CALCAREOUS OOID FORMATION IN CLAY-DOMINATED, TRANSGRESSIVE ENVIRONMENT: DACIAN BASIN, UPPER NEOGENE (ROMANIA)

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Abstract. In this paper the genesis of the *Jitia de Jos* calcareous oolit (Upper Meotian, Eastern Carpathians, Romania) and its appearance as an intercalation in the Upper Meotian clay-dominated deposits are explained using the Bahama ooid model. According to our hypothesis, the *Jitia de Jos* ooids accumulated upon an isolated shallow-water platform bordered by deeper water. Under these conditions, strong shallow-water currents removed the suspended clayey material from the ooid platform, while the clayey-silty sediments accumulated in the deeper water surrounding the elevated relief. This hypothesis explains the hydrodynamic difference between the oolitic wave ripples (formed in high energy shallow water) and the fine-grained sandstone, Meotian-Pontian wave ripples (shaped in deeper water, by lower-energy waves). The genesis of the *Jitia de Jos* oolit was also controlled by the hydrochemical changes that occurred during the initial phase of the Upper Meotian – Lower Pontian transgression.

Key words: Oolit, wave ripples, coarsening upward, Bahama model, sedimentary environment

1. INTRODUCTION

The oolitic limestone occurrence in the Dacian Basin deposits represents a challenge for the scientific investigation of this Paratethyan basin. The Dacian Basin detrital, low-salinity environment is not favorable for the ooid formation. The intercalation of a clay-free, calcareous oolit in clay-dominated deposits is another puzzling problem to be deciphered.

The objective of the present paper is to identify and analyze the features of the oolitic limestone and of the sedimentary succession hosting the oolitic layer intercalation, in order to understand the ooid genesis and evolution.

The scientific investigations reported in this paper were carried out in an area located within the Carpathian Bend zone, in the southern part of the Eastern Carpathians (Fig. 1a). The investigation area is situated in the western margin of the northern extension of the Dacian Basin (Fig. 1b).

Relying on previous regional studies, the present paper investigations focus on the oolitic limestone outcrop, in a small area located 200 m from the *Jitia de Jos* locality (Fig. 1c), at the southern margin of the Vrancea County territory.

The oolitic limestone crops out on both banks of the Râmnicul Sărat River (45°34′05″N 26°46′86″E - Google Earth coordinates). The oolit outcrops are easy to find, as they are located at the base of a hillock that has a big cross on top (Fig. 1d).

2. METHODOLOGY

The field work was carried out in well-exposed natural outcrops in the Râmnicul Sărat River valley. Macroscopic observations were supplemented with examinations of ooids in thin sections.

An important goal of the lithostratigraphic and sedimentological investigations was to make evident the position of the oolitic limestone layer in the sedimentary succession

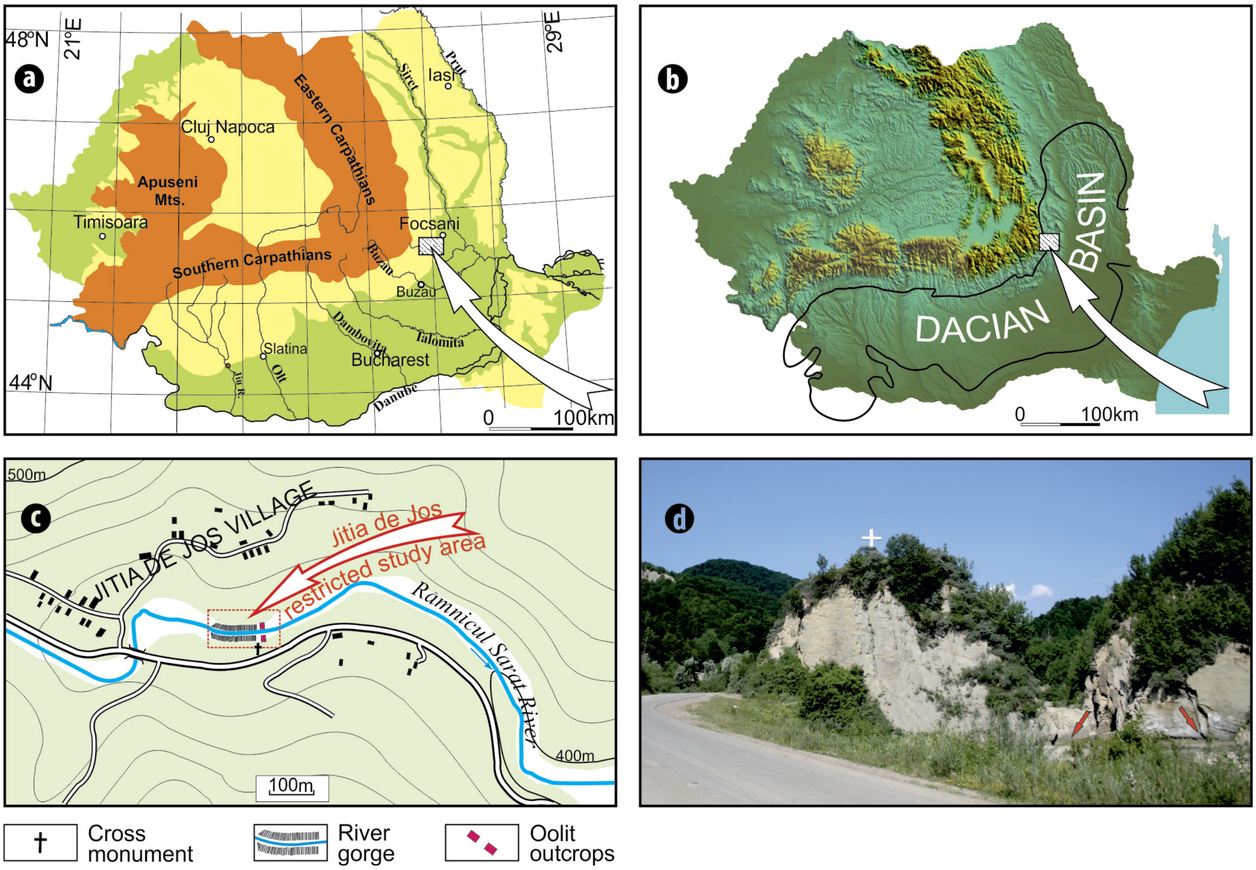


Fig. 1. Study area location in Romania and in the Dacian Basin. (**a**): Study area location on the Romania physical map. (**b**): Study area location in the Dacian Basin area. Romania background image from Wikipedia Commons. (**c**): Topographic sketch of the *Jitia de Jos* investigation area. Based on Google Maps, terrain. (**d**): Photo showing the cross monument, river gorge and the oolit outcrops in the *Jitia de Jos* area.

studied in the *Jitia de Jos* area. Paleontological information from the literature was gathered and sedimentological observations were made for the reconstruction of the ooid formation paleoenvironment.

The stratigraphic and cartographic setting of the field observations relied on the data offered by the geological map of Romania at 1:50,000 scale (sheet 113b – Dumitrești) overviewed by Andreescu and Țicleanu (1976).

The Dacian Basin data regarding the study area came from sedimentological and biostratigraphic papers (*e.g.* Jipa and Olariu, 2009, Olteanu 2006, Stoica *et al.*, 2013).

3. GEOLOGICAL SETTING

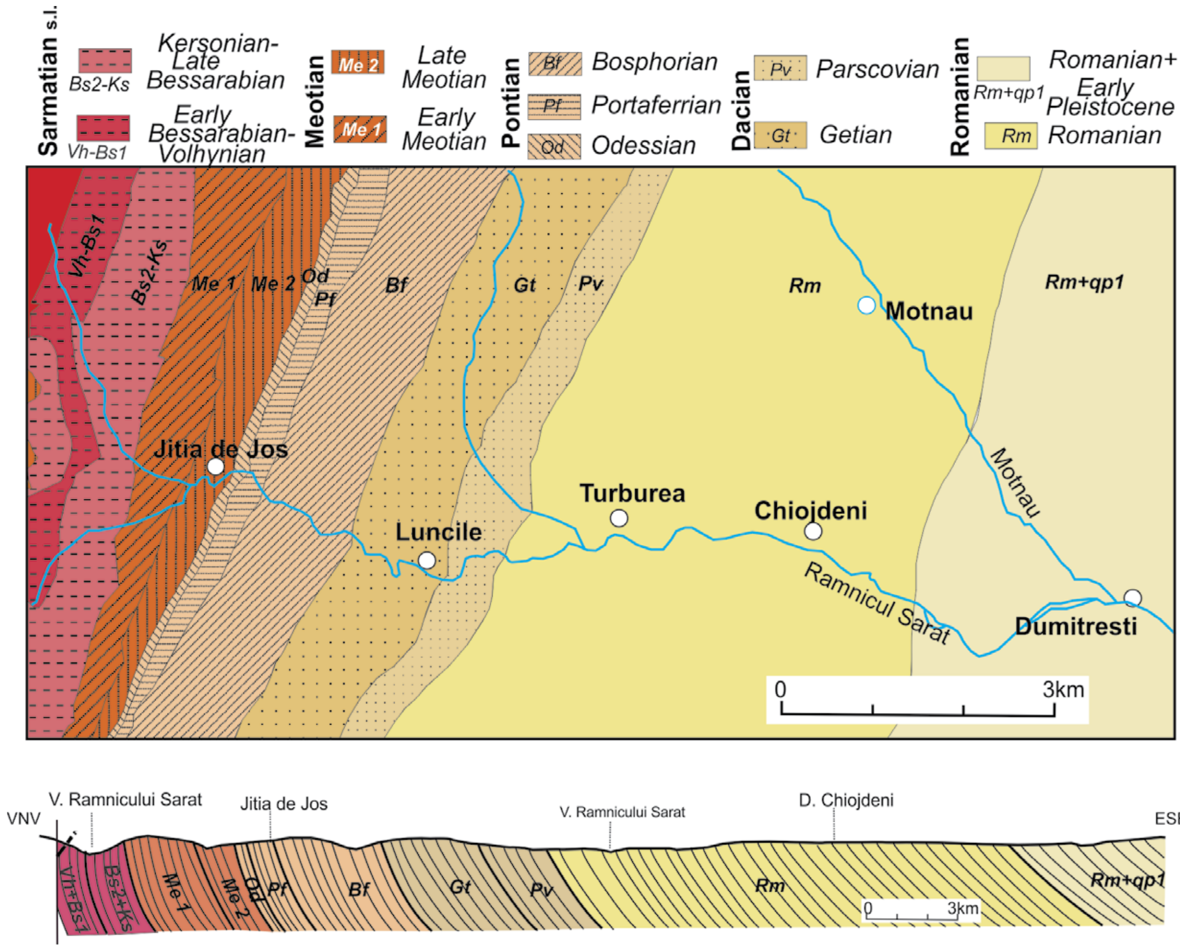
The investigated Upper Neogene deposits are part of the major unit of the Carpathian Foredeep, more precisely, of the Dacian Basin. The Dacian Basin developed during the Late Sarmatian *s.l.* to Early Dacian stratigraphic interval.

In the area between the *Jitia de Jos* and Dumitrești localities, the Dacian Basin deposits appear as a monocline structure (Fig. 3), the stratigraphic units becoming younger to the southeast. The angle of dip is close to 90° in the Sarmatian deposits and becomes progressively shallower in younger deposits (Fig. 3).

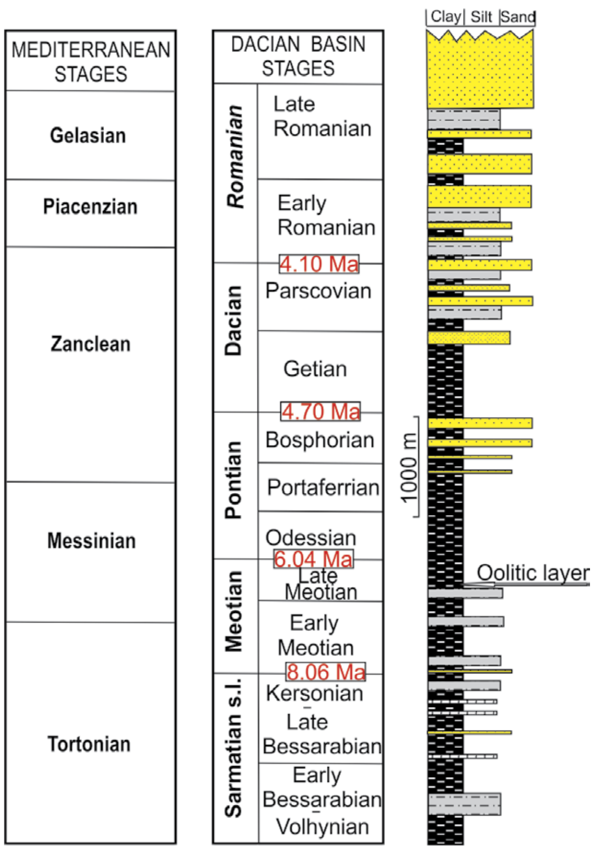
On the lithostratigraphic column attached to the 1:50,000 geological map (Andreescu and Țicleanu, 1976) (Fig. 4), a grain-size lithology transition from sandy-clayey Sarmatian *s.l.* deposits to sandy-gravely Romanian and Quaternary deposits is evident. In this large-scale succession, a dominantly clayey interval occurs, ranging from the uppermost Meotian and continuing into the Lower and Middle Pontian. The oolitic limestone layer representing the subject of this paper is intercalated in the Upper Meotian, the basal part of the clayey interval.

These investigations focused on the Meotian and Pontian deposits. On the Andreescu and Țicleanu (1976) map, deposits of two Meotian and three Pontian substages (Odessian, Portaferrian and Bosphorian) have been mapped. The sedimentary successions of these deposits are hundreds of meters thick (Meotian – 1200 m and Pontian – 1440 m).

The detrital material that accumulated in the Dacian Basin was supplied from four source areas, but mostly from the Eastern and Southern Carpathian sources. The *Jitia de Jos* investigation area is part of the eastern Dacian Basin de-



▲ **Fig. 2.** Geological map of the Neogene deposits in the Dumitresti-*Jitia de Jos* area. Simplified after the Geological map of Romania 1:50,000 scale, sheet 113-Dumitresti (Andreescu and Ticleanu, eds.,1976).



◄ **Fig. 3.** Lithostratigraphic column of the Upper Neogene deposits in the Dumitresti - *Jitia de Jos* area. Based on data from Andreescu and Ticleanu (1976). Time scale data from Stoica *et al.* (2013; after Vasiliev *et al.*, 2004 and Krijgsman *et al.*, 2010).

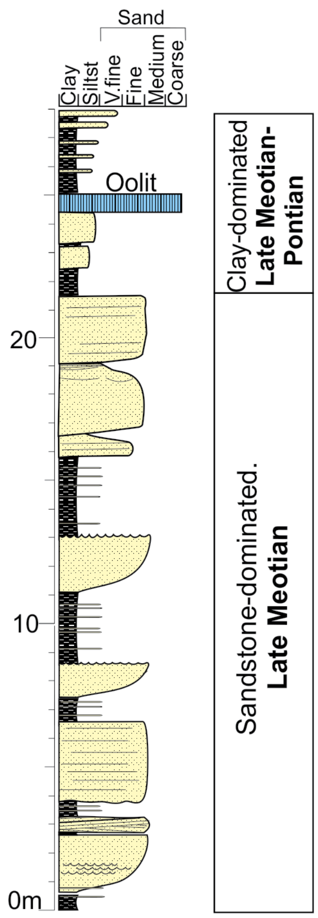


Fig. 4. Sedimentary succession in the *Jitia de Jos* study area.

pocenter that developed under the control of the powerful Eastern Carpathian source area (Jipa and Olariu, 2009).

The presence of the oolitic limestones in the Dacian Basin deposits was first reported by Hanganu (1966) from the Teleajen River area (Prahova County). The second oolitic limestone occurrence in the Dacian Basin, from *Jitia de Jos* area (Vrancea County), has recently been discovered (Stoica *et al.*, 2013).

4. PRESENTATION OF DATA

4.1. Field investigations

4.1.1. Sedimentary successions

Two sedimentary entities can be distinguished in the *Jitia de Jos* study area, with distinct relief morphologies and lithofacies characteristics. In the western part of the area the sedimentary succession consists of thick sandstones alternating with clayey deposits. In the eastern part of the study area a sudden morphology and lithology change takes place. The sedimentary succession becomes dominated by clay and silt and the relief drops abruptly.

Sandstone-dominated sedimentary succession. Five sandstone units occur in the western part of the investigation area, representing the lower and middle *Jitia de Jos* sedimentary sequence (Fig. 4). The thickness of the sandstone units varies between 35 cm (unit III in Fig. 5) and 130 cm (unit V in Fig. 5). The grain-size of the sandstone units is dominantly

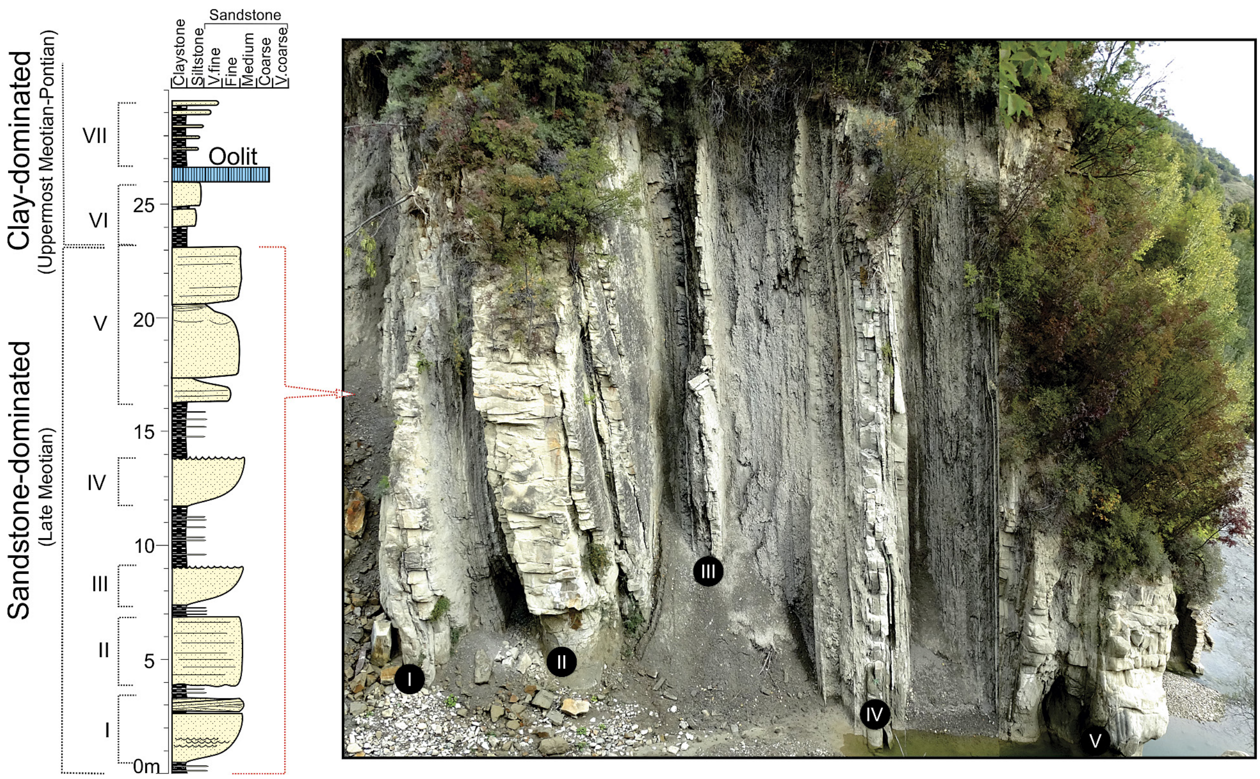


Fig. 5. Upper Meotian sandstone-dominated sedimentary succession cropping out in the Râmnicul Sărat River gorge, downstream from the *Jitia de Jos* locality.

sandy, with variations between fine-grained sand and medium-grained sand. Siltic sediments are also present, representing a smaller percent of the sandstone units.

Three of the five sandstone units (I, III and IV in Fig. 5) are inverse graded (Figs. 6a and 7). These units are silty-clayey at the base and gradually pass upward into fine-grained sandstone sediments (Fig. 6a). The lower boundary of the coarsening-upward units is transitional, while the upper boundary is sharp and non-transitional. In the middle and sometime the upper part of these units thin silty intercalations occur, separating distinct sandy layers. The sandy layers become thicker upward, marking an additional thickening-upward characteristic of the inverse-graded sandstone units, as well as a polygenetic attribute.

Frequently, the component layers of the coarsening-upward units show wave-formed ripples, in cross section appearing as symmetrical undulations with sharp crests and large depressions (A in Fig. 6a; Fig. 7b). The crests of the ripples are sinuous, and the dominant direction of the crests is slightly variable for different rippled beds (Fig. 7b).

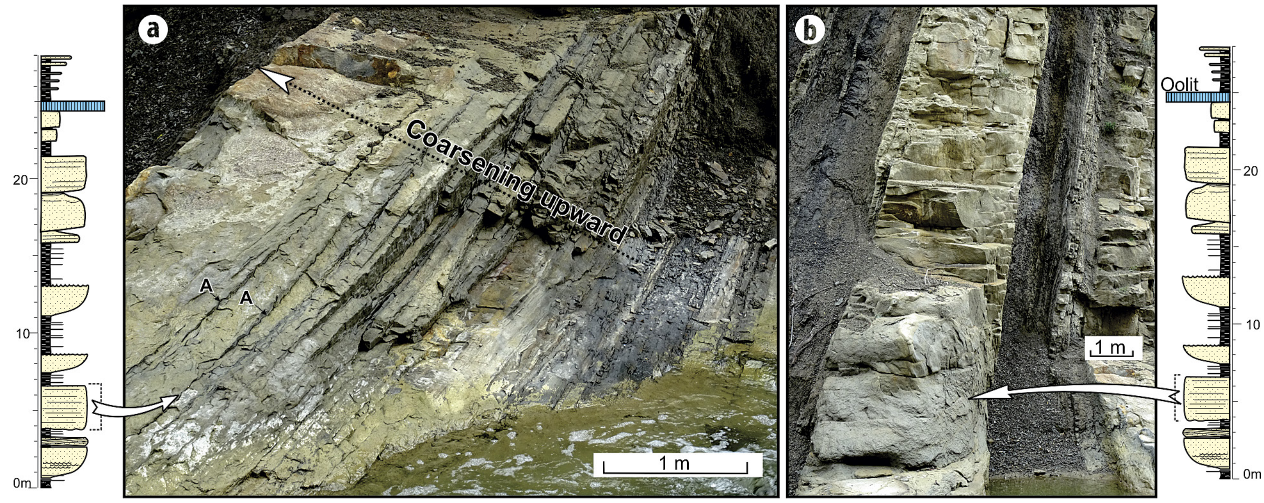


Fig. 6. The Upper Meotian sandstone units II and III, cropping out on the right side bank of the Râmnicul Sărat River. (**a**): Silt-to-sand coarsening and thickening upward sedimentary unit III. Symmetrical ripples (A) occur at several levels. (**b**): Homogeneous, non-graded unit II. Note the sharp base and top bed boundaries.

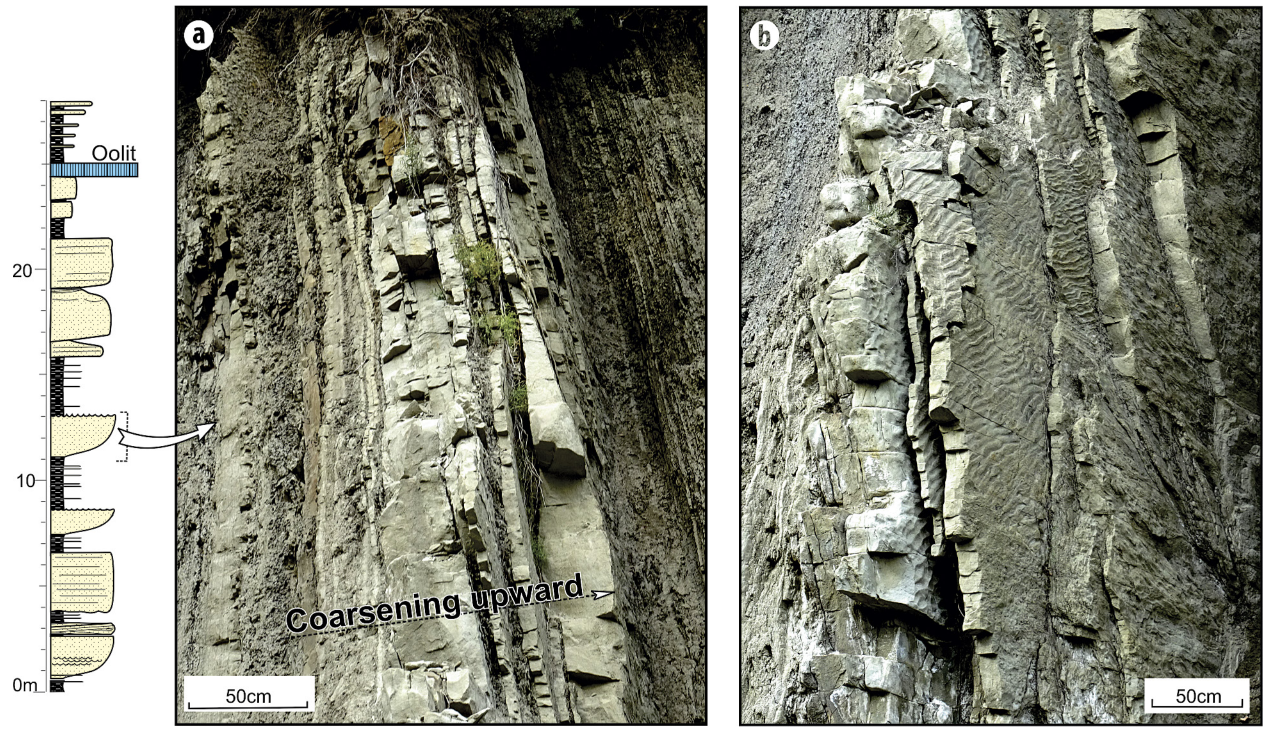


Fig. 7. Coarsening upward sedimentary unit IV (Upper Meotian), with multiple wave-rippled beds. Râmnicul Sărat River, downstream from *Jitia de Jos*. (**a**): Frontal view. (**b**): Oblique view showing the wave-rippled layers. Note the lens-like shape of the top layer.

Usually, the layers within the coarsening-upward units show constant thickness, and are distinct on several meters distances. The coarsening-upward unit IV (Fig. 5) shows lens-shaped layers on top. The most prominent of these layers is up to 50 cm thick, with lateral thinning (Fig. 7b).

Grading is sometime absent. The sandstone unit II (Fig. 5) is homogenous, with no vertical grading trend, and with net, non transitional boundaries on both bedding surfaces (Fig. 6b).

Another type of grading is displayed by unit V (Fig. 5). Three subunits are distinguished in this unit (Fig. 8). A normal, fining-upward grading characterizes the basal subunit, made up of fine-grained sandstone passing upward to siltstone (Fig. 8a). The middle subunit consists of fine-grained sandstone, with unclear wavy structure, topped by a parallel laminated silty-sandy layer with variable thickness (Fig. 8b). The upper subunit is thick, homogeneous sandstone (Fig. 8c). Reworked fresh water mollusk shells (*Unionidae*) occur in the upper part of the sandstone unit V (only in the right bank outcrop) in a clay-pebble breccia (Fig. 8d).

Clay and silt-dominated sedimentary succession. The sandstone unit V, *e.g.* the youngest member of the sandstone-dominated succession, is overlain by a much finer-grained sedimentary series (Fig. 4), dominated by clay and silt. An oolitic limestone intercalation separates two sequences within the clayey-silty succession (Figs. 4 and 9).

The sedimentary sequence underlying the oolitic limestone begins with gray, stratified clay that covers directly the top of unit V sandstone (Fig. 9). Siltic deposits, showing several unclear sequences, overlie the clay deposits. Cross-laminated units are apparent. The coarsest-grained silt material, up to very fine sand-grained, makes the top of the sequence. This suggests a general coarsening-upward of the sequence underlying the oolitic intercalation (Fig. 9).

A clear coarsening-upward succession overlies the oolitic intercalation (Figs. 4 and 10). The lower part of the succession consists of silty-clayey sediments (Fig. 10a, b). Upward in the succession, sandstone intercalations occur, gradually becoming more frequent, coarser-grained and thicker-bedded (Fig. 10b). Starting from the middle part of the succession the sandstone layers show current lamination. Two unclear occurrences of wave ripples have been detected.

4.1.2. The oolitic limestone

A single oolitic limestone bed crops out in the Râmnicul Sărat River valley, westward of the *Jitia de Jos* locality (Figs. 1d and 11). The oolit appears on both river banks. In the left-bank outcrop, the oolitic layer emerges as a constant thickness (40 cm) body, with clear-cut boundaries, embedded in clayey-silty deposits (Fig. 11a).

The oolit internal structure is usually indistinguishable, except in vague laminae segments (Fig. 12b). Only after being well washed, several laminae became visible as thin, irregular dark-colored bands (Fig. 12c). In the natural vertical sections no distribution trend is visible (Fig. 14b), the internal homogeneity being a prominent feature.

Symetrical undulations, wave ripple-type, appear on the upper surface of the oolitic layer (Fig. 13a). The wavelength of

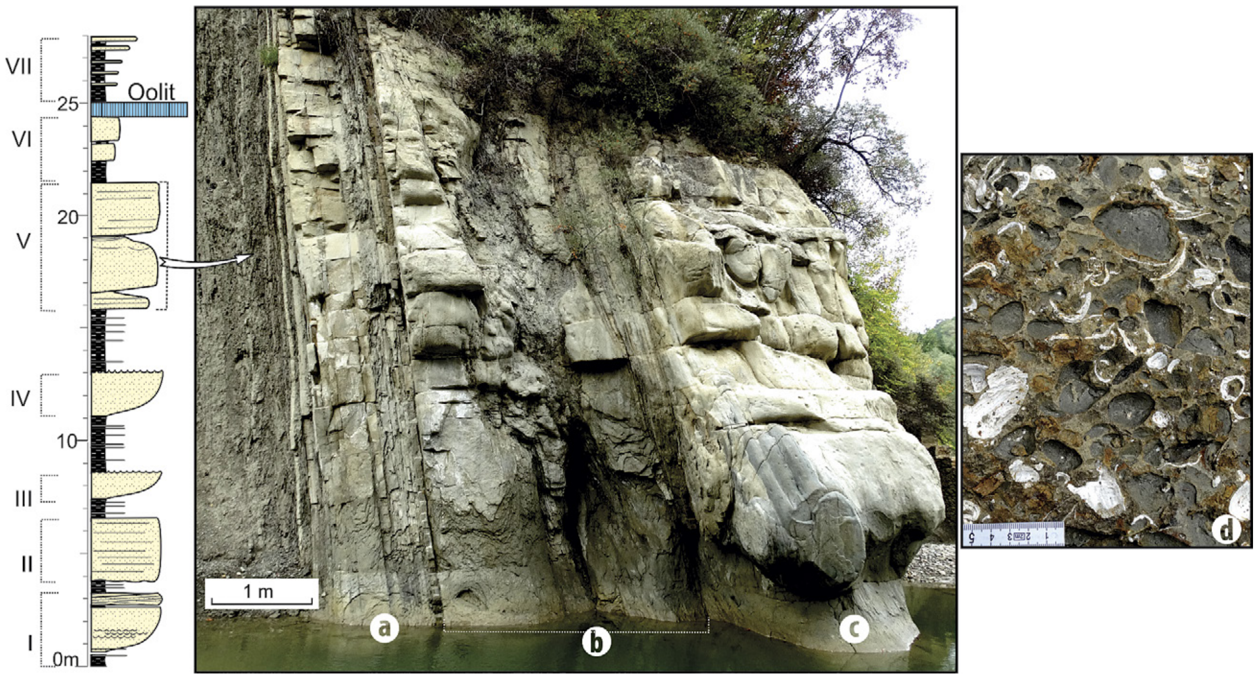


Fig. 8. Unit V, on top of the sandstone-dominated Upper Meotian sedimentary succession. (**a**), (**b**) and (**c**): Lithologic subunits. (**d**): Resedimented freshswater Unio shells associated with clay pebbles, occurring in subunit C.

the oolitic wave ripples is about 30 cm, and the crest height reaches 4-5 cm (Fig. 13b).

The ooids. In the outcrop, the ooids are naked eye-visible, especially on the upper surface of the layer. In outcrop pictures the ooids appear as spherical or slightly elongated bodies, a little larger than 0.5 mm. Ooid grain-size is remarkably uniform (Fig. 14).

The ooid bodies are frequently in direct contact, the calcitic cement material representing a small percent of the rock. The concentric ooid structure is apparent in close-up photos.

Fossil remains and trace fossils. Mollusks shells, mostly bivalves, but also gastropods (Fig. 15), are irregularly distributed within the *Jitia de Jos* oolitic limestone. Shell size varies from 2 to 20 mm, with a few up to 6 cm.

Trace fossils cover the entire visible lower and upper surfaces of the oolitic layer (Figs. 16 and 17).

Stratigraphic setting of the oolitic limestone. The succession investigated in the *Jitia de Jos* study area includes two lithostratigraphic entities whose stratigraphic positions were ascertained by Andreescu and Ţicleanu (1976).

The sandstone-dominated lower entity was assigned to the Late Meotian by Andreescu and Ţicleanu (1976), based on the fossil forms *Congeria panticapea tournoueri, Unio subrecurvus, Dreissenomya rumana, Congeria navicula, Congeria novorossica*. The upper, clayey-silty succession, with *Pontalmyra novorossica, Pontalmyra rostrata, Paradacna* ex gr. *Abichi and Eupatorina* ex gr. *Littoralis* fossil remains was assigned to the Early Pontian.

Detailed biostratigraphic investigations (Motaş and Papaianopol, 1972, Olteanu *in* Jipa and Olteanu, 2007, Stoica *et al*., 2012) pointed out that the Meotian-Pontian boundary does not correspond to the contact between the sandy facies and the clayey-silty facies.

According to Stoica *et al.* (2012, 2013), the Meotian-Pontian boundary is displayed by a biostratigraphic marker with a large extension in the Dacian and Euxinian basins. The *Congeria (Andrusoviconca) amygadaloides novorossica* shell-bed level is the Meotian-Pontian boundary marker. In the clayey sequence immediately below the *Congeria novorossica* level, benthonic and planktonic foraminifers as well as a NN11b nannofossil community have been identified (Stoica *et al*., 2012, 2013).

The *Jitia de Jos* oolitic layer is intercalated in the lowermost part of the clayey-silty facies, only about 3 m above the top of the sandstone-dominated succession (Figs. 4 and 9). Consequently, as a facies developed at the base of the clayey-silty succession, the oolit age is Late Meotian.

4.2. Thin sections

Examined in thin sections, the *Jitia de Jos* oolitic limestone consists of ooids with carbonatic orthochem (Fig. 18). The ooid shape is spherical to sub-spherical, with a diameter up to 0.627 mm. The ooids shape is influenced by the elongation of the nucleus (Fig. 18a, b).

The orthochem represents a small part of the oolitic limestone, between 15% and 30%. The ooids are in direct contact with each other. According to the local variation of the com-

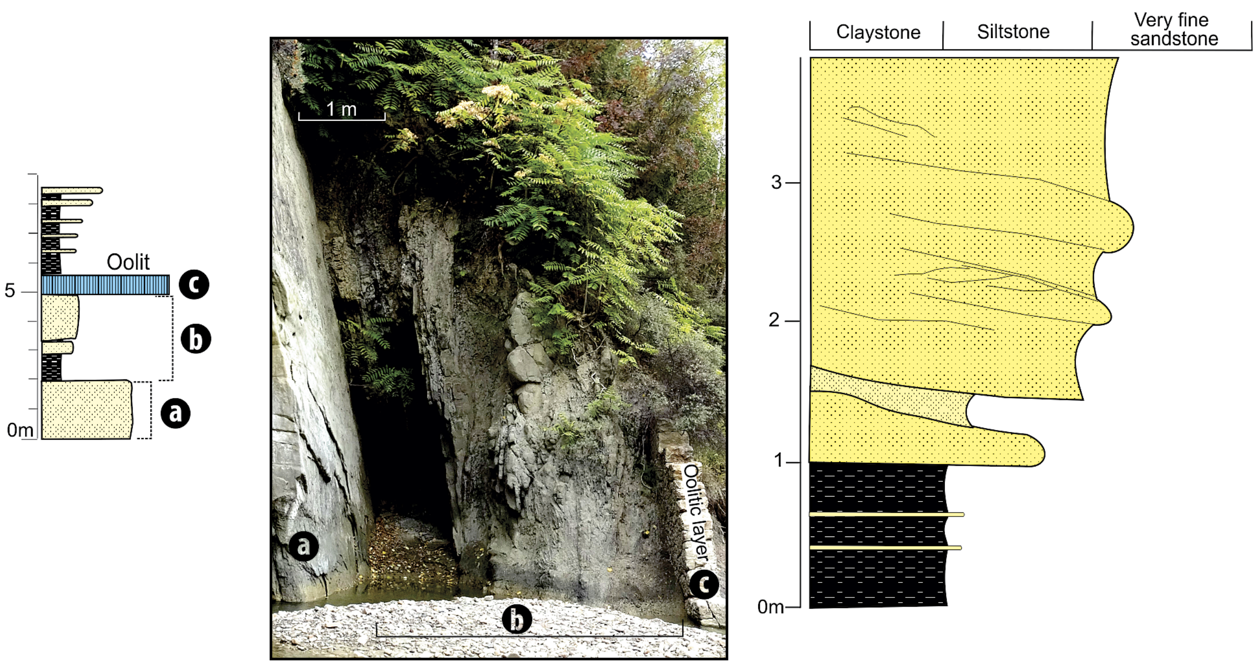


Fig. 9. Clayey-silty sedimentary sequence underlying the *Jitia de Jos* oolitic limestone layer. (**a**): Sandstone at the top of the Upper Meotian unit V. (**b**): Clayey-silty unit VI, at the base of the Pontian transgressive sedimentary succession, stratigraphic entity including the very fine grained uppermost part of the Upper Meotian. (**c**): The *Jitia de Jos* oolitic layer.

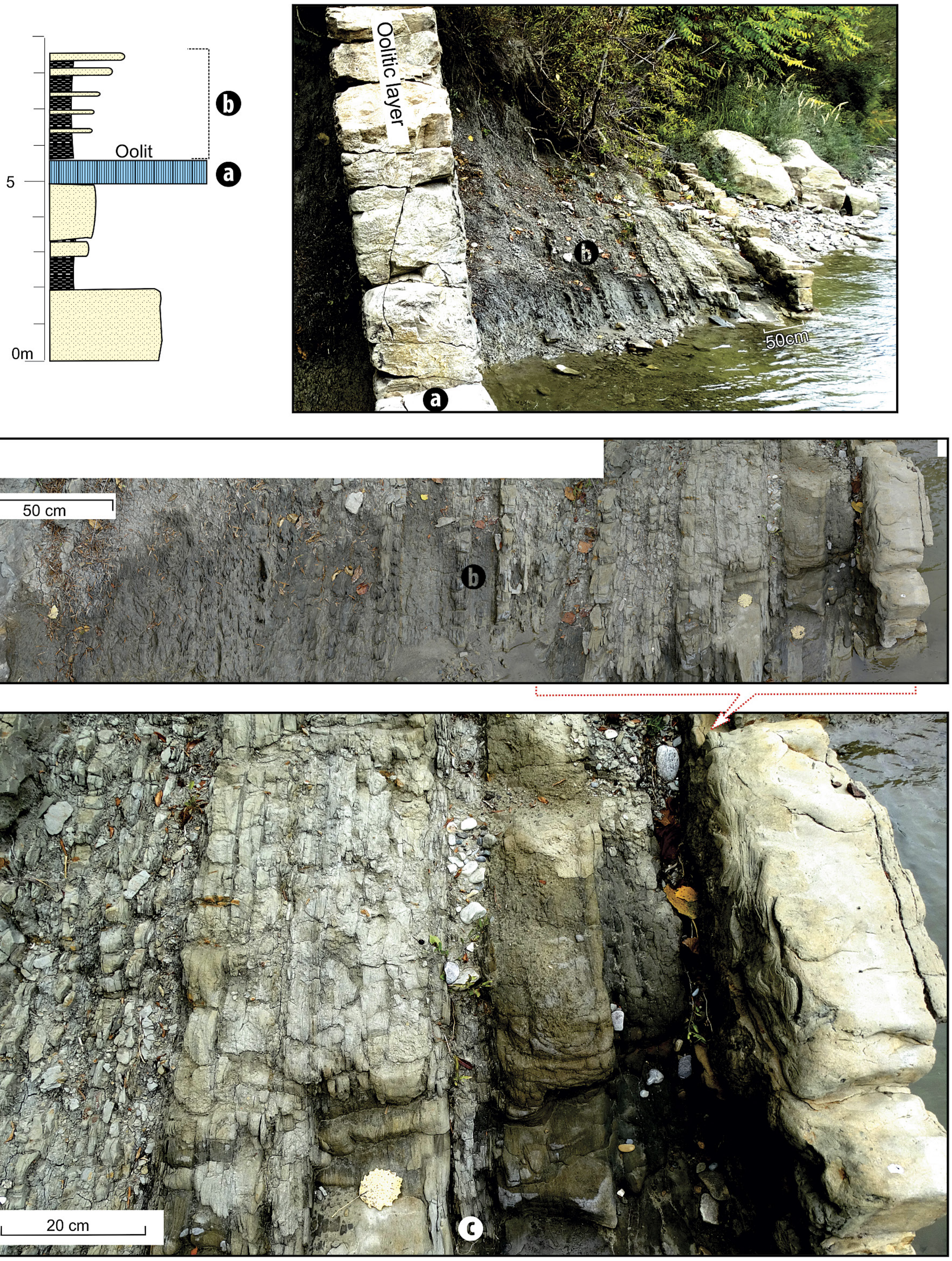


Fig. 10. The coarsening and thickening-upward sedimentary sequence VII (**b**) that overlies the *Jitia de Jos* oolitic limestone layer (**a**). Details of the lithologic sequence in the middle and lower images.

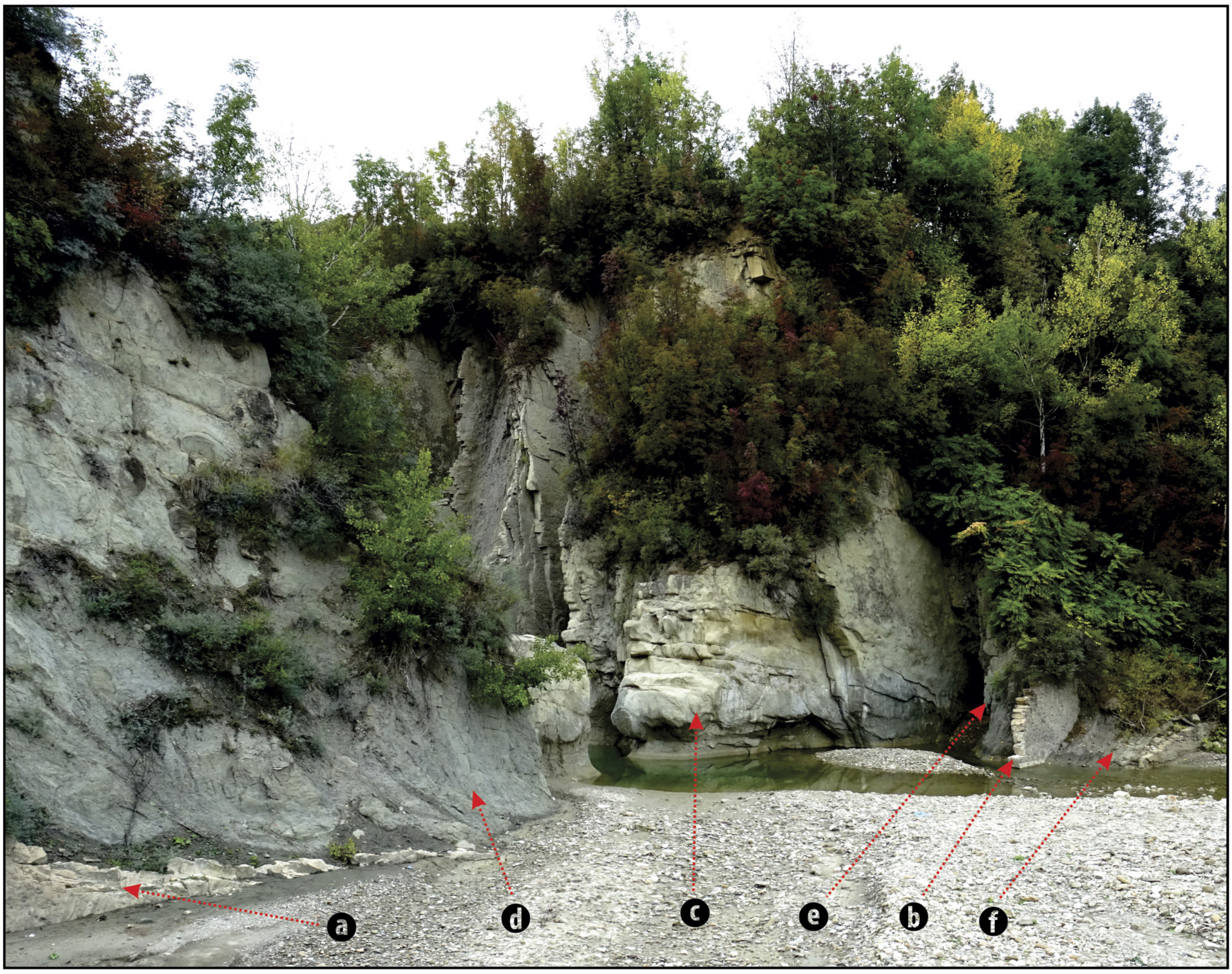


Fig. 11. The *Jitia de Jos* oolitic layer setting on the Râmnicul Sărat River valley. (**a**) and (**b**): oolitic limestone outcrops. (**c**): top subunit of the sandstone-dominated succession. (**d**) and (**e**): clayey-silty unit VI, at the base of the transgressive sedimentary succession. (**f**): Unit VI, the clayey-sandy coarsening upward overlying the oolitic layer intercalation.

paction strength, the contact between the ooids is variable, from tangential to planar and convex-concave, and up to microstylolitic. In some places, the ooids are pressed together by compaction, displaying penetration (microstylolitic) contacts (Fig. 18d). Due to compaction stress, some ooids are slightly deformed (Fig. 18e).

The concentric lamination consists of a number of laminae coating a nucleus. Due to the micritization of the cortex, part of the laminae are obliterated. The concentric lamination is emphasized by opaque, autigenic mineral precipitation (Fig. 19). The cortex with radial structure, crossing the concentric lamination, is uncommon (Fig. 20).

The ooid nuclei are frequently made of quartz grains (Fig. 21a). The nucleus is also represented by microcline (Fig. 21b), plagioclase feldspar (Fig. 21c), quartzite (Fig. 21d) or mica shist (Fig. 21e) granoclasts. Carbonate clasts (Fig. 22a) or bioclasts (Fig. 22b) may also appear as ooid nuclei.

The cement of the ooids is made of sparitic subhedral and anhedral calcite, with druzy structure (Fig. 23). Different types of granoclasts (quartz, glauconite, quartzite and mica shist) appear within the orthochem.

The opaque, authigene minerals are present in the cortex and the orthochem, occurring also as nuclei (Figs. 19 and 23).

5. INTERPRETATION OF DATA

5.1. Sedimentation paleoenvironment

Paleo-biologic environment. The analysis of the faunistic communities offered significant information on the Late Meotian and Early Pontian sedimentation environment. The water salinity existing during this time interval is about 6-10‰, lowering to the limit of the freshwater salinity (Olteanu, 2006b and references therein). The same author considers the Meotian *Congeria* fauna represent a littoral biotope.

The occurrences of the microgastropods *Hydrobia* sp. and *Teodoxus* sp., the unionid bivalve *Psilunio (Psilunio)* ex gr. *su-*

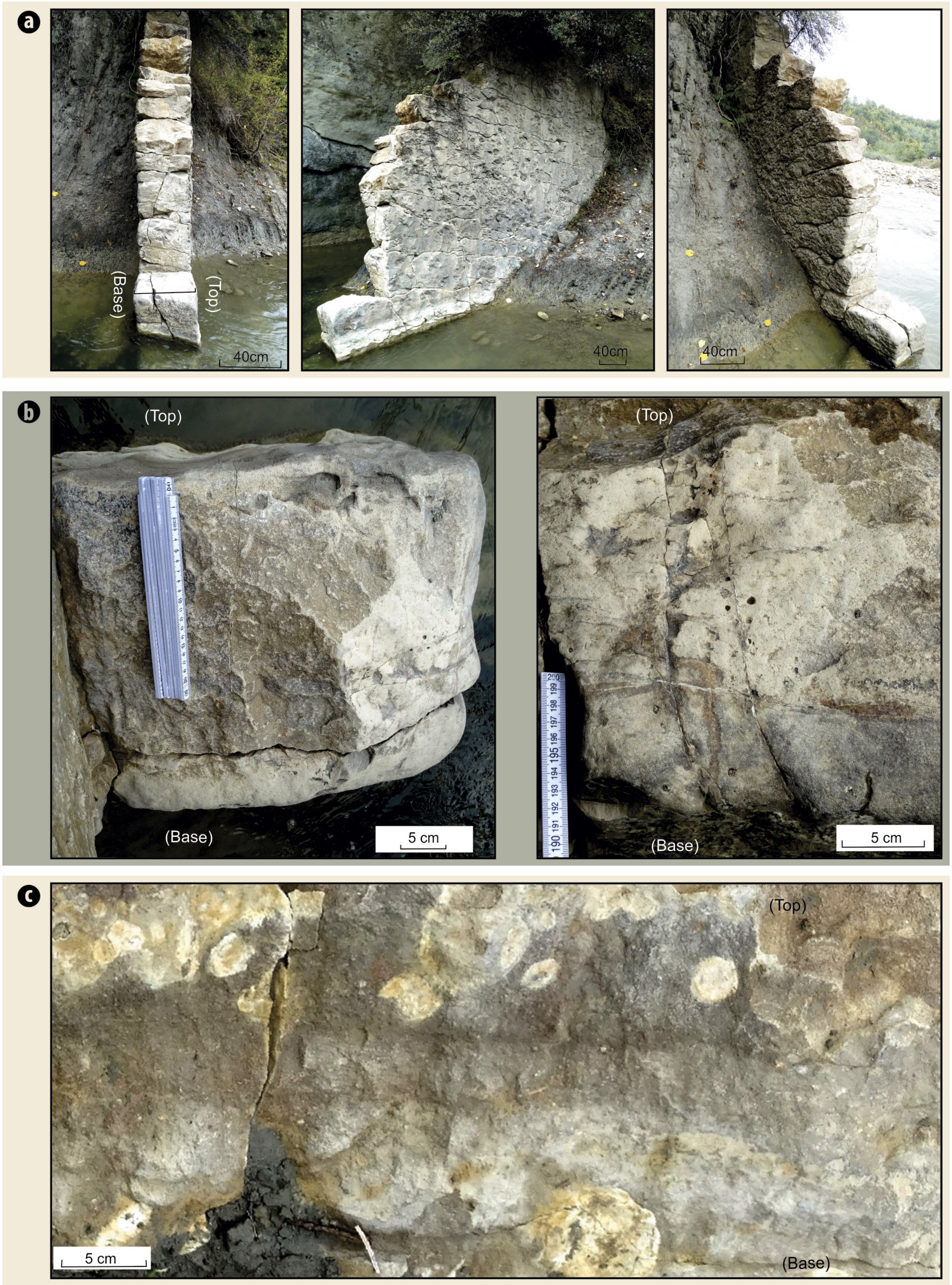


Fig. 12. The *Jitia de Jos* oolitic limestone layer. (**a**): General bed aspect (front, top and bottom faces). (**b**) and (**c**): Closeup images showing vertical sections of the oolitic layer. (**c**): Vague internal lamination, occurring as irregular dark-colored bands.

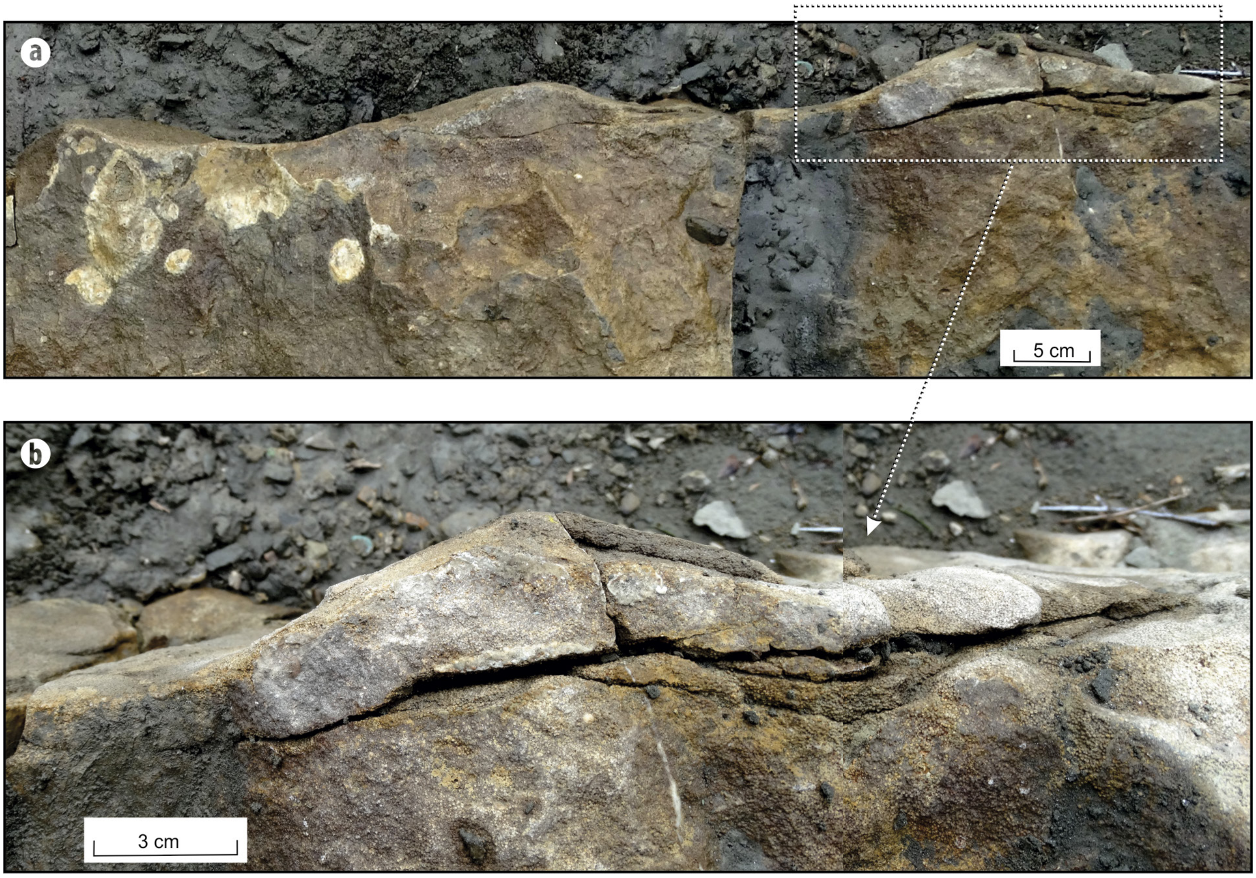


Fig. 13. Symmetrical, wave generated ripples on the upper surface of the oolitic layer. (**a**): Wave ripples transversal section morphology. (**b**): Detail of the ripple crests, showing chevron lamination and internal structure.

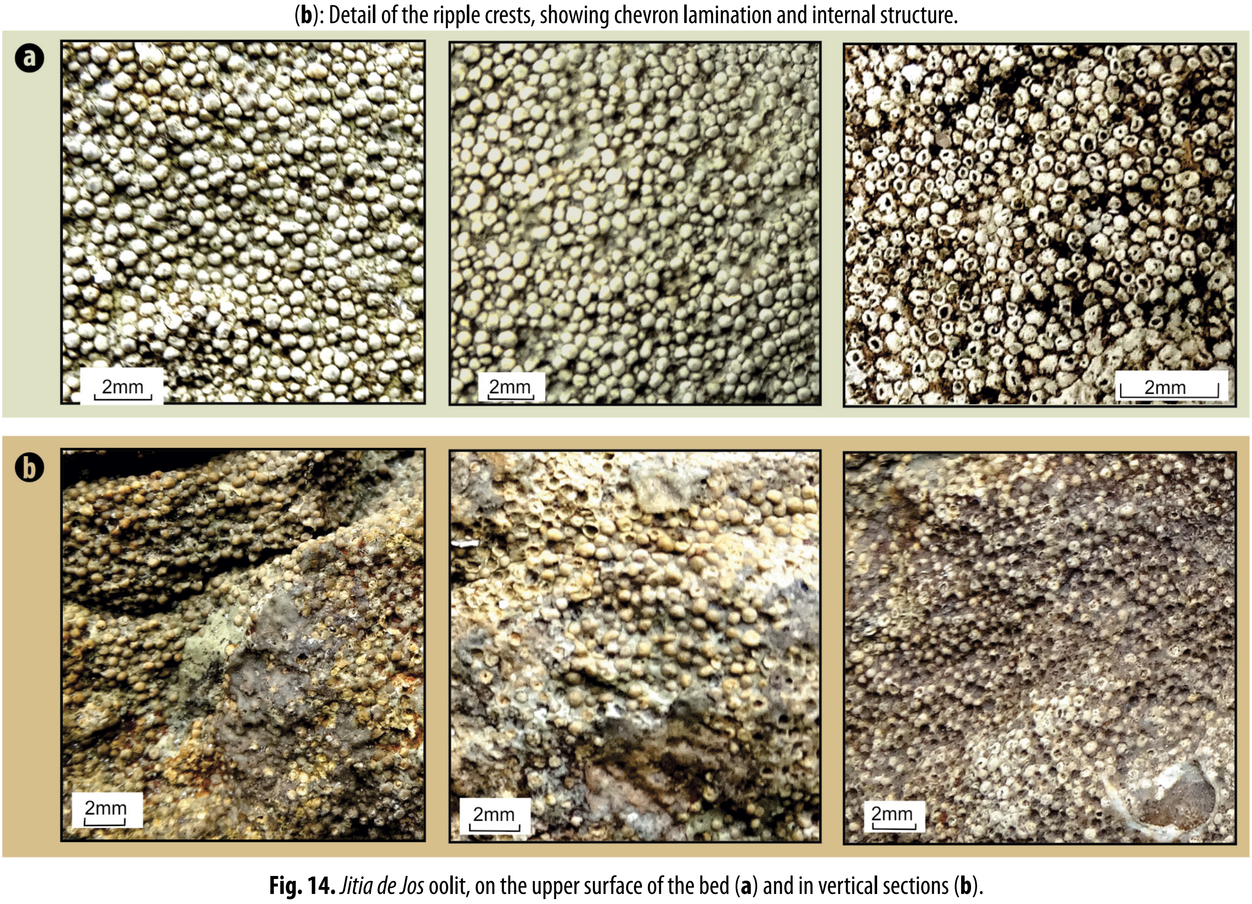


Fig. 14. *Jitia de Jos* oolit, on the upper surface of the bed (**a**) and in vertical sections (**b**).

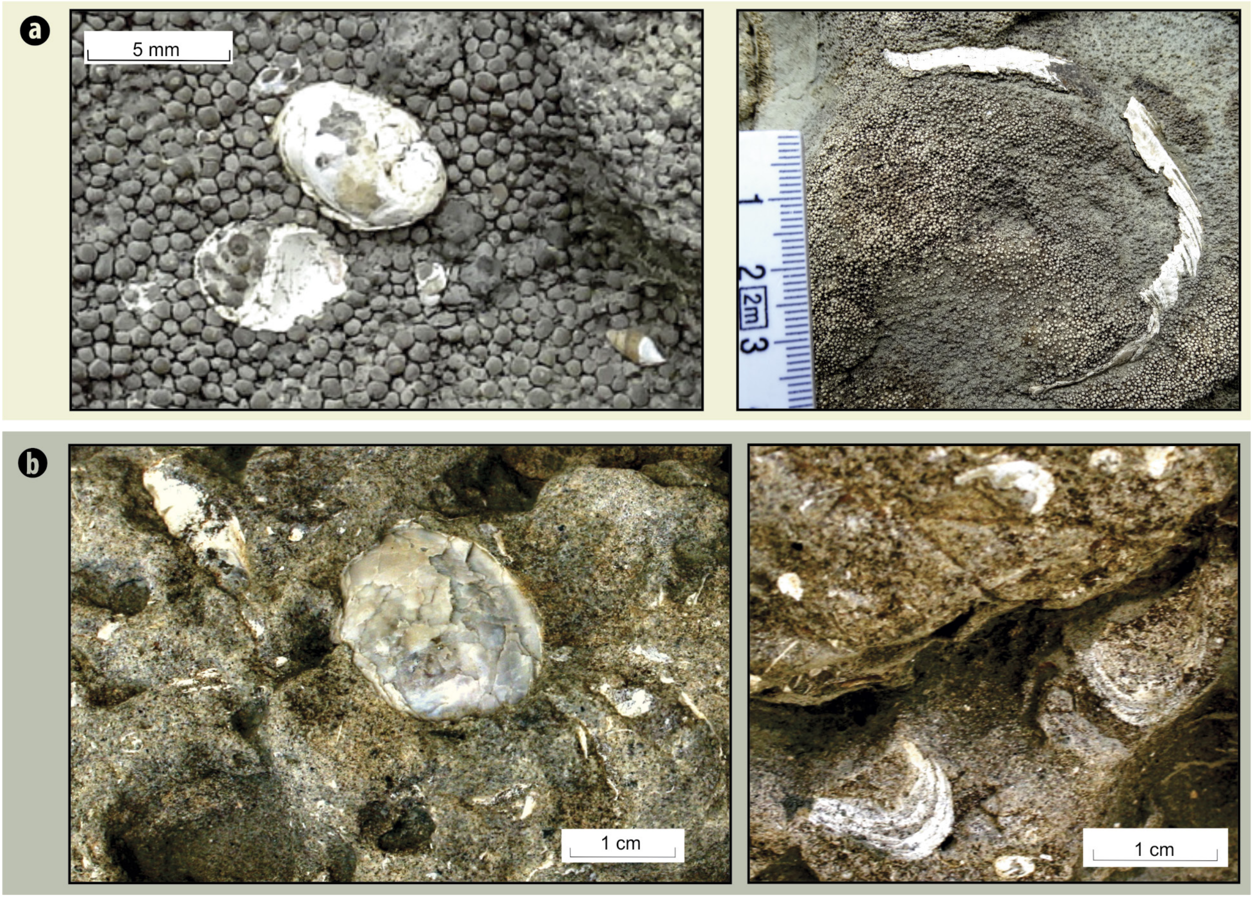


Fig. 15. Mollusk shells on the top (**a**) and on the bottom (**b**) of the *Jitia de Jos* oolitic limestone.

brecurvus together with the ostracod community dominated by *(Psilunio*) ex gr. *Subrecurvus* are regarded by Stoica *et al.* (2013) as indications for a typical littoral environment, with brackish and freshwater characteristics.

In the uppermost Meotian clayey deposits cropping out in the Bizdidel River area (Pucioasa town) in the central Dacian Basin, Olteanu (in Jipa and Olteanu, 2007) reported an exclusively fluvial environment, with freshwater *Ilyocypris, Darwinula* and large size *Candonae* fauna.

Stoica *et al.* (2012) considered the Pontian sedimentation developed in a deeper water environment compared to the Late Meotian environment, but restricted to the photic zone. This statement was based on the presence of Early Pontian eye tubercle ostracodes.

Sedimentogenetic environment. The existence of relatively thick sandstone intercalations in the Upper Meotian succession from *Jitia de Jos* area (Fig. 5) suggests a relatively high-energy facies with important fluxes of clastic material. In contrast, the Lower Pontian deposits, dominated by clayey-silty sediments, belong to a low-energy environment that received scarce, small volumes of clastic material influxes.

Both the Upper Meotian and the Lower Pontian sedimentary successions display coarsening-upward sequences with current lamination and wave ripples (Upper Meotian sandstone units I, III and IV, in Fig. 5; Lower Pontian sandy units VI and VII, in Figs. 9 and 10). This feature suggests the existence of prograding subaquatic bodies (sedimentary waves, small deltaic units) evolving in shallow water environments.

In contrast to the Lower Pontian deposits from the *Jitia de Jos* area, the sandstone-dominated Upper Meotian succession shows more types of vertical grading and even no-grading sequences. The unit II (Figs. 5 and 6b), homogeneous and without grading, is block-type. The sandy unit V (Fig. 5) is made of three subunits: the fining upward subunits A and B and the homogeneous subunit C (Fig. 8). These facies are interpreted as channel-filling deposits, accumulated by distributary fluvial branches that supplied sediment to the prograding, coarsening-upward bodies.

Based on the features that indicate fluvial influences (channel filling deposits and freshwater fauna) associated with prograding and wave-rippled sedimentary units, we consider that the sediment accumulation of the *Jitia de Jos* sandstone-dominated Upper Meotian succession took place in the nearshore environment, possibly on the lower shoreface.

Fig. 16. Trace fossils on the upper bed surface of the *Jitia de Jos* oolitic limestone. (**a**): General view of the top bed surface. (**b**): Detailed view of the trace fossils, probably generated during mollusk activity.

Fig. 17. Unidentified trace fossils on the lower bed surface of the *Jitia de Jos* oolitic limestone. (**a**): General aspect of the lower bed surface, covered with trace fossils. (**b**): Closeup photograph of the trace fossils.

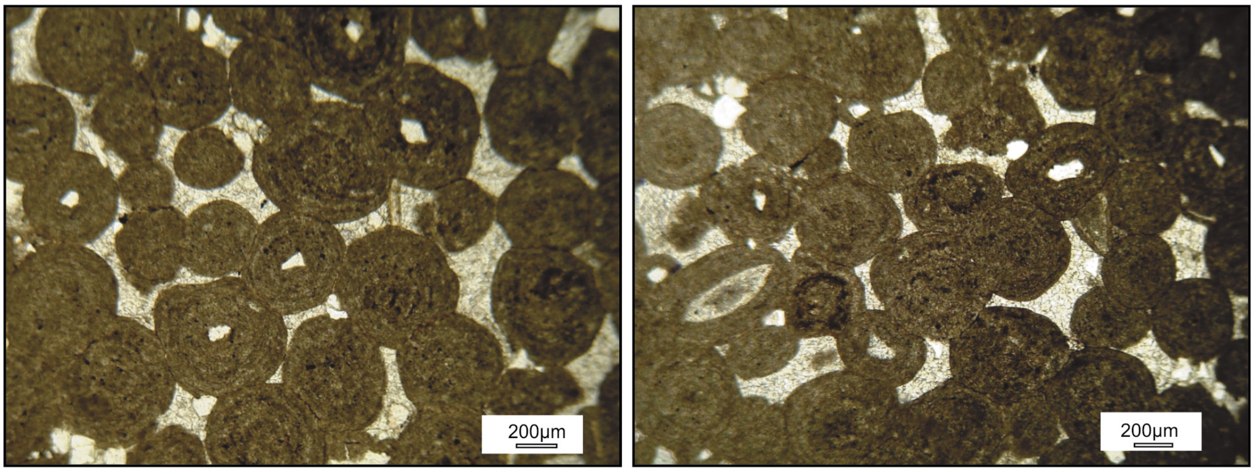


Fig. 18. Ooids, orthochem and their relationships. *Jitia de Jos* oolitic limestone. (**a**): Concentric circular ooid with isometric nucleus. (**b**): Elongated nucleus that influenced the ooid shape. (**c**): Sparry calcite cement. (**d**): Ooids pressed together by compaction. (**e**): Ooids deformed by compaction.

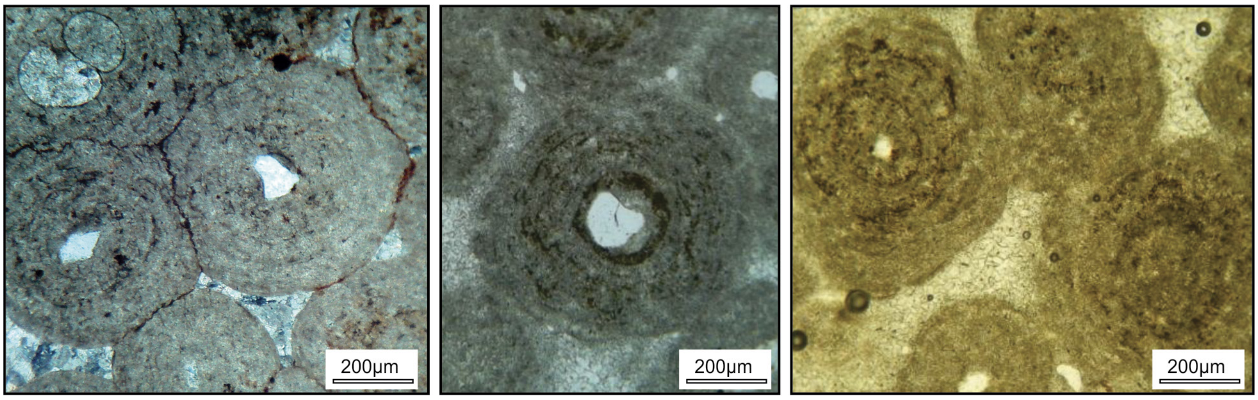


Fig. 19. Authigenic, opaque minerals emphasizing the ooid structure. *Jitia de Jos* oolitic limestone.

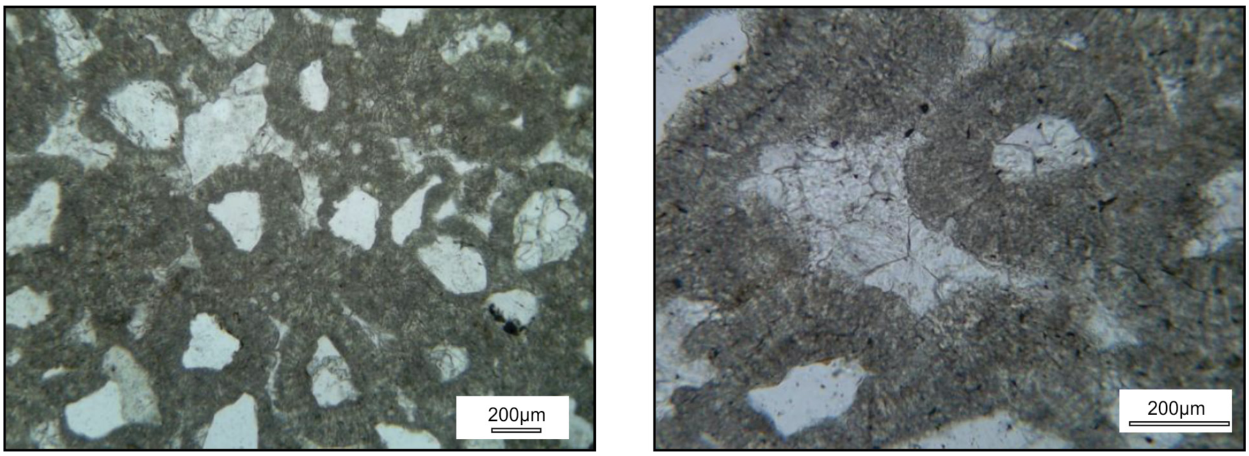


Fig. 20. Secondary, radial structure crossing the concentric laminatied cortex. *Jitia de Jos* oolitic limestone.

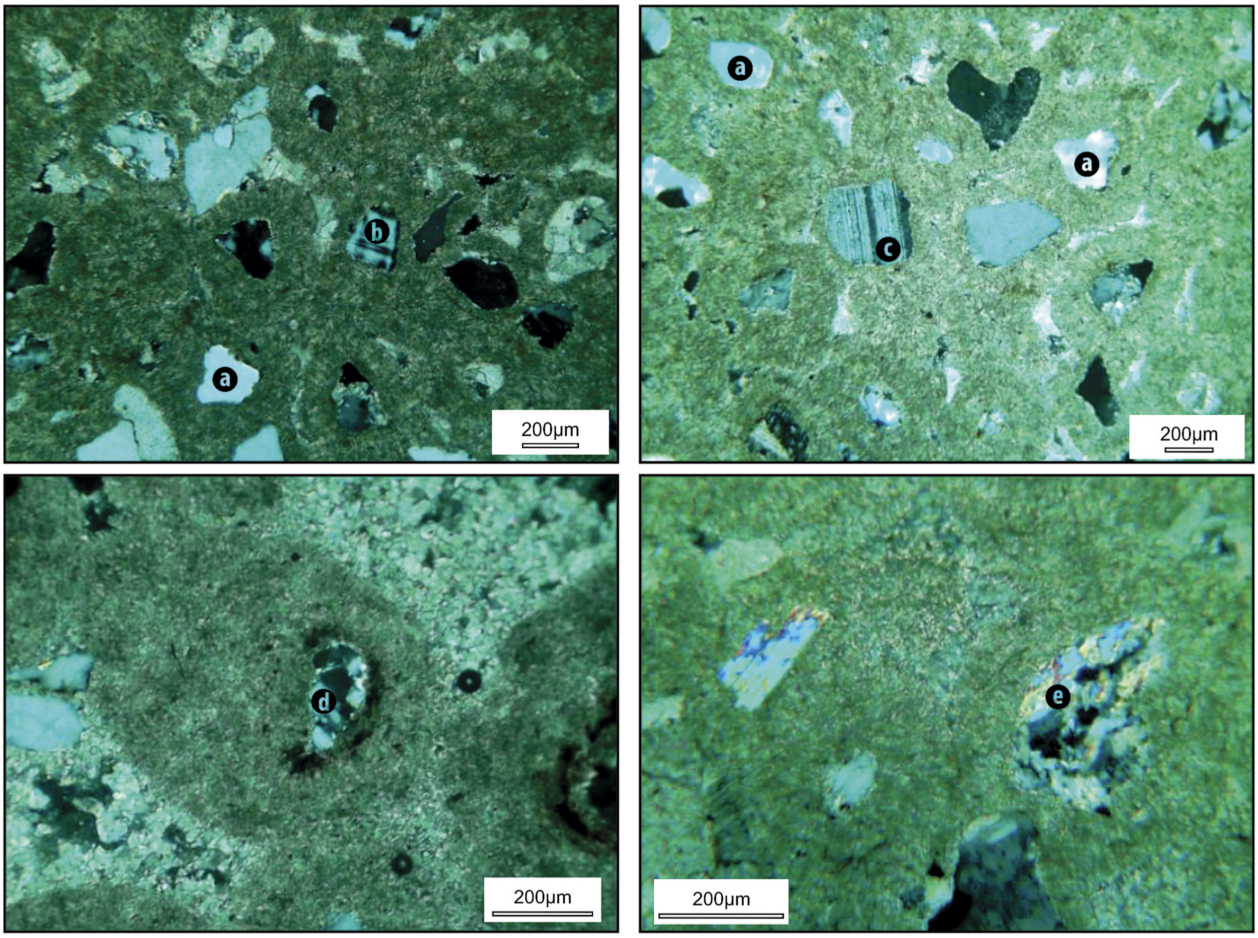


Fig. 21. Ooid nuclei represented by quartz (**a**), microcline felspars (**b**), plagioclase felspar (**c**), micro-cuartzite (**d**) and mica shist (**e**). *Jitia de Jos* oolitic limestone.

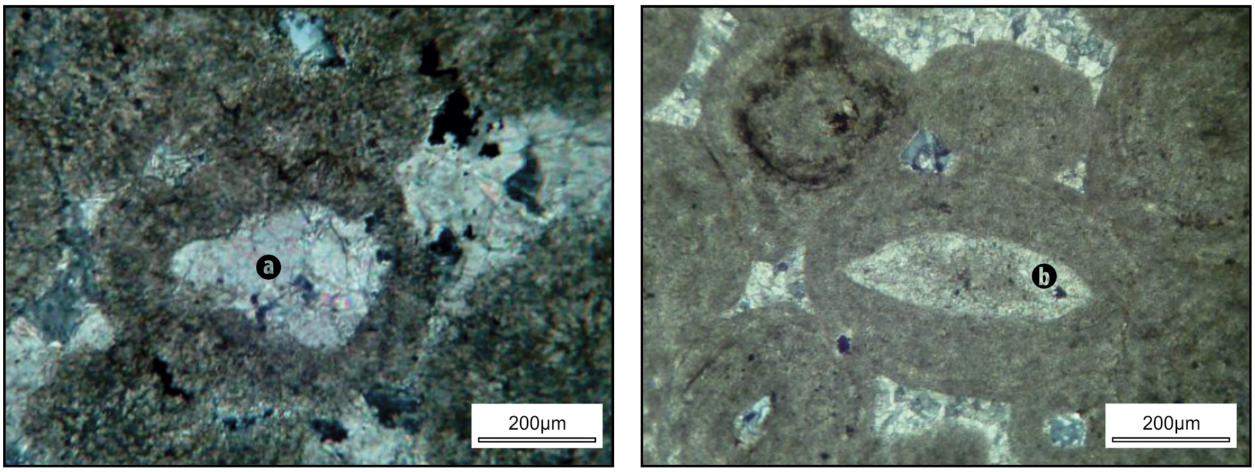


Fig. 22. Ooids with carbonate lithoclast nucleus (**a**) and radial structure cortex with bioclast nucleus (**b**).

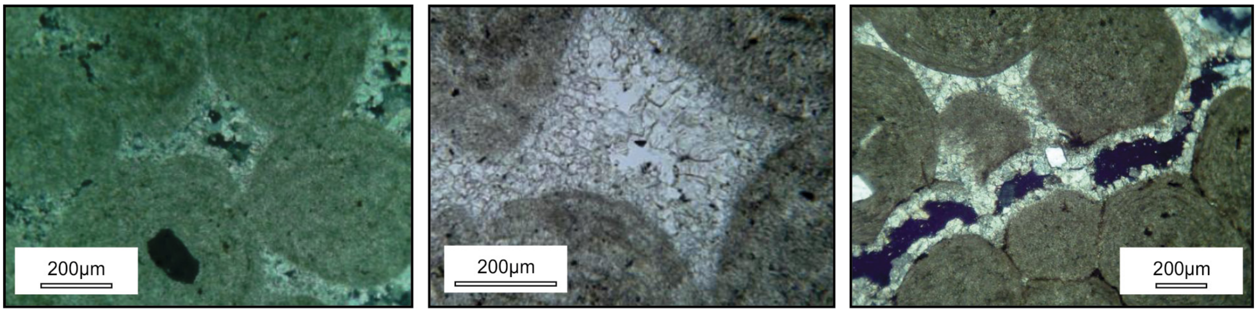


Fig. 23. Orthochem with sparitic subhedral and anhedral calcite, with druzy structure. The right-side image shows calcite precipitated on the walls of a fissure.

Prograding, coarsening upward sedimentary units appear in the Lower Pontian as well as in the Upper Meotian deposits. However, unlike the Upper Meotian deposits, the clayey-silty Pontian deposits are dominantly clayey-silty, display only rare wave ripples and show no features of fluvial influence. On this basis, compared to the Upper Meotian deposits, we believe the sediment accumulation of the *Jitia de Jos* clayey-silty Pontian succession also took place in the nearshore zone, but farther away from the shoreface and closer to the internal offshore zone.

5.2. *Jitia de Jos* oolitic limestone and the Lower Pontian transgression

The stratigraphic interval including the terminal Upper Meotian and the Lower Pontian represents the time when a transgression event took place in the Dacian Basin, and a new biologic cycle began (Olteanu, 1997, 2006). The transgressive character of the Lower Pontian was pointed out by many Dacian Basin researchers, and one of the earliest opinion belonged to Filipescu (1942).

Important paleobiologic and lithofacies changes have been associated with this marine transgression. At the level of the Meotian-Pontian time boundary, the very low salinity Meotian fauna was replaced by a faunistic assemblage indicating higher water salinity. According to Olteanu (1997, 2006a,b) the Early Pontian is a mass extinction time for the Meotian fauna, as well as the time to establish a completely new Pontian faunistic community, where the relict forms are absent.

The second major change brought by the transgression is of a sedimentary nature. The intense Upper Meotian sandy influx, as evidenced by the *Jitia de Jos* sandstone-dominated succession, was replaced with the dominantly clayey and silty Lower Pontian sedimentation.

Beside the brackish fauna introduced in the entire Lower Pontian interval by the transgression event, the very first phase of the transgression process was associated with occurrences of calcareous nannofossils (Mărunțeanu and Papaianopol, 1998 ; Stoica *et al.*, 2012) and benthonic (calcareous and agglutinated) and planktonic *Foraminifera* (Krijgsman *et al.*, 2010; Stoica *et al.*, 2012). This is normal marine salinity fauna that existed in the Dacian Basin, neither before, nor after the transgression. These faunistic appearances were of short-term duration, located in the clayey-sediment of terminal Upper Meotian age (Stoica *et al.*, 2012). The normal marine fauna were replaced promptly, even during the Early Pontian with brackish-water faunistic assemblages (indicated by *Candoninae* abundance; Stoica *et al.*, 2013).

The information presented in this section demonstrates that during this initial stage the transgression produced drastic hydrochemical changes that affected, at least, the water salinity of the sedimentation environment.

The *Jitia de Jos* oolitic layer is intercalated in the clayey deposits, at the base of the clayey-silty series (Fig. 4). Accordingly, the formation and accumulation of the ooids evolved in the special paleo-ecologic conditions, during the initial phase of the transgression.

5.3. Sedimentary dynamics of the *Jitia de Jos* oolit

The *Jitia de Jos* oolitic limestone displays a number of features that outline the dynamic sedimentary environment of the oolit genesis.

A primary feature, which signifies agitated water genetic condition, is the concentric structure of the ooids. A succession of water agitation and resting stages is regarded as the proper environment for the carbonate precipitation to build up the successive concentric laminae of the ooids (Davis *et al.*, 1978; Tucker and Wright, 1990). The spheroidal shape, as in the case of the *Jitia de Jos* ooids, is also considered an outcome of a high-energy regime (Purser, 1980).

Several outcrop-scale features point out the highly dynamic conditions during the formation of the *Jitia de Jos* oolit. The advanced grain-size sorting of the ooids (Fig. 14) and the occurrence of wave ripples (Fig. 13) are the most representative of these features.

The good grain-size sorting of the *Jitia de Jos* ooids (Fig. 14) reveals the ooids were transported by an agent with the transport competence corresponding to the coarse-grained sand (the ooids diameters are 0.5 to 0.6 mm large).

The symmetrical profile ripples at the upper surface of the *Jitia de Jos* oolitic layer (Fig. 13a) attest to the wave oscillation-affected ooid formation environment. The bidirectional, chevron-type lamination (Fig. 13b) is a result of the back-and-forth wave action. Very important is the fact that the oolit wave ripples are much larger than the wave ripples in the Upper Meotian sandy sediments, revealing the action of more powerful waves. The wavelength (L) of the ripples on the oolit bed surface is 30 to 31 cm, while the wavelength of the Upper Meotian ripples is 6 to 8 cm (Fig. 24). The ripple height (H) is 5 cm for the oolitic ripples, compared to 0.7-0.8 cm height of the Meotian sandy wave ripples.

5.4. On the genesis of the *Jitia de Jos* oolitic layer

The investigations provide data for a discussion on the origin of the *Jitia de Jos* oolitic limestone. However, some aspects, especially the hydrochemistry of the ooid formation, are still obscure and need more specialized studies.

Dynamic paleoenvironment. Several sedimentary features reveal the high-energy environment of the *Jitia de Jos* oolit (see section 5.3).

The wave rippled oolit from *Jitia de Jos* indicates, not only the high-energy environment where the ooids formed, but also point out that the ooids accumulated in very shallow water, where the waves can reach the capability to move grains of the *Jitia de Jos* ooids size.

Hydrochemical paleoenvironment. The Dacian Basin is a marine body well-known for its low salinity water (Marinescu, 1978 and many others), but drastic short-term changes occurred during the Upper Meotian – Lower Pontian transgression event. Stoica *et al.* (2012) found that the top Meotian clayey deposits, the first sediment accumulation during the transgression, are rich in foraminifers and nannoplankton. As the *Jitia de Jos* oolits occur at the same top Meotian stratigraphic level, the presence of the foraminifers and nannoplankton is a solid indication for the ooid formation in marine, normal salinity water. This is the only available information on the hydrochemistry of the genetic environment of the autochtonous ooids.

Clayey-silty sedimentation vs. *ooid formation*. Modern oolitic deposits occur in a variety of facies, from the ooid grainstone (oolit sands almost without clay material) to the ooid packstones (with high clay content) (Harris, 1979). The *Jitia de Jos* oolitic limestone belongs to the packstone type.

The *Jitia de Jos* clean ooid-sand facies, apparently without clayey material, contrasts with the clayey-silty deposits that are hosting the oolitic layer intercalation. The fine-grained coarsening-upward sedimentary sequences (VI and VII, in Fig. 5), between which the oolitic layer is intercalated (Figs. 9 and 10), indicate the sediment accumulation was made through the progradation of the silty-clayey, sand-topped units. The *Jitia de Jos* oolit bed is sharply differentiated from the clayey-silty deposits, with non-transitional upper and lower bed boundaries (Fig. 12a). This indicates the ooid transport and accumulation had little or nothing in common with the clayey-silty sediment transport and accumulation.

The elevated relief hypothesis. The Bahama oolite, forming in a modern environment, provides a possible model to reconcile the divergence between the *Jitia de Jos* oolite and its embedding clayey-silty deposits. According to the Bahama model, the ooids accumulate on isolated shallow-water platforms bordered by deeper water (Harris, 1979; Tucker and Wright, 1990). Applying this model to the *Jitia de Jos* case, the ooids accumulated in shallow-water on a raised relief area,

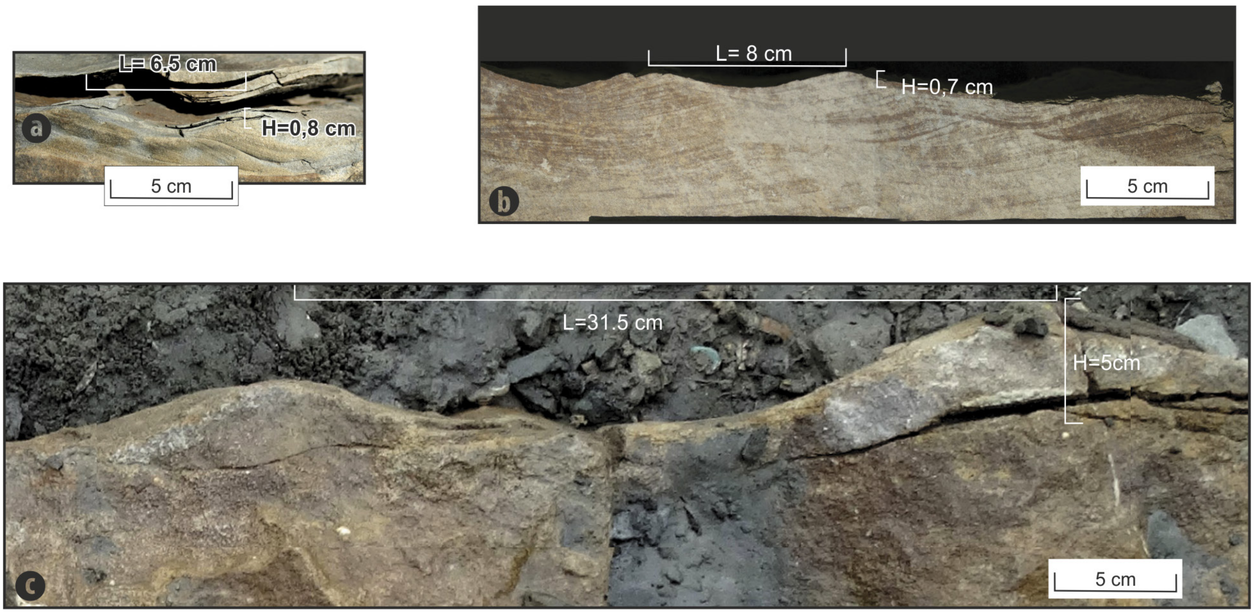


Fig. 24. Comparison between wave ripples from the sandstone-dominated Upper Meotian succession (**a**) and the oolith wave ripples (**b**). Râmnicul Sărat River, downstream from *Jitia de Jos* locality.

while the clayey-silty sediments were transported and deposited in the deeper water surrounding the elevated relief. Under these conditions, the suspended clayey material was removed from the ooid platform by strong shallow-water current, and only a small amount of sand-sized grains were trapped in the ooid forming area.

This hypothesis also explains the hydrodynamic difference between the oolitic wave ripples (formed in high energy, very shallow water) and the fine-grained sandstone, Meotian-Pontian wave ripples (shaped in deeper water, by lower-energy waves).

The lateral extension of the oolitic limestone layer from the *Jitia de Jos* area is limited. No oolitic limestone occurs in the synchronous sedimentary sequence cropping out only about 10 km southwest from the *Jitia de Jos* locality (in the Slanicul de Buzau River valley, at Beşlii locality from Buzău County). This fact points out the small extension of the platform-like site of the *Jitia de Jos* ooid accumulation.

6. CONCLUSIONS

This paper reports the scientific investigations concerning the genesis of the *Jitia de Jos* oolitic limestone, intercalated in a clay and silt-dominated sedimentary succession (Upper Meotian, Dacian Basin, Carpathians Bend).

The formation of the ooids, as well as the sedimentary accumulation of the Upper Meotian clayey-silty deposits, developed under the influence of the water currents and waves. However, the oolit and the clayey deposits show important contrasting characteristics concerning their composition, grain-size and sedimentary environment.

The composition contrast is between the calcareous, clay-free oolit and the dominantly clayey, embedding Upper Meotian deposits. The *Jitia de Jos* oolit bed is intercalated in the clayey-silty deposits but sharply differentiated from them, with non-transitional upper and lower bed boundaries.

The grain-size contrast is between the thin layers of fine-grained sandstone (up to 0.25 mm large grains) intercalated in the clay-dominated Upper Meotian deposits, and the 0.5 to 0.62 mm ooids (corresponding to the coarse to very coarse sand size distribution).

Both the oolit and the fine-grained sand intercalations show wave-generated symmetrical ripples. However, the oolit wave ripples are much larger than the wave ripples in the Upper Meotian sandy sediments that suggest a significant difference in water energy.

The modern Bahama oolitic environment can serve as model that reconciles the mentioned differences between the oolitic layer and its hosting clayey deposits. We hypothesize that the ooids accumulated on a raised relief area (platform-like), at shallow water depths, while the clayey-silty sediments were transported and sedimented in deeper water surrounding the elevated relief. The shallow-water accumulation of the *Jitia de Jos* ooids explains the missing (or very small) clay content and higher energy of the oolit formation setting.

The hydrochemical conditions during formation of the *Jitia de Jos* oolit is an aspect this paper did not elucidate. The large-scale sedimentary succession, into which the oolit is intercalated, is known for very low water salinity (10‰ and decreasing through time). This Upper Meotian – Lower Pontian sedimentary succession is transgressive, and during the initial phase of the transgression important, short-term hydrochemical changes occurred. Faunistic communities attest to the significant transgression-controlled increase of the water salinity, to the level of the normal marine water. The stratigraphic position of the *Jitia de Jos* oolitic limestone corresponds to the time when these changes occurred.

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