PRELIMINARY REPORT ON THE MICROFACIES ANALYSES OF THE HARDGROUNDS AND CONDENSED HORIZONS ASSOCIATED TO THE MIDDLE JURASSIC DEPOSITS FROM TĂTARULUI GORGES (BUCEGI MOUNTAINS, SE CARPATHIANS)

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Abstract. Microfacies and diagenetic features of the hardgrounds and condensed horizons occurring in Middle Jurassic carbonate rocks from Tătarului Gorges (Bucegi Mountains, SE Carpathians) are studied in the present paper. Several different microfacies have been distinguished in the studied sections: bioclastic packstones and wackestones with echinoderm fragments, ooidal grainstones, wackestone/packstones with calcispheres, wackestone/packstones with different types of sponge spicules and stromatolitic bindstones. Endolitic organisms were responsible for bioerosion and for particles' micritisation, while the bacterial activity promoted the frequently clotted and stromatolitic structures as well as the mineralization. The investigated hardgrounds are heavily mineralized with Fe oxides as well as phosphates. Many minor elements are also concentrated in these hardgrounds. The coexistence of borings and burrows in a sedimentary deposit has been considered a criterion of hardground recognition. Both of these features are present in the studied section. Diagenetic features include fibrous marine calcite cement, minor compaction, and selective dissolution of aragonite leading to moldic porosity and several generations of late diagenetic cements as revealed by cathodoluminiscence (CL) observations.

Keywords: hardgrounds, condensed horizons, Jurassic, SE Carpathians, Romania.

INTRODUCTION

Within the Middle Jurassic successions that crop out in Bucegi Mountains, the presence of the condensed horizons associated with limonitic crusts, has been recognized by numerous previous authors (Suess, 1867, Herbich, 1888, Redlich, 1896, Popovici-Hateg, 1905, Simionescu, 1905, Jekelius, 1916, Arkell, 1956, Patrulius, 1957, 1969, Lazăr, 2006); however, no detailed microfacies study exists so far. Few hardground occurrences are located on the western flank of the Bucegi Mountains, but the present paper will refer to one occurrence that has never been described in detail since Patrulius (1969, p. 58-59) gave its brief description. The outcrop is located in the northern part of Tătarului Gorges, on the right slope of Ialomița Valley at 500 meters north from the confluence of the Ialomița Valley with its right tributary, Tătarului Valley.

This paper presents the preliminary data on microfacies and diagenetic features of the Middle Jurassic sequence from Tătarului Gorges that reveal two stratigraphic unconformities corresponding to the Lower Bathonian and to the Middle-Upper Callovian intervals.

The hardground surfaces are located on the top of the condensation horizons and are strongly mineralized with ferruginous crusts.

GEOLOGICAL SETTING

The studied outcrop belongs to the sedimentary cover of the Getic Nappe (Fig. 1), one of the geotectonic units of the Median Dacides that are interpreted as part of the strongly deformed European continental margin (Săndulescu, 1984).

The observed section (Fig. 2) is seven meters thick, and it is represented, from bottom to top, by:

- yellowish calcarenite to calcirudite (2 m - the observed thickness on the base of the section) (CT1);
- a 0.9 m thick calcarenite (ooidal grainstone) bed (CT1-CT4), very rich in ammonites, bivalves, gastropods, crinoids, echinoids; this bed has a nodular aspect and shows numerous ferruginous crusts and macro-oncoids toward the upper part; the top is represented by a hardground surface strongly mineralized with 1 – 2 cm thick ferruginous crusts; the crusts are distributed on the top of the bed, but also in fissures and fractures (possible neptunian-dykes). Patrulius (1969) described from this level a rich ammonite fauna of Middle-Late Bathonian age; the macro-oncoids are represented mainly by fragments of ammonites and belemnites shells; bivalves, brachiopods (*Lacunosella*), gastropods, echinoids and crinoids have been also observed on the upper part of this bed;
- yellow-reddish bioclastic limestone (wackestone to packstone) (CT5-CT6), 1.15 meters thick, with limonitic oolites toward the base; the ammonite fauna recorded by Patrulius (1969) from this bed indicated an Early Callovian age. Neagu (1996) described rich planktonic and benthic foraminifera fauna from an ammonite fragment extracted from this bed; the foraminiferal species are also representative for Lower Callovian. The uppermost part of this bed is topped by numerous thin ferruginous crusts, corresponding to the second hardground identified in the studied succession;
- red crinoidal limestone (wacktone to packstone) (CT7), 1 meter thick, considered by Patrulius (1969) to represent the Oxfordian;

This succession is covered by white-grey massive limestone, more than 100 meters thick. From the lower part of this limestone, Patrulius (1969) and Neagu (1996) recorded ammonites and brachiopods representative for the Kimmeridgian stage.

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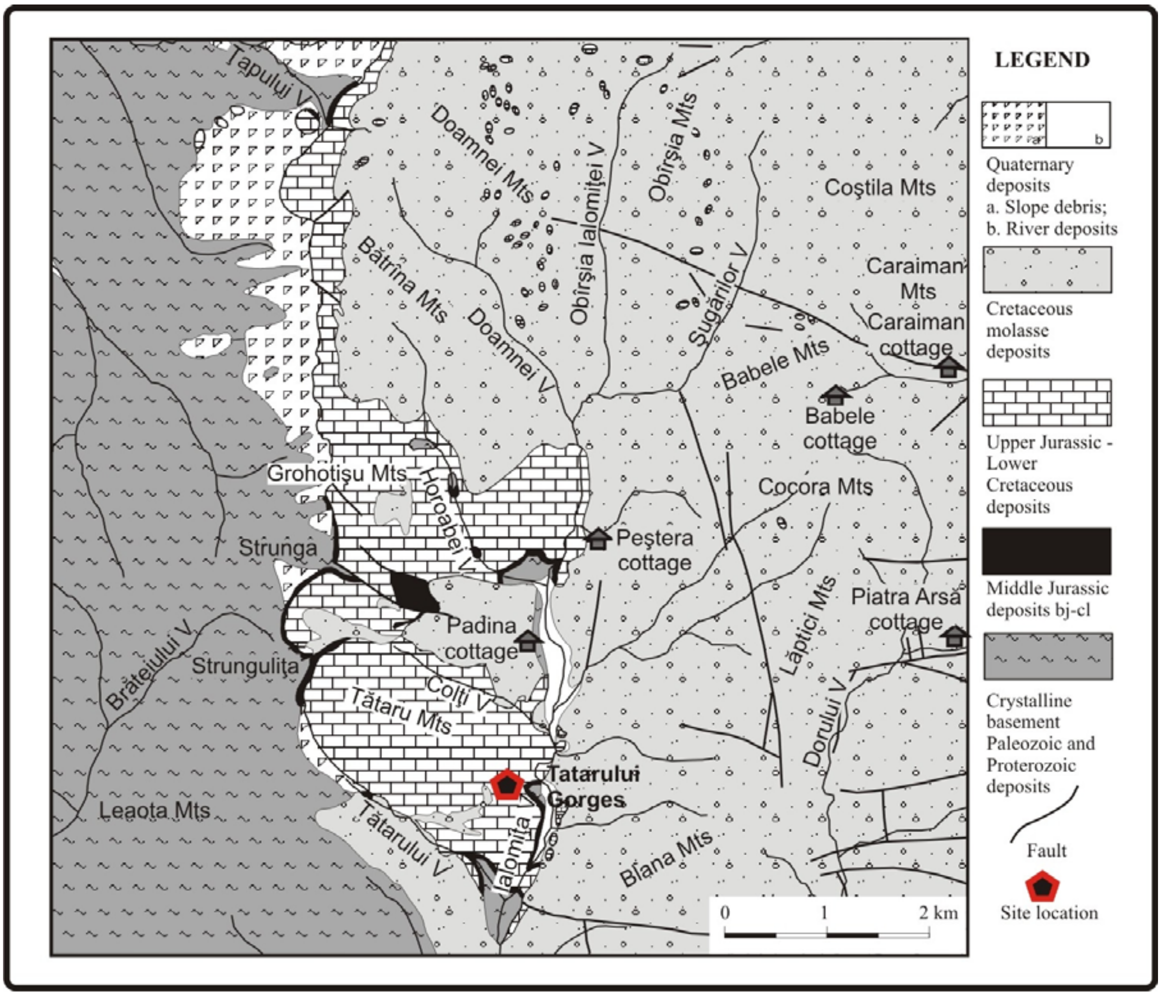

Fig. 1 - Location of the studied section (based on Patrulius, 1969).

MATERIAL AND METHODS

The methodology for this study included complementary sedimentological, diagenetic and geochemical approaches. Over 20 samples were collected from the studied section of which 20 petrographic thin sections have been prepared and analyzed to determine the grain composition and the types of carbonate cements; 10 polished slabs were examined under cathodoluminescence (CL) microscopy, which has been applied to identify the microstructures and diagenetic features. Acetophane peels stained with Alizarin red and Potassium Ferricyanide have been prepared to determine the roks mineralogy, and to check the iron content of the calcite (Dickson, 1966). Chemical composition of the carbonate hardgrounds has been determined by X-ray fluorescence analysis (XRF) using a Horiba XGT 7000 device for major elements, and X-ray diffraction (XRD) data were obtained from powders using a diffractometer.

MICROFACIES ANALYSIS

Several microfacies types have been distinguished within the condensed horizons and the two hardgrounds described from Tătarului Gorges. The microfacies are classified by lithology, frequency and composition of allochems. Sedimentary structures, texture and abundance of allochems were determined qualitatively. The dominant allochem types are ooids, echinoderm fragments, foraminifers, filamentous algae, mollusk small clasts, sponge spicules, intraclasts and silt-sized quartz. The dominant microfacies types identified in Tătarului Gorges were bioclastic packstone and wackestone with echinoderm fragments, ooidal grainstone, wackestone/packstone with calcispheres and stromatolitic bindstone.

Fabric: Acccording to Dunham's (1962) classification the depositional and diagenetic fabrics in these limestones range from wackestone to packstone and grainstone, but predominant sediment fabrics are represented by packstone.

Grain size: The grain size of the carbonate hardgrounds ranges from fine grained (mud to silt sized) to sand particles, and the matrix from micritic to microsparitic. Crinoid fragments dominate; sponge spicules, "filaments", mollusks as well as non-skeletal grains such as fecal pellets and intraclasts are also present. The calcispheres are abundant and have dimensions smaller than 0,1mm; the benthic and planktonic foraminifers are poorly sorted. Terrigenous particles such as angular quartz grains of silt to fine-sand size and clay minerals are less frequent.

Bioturbation affected the original sediment in the matrix; the burrows also affect the host sediment, and sand grains within a fine-grained matrix can also be the result of bioturbation. Intensive burrowing suggesting low sedimentation rates and concentration of organic matter may indicate the relatively deepest environment and the maximum flooding surface (Flügel, 2004). Burrows and bioturbation provide information on life conditions within the sediments (Curran and White, 1991). They also provide valuable indications on synsedimentary and diagenetic deformations (Gaillard and Jautee, 1987).

Bioerosion is the most important factor controlling early marine lithification, and it is also responsible for the enlargement of cavities. According to Flügel (2004), biological erosion destroys organic skeletons, grains and carbonate substrates, and creates cavities. Boring sponges and filamentous cyanobacteria are the major agents of shell destruction in these hardgrounds (Fig. 3A); small vertical burrows are also present (Fig. 3B).

Mineralogy: Carbonates are represented by aragonite derived from bivalves and gastropods, high-magnesian calcite (HMC) from echinoderms, low-magnesian calcite (LMC) from planktonic foraminifers, coccoliths, ostracods. When aragonite becomes metastable and HMC looses Mg with time, all carbonate sediments are transformed into LMC. Calcite composition changes successively from high magnesian to ferroan (Fe-rich) calcite. The composition, morphology and intensity of mineralization in the hardgrounds are defined by iron hydroxides that gradually transform into goethite. The existence of ferruginous crusts on hardground surfaces is often regarded as indicative of relatively long omission phases and low-energy hydrodynamic conditions (Flügel, 2004).

Microfacies

Several types of microfacies have been identified by the microscopic investigation of the carbonate hardgrounds in the study area such as: bioclastic packstone and wackestone with echinoderm fragments, ooidal grainstone, wackestone/packstone with calcispheres, wackestone/packstone with different types of sponge spicules and stromatolitic bindstone.

Wackestone microfacies-type is situated in the upper part of second hardground surface, with reworked fragments of crust. The micritic matrix contains a very fine-grained calcitic microspar; in some areas the matrix is strongly ferruginous (Fig. 2A).

Bioclastic wackestone microfacies is also related to the second hardground surface. It contains crinoidal fragments, partially replaced by tiny calcite crystals, shell fragments, calcispheres and a few filaments. The micritic matrix contains very fine-grained calcitic microspar; also for this facies type the matrix can be locally intensely ferruginous (Fig. 2B).

Wackestone/packstone microfacies is located in the upper part of the first hardground. It consists of calcified radiolarians, calcispheres and crinoidal plates. The sediment is strongly impregnated with iron oxides; ferroan calcite fills fractures cross-cutting both the matrix and grains (Fig. 2C).

Wackestone/packstone is also situated within the large bioerosion cavities. It contains different types of sponge spicules, broken echinoderm fragments, rare calcispheres, foraminifers, filamentous algae and a very fine-grained calcitic microspar with micritic matrix (Fig. 3F).

Bioclastic packstone microfacies is related to the first hardground surface. It is composed of many echinoid fragments with micro-borings created by endolithic organisms; the textures have been locally destroyed by micritization and cementation. Algal fiaments and foraminifers are also abundant in this microfacies; the matrix is micritic (Fig. 2D).

Ooidal grainstone microfacies is situated under the first hardground surface. The ooids display concentric laminar structure with nuclei of quartz grains (Fig. 2E).

Stromatolitic bindstone. The stromatolites are frequently associated with ooids and intraclasts (Fig. 3C); as a rule this suggests shallow-water stromatolites (Hoffman, 1974). The stromatolitic layers show alternation of dark micritic layers with microsparitic layers. This hardground level must have been situated offshore in shallow water, below wave base.

The diagenetic features of the studied hargrounds are:

- microbial micritization, being the first early diagenetic process that affected the grains, mostly developed around the echinoid fragments, foraminifers, ooids and intraclast;
- mineralization by iron concentration which is in the most of the cases result of a microbially induced precipitation;
- selective dissolution of aragonite leading to moldic porosity and early diagenetic cementation, suggest periods of low sedimentation rate or non-deposition.

Discussions:

Considering all the features presented above, most probably the hardgrounds formation included the following steps:

1) A decrease in sedimentation rate led to consolidation of the sediment, abundance of bored micritized grains, encrusted bioclasts and intense mineralization of iron oxides. The very low sedimentation rates allowed more complete bioturbation and many cavities are well preserved.

2) Glauconitization and phosphatization processes occuring at these discontinuity surfaces involved longer periods of time and were often interrupted by episodes of sedimentation. According to Flügel (2004) a break in sedimentation is indicated by accumulations of glauconite grains.

3) Cementation is defined as a good indicator of the diagenetic events and there are several different generations of cement. The first generation of cement is isopachous fibrous cement (IFC) typical of shallow marine environments (James and Choquette, 1990). It is a syndepositional to early diagenetic feature and is found as rimm cement around the ooids (Fig. 3D) preceded by early mechanical compaction features. Staining shows that these fibrous isopachous cements consist of LMC. The second generation of cement has been observed as early syntaxial calcite overgrowth cements (LMC) precipitated around echinoderm fragments. Drusic cement (DC) is found around many ooids, intraclasts, bioclasts and within the inter-granular pores (Fig. 3D). The next generation of cementation is mosaic calcite filling sponge spicule voids, and moldic pores formed by selective dissolution of bioclasts (Fig. 3F); this cement is formed during burial diagenesis in anoxic conditions.

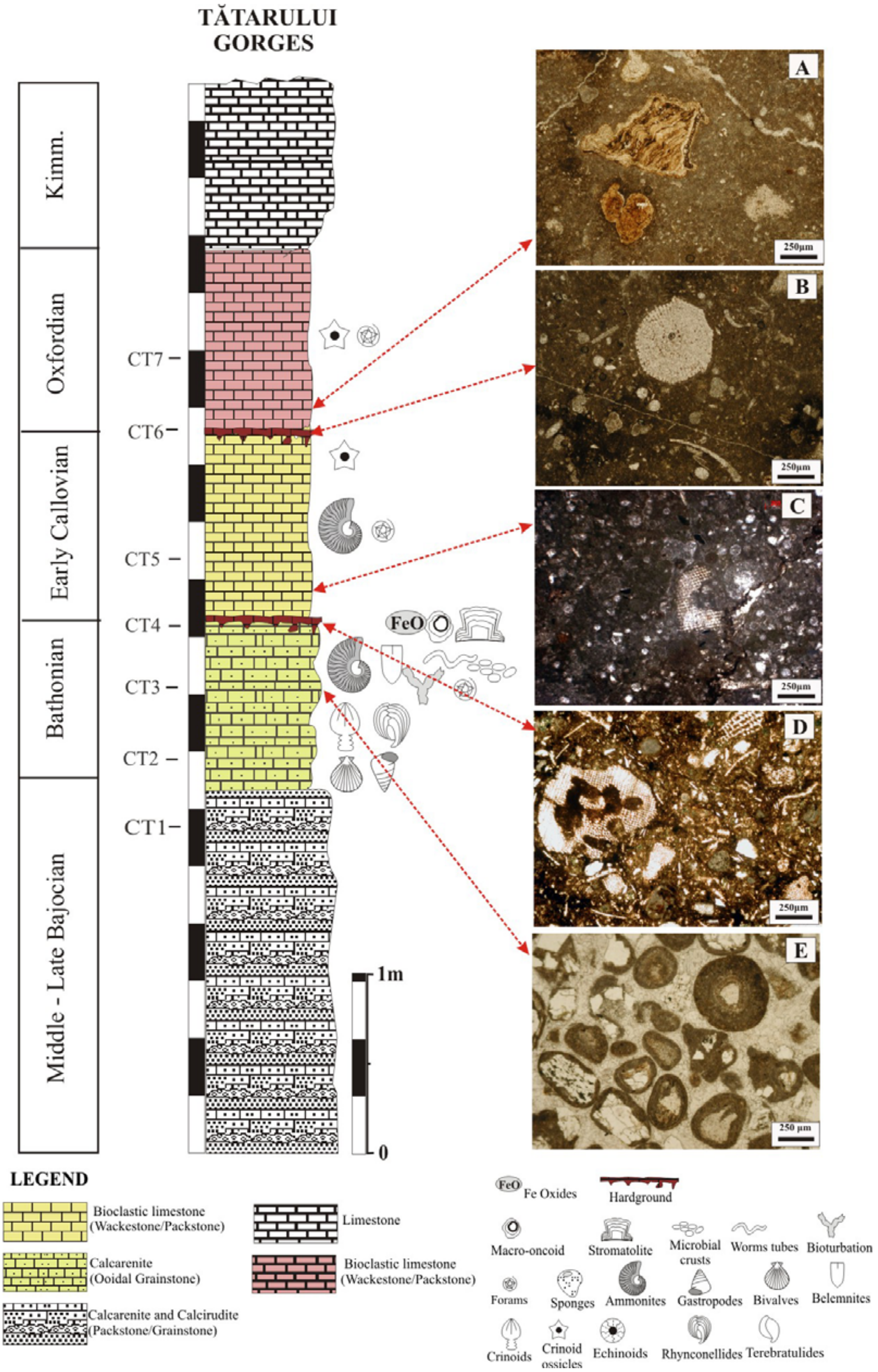

Fig. 2 - Lithostratigraphic column of the Middle Jurassic sequence from Tătarului Gorges, with the location of the samples: A. Wackestone with reworked fragments of crust (CT7); B. Bioclastic Wackestone with crinoids (CT6); C. Wackestone/Packstone with calcified radiolarians, calcispheres and crinoidal fragments (CT5); D. Bioclastic Packstone consisting of many echinoid fragments with some microborings created by endolithic organisms (CT4); E. Ooidal Grainstone with quartz grains in the ooid cores (CT3).

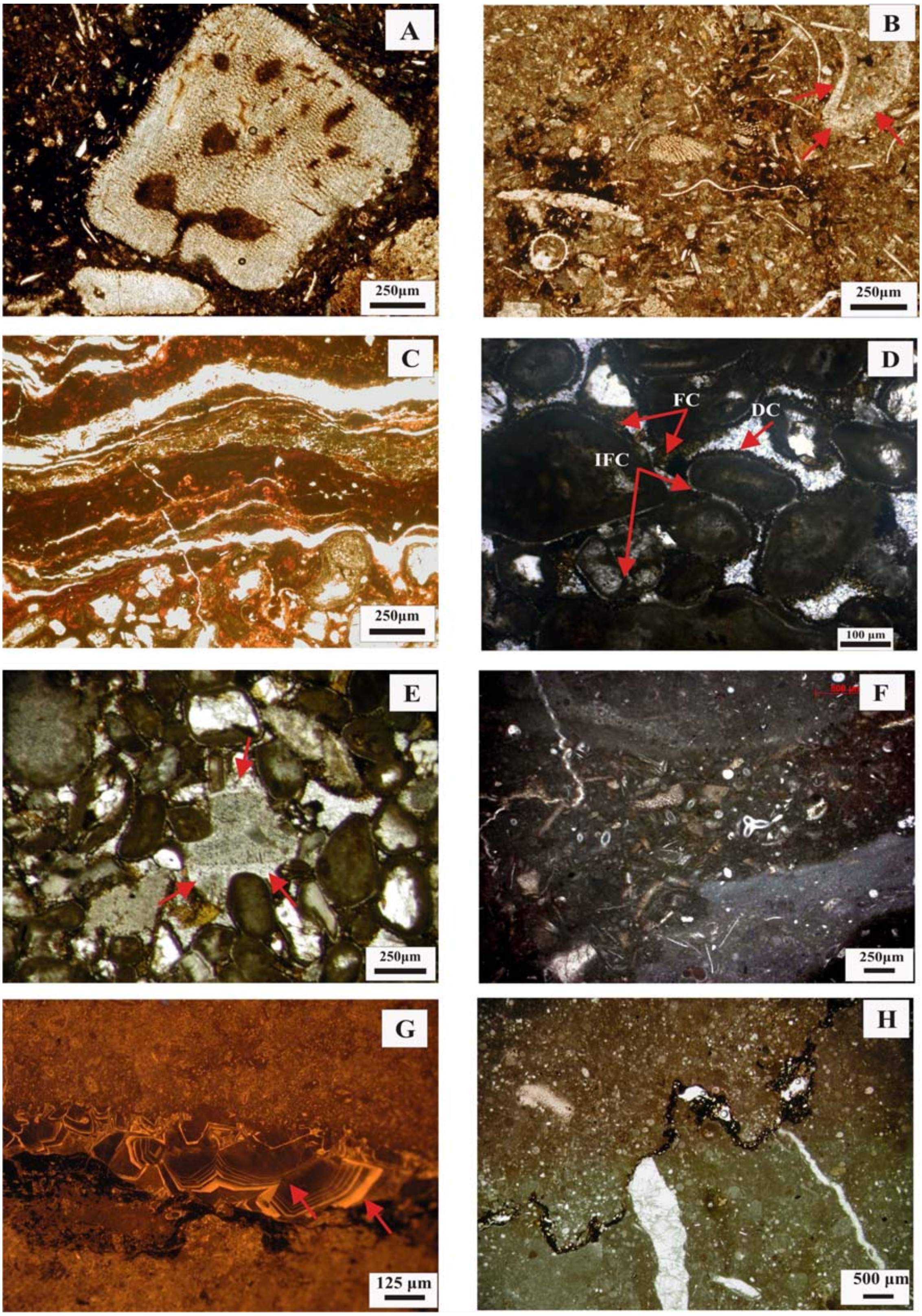

Fig. 3 - Photomicrographs showing borings and burrows from the hardground samples and diagenetic features: A. Crinoidal plates bored by sponges or filamentous cyanobacteria (CT4f); B. Packstone with vertical burrow, radiolarians, crinoidal and bivalve fragments (CT4b); C. Stromatolitic bindstone. The ooids and intraclasts are surrounded and covered by a stromatolitic crust (CT4f). D. IFC (Isopachous Fibrous Cement) coating ooids, DC (Drusy Calcite Cement) filling inter-granular pores, FC (Ferroan Calcite) surrounding the ooids and Q (quartz grains) (CT4g); E. Syntaxial calcite overgrowth cements developed around echinoderm fragment (CT4g); F. Wackestone composed of sponge spicules filled with mosaic calcite spar (CT4c); G. Cathodoluminiscence image of zonate structure with dull-luminiscence and bright luminescence closing the remnant pores during late burial (CT4c). H. Wackestone with a medium amplitude stylolite and a fracture filled by radiaxial cement (CT5).

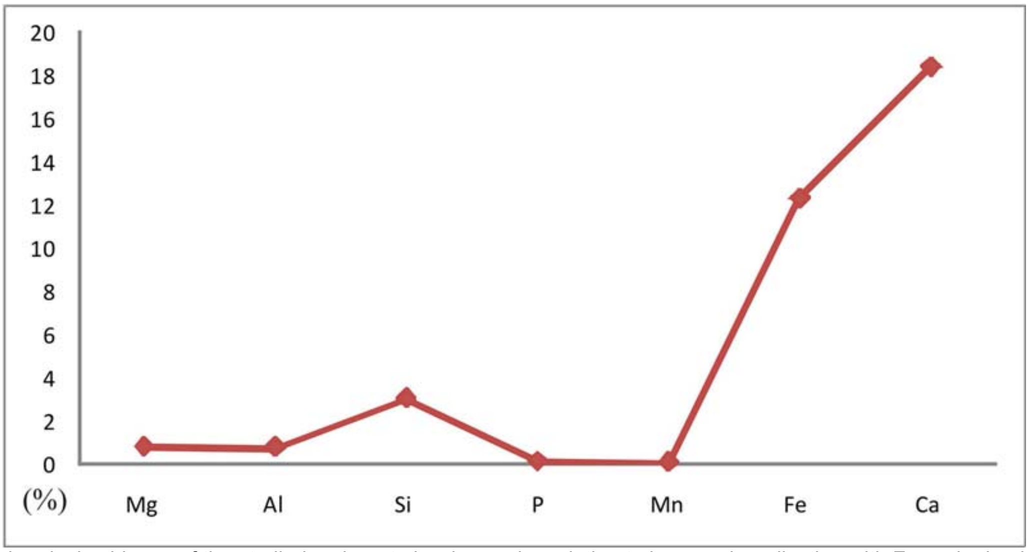

Fig. 4 - Geochemical evidence of the studied carbonate hardgrounds, pointing to heavy mineralization with Fe oxyhydroxides (CT4)

The last generation of cement is ferroan calcite (Fig. 3D). This cement is postdepositional and fills in the fractures and part of the remaining intergranular pore space.

Cathodoluminescence analyses allowed us to reconstruct the diagenetic history of these induration surfaces, a succession of events starting with the early, synsedimentary phases of early marine cementation and ending with late and postdepositional events.

4) Minor mechanical compaction features are observed in compressed grains with tangential and concave–convex contacts which result in the overall reduction of the porosity and permeability of the rock. The compaction changes the contacts between allochems and is also visible as it produces microfractures filled with calcite affecting the sediments and bioclasts. According to Tucker (1990) the chemical compaction and pressure solution are two important burial processes. Chemical compaction and pressure solution involve the dissolution of grains along the sediments when the rock is fully cemented to produce stylolites. Within the hardgrounds from Tătarului Gorges the stylolites are filled with ferroan calcite and affect the sediment and the bioclasts (Fig. 3H).

Chemical composition of the carbonate hardgrounds has been determined by X-ray fluorescence analysis (XRF) and shows a high percentage of iron and calcium with subordinate amounts of manganese and phosphor (Fig. 4). XRD data were obtained from powders and the mineralogical study of the hardground crusts shows that the dominant mineral is goethite with subordinate amounts of calcite.

CONCLUSIONS

The Middle Jurassic sequence from Tătarului Gorges reveals two stratigraphic unconformities corresponding to the Lower Bathonian and to the Middle-Upper Callovian intervals. These uncorfomities are represented by hardgrounds surfaces on top of two condensation horizons.

The investigated hardgrounds are heavily mineralized with iron-oxides as well as phosphate and glauconite.

The microfacies include bioclastic packstone and wackestone with echinoderm fragments, ooidal grainstone, wackestone/packstone with calcispheres, wackestone/packstone with different types of sponge spicules and stromatolitic bindstone.

Microfacies analyses show that these hardground levels have been generated within the shallow shelf environment, with high hidrodynamic energy, showing a decrease in sedimentation rate. These conditions led to sediment consolidation, the abundance of bored micritized grains, encrusted bioclasts and to intense mineralization with iron oxides.

Cementation is defined as a reliable indicator of the early diagenetic events; we have described several different generations of cement.

Geochemical and mineralogical evidence from the studied ferruginous crusts point to high percentage of iron with subordinate amounts of manganese and phosphor. Within the crusts the dominant mineral is goethite with subordinate amounts of calcite.

These data represent preliminary results of a detalied microfacies and geochemical study on the Middle Jurassic hardgrounds from the Bucegi Mountains. These results provided some refinements for the interpretation of the marine depositional environment during the Bathonian-Callovian interval in this part the Getic unit.

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