Deep-water agglutinated foraminifera and palaeoenvironmental implications of the upper Valanginian to Hauterivian Pieniny Limestone Formation (Nad Ráztoky Quarry, Orava sector of the Pieniny Klippen Belt, Western Carpathians)

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Abstract

The upper member of the Pieniny Limestone Formation in the Western Carpathian Pieniny Klippen Belt represents a specific episode in the sedimentation of the Maiolica facies in the Mediterranean Tethys. Microfacies unusually rich in calcareous dinoflagellate cysts have been observed in the black shale intercalations. Among abundant cysts, dissolved samples yielded deep-water agglutinated foraminifera, calcareous benthic foraminifera and radiolaria. Data based on foraminiferal morphogroups and on the presence of other microfossil groups from the limestones and black shale alternations reveal microfaunal changes in this monotonous sequence. Palaeoenvironmental conditions are reflected by changes in the fossil record, influenced generally by nutrient availability and oxygen content.

Keywords: Maiolica limestones, black shales, deep-water agglutinated foraminifera, calcareous dinoflagellates, Valanginian, Hauterivian

INTRODUCTION

The Pieniny Klippen Belt (PKB) represents a narrow zone with complicated structural development and characteristic landscape with distinct topographically positive Jurassic to Lower Cretaceous "klippen" and olistoliths embedded mostly in Upper Cretaceous to Cenozoic marly or flysch deposits (e.g., Štúr, 1860; Andrusov, 1938; Birkenmajer, 1977; Mišík, 1997; Aubrecht & Sýkora, 2004; Plašienka & Mikuš, 2010). Klippen of Maiolica-type limestones are reported in most of the segments of the Slovak PKB as well as in the Polish sector (e.g., Birkenmajer, 1977; Andrusov, 1938; Scheibner & Scheibnerová, 1969).

Maiolica-type limestones in the Western Carpathian area represent a classic but rather monotonous Lower Cretaceous pelagic facies, however with several differentiated sedimentological events (Michalík & Vašíček, 1989; Michalík, 1995). The only documented black shale event is described directly from above the Pieniny Limestone Formation and correlates with the early Aptian Selli event (Michalík *et al.,* 1999). Episodes of black shale sedimentation in the Maiolica Formation were reported in the Southern Alps and Apennines (Bersezio *et al.,* 2002; Cecca *et al.,* 1994; Coccioni *et al.,* 1998). During the Valanginian and Hauterivian, such episodes of black shale sedimentation have been attributed to major perturbations in the global carbon cycle, with increased values of $\delta^{13}C$ in bulk sediment. The first perturbation occurred during the late Valanginian and is known as the Weissert event (Erba *et al.,* 2004). Occurrence of the Weissert event was reported from the Transdanubian range (Főzy *et al.,* 2010) which is the nearest to the West Carpathian area. The later Hauterivian black shale event is represented by the so-called Faraoni event (Cecca *et al.,* 1994; Schootbrugge *et al.,* 2000).

The biostratigraphy of the Maiolica Limestone Formation in the Western Carpathians has been discussed by a number of papers dealing with Upper Jurassic to Lower Cretaceous calcareous dinoflagellates exclusively studied in thin sections (Borza, 1984; Borza & Michalík, 1986; Řehánek, 1992; Vašíček *et al.,* 1994; Reháková, 2000a,b; Reháková & Wierzbowski, 2005; Michalík *et al.,* 2009, 2012).

The oldest assemblages of DWAF have been documented

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across the Tithonian –Berriasian transition from the Argo Abyssal Plain in the Indian Ocean (Holbourn & Kaminski, 1997; Kaminski *et al*., 1999). Assemblages containing Early Cretaceous DWAF have been also reported from the Vocontian Through (Moullade in Kaminski *et al*., 1999), Betic Cordillera (Kuhnt, 1995) and North Atlantic (Luterbacher, 1972). In the Maiolica facies the only and the most recent studies on DWAF are available from the Umbria Marche basin (Patruno *et al.,* 2008, Patruno *et al.,* 2015). The oldest assemblages of deep-water agglutinated foraminifera (DWAF in the following text) were first reported from the West Carpathians in Tithonian to Lower Cretaceous flysch facies (Geroch 1961, 1966).

Observations on living foraminifera show the relation between test morphology and microhabitat (e.g., Jones & Charnock 1985; Kaminski *et al.,* 1988; Murray, 1991; Corliss & Chen, 1988). The composition of the whole assemblage is controlled by parameters such as the flux of organic matter and oxygen concentrations in both bottom and pore water (e.g., Jorissen *et al*., 1995; Kaminski *et al*., 1995; Altenbach *et al.,* 1999; De Rijk et al., 2000; Van der Zwaan, 1999). These parameters create physical and chemical properties of the environment, and influence the ratio of foraminiferal morphogroups. Morphogroup analysis is not only used for modern faunas, but also is applied to Cretaceous assemblages of benthic foraminifera, in order to evaluate the palaeoenvironmental and palaeobathymetric settings (e.g., Koutsoukous & Hart, 1990; Nagy *et al*., 1995; van den Akker *et al*., 2000; Frenzel, 2000; Cetean *et al.,* 2011; Setoyama *et al*., 2011). The main advantage of this method is that it uses a generic definition of foraminiferal morphotaxa, making it less dependant on species level determinations.

The main aim of this study is to analyse the benthic foraminiferal assemblages and their relation to environmental changes with respect to occurrence of calcareous dinoflagellates or radiolaria.

MATERIALS AND METHODS

A total of ten samples of black shales and Maiolica limestones were collected. Foraminifera and calcareous dinoflagellate cysts from the black shales were obtained using non-corrosive methods. For comparison with the black shale assemblages, two samples from the alternating indurated spotty limestones were taken for acid treatment to obtain agglutinated foraminifera. As this method is $CaCO_3$-corrosive, only non calcareous components of the sample prevail from which only the so-called acid treated benthic foraminiferal assemblages are available (ATAs in the following text). Exactly 100 g of indurated limestones were dissolved uncrushed in 5% hydrochloric acid. For non-corrosive treatment 100 g. of black shales were crushed and dissolved in concentrated detergent gradually diluted in ethyl alcohol. Both residues were washed through 200, 150, 125, 71 and 25 micron mesh sieves and dried. The fractions >125 microns were picked completely, whereas the smallest fraction was only checked to determine if it contains extra species. A fraction of the samples 4a, b, c and 5 was picked also in the 71-125 micron residue to achieve a higher resolution between black shale and Maiolica limestone assemblages. SEM images were taken in the Slovak Academy of Sciences, Institute of Informatics using a Quanta FEG 250. Microslides with picked foraminifera and cysts of calcareous dinoflagellates are stored in the micropalaeontology collections at the Department of Geology and Paleontology, Faculty of Natural Sciences, Comenius University in Bratislava. The agglutinated morphogroup categories for agglutinated foraminifera were used after Cetean *et al.* (2011) (Fig. 8). In the calcareous foraminiferal assemblages, only nodosariids are present. For this reason the morphogroup categories proposed by Tyszka (1994) were used (Fig. 8). Foraminifera belonging to epifaunal or shallow infaunal morphogroups M3c and M4a were counted together due to their bad preservation state.

REUSULTS

Geological Setting

The studied quarry is located on the left side of the lower course of the Podbielsky Cickov stream, lying about 600 m NW from the nearest klippe called Nad ráztoky (Fig. 1, GPS: 49°18.257'N 19°28.041'E), and about 1.5 km SW from the Červená skala klippe on the right side of the Orava river, described as the type section of the Podbiel Succession (Andrusov in Borza, 1969). By the time of this study the best exposed parts of the quarry were on the 3rd etage uncovering white pelitic limestones accompanied by a ca. 1.5 m thick band of breccia at its base (Fig. 2.B.[a], Fig.4.A). This breccia is packed with pink, somewhat angular fragments of pelitic limestones in lighter pelitic matrix (Fig. 3.A). Most of the clasts vary in size between less than 1 cm up to around 14 cm in maximum length, however clasts larger than 18 cm have been also observed. A similar breccia was described by Birkenmajer (1977) as the Valanginian Walentowa Breccia Member. The highest part of the quarry is built of Maiolica type limestones formally attributed by Birkenmajer (1977) to the Pieniny Limestone Formation (Fig. 2.A sections 1 and 2, B[c, d] Fig. 3 b-e, Fig.

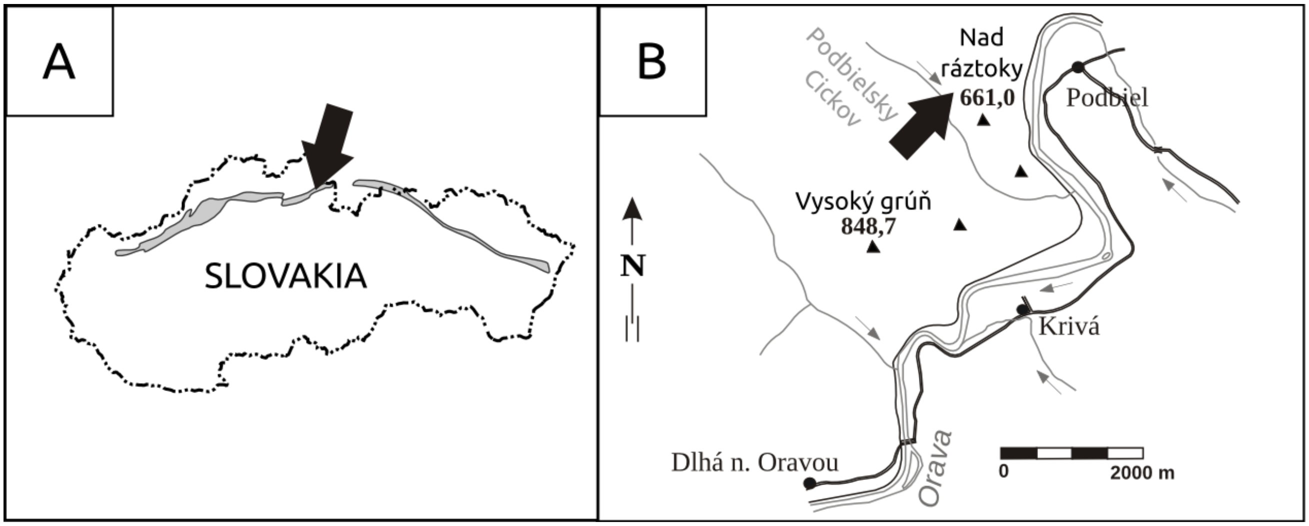

Figure 1. Position of the examined locality. A – position of the locality within the Pieniny Klippen Belt, B – enlarged map of the territory between Podbiel and Dlhá nad Oravou.

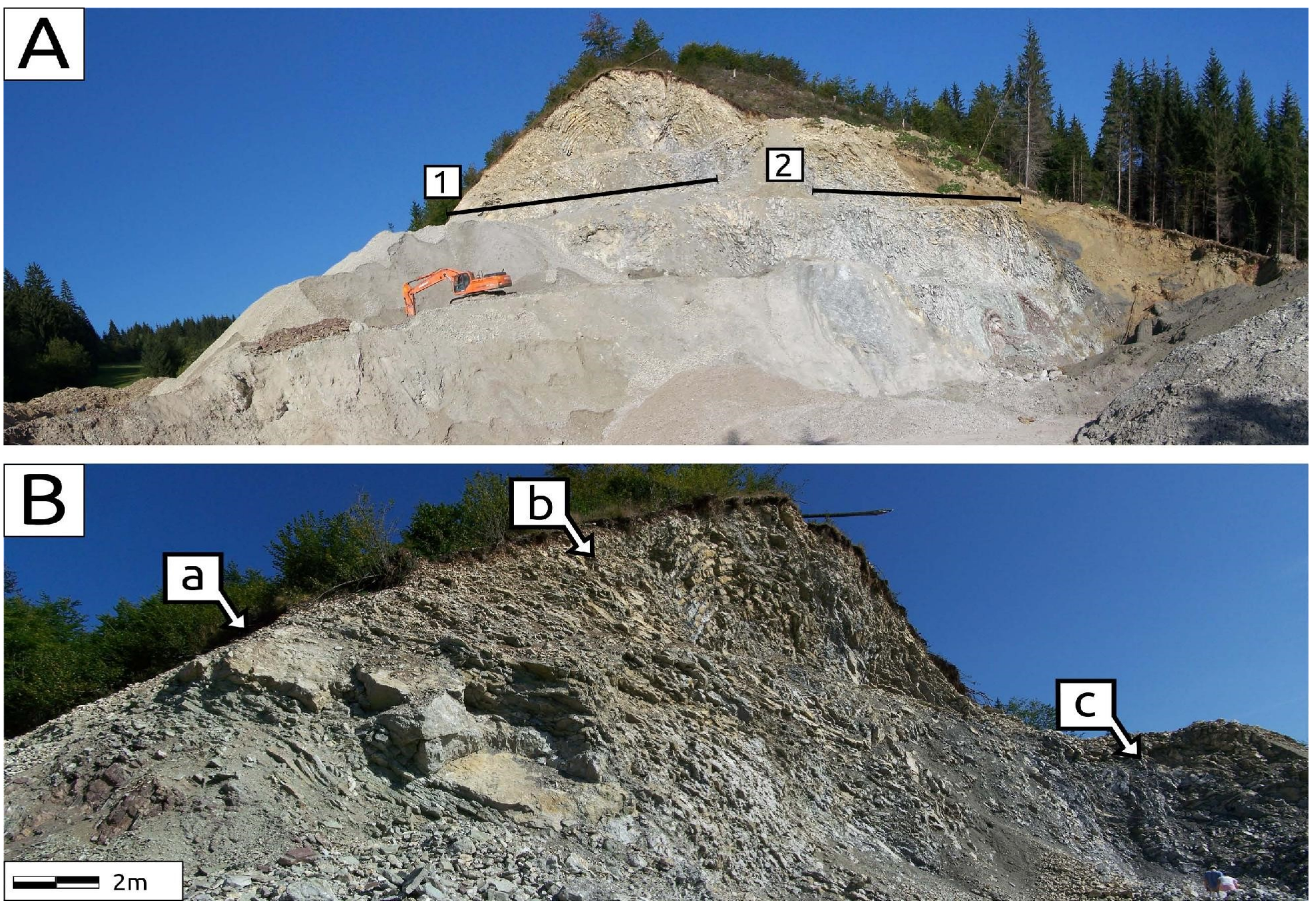

Figure 2. Formations exposed in the Nad Ráztoky klippe Quarry. A – general view of the quarry with marked sections. B – panorama of the left side of the second etage with exposed sedimentary formations. a - Walentowa breccia member – Lysa Limestone Formation. b – Pieniny Limestone Formation (middle member). c – Pieniny Limestone Formation (upper member).

4.B.C.). The microfauna studied is from the upper member of this formation. Limestones of this upper member are strongly spotted (Fig. 3.B), and intercalated by layers of black shales (Fig 3.B). Within the limestone beds sometimes bands of stratiform black cherts are observed (Fig. 3.D). The thickness of the limestone beds varies from 3 to 15 cm, however some of them may exceed 20 cm. The black shale intercalations rarely exceed 7-8 cm in thickness and become more frequent and thicker towards the southern exposures of the klippe. The Pieniny Limestone Formation on the right side of the quarry is in tectonic contact with Lower Aptian Koňhora Formation represented by black, gray or greenish marls with massive pyrite concentrations (Fig. 3.C, Fig. 4.E) and sometimes white clays with polymictic breccia with small clasts usually < 1 cm, attributed to Tvrdošín Breccia Member (Fig. 3.E [B], F, Fig. 4.D). This breccia member is documented from the base of Barremian/Aptian organodetritic limestones of the Nižná Formation (Józsa & Aubrecht, 2008).

Microfossil Studies

Abundant free cysts of calcareous dinoflagellates were obtained from washed samples in the upper part of the Pieniny Limestone Formation (Fig. 2. section no. 2, Fig. 5.1-11), while radiolarian-enriched residues are observed in the lower part of the formation (Fig. 2. section no.1, Fig. 5.13, 14). Impoverished assemblages of agglutinated and calcareous foraminifera were present in the residue from both sections.

The evaluation of seven thin sections confirms that biomicrite limestones (mudstones) with very rare and small bioclasts contain a cyst association dominated by *Colomisphaera vogleri* (Borza) (Fig. 5.1-3), with very rare *Colomisphaera* cf. *conferta* Řehánek (Fig. 5.6), *Colomisphaera* cf. *heliosphaera* (Vogler) (Fig. 5.5) and stomiosphaerid species *Stomiosphaera wanneri* (Borza) (Fig. 5.4) and *Stomiosphaera* cf. *echinata* Nowak (Fig. 5.7). The average abundance of dinocysts is 1-2% (using the optical charts of Bacelle & Bosellini, 1965). The slightly marly micritic matrix is locally rich in organic matter and pyrite.

The study of the isolated cysts under the SEM (Fig. 5, 8-11) revealed a dominance of cysts with a circular apical archeopyle of the type A (Streng *et al.*, 2004) and a pirumellid type of wall ultrastructure. According to systematic features *Pirumella multistrata patriciagreeleyae* (Bolli) was identified among the isolated cyst assemblage (Fig. 5, 8-11).

Among other microfossils, pyritized or calcified radiolaria are present in the lower samples (PC1, PC3). Common to abundant spumellaria and scarce to common nasellaria were found in the lower part of the formation (Fig. 5.13, 14). SEM observations of dinocyst surfaces show elements of calcareous nannoplankton belonging to the genus *Watznaueria* (Fig. 5.15). Sample PC4a yielded also occasional sponge spicules (rhaxes and hexactinic spicules). Small aptychi were noted in samples PC1, PC4a and PC6. Ostracods are noted only in the green marls at the base of the Koňhora Formation.

Foraminifera

The lower parts of the member yielded relatively rich assemblages of agglutinated foraminifera (Fig. 2 – upper part of the section no. 1, Fig. 4 samples PC1, PC3). The species *Glomospira gordialis* (Jones & Parker), *Ammodiscus* spp. (Fig. 6.7-10), *Pseudoreophax cisovnicensis* Geroch, *Eobigenerina variabilis* (Vašíček) (Fig. 6.16-20, 22, 23), *Conglophragmium* sp., *Haplophragmoides* sp. (Fig. 7.1, 4) and tubular forms (Fig. 6.2-6) dominate the assemblages. Calcareous foraminifera are impoverished and consist of smooth-walled *Lenticulina* and rare nodosariids. Foraminifera rarely exceed 200 μm in size.

The upper part of the member situated on the right side of the quarry (Fig. 2 section no. 2, Fig. 4 samples PC4-6) yielded agglutinated foraminifera that are even smaller, and much less represented in the residue > 125 μm. These are associated with the enhanced bioproductivity of calcareous dinoflagellates. Black shale intercalations record a distinct drop in the abundance of agglutinated foraminifera and an increase in calcareous benthic foraminifera (Fig. 4, sample PC4a). The opposite trend is observed in the Maiolica limestone beds, with increased numbers of agglutinated foraminifera (Fig. 4, sample PC4b, PC4c). An increase in tubular forms (Fig. 6.1, Fig. 9, morphogroup M1) and the appearance of common to abundant *Haplophragmoides* spp. have been observed within the limestones (Fig. 7.2,3,5,6, Fig. 9, morphogroups M3c, M4a), whereas none of the taxa occur in the black shales. The occurrence of rare *Glomospira charoides* (Jones & Parker) was also noted only in the limestones.

Greenish marls towards the base of Koňhora Formation yielded a different assemblage of agglutinated foraminifera. The most characteristic taxon is *Verneuilinoides* cf. *neocomiensis* Mjatliuk (Fig. 7.7,8), which forms an acme in this horizon (Fig. 4). *Rhizammina* sp., *Glomospira gordialis* (Jones & Parker) and *Ammogloborotalia globorotaliaeformis* (Gradstein & Kaminski) (Fig. 7.9-11) are also abundant. The species *Glomospira charoides* (Jones & Parker), *Reophax* sp. and *Haplophragmoides* sp. are scarce. Calcareous benthic foraminifera are rather scarce and represented by *Lenticulina*, *Astacolus*, *Laevidentalina*, *Marginulina* and

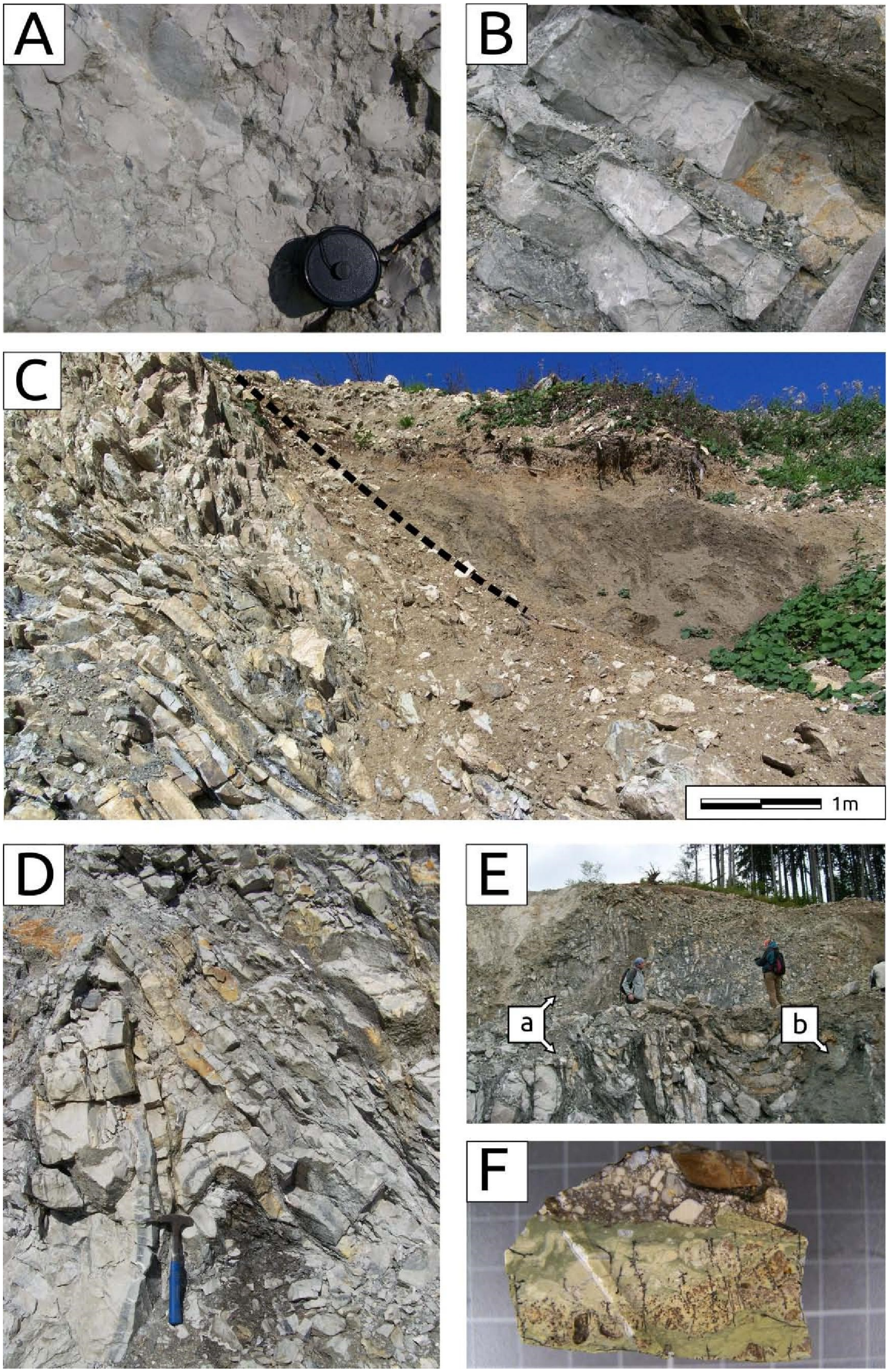

Figure 3. Detailed features of the formations exposed by the quarry. A – Walentova breccia with subangular clasts of pink pelitic limestones. B – bioturbated light gray Maiolica type limestone beds of Pieniny Limestone Formation with black shale intercalations. C – contact of the Pieniny Limestone Formation with black to green marls on the right side of the quarry (dotted line). D – fold in the upper member of Pieniny Limestone Formation with stratiform black cherts in the limestone beds. E – right side of the quarry with the folded upper member of the Pieniny Limestone Formation (a) and green marls with breccia (b). F – polished sample of the polymictic Tvrdošín breccia from the contact with the Pieniny Limestone Formation (scale: 1 background square= 1 cm).

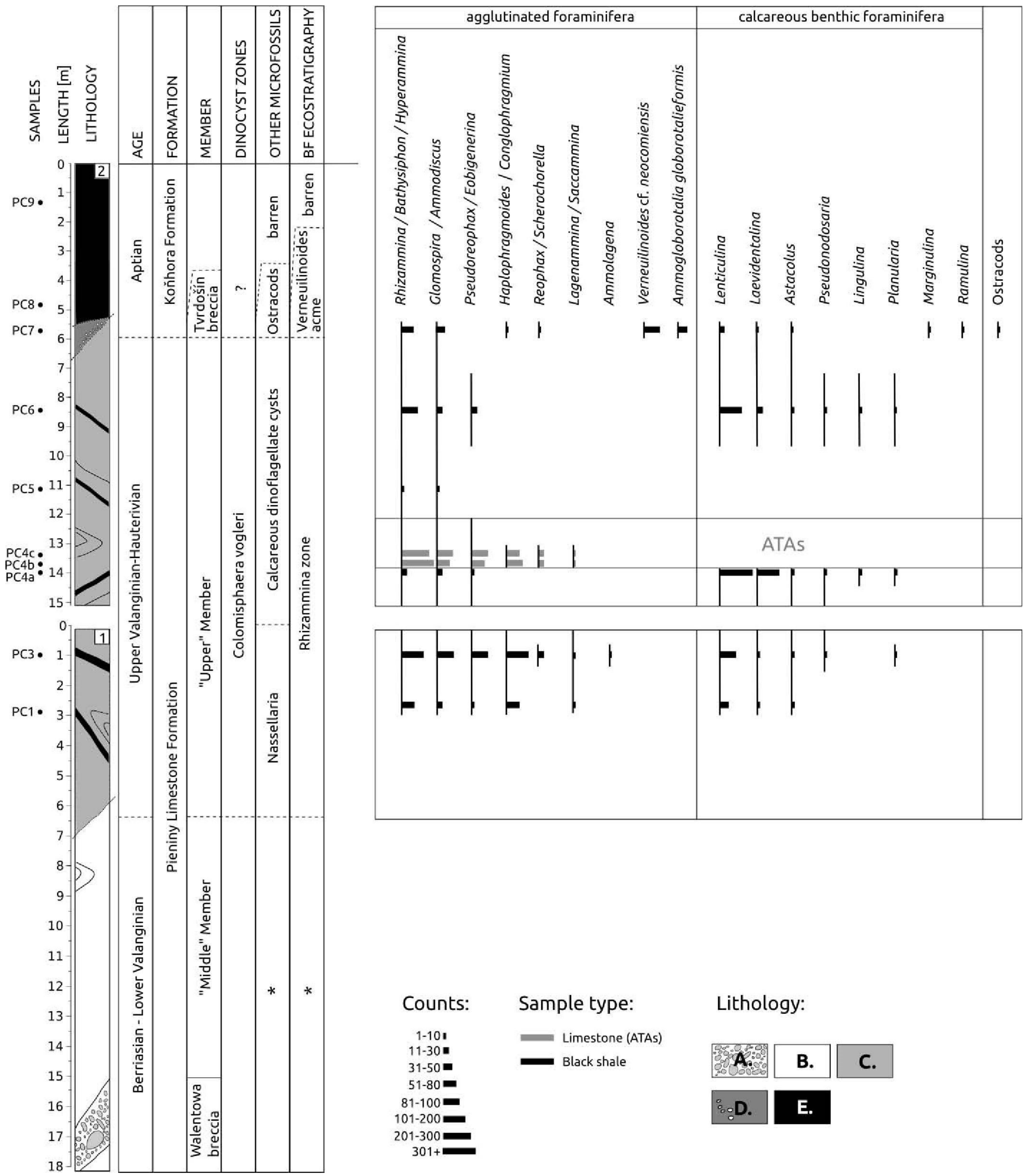

Figure 4. General lithological profile of the second etage of the quarry, with position of the samples and rangechart with foraminifera. ATA – acid treated assemblages, * – member not studied. Lithology column: A – breccia with pink angular pelitic limestones in white matrix (Walentowa breccia member – Lysa Limestone Formation). B – white pelitic limestones (Pieniny Limestone Formation). C – light gray bioturbated limestones with black marl intercalations and black cherts (upper member of the Pieniny Limestone Formation). D – green, white marls to clays with breccia (Tvrdošín breccia). E – black to green marls with pyrite (Koňhora Formation).

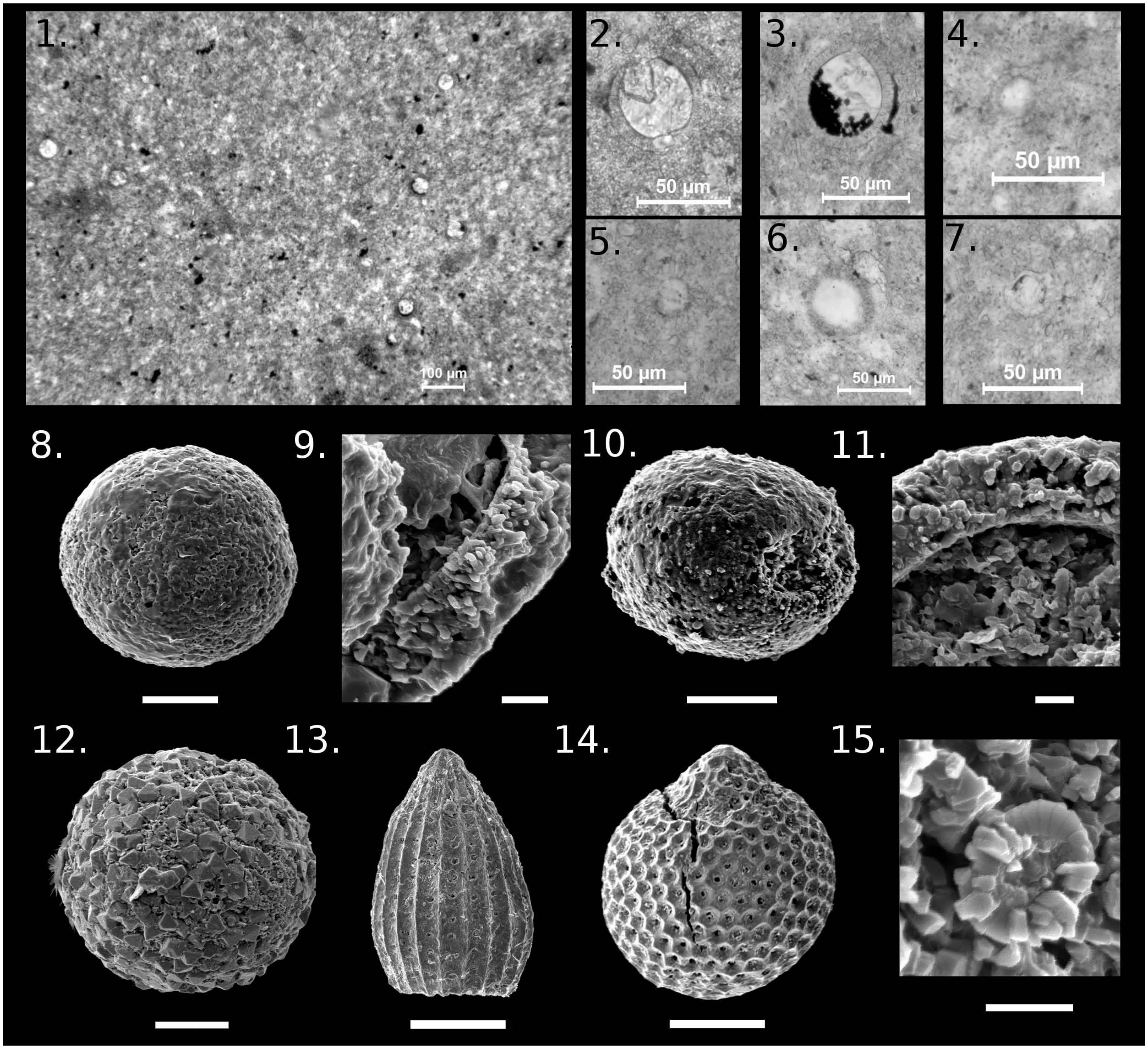

Figure 5. Calcareous dinoflagellate cysts, radiolaria and nannofossils. 1 – calcareous dinocyst microfacies, 2, 3 – *Colomisphaera vogleri* (Borza), 4 – *Stomiosphaera wanneri* (Borza), 5 – *Colomisphaera* cf. *heliosphaera* (Vogler), 6 – *Colomisphaera* cf. *conferta* (Řehánek), 7 – *Stomiosphaera* cf. *echinata* Nowak, 8, 9 – *Pirumella multistrata patriciagreelaeyae* (Bolli), 9 – close up of the cyst wall section, 10, 11 – *Pirumella multistrata* cf. *patriciagreelaeyae* (Bolli), 11 – close up of the cyst wall section. 12 – pyrite cast of dinocyst. 13, 14 – Nasellaria, 15 – *Watznaueria* sp. Scale bars: 1 – 100µm, 2 – 7, 13, 14 50µm, 8 – 20µm, 10, 12 – 10µm, 9, 11, 15 – 3µm. Samples: 1–12 PC4a, 13 –15 PC3.

Ramulina.

Palaeoecology

As presented by this study, beds of the Maiolica limestones alternate with cyclic short-term episodes of black shale sedimentation (Fig. 3.B). The black shales in the lower part of the formation indicate more favourable conditions for agglutinated foraminifera than the black shales in the upper part. This is supported by the relatively high abundance of this group, including the presence of abundant infaunal taxa represented by morphogroup M4b (Fig. 9.A sample PC3). The black shales in the upper part of the formation yield only low numbers of agglutinated foraminifera, while these are common in the alternating Maiolica limestones (Fig. 9.A samples PC 4b, PC4c). Characteristic for the upper black shales is the C8 morphogroup represented predominantly by

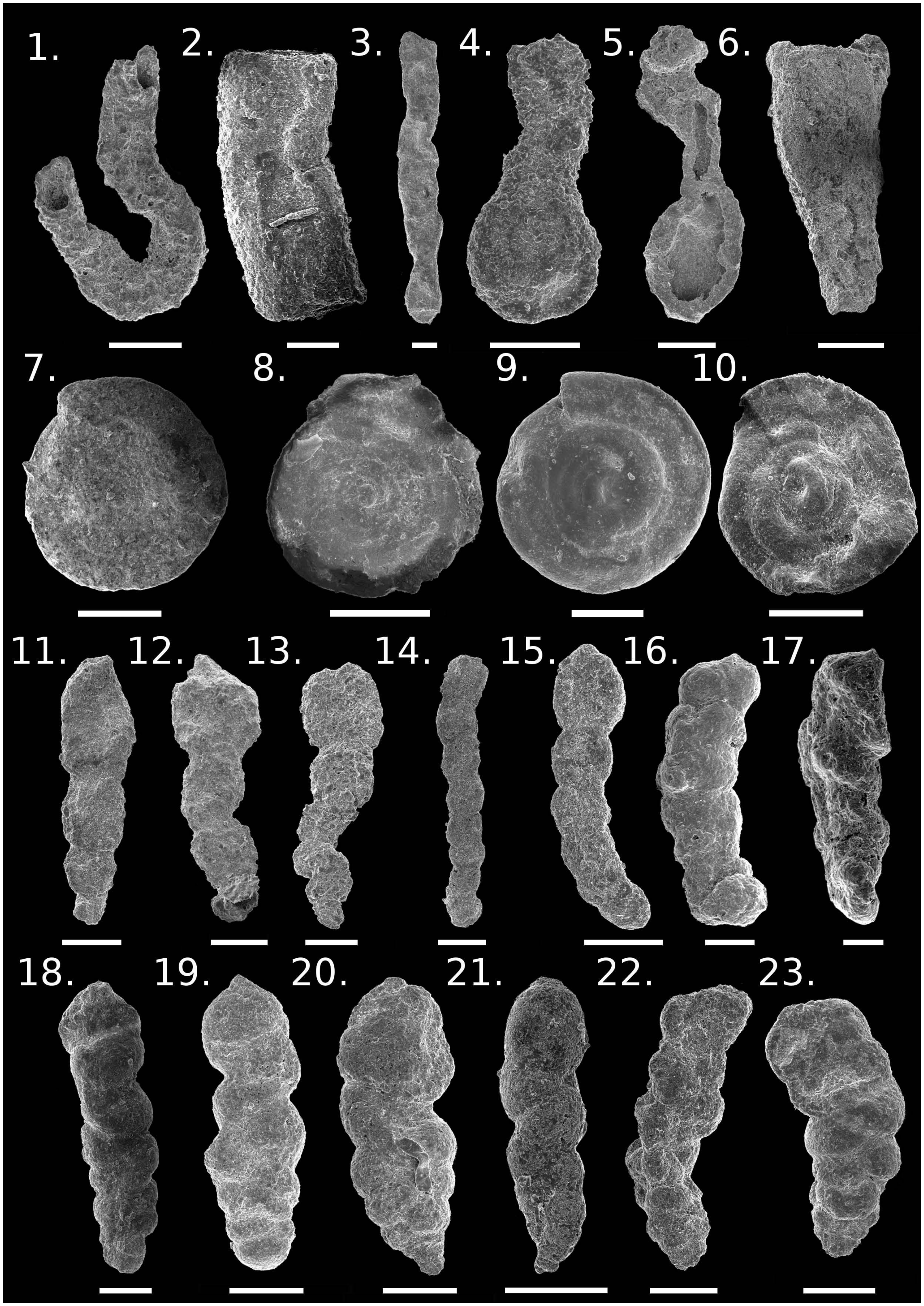

Figure 6. Agglutinated foraminifera. 1 – *Rhizammina* sp., 2 – *Bathysiphon* sp., 3 – *Hyperammina gaultina* (Ten Dam), 4 – *Lagenammina distributa* Mjatliuk, 5 – *Ammolagena* sp., 6 – *Hippocrepina depressa* Vašíček, 7 – *Ammodiscus infimus* Franke, 8 – *Ammodiscus tenuissimus* (Gümbel), 9, 10, *Glomospira gordialis* (Jones & Parker), 11 – *Reophax helveticus* (Haeusler), 12, 13 – *Reophax* sp., 14 – *Reophax* cf. *parvulus* Huss 15 – *Scherochorella minuta* (Tappan), 16, 17 – *Pseudoreophax cisovnicensis* Geroch, 18 – 21 – *Eobigenerina variabilis* (Vašíček), 22, 23 – *Eobigenerina* sp. Samples: 14, 15, 18, 22 – PC1, 2 – 13, 16, 17, 20, 23 – PC3, 1– PC4b, 21 – PC4c, 19 – PC6, Scale bar 100μm.

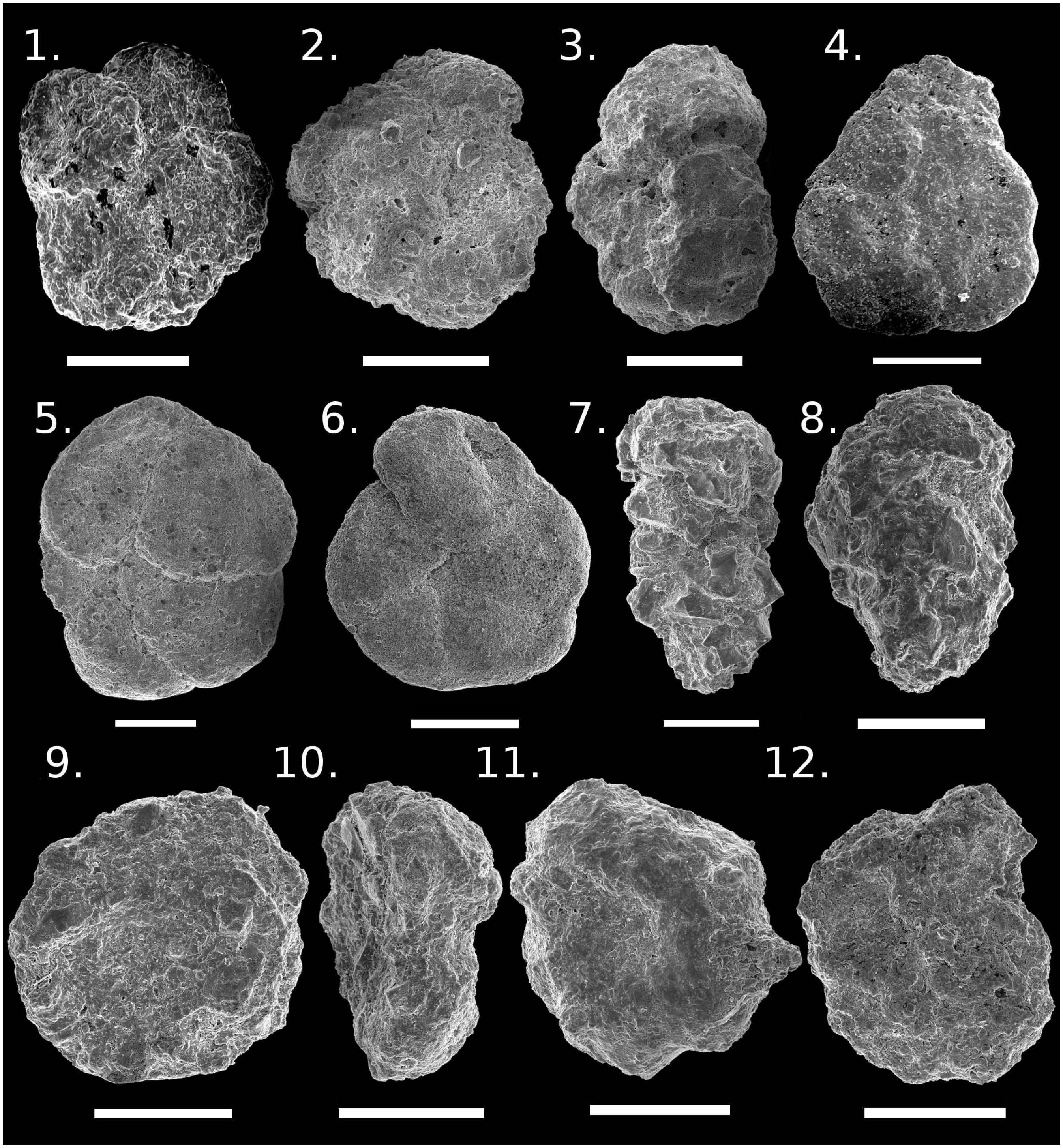

Figure 7. 1 – *Conglophragmium* sp., 2, 3 – *Haplophragmoides* sp., 4 – 6 – *Haplophragmoides gigas minor* (Nauss), 7, 8 – *Verneuilinoides* cf. *neocomiensis* Mjatliuk, 9 – 11 – *Ammogloborotalia globorotaliaeformis* (Gradstein & Kaminski), 12 – *Trochammina* sp., Samples: 1 – PC1, 2, 5 – PC4a, 3, 6 – PC4b, 4, 12 – PC3, 7 – 11 – PC7, Scale bar 100µm.

smooth walled *Lenticulina* (Fig. 9.B, samples PC4a, PC6). According to Tyszka (1994), this genus has an opportunistic behavior. Calcareous benthic foraminifera seem to have colonised the substrate preferentially after episodes of unfavourable conditions before the agglutinated foraminifera. The few numbers and low diversity of agglutinated foraminifera in the upper black shales suggest that they responded to recolonization of the substrate more slowly after a crisis (Fig. 9.A, sample PC4a). Fully recovered assemblages are observed later in the alternating Maiolica limestone beds (Fig. 9, samples PC4b, PC4c). An increase in the C8 morphogroup and lower ratios of agglutinated foraminifera correlate with the mass occurrence of calcareous dinoflagellate

	Morphogroup	Test form	Life position	Feeding habit	Genera
AGGLUTINATED FORAMINIFERA	M1	Tubular	Epifaunal erect	Suspension feeders	*Rhizammina, Bathysiphon, Hyperammina, Hippocrepina, Lagenammina*
	M2a	Globular	Shallow infaunal	Suspension feeding / or passive deposit feeding	*Saccammina*
	M2b	Planoconvex trochospiral	Epifaunal	Active deposit feeding	*Trochammina, Ammogloborotalia*
	M2c	Elongate keeled	Epifaunal	Active deposit feeding	NOT PRESENT
	M3a	Flattened planispiral and streptospiral	Epifaunal	Active and passive deposit feeding	*Ammodiscus, Glomospira*
	M3b	Flattened iregular	Epifaunal	Suspension feeding	*Ammolagena*
	M3c	Flattened irregular	Epifaunal	Active and passive deposit feeding	*Conglophragmium*
	M4a	Rounded planispiral	Epifaunal / shallow infaunal	Active depostit feeding	*Haplophragmoides*
	M4b	Elongated subcylindrical	Deep infaunal	Active depostit feeding	*Verneuilinoides*
		Elongated tapered	Deep infaunal	Active depostit feeding	*Reophax, Pseudoreophax, Eobigenerina*
	Morphogroup	Test form	Life position	Feeding habit	Genera
CALCAREOUS BENTHIC FORAMINIFERA	C1	trochospiral, biconvex or planoconvex	Epifaunal	Primary weed fauna	NOT PRESENT
	C2	Irregular meandrine	Epifaunal	Deposit feeding	*Ramulina*
	C3	Planispiral (discoidal flatened) or trochospiral (planoconvex)	Epifaunal	Primary weed fauna	NOT PRESENT
	C4	Planispiral (discoidal flatened)	Epifaunal	Active deposit feedeers	NOT PRESENT
	C5	Elongated inflated	Shallow infaunal	Deposit feeders	NOT PRESENT
	C6	Elongated flattened	Shallow to deep infaunal	Active deposit feedeers	*Astacolus, Planularia, Lingulina, Vaginulinopsis*
	C7	Elongated straight periphery	Shallow to deep infaunal	Deposit feeders	*Laevidentalina, Pseudonodosaria*
	C8	Biconvex	Epifaunal to infaunal	Active deposit feedeers	*Lenticulina*

Figure 8. Calcareous benthic and agglutinated foraminiferal morphotypes (after Tyszka 1994 and Cetean *et al.* 2011).

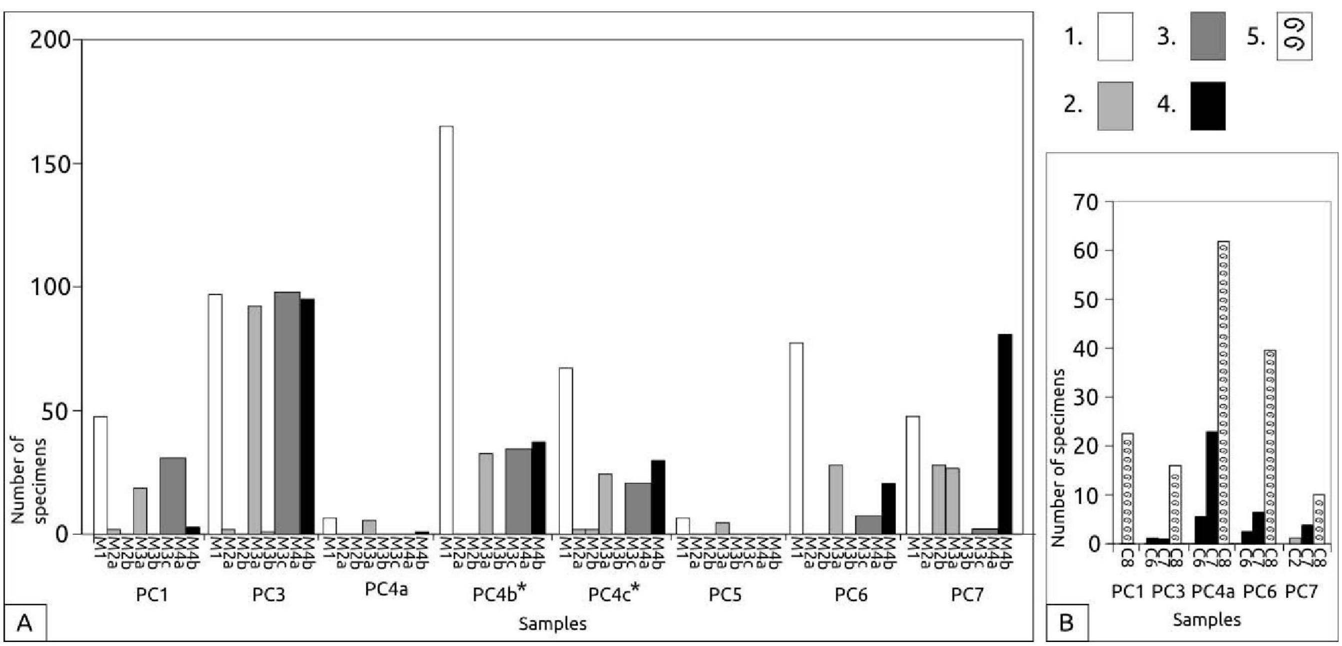

Figure 9. Numbers of specimens belonging to particular morphogroups. Samples with ATA's marked with an asterisk. A – agglutinated foraminiferal morphogroups. B – calcareous foraminiferal morphogroups. 1 – tubular epifaunal morphogroups. 2 – epifaunal morphogroups. 3 – epifaunal or alternatively shallow infaunal morphogroups. 4 – infaunal morphogroups. 5 – epifaunal to infaunal morphogroups.

cysts in the upper black shales.

The M1 morphogroup represented with tubular forms is mostly dominant in the "Upper" member in the Pieniny Limestone Formation. This morphogroup is represented by suspension feeders, preferring low organic carbon flux and high dissolved oxygen content (e.g., Nagy, 1992; Tyszka, 1994; Kaminski & Kuhnt, 1995). Similar assemblages are also observed in the Barremian of the Maiolica Formation in the Umbria Marche basin described as the *'Rhizammina'* spp. assemblage (Patruno *et al*., 2015). At the base of the Koňhora formation an acme of *Verneuilinoides* cf. *neocomiensis* Mjatliuk was observed. A similar assemblage was observed by Patruno *et al.,* (2015) directly below the Selli black shale level. The dominance of infauna indicates poorly oxygenated conditions.

O'Dogherty & Guex (2002) concluded that in some cases nassellaria are less resistant to environmental stress and are more common in stable environments. The presence of common nassellaria in the lower part of the formation might represent a relatively more stable environment of the water column, as opposed to the environment with enhanced dinocyst production. As observed through the section, this changing environment of the water column is accompanied by changes in the composition of deep-water benthic assemblages as well.

During the Early Cretaceous, episodes of environmental change occurred, linked to ocean fertilization and/or black shale sedimentation (Coccioni *et al*., 1998; Erba *et al*., 2004; Fölmi, 2012). The response of deep-water agglutinated benthic foraminiferal communities at first might have profited from the enhanced organic carbon flux, however, the decrease in oxygen at some critical point limited their distribution (Fig. 9.A, sample PC4a, PC5). Eutrophic conditions may have favored opportunistic species of calcareous benthic foraminifera and the production of the calcareous dinoflagellate cysts (Fig. 9.B, sample PC4a, PC6). During dinocyst events, assemblages were dominated by a single taxon, larger and with thicker walls. We explain this feature to be caused by changing water temperature in the environment. Good preservation of the cysts may be related to the broadening of organic wall preserving the calcitic test before dissolution or recrystallisation during diagenesis.

Notes on Stratigraphy

Spotted limestones with black shales from the Pieniny Limestone Formation are reported by Birkenmajer (1977) as Hauterivian – Barremian, with age assignments confirmed by ammonites, aptychi, belemnites, and nannoplankton. The limestones of this upper member are overlying white limestones of the Berriasian – Valanginian "middle" member. Several events with dinocyst-enriched facies from the Western Carpathian Maiolica facies are reported by Borza (1984), Reháková (2000a) from the Upper Jurassic and Lower Cretaceous, however, such a florishment of *Colomisphaera vogleri* (Borza) was not observed until now. This species is rare in upper Berriasian sediments (Reháková in Vašíček *et al.,* 1999). Its presence in microfacies with absence of calpionellids suggests an age younger than late Valanginian (Reháková, 2000b).

The agglutinated foraminifera are of little stratigraphic value, however, some species seem to have a common occurrence. The species *Pseudoreophax cisovnicensis* Geroch (fig.5 16, 17) ranges from the upper Tithonian up to the Barremian in the Carpathians (Geroch & Nowak, 1984). An acme of *Verneuilinoides* cf. *neocomiensis* Mjatliuk was observed by Patruno *et al*. (2015) from the Gorgo Cerbara stratotype section and predates the lower Aptian Selli anoxic event (OAE1). *Ammogloborotalia globorataliaeformis* (Gradstein & Kaminski) was originally described from Aptian/Albian of the Norwegian Sea (Kaminski *et al.,* 2007).

DISCUSSION

The composition of the foraminiferal assemblage is typical for abyssal depths. The only calcareous microfossils present are calcareous dinoflagellate cysts, nodosariids, and the nannofossil *Watznaueria*, which is considered to be more resistant to dissolution than other coeval nannofossils (Roth & Bowdler 1981).

The presence of black shales points to a relation with the Early Cretaceous episodes of major perturbations in the carbon cycle. Similar distributions of the radiolarian and agglutinated foraminifera associations are reported from the Hauterivian Faraoni level of the Fiumo Boso section (Coccioni *et al*., 1998), however the absence of planktonic foraminifera might point to the older late Valanginian Weissert event (Erba *et al*., 2004; Coccioni *et al*., 2006). The Koňhora Formation is correlated with the lower Aptian Selli event (Michalík *et al*., 1999).

CONCLUSIONS

The section through the upper part of the Pieniny Limestone Formation in the Nad ráztoky Quarry represents a monotonous sequence of Maiolica type formation. Noticeable palaeoenvironmental changes affecting benthic foraminiferal assemblages and other microfossil groups have been inferred across this section. The lower black shale intercalations with nasellaria are richer in agglutinated foraminifera whereas the upper ones are clearly dominated by calcareous foraminifera. Within the upper black shales, enhanced dinocyst bioproduction was observed. These facies were less favourable for the development of agglutinated foraminifera due to oxygen depleted conditions, and the substrate was colonised by opportunistic calcareous species. A more oxic environment has been inferred for the limestone alternations, where the diversity, abundance and morphogroup spectrum of agglutinated foraminifera significantly increased. Such taxa as *Haplophragmoides* or *Conglophragmium,* and maxima of the M1 tubular morphogroup have been observed only in the more oxic Maiolica limestones and the lower black shales. The change from a nasselarian association to a calcareous dinocyst abundant association through the section reflects increasing ecological stress in the water column and it also correlates with changes in benthic foraminifera.

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