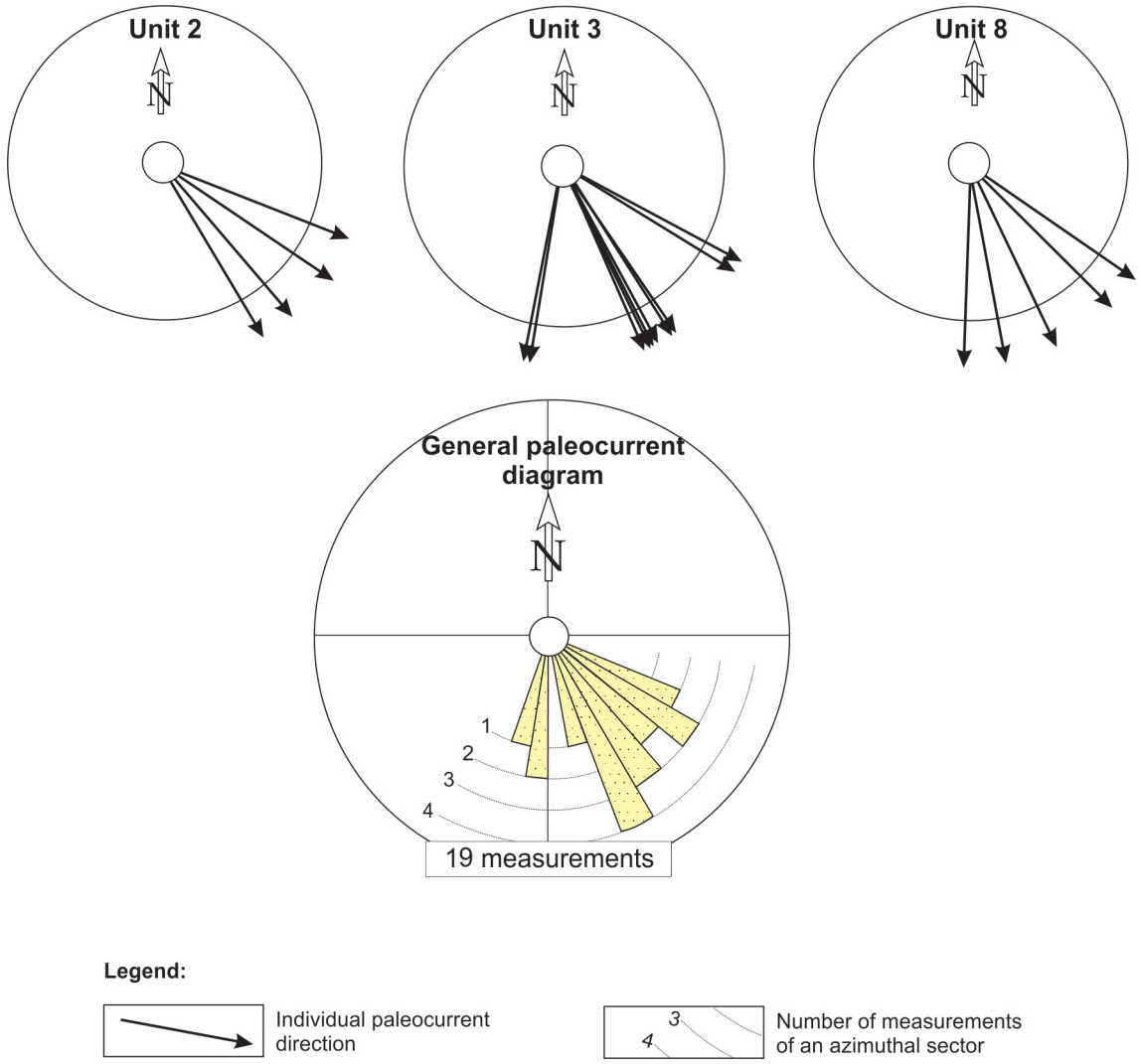


Fig. 17 Paleocurrent measurements in the Middle Pontian coarsening upward deposits from the Pucioasa area (Ialomița River).

Located on the onshore margin of the Dacian Basin, the Middle Pontian sandy deposits from Pucioasa area are part of a shoreline system.

The accumulation of the Middle Pontian coarsening upward sediments cropping out in the Pucioasa area represents a prograding event, which took place during a marine transgression period. In the present paper, three hypothetic processes are considered to explain the accumulation of these sediments: sea-level drop, tectonic uplift or climate variation.

In view of the arguments showing that the Dacian Basin Pontian sedimentation evolved during a marine transgression, one cannot take into consideration the sea-level drop, as the factor which determined the accumulation of the coarsening upward deposits of the Pucioasa area.

Considering the data submitted in this paper, it is reasonable to support the idea that the accumulation of the investigated Middle Pontian delta-type sediment, was governed by processes activated in the Carpathian source-area.

A change of tectonic or only of climatic nature activated the erosion process in the Carpathian source-area, during the Middle Pontian. This determined the release of a large volume of sandy material into the sub-Carpathian shoreline zone of the Dacian Basin, where it suffered a limited seaward progradation advancement.

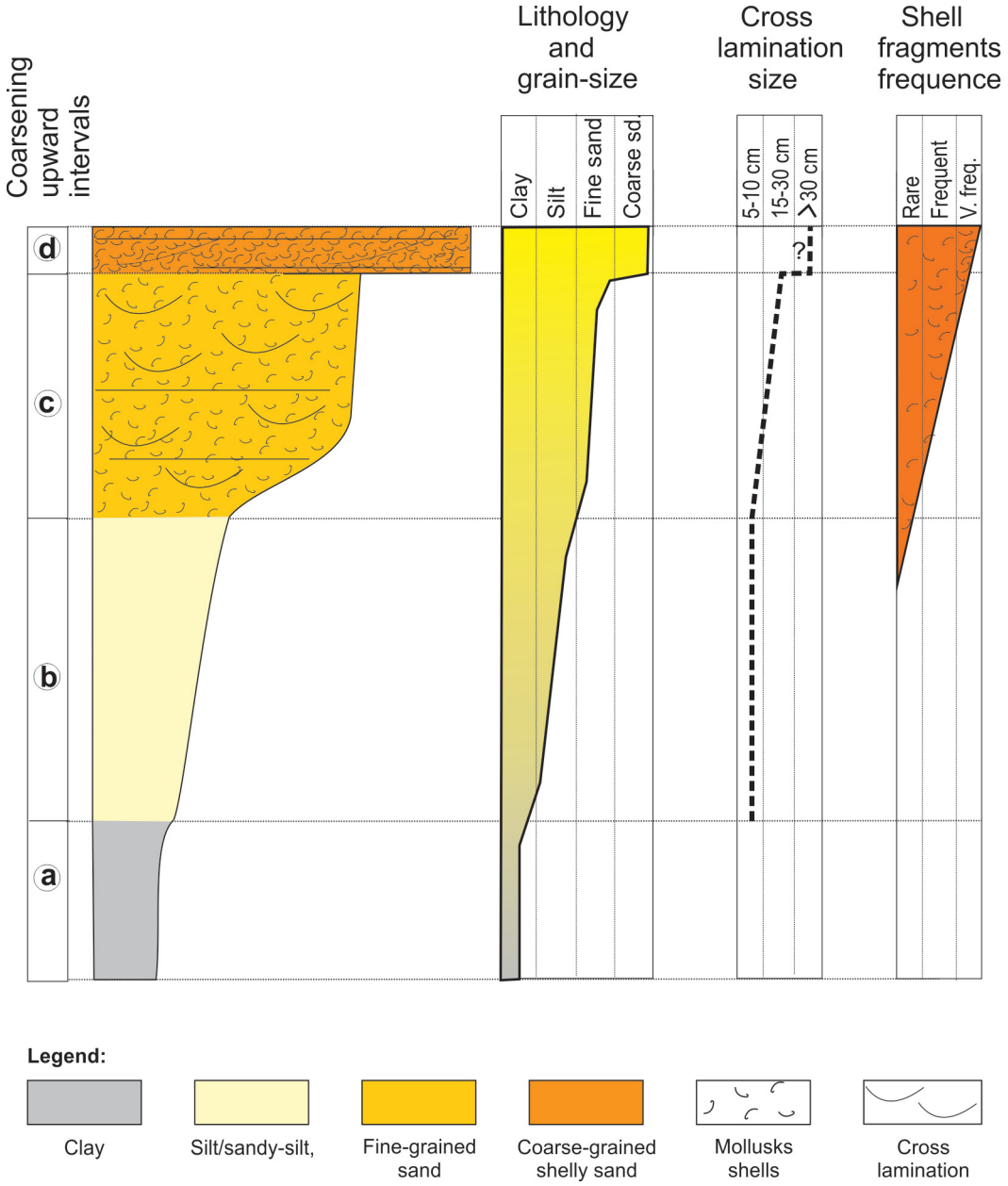


Fig. 18 Conceptual sedimentologic model of the Middle Pontian coarsening upward deposits investigated on Ialomița River, Pucioasa area.

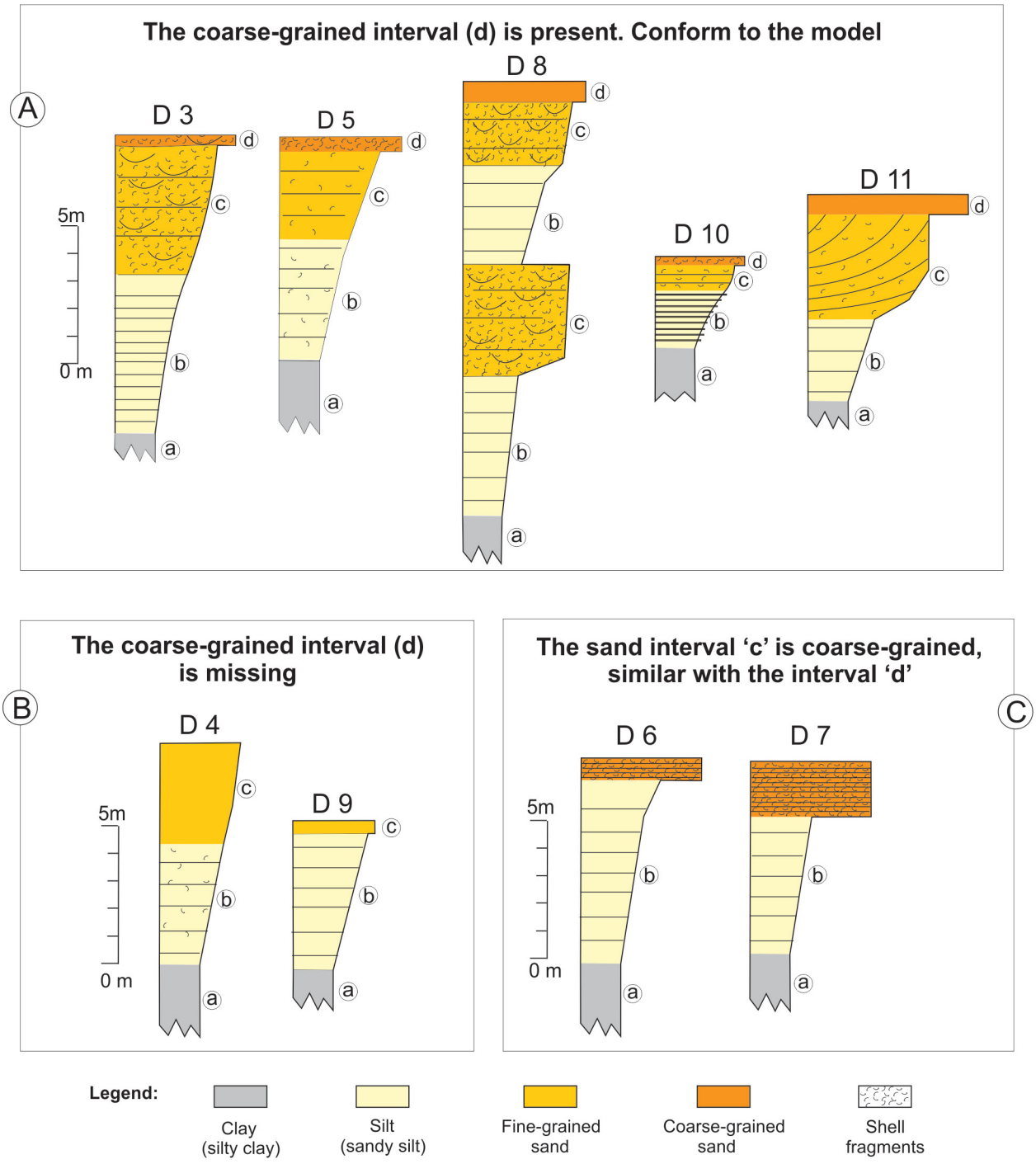


Fig. 19 Exceptions to the model of the coarsening upward lithologic succession (Middle Pontian, Ialomița River, Pucioasa area).

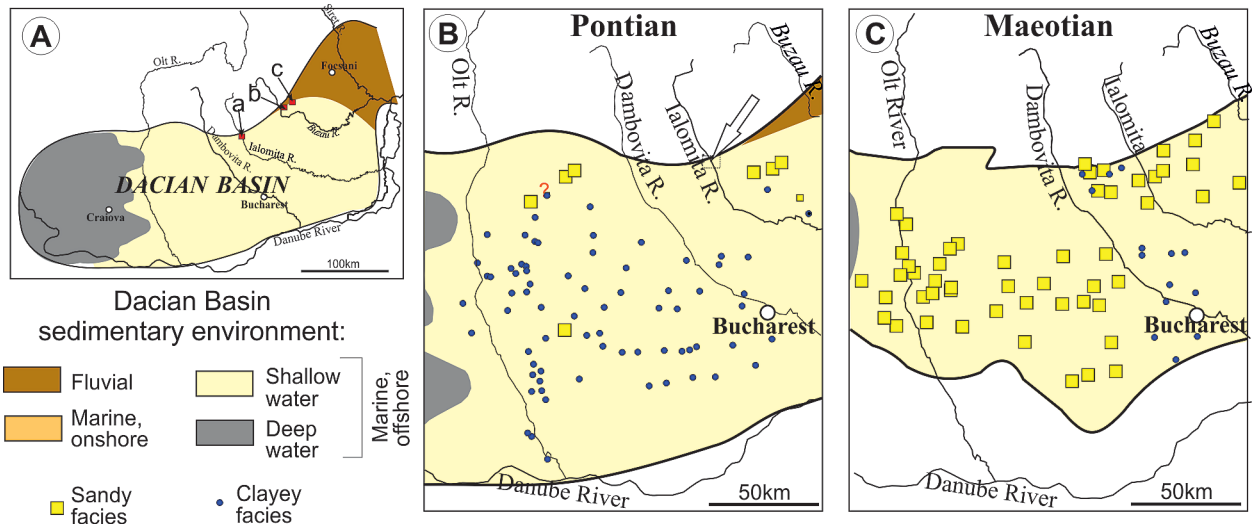


Fig. 20 Large scale geological setting of the coarsening upward deposits from Pucioasa area in the Dacian Basin area. **A**. Schemathic picture of the major Dacian Basin paleoenvironmental subdivisions. Location of Middle Pontian sandy sections: a = Ialomița R. (Pucioasa); b = Doftana R. (Campina); c = Slănic de Buzau R. (Sârbești) section. **B**. Pontian litho-facies distribution in the shallow marine Dacian Basin. Based on subsurface information. **C**. Upper Maeotian litho-facies distribution in the shallow marine Dacian Basin. Based on subsurface information. The arrow points out the location of the Pucioasa study area. Dacian Basin extension during the Maeotian and Pontian from Saulea *et al*. (1969) and Hamor *et al*. (1988).

REFERENCES

Damian, R., 2003. Geologia depozitelor Neogen superioare dintre Dambovița și Prahova. Interpretări geochimice. Ed. Universității din Bucureşti, 111 pp.

Hamor, G. *et al*., 1988. Neogene paleogeographic atlas of Central and Eastern Europe. Hungarian Geological Institute, Budapest.

International Comission on Stratigraphy, 2009. International stratigraphic chart.

Jipa, D.C., Olteanu, R., 2005. Sedimentary and biological paleoenvironments at the Meotian – Pontian boundary: Central Dacian Basin, Bizdidel Valley (in Romanian). Studii si Cercetări de Geologie, 49-50 (2004-2005), 75-98. Bucureşti

Jipa, D.C., Olariu, 2009. Dacian Basin. Depositional architecture and sedimentary history of a Paratethys sea. Geo-Eco-Marina Special Publication no. 3. 264 pp.

Jipa, D.C., Olariu, C., 2012. Sediment routing in a semi-enclosed epicontinental sea: Dacian Basin, Paratethys domain, Late Neogene, Romania. Global and Planetary Change. http://dx.doi.org/10.1016/j.gloplacha.2012.06.009

Krijgsman, W., Stoica, M., Vasiliev, I., Popov, V.V., 2010. Rise and fall of the Paratethys Sea during the Messinian Salinity Crisis. Earth and Planetary Science Letters, 290. 183–191.

Marinescu, Fl., 1978. Stratigrafia Neogenului superior din sectorul vestic al Bazinului Dacic. Editura Academiei, Bucureşti, 155 p. (in Romanian)

Papaianopol, I., Jipa, D., Marinescu, F., Ticleanu, N., Macaleț, R., 1995. Guide to excursion B2 (post-congress). Upper neogene from the Dacic Basin. Dări de Seama Inst Geol. Geof. 76/1, 43 pp.

Sanders, C.A.E., 1998. Erosion and tectonics competitive forces in a compressed orogen. A fission track study of the Romanian Carpathians. PhD thesis. Netherlands Research School of Sedimentary Geology (NSG), Amsterdam.

Saulea, E., Popescu,I., Săndulescu, J., 1969. Atlas litofacial. VI – Neogen, 1:200,000. Institutul Geologic. Bucureşti.

Ștefănescu, M., Papaianopol, I., 1988. Harta geologică la scara 1:50.000 a României, foaia 128-d Pucioasa. Institutul Geologic al României, Bucureşti.

Vasiliev, I., Krijgsman, W., Langereis, C.G., Panaiotu, C.E., Maţenco, L., Bertotti, G., 2004. Towards an astrochronological framework for the eastern Paratethys Mio-Pliocene sedimentary sequences of the Focşani basin (Romania). Earth and Planetary Science Letters, 227, 231–247.