MICROFACIES, MICROFOSILS AND SEDIMENTARY EVOLUTION OF THE SĂNDULEȘTI LIMESTONE FORMATION IN CHEILE TURZII (APUSENI MOUNTAINS, ROMANIA)

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Abstract. The northern ending of the Trascău Mountains is represented by Upper Jurassic-Lower Cretaceous limestones. They crop out from Cheile Turzii up to the south of the Mureș Valley and are located on the main ophiolitic area of the Apuseni Mountains. In the Cheile Turzii – Buru area these limestones overlie a magmatic arc. In this area the carbonate deposits belong to the Bedeleu Nappe and were separated into two units (Dragastan et al., 1987): Săndulești Formation (Upper Oxfordian-Lower Berriasian) and Petridu Formation (Upper Berriasian - Valanginian). The carbonate deposits of Săndulești Formation in Cheile Turzii allowed the reconstruction of the evolution of specific carbonate platform. The evolution of the sedimentary systems was strongly influenced by the changes of the accommodation space. Facies and microfacies analysis facilitates the study of carbonate environments, which functioned on these platforms. The elongated geometry of the platforms and the periodicity of the input of siliciclastics evidence that this area activated as attached platforms. The analysis of the space/time evolution of the sedimentary systems shows consecutive stages in the formation, morphology transformation and destruction of these platforms. The time evolution analysis of the carbonate deposits is based on the application of the concepts of sequence stratigraphy, combined with the biostratigraphical data and their detailed facies analysis.

Keywords: limestone, microfacies, microfossils, sedimentary evolution, Apuseni Mountains, Late Jurassic, Early Cretaceous.

INTRODUCTION

The limestones in Cheile Turzii belong to the Bedeleu Nappe, which is a component of the Transylvanides. The Transylvanides represent typical obduction nappes (Sândulescu, 1984), which consist of ophiolites and their associated sedimentary deposits. They have been formed during the austrian tectogenesis and were reactivated during the laramian one (Balintoni, 1996).

The Bedeleu Nappe consists of a basal ophiolitic complex belonging to the tethyan suture, which is represented by keratophires and calcalkaline ophiolites associated with jaspers. The basal complex is overlayed by carbonate rocks of Oxfordian-Tithonian age (Stramberk-type facies), locally followed by Neocomian limestones (Ilie, 1936; Balintoni, Iancu, 1986; Balintoni, 1996).

a. The ophiolitic complex in Cheile Turzii area is represented by pyroclastites (breccias, rhyolitic agglomerates and tuffs), alternating with lava flows. These rocks form a continuous band outcropping between Cheile Turenilor area and Buru locality (Pl. I - Fig 1).

b. The Upper Jurassic - Lower Cretaceous limestones represent the northern ending of the Trascău Mountains. They cropout from Cheile Turzii up to the south of the Mureș Valley and are located on the main ophiolitic area of the Apuseni Mountains. In the Cheile Turzii – Buru area these limestones overlie a magmatic arc (Balintoni, 1996). The carbonate deposits in the Bedeleu Nappe were separated into two units: Săndulești Formation (Upper Oxfordian-Lower Berriasian) and Petridu Formation (Upper Berriasian - Valanginian) (Dragastan et al., 1987).

The present study focused on the microfacies and microfossil analysis as well as on the sedimentary evolution of the Upper Jurassic carbonate platform outcropping in Cheile Turzii.

CARBONATE SEDIMENTARY FACIES AND MICROFACIES

1. Extraclastic rudstone

Description: Overlaying the island arc complex, a ruditic melange of limestone and ophiolite fragments develops 6 to 8 m in thickness. The limestone pebbles are subangular to subrounded and are up to 20-25cm in size, while the ophiolite pebbles are dominant subangular. The matrix contains subangular to subrounded carbonate fragments, coral, mollusc, gastropod and echinoderm bioclasts as well as extraclasts represented by ophiolite lithoclasts, quartz and feldspar.

The sedimentary bodies present erosional incisions, while the sedimentary infilling is represented by Gm and/or Gms-type facies (Miall, 1978). They show a lens-shaped geometry with reduced lateral continuity up to meters, or tens of meters and decimetric to metric thickness (Pl. II, Fig. 1,2).

The microfacies identified within the carbonate pebbles are the following:

- **Coralgal boundstone** with Thaumatoporella parvovesiculifera RAINERI, Lithocodium aggregatum ELLIOTT, Troglotella incrustans WERNLI & FOOKES, “Tubiphytes” mornonensis CRESCENTI incrustations, as well as problematic crusts – probably of microbial and/or bryozoan origin. The sediment between the corals contains Bacinella irregularis RADOICIC, sponges, coral, mollusc, and echinoderm fragments, foraminifers with alveolar test and milolids (Pl. III, Fig. 1-3).

- **Bioclastic peloidal grainstone/packstone** with Andersenolina sp., Mohlerina basiliensis (MOHLER), Protopenoeroplis sp., Cayeuxia sp., coral, echinoderm and miloloid fragments.

It is not possible to establish the exact age of the deposits on the base of microfossils identified in the limestone pebbles, but anyway they belong to the Upper Jurassic.
Most of the pebbles show a vuggy-type porosity and vadose silt accumulations. The diagenetic processes do not affect exclusively the surface of the pebbles, their presence being noticed in the whole mass of the limestone (Pi. II - Fig.3).

Interpretation: The erosional incision, the poor sorting, the reduced lateral continuity of these lens-shaped bodies are all arguments for considering them chanel deposits associated with subaqueous debris flow (Middleton and Hampton, 1976; McIreath and James, 1984; Walker, 1978; Einsele, 1987; Einsele, 1991; Scholle et al., 1983).

Features of subaerial diagenesis such as vuggy-type porosity and vadose silt pleads for the subaerial exposure of some pre-existing carbonate deposits and diagenetic processes which took place in a vadose environment. The formation of pebbles was a result of the erosion and distruption of a platform. The resulting material was reworked and accumulated as submerse fans.

2. Oolithic/bioclastic grainstone/packstone

Description: On the top of the submerse fans, a series of bioaccumulated limestone of about 15 meters thick was observed. In their lower part bioclastic facies dominate, while towards the upper third the oolitic facies becomes significant.

In the lower section bodies of bioclastic grainstones / packstones develop, containing coral, echinoderm and mollusc fragments as well as "Tubiphytes morrionensis" CRESCENTI, Andersenolina sp., Salpingoparella pygmaea (GUENBEL), Mohlerina basiliensis (MOHLER), Protopenoporella sp., ?Coscinophragma sp., miliolids, peloids and a large amount of millimetric fragments of ophiolites and quartz clasts. The grains are well sorted, the carbonate intraclasts are rounded while the ophite fragments and the quartz clasts are angular to subangular.

The sedimentary bodies are lens-shaped and rarely have layered geometry. Their base is slightly erosion, the lateral extensions are meter to tens of meters respectively, while the thickness is decimetric to metric. The rock bodies are erosionally overlaying each other and they gradually pass to ooidic bodies in the middle and in the upper part. Progressively, there is a decrease in the amount of ophiolitic fragments and quartz clasts, and a replacement with ooids (Pi. II – Fig.4).

Within this succession bioclastic wackestone / mudstone intercalations were noticed, becoming more frequent and diversified towards the upper part. The rapid change of the facies from ooidic-bioclastic grainstone/packstone to bioclastic wackestone/ mudstone is accompanied by the decrease of the diversity degree of the clastic material and by the dominance of the ripple structures.

The top is dominated by bioclastic wackestone / mudstone which was identified in the whole outcropping area. This level shows decimetric thickness and contains "Tubiphytes morrionensis" CRESCENTI, Thaumatoporella parvovesiculifera RAINERI and miliolids.

Interpretation: The abundance of the oblique and ripple structures as well as the high frequency of erosion surfaces indicate the accumulation of the material in a high energy environment above the normal waves base (FWB). Such genetic conditions generate lime grainstones. The progressively increasing frequency of the bioclastic wackestones / mudstones intercalation, the decrease of the diversity degree of the clastic material, as well as the decrease of the frequency of trough-cross structures indicate a progressive decrease of the environmental dynamics and an increase of the depth towards the area below normal waves. The dominance of the ripple structures suggests the accumulation of the sediments in a progressively low energy environment below FWB or at its limit (James and Desrochers, 1992; Einsele, 1992).

3. Peloidal – bioclastic grainstones

Description: The succession of bioclastic-peloidal-ooidic limestone with locally interstratified thin lens of laminitic mudstones has a total thickness of about 50m. The deposits form bioclastic-ooidic, lens-shaped and erosions bodies have metric lateral extensions and decimetric to metric thickness. The deposits consist of bioclastic-ooidic grainstones with Thaumatoporella parvovesiculifera RAINERI, Mohlerina basiliensis (MOHLER), Protopenoporella sp., Andersenolina sp., Salpingoparella pygmaea (GUENBEL), echinoderm, mollusk, miliolid, briozoan and sponge fragments.

In the basal part a 15 centimeters thick ruditic level showing a significant erosions basis with a large lateral extension was identified. It consists of pebbles about 10 cm in diameter caught in a carbonate matrix. They originate in the subjacent deposits and are represented by ooidic-bioclastic grainstones / packstones, bioclastic wackestones / mudstones, and small fragments of ophiolites and bioclasts represented by fragments of echinoderm and mollusks.

Interpretation: The basal level of pebbles derived from erosion processes and was accumulated as a distinctive level within the proximal facies. These features, correlated with the significant lateral extension are arguments in attributing these deposits to a transgressive lag (Handford and Loucks, 1993).

The obvious clastic character of the limestone in the top, the numerous erosions surfaces and the frequency of the small and medium scale trough-cross structures, as well as the presence of ooids and fragmented bioclasts plead for attributing these deposits to bioclastic-ooidic shoals.

4. Boundstones and associated peloidal / bioclastic packstones

Description: A succession of bioclastic-peloidal packstones of about 150 m thick forming lens-shaped isolated bioconstructions. In the lower part, a bioclastic packstone dominates in which small-sized (metrical) and isolated bioconstructions develop. While towards the middle and upper part the bioconstructions become larger (tens of meters), are more frequent and the sediment in between shows a peloidal character. The lateral sides of the bioconstructions consist of an intraclastic-bioclastic grainstone / packstone.

The coral and sponge bioconstructions developed on the surface of the bioclastic shoals. The microbial carbonate crusts represented by thrombolitic-type structures also had an important contribution. The millimetric-centimeter microbial crusts generate a positive relief around the corals, sponges, and briozoans or directly on the sediment between the corals. Grimelous thrombolitic structures with peloidal microstructures and dense peloidal thrombolites, according to the terms in Kenard & James (1986) were identified (Pi. III - Fig.4-6).

Besides microbialites, several other encrusting microorganisms of a presumed algal or cyanobacterial origin, represented by taxa with uncertain systematic.
position were also noticed. The main encrusting microorganisms are represented by *Thaumatoporella parvovesiculifera* RAINERI, *Lithocodium aggregatum* ELLIOTT, *Troglotella incrustans* WERNLI & FOOKES, aggregates of "*Tubiphytes*" *morronensis* CRESCENTI, *Koskinobullina socialis* CHERCHI & SCHROEDER, and bryozoans.

The sediment within bioconstructions constitutes a bioclastic-peloidal packstone with *Mercierella dacica* DRAGASTAN, *Clupeina sulcata* (ALTH), agglutinated foraminifers and miliolids, coral, sponge, bryozoan, echinid and mollusk fragments.

**Interpretation:** Isolated, lens-shaped bioconstructions, tens of meters in size generated by corals and sponges define the patch reefs (Tucker and Wright, 1990; Wright and Burchette, 1996). In their lower part they develop in shallow high-energy environments, on bioclastic shoals. Towards the middle and upper part these deposits progressively become more frequent and larger building-up "reef complexes". The progressively higher frequency of the peloids, the increase of the amount of carbonate mud as well as the decrease of the number of trough-cross structures argue for a gradual decrease of the dynamics, i.e. a deepening of the depositional environment towards the area below the normal waves base.
5. Oncolithic bioclastic wackestones / mudstones

**Description:** Oncoid wackestones / mudstones about 40 m thick with *Suppiluliumaella delfphica* (CARAS), *Cyprinea sulcata* (ALTH), *Lithocodium aggregatum* ELLIOTT, *Haddonia sp.*, *Conocorynema sp.*, *Protodictyon sp.*, *Labyrinthina mirabilis* WEYNSCHENK, mioloids, oncoids encrusted by microbial and/or encrusting microorganisms, granular aggregates and peoids (PI. III - Fig.7,8; PI. IV - Fig.3). The oncoids and granular aggregates are milimetric-centimetric in size and are surrounded by a micritic matrix. The cortex of the oncoids consists of microbial and/or algal (cyanobacterial) laminae and of encrustations of *Haddonia sp.* or *Lithocodium aggregatum* ELLIOTT. The nuclei are represented by bioclastics (fragments of corals, gastropods and bivalves), green algae (*Cyprinea sulcata* (ALTH)), foraminifers and intraclasts. Within the granular aggregates, adjacent carbonate grains represented by peoids, mioloids, algae, fragments of bivalves and gastropods were agglutinated. Associated to this facies, lens-shaped erosion bodies with limited lateral extensions and metric thickness was identified at certain levels. In the basal part, ruditic fragments of limestone originating in the subjacent deposits, granular aggregates, oncoids, and foraminifers with alveolar test, algae, gastropods, bivalves caught in bloky cement were concentrated as a lag-type deposit. Towards the upper part, the lag shows a gradual passage to an oncoidal - bioclastic grainstone / packstone with well-sorted and rounded carbonate clasts.

The deposits of the oncoidic facies gradually pass to peloidal-bioclastic wackestones / mudstones with *Bacinella irregularis* RADOICIC (PL. IV – Fig. 2), *Lithocodium aggregatum* ELLIOTT, *Thaumatoporella parvesiculifera* RAINERI, *Cyprinea sulcata* (ALTH), *Rivularia sp.*, gastropods, bivalves and peoids. It is worth mentioning that beginning with this facies type, *"Tubiphytes" moronensis* (CRESCENTI) was no longer identified along the whole carbonate succession in Cheile Turzii area. Meanwhile, there is a high frequency of peloids, algae (*Cyprinea sulcata* (ALTH), *Rivularia sp.*), of the *Bacinella irregularis* - type and fenestral structures within these levels.

**Interpretation:** The granular aggregates associated with oncoids surrounded by a micritic matrix plead for subtidal and intertidal environments with a restrictive circulation (Fluegel, 1982). The lens-shaped and erosional bodies, which occur at certain levels and consist of carbonate material of the subjacent deposits, can be attributed to some tidal channels.

6. Charophytes – bearing limestones

**Description:** Decimetric-metric limestones rich in charophytes, ostracods and terrigenous material. In their basal part they contain centimetric-decimetric levels of marls, gradually replaced by bioclastic wackestones and peloidal-bioclastic packstones / wackestones.

**Interpretation:** Most probably, the deposits in the top of the platform were subaerial exposed. The increasing of the terrigenous and fresh water supply lead to the deposition of charophytes-bearing limestones. The change from the environment in which the oncoidic deposits were formed to the lacustrine environment suggests the progressive decrease of the accomodation space. Thus, the coastal facies prograded on the top of the marine facies and the latter was subsequently subaeral exposed.

7. Peloidal-bioclastic packstones / wackestones

**Description:** In the top of the carbonate succession in Cheile Turzii area, crop out layers of decimetric to metric limestones of a total thickness of about 50 m. They contain centimetric to decimetric levels of marls in the basal part, gradually replaced by bioclastic wackestones / mudstone and peloidal-bioclastic packstones / wackestones. The following microfossils were identified: *Cyprinea sulcata* (ALTH), *Seliporella neocomiensis* (RADOICIC), *Andersenolina sp.*, *Favreina solavensis* (PAREJAS), *Rivularia sp.*, small gastropods, bivalves, and agglutinated foraminifers and mioloids (PI. IV - Fig. 4-8). The Berriasian age of these deposits is based on the dasyclad alga *Seliporella neocomiensis*.

Towards the upper part of the succession two banks of ooidal-bioclastic grainstones / packstones showing metric thickness and lateral extension at the outcrop scale were observed.

**Interpretation:** The deposits presented above show shallowing-upward facies trends, which can be interpreted as elementary sequences (parasequences).

**SUCCESSIVE STAGES OF THE CARBONATE PLATFORMS**

The evolution of the studied sedimentary systems was strongly influenced by the changes of the platform accomodation. The present knowledge on the time evolution of the Tithonian-Lower Berriasian carbonate deposits from Cheile Turzii area is based on the application of the concepts of sequence stratigraphy, combined with the biostratigraphical data and their detailed facies analysis (Handford and Loucks, 1993).

1. The first deposits from the Cheile Turzii section were accumulated directly on the top of the magmatic island arc, as a consequence of a significant decrease of the accomodation space. This context favoured the erosion of a former carbonate platform, including the substrate represented by the island arc, leading to of an unconformity (SB1). As a result, a large amount of carbonate and magmatic clastic material, was reworked and transferred towards the basin as extraclastic rudstones, being accumulated as a slope facies attributed to *lowstand fan*. The reduced degree of reworking of the magmatic clasts and the abundance of well preserved feldspars in contrast with the well rounded and flattened sedimentary pebbles, as well as the presence of small-sized patch reefs suggest the accumulation of fans in the close neighbourhood of the platform margin (Fig. 1).

2. At the end of the decrease of the accomodation trend, on the top of the submersic fan a succession of prograde parasequences mainly constituted of oolithic / bioclastic grainstone / packstones accumulated in the upper part of the slope, as a *lowstand wedge*. The two types of deposits were regrouped and attributed to the *lowstand system tract*.

3. The gradual increase of accomodation facilitated the accumulation of a succession of thin, retrograde parasequences consisting of peloidal – bioclastic grainstones on the top of the lowstand deposits, which in the basal part formed to a lag. These deposits were attributed to the *transgressive system tract*.

4. The succession continues with deepening-
upward deposits represented by progressively thinner parasequences of peloidal / bioclastic packstones associated with bioclastic wackestones; within the latter, isolated patch-reefs formed towards the upper part. The dominance of low-energy facies in the upper part of this succession and the presence of small-sized and dispersed patch-reefs indicate the proximity of the maximum flooding surface.

5. Progressively, the boundstone-type facies and associated peloidal / bioclastic packstones / grainstones become dominant, marking the shelf edge. The facies is dominated by large and grouped patch-reefs, while the interstices are filled with bioclastic granular material. This succession generated a “reefal complex” with considerable thickness, suggesting a constant vertical accretion. The result is a gradual decrease of accommodation within the newly formed carbonate platform which determined the vertical replacement of bioconstructions with oncolithic bioclastic wackestones / mudstones and, in the last stage, with limestones with charophytes. The last two types of facies suggest the development of a progradation process. The whole succession was attributed to the high stand. The subaerial exposure of the deposits in the top of the platform explains the increase in terrigenous supply and the presence of the vadose diagenetic processes which characterise the accumulation of the charophytes limestones. The SB2 was located in the lower part of these deposits.

6. The top of the succession from Cheile Turzii is indicated by a series of retrograde parasequences consisting of peloidal - bioclastic packstones / wackestones and towards the upper part of ooidic-bioclastic grainstones / packstones, respectively. This succession was attributed to the shelf-margin system tract belonging to the base of the second sequence.

CONCLUSIONS

The Tithonian carbonate deposits from Cheile Turzii allow reconstructing the evolution of the specific carbonate platforms superposed on the top of a volcanic island arc that activated in the Transylvanian branch of the tethyan suture. The main groups of organisms contributing to the formation of this limestone are corals, sponges, bryozoans, echinoderms, foraminifers, algae, anelid worms, mollusks, but also microbialites generated by bacteria, cyanobacteria and algae. Besides the corals and sponges, the microbial deposits played an important role in the reefal bioconstruction.

The evolution of the sedimentary systems was strongly influenced by the changes of the accommodation space. Facies and microfacies analyses facilitated the study of the carbonate environments from the platforms. The elongated geometry of the platforms and the periodicity of the siliciclastic input are evidence that this area activated as attached platforms. The analysis of the space/time evolution of the sedimentary systems suggests consecutive stages in the formation, morpho-

logical change and destruction of these platforms.

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PLATES

Plate I

Fig. 1 - The limit between the volcanic island arc and the Tithonian carbonate deposits.
Fig. 2 - The limit between Tithonian and Berriasian carbonate deposits.

Plate II

Fig. 1 - The first deposits from the Cheile Turzii section accumulated directly on the top of the magmatic island arc, considered as channel deposits associated with submarine debris flow.
Fig. 2 - Detail of the debris flow facies.
Fig. 3 - Diagenesis within the freshwater vadose zone is indicated by vadose silt filling up the voids.
Fig. 4 - Oolitic/bioclastic/extraclastic grainstone/packstone, x25
Fig. 5 - "Tubiphytes" morronensis CRESCENTI x25

Plate III

Fig. 1 - Thaumatoporella parvovesiculifera RAINERI x25
Fig. 2 - Troglotella incrustans WERNLI & FOOKES, perforating a coral fragment encrusted by Lithocodium aggregatum ELLIOTT x25
Fig. 3 - Koskinobullina socialis CHERCHI & SCHROEDER x25
Fig. 4-6 - Layered thrombolite x25
Fig. 7 – Clypeina sulcata (ALTH). Oncolithic facies x25
Fig. 8 - Labyrinthina mirabilis WEYNSCHENK x25

Plate IV

Fig. 1 - Andersenolina sp., x25
Fig. 2 - Bacinella irregularis RADOICIC x25
Fig. 3 - Suppiluliumaella delphica (CARAS) x25
Fig. 4 - Rivularia sp. x25
Fig. 5 - Clypeina sulcata (ALTH) x25
Fig. 6 - Seliporella neocomiensis (RADOICIC). Detail from fig. 8, x50
Fig. 7 - Favreina solavensis (PAREJAS) x25
Fig. 8 - Seliporella neocomiensis (RADOICIC) x25