

# Stratigraphy and palaeoenvironments in the upper Turonian to lower Coniacian of the Saxonian Cretaceous Basin (Germany) – insights from calcareous and agglutinated foraminifers

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## ABSTRACT:

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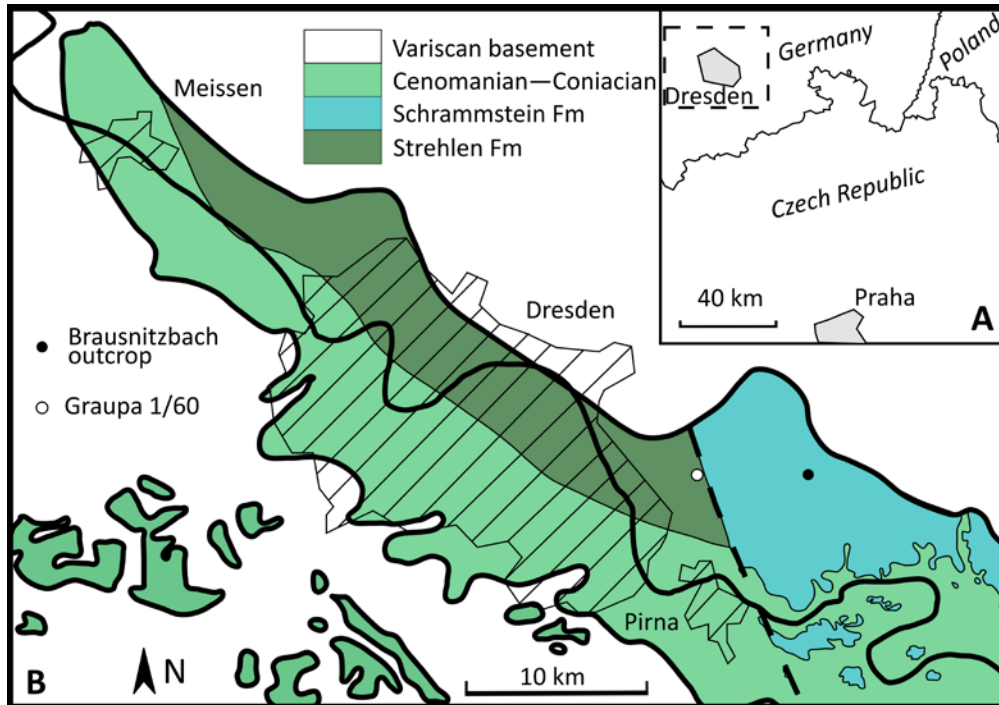
Upper Turonian to lower Coniacian marls of the Strehlen Formation of the Graupa 60/1 core were investigated for their foraminiferal content to add stratigraphical and palaeoenvironmental information about the transitional facies zone of the Saxonian Cretaceous Basin. Further comparison with foraminiferal faunas of the Braunsnitzbach Marl (Schrammstein Formation) were carried out to clarify its relationship to the marls of the Graupa 60/1 core. Tethyan agglutinated marker species for the late Turonian to early Coniacian confirm the proposed age of the marls of the Graupa 60/1 core and the Braunsnitzbach Marl. The palaeoenvironment of the marls reflects middle to outer shelf conditions. The maximum flooding zones of genetic sequences TUR6, TUR7 and CON1 could be linked to acmes of foraminiferal species and foraminiferal morphogroups. In general, a rise of the relative sea-level can be recognised from the base to the top of the marls of the Graupa 60/1 core. While agglutinated foraminiferal assemblages suggest a generally high organic matter influx and variable but high productivity in the Graupa 60/1 core, the Braunsnitzbach Marl deposition was characterized by moderate productivity and a generally shallower water depth.

**Key words:** Foraminifera; Palaeoecology; Biostratigraphy; Turonian; Coniacian; SE Germany.

## INTRODUCTION

Stratigraphy and facies analysis of Cretaceous clastic deposits in Central Europe meets the problem that the pure quartz sandstones that originated close to the coastline are mostly non-fossiliferous, except of occasional occurrences of inoceramids. The often-observed structureless appearance of these sandstones even hinders the reconstruction of dep-

ositional conditions, such as water depth, currents, and influence of tides and storms. In contrast, the deeper water facies represents an open, well-oxygenated shelf environment with rich faunal communities. Biostratigraphy and palaeoecology of the marginal parts of the basins are therefore mainly based on intercalations of finer-grained sediments such as marls and calcareous siltstones within the sandstones. Although thicker marl packages are sometimes as



Text-fig. 1. A – Geographical position of the study area (indicated by dashed box). B – Simplified geological map of the Dresden area; shaded areas indicate urban areas, dashed line indicates the tentative boundary between Schrammstein and Strehlen formations; redrawn and modified after Schönfeld and Voigt (2020).

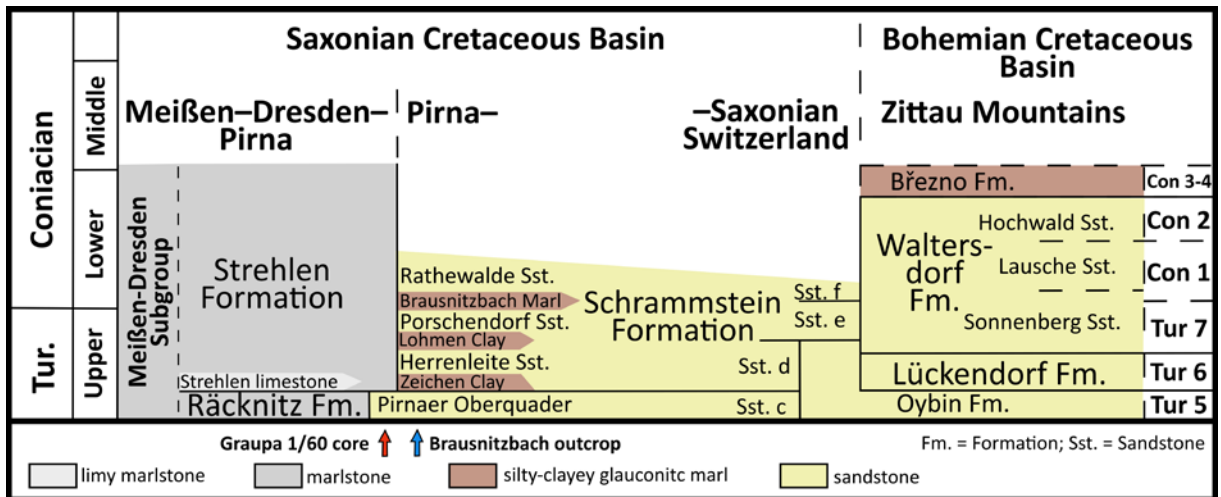
monotonous as the sandstones, caused by intense to complete bioturbation, palaeontological investigations of the mid-Cretaceous deposits from the Lower Saxony Basin and the Subhercynian Cretaceous Basin showed that variations of the foraminiferal faunal communities and palaeoecological features may sensitively reflect sea-level fluctuations, temperature trends, and clastic input (Prokoph *et al.* 1999; Tyszka 2009; Friedrich *et al.* 2011; Meischner and Elicki 2018; Elicki *et al.* 2020).

The Graupa 60/1 borehole is a key section for the basin fill interpretation of the Saxonian Cretaceous Basin concerning sea-level, tectonics, and depositional environments because it is situated at the transition of coastal sands to basinal marlstones (Tröger 1964). Especially the upper Turonian to lower Coniacian succession is crucial for understanding the interaction of tectonics, climate, and depositional processes, because only a few hundred meters to the southeast, the marly unit of the Strehlen Formation is completely replaced by thick sandstone packages with only a few fine-grained intercalations (Schrammstein Formation). While a biostratigraphic subdivision based on macrofossils was already established by Tröger and Wejda (1997, 1998), this study

aims to confirm the proposed age, add stratigraphic information to the Strehlen Formation of the Graupa 60/1 core, and clarify the stratigraphic position of the Brausnitzbach Marl (Schrammstein Formation). Changes in foraminiferal assemblages tracked by their relative abundances, distribution of morpho-groups, calculated diversity, planktic/benthic ratio, and similarities should give hints on the palaeoenvironmental settings and their changes during the late Turonian to early Coniacian. Especially, this study focuses on sea-level fluctuations and aims at connecting them to the genetic sequences proposed by Uličný *et al.* (2009) and Nádaskay *et al.* (2019).

## REGIONAL AND GEOLOGICAL SETTING

The Saxonian Cretaceous Basin represents the connecting strait between the Bohemian Cretaceous Basin and the North German shelf sea, and comprises a succession from the lower Cenomanian to the lower Coniacian (e.g., Tröger 2004; Wilmsen *et al.* 2019). The basin fill is composed of massive sandstones with low to absent fossil content close to an actively uplifting basin margin, and hemipelagic marlstones



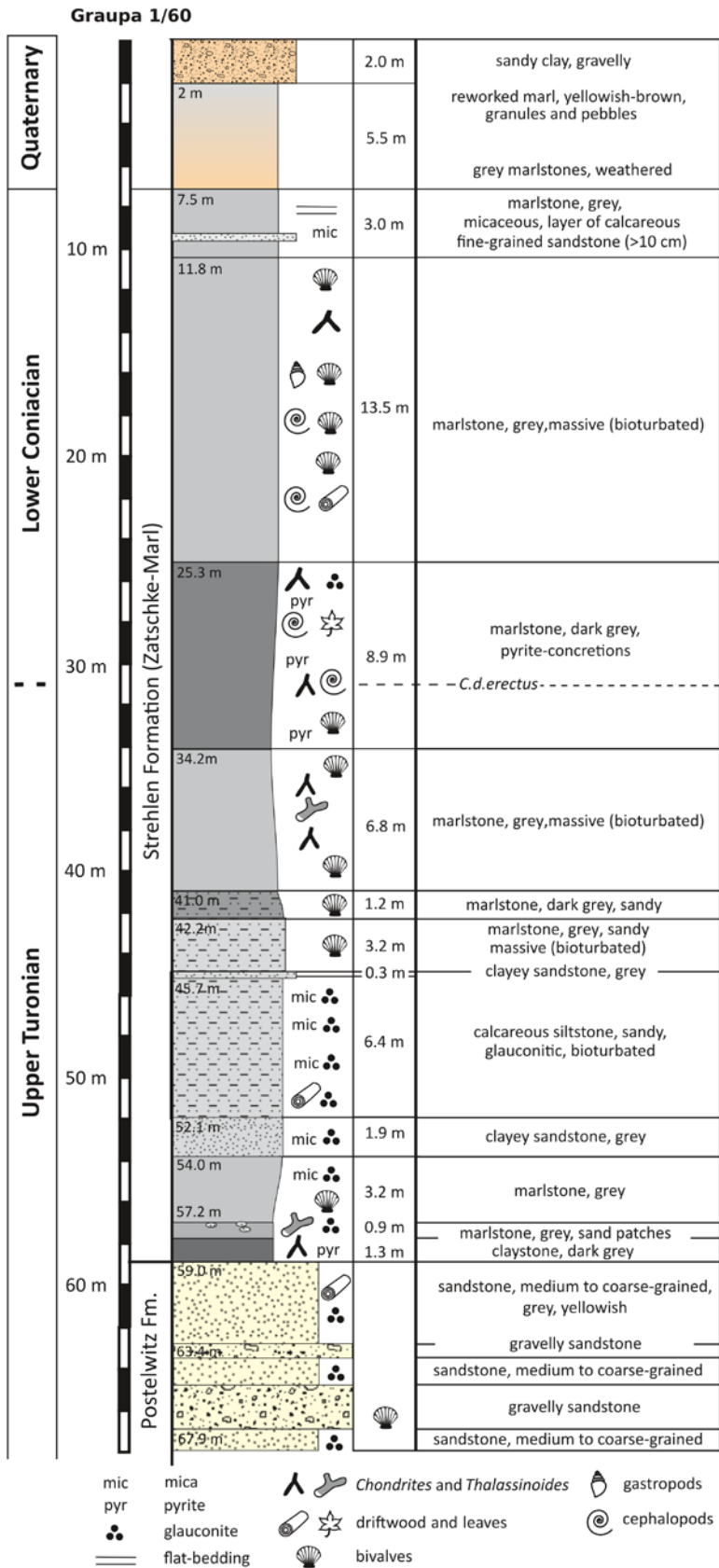
Text-fig. 2. Upper Turonian to Coniacian chrono- and lithostratigraphy of the Elbtal Group in the Saxonian Cretaceous and the north-western Bohemian Cretaceous basins; redrawn and modified after Niebuhr *et al.* (2020); genetic sequences adapted from Uličný *et al.* (2009), Nádaskay and Uličný (2014), and Nádaskay *et al.* (2019).

in the distal regions (Text-figs 1 and 2). Intercalations of distal to proximal facies occur contemporaneously across the whole basin and are interpreted to be related to global sea-level fluctuations (Tröger and Voigt 1995; Laurin and Uličný 2004; Uličný *et al.* 2009; Janetschke and Wilmsen 2014; Janetschke *et al.* 2015; Nádaskay *et al.* 2019; Wilmsen *et al.* 2019; Niebuhr *et al.* 2020; Čech and Uličný 2021). Sedimentation in the basin margin is related to the Late Cretaceous basin inversion in Central Europe (e.g., Voigt 2009; Nádaskay *et al.* 2019), creating an uplifting source area and an adjacent marginal trough. The inversion likely started slowly in the Cenomanian and culminated from the Coniacian to the Campanian according to apatite fission track data (Lange *et al.* 2008; Danišik *et al.* 2010; Käšner *et al.* 2020; compiled by Voigt *et al.* 2021). Nevertheless, deposits younger than the Coniacian were not preserved in the Saxonian part of the basin, pointing to the Cenozoic regional uplift, which affected both the source area and the basin. General biostratigraphy of the basin fill is based on inoceramids and, to a minor degree, on ammonites in the hemipelagic and the deeper shelf facies, while only a few units of the coastal sandstones were dated with inoceramids (compare Niebuhr *et al.* 2020). The boundary to the former source area is represented by a major fault (Lausitz Thrust), formed in the late stages of basin inversion. It cuts through both marginal and basinal deposits. The sediments dip towards this fault, resulting in the preservation of the youngest sediments close to the thrust.

### Graupa 60/1 borehole

The Graupa 60/1 borehole was drilled between Graupa and Hinterjessen, north of Pirna (Text-fig. 1). It reached a final depth of 333.3 m. The position of the borehole is within the transitional facies belt described by Petrascheck (1900), Seifert (1955), and Tröger (2004) between pure coastal sandstones and basinal fine-grained marlstones (Dresden-Meißen Subgroup, Text-fig. 2). The borehole cored an almost complete succession of the Elbtal Group from the basement (lower Cambrian granodiorite) to the lower Coniacian marls and some meters of Quaternary deposits. Lithostratigraphy of the Elbtal Group is based on Tröger and Voigt (1995), Tröger and Wejda (1998), Voigt and Tröger (2007), and Niebuhr *et al.* (2020). In this paper we focus on the 55 m thick upper Turonian to lower Coniacian Strehlen Formation (4.0–59.0 m core depth), overlying the middle to upper Turonian Postelwitz Formation (Text-fig. 3). The biostratigraphy is based on inoceramids (Tröger *et al.* 1961; Tröger and Wejda 1997).

The massive upper Turonian to lower Coniacian marlstones, assigned to the Strehlen Formation, start with a sharp base directly on a massive, middle- to coarse-grained quartz sandstone with glauconite grains ('Pirnaer Oberquader'), which represents the top of the underlying Postelwitz Formation (Text-figs 2 and 3). The marls and claystones in the basal unit (59.0–45.4 m) are dark grey and contain detritic mica and fine quartz sand, either dispersed or in patches and lenses (Text-fig. 3). Dense bioturbation is ex-



Text-fig. 3. Lithological log of the upper part of the Graupa 60/1 core, lithological documentation from Tröger *et al.* (1961), position of the first occurrence of *Cremonoceras deformis erectus* from Tröger and Wejda (1998).

pressed with a domination of small traces (mainly *Zoophycos* isp., 3–10 mm thick, and *Chondrites* isp.). Pyrite concretions and glauconite are common. At a depth of 45.4 m occurs an intercalation of a sandy marlstone. Between 41.0 and 45.4 m, marly to sandy siltstones ('Pläner') prevail (Text-fig. 3). Above this unit, massive, structureless grey marlstones without any bedding planes and only rare traces of bioturbation follow (Text-fig. 3). Visible bioturbation is limited to dark *Chondrites* isp. burrows. The marlstones are rich in fossils (bivalves, gastropods, ammonites, benthic foraminifers) and contain small pieces of driftwood. In the lower part of this unit, between 34.2 and 41.0 m, the carbonate content is lower than up-section. Tröger and Wejda (1997) placed the boundary between the Turonian and Coniacian in an interval at around 31 m, with the first appearance of *Cremonoceras rotundatus* (*sensu* Tröger, 1967, *non* Fiege, 1930), which is considered to be a synonym of *Cremonoceras deformis erectus* (Meek, 1877) (see Walaszczyk and Cobban 1999, 2000 and Walaszczyk and Wood 1999; Text-fig. 3). A revision of Cretaceous inoceramid biostratigraphy by Walaszczyk *et al.* (2010) proposed the base of the Coniacian at the FAD of *Cremonoceras deformis erectus*, which now defines the Turonian/Coniacian boundary (Walaszczyk *et al.* 2021). Tröger and Wejda (1998) reported also the inoceramid *Cremonoceras waltersdorfensis hannovrensis* (Heinz, 1932) occurring even earlier in the Graupa 60/1 borehole, but these specimens most likely belong to the late Turonian mytiloids (personal communication Walaszczyk 12.2020).

### Braunsnitzbach Marl

The Braunsnitzbach Marl of the Schrammstein Formation is a c. 10–20 m thick lower Coniacian sandy marlstone unit, naturally exposed in a small creek north of Lohmen (Text-figs 1 and 2). It is bordered by the Porschendorf Sandstone at the base and by the Rathewalde Sandstone at the top (Niebuhr *et al.* 2020; Text-fig. 2). The Rathewalde Sandstone represents the uppermost sandstone unit in the Saxonian Cretaceous Basin (Text-fig. 2) and reaches a thickness of 50–70 m.

## MATERIAL AND METHODS

The Graupa 60/1 core was reduced to representative samples of marls already in the 1960s, which limited the sampling and caused that the samples are referred to a depth interval, not a designated depth.

16 samples of the Graupa 60/1 core from depth interval between 11.8 and 56.7 m, and 2 samples from the Braunsnitzbach Marl were split into two subsamples each and treated both with formic acid and acetic acid in combination of copper-II-sulphate, respectively. Afterwards, the residues were washed, dried, and studied with a stereomicroscope. The photographs were taken with a Keyence Digital Microscope. The applied taxonomy of the calcareous foraminifers is based on Caron (1983a), Frenzel (2000) and the online platform WoRMS; the taxonomy of the agglutinated foraminifers is based on Neagu (1968), Frieg (1980), Gawor-Biedowa (1980), Frieg and Price (1982), Loeblich and Tappan (1987), Frieg *et al.* (1989), Bubík (1995), Kuhnt and Kaminski (1997), Frenzel (2000), Kaminski and Gradstein (2005), Cetean *et al.* (2011b), Kaminski *et al.* (2011, 2021), and Setoyama *et al.* (2011, 2017).

From the formic acid residue, at least 300 specimens per sample were identified. Indeterminable specimens were not included. As far as possible, specimens were taxonomically assigned to species level, as the generic information does not seem to be fully reliable for biodiversity data analyses (Wiese *et al.* 2016). Agglutinated tubular specimen counts were divided by the factor of five to get more reliable data because this group is in general fragmented to several pieces (Bubík 2019). Cluster analyses were performed on the formic acid residue dataset with application of the CONISS function (Grimm 1987) for a constrained total sum of square cluster analysis. The morphogroup analysis bases on the idea that different groups of agglutinated foraminifera can be divided by their morphology, which differs due to preferred habitats and thus, different factors as mainly feeding strategies. Based on this, relative abundances of different morphogroups can be assigned to environmental changes (Jones and Charnock 1985). This concept was subsequently modified by Bąk *et al.* (1997), Peryt *et al.* (1997, 2004), van den Akker *et al.* (2000) and Murray *et al.* (2011). The present study follows the morphogroup scheme of Cetean *et al.* (2011a) and Setoyama *et al.* (2017; Table 1).

The Fisher-Alpha diversity indices (Fisher *et al.* 1943), correlations and multivariate analyses were calculated on raw counts using the PAST program package (Hammer *et al.* 2001). Rare taxa, i.e., occurring only in one sample or with smaller relative abundance than the error of the counts, were excluded from the multivariate analyses. Because of low foraminifer counts, especially for benthic foraminifers in samples treated with acetic acid, successive samples were grouped into larger entities for a multivariate



| Morphogroup | Test Form   | Life position                                     | Environment                         | Main genera   |
|-------------|---|---|-------------------------------------|---|
| M1          | Tubular   | Erect epifauna                                    | Bathyal and abyssal                 | <i>Bathysiphon</i><br><i>Nothia</i><br><i>Psammosiphonella</i>                              |
| M2a         | Globular  | Shallow infaunal                                  | Bathyal and abyssal                 | <i>Caudammina</i><br><i>Psammosphaera</i><br><i>Saccammina</i>                              |
| M2b         | Rounded trocho- and<br>streptospiral, plano-<br>convex trochospiral | Surficial epifaunal                               | Shelf to deep marine                | <i>Ataxophragmium</i><br><i>Trochammina</i>   |
| M2c         | Elongate keeled   | Surficial epifaunal                               | Shelf to marginal marine            | <i>Spiroplectammina</i>   |
| M3a         | Flattened planispiral<br>and<br>streptospiral                       | Surficial epifaunal                               | Lagoonal<br>to<br>abyssal           | <i>Ammodiscus</i><br><i>Glomospira</i><br><i>Repmanina</i>                                  |
| M3b         | Flattened irregular   | Surficial epifaunal                               | Upper bathyal<br>to<br>abyssal      | <i>Ammolagena</i><br><i>Hemisphaerammina</i>  |
| M3c         | Flattened streptospiral   | Surficial epifaunal                               | Upper bathyal<br>to<br>abyssal      | <i>Ammosphaeroidina</i><br><i>Praecystammina</i><br><i>Trochamminoides</i>                  |
| M4a         | Rounded planispiral   | Surficial epifaunal<br>and/or<br>shallow infaunal | Inner shelf<br>to<br>upper bathyal  | <i>Haplophragmoides</i>   |
| M4b         | Elongate subcylindrical   | Deep infaunal                                     | Inner shelf<br><br>to upper bathyal | <i>Arenobulimina</i><br><i>Dorothia</i><br><i>Gaudryina</i><br><i>Tritaxia</i>              |
|             | Elongate tapered  |   |                                     | <i>Ammobaculites</i><br><i>Bulbobaculites</i><br><i>Reophax</i><br><i>Pseudonodosinella</i> |

Table 1. Agglutinated foraminiferal morphogroups and morphotypes. Modified from Cetaan *et al.* (2011) and Setoyama *et al.* (2017).

analysis of the whole dataset. Samples with low foraminiferal abundance, e.g., Graupa 60/1 49 m and 49.4 m and the Braunsitzbach samples, were excluded from the multivariate analysis on the counts of the acid residue. All included foraminifer data were standardized before analyses to set the same weight to relative abundances and indices. The dataset with indices is given in the Appendix – Supplementary Table available only in the online version.

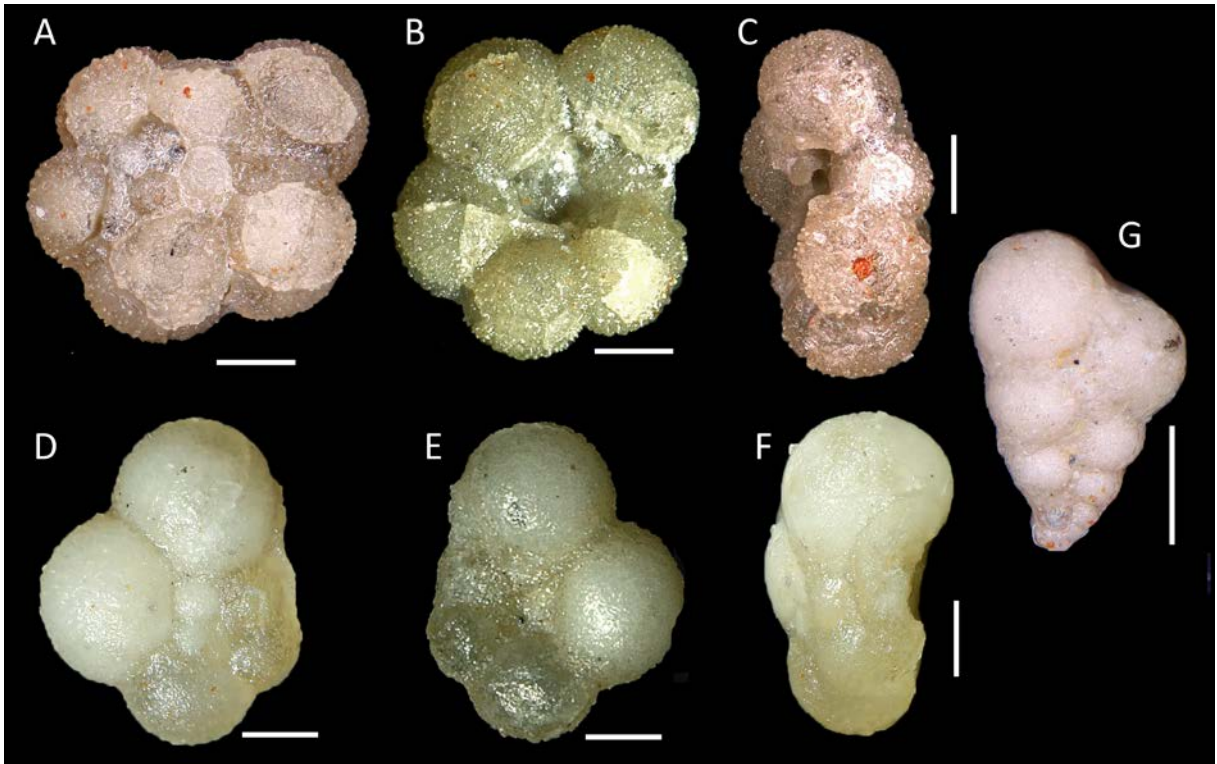
The genetic sequence concept by Galloway (1989) was combined with data from the foraminiferal record. Genetic sequences are bounded by maximum transgressive surfaces and are interpreted to correspond to relative sea-level changes (Galloway 1989), which enables interregional correlations.

## RESULTS

### Taxa and preservation

In samples treated with acetic acid and copper-II-sulphate, 933 planktic foraminiferal specimens of 5 taxa and 289 benthic specimens of 15 both calcareous and agglutinated taxa could be determined, while in contrast the samples treated with formic acid allowed a determination of altogether 4,735 agglutinated foraminiferal specimens including 78 species.

Agglutinated and calcareous foraminifera recovered with application of acetic acid and copper-II-sulphate processing are medium- to well-preserved both



Text-fig. 4. Selected planktic foraminifera from the Strehlen Formation of the Graupa 60/1 core. A–C – *Whiteinella aprica* (Loeblich and Tappan, 1961) (41 m core depth). D–F – *Whiteinella baltica* (Douglas and Rankin, 1969) (41 m core depth). G – *Planoheterohelix globulosa* (Ehrenberg, 1840) (41 m core depth). Scale bars 100 µm.

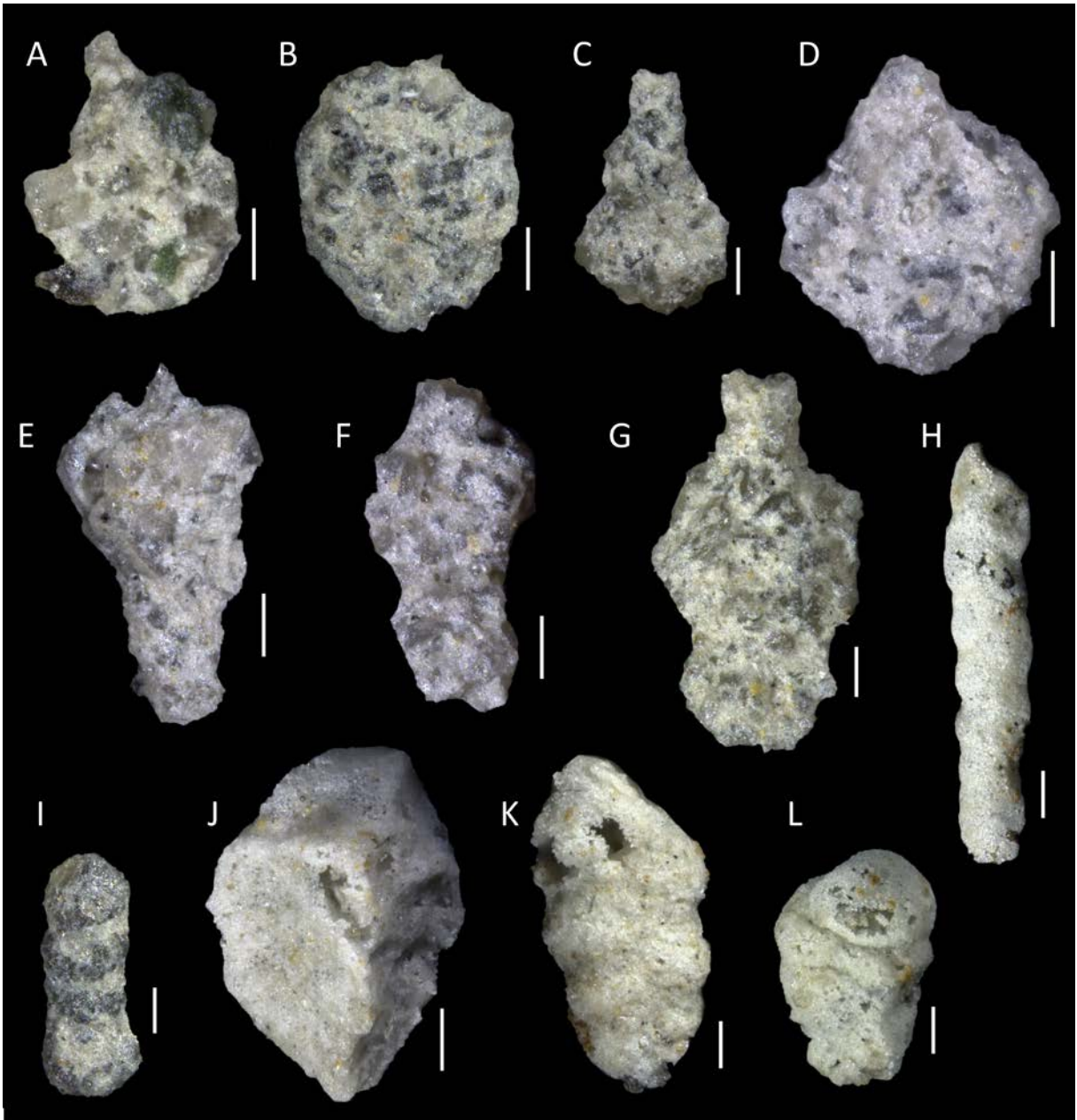
in the Graupa 60/1 core and the Brausnitzbach outcrop. Because of the dominant fine fraction of the limy marlstones of the Strehlen Formation, most of the specimens are completely preserved, sometimes with the outer chamber missing most likely due to post-sedimentary diagenetic processes. Some calcareous specimens seem to be reworked and encrusted, thus hindering further taxonomical determination. Agglutinated foraminifera extracted from the same samples with formic acid are generally well-preserved due to complete removal of the calcareous matrix and no mechanical strain during acetolysis. Some specimens appear fragmented due to mechanical treatment before or during burial, washing, or diagenetic processes.

In the upper part of the core in every sample, except for an interval between c. 47 and 50 m of core depth, at least 300 specimens per sample treated with formic acid could be identified. The interval between c. 47 and 50 m of the Graupa 60/1 core and all samples from the Brausnitzbach Marl contain only a few agglutinated foraminifer specimens which could not be used for statistical purposes.

#### Distribution of foraminifera

*Whiteinella* spp. (Text-fig. 4A–F) is the most abundant foraminifer group of the acetic acid residues along the core, with peaks higher than 85%. Their abundance is well above the benthic foraminifera reaching 563.4 individuals per 1 g. Compared to the planktic (hyaline) foraminifera, the benthic ones played a minor role in the associations. Only the taxa *Gyroidinoides umbilicatus* (d'Orbigny, 1840), *Ataxophragmium variabile?* (d'Orbigny, 1840) and *Lenticulina* sp. are common in a few samples, with the latter dominant at the depth of 52.1 m, which is also the only sample with benthic foraminifera being dominant, representing 73% of the total abundance.

In formic acid-treated samples, some species appear with high abundances in certain parts of the marl of the Graupa 60/1 borehole. At core depth of 42.2 m, both *Ataxophragmium depressum* (Perner, 1892) and *Psammosphaera fusca* Schultze, 1875 (Text-fig. 5A) are abundant in high numbers. The first species occurs with 20.5% relative abundance, the second with almost 25%. Other mass occurrences

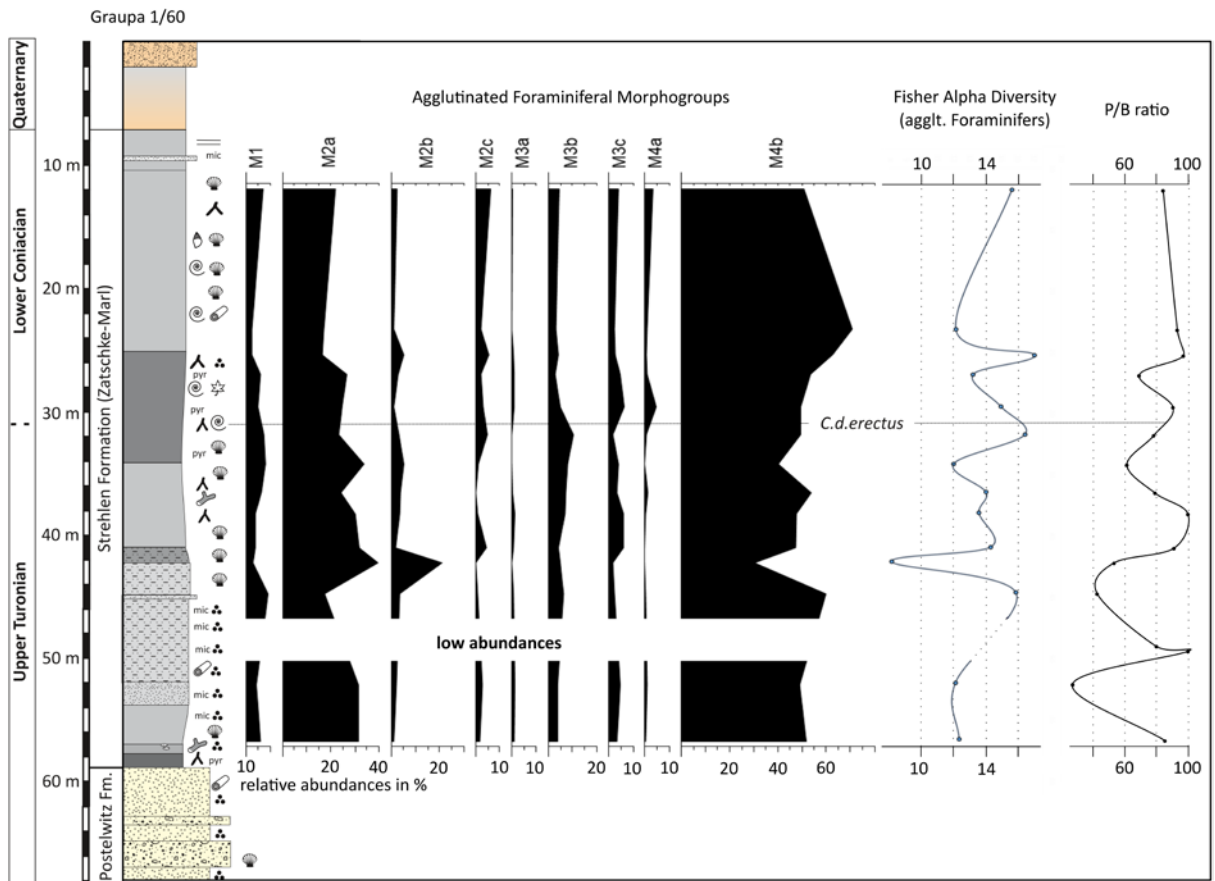


Text-fig. 5. Important agglutinated foraminifera from the Strehlen Formation of the Graupa 60/1 core. **A** – *Psammospaera fusca* Schultze, 1875 (42.2 m core depth). **B** – *Psammospaera irregularis* (Grzybowski, 1896) (38.2 m core depth). **C** – *Lagenammina difflugiformis* (Brady, 1879) (34.2 m core depth). **D** – *Saccamina grzybowskii* (Schubert, 1902) (42.2 m core depth). **E** – *Tipeammina elliptica* (Deecke, 1884) (44.7 m core depth). **F** – *Reophax globosus* Sliter, 1968 (56.7 m core depth). **G** – *Reophax subfusiformis* (Earland, 1933) (52.1 m core depth). **H** – *Spiroplectammina praelonga* (Reuss, 1845) (41 m core depth). **I** – *Bulbobaculites problematicus* (Neagu, 1962) (26.9 m core depth). **J** – *Tritaxia tricarinata* (Reuss, 1845) (26.9 m core depth). **K** – *Dorothia conula* (Reuss, 1845) (23.2 m core depth). **L** – *Gaudryina carinata* Franke, 1914 (31.8 m core depth). Scale bars 100  $\mu\text{m}$ .

in the latter section are all represented by *Dorothia conula* (Reuss, 1845) (Text-fig. 5K; see Discussion). At the depth of 41 m, the first acme appears with 17% relative abundance, shortly followed by another

one c. 5 m above with 24.2%. The highest relative abundance recorded for *D. conula* was noted in depth interval between 25.3 and 23.2 m with 25.7 to 38.6% (see Discussion).





Text-fig. 6. Relative abundances of agglutinated foraminiferal morphogroups, Fisher-Alpha diversity, and P/B ratio recorded in the Strehlen Formation of the Graupa 60/1 core. For lithological descriptions see Text-fig. 2.

### Fisher Alpha

The calculated Fisher-Alpha index for the agglutinated foraminiferal fauna ranges from 8 to 17 with a median of 14. A pronounced minimum occurs at core depth of 42.2 m with an index of 8. Several maxima are notable. They appear at core depth of 44.7 m with 16, at 31.8 m with 16.5, and at 25.3 m with a Fisher-Alpha index of 17 (Text-fig. 6).

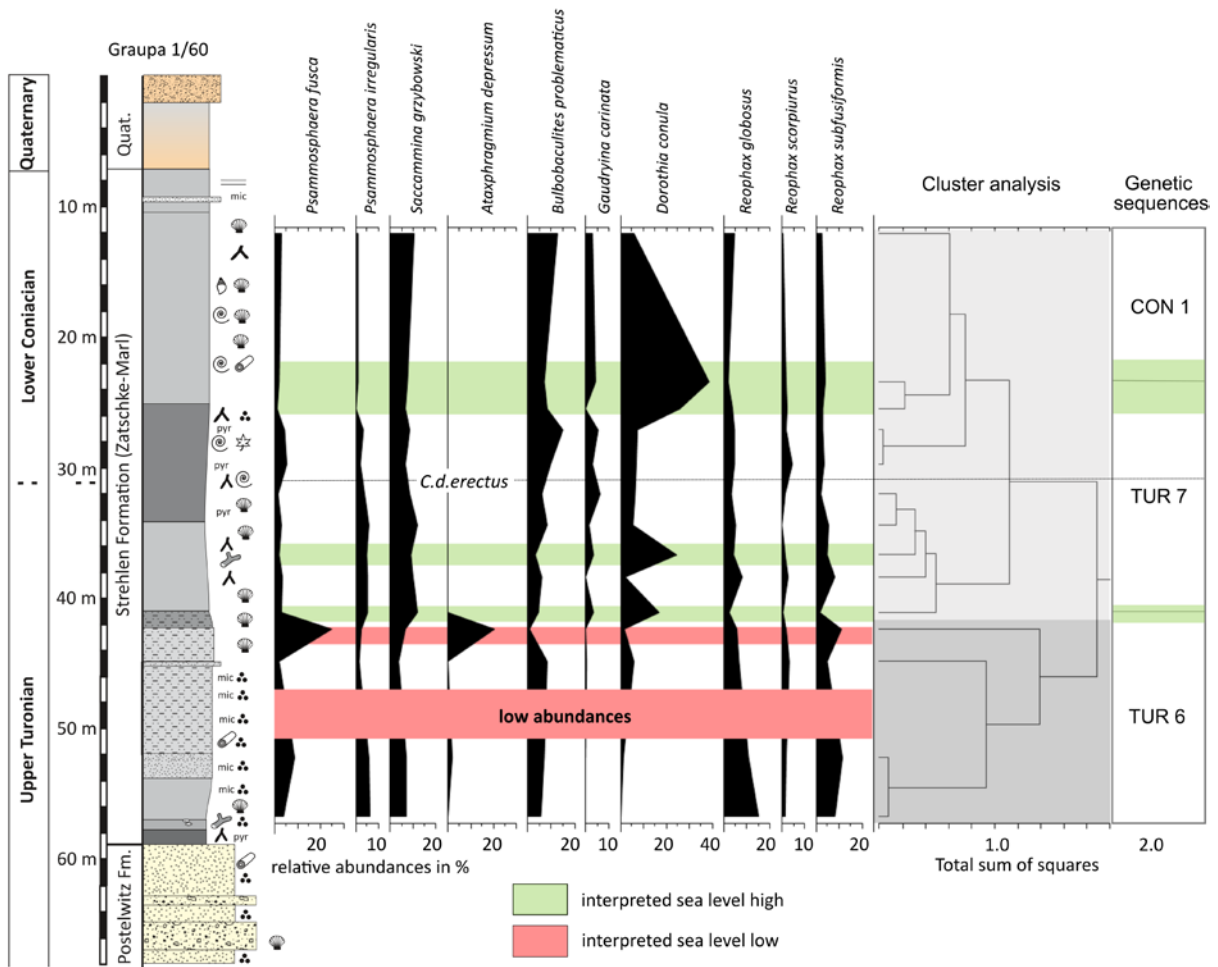
### Clusters

All included samples contain relatively similar faunas regarding agglutinated foraminifers. Nevertheless, with help of a stratigraphically constrained cluster analysis, CONISS, two clusters could be identified (see Discussion and Text-fig. 7). Both yield the same taxa, but at different ratios. The most important taxa are *Bulbobaculites problematicus* (Neagu, 1962), *Dorothia conula*, *Lagenamina dif-*

*flugiformis* (Brady, 1879), *Psammosphaera fusca*, *Psammosphaera irregularis* (Grzybowski, 1896), *Reophax globosus* Sliter, 1968, *Reophax subfusiformis* (Earland, 1933) and *Saccamina grzybowskii* (Schubert, 1902) (Text-fig. 5). The first cluster G1 from depth interval of 56.7 to 42.2 m differs from cluster G2 in its higher relative abundance of *Psammosphaera fusca* and different *Reophax* spp. species (Text-fig. 5F, G). In contrast, cluster G2 from depth interval 41 to 11.2 m yields higher numbers of *Bulbobaculites problematicus*, *Dorothia conula* and *Saccamina grzybowskii* (Text-fig. 5I, K and D, respectively).

### Morphogroups

Tubular agglutinated foraminifers of morphogroup M1 range below 10% (Text-fig. 6). Epifauna from morphogroups M2b, M2c, M3a, M3c and M4a are common in low abundances not exceeding



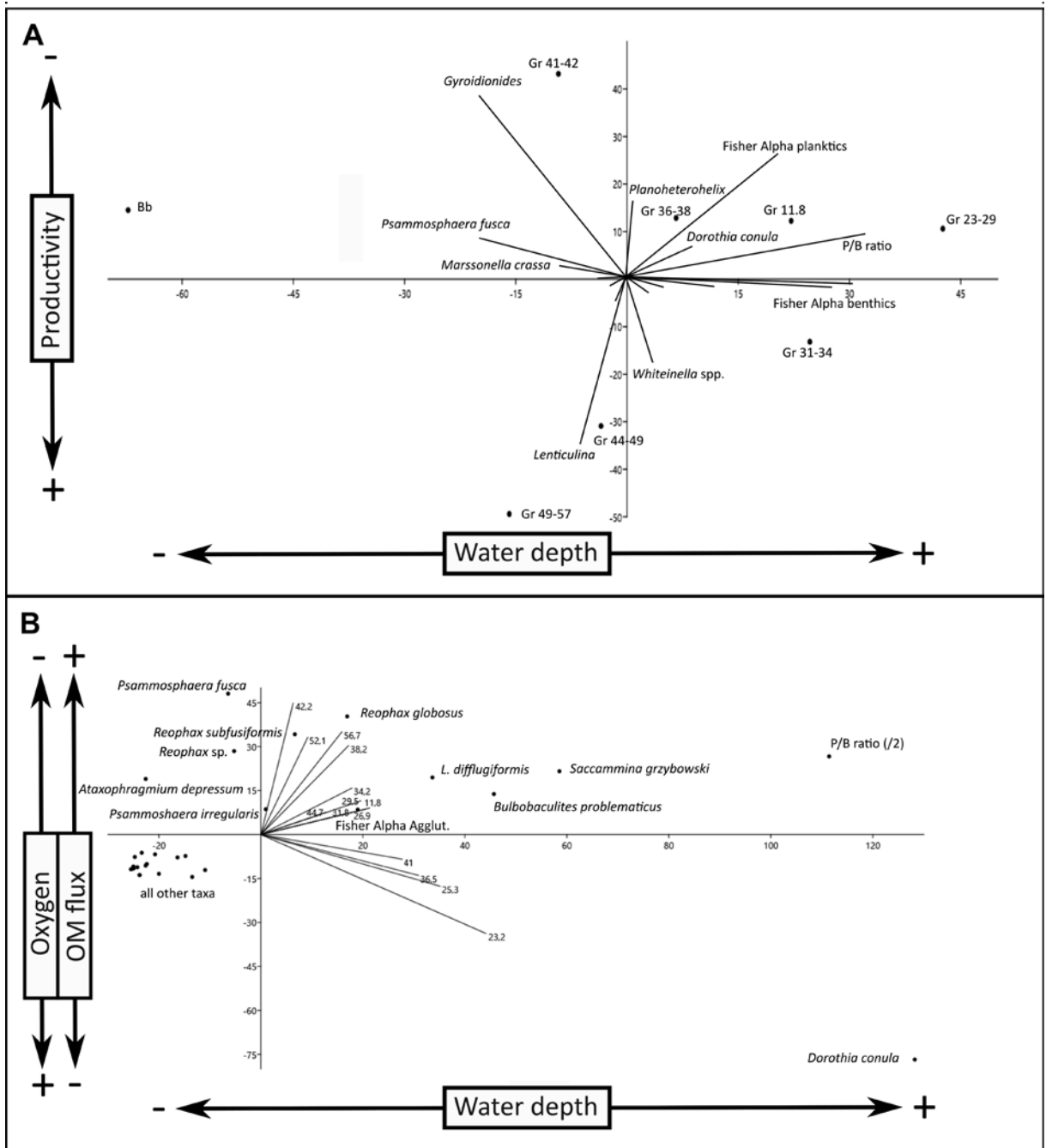
Text-fig. 7. Relative abundances of selected agglutinated foraminiferal species, a constrained cluster analysis based on agglutinated foraminiferal abundances, and interpreted genetic sequences (based on maximum flooding surfaces) of the Strehlen Formation of the Graupa 60/1 core. Red bars indicate possible sea level lowstand intervals, green bars mark proposed maximum flooding zones. Different grey areas show both clusters. For more detailed lithological explanations, see Text-fig. 2. Genetic sequences after Uličný *et al.* (2009), Nádaskay *et al.* (2019) and Niebuhr *et al.* (2020).

6% relative abundance, mostly even not that high (Text-fig. 6). Exceptionally, one mass occurrence of *Ataxophragmium depressum* enhances the ratio of yielding M2b up to 21% at the depth of 42.2 m (Text-fig. 6). Attached epifaunal specimens of morphogroup M3b, e.g., *Ammolagena* spp., reach relative abundances up to 10% (Text-fig. 6). The most dominant morphogroups of the evaluated section are M2a (shallow infaunal) and M4b (deep infaunal). M2a occurs with relative abundances between 16 and 40%, M4b – with 30 up to 71% (Text-fig. 6). Their ratios evolve contrary to each other. Maximum values of M2a are recorded at the depth of 42.2 m with 40% and at 34.2 m with 34% (Text-fig. 6). The relative abundance of M4b reaches its minima at these points.

M4b (deep infaunal) faunas show their highest relative abundances at the depth of 44.7 m with 60%, at 36.5 m with 54% and at 23.2 m with 71%, while exactly at these depths M2a fauna is of smallest relative abundance with 17.5, 24 and 17% (Text-fig. 6).

### Principal component analysis

The principal component analysis (PCA) was performed on the dataset of agglutinated foraminiferal counts including the Fisher-Alpha index for the agglutinated foraminiferal fauna and the P/B ratio of the acetic acid residues. Taxa which appear only in a single sample or occur in low abundances ( $\leq 10$  specimens) were excluded from the analysis. The first



Text-fig. 8. Principal component analysis based on: A – the whole dataset including calcareous and agglutinated foraminifers, P/B ratio and diversity indices, variance: PC1 (water depth) 39.2, PC2 (productivity) 30.4; B – agglutinated foraminifers, P/B ratio and Fisher Alpha diversity of agglutinated foraminifers, variance: PC1 (water depth) 56.7, PC2 (oxygen/OM flux) 20.3.

principal component (PC1) is responsible for 56.7% and PC2 – for 20.3% of the variance. PCA performed on the whole dataset including all counts and samples, diversity indices, and P/B ratio, showed PC1 explaining 39.2% and PC2 30.4% of the variance (see Discussion and Text-fig. 8).

DISCUSSION

Palaeoenvironmental implications

The recorded foraminiferal fauna in general reflects shelf conditions containing typical shelf as-

sociated planktic, calcareous and agglutinated foraminifers comparable to findings by Frieg and Price (1982), Frenzel (2000), and Neagu (2011). The foraminiferal assemblage from the Strehlen Formation of the Graupa 60/1 core can be assigned to the 'Slope Marl Biofacies' after Kaminski and Gradstein (2005). The 'mixed' low-latitude calcareous-agglutinated assemblage of this facies contains an admixture of calcareous benthic and planktonic, and agglutinated foraminifers. Calcareous-cemented agglutinated foraminiferal species, such as *Dorothia* spp. and *Marssonella* spp., are present.

High abundances of morphogroup M4b (deep infaunal) and M2a (shallow infaunal) and appearance of M1 (tubular) indicate relatively high fluxes of organic matter for the Strehlen Formation of the Graupa 60/1 core after Jorissen *et al.* (1995), van der Zwaan *et al.* (1999) and Setoyama *et al.* (2017). In general, the recorded fauna of the Graupa 60/1 core yields a lot of opportunistic taxa such as *Reophax* spp., *Bulbobaculites problematicus*, *Psammosphaera fusca* or *Saccammina grzybowskii* (Text-fig. 5). Substrate disturbance due to strong bottom currents on the seafloor can lead to an increased dominance of these opportunistic taxa (Kaminski 1985). This can be excluded for the marl of the Graupa 60/1 core as there are no signs for such disturbance in the sedimentary record. More likely, in this case responsible is the periodically occurring anoxia on the seafloor, which can result in similar features (Kaminski *et al.* 1995). These opportunistic and mostly deep infaunal taxa are mostly related to a low oxygen content and higher organic matter supply (Text-fig. 8) and/or fast recolonizing behaviour due to a fast reproduction mode (Kaminski *et al.* 1995).

The P/B ratio is generally low at the base of the Strehlen Formation except for depth interval 59.5–54.0 m (Text-fig. 6), which could indicate the maximum flooding zone of the Zeichen Clay or Strehlen Kalkstein (Text-fig. 2), related also to the base of genetic sequence TUR 6 (Niebuhr *et al.* 2020). At the depth of 49 m of the Graupa 60/1 core (Text-fig. 7), strongly decreased agglutinated and calcareous foraminiferal abundances support a sea-level lowstand, while P/B ratios suggest a sea-level highstand. Both interpretations remain doubtful due to the low numbers of foraminiferal specimens. A sea-level lowstand can be interpreted for the depth of 42.2 m (Text-fig. 7). High abundances of *Ataxophragmium depressum* and *Psammosphaera fusca* indicate relatively low water depth and high organic matter flux (Text-figs 7 and 8).

Up-section, the enhanced presence of *Dorothia conula* is interpreted herein as a migration bio-event

during maximum flooding because of its preference for more oligotrophic conditions and greater water depths (Text-figs 7 and 8). *Dorothia conula* occurs in high numbers at the depth of 41 m which also yields high P/B ratios (Text-figs 6 and 7). This position conforms with the boundary of genetic sequences TUR 6 and TUR 7 proposed by Uličný *et al.* (2009) and Olde *et al.* (2015), the Lohmen Clay (Niebuhr *et al.* 2020; Text-fig. 2) and the *Didymotis* Event I in northern Germany (Wood *et al.* 1984). The acme of *D. conula* at the depth of 36.5 m is interpreted as the base of the lower order genetic sequence TUR7/3 (Nádaskay *et al.* 2019) and the *Didymotis* Event II in northern Germany (Wood *et al.* 1984). This event is positioned slightly below the Turonian/Coniacian boundary around the depth of 31 m as indicated by the FO of *Cremnoceramus deformis erectus* in the Graupa 60/1 core (Tröger and Wejda 1998). Another maximum flooding is evident from the high P/B ratios and increased abundances of *D. conula* in depth interval of 25.3 to 23.2 m (Text-figs 6 and 7), which again corresponds to the boundary of genetic sequences TUR 7 and CON 1 in the Bohemian Cretaceous Basin and the Zittau Mountains (Nádaskay *et al.* 2019; Niebuhr *et al.* 2020; Text-fig. 2). This stratigraphic interval likely correlates with the Braunsnitzbach Marl (Niebuhr *et al.* 2020; Text-fig. 2).

Foraminiferal diversities with Fisher-Alpha indices between 8 and 17 for the marl of the Graupa 60/1 core are medium to relatively high for agglutinated foraminiferal assemblages (Text-fig. 6). Thus, mesotrophic conditions without sediment disturbance, with periodical oxygen depletion as the generally favourable living conditions for agglutinated foraminiferal communities, likely follow the observations in other sections by Kaminski *et al.* (1995, 2011), Kuhnt and Kaminski (1997), Bindui *et al.* (2013), and Setoyama *et al.* (2013).

Indicated by the P/B ratio, PCA and diversity trends of calcareous foraminifers (Frenzel 2000), the Strehlen Formation of the Graupa 60/1 core reflects a deepening from its base towards the depth of 23.2 m, while the topmost sample from the depth of 11.8 m indicates a shallower environment (Text-figs 6 and 8). The Braunsnitzbach Marl was deposited in much shallower conditions than the Strehlen Formation of the Graupa 60/1 core (Text-fig. 8), complying with the general architecture of the Saxonian Cretaceous Basin (Wilmsen and Niebuhr 2014). At the base (depth interval 49–57 m) of the investigated Strehlen Formation, the productivity was the highest (Text-fig. 8), followed by a decrease in depth interval 41–42 m (Text-fig. 8) as indicated by the presence



of *Gyroidinoides* sp. typical of low productivity environments (Frenzel 2000), and high productivity equivalents such as *Lenticulina* sp. (Frenzel 2000) and *Whiteinella* sp. (Caron 1983b). Subsequently in the Graupa 60/1 core, the productivity was more variable but still relatively high (Text-fig. 8) and not necessarily coupled with relative sea-level changes. The productivity of the Braunsnitzbach Marl was comparably moderate (Text-fig. 8).

## Stratigraphy

### *Foraminiferal stratigraphy*

Typical late Turonian to Coniacian agglutinated Tethyan marker species, such as *Gaudryina carinata* Franke, 1914, *Marssonella crassa* (Marsson, 1878) and *Spiroplectammina praelonga* (Reuss, 1845) (Neagu 1968, 2011) occur in the marls of the Strehlen Formation of the Graupa 60/1 core and the Braunsnitzbach Marl (Schrammstein Formation). The studied interval can be assigned to the *Uvigerinamina jankoi* biozone. However, the occurrence of *U. jankoi* Majzon, 1943 is rare in the Strehlen Formation of the Graupa 60/1 core. The stratigraphic range of *U. jankoi* beginning in the upper Turonian seems to be more related to the zonation of the Carpathian and central Tethyan realms (see Geroch and Nowak 1984; Kaminski *et al.* 2011; Józsa 2017) than to those of the western Tethyan and Atlantic realm (Kuhnt and Kaminski 1997). A further subdivision of the studied interval by agglutinated foraminifers is not possible because of the lack of the first or last appearances of taxa.

## Method comparison

The application of two different methods to receive foraminiferal assemblages allows to compare both methods. While no calcareous foraminifers are preserved in the formic acid treated residues due to dissolution, only a few agglutinated foraminifers of a small number of different genera could be identified in the acetic acid – copper-II-sulphate treated samples. Possibly, this effect is related to the different functionalities of the applied methods. The formic acid method is based completely on dissolution effects of calcareous matter, whereas the acetic acid – copper-II-sulphate method links slight dissolution effects with mechanic dissection along weak points within the rock matrix. Therefore, coarse-grained agglutinated foraminifers are most likely dissected along the grain borders during mechanical disintegration. Although calcareous matter is completely

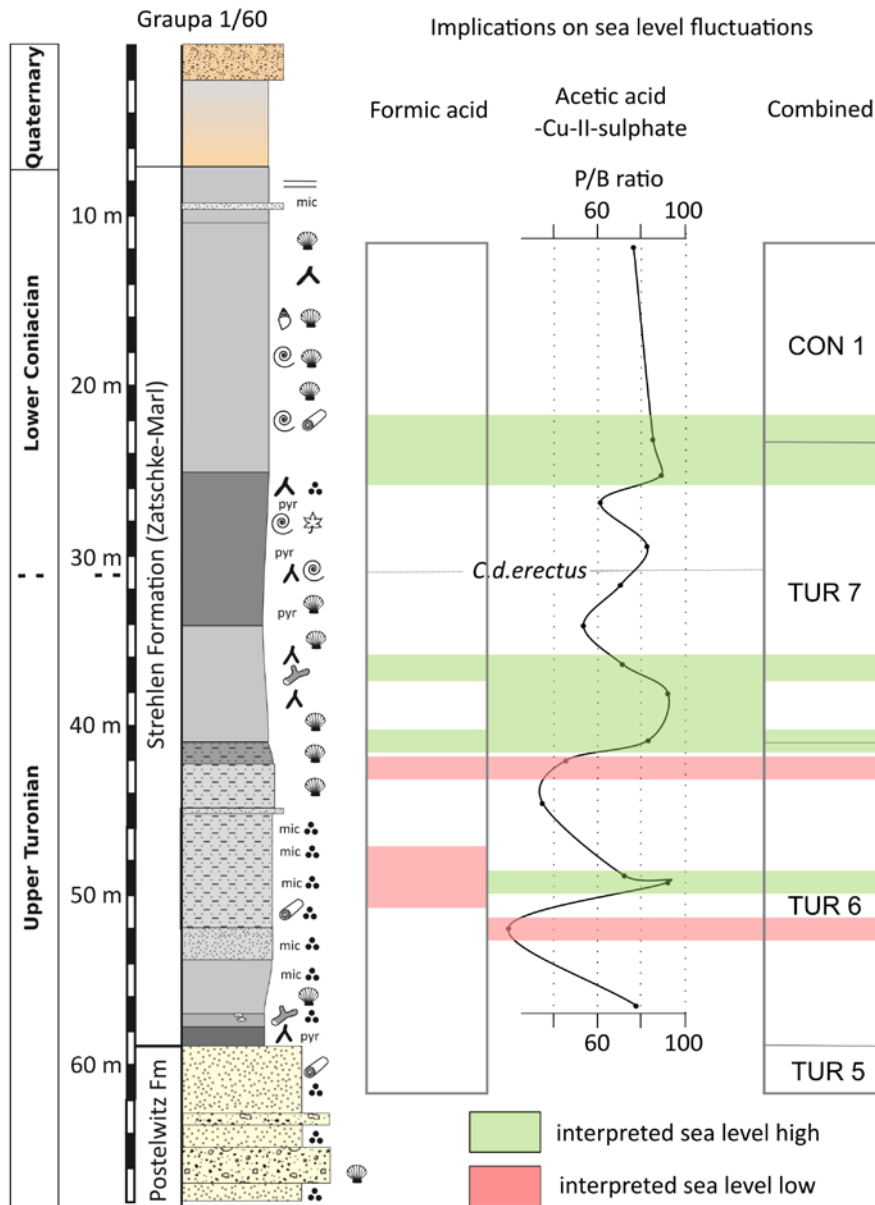
dissolved in formic acid residues, calcareous-cemented agglutinated foraminifers, such as *Dorothia* spp., *Eggerellina* spp., *Marssonella* spp. and *Tritaxia* spp. occur in higher numbers. Similar observations were made from deep-water calcareous sediments by Kuhnt (1990), Kaminski and Gradstein (2005) and Kaminski *et al.* (2011). Kaminski and Gradstein (2005) explain this observation by later diagenetic silicification.

In general, the implications for the reconstructed sea-level fluctuations from the foraminifers recorded by both methods are mostly in accordance. The P/B ratio derived from foraminifers from the acetic acid residue seems to show minor sea-level fluctuations as well, while implications from the agglutinated foraminifers lead to distinct identification of major sea-level changes with an ecological impact on the benthic communities (Text-fig. 9). A combined application of both methods leads to extended and more complete foraminiferal record and more precise implications on palaeoenvironmental changes.

## CONCLUSIONS

A rich foraminiferal fauna was received from samples of the upper Turonian to lower Coniacian Strehlen Formation of the Graupa 60/1 borehole and from the Braunsnitzbach Marl of the Schrammstein Formation (Elbtal Group) in intention to add stratigraphic information and a palaeoenvironmental framework for the transitional facies zone of the Saxonian Cretaceous Basin. Tethyan agglutinated marker species for the late Turonian to early Coniacian confirm the proposed age of the Strehlen Formation of the Graupa 60/1 core and the Braunsnitzbach Marl (Schrammstein Formation). Typical middle to outer shelf associated planktic, calcareous and agglutinated foraminifers occur in all samples. Their relation to each other calculated with PCA, changes in the P/B ratio and relative abundances of agglutinated foraminiferal morphogroups display sea-level fluctuations which can be connected to genetic sequences in the Saxonian, and Bohemian Cretaceous basins as proposed by Uličný *et al.* (2009) and Nádaskay *et al.* (2019). Special features of genetic sequences are highlighted by acmes of certain species/micro-fossil-bioevents.

- sea-level lowstand at the depth of 42.2 m, acmes of *Ataxophragmium depressum* and *Psammospaera fusca*.
- maximum flooding (TUR6/TUR7) at the depth of 41.0 m, acme of *Dorothia conula*.



Text-fig. 9. Implications on sea-level fluctuations by foraminiferal evidence recorded by the application of different processing methods on the marlstone samples from the Graupa 60/1 core; for more detailed lithological explanations, see Text-fig. 2. Genetic sequences after Uličný *et al.* (2009), Nádaskay *et al.* (2019) and Niebuhr *et al.* (2020).

- maximum flooding (lower order) at the depth of 36.5 m, acme of *Dorothia conula*.
- maximum flooding (TUR7/CON1) in depth interval 25.3 to 23.2 m, acme of *Dorothia conula*.

In general, an increase of water depth over time can be constructed for the Strehlen Formation in the Graupa 60/1 core, while deposits at the depth of 42.2 m and 11.8 m indicate shallower conditions.

High numbers of infaunal agglutinated foraminifers suggest a generally high organic matter influx while

the occurrences of opportunistic taxa, e.g., *Reophax* spp., *Bulbobaculites problematicus*, *Psammosphaera fusca* and *Saccamina grzybowskii*, point towards periodic oxygen depletion of the bottom water following the observations of Kaminski *et al.* (1995). While the productivity in the Graupa 60/1 core was variable and not necessarily related to sea-level fluctuations, the setting during the formation of the Braunsnitzbach Marl was characterized by shallower water depth with relatively moderate productivity.

## FAUNAL REFERENCE LIST

In the following, agglutinated and calcareous foraminifera, including planktic forms, received in application of the acetic acid – copper-II-sulphate and formic acid method are listed alphabetically. Only important or hitherto not known species are described in detail. Increased abundances of certain species are added. The synonymy lists contain first descriptions and selected other literature used for identification.

*Agathamminoides serpens* (Grzybowski, 1898)

pars 1898. *Ammodiscus serpens* Grzybowski, p. 285, pl. 10, fig. 31 (non figs 32 and 33).

1993. *Glomospira serpens* (Grzybowski); Kaminski and Geroch, p. 256, pl. 6, figs 2–5.

2005. “*Glomospira*” *serpens* (Grzybowski); Kaminski and Gradstein, p. 189, pl. 27, figs 1a–6b.

2021. *Agathamminoides serpens* (Grzybowski); Kaminski *et al.*, p. 347, pl. 2, fig. 11.

MATERIAL: 2 specimens (in formic acid treated samples).

*Ammobaculites agglutinans* (d’Orbigny, 1846)

1846. *Spirolina agglutinans* d’Orbigny, p. 137, pl. 7, figs 10–12.

1952. *Ammobaculites agglutinans* (d’Orbigny); Bartenstein, p. 318, pl. 1, fig. 1a–c; pl. 2, figs 10–16.

2005. *Ammobaculites agglutinans* (d’Orbigny); Kaminski and Gradstein, p. 324, pl. 70, figs 1–8.

MATERIAL: 29 specimens (in formic acid treated samples).

*Ammobaculites* sp.

REMARKS: Broken specimens of the genus *Ammobaculites*.

*Ammodiscus cretaceus* (Reuss, 1845)

1845. *Operculina cretacea* Reuss, p. 35, pl. 13, figs 64, 65.

1934. *Ammodiscus cretacea* (Reuss); Cushman, p. 45.

2005. *Ammodiscus cretaceus* (Reuss); Kaminski and Gradstein, p. 145, pl. 14, figs 1a–10.

MATERIAL: 2 specimens (in formic acid treated samples).

*Ammodiscus peruvianus* Berry, 1928

1928. *Ammodiscus peruvianus* Berry, p. 392, fig. 27.

2005. *Ammodiscus peruvianus* Berry; Kaminski and Gradstein, p. 157, pl. 18, figs 1a–6.

MATERIAL: 3 specimens (in formic acid treated samples).

*Ammodiscus tenuissimus* Grzybowski, 1898

1898. *Ammodiscus tenuissimus* Grzybowski, p. 282, pl. 10, fig. 35.

2005. *Ammodiscus tenuissimus* Grzybowski; Kaminski and Gradstein, p. 163, pl. 20, figs 1a–7.

MATERIAL: 1 specimen (in formic acid treated samples).

*Ammolagena clavata* (Jones and Parker, 1860)

1860. *Trochammina irregularis* (d’Orbigny) var. *clavata* Jones and Parker, p. 304.

1987. *Ammolagena clavata* (Jones and Parker); Loeblich and Tappan, p. 49, pl. 36, fig. 16.

2005. *Ammolagena clavata* (Jones and Parker); Kaminski and Gradstein, pp. 165–168, pl. 21, fig. 21.

MATERIAL: 5 specimens (in formic acid treated samples).

*Ammolagena contorta* Waters, 1927

1927. *Ammolagena contorta* Waters, p. 132, pl. 22, fig. 4.

2017. *Ammolagena contorta* Waters; Setoyama *et al.*, p. 211, pl. 1, fig. 2.

MATERIAL: 7 specimens (in formic acid treated samples).

*Ammosphaeroidina pseudopauciloculata* (Mjatliuk, 1966)

1966. *Cystamminella pseudopauciloculata* Mjatliuk, p. 264, pl. 1, figs 5–8; pl. 2, fig. 6; pl. 3, fig. 3.

1988. *Ammosphaeroidina pseudopauciloculata* (Mjatliuk); Kaminski *et al.*, p. 193, pl. 8, figs 3a–5.

MATERIAL: 86 specimens (in formic acid treated samples).

REMARKS: This species is a typical deep-water species (Nagy *et al.* 1987).

*Arenobulimina bochumensis* Frieg, 1980

1980. *Arenobulimina bochumensis* Frieg, p. 235, pl. 2, figs 1–3.

1980. *A. (Arenobulimina) macfadyeni elongata* Barnard and Banner, p. 403, pl. 2, fig. 7, pl. 6, figs 2–4.

1989. *A. (Pasternakia) bochumensis* Frieg; Frieg *et al.*, p. 90, pl. 3, figs 1–29.

MATERIAL: 28 specimens (in formic acid treated samples).

*Arenobulimina preslii* (Reuss, 1845)

1845. *Bulimina preslii* Reuss, p. 38, pl. 13, fig. 72.  
 1972. *Arenobulimina preslii* (Reuss); Voloshina, p. 59, pl. 1, figs 2–3.

MATERIAL: 53 specimens (in formic acid treated samples).

*Arenobulimina truncata* (Reuss, 1844)

1844. *Bulimina truncata* Reuss, p. 215, pl. 8, fig. 73.  
 1937. *Arenobulimina truncata* (Reuss); Cushman, p. 40, pl. 4, figs 15, 16.

MATERIAL: 69 specimens (in formic acid treated samples) and 6 specimens (in acetic acid – copper-II-sulphate treated samples).

## Arenobuliminid fragments

REMARKS: Includes indeterminable fragments of the genera *Arenobulimina*.

*Ataxophragmium depressum* (Perner, 1892)

1892. *Bulimina depressum* Perner, p. 55, pl. 3, fig. 3.  
 1972. *Ataxophragmium depressum* (Perner); Voloshina, p. 104, pl. 11, fig. 6.

MATERIAL: 76 specimens (in formic acid treated samples).

DESCRIPTION: Test half-spheroidal. Last whorl with 5 to 6 chambers. Sutures with coarser material agglutinated. Apertural face plane or slightly concave. Aperture loop- or Y-shaped or with a V-shaped tooth. Finely agglutinated.

REMARKS: Acme at 42.2 m core depth.

*Ataxophragmium variabile?* (d'Orbigny, 1840)

1840. *Bulimina variabile* d'Orbigny, p. 40, pl. 4, figs 9–11.  
 1980. *Ataxophragmium variabile* (d'Orbigny); Gawor-Biedowa, p. 21, pl. 2, figs 16, 17.

MATERIAL: 9 specimens (in acetic acid – copper-II-sulphate treated samples).

*Ataxophragmium* sp.

REMARKS: Indeterminable fragments of the genus *Ataxophragmium*.

*Bathysiphon* sp.

MATERIAL: 33 specimens (in formic acid treated samples).

DESCRIPTION: Test unbranched, elongate tube with lots of debris agglutinated. In most cases in fragments.

REMARKS: The sum of counted fragments of this genus was divided by the factor “5” for each sample to obtain more reliable data.

*Bulbobaculites problematicus* (Neagu, 1962)  
(Text-fig. 51)

1962. *Ammobaculites agglutinans problematicus* Neagu, p. 61, pl. 2, figs 22–24.  
 1970. *Ammobaculites problematicus* (Neagu); Neagu, p. 39, pl. 6, figs 1–5.  
 1990. *Haplophragmium problematicum* (Neagu); Kuhnt, p. 312, pl. 4, figs 3–9.  
 1990. *Bulbobaculites problematicus* (Neagu); Kuhnt and Kaminski, p. 465, text fig. 5, 5A.

MATERIAL: 336 specimens (in formic acid treated samples).

REMARKS: High abundances at core depth 26.9 m and 11.8 m.

*Caudammia ovula* (Grzybowski, 1896)

1896. *Reophax ovulum* Grzybowski, p. 276, pl. 8, figs 19–21.  
 1988. *Hormosina ovulum ovulum* (Grzybowski); Kaminski *et al.*, p. 186, pl. 2, fig. 10.  
 2005. *Caudammia ovula* (Grzybowski); Kaminski and Gradstein, p. 233, pl. 41, figs 1a–8.

MATERIAL: 9 specimens (in formic acid treated samples).

*Caudammia* sp.

REMARKS: Fragmented specimen from the genus *Caudammia* Montanaro Gallitelli, 1955, most likely belonging to *Caudammia ovula*.

*Clavulinoides* sp.

MATERIAL: 42 specimens (in formic acid treated samples).

*Cribrostomoides* sp.

MATERIAL: 33 specimens (in formic acid treated samples).

*Dicarinella* cf. *concovata* (Brotzen, 1934)

1934. *Rotalia concavata* Brotzen, p. 66, pl. 3, fig. 6.  
 1980. *Dicarinella concavata* (Brotzen); Gawor-Biedowa, p. 36, pl. 4, figs 4–7.



MATERIAL: 1 specimen (in acetic acid – copper-II-sulphate treated samples).

*Dolgenia pennyi* (Cushman and Jarvis, 1928)

1928. *Ammodiscus pennyi* Cushman and Jarvis, p. 87, pl. 12, figs 4, 5.

2005. *Ammodiscus pennyi* Cushman and Jarvis; Kaminski and Gradstein, p. 155, pl. 17, figs 1–6.

2011. *Dolgenia pennyi* Cushman and Jarvis; Setoyama *et al.*, p. 271, pl. 3, fig. 12a–b.

MATERIAL: 2 specimens (in formic acid treated samples).

*Dorothia conula* (Reuss, 1845)

(Text-fig. 5K)

1845. *Textularia conulus* Reuss, pp. 38, 39, pl. 8, fig. 59a–b, pl. 13, fig. 75a–b.

1937. *Dorothia conula* (Reuss); Cushman, pp. 76, 77, pl. 8, figs 11–14.

MATERIAL: 481 specimens (in formic acid treated samples).

REMARKS: Acmes recorded at core depths of 41, 36.5, and 25.3–23.2 m. A Tethyan warm water species (Frenzel 2000).

*Eggerellina brevis* (d'Orbigny, 1840)

1840. *Bulimina brevis* d'Orbigny, p. 41, pl. 4, figs 13, 14.

1972. *Eggerellina brevis* (d'Orbigny); Voloshina, p. 92, pl. 9, figs 2, 3; pl. 21, fig. 2.

MATERIAL: 23 specimens (in formic acid treated samples).

*Eggerellina mariae* Ten Dam, 1950

1950. *Eggerellina mariae* Ten Dam, p. 15, pl. 1, fig. 17a–e.

1975. *Eggerellina mariae* Ten Dam; Magniez-Jannin, p. 94, pl. 6, figs 12–21.

MATERIAL: 28 specimens (in formic acid treated samples).

*Eobigenerina kuhnti*

Cetean, Setoyama, Kaminski, Neagu, Bubík, Filipescu and Tyszká, 2011

2011b. *Eobigenerina kuhnti* Cetean *et al.*, p. 22, pl. 1, figs 13–16.

MATERIAL: 10 specimens (in formic acid treated samples).

*Eobigenerina variabilis* (Vašíček, 1947)

1947. *Bigenerina variabilis* Vašíček, p. 246, pl. 1, figs 10–12.

1970. *Pseudobolivina variabilis* (Vašíček); Neagu, p. 41, pl. 5, figs 13–16.

2011b. *Eobigenerina variabilis* (Vašíček); Cetean *et al.*, pp. 6, 7.

MATERIAL: 79 specimens (in formic acid treated samples).

*Gaudryina carinata* Franke, 1914

(Text-fig. 5L)

1914. *Gaudryina carinata* Franke, p. 431, pl. 27, figs 4–6.

MATERIAL: 93 specimens (in formic acid treated samples).

*Gavelinella* sp.

MATERIAL: 10 specimens (in acetic acid – copper-II-sulphate treated samples).

*Gerochammina* aff. *lenis* (Grzybowski, 1896)

1896. *Spiroplectina lenis* Grzybowski, p. 288, pl. 9, figs 24, 25.

1990. *Gerochammina lenis* (Grzybowski); Neagu, p. 260, pl. 2, figs 22–32, p. 254, pl. 4, figs 28–31.

MATERIAL: 1 specimen (in formic acid treated samples).

*Gerochammina stanislawi* Neagu, 1990

1990. *Gerochammina stanislawi* Neagu, p. 253, pl. 1, figs 1–26.

MATERIAL: 4 specimens (in formic acid treated samples).

*Glomospira gordialis* (Jones and Parker, 1860)

1860. *Trochammina squamata* (Jones and Parker) var. *gordialis* Jones and Parker, pp. 292–307.

1990. *Glomospira gordialis* (Jones and Parker); Berggren and Kaminski, p. 73, pl. 1, fig. 1.

2005. *Glomospira gordialis* (Jones and Parker); Kaminski and Gradstein, p. 181, pl. 25, figs 1–8.

MATERIAL: 8 specimens (in formic acid treated samples).

*Glomospira irregularis* (Grzybowski, 1898)

1898. *Ammodiscus irregularis* Grzybowski, p. 285, pl. 11, figs 2, 3.

1984. *Glomospira? irregularis* (Grzybowski); Hemleben and Troester, p. 519, pl. 1, fig. 22.

1993. *Glomospira irregularis* (Grzybowski); Kaminski and Geroch, p. 256, pl. 6, figs 6–8b. 2005. “*Glomospira irregularis* (Grzybowski); Kaminski and Gradstein, p. 185, pl. 26, figs 1a–7.

MATERIAL: 2 specimens (in formic acid treated samples).

*Gyroidinoides umbilicatus* (d’Orbigny, 1840)

1840. *Rotalina umbilicatus* d’Orbigny, p. 32, pl. 3, figs 4–6.

2000. *Gyroidinoides umbilicatus* (d’Orbigny); Frenzel, p. 201, pl. 40, figs 6–9.

MATERIAL: 98 specimens (in acetic acid – copper-II-sulphate treated samples).

*Hagenowella elevata* (d’Orbigny, 1840)

1840. *Globigerina elevata* d’Orbigny, p. 34, pl. 3, figs 15, 16.

1982. *Hagenowella elevata* (d’Orbigny); Frieg and Price, p. 55, pl. 2.1, fig. 1; pl. 2.2, figs a–b.

MATERIAL: 42 specimens (in formic acid treated samples).

*Hagenowella obesa* (Reuss, 1851)

1851. *Bulimina obesa* Reuss, p. 40, pl. 4, fig. 12; pl. 5, fig. 1.

1982. *Hagenowella obesa* (Reuss); Frieg and Price, p. 56, pl. 2.2, figs c–d; pl. 2.3, fig. i.

MATERIAL: 10 specimens (in formic acid treated samples).

*Haplophragmoides bulloides* (Beissel, 1891)

1891. aff. *Haplophragmium bulloides* Beissel, p. 17, pl. 2, figs 1–3, pl. 4, figs 24–30.

1966. *Haplophragmoides bulloides* (Beissel); Huss, p. 23, pl. 3, figs 17–24.

MATERIAL: 7 specimens (in formic acid treated samples).

*Haplophragmoides cf. stomatus* (Grzybowski, 1898)

1898. *Trochammina stomata* Grzybowski, p. 290, pl. 11, figs 26, 27.

1993. *Haplophragmoides stomatus* Grzybowski; Kaminski and Geroch, 1993, p. 311, pl. 11, figs 1a–2b.

2005. *Haplophragmoides stomatus* Grzybowski; Kaminski and Gradstein, p. 357, pl. 80, figs 1a–6b.

MATERIAL: 1 specimen (in formic acid treated samples).

Haplophragmoid fragments

DESCRIPTION: Test planispirally enrolled, with several chambers. Aperture an elongate equatorial slit at the base of the apertural face.

REMARKS: Mainly broken tests (in formic acid treated samples).

*Hemisphaerammina batalleri*

Loeblich and Tappan, 1987

1987. *Hemisphaerammina batalleri* Loeblich and Tappan, p. 224, pl. 72, fig. 3.

MATERIAL: 132 specimens (in formic acid treated samples).

*Hemisphaerammina glandiformis*

Hercogová and Kriz, 1983

1983. *Hemisphaerammina glandiformis* Hercogová and Kriz, p. 210, pl. 5, fig. 5a, b.

MATERIAL: 95 specimens (in formic acid treated samples).

*Hormosinella distans* (Brady, 1881)

1881. *Reophax distans* Brady, p. 50, no figure given.

2005. *Hormosinella distans* (Brady); Kaminski and Gradstein, p. 246, pl. 45, figs 1–11.

MATERIAL: 1 specimen (in formic acid treated sample).

*Hormosinella fusiformis*

Kaminski, Cetean, Bălc and Coccioni, 2011

2011. *Hormosinella fusiformis* Kaminski *et al.*, p. 87, pl. 2, figs 6–12.

MATERIAL: 43 specimens (in formic acid treated samples).

*Hyperammina gaultina* Ten Dam, 1950

1950. *Hyperammina gaultina* Ten Dam, p. 5, pl. 1, fig. 2.

MATERIAL: 6 specimens (in formic acid treated samples).

*Hyperammina* sp.

REMARKS: Not further determinable because of fragmentation or compaction (in formic acid treated samples).

*Kecheotiske* sp. 1

MATERIAL: 12 specimens (in formic acid treated samples).

DESCRIPTION: Proloculus at initial rounded end. Second chamber rapidly increasing in size. Aperture as a broad opening of the last chamber. Thin wall, finely agglutinated, smooth finished.

REMARKS: Probably can be assigned to *Keche-notiske expansa* (Plummer, 1945) described from the Carboniferous. However, left open in nomenclature because of the first ever appearance of this genus in the Upper Cretaceous and the big stratigraphical gap.

*Laevidentalina* sp.

MATERIAL: 15 specimens (in acetic acid – copper-II-sulphate treated samples).

*Lagena* sp.

MATERIAL: 4 specimens (in acetic acid – copper-II-sulphate treated samples).

*Lagenammina difflugiformis* (Brady, 1879)  
(Text-fig. 5C)

1879. *Reophax difflugiformis* Brady, p. 51, pl. 4, fig. 3.

1990. *Lagenammina difflugiformis* (Brady); Charnock and Jones, p. 146, pl. 1, fig. 2, pl. 13, fig. 2.

MATERIAL: 286 specimens (in formic acid treated samples).

*Lenticulina* sp.

MATERIAL: 94 specimens (in acetic acid – copper-II-sulphate treated samples).

*Marssonella crassa* (Marsson, 1878)

1878. *Gaudryina crassa*; Marsson, p. 108, pl. 13, fig. 27.

1995. *Marssonella crassa* (Marsson); Bubík, p. 83, pl. 15, figs 12a–13.

MATERIAL: 59 specimens (in formic acid treated samples).

*Muricohedbergella crassa* (Bolli, 1959)

1959. *Praeglobotruncana crassa* Bolli, p. 265, pl. 21, figs 1, 2.

2011. *Muricohedbergella crassa* (Bolli); Huber and Leckie, p. 84.

MATERIAL: 33 specimens (in acetic acid – copper-II-sulphate treated samples).

*Nothia* sp.

MATERIAL: 21 specimens (in formic acid treated samples)

DESCRIPTION: Test elongate, tubular, sparsely branched. Wall bilamellar, built up of different materials.

REMARKS: The sum of counted fragments of this genus was divided by the factor “5” for each sample to get more reliable data. This species group includes several species, which differ in their agglutinating materials and wall structure.

*Placentammina placenta*  
(Grzybowski, 1898)

1898. *Reophax placenta* Grzybowski, p. 276, pl. 10, figs 9, 10.

1993. *Saccammina placenta* (Grzybowski); Kaminski and Geroch, p. 249, pl. 2, figs 5–7.

2005. *Placentammina placenta* (Grzybowski); Kaminski and Gradstein, p. 136, pl. 11, figs 1–6.

MATERIAL: 57 specimens (in formic acid treated samples).

*Planoheterohelix globulosa* (Ehrenberg, 1840)  
(Text-fig. 4G)

1840. *Textularia globulosa* Ehrenberg, p. 135, pl. 4, figs 2β, 5β, 7β, 8β.

2015. *Planoheterohelix globulosa* (Ehrenberg); Haynes *et al.*, p. 55, fig. 11.1–11.14.

MATERIAL: 91 specimens (in acetic acid – copper-II-sulphate treated samples).

*Praebulimina* sp.

MATERIAL: 16 specimens (in acetic acid – copper-II-sulphate treated samples).

*Praecystammina* sp.

MATERIAL: 3 specimens (in formic acid treated samples).

*Psammosiphonella* sp.

MATERIAL: 13 specimens (in formic acid treated samples).

REMARKS: The sum of counted fragments of this genus was divided by the factor “5” for each sample to get more reliable data.

*Psammosphaera fusca* Schultze, 1875  
(Text-fig. 5A)

1875. *Psammosphaera fusca* Schultze, p. 113, pl. 2, fig. 8a–f.

2005. *Psammosphaera fusca* Schultze; Kaminski and Gradstein, p. 125, pl. 8, figs 1–9.

MATERIAL: 220 specimens (in formic acid treated samples).

DESCRIPTION: Test free or attached, globular, small to large. Coarsely agglutinated.

REMARKS: High relative abundance at core depth of 42.2 m.

*Psammosphaera irregularis* (Grzybowski, 1896)  
(Text-fig. 5B)

1896. *Keramosphaera irregularis* Grzybowski, p. 273, pl. 8, figs 12, 13.

2005. *Psammosphaera irregularis* (Grzybowski); Kaminski and Gradstein, p. 131, pl. 9, figs 1–9.

MATERIAL: 169 specimens (in formic acid treated samples).

DESCRIPTION: Test free, medium to large, circular in outline. Agglutinated with medium sized well-sorted grains.

*Pseudonodosinella parvula* (Huss, 1966)

1966. *Reophax parvulus* Huss, p. 21, pl. 1, figs 26–30.

1995. *Pseudonodosinella parvula* (Huss); Geroch and Kaminski, p. 118, pl. 2, figs 1–19.

MATERIAL: 1 specimen (in formic acid treated sample).

*Quinqueloculina* sp.

MATERIAL: 6 specimens (in acetic acid – copper-II-sulphate treated samples).

*Ramulina wrightii* Barnard, 1972

1972. *Ramulina wrightii* (Wright); Barnard, p. 390, pl. 1, figs 2, 3.

MATERIAL: 3 specimens (in acetic acid – copper-II-sulphate treated samples).

*Rectogerochammina eugubina*  
Kaminski, Cetean and Neagu, 2010

2010. *Rectogerochammina eugubina* Kaminski *et al.*, p. 122, text-figs 1, 2.

MATERIAL: 10 specimens (in formic acid treated samples).

*Recurvoides* sp.

MATERIAL: 55 specimens (in formic acid treated samples).

*Remaneica* sp.

MATERIAL: 10 specimens (in formic acid treated samples).

*Reophax globosus* Sliter, 1968  
(Text-fig. 5F)

1968. *Reophax globosus* Sliter, p. 43, pl. 1, fig. 12.

MATERIAL: 261 specimens (in formic acid treated samples).

REMARKS: Acme in 56.7 to 52.1 m core depth interval.

*Reophax* cf. *scorpiurus* de Montfort, 1808

1808. *Reophax scorpiurus* de Montfort, p. 331.

MATERIAL: 85 specimens (in formic acid treated samples).

*Reophax subfusiformis* (Earland, 1933)  
(Text-fig. 5G)

1933. *Reophax subfusiformis* Earland, p. 74, pl. 2, figs 16–19.

2005. *Reophax subfusiformis* Earland; Kaminski and Gradstein, p. 275, pl. 54, figs 1–8.

MATERIAL: 240 specimens (in formic acid treated samples).

DESCRIPTION: Test uniserial, tapering, arched, consisting of three chambers. Chambers increasing in size very rapidly. Aperture terminal on a short neck. Coarsely agglutinated.

REMARKS: High relative abundances at core depths of 52.1 and 42.2 m.

*Reophax* sp. indet.

REMARKS: Not further determinable specimens of the genus *Reophax* Montfort, 1808.

*Repmanina charoides*  
(Jones and Parker, 1860)

1860. *Trochammina squamata* var. *charoides* Jones and Parker, p. 304.

1990. *Glomospira charoides* (Jones and Parker); Berggren and Kaminski, p. 60, pl. 1, fig. 2.

2017. *Repmanina charoides* (Jones and Parker); Setoyama *et al.*, p. 194, pl. 1, figs 11, 12.

MATERIAL: 6 specimens (in formic acid treated samples).



*Rhabdammina* sp.

MATERIAL: 1 specimen (in formic acid treated sample).

*Saccamina grzybowskii* (Schubert, 1902)  
(Text-fig. 5D)

1902. *Reophax grzybowskii* Schubert, p. 20, pl. 1, fig. 13a–b.  
1993. *Saccamina grzybowskii* (Schubert); Kaminski and Geroch, p. 248, pl. 2, figs 1a–4b.  
2005. *Saccamina grzybowskii* (Schubert); Kaminski and Gradstein, p. 132, pl. 10, figs 1–9.

MATERIAL: 376 specimens (in formic acid treated samples).

DESCRIPTION: Test small, circular, generally compressed. Aperture rounded on a short neck. Medium to coarsely agglutinated.

REMARKS: High relative abundances at core depths of 41, 34.2 and 11.8 m.

*Saccamina sphaerica* Brady, 1871

1871. *Saccamina sphaerica* Brady, p. 183.

MATERIAL: 76 specimens (in formic acid treated samples).

*Spirillina* sp.

MATERIAL: 1 specimen (in acetic acid – copper-II-sulphate treated samples).

*Spiroloculina* sp.

MATERIAL: 1 specimen (in acetic acid – copper-II-sulphate treated samples).

*Spiroplectamina navarroana* Cushman, 1932

1932. *Spiroplectamina navarroana* Cushman, p. 96, pl. 11, fig. 14.  
1989. *Spiroplectamina navarroana* Cushman; Gradstein and Kaminski, p. 83, pl. 9, figs 1a–12.  
2005. *Spiroplectamina navarroana* Cushman; Kaminski and Gradstein, p. 426, pl. 103, figs 1a–12.

MATERIAL: 9 specimens (in formic acid treated samples).

*Spiroplectamina praelonga* (Reuss, 1845)  
(Text-fig. 5H)

1845. *Textularia praelonga* Reuss, p. 72, pl. 26, fig. 8  
1970. *Spiroplectamina praelonga* (Reuss); Neagu, p. 40, pl. 5, fig. 4–6.

MATERIAL: 40 specimens (in formic acid treated samples).

*Spiroplectamina* sp.

MATERIAL: 2 specimens (in formic acid treated samples).

*Subbdelloidina* sp.

MATERIAL: 19 specimens (in formic acid treated samples).

*Subreophax scalaris* (Grzybowski, 1896)

1896. *Reophax guttifera* (Brady) var. *scalaria* Grzybowski, p. 277, pl. 8, fig. 26a–b.  
1988. *Subreophax scalaris* (Grzybowski); Kaminski *et al.*, p. 187, pl. 2, figs 16, 17.  
2005. *Subreophax scalaris* (Grzybowski); Kaminski and Gradstein, p. 278, pl. 55, figs 1–7.

MATERIAL: 12 specimens (in formic acid treated samples).

*Tipeammina elliptica* (Deecke, 1884)  
(Text-fig. 5E)

1884. *Rhabdammina elliptica* Deecke, p. 23, pl. 1, fig. 1a, b.  
2004. *Tipeammina elliptica* (Deecke); Neagu, pl. 1, figs 10–12, fig. 2.

MATERIAL: 72 specimens (in formic acid treated samples).

*Tipeammina* sp. 1

MATERIAL: 49 specimens (in formic acid treated samples).

DESCRIPTION: Test free, bilocular. Coarsely agglutinated, thick test. Aperture at the end of the tube as simple opening. Initial chamber is mostly not preserved, second chamber growing rapidly in diameter. Differs from *Tipeammina elliptica* in its much faster growth in diameter.

*Tipeammina* sp. indet.

REMARKS: Broken specimens, not further determinable.

*Tritaxia tricarinata* (Reuss, 1845)  
(Text-fig. 5J)

1845. *Textularia tricarinata* Reuss, p. 39, pl. 8, fig. 60.  
1863. *Dentalinopsis tricarinatum* Reuss; Reuss, p. 119, pl. 18, fig. 13.

1892. *Tritaxia tricarinata* (Reuss); Chapman, pp. 34, 35, pl. 11, fig. 1.

1972. *Tritaxia tricarinata* (Reuss); Hanzlíková, p. 54, pl. 11, fig. 11.

MATERIAL: 114 specimens (in formic acid treated samples).

DESCRIPTION: Test free, triserial and relatively big. Wall calcareous agglutinated. Aperture obscured.

*Trochammina* sp. 1

MATERIAL: 37 specimens (in formic acid treated samples).

DESCRIPTION: Low trochospiral, chambers deflated, chamber size increases rapidly in size, smooth wall, finely agglutinated, initial chambers obscured by outer chambers.

*Trochammina* sp. 2

MATERIAL: 15 specimens (in formic acid treated samples).

DESCRIPTION: Low trochospiral, chambers inflated, chamber size increases slowly in size, smooth wall, finely agglutinated, initial chambers obscured by outer chambers.

*Trochamminoides* spp.

MATERIAL: 87 specimens (in formic acid treated samples).

*Verneulinoides* sp.

MATERIAL: 87 specimens (in formic acid treated samples).

REMARKS: This species group includes different species of the genus *Verneulinoides* Mjatluk, 1939.

*Whiteinella* cf. *archaeocretacea* Pessagno, 1967

1967. *Whiteinella archaeocretacea* Pessagno, p. 298, pl. 41, figs 2–4, pl. 54, figs 19–25, pl. 100, fig. 8.

MATERIAL: 1 specimen (in acetic acid – copper-II-sulphate treated sample).

*Whiteinella* spp.  
(Text-fig. 4A–F)

MATERIAL: 958 specimens (in acetic acid – copper-II-sulphate treated samples).

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