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FIRST NOTICE OF THE *ZOOPHYCOS* IN THE UPPER VALANGINIAN DEPOSITS FROM THE BUCEGI MOUNTAINS (SOUTH CARPATHIANS)

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Abstract: The complex trace fossil *Zoophycos* is recorded worldwide, from Cambrian to Holocene. It remains an enigmatic ichnofossil. *Zoophycos* is used in environmental reconstruction, mostly for the interpretation of the paleobathymetry and the paleo-oxygenation in bottom waters. *Zoophycos* now has been discovered in two outcrops of Valanginian to Lower Hauterivian age rocks in the southern part of the Bucegi Mountains (Southern Carpathians). The host rocks are pelagic limestones. These rocks contain 70.24% to 88.17% $CaCO_3$ and 0.64 to 2.64% organic matter (LOI method). The *Zoophycos* specimens exhibit simple planar form morphologies. *Zoophycos* from the Upper Valanginian – Lower Hauterivian rocks indicate deep water environments and dysaerobic/anaerobic conditions. This deep environment is confirmed by the presence of the small benthic foraminifera assemblages (*Spirillina*, *Patellina* and *Lenticulina*). The occurence of the benthic genus *Spirillina* indicates local dysaerobic conditions on the sea floor. Dysaerobic conditions are usually caused by high organic productivity in the surface seawater. *Zeugrhabdotus* spp. nannofossils are markers of high-fertility surface seawater in unstable environments such as oceanic sites of upwelling or shelf areas where trophic conditions may have been enhanced by storms. The presence of pyrite is also indicative of fluctuations in palaeoredox conditions.

Keywords: *Zoophycos*; morphology; paleoenvironment; Upper Valanginian; Bucegi Mountains; Southern Carpathians.

INTRODUCTION

Trace fossils have often been used as environmental indicators in land-based outcrops for reconstructing paleobathymetry and paleo-oxygenation (Seilacher, 1967; Savrda & Bottjer, 1986; Ekdale, 1988; Frey *et al.*, 1990; Savrda, 1992; Bottjer & Savrda, 1994; Fu & Werner, 1994; Pemberton *et al.*, 1994; Savrda, 1995; Wetzel & Uchman, 1998a; Knaust, 2004). Environmental changes recorded by trace fossils are detected by analysis of ichnofabric (Bromley & Ekdale, 1986). Ichnofabrics result from bioturbation processes, and they vary in response to changes in sediment accumulation and other environmental factors (Taylor & Goldring, 1993; Goldring, 1995). Ecologic conditions change with depth below the sediment-water interface - porosity and permeability decrease, organic matter decomposes, and oxygen content of the pore water decreases (Bottjer & Droser, 1992; Bromley, 1996; Wetzel & Uchman, 1998a). Detailed ecological analysis of trace fossils can not be directly determined in outcrops. In contrast, environmental conditions in recent sediments can be directly measured. Relationships between biogenic structures and environmental conditions enhance the ecological interpretation of trace fossils in ancient sediments (Fu & Werner, 1995).

Although *Zoophycos* is known from all over world and has frequently been studied, it is still an enigmatic trace fossil. The signification of *Zoophycos* is unclear. Traditionally, *Zoophycos* has been interpreted as a deposit feeder (Seilacher, 1967), but there has been extensive discussion about the affinities of the producing organism(s) over the years (e.g., Lewis, 1970; Wetzel & Werner, 1981; Ekdale & Lewis, 1991; Kotake, 1992). However, in the last two decades, several alternative ethological hypotheses have been put forward such as inverse conveyor activity (Kotake, 1989), cache (Jumars *et al.*, 1990; Bromley, 1991; Miller & D'Alberto, 2001), refuse dump (Bromley, 1991), gardening of symbiotic microorganisms (Bromley, 1991; Fu & Werner, 1995; Bromley & Hanken, 2003), and a combination of surface detritus feeding and cache-behavior (Löwemark & Schäfer, 2003).

Zoophycos has been reported from marine deposits from the Cambrian to the Holocene, and in environments ranging from sublittoral to bathyal (Ekdale & Lewis, 1991). In Paleozoic sediments, *Zoophycos* occurs in both shallow water (Osgood & Szmuc, 1972; Miller, 1991) and slope facies (Bottjer *et al.*, 1988; Burton & Link, 1991), whereas it is restricted to deep-sea environments in the Mesozoic and Cenozoic (Bottjer *et al.*, 1988; Bottjer & Droser, 1992; Olivero, 2003). In modern seas it is only know from the middle bathyal to abyssal sediments (Wetzel & Werner, 1981; Wetzel, 1985, 1991; Löwemark & Werner, 2001; Löwemark & Schäfer, 2003; Löwemark & Grootes, 2004).

During field studies of Lower Cretaceous (Late Valanginian – Early Hauterivian age) deposits exposed in the Mount Lespezi (southern part of the Bucegi Mountains), three samples of specimens of *Zoophycos* were collected.

This article reports the first discovery of *Zoophycos* in Upper Valanginian strata in Romania. The purposes of this paper are (1) to describe the morphological organization of *Zoophycos* trace fossils and (2) to comment on their paleoenvironmental significance.

In Romania *Zoophycos* occurences have been reported from North Dobrogea (Early – Middle

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Jurassic) (Grădinaru, 1984), External Flysch from East Carpathians (Late Cretaceous, Paleocene, Eocene) in silciclastic rocks and Hăghimaş Mts. (Middle Triassic - Anisian) in carbonate rocks (Brustur, 1997 and personal communication).

GEOGRAPHIC AND GEOLOGICAL SETTING

The investigate area, Mount Lespezi, is located in the southern part of the Bucegi Mountains (Fig. 1). The GPS reading for this point is 45 18' 36"N; 25 23' 59"E alt. 1657m.

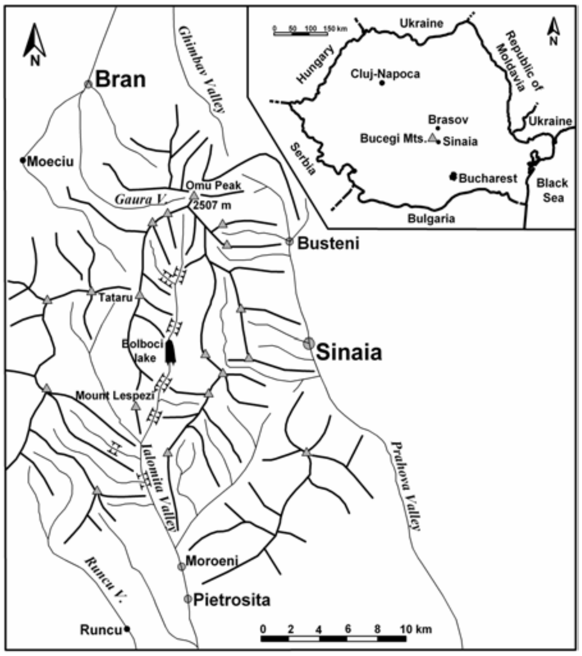

Figure 1. Geographic location of the study area - Mount Lespezi (southern part of Bucegi Mts.)

Middle Jurassic to Lower Cretaceous deposits crop out (Fig. 2) on Mount Lespezi. These deposits are included in the sedimentary cover of the Getic Nappe, belonging to the Median Dacides, South Carpathians (Săndulescu, 1984).

Patrulius *et al.*, (1976) interpreted the overall Upper Jurassic to Lower Cretaceous carbonate rocks from South Carpathians as having been formed within several carbonate platforms grouped under the more general name of Getic Carbonate Platform.

Geological studies in this area have been conducted by Patrulius (1953, 1969), E. Manoliu *et al.* (1978), Dragastan (pers. comm., 2000), Barbu (2002; 2005), Barbu *et al.* (2002) and Barbu & Melinte (2005).

LITHOLOGY AND PALAEONTOLOGIC CONTENT

In the upper part of Mount Lespezi two very close outcrops occur - AF2 and AF3 sections – (Plate 1, Figs. 1 and 2) and in each outcrop a hardground discontinuity surface can be identified.

This hardground is marked by breccias with glauconitic cement and a glauconitic level (1 - 1.5 cm thick) (Fig. 3). Just below this discontinuity surface a bio-intraclastic limestone is exposed. The microfacies consist of packstones with bioclasts: calpionellids (very frequent – *Crassicollaria intermedia*, *Cr. brevis*, *Calpionella alpina*, *C. elliptica*, *Tintinnopsella carpathica*, *T. oblonga*, *Calpionellopsis simplex*, *C. oblonga*, *Lorenziella plicata*, *Remaniella filipescui*), rare benthic foraminifera, ostracods, bivalves and echinoid debris. The Late Tithonian - Late Berriasian age of this limestone was documented by calpionellid assemblages, assigned to the *Crassicollaria*, *Calpionella,* and *Calpionellopsis* Zones (Barbu & Melinte, 2005).

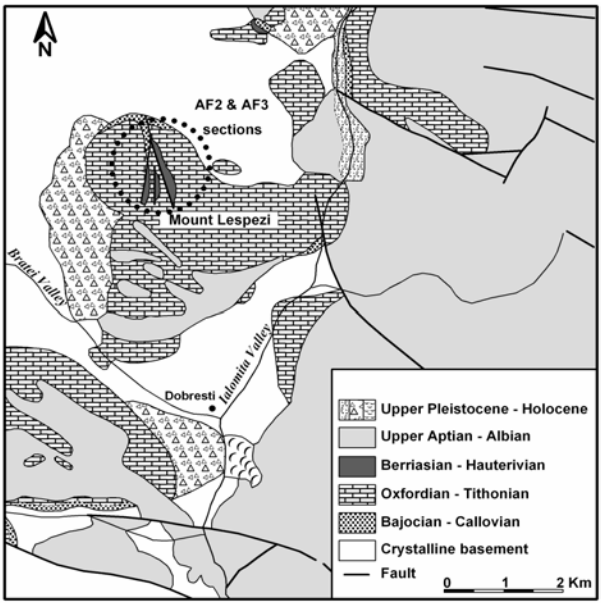

Figure 2. Simplified geological map of the southern part of Bucegi Mountains – dash line delimits area study (redrawn with modifications after Patrulius, 1969)

Pelagic limestone overlying this discontinuity surface, within which the first layer is rich in glauconite associated with fish teeth. The thickness of these deposits is 6 m in the AF2 section and 21 m in the AF3 section. The microfacies consist of mudstone with rare bioclastic and siliciclastic elements. The bioclasts are rare benthic foraminifera, ostracods, sponge spicules and radiolarians.

The calcium carbonate content varies between 70.24% - 88.17%, with a mean of 81.82% (Barbu *et al.*, 2002). The organic matter (LOI = loss on ignition method – Heire et al, 2001) contents between 1.45% - 2.64%, with a mean of 1.94% for the AF2 section, and 0.64% - 2.21%, with a mean of 1.34% for the AF3 section.

In both sections, the pelagic limestones contain pyrite and iron oxide pseudomorph after pyrite, at different levels.

Macrofossils include a few ammonite fragments, a nautiloid (*Cymatoceras* sp.), belemnites [*Duvalia dilatata dilatata* (Blainville), *Pseudobelus* cf. *brevis* Paquire], and sponges.

The marls beds contain abundant calcareous nannofossil. The age of these deposits, based on

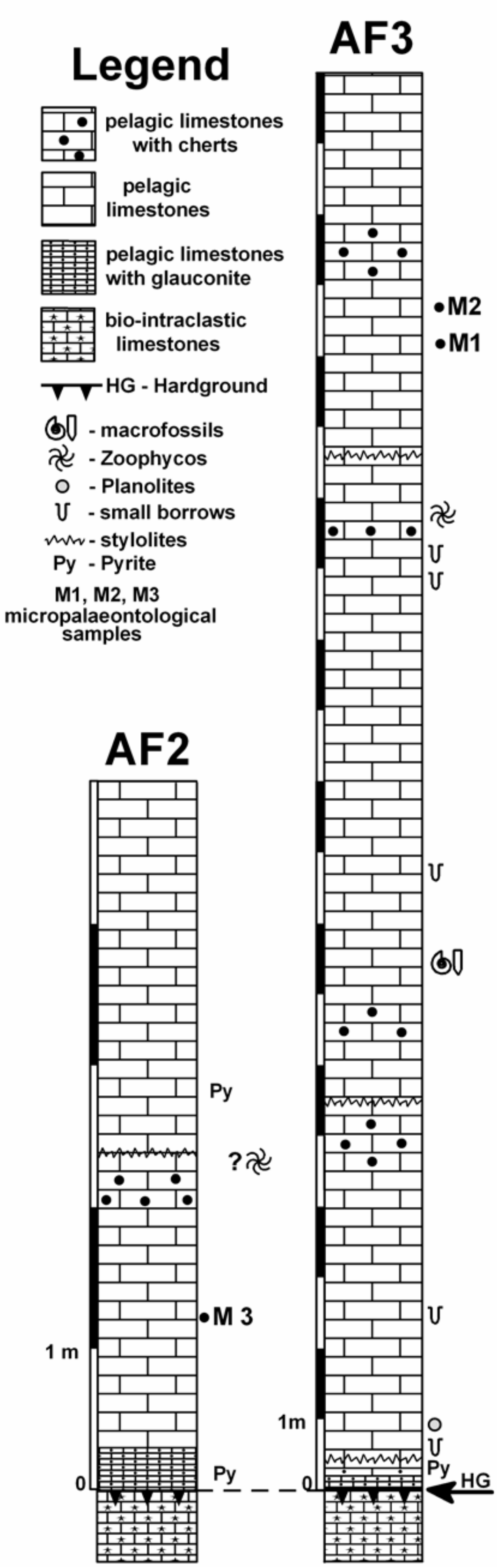

Figure 3. Lithological sections of the Mount Lespezi.

the calcareous nannofossil assemblage, is Late Valanginian (NK3B Nannoplankton Subzone) for AF2 outcrop and Late Valanginian – earliest Hauterivian (NK3B – NC4A Nannoplankton Subzones) for AF3 outcrop. The most indicative species are: *Calcicalathina oblongata*, *Tubodiscus verenae*, *Conusphaera rothii*, *C. mexicana*, *Eiffellithus striatus* for NK3B Nannofossil Subzone, and *Nannoconus bucheri* for NC4A Nannofossil Subzone (Barbu & Melinte, 2005).

In these pelagic limestone deposits, three samples of *Zoophycos* were collected. Two samples were found in the AF2 section, but in the detritus (Plate 1, Figs. 3 A and B) on bed surfaces, and one sample, in cross-section, was found in the bulk rock sample (no. 70) from AF3 section (Plate 1, Figs. 4 A and B).

Structural and sedimentological data (micro-facies change, and presence of glauconitic hardground) indicate drowning of the carbonate platform in the Bucegi Mts. area due to extensional tectonics around the Berriasian - Valanginian boundary (Barbu & Melinte, 2005).

DESCRIPTION OF *ZOOPHYCOS*

Basically *Zoophycos* is characterized by a few millimetres thick lamina (spreite) bordered by a marginal tube and furrowed by numerous curved lamellae. The marginal tube represents the last tunnel built by the organism. In cross-section, the marginal tube is circular while the lamina shows a characteristic backfill structure: a set of little arches (en-echelon like) with different colour and/or composition, each corresponding to the section of a lamina (Fig. 4). These arches indicate the displacement of the marginal tube towards the concave side and hence, the construction of lamina. On the contrary, on a planar view it is the convex side of the lamellae which marks the direction of progradation (Fig. 4) (Olivero & Gaillard, 1996).

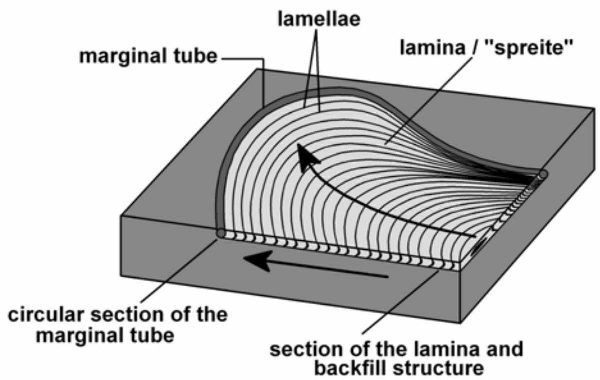

Figure 4. Main characteristic of a *Zoophycos* lamina. The arrows represent the direction of construction of the lamina (redrawn with modification after Olivero, 1994)

The *Zoophycos* specimens from section AF2 resemble the constructional model of Gaillard & Olivero (1993) and are simple planar forms similar to those described in Lower Carboniferous deposits from northeast Japan (Kotake, 1997) and Belgium (Gaillard *et al.*, 1999), as well as from Toarcian to Bathonian (Olivero, 1994; 2003;

Olivero & Gaillard, 1996) deposits from south-eastern France.

The simple planar form of *Zoophycos* was described by Gaillard & Olivero (1993) and Olivero & Gaillard (1996). This form is characterized by a planar to sub-planar lamina developing parallel to the bedding plane. The laminas are asymmetric, lunate - shaped, with two extremities and a strongly curved central part (Fig. 5). The oldest primary lamella, corresponding to the first position of the tube of the causative, is straight or slightly curved. The following ones are longer and increasingly curved. This suggests a simple tunnel regularly displaced laterally. These simple planar forms are not exactly planar because one of their sharp extremities usually is located deeper below the sediment surface than is the other. It forms a "lower apex" in opposition to an "upper apex". This could indicate a tunnel reaching the sediment - water interface only at the upper apex. Evidently, the tunnel has only one opening at the seafloor. Therefore, the structure is not a "U" tube, but a "J" tube, a form suggested by Wetzel & Werner (1981). The original position of the tube is oblique, sometimes nearly vertical, but after, it usually turns to the horizontal plane, parallel to bedding.

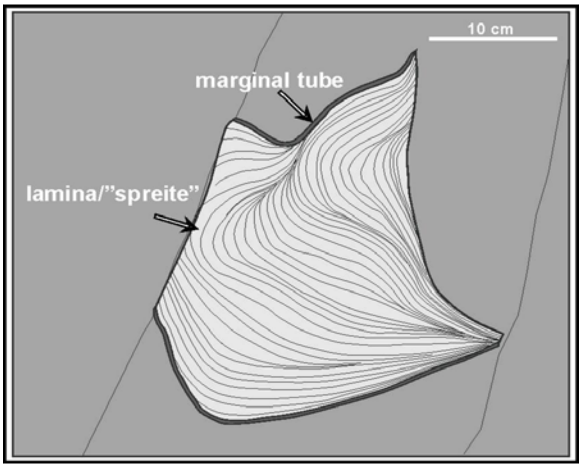

Figure 5. *Zoophycos* - simple planar form morphology (drawn after photo of the Upper Bathonian *Zoophycos* sample from Alpes de Haute Provance, SE France)

The *Zoophycos* specimens from section AF2 permit precise description of the simple planar forms. The observed trace fossil documents the growth pattern, but does not reveal the marginal tube (Plate 1, Figs. 3 A and B). The specimens are not very large (14 - 17 cm).

The *Zoophycos* specimen from section AF3 is an exposed cross-section (Plate 1, Figs. 4 A and B). The burrow shows a characteristic backfill structure: a set of small arches (en-echelon like) with different colour, each corresponding to the section of a lamina (Fig. 4). Unfortunately, this sample does not preserve the marginal tube. No pellets were observed within the spreite. All three samples are located at the top of the beds.

DEPOSITIONAL ENVIRONMENT OF THE UPPER VALANGINIAN DEPOSITS FROM THE MOUNT LESPEZI

Early Cretaceous *Zoophycos* have been reported in slope to bathyal environment, in pelagic limestones (Olivero, 1996; 2003; Olivero & Gaillard, 1996).

The Upper Valanginian – lowermost Hauterivian deposits are dominated by well stratified pale grey pelagic limestone. The beds are generally about 10 - 15 cm thick, only rarely 25 - 30 cm thick. These deposits exhibiting minor bioturbation, at different levels. The microfacies consist of a mudstone with rare bioclastic and siliciclastic elements. This microfacies is characteristic of the slope environment.

The micropaleontological samples (M1, M2, M3) contains small benthic foraminifers: *Lenticulina eichenbergi*, *L. ouachensis*, *L. ouachensis bartensteini*, *L. macrodisca*, *Miliospirella cretaceae*, *M. sardoa, Patellina subcretacea*, *Rumanollina feifeli*, *Spirillina minima*, *Vaginulina arguta*, *V. recta*, *Ammodiscus siliceus*, ostracods (very rare), radiolarians, fish teeth, but and a small amount of glauconite. The planktonic foraminifers are totally absent. The mixed calcareous/agglutinated small benthic foraminifera associations suggest that Lower Cretaceous pelagic limestone was depo-sited along an outer shelf approaching a bathyal environment, but above CCD (Holbourn & Kaminski, 1997). Assemblages with *Lenticulina*, *Patellina*, and *Spirillina* are generally considered to be an indicator of deep water.

Zoophycos is indicative of a lower dysaerobic to nearly anaerobic environment, reflecting a decrease in oxygenation of the substrate (Ekdale, 1988; Wetzel, 1991; Savrda, 1992; Bromley, 1996; Wetzel & Uchman, 1998b). The benthic fora-miniferal assemblage with small, thin, and unornamented shell also indicates anaerobic conditions (Brasier, 1996).

Lower diversity within benthic foraminiferal assemblage as well as small size and pre-dominance of flattened morphologies has been frequently observed in deposits that were accu-mulated when oxygen levels were low (Coccioni & Galeotti, 1993; Kaiho & Hasegawa, 1994; Kaminski et al, 1995; Erbacher *et al.*, 1998).

Dysaerobic conditions of the sea floor are suggested by occurrence of small *Spirillina* among the benthic foraminiferal assemblage (Cobianchi *et al.*, 1999).

Another argument for the existence of low oxygenation conditions within the sediments is the presence of pyrite and iron oxide pseudomorph after pyrite, in the pelagic limestones of the Mount Lespezi (Plate 1, Figs. 5 A and B).

Dysaerobic to anaerobic conditions were favourable to preservation of organic matter. In the Mount Lespezi sections, the organic matter (LOI method) content varies between 1.45% - 2.64%, with a mean of 1.94% for AF2 section, and 0.64% - 2.21%, with a mean of 1.34% for AF3 section (Fig. 6). The organic matter content in sample no. 70 in which *Zoophycos* was discovered is 0.94%. Wetzel and Werner (1981) indicated that in the deep sediments off NW Africa characterized by high organic carbon (> 2%) *Zoophycos* is missing. Thus, organic carbon which is best preserved under conditions of high sedimentation rate may be considered as a possible limiting factor for the *Zoophycos* distribution.

Oxygen deficiency is usually caused by high organic productivity at the sea surface leading to anaerobic bacterial blooms and production of H_2S (Brasier, 1996). Calcareous nannofossils are good indicators for reconstructing the fertility of surface waters. The nannofossils assemblages contain *Watznaueria barnesae*, *Nannoconus* spp., *Zeugrhabdotus* spp., *Conusphaera* spp., *Cyclagelosphaera* spp., and *Diazomatholithus lehmanii* (Barbu & Melinte, 2005).

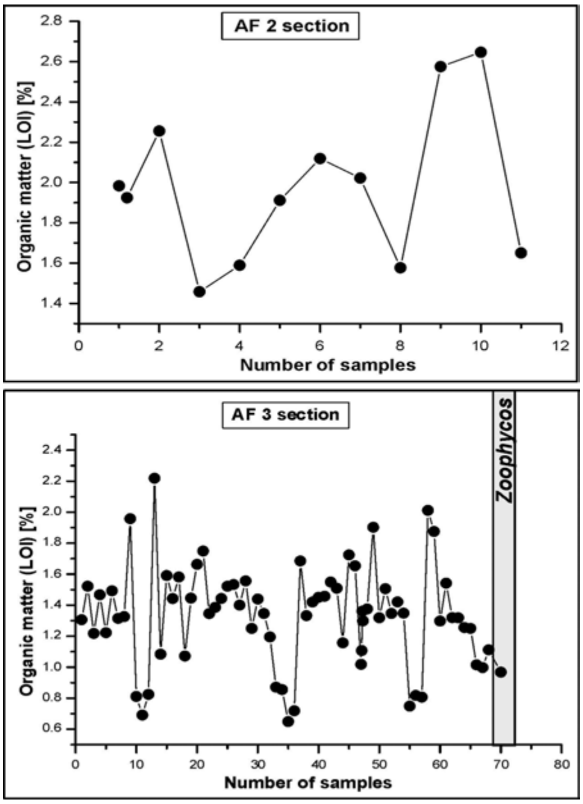

Figure 6. Organic matter content from AF2 and AF3 sections – Mount Lespezi

Zeugrhabdotus erectus is considered a good indicator of high surface seawater fertility in unstable environments, such as continental margins with intense upwelling of cold water rich in nutrients or shallow epicontinental seas characterized by intensified storm mixing and high continental nutrient runoff (Roth & Krumbach, 1986; Williams & Bralower, 1995; Melinte & Mutterlose, 2001; Mutterlose *et al.*, 2005).

Zeugrhabdotus erectus, *Cyclagelosphaera margerelii*, and *Diazomatholithus lehmanii* vs. *Nannoconus* spp. are useful for reconstructing the fertility of surface seawater.

In our sections, particularly in AF3, a progressive decrease in abundance of oligotrophic nannoconids, together with a significant increase in abundance of cosmopolitan nannofossils *D. lehmanii*, *Z. erectus*, and *C. margerelii* (Fig. 7) is observed for the Late Valanginian - earliest Hauterivian. This suggests cooler surface seawaters, higher fertility episodes, and eutrophic environments (Barbu & Melinte, 2005).

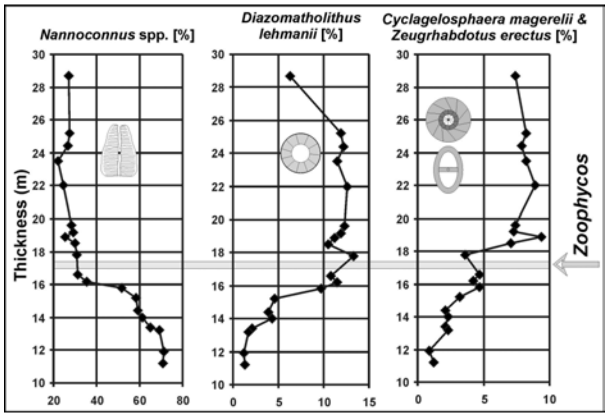

Figure 7. Trends of calcareous nannofossils in the AF3 section – Mount Lespezi

In other Tethyan areas such nannofloral events are related to the Valanginian Weissert Oceanic Anoxic Event. The nannoconids declined as a result of combined higher fertility and higher atmospheric CO_2. Volcanism of the Paranà-Etendeka large igneous province (LIP) was presumably a source for the increase of CO_2, triggering a climate change and accelerated hydrological cycling, possible causing an indirect fertilization of the oceans (Erba & Tremolada, 2004; Erba et al. 2004).

Zoophycos specimen from AF3 section appears at the moment in which environmental conditions became relative stable (Fig. 7).

SUMMARY AND CONCLUSIONS

The morphological organization of *Zoophycos* specimens from Mount Lespezi, in the southern part of the Bucegi Mountains may be interpreted as the simpler planar constructional model proposed by Gaillard & Olivero (1993) for Mesozoic specimens from south-eastern France. *Zoophycos* occurred in slope environment, with dysaerobic conditions at the bottom seawater. This interpretation is based upon:

(1) Pelagic limestone deposits, which are dominantly well stratified. The microfacies consist of mudstone with sparse bioclastic and siliciclastic elements. This microfacies is characteristic of the slope environments.

(2) Benthic foraminifera assemblages with *Lenticulina*, *Patellina*, and *Spirillina* species, that indicates deep water.

(3) The lower diversity, the small size, and predominance of flattened morphologies, observed in the benthic foraminiferal assemblages, which indicate oxygen deficiency in the bottom seawater. Moreover, the occurrence of the benthic genus *Spirillina* argues for dysaerobic conditions.

(4) Dysaerobic to anaerobic conditions, that was favourable to organic matter preservations. In our sections, the organic matter (LOI) contents varies between 0.64 – 2.64%.

(5) The presence of pyrite, that is also indicative of low oxygenation, and the presence of organic matter within sediments.

(6) Oxygen deficiency as a possible consequence of high fertility at the seawater surface. Calcareous nannofossils were used in fertility reconstruction. Taxa used included *Diazomatholithus lehmanii*, *Cyclagelosphaera margerelii*, and *Zeughrabdotus erectus* as high productivity indicators. In late Valanginian – earliest Hauterivian sections, decreasing nannoconids abundance, together with an increasing in the abundance of *D. lehmanii*, *C. margerelii*, and *Z. erectus*, suggest cool surface seawater, higher fertility episode, and eutrophic environments. The nannoconid decline resulted from higher pCO_2 and higher fertility. In the Valanginian, increase pCO_2 was correlatable with the main magmatic activity of Paranà-Etendeka LIP.

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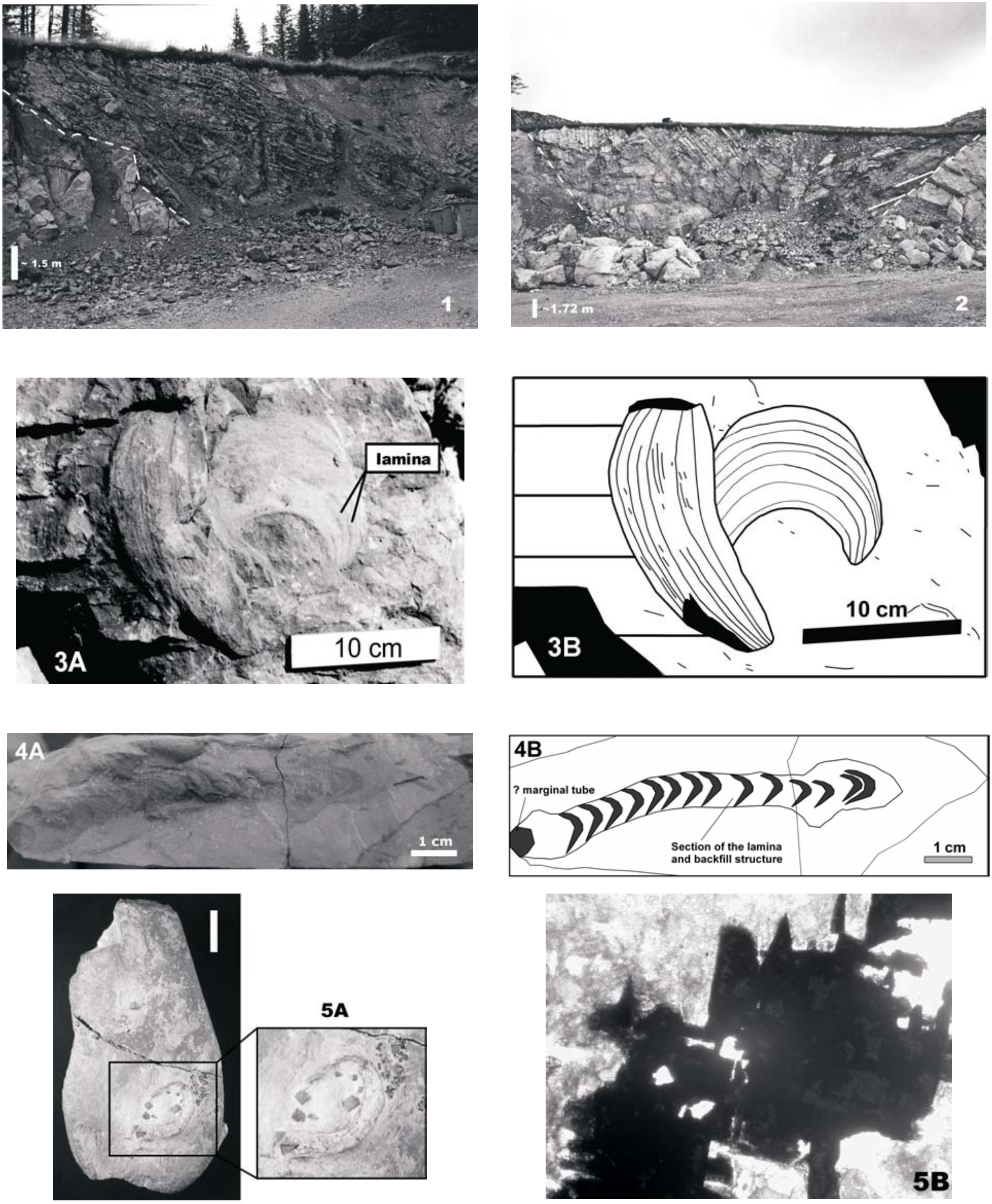
PLATE 1

Fig. 1. Outcrop section AF2, Mount Lespezi - dash line delimits Upper Berriasian and Upper Valanginian deposits;
Fig. 2. Outcrop section AF3, Mount Lespezi - dash line delimits Upper Berriasian and Upper Valanginian deposits;
Fig. 3. Organization of the *Zoophycos* burrow system: backwards, arched lamellae are clearly visible. Mount Lespezi outcrop AF2 (A - photo; B - drawing after photo);
Fig. 4. *Zoophycos* from outcrop AF3 - polished cross-sectional view of spreite filled (A - photo; B - drawing after photo)
Fig. 5. (A) Pyrite, in medallion have detail - scale bare = 1 cm; (B) thin sections with iron oxide pseudomorph after pyrite.

PLATE 1


~ 1.5 m
1
~1.72 m
2
lamina
10 cm
3A
3B
10 cm
4A
1 cm
4B
? marginal tube
Section of the lamina
and backfill structure
1 cm
5A
5B