Agglutinated foraminifera from the ‘mid’-Cretaceous of the European Boreal Realm:
Taxonomy, biostratigraphy and implications to paleoenvironment/climate/biogeography and depositional sequences

Dissertation

Submitted in Partial Fulfilment of the Requirements for the Degree
Doktor der Naturwissenschaften (doctor rerum naturalium)

Vorgelegt von:
Richard Martin Besen

Freie Universität Berlin
Fachbereich Geowissenschaften
Berlin, 2023

Gutachter:

Prof. Dr. Frank Riedel

Prof. Dr. Ulrich Struck

Disputationsdatum: 04.07.2023

Erklärung:

Hiermit versichere ich, die vorliegende Arbeit selbständig verfasst zu haben. Es wurden keine anderen Quellen und Hilfsmittel als die in der Arbeit angegebenen verwendet. Alle Ausführungen, die anderen Schriften wörtlich oder sinngemäß entnommen wurden, sind kenntlich gemacht. Diese Arbeit wurde bisher weder in gleicher noch in ähnlicher Form einer Prüfungsbehörde vorgelegt.

Berlin, 2023

„Es ist nicht ihr Ziel,

der unendlichen Weisheit eine Tür zu öffnen,

sondern eine Grenze zu setzen dem unendlichen Irrtum.“

– über die Wissenschaft: **Bertolt Brecht**

Table of contents

Summary

Agglutinated foraminifera are traditionally used for resolving biostratigraphical and paleoenvironmental queries in scenarios where calcareous-shelled microfossils are absent. Typically, such deposits occur in diagenetically altered carbonate-deficient flysch or deposits originating from high latitudes, as well as deep-sea sediments deposited below the CCD (carbonate compensation depth). However, during the mid-Cretaceous, the paleoceanographic setting was vastly different, featuring warm shelf seas that caused extensive carbonate deposition on shelves due to higher sea levels. Micropaleontological comparison and correlation of such carbonate deposits to the previously mentioned carbonate-deficient deposits are difficult and rarely documented.

By examining agglutinated foraminiferal assemblages in shelf-related carbonate deposits, this study reveals their distribution and diversity as well investigates potential for use in biostratigraphy and paleoenvironmental reconstructions. With the findings, this study attempts to bridge the gap between deep-sea environments and the extensive shelf areas during the mid-Cretaceous.

Comparisons of various micropaleontological techniques for disaggregating calcareous rock material have demonstrated 1) that techniques based on carbonate dissolution such as the formic acid method are most effective to obtain diverse agglutinated foraminiferal assemblages and 2) that with application of standard micropaleontological methods an absolute majority of the agglutinated foraminiferal genera and species are absent. We demonstrated that a bias of knowledge about the agglutinated foraminifera and possible applications in various research queries for carbonate deposits from the mid-Cretaceous exists.

This study firstly documents and describes the diverse agglutinated foraminiferal assemblages from Albian to Coniacian carbonate deposits from different European shelf basins. These assemblages consisting of typical shelf related and deep-water related taxa resemble in a newly described agglutinated foraminiferal biofacies: the mid-latitude shelf biofacies. Based on findings of this study, regional and interregional biostratigraphical schemes based on agglutinated foraminifera were tested. Ranges of regional marker species were either confirmed or refined. However, also typical DWAF (Deep Water Agglutinated Foraminifera) biostratigraphical marker species were found in all successions

from the European shelf enabling interregional correlation based on the classical biozonation scheme from the Atlantic and Tethyan realm.

Mass occurrences (acmes) of agglutinated foraminiferal species and/or genera often can be linked to classical macro-bioevents which are usually expressed by mass occurrences of inoceramids, ammonites, or belemnites in the mid-Cretaceous deposits. These micro-bioevents can be used for regional and interregional stratigraphic correlation. However, micro-bioevents but also changes in relative abundances of agglutinated foraminiferal morphogroups often correspond to specific aspects of depositional sequences.

The distribution and diversity of agglutinated foraminifera in a basin is controlled by different factors. Differences in relative abundances of foraminiferal morphogroups are partly related to the location inside of the basin. Comparison of agglutinated foraminiferal assemblages from proximally and distally deposited successions from the Lower Saxony Basin shown increased numbers of deep infaunal living elongate forms and shallow infaunal globular morphotypes in proximal settings, distally free epifaunal flattened forms occur more frequently and abundances of deep infaunal forms are decreased. These different compositions of agglutinated foraminiferal assemblages are likely related to differing food availabilities with increased supply in proximal settings in the Cenomanian and/or can indicate enhanced mixing of the water column during times of pelagization of the shelf seas and stratification of the water column in the Turonian. Thus, agglutinated foraminifera reveal potential to differentiate between basin- or interbasin-wide and regional environmental changes.

In general, all agglutinated morphogroups are obtained from the Albian to Coniacian successions from the study area – even those morphogroups occur which today are only observed in bathyal to abyssal settings. These findings underline the substantial different conditions in the shallow shelf seas of the studied time interval.

This study shows that agglutinated foraminifera have potential as an underestimated tool particularly for the reconstruction of paleoenvironmental changes in Cretaceous carbonate successions. Especially, sea level changes, changes in food availability and/or oxygen concentration in bottom water conditions can be reconstructed with agglutinated foraminifera.

Zusammenfassung

Üblicherweise werden agglutinierende Foraminiferen für verschiedene wissenschaftliche Fragestellungen der Biostratigraphie oder Paläoumweltforschung besonders in Gesteinen genutzt, in denen keine kalkigen Mikrofossilien gefunden werden können. Solche Ablagerungen sind zum Beispiel Flysch, klastische Sedimente aus höheren Breiten und Tiefseesedimente, die unterhalb der Karbonat-Kompensationstiefe abgelagert wurden. Jedoch waren in der ‚mittleren' Kreide die paläoozeanographischen Bedingungen gänzlich anders als heutzutage bedingt durch besonders hohe Meeresspiegel, welche weithin überflutete, warme Schelfbereiche nach sich zogen. In diesen Bereichen wurden mächtige karbonatische Abfolgen abgelagert. Der Vergleich und die Korrelation dieser Ablagerungsräume mit den oben genannten nicht-karbonatischen Gesteinen sind generell schwierig und nur selten dokumentiert.

Diese Studie untersucht sowohl die Verbreitung und Diversität von agglutinierenden Foraminiferen als auch deren mögliches Potential in der Anwendung in der Biostratigraphie und Paläoumwelt-Rekonstruktion in den karbonatischen Schelf-Abfolgen. Die Wissenslücke zwischen Tiefseeablagerungen und den ausgedehnten Schelfbereichen der Kreide soll geschlossen werden.

Mit einem Vergleich verschiedener mikropaläontologischer Aufbereitungsmethoden konnte folgendes festgestellt werden: 1. Die effektivste Methode zur Aufbereitung agglutinierender Foraminiferen in karbonatischen Gesteinen ist die Anwendung von Ameisensäure. 2. Mit anderen bisher überwiegend genutzten Aufbereitungsmethoden ist ein Großteil der Arten und Gattungen agglutinierenden Foraminiferen nicht feststellbar. Deshalb ist anzunehmen, dass eine große Wissenslücke in Bezug auf die agglutinierenden Foraminiferen und deren Verbreitung und Anwendungsmöglichkeiten in den karbonatischen Gesteinen der Kreide besteht.

Diese Studie beschreibt erstmalig die diversen Vergesellschaftung von agglutinierenden Foraminiferen des Albiums bis Coniaciums aus verschiedenen europäischen Schelfbecken. Die dokumentierten Foraminiferen-Faunen setzten sich zusammen aus typischen Flach- und Tiefwasserformen und können als komplett neue agglutinierende Foraminiferen-Biofazies, der ‚mid-latitude shelf biofacies', beschrieben werden. Basierend auf Beobachtungen dieser Studie, können außerdem regionale und überregionale biostratigraphische Konzepte überprüft und/oder angewendet werden. So wurden Reichweiten regionaler Indexfossilien bestätigt und angepasst. Des Weiteren

wurden auch typische Indexfossilien für die Tiefsee (DWAF: Deep Water Agglutinated Foraminifera) gefunden und so erstmalig die agglutinierenden Foraminiferen des europäischen Schelfs mit Tiefseebereichen des Atlantiks und der Tethys korreliert.

Außerdem können Massenauftreten von bestimmten Arten und/oder Gattungen agglutinierenden Foraminiferen für die regionale und überregionale Korrelation genutzt werden. Oft können diese Mikro-Bioevents mit Makro-Bioevents aus der klassischen Eventstratigraphie verknüpft werden. Außerdem können sowohl Mikro-Bioevents als auch Veränderungen der relativen Häufigkeit von Morphogruppen agglutinierender Foraminiferen mit einzelnen Aspekten der Sequenzsstratigraphie verknüpft werden.

Unterschiede des Vorkommens aber auch der Diversität der Foraminiferen-Gemeinschaften sind abhängig von zahlreichen Faktoren. Das relative Vorkommen von Morphogruppen agglutinierenden Foraminiferen ist teilweise abhängig von der Position innerhalb des Beckens. Während unter proximalen Bedingungen besonders tief-infaunal und flach-infaunal lebende Formen auftreten, kommen in distalen Bereichen mehr epifaunal lebende und weniger infaunal lebende Formen vor. Diese Unterschiede in der Komposition sind vermutlich auf unterschiedliche Nahrungsverfügbarkeit zurückzuführen. Im Cenomanium ist diese abhängig von der Entfernung zur Küste. Wohingegen während des Turoniums – einer Zeit mit deutlichen Meeresspiegelanstiegen, und darauffolgend der Pelagisierung und Stratifizierung der Schelfmeere – hauptsächlich die Durchmischung des Wasserkörpers das Nahrungsangebot bestimmt hat. Agglutinierende Foraminiferen können also gut genutzt werden, um zwischen regionalen und überregionalen paläokologischen Veränderungen zu unterscheiden.

Generell kommen in allen untersuchten Abfolgen des Albiums bis Coniaciums alle Morphogruppen agglutinierender Foraminiferen vor, auch jene die heutzutage nur in bathyalen bis abyssalen Ablagerungsbedingungen vorkommen. Diese Beobachtung unterstreicht die grundsätzlich unterschiedlichen Bedingungen, die in den kreidezeitlichen Schelfen im Vergleich zu heutigen Flachwasserbereichen geherrscht haben.

Diese Studie zeigt auf, welches bisher unbekannte Potential agglutinierende Foraminiferen aus kretazischen Karbonatabfolgen in der Biostratigraphie aber besonders auch für die Rekonstruktion von Veränderungen der Paläoumwelt aufweisen. Insbesondere Meeresspiegelschwankungen, Änderung der

Nahrungs- und/oder Sauerstoffverfügbarkeit in bodennahem Meereswasser können mit agglutinierenden Foraminiferen abgebildet werden.

Chapter 1

Introduction

1.1 The Cretaceous Hot Greenhouse

Our world is changing. Due to the intensive anthropogenic emission of greenhouse gases to the atmosphere a definite global warming already was implemented, and further warming for the next centuries is proposed by the vast majority of climate researchers all over the world. This resulting dramatic changes are affecting already and will further be affecting all habitats and environments on our planet (IPCC, 2022).

To understand the feedback of certain habitats and organisms to such changes, it is always worth looking into the past. Because not only the present is the key to the past, indeed, the past is the key to the future. Therefore, especially times of much warmer climatic conditions and (geologically) rapid climate changes such as during the Cretaceous Greenhouse phase can give hints to the changes that will occur in future days.

The mid-Cretaceous (Albian to Coniacian) is known as a time of much higher temperatures worldwide resulting in glacier-free poles, higher greenhouse gas concentrations in the atmosphere and oceans, more acidic water conditions in the oceans, and higher sea-levels than today (see Skelton, 2003; Voigt et al., 2004; Haq, 2014; see also Fig. 1.1). This time interval represents the thermal peak of the Cretaceous Greenhouse phase and is called the Cretaceous Hot Greenhouse (Huber et al., 2018) or Cretaceous Hothouse (Kidder and Worsley, 2010; Hay and Floegel, 2012).

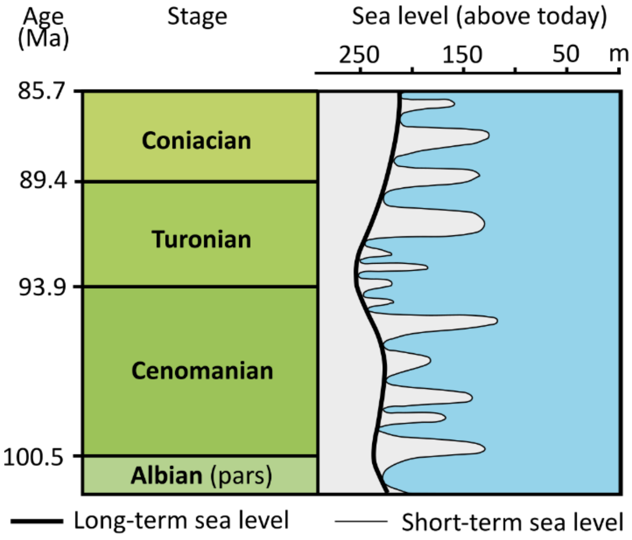


Figure 1.1. Albian to Coniacian long- and short-term sea level changes compared to the recent sea level, modified from Haq (2014).

Even at this time, there were (geologically) rapid changes of the climatic conditions including intense warming in the early Cenomanian, and in the late Cenomanian (e.g., Voigt et al., 2004, 2008; Haq, 2014). These warmings and subsequent sea level rises (Fig. 1.1) are worldwide expressed transgressive features in the sedimentological record. The latter mentioned late Cenomanian transgression is likely linked to intense LIP (Large Igneous Provinces) volcanism of the Caribbean LIP and the High Arctic LIP (e.g., Snow et al., 2005; Tegner et al., 2011, Zheng et al., 2013; Schröder-Adams et al., 2019). Basalt-sea water interaction and outgassing greenhouse gases resulted in a globally recognizable anoxic event – the OAE2 – with widespread anoxia from shallower to deeper water settings (e.g., Schlanger and Jenkyns, 1976; Arthur et al., 1990; Jenkyns, 2010; Jarvis et al., 2011). After these major perturbations of the carbon cycle, times of wide flooded shelfs (Fig. 1.2) with expanded oligotrophic conditions persisted over several million years during the Turonian (Wiese et al., 2015, 2017). However, even distinct cooling events occurred such as during the *plenus* Event (e.g., Gale and Christensen, 1996; Helmond et al., 2015; Jenkyns et al., 2017; O'Connor et al., 2019), and Late Turonian Cooling Event (LTCE; Voigt and Wiese, 2000; Wiese and Voigt, 2002). For the LTCE even short-lasting glaciations in the polar regions are proposed (Bornemann et al., 2008; Miller et al., 2008).

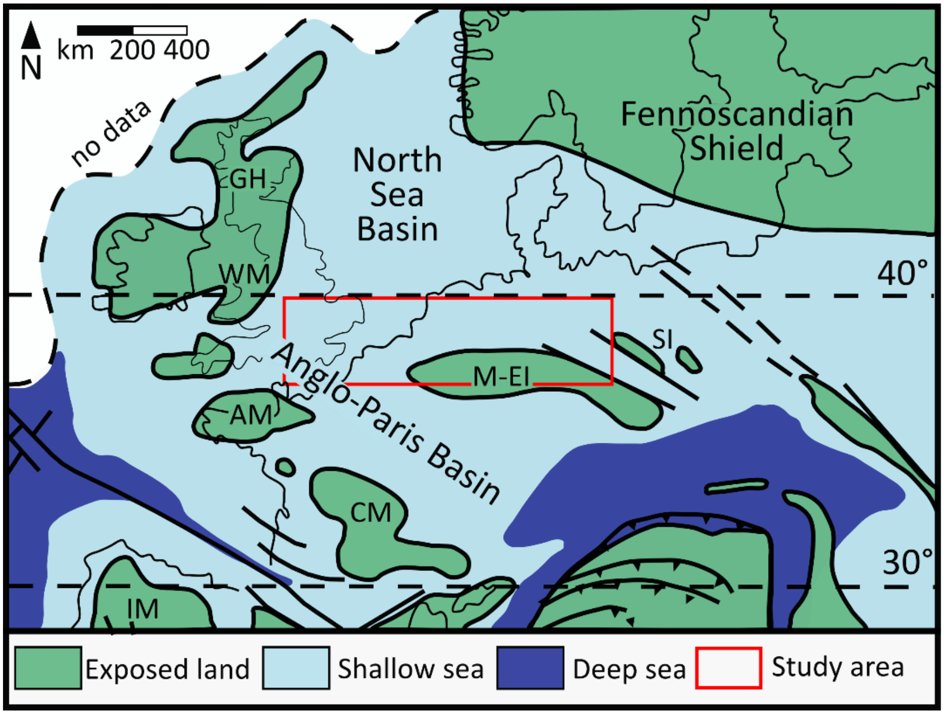


Figure 1.2. Palaeogeographical map of Europe during the mid-Cretaceous, modified after Philip and Floquet (2000); red box = study area; abbreviations: AM = Americian Massif, CM = Central Massif, GH = Grampian High, IM = Iberian Massif, M–EI = Mid–European Island, SI = Sudetian Islands, WM = Welsh Massif.

With sea levels approximately up to 250 m higher than today vast shelf areas were flooded developing epicontinental shelf seas all-over most of the continents (Haq, 2014; see also Fig. 1.2). Even in today temperate climate zones like in middle to northern Europe, calcareous oozes were deposited in hemipelagic to pelagic settings dependent on the actual paleoceanographical configuration due to tropical to subtropical climates in the mid-Cretaceous time (e.g., Burgener et al., 2023, see Fig. 1.3). These oozes resulted in extended marlstone successions, marl- to limestone alternations, and chalk deposits in hemipelagic to pelagic settings followed by diagenesis and overburden (e.g, Skelton, 2003; Voigt et al., 2004; Janetschke et al., 2015). A setting like this has no equivalent in today's world.

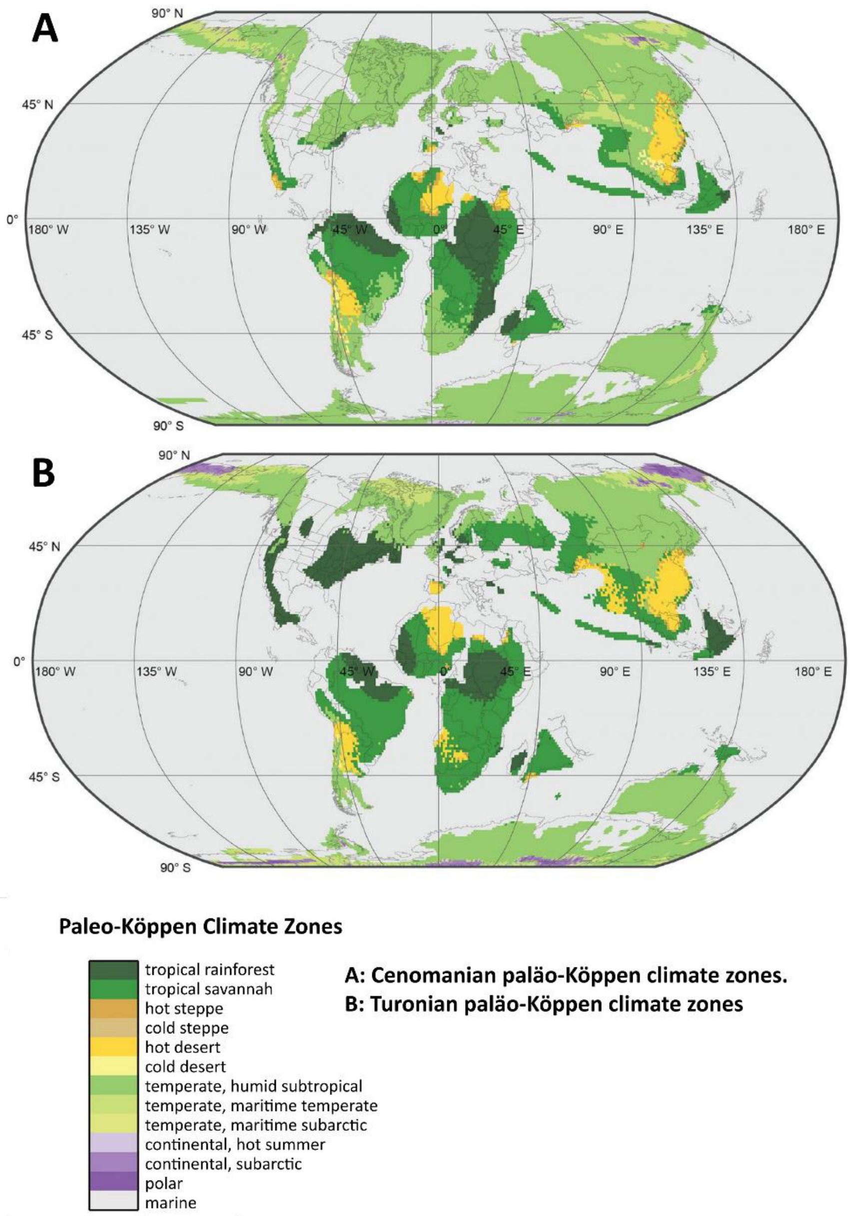


Figure 1.3. Paleo-Köppen climate zones in the mid-Cretaceous world; A: Cenomanian; B: Turonian.

1.2 History of agglutinated foraminiferal research

The history of agglutinated foraminiferal research can be divided into three major phases.

1. First reports on agglutinated foraminiferal faunas were conducted in the context of the 19th century oceanic research expeditions (Brady, 1879, 1884). These mostly first descriptions of many modern agglutinated (and calcareous) foraminiferal genera and species are mainly based on samples taken by dredging of sea bottom sediments. Also, fossil (but usually not exclusively) agglutinated foraminiferal assemblages of different age were described during this time and in the first half of the 20th century (e,g., d'Orbignyi, 1840, 1846; Reuss, 1844, 1845, 1846, 1851, 1863; Jones and Parker, 1860; Karrer, 1866; Schultze, 1875; Marsson, 1878; Berthelin, 1880; Deeke, 1884; Beissel, 1891; Chapman, 1892; Perner, 1892; Grzybowksi, 1896, 1898, 1901; Friedberg, 1901; Schubert, 1902; Berry, 1928; Franke, 1914, 1928; Dylążanka, 1923; Cushman and Jarvis, 1928; see also Fig. 1.4).

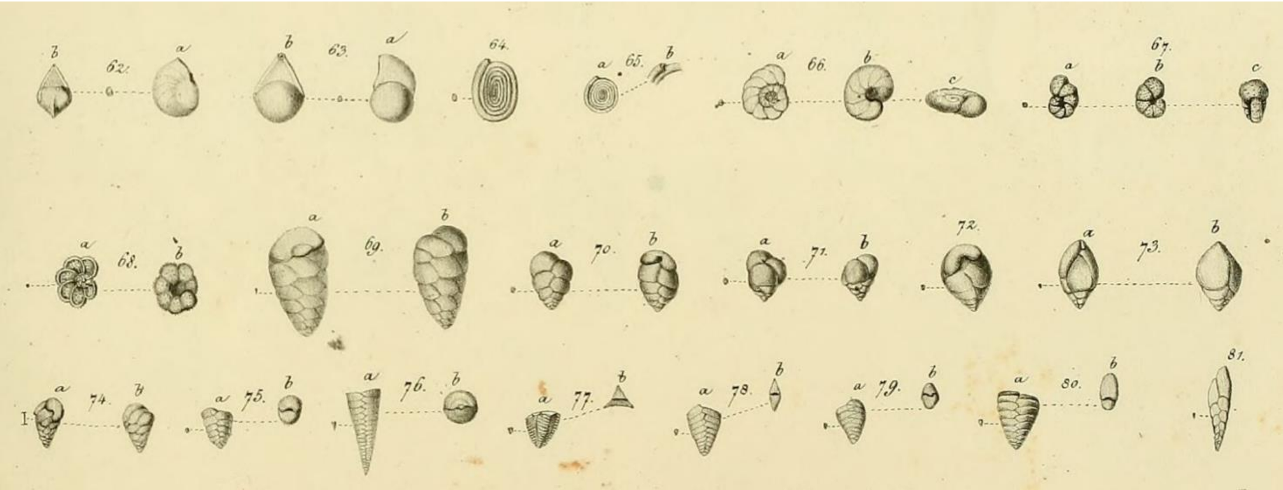


Figure 1.4. Historical drawings of foraminifera from Bohemian Cretaceous deposits belonging to first or secondary descriptions of the displayed species (Reuss, 1845-1846; table XIII); 62–63. *Cristellaria ovalis*: accepted as *Lenticulina ovalis* (Reuss, 1844); 64–65. *Operculina cretacea*: accepted as *Ammodiscus cretaceus* (Reuss, 1845); 66. *Rosalina ammonoides*: accepted as *Gavelinella ammonoides* (Reuss, 1844); 67. *Rosalina moniliformis*: accepted as *Gavelinella moniliformis* (Reuss, 1844); 68. *Rosalina marginata*: accepted as *Marginotruncata marginata* (Reuss, 1845); 69. *Valvulina spicula* Reuss, 1844; 70. *Bulimina murchisoniana* d'Orbignyi, 1840; 71. *Bulimina intermedia*: accepted as *Eggerellina intermedia* (Reuss, 1845); 72. *Bulimina preslii*: accepted as *Arenobulimina preslii* (Reuss, 1845); 73. *Bulimina ovulum*: accepted as *Praebulimina ovulum* (Reuss, 1844); 74. *Bulimina d'orbignyi*: accepted *Voloshinoides d'orbignyi* (Reuss, 1845); 75. *Textularia conulus*: accepted as *Dorothia conulus* (Reuss, 1844); 76. *Textularia turris*: accepted as *Marssonella trochus* (d'Orbignyi, 1840); 77. *Textularia triquetra*: accepted as *Verneuilina triquetra* (Münster, 1838); 78. *Textularia anceps*: accepted as *Spiroplectammina anceps* (Reuss, 1845); 79. *Textularia obsoleta*

Reuss, 1845; 80. *Textularia partschii* Reuss, 1845; 81. *Virgulina tegulata*: accepted as *Fursenkoina tegulata* (Reuss, 1846).

2. In context of the growing importance of hydrocarbon-based resources during the second half of the 20th century, the stratigraphical significance of Deep Water Agglutinated Foraminifera (DWAF) was studied mainly from flysch deposits in and around the Alps/Carpathians (e.g., Vašíček, 1947; Noth, 1951; Hanzlíková, 1953, 1972; Emiliani, 1954; Geroch and Gradziński, 1955; Maslakova, 1955; Geroch, 1959, 1960; Jurkiewicz, 1960, 1967; Neagu, 1962, 1968 1970; Huss, 1966; Fuchs, 1971; Olszewska and Morgiel, 1981; Geroch and Nowak, 1984; Bubík, 1995; Bąk et al., 1997; Peryt et al., 1997; Bąk, 2000). These were compared to faunas which were found in deep sea sediments obtained during the Ocean Drilling Program (ODP) and the International Ocean Drilling Program (IODP), especially from the Atlantic Ocean (e.g., Krasheninnikov, 1973, 1974; Hemleben and Troester, 1984; Kaminski et al., 1988, 1989; Kuhnt et al., 1989, 1992; Kuhnt and Kaminski, 1990, 1997; see also Kaminski and Gradstein, 2005) and deposits from localities/areas of high latitudes (e.g., Gradstein and Berggren, 1981; Gradstein and Kaminski, 1989; Charnock and Jones, 1990; Kaminski et al., 1990; Schröder-Adams and McNeil, 1994a,b; Evans and Kaminski, 1997; McNeil, 1997; Nagy et al., 1997, 2000; Gradstein et al., 1999, Akker et al., 2000).

3. During the 1990th until today, again modern foraminiferal assemblages went back to the general interest of science. Their life mode and feeding behaviour was studied intensively and based on these observations, models such as the TROX model (Fig. 1.5), the morphogroup scheme (Fig. 1.6), and other models were developed and improved to explain foraminiferal distribution (e.g., Jones and Charnock, 1985; Kaminski, 1985; Schröder, 1986; Kaminski et al., 1995; Murray and Alve, 1994, 1999a, 1999b, 2011; Jorissen et al., 1995; Alve, 1996; Zwaan et al., 1999; De Rijk et al., 2000; Kuhnt et al., 2000; Murray et al., 2003, 2011; Murray, 2006; Bubík, 2019).

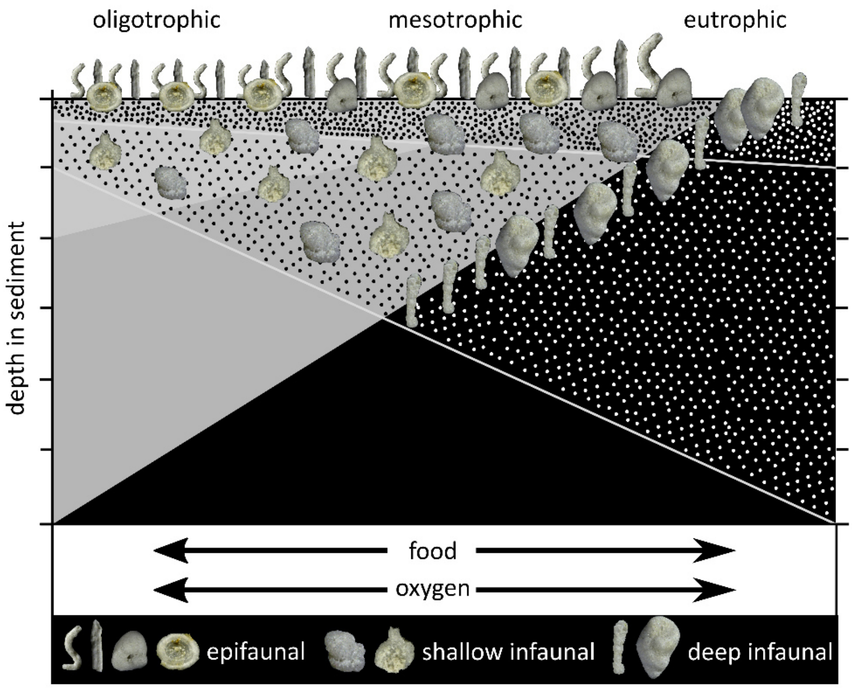
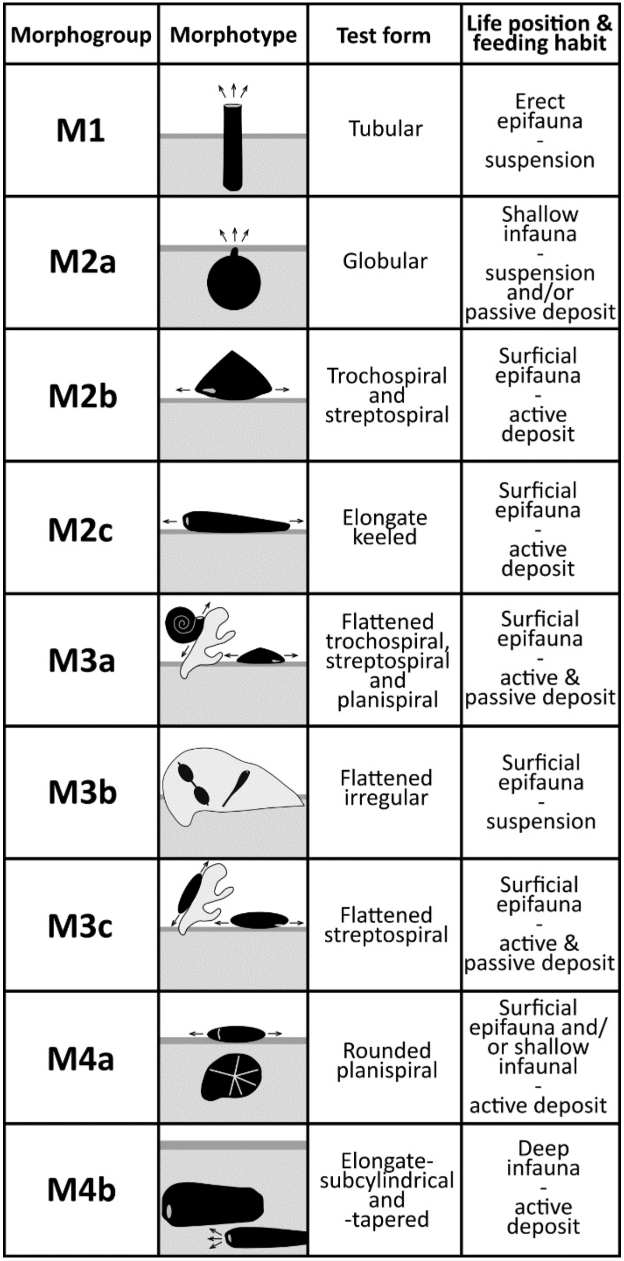


Figure 1.5. TROX model (redrawn and modified after Jorissen et al. 1995, Zwaan et al. 1999, Setoyama et al. 2017; see also Besen et al., in prep.: chapter 4). Shelf associated deep infaunal morphotypes are added reflecting the mid-latitude shelf biofacies.

With the increasing knowledge of the feedback of modern agglutinated foraminiferal assemblages to environmental changes, the developed models were increasingly adapted and applied to reconstruct past environments based on fossil agglutinated foraminiferal assemblages (e.g., Kuhnt and Kaminski, 1990; Coccioni et al., 1995; Bąk et al., 1997; Peryt et al., 1997, 2004; Gräfe, 1999; Akker et al., 2000; Frenzel, 2000; Nagy et al., 2000, 2011, 2013; Alegret and Thomas, 2001; Tyszka, 2009; Cetean et al., 2011; Setoyama et al., 2011, 2017; Bindui et al., 2013; Józsa, 2017; Bubík, 2019; Kaminski et al., 2021, Hikmahtiar et al., 2022; Hjálmarsdóttir et al., 2022).



Morphogroup	Morphotype	Test form	Life position & feeding habit
M1		Tubular	Erect epifauna - suspension
M2a		Globular	Shallow infauna - suspension and/or passive deposit
M2b		Trochospiral and streptospiral	Surficial epifauna - active deposit
M2c		Elongate keeled	Surficial epifauna - active deposit
M3a		Flattened trochospiral, streptospiral and planispiral	Surficial epifauna - active & passive deposit
M3b		Flattened irregular	Surficial epifauna - suspension
M3c		Flattened streptospiral	Surficial epifauna - active & passive deposit
M4a		Rounded planispiral	Surficial epifauna and/ or shallow infaunal - active deposit
M4b		Elongate-subcylindrical and -tapered	Deep infauna - active deposit

Figure 1.6. Agglutinated foraminiferal morphogroups, morphotypes/test forms, life position, and feeding habit, redrawn and modified after Frenzel (2000), Cetean et al. (2011), and Setoyama et al. (2017).

1.3 Cretaceous agglutinated foraminifera from the European shelf sea

Although agglutinated foraminiferal assemblages, stratigraphic ranges, and general evolutionary trends of the group are well documented for assemblages found in rocks deposited in deep water settings in the Atlantic and Tethyan realm, and from the high Arctic latitudes, this does not hold true for shelf related deposits.

In deposits from the mid-Cretaceous European shelf, only a few different genera of agglutinated foraminifera are reported until today. Reports about the occurrence and ranges of mid-Cretaceous agglutinated foraminifera are made for the English and French Chalk of the Anglo-Paris Basin (e.g., Barnard and Banner, 1953, 1981; Hart, 1970; Carter and Hart, 1977; Robazynski et al., 1980; Robazynski and Amédro, 1986; Leary, 1987; Hart et al., 1989, 1993, 2020; Mitchell, 1996; Gräfe, 1999; Wilkinson and Hopson, 2011), for the Polish basins (Gawor-Biedowa, 1969, 1972, 1980; Peryt et al., 1994; Dubicka and Machalski, 2017; Dubicka et al., 2021), for the carbonates from the Bohemian Cretaceous Basins (Hercogová, 1969, 1974; Hradecká and Švábenická, 1997; Hradecká 1999; Chroustová et al., 2021), and for the Northern German basins (Frieg, 1980; Frieg and Price, 1982; Frieg and Kemper, 1989; Wejda, 1993; Kuhnt and Wiedmann, 1995; Prokoph et al., 1999; Szarek, 2000; Tyszka, 2009, Friedrich et al., 2011; Elicki et al., 2020). Most herein described and documented species belong to the mostly 'shelf-related' superfamilies Ataxophragmioidea Schwager, 1887 and Verneuilinoidea Cushman, 1911. They possess a relatively large test which makes them easy to find and identify.

1.4 Aim of the thesis

The objectives of this study are:

1. To firstly document the whole agglutinated foraminiferal assemblages from Albian to Coniacian outcrops and cores from carbonates deposited in the 'Boreal' European shelf sea.
2. To test previously published biostratigraphical zonation schemes of the study region and other adjacent realms, and search for other biostratigraphical markers.
3. To test schemes that are used for paleoenvironmental reconstruction in deep water settings based on agglutinated foraminifera on Cretaceous agglutinated foraminiferal shelf assemblages.
4. To reconstruct paleoenvironmental changes based on both quantitatively and qualitatively (e.g., trophic conditions, paleo-productivity, water depth, oxygenation) for different basins of the European shelf and compare and correlate them with each other.
5. To access the response of agglutinated foraminiferal assemblages to global perturbations and events (e.g., anoxic events, sea level changes, warming- or cooling events).

1.5 Outline of the thesis

The presented dissertation is constructed as a thesis of cumulative approach. Overall, four different publications which are already published (chapter 2–3, 5) or submitted for publication (chapter 4) should focalize on one or more aspects of the distribution of agglutinated foraminiferal assemblages from calcareous shelf deposits from the Albian to Coniacian and their capability to solve stratigraphical and paleoenvironmental issues. Contributions and data besides or along the presented chapters are listed in the Appendix.

1.5.1 Chapter 2 (published in *Marine Micropaleontology*)

This chapter debates in detail the applied formic acid method in comparison to other standard micropaleontological method in application on calcareous rock material. The methods are particularly studied for their different number of agglutinated foraminifera which are obtained per gram, and number of genera and species. The study reveals that significant parts of the agglutinated foraminiferal fauna are not observable with standard micropaleontological methods but with the formic acid method. Consequently, a bias of knowledge of agglutinated foraminifera for hemipelagic calcareous deposits from the Upper Cretaceous was proven.

The initial design for this study was developed by Ulrich Struck and Richard M. Besen. Richard M. Besen performed the field work and took the samples. Jasmin Hegert and Richard M. Besen performed the laboratory work and studied the sample residues with a stereo-microscope. All given images were designed or taken by Richard M. Besen. All authors discussed and interpreted the results of the study. Richard M. Besen wrote the manuscript. All authors edited and commented on several versions of the manuscript.

1.5.2 Chapter 3 (published in *Fossil Record*)

This chapter is characterized as an extensive description, documentation, and interpretation of the diverse agglutinated foraminiferal fauna in marl-/limestone alternations of the Lower Saxony Basin. It compares the assemblages of proximal deposits from the Subhercynian Cretaceous subbasin in the southern Lower Saxony Basin to those distally deposited in the centre of the basin. A new and former completely unknown agglutinated foraminiferal biofacies was proposed: the mid-latitude shelf biofacies. Changes in bottom water conditions – mainly food availability – are likely displayed by changes in relative abundances of agglutinated foraminiferal morphogroups. Mass occurrences of specific agglutinated foraminiferal species seem to correspond to classical bioevents (based on macrofossils) and can be attributed to different subtypes of bioevents.

The concept for this study was designed by Ekbert Seibertz and Richard M. Besen. The sampling during field work and processing of the drill cores were conducted by Richard M. Besen. All laboratory efforts were made by Richard M. Besen. Ulrich Struck performed the stable isotope analysis. Richard M. Besen did the imaging for this study. The results were discussed by all authors. Richard M. Besen wrote the initial draft of the manuscript. All authors were involved during editing the manuscript.

1.5.3 Chapter 4 (submitted to *Journal of Micropalaeontology*)

This chapter addresses the late Turonian to early Coniacian agglutinated foraminiferal fauna and their paleoenvironmental and stratigraphical implications. Interbasinal correlations were attempted in between the ratified GSSP section Salzgitter-Salder in the Lower Saxony Basin, with successions from the Münsterland Cretaceous Basin, the Anglo-Paris Basin, and the Saxonian Cretaceous Basin. The highly diverse agglutinated foraminiferal assemblages mainly consist of typical bathyal living forms such as tubular, globular, and elongated serial forms. Acmes of different foraminiferal species (*Ammolagena contorta, Bulbobaculites problematicus*) could be correlated in between different basins, and reveal stratigraphical potential. These acmes likely attribute to shifts in the trophic structure of the bottom water environment, either to more oligotrophic conditions (*Ammolagena contorta*), or vice versa (*Bulbobaculites problematicus*). Changes of agglutinated foraminiferal assemblages during the studied interval likely indicate a general shift to more eutrophic conditions from the late Turonian to the early Coniacian.

The initial design of this study was developed by Richard M. Besen. Fieldwork including sample collection was conducted by Richard M. Besen, Andrew S. Gale, and Kathleen Schindler. The laboratory processing of the rock material for micropaleontological purposes was performed by Richard M. Besen, while Kathleen Schindler prepared the samples for isotope measurements. The stable isotope measurements were done by Kathleen Schindler and Ulrich Struck. All images were processed by Richard M. Besen. The results were discussed by all authors. Richard M. Besen prepared the early draft of the manuscript. All authors edited the manuscript before journal submission.

1.5.4 Chapter 5 (published in *Acta Geologica Polonica*)

This chapter accesses micropaleontological aspects (both agglutinated and calcareous foraminifera) from the upper Turonian to lower Coniacian of the transitional facies zone (sandstone facies – marlstone facies) from the Saxonian Cretaceous Basin. The findings were compared to faunas from the Brausnitzbach Marl (sandstone facies). Maximum flooding zones of genetic sequences of the time interval could be linked to different features of the foraminiferal assemblages (acmes, morphogroups). A deepening of the water depth throughout the interval is expressed by foraminiferal changes. While agglutinated foraminiferal assemblages suggest a generally high organic matter influx and variable but high productivity in the Graupa 60/1 core, the Brausnitzbach Marl deposition was characterized by moderate productivity and a generally shallower water depth.

The concept of this study was initially developed by Richard M. Besen, Thomas Voigt, and Peter Frenzel. Richard M. Besen and Mareike Achilles conducted the core sampling. Thomas Voigt took samples of the Brausnitzbach Marl. Richard M. Besen processed the samples in the laboratory for agglutinated foraminiferal analysis and determined and documented the agglutinated foraminifera. Mareike Achilles, Mauro Alivernini, and Peter Frenzel processed and analysed the calcareous foraminiferal fauna. Images of foraminifers were taken by Richard M. Besen, Mareike Achilles, Mauro Alivernini, and Peter Frenzel. Richard M. Besen and Peter Frenzel performed the statistical analyses. Digital imaging was contributed by Richard M. Besen and Thomas Voigt. The results were discussed by all authors. The initial draft of the manuscript was written by Richard M. Besen, Thomas Voigt and Peter Frenzel. All authors edited the manuscript before submission.

1.6 References

Akker van den, T.J.H.A., Kaminski, M.A., Gradstein, F.M. and Wood, J. 2000. Campanian to Palaeocene biostratigraphy and palaeoenvironments in the Foula Sub-basin, west of the Shetland Islands, UK. *Journal of Micropalaeontology*, 19 (1), 23–43, https://doi:10.1144/jm.19.1.23.

Alegret, L. and Thomas, E. 2001. Upper Cretaceous and lower Paleogene benthic foraminifera from northeastern Mexico. M*icropaleontology*, 47 (4), 269–316.

Alve., E. 1996. Benthic foraminiferal evidence of environmental change in the Skagerrak over the past six decades. *Norges geologiske undersøkelse Bulletin*, 430, 85–93.

Arthur, M.A., Brumsack, H.-J., Jenkyns, H.C. and Schlanger, S.O. 1990. Stratigraphy, Geochemistry, and Paleoceanography of Organic Carbon-Rich Cretaceous Sequences. In: Ginsburg, R.N. and Beaudoin, B. (Eds.) Cretaceous Resources, Events and Rhythms. *NATO ASI Series*, 304, 75–119.

Bąk, K. 2000. Biostratigraphy of deep-water agglutinated Foraminifera in Scaglia Rossa-type deposits of the Pieniny Klippen Belt, Carpathians, Poland. In: Hart, M.B., Kaminski, M.A. and Smart, C.W. (Eds.) Proceedings of the Fifth International Workshop on Agglutinated Foraminifera. *Grzybowski Foundation Special Publication*, 7, 15–41.

Bąk, K., Bąk, M., Geroch, S. and Manecki, M. 1997. Biostratigraphy and paleoenvironmental analysis of benthic foraminifera and radiolarians in Paleogene variegated shales in the Skole unit, Polish Flysch Carpathians. *Annales Societatis Geologorum Poloniae*, 67, 135–154.

Barnard, T. and Banner, F.T. 1953. Arenaceous Foraminifera from the Upper Cretaceous of England. *The Quarterly Journal of the Geological Society*, 109 (1–4), 173–216.

Barnard, T. and Banner, F.T. 1980. The Ataxophragmiidae of England: Part 1, Albian–Cenomanian *Arenobulimina* and *Crenaverneuilina*. *Revista Española de Micropaleontología*, 12, 383–430.

Beissel, I. 1891. Die Foraminiferen der Aachener Kreide. *Königliche Preussische Geologische Landesanstalt Abhandlungen*, 3, 1–78.

Berthelin, M. 1880. Mémoire sur les foraminifères fossiles de l'étage Albien de Montcley (Doubs). *Mémoirs de Société géologique de France*, 3éme Sér, 1, 85 pp.

Berry, E.W. 1928. The smaller foraminifera of the middle *Lobitos* shales of northwestern Peru. *Eclogae Geologae Helvetiae*, 21, 390–405.

Besen, R.M., Schindler, K., Gale, A.S. and Struck, U. in prep. Agglutinated foraminifera from the Turonian–Coniacian boundary interval in Europe – stratigraphy and paleoenvironmental remarks. Submitted to *Journal of Micropaleontology*, (currently under revision, 08.05.2023).

Bindui, R., Filipescu, S. and Bălc, R. 2013. Biostratigraphy and paleoenvironment of the Upper Cretaceous deposits in the northern Tarcău Nappe (Eastern Carpathians) based on foraminifera and calcareous nannoplankton. *Geologica Carpathica*, 62, 117–132.

Bornemann, A., Norris, R.D., Friedrich, O., Beckmann, B., Schouten, S., Sinninghe Damsté, Vogel, J., Hofmann, P. and Wagner, T. 2008. Isotopic Evidence for Glaciation During the Cretaceous Supergreenhouse. *Science*, 319, 189–192.

Brady, H.B. 1879. Notes on some of the reticularian Rhizopoda of the “CHALLENGER” Expedition; Part 1. On new or little known Arenaceous types. *Quarterly Journal of Microscopical Sciences*, 19, 20–67.

Brady, H.B. 1884. Report on the Foraminifera dredged by H.M.S. Challenger during the years 1873 – 1876. *Report on the Scientific Results of the Voyage of the HMS Challenger Zoology*, 9 (22), 814 pp., London.

Bubík, M. 1995. Cretaceous to Paleogene agglutinated foraminifera of the Bílé Karpaty unit (West Carpathians, Czech Republic). In: Kaminski, M.A., Geroch, S. and Gasinski, M.A. (Eds.) Proceedings of the Fourth International Workshop on agglutinated Foraminifera. *Grzybowski Foundation Special Publication*, 3, 71–116.

Bubík, M. 2019. Remarks on quantitative analysis of deep-sea foraminifer taphocoenosis with special attention to tubular astrorhizids. *Micropaleontology*, 65, 63–74.

Burgener, L., Hyland, E., Reich, B.J. and Scotese, C. 2023. Cretaceous climates: Mapping paleo-Köppen climatic zones using Bayesian statistical analysis of lithologic, paleontologic, and geochemical proxies. *Palaeogeography, Palaeoclimatology, Palaeoecology*, 613, 111373, https://doi.org/10.1016/j.palaeo.2022.111373.

Carter, D.J. and Hart, M.B. 1977. Aspects of mid-Cretaceous stratigraphical micropalaeontology. *Bulletin of the British Museum (Natural History) Geology*, 135 pp.

Cetean, C.G., Bălc, R., Kaminski, M.A. and Filipescu, S. 2011. Integrated biostratigraphy and palaeoenvironments of an upper Santonian–upper Campanian succession from the southern part of the Eastern Carpathians, Romania. *Cretaceous Research*, 32 (5), 575–590, https://doi:10.1016/j.cretres.2010.11.001.

Chapman, F. 1892. 7. – The Foraminifera of the Gault of Folkestone. 2. *Journal of Microscopy*, 12 (3), 319–330.

Charnock, M.A. and Jones, R.W. 1990. Agglutinated foraminifera from the Paleogene of the North Sea. In: Hemleben, C., Kaminski, M.A., Kuhnt, W. and Scott, D.B. (Eds.) Paleoecology, biostratigraphy, paleoceanography and taxonomy of agglutinated foraminifera. NATO ASI Ser. C327, *Kluwer Academic Publishers*, 139–244.

Chroustová, M., Holcová, K., Laurin, J., Uličný, D., Hradecká, L., Hrnková, M, Čech, S., Hrouda, F. and Jarvis, I. 2021. Response of foraminiferal assemblages to precession-paced environmental variation in a mid-latitude seaway: Late Turonian greenhouse of Central Europe. *Marine Micropaleontology*, 167, 102025.

Coccioni, R., Galeotti, S. and Gravili, M. 1995. Latest Albian–earliest Turonian deep-water agglutinated foraminifera in the Bottaccione section (Gubbio, Italy) – Biostratigraphic and palaeoecologic implications. *Revista Española de Paleontologia*, No. Homenaje al Dr. Guillermo Colom, 135–152.

Cushman, J.A. and Jarvis, P.W. 1928. Cretaceous foraminifera from Trinidad. *Contributions from the Cushman Laboratory for Foraminiferal Research*, 4, 85–103.

Deeke, W. 1884. Die Foraminiferenfauna der Zone des *Stephanoceras humphriesianum* im Unter-Elsass. *Abhandlungen zur geologischen Specialkarte von Elsass-Lothringen*, 4, 1–68.

De Rijk, S., Jorissen, F.J., Rohling, E.J. and Troelstra, S.R. 2000. Organic flux control on bathymetric zonation of Mediterranean benthic foraminifera. Marine Micropaleontology, 40 (3), 151–166.

d'Orbigny, A. 1840. Paléontologie française: description zoologique et géologique de tous les animaux mollusques et rayonnés fossiles de France. Terrains crétacés. Les céphalopodes, *A. Bertrand*, Paris, 696 pp.

d'Orbigny, A. 1846. Die fossilien Foraminiferen des tertiären Bekens von Wien. *Gide et Comp.,* Paris, 312pp.

Dubicka, Z. and Machalski, M. 2017. Foraminiferal record in a condensed marine succession: a case study from the Albian and Cenomanian (mid-Cretaceous) of Annopol. *Geological Magazine*, 154 (3), 399–418.

Dubicka, Z., Bojanowski, M., Peryt, D. and Barski, M. 2021. Biotic and isotopic vestiges of oligotrophy on continental shelves during Oceanic Anoxic Event 2. *Global Biogeochemical Cycles*, 35, e2020GB006831.

Dylążanka, M. 1923. Warstwy inoceramowe z łomu w Szymbarku koło Gorlic. *Rocznik Polskiego Towarzystwa Geologicznego*, 1, 36–80.

Elicki, O., Suhr, P. and Walter, H. 2020. Oberkretazische Foraminiferen aus Reliktvorkommen bei Siebenlehn (Mittelsachsen). *Freiberger Forschungshefte*, C 558 (25), 121–139.

Emiliani, C. 1954. The Oligocene microfaunas of the central of the northern Apennines. *Paleontographica Italica*, 48, 77–184.

Evans, J.R. and Kaminski, M.A. 1998. Pliocene and Pleistocene Chronostratigraphy and Paleoenvironment of the Central Arctic Ocean, Using Deep Water Agglutinated Foraminifera. *Micropaleontology,* 44, 109–130.

Franke, A. 1914. Die Foraminiferen und Ostracoden des Emschers, besonders von Obereving und Derne nördlich Dortmund. *Zeitschrift der Deutschen Geologischen Gesellschaft*, 66 (3), 428–443.

Franke, A. 1928. Die Foraminiferen der Oberen Kreide Nord-und Mitteldeutschlands. *Abhandlungen der Preußischen Geologischen Landesanstalt*, n. F. 111, 1–207.

Frenzel, P. 2000. Die benthischen Foraminiferen der Rügener Schreibkreide (Unter-Maastricht, NE-Deutschland), *Neue Paläontologische Abhandlungen*, 3, pp. 361.

Friedberg, W. 1901. Otwornice warstw inoceramowych okolic Rzeszowa i Dębicy. *Rozprawy Wydziału matematyczno-przyrodniczego, Akademia Umiejętnosci w Krakowie*, 2, 41, 601–668.

Friedrich, O., Voigt, S., Kuhnt, T. and Koch, M.C. 2011. Repeated bottom-water oxygenation during OAE 2: timing and duration of short-lived benthic foraminiferal repopulation events (Wunstorf, northern Germany). *Journal of Micropalaeontology*, 30, 119–128.

Frieg, C., 1980. Neue Ergebnisse zur Systematik sandschaliger Foraminiferen im Cenoman des südwestlichen Münsterlandes, *Paläontologische Zeitschrift,* 54 (3), 225–240.

Frieg, C. and Kemper, E. 1989. Mikropaläontologische Gliederung und Abgrenzung von Ober-Alb und Unter-Cenoman in Nordwestdeutschland, *Geologisches Jahrbuch*, 113, 73–193.

Frieg, C. and Price, R.J. 1982. The subgeneric classification of *Arenobulimina*, In: Banner, F.T. and Lord, A.R. (Eds.) Aspects of Micropalaeontology. *Springer*, 42–80.

Fuchs, W. 1971. Eine alpine Foraminiferenfauna des tieferen Mittel-Barreme aus den Drusbergschichten vom Ranzenberg bei Hohenems in Vorarlberg (Österreich). *Abhandlungen der Geologischen Bundesanstalt*, 27, 1–49.

Gale, A. and Christensen, W.K. 1996. Occurrence of the belemnite *Actinocamax plenus* in the Cenomanian of SE France and its significance. *Bulletin of the Geological Society of Denmark*, 43, 68–77.

Gawor-Biedowa, E. 1969. The genus *Arenobulimina* Cushman from the Upper Albian and Cenomanian of the Polish lowlands. *Annales Societatis Geologorum Poloniae*, 39 (1–3), 73–102.

Gawor-Biedowa, E. 1972. The Albian, Cenomanian and Turonian foraminifers of Poland and their stratigraphic importance. *Acta Palaeontologica Polonica*, 17, (1), 3–183.

Gawor-Biedowa, E. 1980. Turonian and Coniacian Foraminifera from the Nysa Trough, Sudetes, Poland. *Acta Paleontologica Polonica*, 25, 3–54.

Geroch, V.S. 1959. Stratigraphic significance of arenaceous foraminifera in the Carpathian flysch. *Paläontologische Zeitschrift*, 33, 113–122.

Geroch, V.S. 1966. Lower Cretaceous small foraminifera of the Silesian series, Polish Carpathians. *Rocznik Polskiego Towarzystwa Geologicznego*, 36, 413–480.

Geroch, V.S. and Gradziński, R. 1955. Stratigrafia serii podląskiej Żywieckiego okna tektonicznegi. *Rocznik Polskiego Towarzystwa Geologicznego*, 24, 3–62.

Geroch, V.S. and Nowak, W. 1984. Proposal of zonation for the Late Tithonian–Late Eocene, based upon arenaceous Foraminifera from the Outer Carpathians, Poland. *Benthos*, 83 (2), 225–239.

Gradstein, F.M. and Berggren, W.A. 1981. Flysch-type agglutinated foraminifera and the Maastrichtian to Paleogene history of the Labrador and the North Seas. *Marine Micropaleontology*, 6, 211–268.

Gradstein, F.M. and Kaminski, M.A. 1989. Taxonomy and biostratigraphy of new and emended species of Cenozoic deep-water agglutinated foraminifera from the Labrador and North Seas. *Micropaleontology*, 35, 75–92.

Gradstein, F., Kaminski, M.A. and Agterberg, F. 1999. Biostratigraphy and paleoceanography of the Cretaceous seaway between Norway and Greenland. Earth-Science Reviews, 46, (1), 27–98, https://doi:10.1016/S0012-8252(99)00018-5.

Gräfe, K.-U. 1999. Foraminiferal evidence for Cenomanian sequence stratigraphy and palaeoceanography of the Boulonnais (Paris Basin, northern France). *Palaeogeography, Palaeoclimatology, Palaeoecology*, 153, 41–70. https://doi.org/10.1016/S0031-0182(99)00080-2.

Grzybowski, J. 1896. Otwornice czerwonych ilow z Wadowic. Rozprawy Wydzialu Matematyczno-Przyrodniczego, *Akademia Umiejętności w Krakowie*, serya 2, 30, 261–308, 1896.

Grzybowski, J. 1898. Otwornice pokladow naftonosnych okolicy Krosna. Rozprawy Wydzialu Matematyczno-Przyrodniczego, *Akademia Umiejętności w Krakowie*, serya 2, 33, 257–305.

Grzybowski, J. 1901. Otwornice warstw inoceramowych okolicy Gorlic. Rozprawy Wydzialu Matematyczno-Przyrodniczego, *Akademia Umiejętności w Krakowie*, 41, 201–286.

Hanzlíková, E. 1953. Mikropaleontologicko-stratigrafickę zhodnocení vrtby Žukov NP15. *Sbornik Ústfiedniho Ústavu Geologického, oddil paleontologický*, 20, 1–83.

Hanzlíková, E. 1972. Carpathian Upper Cretaceous foraminifera from Moravia (Turonian–Maastrichtian). *Rozpravy Ústavu Geologického*, 39, 5–160.

Haq, B.U. 2014. Cretaceous eustasy revisited. *Global Planetary Change*, 113, 44–58, https://doi:10.1016/j.gloplacha.2013.12.007.

Hart, M.B. 1970. The Distribution of Foraminiferida in the Albian and Cenomanian of S.W. England. PhD thesis, *London*, 356 pp.

Hart, M.B., Bailey, H.W., Crittenden, S., Fletcher, B.N., Price, R. and Swiecicki, A. 1989. Chapter 7. Cretaceous. In: Jenkins, D.G. and Murray, J.W. (Eds.) Stratigraphical Atlas of Fossil Foraminifera. *Ellis Horwood Limited*, Chichester, 273–371.

Hart, M.B., Dodsworth, P. and Duane, A.M. 1993. The late Cenomanian Event in eastern England. *Cretaceous Research*, 14, 495–508.

Hart, M.B., Fogerty, T. and Smart, C.W. 2020. Foraminifera of the Gault Clay Formation: An update. *Proceedings of the Geologists Association*, 131, 386–396.

Hay, W.W. and Floegel, S. 2012. New thoughts about the Cretaceous climate and oceans. *Earth-Science Reviews*, 115, 262–272.

Hemleben, C. and Troester, J. 1984. Campanian–Maastrichtian deep-water foraminifers from Hole 543A, Deep Sea Drilling Project. *Initial Reports of the Deep Sea Drilling Project*, 78A, 509–532.

Helmond, N.A.G.M. van, Sluijs, A., Sinninghe Damste, J.S., Reichart, G.-J., Voigt, S., Erbacher, J., Pross, J. and Brinkhuis, H. 2015. Freshwater discharge controlled deposition of Cenomanian-Turonian black shales on the NW European epicontinental shelf (Wunstorf, northern Germany). *Climate of the Past*, 11, 495–508, https://doi:10.5194/cp-11-495-2015.

Hercogová, J. 1969. Foraminifery v cenomanu Českého masívu. MS *Česká geologická služba*, Praha. 1–123.

Hercogová, J. 1974. Foraminifera from the Cenomanian of the Bohemian Massif. *Sborník geologických věd Paleontologie*, 16, 69–103.

Hikmahtiar, S., Kaminski, M.A. and Cetean, C.G. 2022. Lower Paleocene Deep-Water Agglutinated Foraminifera from the Contessa Highway Section (Umbria-Marche Basin, Italy): taxonomy, stratigraphic distribution and assemblage turnover across the Cretaceous/Paleogene Boundary. *Rivista Italiana di Paleontologia e Stratigrafia*, 128 (3), 719–744.

Hjálmarsdóttir, H.R., Hammer, Ø., Nagy, J. and Grundvåg, S.-A. 2022. Foraminiferal stratigraphy and palaeoenvironment of a storm-influenced marine shelf: Upper Aptian – lower Albian, Svalbard, Arctic Norway. Cretaceous Research, 105033, 1–41, https://doi.org/10.1016/j.cretres.2021.105033.

Huber, B.T., MacLeod, K.G., Watkins, D.K. and Coffin, M.F. 2018. The rise and fall of the Cretaceous Hot Greenhouse climate. *Global and Planetary Change*, 167, 1–23.

Huss, F. 1966. Otwornice aglutynujace serii podslaskiej jednostki roponosnej Weglowki (Polskie Karpaty Fliszowe)(Agglutinated foraminifera of the oil-bearing subsilesian series in Weglowka (Polish Flysch Carpathians). *Prace Geologiczne, Polska Akademia Nauk*, 34, 7–76.

Hradecká, L. 1999. Correlation of the upper Turonian foraminiferal assemblage from the Úpohlavy and Březno sections (Bohemian Cretaceous Basin) with some other localities (South Moravia, Germany and Lower Austria). *Geologica Carpathica*, 50 (2), 145–150.

Hradecká, L. and Švábenická, L. 1997. Microbiostratigraphy of the Jizera and Teplice formations in the Úpohlavy quarry, Bohemian Cretaceous Basin. *Geoscience Research Reports*, 30, 115–117.

IPCC 2022. Climate Change 2022: Impacts, Adaptation and Vulnerability. In: Pörtner, H.-O., Roberts, D.C., Tignor, M., Poloczanska, E.S., Mintenbeck, K., Alegría, A., Craig, M., Langsdorf, S., Löschke, S., Möller, V., Okem, A. and Rama, B. (Eds.) Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change. *Cambridge University Press*. Cambridge and New York, 3056 pp., https://doi:10.1017/9781009325844.

Janetschke, N., Niebuhr, B. and Wilmsen, M. 2015. Inter-regional sequence-stratigraphical synthesis of the Plänerkalk, Elbtal and Danubian Cretaceous groups (Germany): Cenomanian–Turonian correlations around the Mid-European Island. *Cretaceous Research*, 56, 530–549, https://doi:10.1016/j.cretres.2015.04.007.

Jarvis, I., Lignum, J.S., Gröcke, D.R., Jenkyns, H.C. and Pearce, M.A. 2011. Black shale deposition, atmospheric CO_2 drawdown, and cooling during the Cenomanian–Turonian Oceanic Anoxic Event. *Palaeoceanography*, 26, 3, PA3201.

Jenkyns, H.C. 2010. Geochemistry of oceanic anoxic events. *Geochemistry, Geophysics, Geosystems*, 11, 3, Q03004.

Jenkyns, H.C., Dickson, A.J., Ruhl, M. and Boorn, S.H.J.M. van den 2017. Basalt-seawater interaction, the Plenus Cold Event, enhanced weathering and geochemical change: deconstructing Oceanic Anoxic Event 2 (Cenomanian–Turonian, Late Cretaceous). *Sedimentology*, 64, 16–43, https://doi.org/10.1111/sed.12305.

Jones, R.W. and Charnock, M.A. 1985. "Morphogroups" of agglutinated foraminifera. Their life positions and feeding habits and potential applicability in (paleo)ecological studies. *Revue de Paléobiologie*, 4, (2), 311–320.

Jones, T.R. and Parker, W.K. 1860. On the Rhizopodal fauna of the Mediterranean compared with that of the Italian and some other Tertiary deposits. *Quarterly Journal of the Geological Society of London*, 16, 292–307.

Jorissen, J.J., Stiger, H.C. and Widmark, J.G.V. 1995. A conceptual model explaining benthic foraminiferal microhabitats. *Marine Micropaleontology*, 26, 3-15.

Józsa, Š. 2017. Deep water agglutinated foraminifera from the Jurassic/Cretaceous boundary and paleoenvironmental settings of the Maiolica type facies from the Czorstyn ridge (Pieniny Klippen Belt, Western Carpathians). *Rivista Italiana di Paleontologia e Stratigrafia*, 123 (3), 387–398.

Jurkiewicz, H. 1960. Otwornice z łupków czarnozeckich wschodniej częsci jednostki śląskiej. *Rocznik Polskiego Towarzystwa Geologicznego*, 30, 333–344.

Jurkiewicz, H. 1967. Foraminifers in the sub-Menilitic Paleogene of the Polish Middle Carpathians. *Biuletyn Instytutu Geologicznego*, 210, 5–116.

Kaminski, M.A. 1985. Evidence for control of abyssal agglutinated foraminiferal community structure by substrate disturbance: Results from the Hebble Area. *Marine Geology*, 66, 113–131.

Kaminski, M.A. 1988.

Kaminski, M.A. and Gradstein, F.M. 2005. Atlas of Paleogene cosmopolitan deep-water agglutinated foraminifera. *Grzybowski Foundation Special Publication*, 10, 1–547.

Kaminski, M.A., Gradstein, F. and Berggren, W. 1988. Flysch-type agglutinated foraminiferal assemblages from Trinidad: taxonomy, stratigraphy and paleobathymetry. *Abhandlungen der geologischen Bundesanstalt*, 41, 155–227.

Kaminski, M.A., Gradstein, F.M., Goll, R.M. and Grieg, D. 1990. Biostratigraphy and paleoecology of deep-water agglutinated foraminifera at ODP Site 643, Norwegian-Greenland Sea. In:

Hemleben, C., Kaminski, M.A., Kuhnt, W. and Scott, D.B. (Eds.) Paleoecology, Biostratigraphy, Paleoceanography and Taxonomy of Agglutinated Foraminifera. *NATO ASI Series, Kluwer Academic Publishers*, 345–386.

Kaminski, M.A., Boersma, E., Tyszka, J. and Holbourn, A.E. 1995. Response of deep-water agglutinated foraminifera to dysoxic conditions in the California Borderland basins. In: Kaminski, M.A., Geroch. S. and Gasinski, M.A. (Eds.) Proceedings of the Fourth International Workshop on agglutinated Foraminifera. *Grzybowski Foundation Special Publication*, 3, 131–140.

Kaminski, M.A., Alegret, L., Hikmahtiar, S. and Waśkowska, A. 2021. The Paleocene of IODP Site U1511, Tasman Sea: A lagerstatte deposit for deep-water agglutinated foraminifera. *Micropaleontology*, 67 (4), 341–364.

Karrer, F. 1866. Über das Auftreten von Foraminiferen in den älteren Schichten des Wiener Sandsteins. *Sitzungsberichte der Kaiserlichen Akademie der Wissenschaften. Mathematisch-Naturwissenschaftliche Classe*, 52, 1, 9, 492–497.

Kidder, D.L. and Worsley, T.R. 2010. Phanerozoic Large Igneous Provinces (LIPs), HEATT (Haline Euxinic Acidic Thermal Transgression) episodes, and mass extinctions. *Palaeogeography, Palaeoclimatology, Palaeoecology*, 295, 162–191.

Krasheninnikov, V. 1973. Cretaceous benthonic foraminifera, Leg 20, Deep Sea Drilling Project. *Initial Reports of the Deep Sea Drilling Project*, 20, 205–221.

Krasheninnikov, V. 1974. Upper Cretaceous benthonic agglutinated foraminifera, Leg 27 of the Deep Sea Drilling Project. *Initial Reports of the Deep Sea Drilling Project*, 27, 631–661.

Kuhnt, W. and Kaminski, M.A. 1990. Paleoecology of Late Cretaceous to Paleocene deep-water agglutinated foraminifera from the North Atlantic and Western Tethys. In: Hemleben, C., Kaminski, M.A., Kuhnt, W. and Scott, D.B. (Eds.) Paleoecology, biostratigraphy, paleoceanography and taxonomy of agglutinated foraminifera. NATO ASI Ser. C327, *Kluwer Academic Publishers*, 433–506.

Kuhnt, W. and Kaminski, M.A. 1997. Cenomanian to lower Eocene deep-water agglutinated foraminifera from the Zumaya section, northern Spain. *Annales Societatis Geologorum Poloniae*, 67 (2–3), 257–270.

Kuhnt, W. and Wiedmann, J. 1995. Chapter 10. Cenomanian–Turonian Source Rocks: Paleobiogeographic and Paleoenvironmental Aspects. In: Huc, A.-Y. (Eds.) Paleogeography, Paleoclimate, and Source Rocks. *AAPG Studies in Geology*, 40, 213–232.

Kuhnt, W., Kaminski, M.A. and Moullade, M. 1989. Late Cretaceous deep-water agglutinated foraminiferal assemblages from the North Atlantic and its marginal seas. *Geologische Rundschau* ,78, (3), 1121–1140.

Kuhnt, W., Geroch, S., Kaminski, M.A., Moullade, M. and Neagu, T. 1992. Upper Cretaceous abyssal claystones in the North Atlantic and Western Tethys: current status of biostratigraphical correlation using agglutinated foraminifers and palaeoceanographic events. *Cretaceous Research*, 13, (5–6), 467–478, https://doi:10.1016/0195-6671(92)90011-E.

Kuhnt, W., Collins, E. and Scott, D.B. 2000. Deep Water Agglutinated Foraminiferal Assemblages across the Gulf Stream: Distribution Patterns and Taphonomy. In: Hart, M.B., Kaminski, M.A. and Smart, C.W. (Eds.) Proceedings of the Fifth International Workshop on Agglutinated Foraminifera. *Grzybowski Foundation Special Publication*, 7, 261–298.

Leary, P. N. 1987. The Late Cenomanian Anoxic Event; Implications for foraminiferal evolution. PhD thesis, *Plymouth University*, 325 pp.

Marsson, T. 1878. Die Foraminiferen der weissen Schreibkreide der Insel Rügen. *Mitteilungen des Naturwissenschaftlichen Verein für Neu-Vorpommern und Rügen in Greifswald*, 10, 115–196.

Maslakova, N. 1955. Stratigrafiya i fauna melkikh foraminifer paleogenovykh otlozhenii Vostochnykh Karpat. *Materialy po Biostratigrafi zapadnykh oblastii Ukrainskoi SSR*, 5–132.

McNeil, D.H. 1997. New foraminifera from the Upper Cretaceous and Cenozoic of the Beaufort-MacKenzie Basin of Arctic Canada. *Cushman Foundation for Foraminiferal Research Special Publication,* 35, 95 pp.

Miller, K.G., Wright, J.D., Katz, M.E., Browning, J.V., Cramer, B.S., Wade, B.S. and Mizintseva, S.F. 2008. A View of Antarctic Ice-Sheet Evolution from Sea-Level and Deep-Sea Isotope Changes During the Late Cretaceous –Cenozoic. In: Cooper, A.K., Barrett, P.J., Stagg, H., Storey, B., Stump, E., Wise, W. and the 10th ISAES editorial team (Eds.) Antarctica: A Keystone in a Changing World. *Proceedings of the 10th International Symposium on Antarctic Earth Sciences*. Washington, DC: The National Academies Press.

Mitchell, S.F. 1996. Foraminiferal assemblages from the late Lower and Middle Cenomanian of Speeton (North Yorkshire, UK): relationships with sea-level fluctuations and watermass distribution. *Journal of Micropalaeontology*, 15, 37–54.

Murray, J.W. 2006. Ecology and applications of benthic foraminifera. *Cambridge University Press*, New York, 422 pp.

Murray, J.W. and Alve, E. 1994. High diversity agglutinated foraminiferal assemblages from the NE Atlantic: Dissolution experiments. *Cushman Foundation Special Publication,* 32, 33–51.

Murray, J.W. and Alve, E. 1999a. Taphonomic experiments on marginal marine foraminiferal assemblages: how much ecological information is preserved? *Palaeogeography, Palaeoclimatology, Palaeoecology*, 149, 183–197. https://doi.org/10.1016/S0031-0182(98)00200-4.

Murray, J.W. and Alve, E. 1999b. Natural dissolution of modern shallow water benthic foraminifera: taphonomic effects on the palaeoecological record. *Palaeogeography, Palaeoclimatology, Palaeoecology*, 146, 195–209. https://doi.org/10.1016/S0031-0182(98)00132-1.

Murray, J.W. and Alve, E. 2011. The distribution of agglutinated foraminifera in NW European seas: Baseline data for the interpretation of fossil assemblages. *Palaeontologia Electronica*, 14 (2), 1–41.

Murray, J.W., Alve, E. and Cundy, A. 2003. The origin of modern agglutinated foraminiferal assemblages: evidence from a stratified fjord. *Eastuarine, Coastal and Shelf Science*, 58, 677–697. https://doi.org/10.1016/S0272-7714(03)00179-3.

Murray, J.W., Alve, E. and Jones, B.W. 2011. A new look at modern agglutinated benthic foraminiferal morphogroups: their value in palaeoecological interpretation. *Palaeogeography, Palaeoclimatology, Palaeoecology*, 309, (3), 229-241.

Nagy, J., Kaminski, M.A., Johnsen, K. and Mitlehner, A.G. 1997. Foraminiferal, palynomorph, and diatom biostratigraphy and paleoenvironments of the Torsk Formation: A reference section for the Paleocene-Eocene transition in the western Barents Sea. In: Hass, H.C. and Kaminski, M.A. (Eds.) Contributions to the Micropaleontology and Paleoceanography of the Northern North Atlantic. *Grzybowski Foundation Special Publication*, 5, 15–38.

Nagy, J., Kaminski, M.A., Kuhnt, W. and Bremer, M.A. 2000. Agglutinated Foraminifera from Neritic to Bathyal Facies in the Palaeogene of Spitsbergen and the Barents Sea. In: Hart, M.B., Kaminski, M.A. and Smart, C.W. (Eds.) Proceedings of the Fifth International Workshop on Agglutinated Foraminifera. *Grzybowski Foundation Special Publication*, 7, 333–361, 2000.

Nagy, J., Hess, S., Dypvik, H. and Bjærke, T. 2011. Marine shelf to paralic biofacies of Upper Triassic to Lower Jurassic deposits in Spitsbergen. *Palaeogeography, Palaeoclimatology, Palaeoecology*, 300, 138–151, https://doi.org/10.1016/j.palaeo.2010.12.018.

Nagy, J., Jargvoll, D., Dypvik, H., Jochmann, M. and Riber, L. 2013. Environmental changes during the Paleocene–Eocene Thermal Maximum in Spitsbergen as reflected by benthic foraminifera. *Polar Research*, 32, 19737, http://dx.doi.org/10.3402/polar.v32i0.19737.

Neagu, T. 1962. Studiul foraminiferelor aglutinante din argilele Cretacic superiorare de pe Valea Sadovei (Câmpulung Moldovenesc) şi bazinul superior al Văii Buzăuliu. *Studii Cercetari Geologie, Academia Republicii Populare Romine, Sectia de Geologie si Geografie si Istitutul de Geologie si Geografie*, 7 (1), 45–81.

Neagu, T. 1968. Biostratigraphy of Upper Cretaceous deposits in the Southern Eastern Carpathians near Braşov. *Micropaleontology*, 14 (2), 225–241.

Neagu, T. 1970. Micropaleontological and stratigraphical study of the Upper Cretaceous deposits between the upper valleys of the Buzau and Riul Negru Rivers (Eastern Carpathians). *Memorii, Institutul Geologic*, 12, 7–109.

Noth, R. 1951. Foraminiferen aus Unter- und Oberkreide des österreichischen Anteils des Flysch, Helvetikum und Vorlandvorkommen. *Jahrbuch der Geologischen Bundesanstalt*, Sonderband 3, 1–91.

Olszewska, B. and Morgiel, J. 1981. Biostratigraphy of the Polish External Carpathians based on agglutinated foraminifera. *Micropaleontology*, 27 (1), 1–24.

Perner, J. 1892. Über die Foraminiferen des böhmischen Cenomans. Česká Akademie Císaře Frantiska Josefa, pro Vědy, Slovesnost a Uměni v Praze 2 (*Paleontographica Bohemiae*), 1, 65 pp.

Peryt, D., Wyrwicka, K., Orth, C., Attrep, M. Jr. and Quintana, L.R. 1994. Foraminiferal changes and geochemical profiles across the Cenomanian/Turonian boundary in central and southeast Poland. *Terra Nova*, 6, 158–165.

Peryt, D., Lahodynsky, R. and Durakiewicz, T. 1997. Deep-water agglutinated foraminiferal changes and stable isotope profiles across the Cretaceous–Paleogene boundary in the Rotwand-graben section, Eastern Alps (Austria). *Palaeogeography, Palaeoclimatology, Palaeoecology*, 132, (1–4), 287–307, https://doi:10.1016/S0031-0182(97)00056-4.

Peryt, D., Alegret, L. and Molina, E. 2004. Agglutinated foraminifers and their response to the Cretaceous/Paleogene (K/P) boundary event at Aïn Settara, Tunisia. In: Bubík, M. and Kaminski, M.A. (Eds.) Proceedings of the Sixth International Workshop on agglutinated Foraminifera. *Grzybowski Foundation Special Publication*, 8, 393–412.

Philip, J. and Floquet, M. 2000. Late Cenomanian (94.7–93.5). In: Dercourt, J., Gaetani, M., Vrielynck, B., Barrier, E., Biju-Duval, B., Brunet, M. F., Cadet, J. P., Crasquin, S. and Sandulescu, M. (Eds.) Atlas Peri-Tethys palaeogeographical maps. *CCGM/CGMW*, Paris, 129–136.

Prokoph, A., Szarek, R., Kłosowska, B. and Kuhnt, W. 1999. Late Albian benthic foraminiferal biofacies and paleogeography of Northeast Germany. *Neues Jahrbuch für Geologie und Paläontologie, Abhandlungen*, 212, 289–334.

Reuss, A. E. 1844. Geognostische Skizzen aus Böhmen. Bd. 2: Die Kreidegebilde des westlichen Böhmens, ein monographischer Versuch. Nebst Bemerkungen über die Braunkohlenlager jenseits der Elbe und eine Uebersicht der fossilen Fischreste Böhmens. Medau & Comp., Prag, 304 pp.

Reuss, A. E. 1845. Die Versteinerungen der böhmischen Kreideformation. Mit Abbildungen der neuen oder weniger bekannten Arten, Abt. 1. *Schweizerbart'sohne Verlagsbuchhandlung*, Stuttgart, 58 pp.

Reuss, A.E. 1846. Die Versteinerungen der böhmischen Kreideformation. Mit Abbildungen der neuen oder weniger bekannten Arten, Abt. 2. *Schweizerbart'sohne Verlagsbuchhandlung*, Stuttgart, 148 pp.

Reuss, A. E. 1851. Über die fossilen Foraminiferen und Entomostraceen der Septarianthone der Umgegend von Berlin. Zeitschrift der Deutschen Geologischen Gesellschaft, 3, 49–91.

Reuss, A. E. 1863. Die Foraminiferen der norddeutschen Hils und Gault. *Sitzungsberichte der Kaiserlichen Akademie der Wissenschaften. Mathematisch-Naturwissenschaftliche Classe*, 46, 5–100.

Robaszynski, F. and Amédro, F. 1986. The Cretaceous of the Boulonnais (France) and a comparison with the Cretaceous of Kent (United Kingdom). *Proceedings of the Geologists Association*, 97 (2), 171–208.

Robaszynski, F., Amédro, F., Foucher, J.-C., Gaspard, D., Magniez-Jannin, F., Manivit, H. and Sornay, J. 1980. Synthèse biostratigraphique de l'Aptien au Santonien du Boulonnais à partir de sept groupes paléontologiques: Foraminifères, Nannoplancton, Dinoflagellés et Macrofaunes. *Revue de Micropaléontologie*, 22, 195–321.

Schlanger, S.O. and Jenkyns, H.C. 1976. Cretaceous oceanic anoxic events: Causes and consequences. *Geologie en Mijnbouw*, 55, 3–4.

Schröder, C.J. 1986. Deep-water arenaceous foraminifera in the northwest Atlantic Ocean. *Canadian Technical Report of Hydrography and Ocean Sciences,* 71, 191pp.

Schröder-Adams, C.J. and McNeil, D.H. 1994a. New paleoenvironmentally important species of agglutinated foraminifera from the Oligocene and Miocene of the Beaufort Sea, Arctic Canada. *Journal of Foraminiferal Research*, 24, 178–190.

Schröder-Adams, C.J. and McNeil, D.H. 1994b. Oligocene to Miocene agglutinated foraminifers in deltaic and deep-water facies of the Beaufort-Mackenzie Basin. *Geological Survey of Canada Bulletin*, 477, 67 pp.

Schröder-Adams, C.J., Herrle, J.O., Selby, D., Quesnel, A. and Froude, G. 2019. Influence of the High Arctic Igneous Province on the Cenomanian/Turonian boundary interval, Sverdrup Basin, High Canadian Arctic. *Earth and Planetary Science Letters*, 511, 76–88.

Schubert, R.J. 1902. Neue und interessante Foraminiferen aus dem südtiroler Alttertiär. *Beiträge zur Paläontologie und Geologie Österreich-Ungarn und des Orients*, 14, 9–26.

Schultze, F.E. 1875. Zoologische Ergebnisse der Nordseefahrt, vom 21. Juli bis 9. September 1872. I, Rhizopoden. *Jahresberichte Kommission zur Untersuchung der Deutschen Meere*, Kiel, 1872–1873, 99–114.

Setoyama, E., Kaminski, MA. and Tyszka, J. 2011. Late Cretaceous agglutinated foraminifera and implications for the biostratigraphy and palaeobiogeography of the southwestern Barents Sea. In: Kaminski, M.A. and Filipescu, S. (Eds.) Proceedings of the Eighth International Workshop on agglutinated Foraminifera. *Grzybowski Foundation Special Publication*, 20, 251–309.

Setoyama, E., Kaminski, M.A. and Tyska, J. 2017. Late Cretaceous–Paleogene foraminiferal morphogroups as palaeoenvironmental tracers of the rifted Labrador margin, northern proto-Atlantic. In: Kaminski, M.A. and Alegret, L. (Eds.) Proceedings of the Ninth International

Workshop on agglutinated Foraminifera. *Grzybowski Foundation Special Publication*, 22, 179–220.

Skelton, P.W. 2003. Introduction to the Cretaceous. In: P.W. Skelton (Eds.) The cretaceous world. *Cambridge University Press*, 9–41.

Snow, L.J., Duncan, R.A. and Bralower, T.J. 2005. Trace element abundances in the Rock Canyon Anticline, Pueblo, Colorado, marine sedimentary section and their relationship to Caribbean plateau construction and oxygen anoxic event 2. *Paleoceanography*, 20, PA3005.

Szarek, R., Kłosowska, B., Prokoph, A., Kuhnt, W. and Wagner, T. 2000. Upper Albian agglutinated foraminifera from two wells in Northeast Germany. In: Hart, M.B., Kaminski, M.A. and Smart, C.W. (Eds.) Proceedings of the Fifth International Workshop on Agglutinated Foraminifera. *Grzybowski Foundation Special Publication*, 7, 445–463.

Tegner, C., Storey, M., Holm, P.M., Thorarinsson, S.B., Zhao, X., Lo, C.-H. and Knudsen, M.F. 2011. Magmatism and Eurekan deformation in the High Arctic Large Igneous Province: ^{40}Ar–^{39}Ar age of Kap Washington Group volcanics, North Greenland. *Earth and Planetary Science Letters*, 303, 203–214.

Tyszka, J. 2009. Foraminiferal response to seasonality modulated by orbital cycles in the Cretaceous mid-latitudes: The Albian record from the Lower Saxony Basin. *Palaeogeography, Palaeoclimatology, Palaeecology*, 276, 148–159, https://doi:10.1016/j.palaeo.2009.03.006.

Vašíćek, M. 1947. Poznámky k mikrobiostratigrafii magurského flyše na Moravě. *Věstník Státního Geologického Ústavu Československé Republiky*, 22, 235–256.

Voigt, S. and Wiese, F. 2000. Evidence for Late Cretaceous (Late Turonian) climate cooling from oxygen-isotope variations and palaeobiogeographic changes in Western and Central Europe. *Journal of the Geological Society*, 157, 737–743, https://doi:10.1144/jgs.157.4.737.

Voigt, S., Gale, A.S. and Flögel, S. 2004. Midlatitude shelf seas in the Cenomanian–Turonian greenhouse world: Temperature evolution and North Atlantic circulation. *Paleoceanography*, 19, 1–17, https://doi:10.1029/2004PA001015.

Voigt, S., Wagreich, M., Surlyk, F., Walaszczyk, I., Uličný, D. and Čech, S. 2008a. Cretaceous. In: T. McCann (Eds.) Geology of central Europe, vol. 2. London, *The Geological Society*, 923–997.

Wejda, M. 1993. Biostratigraphie und Palökologie kretazischen Foraminiferen Faunen des Oberen Turon bis Unter Coniac auf dem Kartenblatt Dresden. Manuscript, Diploma thesis. *Berakademie Freiberg*, pp. 53.

Wiese, F. and Voigt, S. 2002. Late Turonian (Cretaceous) climate cooling in Europe: faunal response and possible causes. *Geobios*, 35, 65–77, https://doi:10.1016/S0016-6995(02)00010-4.

Wiese, F., Zobel, K. and Keupp, H. 2015. Calcareous dinoflagellate cysts and the Turonian nutrient crisis – Data from the upper Turonian of the Lower Saxony Basin (northern Germany). *Cretaceous Research*, 56, 673–688, https://doi:10.1016/j.cretres.2015.06.007.

Wiese, F., Zobel, K. and Mortimore, R.N. 2017. Intrinsic processes control late Turonian calcareous dinoflagellate cyst assemblages – A case study from the Sussex chalk (England). *Cretaceous Research*, 56, 1–12, https://doi:10.1016/j.cretres.2017.04.003.

Wilkinson, I.P. and Hopson, P.M. 2011. The stratigraphical distribution of mid-Cretaceous Foraminifera near Ventnor, Isle of Wight. *Proceedings of the Geologists Association*, 122, 831–841.

Zheng, X.-Y., Jenkyns, H.C., Gale, A.S., Ward, D.J. and Henderson, G.M. 2013. Changing ocean circulation and hydrothermal inputs during Ocean Anoxic Event 2 (Cenomanian–Turonian): Evidence from Nd-isotopes in the European shelf sea. *Earth and Planetary Science Letters*, 375, 338–348.

Zwaan, G.J. van der, Duijnstee, I.A.P., Dulk, M. den, Ernst, S.R., Jannink, N.T. and Kouwenhoven, T.J. 1999. Benthic foraminifers: proxies or problems? A review of paleocological concepts. Earth-Science Reviews, 46, 213–236.

Chapter 2

The hidden agglutinated foraminifera of the mid-Cretaceous hemipelagic carbonate deposits: a method–derived bias?

Published as:

Besen, R.M., Hegert, J. and Struck, U., 2022. The hidden agglutinated foraminifera of the mid-Cretaceous hemipelagic carbonate deposits: A method–derived bias? *Marine Micropaleontology*, 176, 102168, https://doi.org/10.1016/j.marmicro.2022.102168.

This article is not available in the online version due to copyright restrictions.

Chapter 3

Documentation and evaluation of the Albian to Turonian agglutinated foraminiferal assemblages of the Lower Saxony Cretaceous sub-basins – a proximal vs. distal intrabasinal comparison.

Published as:

Besen, R.M., Struck, U. and Seibertz, E., 2021. Albian to Turonian agglutinated foraminiferal assemblages of the Lower Saxony Cretaceous sub-basins – implications for sequence stratigraphy and paleoenvironmental interpretation. *Fossil Record*, 24, 395–441, https://doi.org/10.5194/fr-24-395-2021.

Abstract

Albian to Turonian carbonate deposits at three different locations of the Lower Saxony Cretaceous and thereby, of the European mid-Cretaceous epeiric shelf sea were investigated for their fossil agglutinated foraminiferal fauna. In this study, 71 samples from two quarries and three drill cores were treated with formic acid which enabled the study of agglutinated foraminiferal assemblages even in highly lithified limestones. In total, 114 species were determined and classified as belonging to nine morphogroups. In general, four agglutinated foraminiferal assemblages are distinguished: 1. An uppermost Albian–lowermost Cenomanian assemblage from the Wunstorf drill cores, with the dominant taxa *Bathysiphon* spp., *Nothia* spp., *Psammosphaera fusca, Reophax subfusiformis, Bulbobaculites problematicus, Tritaxia tricarinata, Flourensina intermedia, Vialovella frankei, Arenobulimina truncata*, and *Voloshinoides advenus*, 2. A Cenomanian assemblage from the Baddeckenstedt quarry and Wunstorf drill cores, with *Ammolagena clavata, Tritaxia tricarinata, Vialovella frankei, Arenobulimina truncata*, and *Voloshinoides advenus*, 3. An assemblage related to the Cenomanian–Turonian Boundary Event in Wunstorf and Söhlde dominated by *Bulbobaculites problematicus*, 4. A Turonian assemblage in the Wunstorf and Söhlde sections with high numbers of *Ammolagena contorta, Repmanina charoides, Bulbobaculites problematicus, Gerochammina stanislawi*, and *Spiroplectammina navarroana*. The latest Albian–earliest Cenomanian assemblage consists of tubular, globular and elongate foraminiferal morphogroups which are typical for the Low to mid-Latitude Slope Biofacies. All other assemblages are composed of elongate foraminiferal morphogroups with additionally globular forms in the proximal settings of Baddeckenstedt and Söhlde or flattened planispiral and streptospiral forms in more distal settings of Wunstorf. For these assemblages, a new agglutinated foraminiferal biofacies named “Mid-Latitude Shelf Biofacies” is proposed herein. Changes in the relative abundance of different morphogroups often can be referred to single features of depositional sequences. Furthermore, classical macro-bioevents, which are often depositional-related, of the Lower Saxony Cretaceous seem to have a micro-bioevent or acme equivalent of the agglutinated foraminiferal fauna.

3.1 Introduction

During the mid-Cretaceous, sedimentary sub-basins of Lower Saxony and the Subhercynian were part of a wide epeiric continental shelf sea connected with the Arctic realm, the young North and

Central Atlantic Ocean and the Tethyan Ocean, which were separated by the Mid-European Island (Janetschke et al., 2015). High relative sea-level (Haq, 2014) and high relative temperatures (Voigt et al., 2004) favoured carbonate deposition in wide parts of these and other basins worldwide during that time (Skelton, 2003; Voigt et al., 2008a; Janetschke et al., 2015). Long-term sea-level trends and changes in bottom water temperature, nutrient availability, oxygen concentration of bottom waters, and paleoceanographical current patterns like those during the early Cenomanian transgression, Mid-Cenomanian Event (MCE) and Oceanic Anoxic Event 2 (OAE2)/Cenomanian Turonian Boundary Event (CTBE) made this time interval attractive for research (Skelton, 2003; Voigt et al., 2004, 2008a). To understand the sea-level/depositional sequences coupling and other paleoenvironmental changes in the Lower Saxony Basin, investigations were made for the Albian (e.g., Fenner, 1996; Tyszka, 2009; Bornemann et al., 2017), for the Cenomanian (e.g., Wilmsen, 2003; 2007; Wilmsen et al., 2005; Voigt et al., 2006), for the CTBE (e.g., Linnert et al., 2010; Hetzel et al., 2011; Blumenberg and Wiese, 2012; Helmond et al., 2015) and for the Turonian (Wiese et al., 2015). Most of these studies approach the former conditions in the upper water layers of this Cretaceous shelf sea by focussing on planktic foraminifers, and calcareous nannofossils. Thus, to get a better understanding of the paleoenvironment of the mid-Cretaceous deposits of Lower Saxony especially additional information of the bottom water conditions are necessary.

The reconstructions of past bottom water conditions based on agglutinated foraminifera morphogroup analyses have been established by Jones and Charnock (1985) modified by Bąk et al. (1997), Peryt et al. (1997, 2004), Akker et al. (2000) and Murray et al. (2011). Our study follows the morphogroup scheme applied on Cretaceous foraminiferal assemblages by Frenzel (2000), Cetean et al. (2011), and Setoyama et al. (2017). Agglutinated foraminifers are widely used to investigate mid-Cretaceous deep-water deposits with focus on the Arctic realm (Gradstein et al., 1999; Setoyama et al., 2017), the Atlantic Ocean (Kuhnt et al., 1989; 1992; Kuhnt and Kaminski, 1997) and the Tethyan realm (Coccioni et al., 1995; Kaminski et al., 2011) with special accentuation on the Carpathians (Geroch and Nowak, 1984; Bubík, 1995; Bąk, 2007; Józsa et al., 2017a).

A detailed stratigraphic framework of the mid-Cretaceous of Lower Saxony exists (e.g., Ernst et al., 1983; Voigt and Hilbrecht, 1997; Wilmsen and Niebuhr, 2002; Wilmsen, 2003; 2007; Voigt et al., 2008b; Wiese, 2009; Bornemann et al., 2017; Erbacher et al., 2020) and is supported by correlations of stable carbon isotope patterns of the Wunstorf drill cores conducted in this study. This framework allows a precise stratigraphic correlation of the agglutinated foraminiferal assemblages and their application as a proxy for paleoenvironmental reconstructions in a shelf setting with high carbonate production. Firstly, high lithified limestones of the Lower Saxony Cretaceous are investigated on their agglutinated foraminiferal content, whereas former studies focussed on less lithified marlstones to marly limestones (Frieg and Kemper, 1989). Therefore, the main objectives of the present study are the documentation of agglutinated foraminiferal assemblages and the linkage of the assemblage composition and palaeoenvironmental information provided by former studies. Furthermore, the biostratigraphical utility of agglutinated foraminifers for the basins is examined by applying existing biostratigraphical schemes (Geroch and Nowak, 1984; Frieg and Kemper, 1989; Hart et al., 1989; Kuhnt and Kaminski, 1997; Kaminski et al., 2011) and assessing regional biomarkers and agglutinated foraminiferal acmes.

3.2 Geology and lithostratigraphy

3.2.1 Geological overview

The study area is located in the southern part of Lower Saxony (Northern Germany) comprising the Lower Saxony and Subhercynian Cretaceous sub-basins (Fig. 3.1). These were part of a wide epicontinental shelf sea spanned over large parts of the Mid to North European shelf area. This shelf sea was bordered in the south by the Mid-European Island, in the north by the Fennoscandian Shield, and in the west by several smaller landmasses (Fig. 3.1). To the east the shelf sea reached onto the Russian Platform (Skelton, 2003; Voigt et al., 2008a; Janetschke et al., 2015). Widespread marine sediments were deposited in the Cenomanian to Turonian favoured by a major, second order sea level highstand phase (Haq, 2014; Fig. 3.2). While nearshore mainly siliciclastic-glauconitic sediments were deposited, offshore marl-/limestone alternations to chalk deposits were formed.

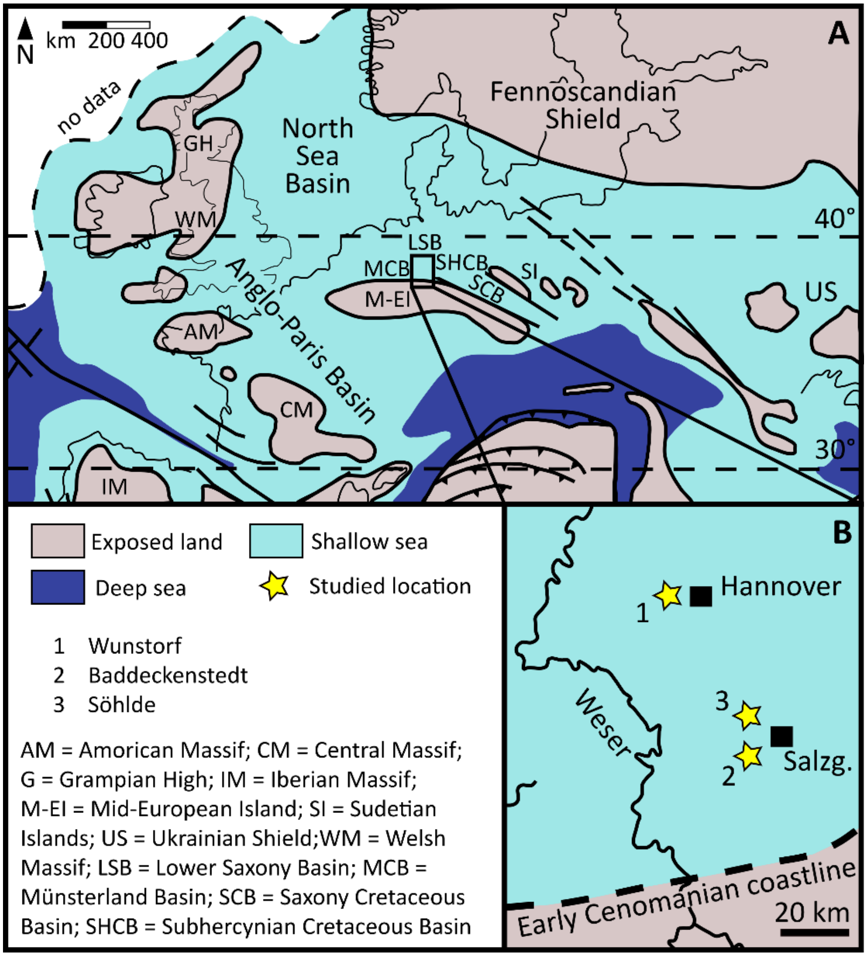


Figure 3.1. Palaeogeographical map of Europe and the study area. A: Palaeogeography of Europe during the Cenomanian, modified after Philip and Floquet (2000). B: Palaeogeography of southern Lower Saxony during the early Cenomanian, modified from Wilmsen et al. (2021), base map from Hiss (1995).

During the late-early Cenomanian, water depths of 20–30 m in a proximal position at Baddeckenstedt of about 30–40 km distance from the shore, while about 80–100 km from the former coastline at Wunstorf, a water depth of ca. 50 m are assumed by Wilmsen (2003). During the Cenomanian–Turonian boundary, a water depth of 100–150 m is proposed.

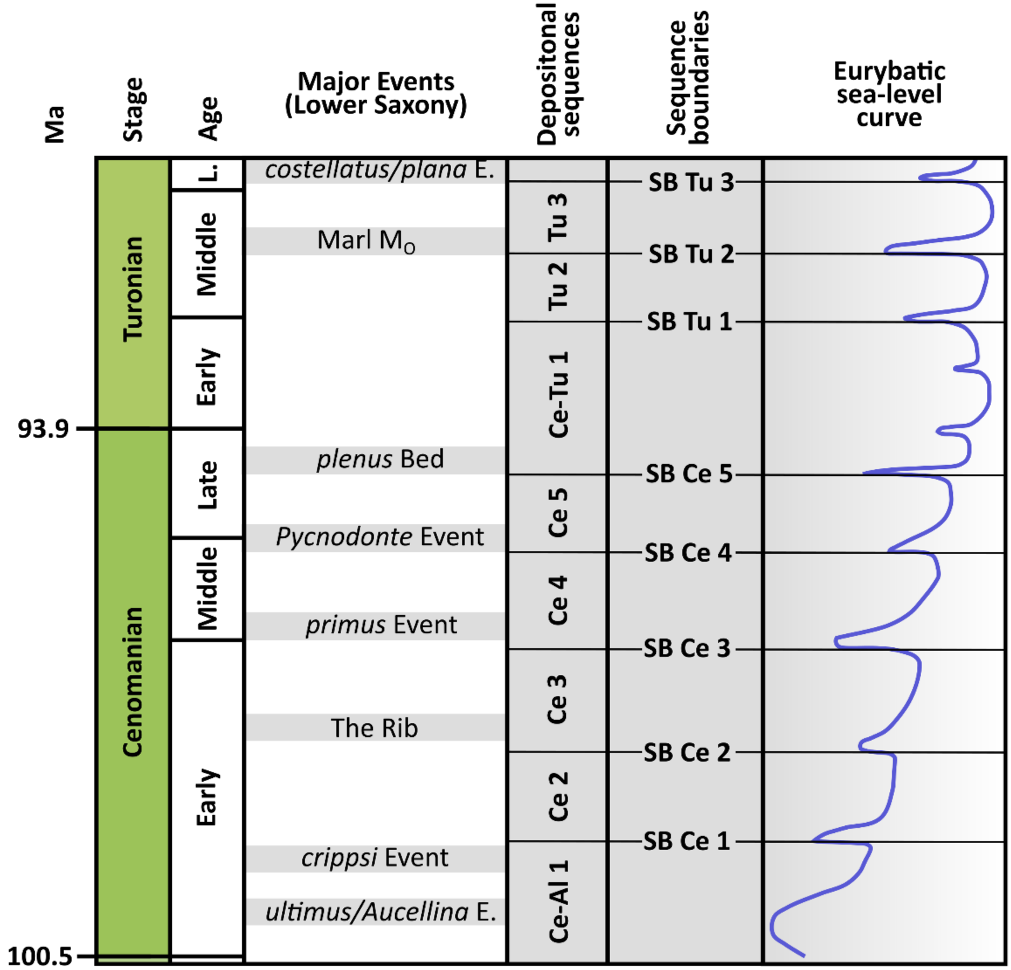


Figure 3.2. Chronostratigraphy, selected events, and depositional sequences, and interpreted sea-level curve of the Lower Saxony Cretaceous. Depositional sequences, associated sequence boundaries, and sea-level curve are from Janetschke et al. (2015). Age of stage boundaries are from Gradstein et al. (2020).

3.2.2 Studied sections

3.2.2.1 Wunstorf

The Wunstorf-Kolenfeld quarry is located around 20 km West of Hanover with WGS84 coordinates 52.40146° N, and 9.48940° E, at the quarry centre. The area belongs to the Wunstorf Cretaceous Syncline as part of the Lower Saxony Basin (Fig. 3.1). The Cretaceous strata dips with 15°

towards southwest. Three drill cores from an exploration campaign on the quarry surrounding area by the Holcim (Deutschland) Höver GmbH were investigated in detail by Seibertz (2013; see Fig. 3.3; Wunstorf Wu2010/1, (WGS84) 52.405868° N, 9.496213° E, 51.50 m above sea-level, 70 m core depth; Wunstorf Wu2010/3, (WGS84) 52.400093° N, 9.484749° E, 51.70 m above sea-level, 99 m core depth; Wunstorf Wu2010/4, (WGS84) 52.397263° N, 9.479357° E, 52.70 m above sea-level, 101 m core depth) and compared to the Wunstorf quarry succession (Wilmsen, 3004) and three cores from former studies (Voigt et al., 2008b; Erbacher et al., 2020; Fig. 3.3). Wunstorf Wu 2010/1 (Fig. 3.4) core contains uppermost Albian to lower Cenomanian clay- to marlstones of the Herbram Formation (70–15 m core depth). Wunstorf Wu 2010/3 core (Fig. 3.4) consists of ca. 23 m clay- to marlstones of the Herbram Formation (95–72 m core depth) and about 47 m of marl/limestone alternations of the Baddeckenstedt Formation (72–25 m core depth). The Wunstorf Wu 2010/4 (Fig. 3.5) core comprises three metres of limestone of the Brochterbeck Formation (86–83 m core depth), 20 m of black shale/marlstone alternations of the Hesseltal Formation (83–63 m core depth), and 27 m limestones of the Söhlde Formation (63–36 m core depth). Detailed stratigraphical framework mainly based on stable isotope, event- and sequence stratigraphy, and biostratigraphy applied on the quarry section and three drill cores is derived from Meyer (1990), Wilmsen (2003; 2007), Erbacher et al. (2007), Voigt et al. (2008b), Seibertz (2013), and Erbacher et al. (2020).

In the Wunstorf Wu 2010/1 core, the *ultimus/Aucellina* Event could be identified at 54 m depth, and the prominent marker limestone The Rib at 15 m depth; the *crippsi* Event is probably located at a depth of 38 m (Seibertz, 2013; Fig. 3.4). The *crippsi* Event and The Rib were also recorded in the Wunstorf Wu2010/3 core at 94 m, and 72 m depth respectively (Seibertz, 2013; Fig. 3.4). Both can be used for correlation, meanwhile the positions of other Cenomanian events remain doubtful.

Above the Facies Change (82 m core depth), the *plenus* Bed (81–79 m core depth), Fischschiefer (78–76 m core depth), the *Mytiloides* events (at about 64 m core depth), the Weiße Grenzbank (46–44 m core depth), and marl M_0 (at about 44 m core depth) could be identified in the Wunstorf Wu2010/4 core. Above the *Mytiloides* events, slumping structures occur in the Wunstorf Wu2010/4 core (Seibertz, 2013; Fig. 3.5).

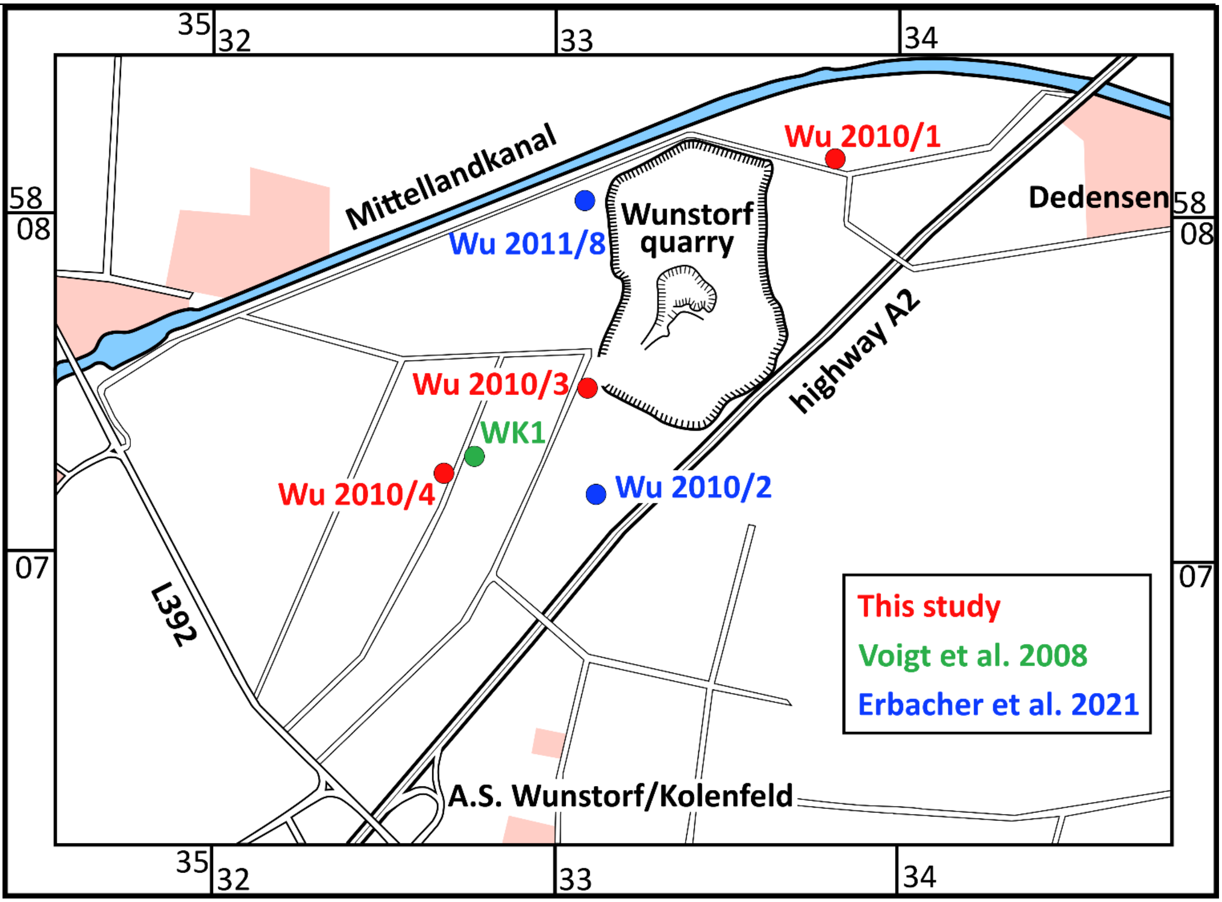


Figure 3.3. Schematic locality details of the study area of Wunstorf and position of the cores: green (Voigt et al., 2008b); blue (Erbacher et al., 2020); red (this study). Modified from Seibertz (2013: Fig. 5).

3.2.2.2 Baddeckenstedt

The abandoned quarry of Baddeckenstedt with WGS84 coordinates 52.091128° N, and 10.229590° E is situated at the northern border of the Innerste Syncline and is part of the westerly Subhercynian Basin (Fig. 3.1). The outcrop shows a sequence of marl/limestone alternations of early and middle Cenomanian age and limestones of late Cenomanian to middle Turonian age. It contains ca. 24 m marl/limestone alternations of the Baddeckenstedt Formation (0–24 m), and 17.50 m limestones of the Brochterbeck Formation (24–41.50 m). The overlying Hesseltal and Söhlde formations are not considered in this study. A detailed framework is provided by Badaye (1986), Ernst and Rehfeld (1997;

1998) and Wilmsen and Niebuhr (2002) and a correlation to other Lower Saxonian outcrops is given by Wilmsen (2003; 2007).

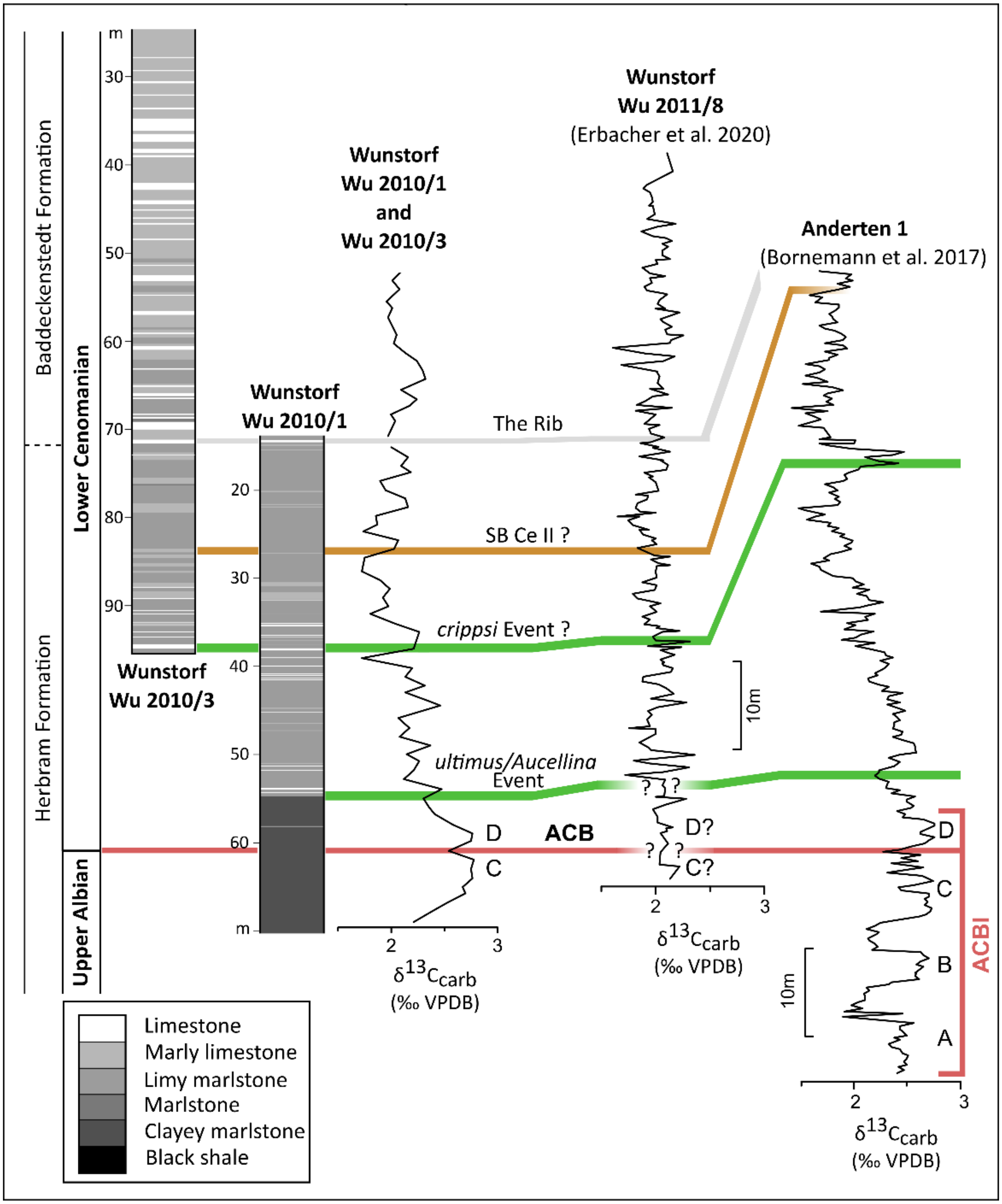


Figure 3.4. Correlated columnar sections of the Wunstorf cores Wu 2010/1, and Wu 2010/3, and their carbon isotope patterns. On the right correlation to the carbon isotopes of the Wunstorf Wu 2011/8 core of Erbacher et al. (2020: Fig. 3), and to the Anderten-1 core of Bornemann et al. (2017: Fig. 3)., Brown

bar = correlation of a sequence boundary based on the isotopic pattern, green bar = correlation based on a bio-event, grey bar = correlation based on a litho-event.

3.2.2.3 Söhlde

The Söhlde-Loges quarry yields around 40 m of the uppermost Cenomanian to the upper Turonian limestones. The stratigraphic succession contains about one metre limestones of the Brochterbeck Formation (-1–0 m), 34 m limestones of the Söhlde Formation (0–34 m), and three metres limestones of the Salder Formation (34–37 m). The quarry lies within the Lesse Syncline with WGS84 coordinates 52.186238° N, and 10.247489° E and is thus part of the westerly Subhercynian Basin (Fig. 3.1). Detailed stratigraphic information is given in Ernst and Wood (1995; 1997), Voigt and Hilbrecht (1997), Ernst et al. (1998) and Wiese (2009).

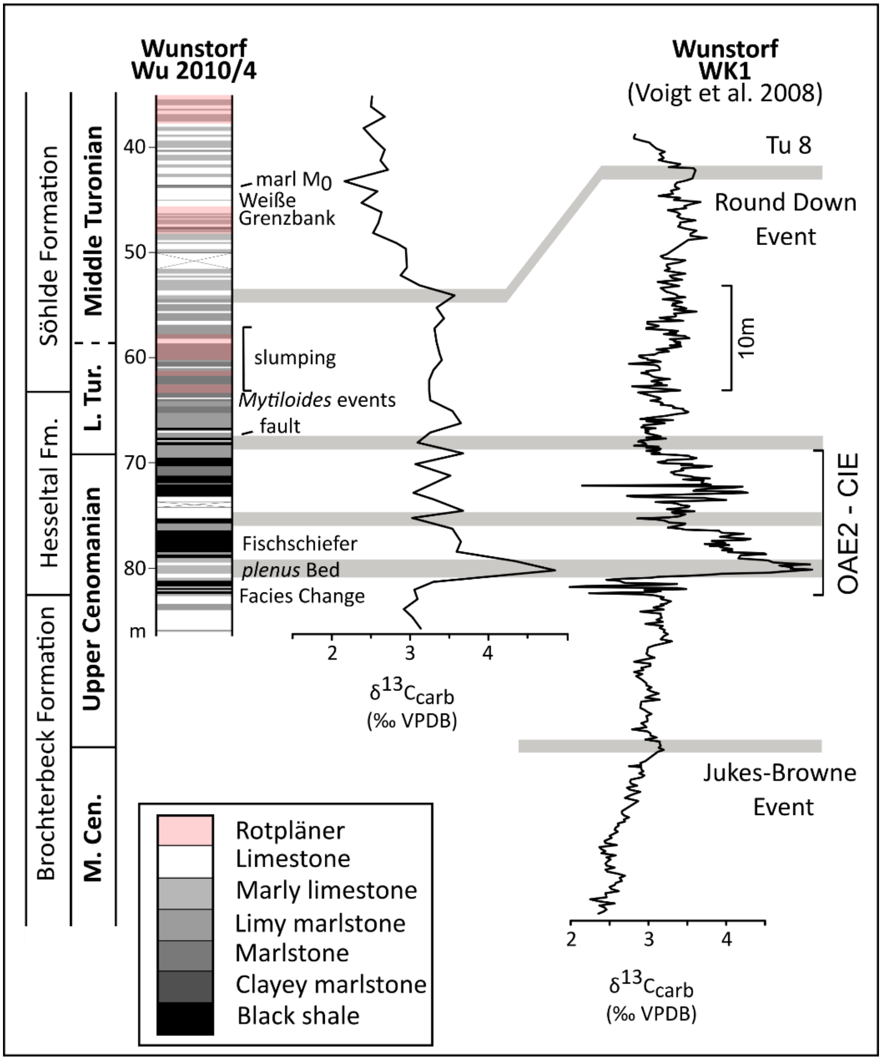


Figure 3.5. Columnar section of the Wunstorf core Wu 2010/4, and its carbon isotope patterns. Correlations to the Wunstorf WK1 core of Voigt et al. (2008b: Fig. 2) are based on the isotopic patterns and the thicknesses of strata. Grey bars = correlation of carbon isotope patterns.

3.2.3 Sequence stratigraphical framework

Several sequence stratigraphic investigations provided a detailed stratigraphical framework for the Cretaceous deposits of Lower Saxony (e.g., Wilmsen, 2003; Janetschke et al., 2015). Based on the sequence stratigraphical analysis by Ernst et al. (1996) and Robaszynski et al. (1998), depositional sequences are bounded by unconformities called sequence boundaries (SB; Fig. 3.3).

Five Cenomanian depositional sequences (DS) are noted at Baddeckenstedt and Wunstorf: DS Al–Ce 1, DS Ce 2–5; the Turonian strata of Söhlde and Wunstorf mentioned in this study yields three complete depositional sequences: DS Ce–Tu 1, DS Tu 2–3 (Fig. 3.3).

3.3 Material and methods

The Wunstorf cores were sampled in around 5 m intervals, the Baddeckenstedt, and Söhlde-Loges section in about 3 m intervals. Most of the 40 samples from Wunstorf and 31 samples from Baddeckenstedt and Söhlde consist of limestones or marly limestones. Samples from the black shale/marlstone interval around the Cenomanian–Turonian boundary at Wunstorf were collected from marly limestones between the bituminous layers. Samples of about 100 g were treated with formic acid (CH_2O_2) for about 24 hours at 20°C. After the complete dissolution of carbonate, the residue was washed carefully within a 63 µm-sieve to remove all clay particles from it. This method enables studies of the agglutinated foraminiferal fauna in compacted and highly lithified limestones, which were previously not studied (Frieg and Kemper (1989). The taxonomy is mainly based on Loeblich and Tappan (1987), Frieg (1980), Frieg and Kemper (1989) Kaminski and Gradstein (2005), Kaminski et al. (2011), and Setoyama et al. (2017). The classification scheme for agglutinated foraminifers of Kaminski (2004) was applied. At least 300 specimens from each sample were counted; indeterminable specimens were not counted. As far as possible, specimens were taxonomically assigned on species level, as generic information does not seem to be fully reliable for biodiversity data analyses (Wiese et al., 2016). Tubular agglutinated foraminifers are usually preserved highly fragmented. The minimum fragmentation factor is 5 (Bubík, 2019). Thus, tubular specimen counts were divided by the factor five, to reduce the impact of tubular foraminifera on the relative abundances. They are displayed as 'calculated specimens' in chapter 3.5. Abundances based on relative abundances are given as followed: very abundant (> 15 %), abundant (15–5 %), common (5–2 %), rare (2–1 %), and very rare (< 1 %). For diversity analysis, the Fisher-Alpha Index (Fisher et al., 1943) was calculated with PAST (version 3.26; Hammer et al., 2001), and the total species richness (number of taxa) was calculated. High Fisher-Alpha Index and species richness reflect highly divers assemblages, while low values correspond to low diverse foraminiferal assemblages. Morphogroup analysis is based 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. Relative abundances of different morphogroups can be linked to environmental changes interpreted based on modern foraminiferal studies (Jones and Charnock, 1985; Jorissen et al., 1995; Zwaan et al., 1999; Murray et al., 2011). The scheme used in this study (see Table 3.1) is modified for Cretaceous agglutinated foraminiferal assemblages after Frenzel (2000), Cetean et al. (2011), and Setoyama et al. (2017). All photographs were taken on a Keyence VHX-1000 Digital Microscope Multi Scan at Freie Universität, Berlin, Section Palaeontology.

Morphogroup	**Test Form**	**Life position**	**Environment**	**Main genera**
M1	Tubular	Erect epifauna	bathyal and abyssal	*Bathysiphon* *Nothia* *Psammosiphonella*
M2a	Globular	Shallow infaunal	bathyal and abyssal	*Caudammina* *Psammosphaera* *Saccammina*
M2b	Rounded trocho- and streptospiral, planoconvex trochospiral	Surficial epifaunal	Shelf to deep marine	*Ataxophragmium* *Trochammina*
M2c	Elongate keeled	Surficial epifaunal	Shelf to marginal marine	*Spiroplectammina*
M3a	Flattened planispiral and streptospiral	Surficial epifaunal	Lagoonal to abyssal	*Ammodiscus* *Glomospira* *Repmanina*
M3b	Flattened irregular	Surficial epifaunal	Upper bathyal to abyssal	*Ammolagena*

M3c	Flattened streptospiral	Surficial epifaunal	Upper bathyal to abyssal	*Ammosphaeroidina* *Praecystammina* *Trochamminoides*
M4a	Rounded planispiral	Surficial epifaunal and/or shallow infaunal	Inner shelf to upper bathyal	*Haplophragmoides*
M4b	Elongate subcylindrical	Deep infaunal	Inner shelf to upper bathyal	*Arenobulimina* *Gerochammina* *Tritaxia*
	Elongate tapered			*Ammobaculites* *Bulbobaculites* *Pseudonodosinella*

Table 3.1. Agglutinated foraminiferal morphogroups, morphotypes/test forms, and life environments modified after Frenzel (2000), Cetean et al. (2011), and Setoyama et al. (2017) correlated to main genera treated with in this study.

The bulk-carbonate carbon isotope measurements of samples of the Wunstorf cores Wu2010/1, Wu2010/3 and Wu2010/4 were conducted at the Museum für Naturkunde, Berlin, using a GasBench II linked to a ThermoFischer Scientific DeltaV isotope ratio mass spectrometer. All values are given in permil (‰) versus VPDB. The analytical precision of repeated in-house standards material (Limestone) is generally better than +-0.1‰.

3.4 Systematics

The classification for agglutinated foraminifers of Kaminski (2004) was used for the taxa recorded from the Wunstorf cores, Baddeckenstedt and Söhlde sections. 14,522 specimens of 90 species and taxa of a higher level of Wunstorf were determined, 10,406 specimens consisting of 105 taxa of samples from the Baddeckenstedt and Söhlde sections. Hereinafter used literature contains first descriptions of taxa and for identification used information.

Class FORAMINIFERA d’Orbigny 1826

Subclass MONOTHALAMANA Pawlowski, Holzmann and Tyszka 2013
Order ASTRORHIZIDA Lankester 1885
Suborder ASTRORHIZINA Lankester 1885
Superfamily ASTRORHIZOIDEA Brady 1881
Family ASTRORHIZIDAE Brady 1881
Genus *Astrorhiza* Sandahl 1858

Astrorhiza sp.

Material. One specimen from the Baddeckenstedt section.

Occurence. Very rare.

Family RHABDAMMINIDAE Brady 1884
Subfamily RHABDAMMININAE Brady 1884
Genus *Rhabdammina* Sars in Carpenter 1869

Rhabdammina sp.

Material. Ten specimens from the Baddeckenstedt section, and 15 specimens from the Söhlde section

Occurence. Very rare.

Subfamily BATHYSIPHONINAE Avnimelech 1952
Genus *Bathysiphon* Sars 1872

Bathysiphon spp.

Material. 118 calculated specimens from the Baddeckenstedt section, 131 specimens from the Söhlde section, 235 specimens from the Wunstorf Wu2010/1 core, 176 specimens from the Wunstorf Wu2010/3 core, and 112 specimens from the Wunstorf Wu2010/4 core.

Occurrence. Abundant in the uppermost Albian to lowermost Cenomanian at Wunstorf, common to rare in the Cenomanian to Turonian of Lower Saxony.

Genus *Nothia* Pflaumann 1964

Nothia spp.

Material. 68 calculated specimens from the Baddeckenstedt section, 15 specimens from the Söhlde section, 235 specimens from the Wunstorf Wu2010/1 core, 70 specimens from the Wunstorf Wu2010/3 core, and 31 specimens from the Wunstorf Wu2010/4 core.

Occurrence. Abundant in the uppermost Albian at Wunstorf, common to rare in the Cenomanian, rare to very rare in the Turonian.

Genus *Psammosiphonella* Avnimelich 1952

Psammosiphonella spp.

Material. 99 calculated specimens from the Baddeckenstedt section, 125 specimens from the Söhlde section, 100 specimens from the Wunstorf Wu2010/1 core, 65 specimens from the Wunstorf Wu2010/3 core, and 68 specimens from the Wunstorf Wu2010/4 core.

Occurrence. Common to rare.

Order SACCAMMININA Lankester 1885

Suborder HEMISPHAERAMMININAE Loeblich and Tappan 1961, emend Mikhalevich 1995

Genus *Hemisphaerammina* Loeblich and Tappan 1957

Hemisphaerammina batalleri Loeblich and Tappan, 1957

1957. *Hemisphaerammina batalleri*, Loeblich and Tappan, p. 224, pl. 72, fig. 3.

Material. Four specimens from the Baddeckenstedt section, and 6 specimens from the Söhlde section.

Occurrence. Very rare.

Hemisphaerammina glandiformis Hercogova and Kriz 1983

1983. *Hemisphaerammina glandiformis* Hercogova and Kriz, p. 210, pl. 5, figs. 5a, b.

Material. 6 specimens from the Baddeckenstedt section, and one specimen from the Söhlde section.

Occurrence. Very rare.

Suborder SACCAMMINOIDEA Brady 1884
Family SACCAMMINIDAE Brady 1884
Subfamily SACCAMMININAE Brady 1884
Genus *Lagenammina* Rhumbler 1911

Lagenammina difflugiformis (Brady, 1879)
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. 17 specimens from the Baddeckenstedt section, and two specimens from the Söhlde section.

Occurrence. Rare to very rare.

Genus *Placentammina* Thalmann 1947

Placentammina cf. *placenta* (Grzybowski, 1898)
1898. *Reophax placenta* Grzybowski, p. 276, pl. 10, figs. 9–10.
1990. *Saccammina placenta* (Grzybowski); Kuhnt, p. 325, pl. 2, fig. 1.
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.
2011. *Placentammina placenta* (Grzybowski); Kaminski et al., p. 84, pl. 1, fig. 4.

Material. Eight specimens from the Baddeckenstedt section, 16 specimens from the Söhlde section, 26 specimens from the Wunstorf Wu2010/1 core, and one specimen from the Wunstorf Wu2010/3 core.

Remarks. This species is reported not earlier than Santonian (Kuhnt, 1990), but appears already in the uppermost Albian of the Wunstorf cores.

Occurrence. Common to rare in the uppermost Albian at Wunstorf, otherwise very rare.

Genus *Saccammina* Carpenter 1869

Saccammina grzybowskii (Schubert, 1902)

Figure 3.6a

1902. *Reophax grzybowskii* Schubert, p. 20, pl. 1, figs. 13a–b.

1993. *Saccammina grzybowskii* (Schubert); Kaminski and Geroch, p. 248, pl. 2, figs. 1a-–4b.

2005. *Saccammina grzybowskii* (Schubert); Kaminski and Gradstein, p. 132, pl. 10, figs. 1-9.

2011. *Saccammina grzybowskii* (Schubert); Kaminski et al., p. 84, pl. 1, fig. 5.

Material. 23 specimens from the Baddeckenstedt section, 81 specimens from the Söhlde section, 82 specimens from the Wunstorf Wu2010/1 core, 32 specimens from the Wunstorf Wu2010/3 core, and 55 specimens from the Wunstorf Wu2010/4 core.

Occurrence. Abundant to common in the uppermost Albian of Wunstorf and in the Turonian of Söhlde, rare to very rare in all other studied stratigraphical intervals.

Saccammina sphaerica Brady, 1871

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

Material. Three specimens from the Söhlde section.

Occurrence. Very rare in the late Turonian.

Superfamily PSAMMOSPHAEROIDEA Haeckel 1894

Family PSAMMOSPHAERIDAE Haeckel 1894

Subfamily PSAMMOSPHAERINAE Haeckel 1894

Genus *Psammosphaera* Schultze 1875

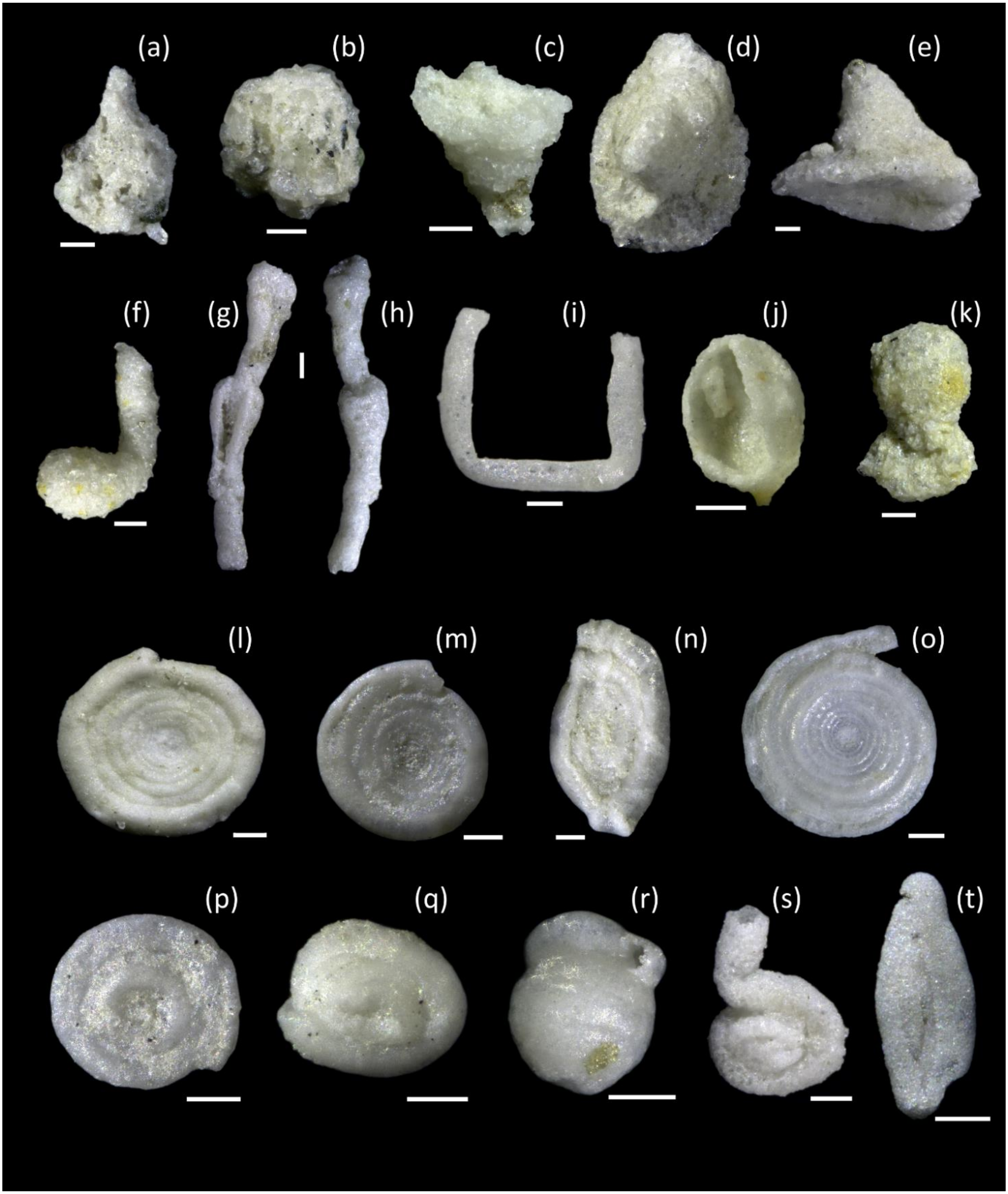

(a)
(b)
(c)
(d)
(e)
(f)
(g)
(h)
(i)
(j)
(k)
(l)
(m)
(n)
(o)
(p)
(q)
(r)
(s)
(t)

Figure 3.6. Late Albian to Turonian agglutinated foraminifera from the Lower Saxonian Cretaceous; scale bars are 100 µm. (a) *Saccammina grzybowskii*, Wunstorf Wu 2010/1, 54.00 m. (b) *Psammosphaera fusca*, Wunstorf Wu 2010/1, 59.05 m). (c) *Tipeammina elliptica*, Söhlde section, 31.00 m). (d–e) *Tipeammina* sp. 1, Wunstorf Wu 2010/4, 43.30 m. (f) *Hyperammina gaultina*, Wunstorf Wu 2010/4, 48.20 m. (g–h) *Ammolagena clavata*, two specimens sticking together, Wunstorf Wu 2010/3, 25.50 m. (i) *Ammolagena contorta*, possibly previously attached on an inoceramid prism, Wunstorf Wu 2010/4, 38.20 m. (j) *Caudammina ovula*, Söhlde section, 31.00 m. (k) *Subreophax scalaris*, Wunstorf Wu 2010/1, 69.10 m. (l) *Ammodiscus cretaceus*, Wunstorf Wu 2010/4, 48.20 m. (m) *Ammodiscus glabratus*, Wunstorf Wu 2010/1, 54.65 m. (n) *Ammodiscus peruvianus*, Wunstorf Wu 2010/1, 54.00 m. (o) *Ammodiscus tenuissimus*, Wunstorf Wu 2010/4, 43.30 m. (p) *Glomospira diffundens*, Wunstorf Wu 2010/1, 49.05 m. (q) *Glomospira gordialis*, Wunstorf Wu 2010/3, 66.05 m. (r) *Repmanina charoides*, Wunstorf Wu 2010/4, 38.20 m. (s) *Lituotuba lituiformis*, Wunstorf Wu 2010/4, 48.95 m. (t) *Rzehakina minima*, Wunstorf Wu 2010/1, 54.80 m.

Psammosphaera fusca Schultze, 1875

Figure 3.6b

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

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

Material. 14 specimens from the Baddeckenstedt section, five specimens from the Söhlde section, 129 specimens from the Wunstorf Wu2010/1 core, and seven specimens from the Wunstorf Wu2010/3 core.

Occurrence. Abundant in the uppermost Albian to lowermost Cenomanian of Wunstorf, otherwise very rare.

Psammosphaera irregularis (Grzybowski, 1896)

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. 64 specimens from the Baddeckenstedt section, 74 specimens from the Söhlde section, 30 specimens from the Wunstorf Wu2010/1 core, three specimens from the Wunstorf Wu2010/3 core, and two specimens from the Wunstorf Wu2010/4 core

Occurrence. Common in the uppermost Albian at Wunstorf and Turonian at Söhlde, otherwise rare to very rare.

Subclass TUBOTHALAMA Pawlowski, Holzmann and Tyszka 2013

Order AMMODISCIDA Mikhalevich 1980

Suborder HIPPOCREPININA Saidova 1981

Superfamily HIPPOCREPINOIDEA Rhumbler 1895

Family HIPPOCREPINIDAE Rhumbler 1895

Subfamily JACULELLINAE Mikhalevich 1995

Genus *Kechenotiske* Loeblich and Tappan 1984

Kechenotiske sp.

Material. Five specimens from the Baddeckenstedt section, and one specimen from the Söhlde section.

Occurrence. Very rare.

Genus *Tipeammina* Neagu 2004

Tipeammina elliptica (Deeke, 1884)

Figure 3.6c

1884. *Rhabdammina elliptica* Deeke, p. 23, pl. 1, figs. 1a, b.

2004. *Tipeammina elliptica* (Deeke); Neagu, pl. 1, figs. 10–12, fig. 2.

Material. Three specimens from the Baddeckenstedt section, and 15 specimens from the Söhlde section.

Occurrence. Rare to very rare in the Turonian at Söhlde, otherwise very rare.

Tipeammina sp. 1

Figure 3.6d–e

Remarks. 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.

Material. 18 specimens from the Baddeckenstedt section, 38 specimens from the Söhlde section, two specimens from the Wunstorf Wu2010/1 core, three specimens from the Wunstorf Wu2010/3 core, and 29 specimens from the Wunstorf Wu2010/4 core.

Occurrence. Rare to very rare.

Family HYPERAMMINIDAE Eimer and Fickert 1899

Subfamily HYPERAMMININAE Eimer and Fickert 1899

Genus *Hyperammina* Brady 1878

Hyperammina gaultina Ten Dam, 1950

Figure 3.6f

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

Material. Four specimens from the Baddeckenstedt section, 19 specimens from the Wunstorf Wu2010/1 core, and one specimen from the Wunstorf Wu2010/4 core.

Occurrence. Common in the uppermost Albian at Wunstorf, otherwise very rare.

Hyperammina sp.

Material. Six specimens from the Söhlde section.

Occurrence. Very rare.

Superfamily HORMOSINELLOIDEA Rauser and Reitlinger 1986

Family AMMOLAGENIDAE Kaminski, Henderson, Cetean and Waśkowska 2009

Genus *Ammolagena* Eimer and Fickert 1899

Ammolagena clavata (Jones and Parker, 1860)

Figure 3.6g–h

1860. *Trochammina irregularis* (d`Orbigny) var. *clavata* Jones and Parker; Carpenter et al., p. 142, pl. 11, fig. 6.

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

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

Material. 141 specimens from the Baddeckenstedt section, 28 specimens from the Söhlde section, 100 specimens from the Wunstorf Wu2010/1 core, 154 specimens from the Wunstorf Wu2010/3 core, and 15 specimens from the Wunstorf Wu2010/4 core.

Remarks. This species occurs usually only in divers agglutinated foraminiferal assemblages and can be used as indicator for a low supply of clastic material (Waśkowska, 2014).

Occurrence. Abundant to common in the Cenomanian, rare to very rare in the Turonian.

Ammolagena contorta Waters, 1927

Figure 3.6i

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

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

Material. 181 specimens from the Baddeckenstedt section, 664 specimens from the Söhlde section, 44 specimens from the Wunstorf Wu2010/1 core, 64 specimens from the Wunstorf Wu2010/3 core, and 125 specimens from the Wunstorf Wu2010/4 core.

Remarks. *Ammolagena contorta* was reported from the Upper Cretaceous of the Arctic realm (Setoyama et al., 2011; 2017). A preference of colder temperate environments of this species is therefore likely.

Occurrence. Common to rare in the Cenomanian, abundant to common in the Turonian at Wunstorf, very abundant to abundant in the Turonian at Söhlde.

Family HORMOSINELLIDAE Rauser and Reitlinger 1986

Genus *Caudammina* Montanaro-Gallitelli 1955

Caudammina cf. *excelsa* (Dylążanka, 1923)

1923. *Hyperammina excelsa* Dylążanka, p. 66, pl. 1, fig. 3.

1993. *Hormosina excelsa* (Dylążanka); Kaminski and Geroch, p. 281, pl. 17, figs. 1–4b.

2005. *Caudammina excelsa* (Dylążanka); Kaminski and Gradstein, p. 230, pl. 40, figs. 1a–5.

2011. *Caudammina excelsa* (Dylążanka); Kaminski et al., p. 86, pl. 2, fig. 1.

Material. Five specimens from the Wunstorf Wu2010/1 core.

Remarks. The known stratigraphic range of this species spans from the Turonian to the Eocene (Kaminski and Gradstein, 2005), Weidich (1990) reported it from the Berriasian to the Cenomanian from the northern Calcareous Alps, while Kaminski et al. (1992) cited a similar form from the Lower Cretaceous of the Indian Ocean.

Occurrence. Very rare in the uppermost Albian and lowermost Cenomanian of Wunstorf.

Caudammina ovula (Grzybowski, 1896)

Figure 3.6j

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. *Caudammina ovula* (Grzybowski); Kaminski and Gradstein, p. 233, pl. 41, figs. 1a–8.

2011. *Caudammina ovula* (Grzybowski); Kaminski et al., p. 86, pl. 2, figs. 3.

Material. 58 specimens from the Baddeckenstedt section, 63 specimens from the Söhlde section, three specimens from the Wunstorf Wu2010/1 core, four specimens from the Wunstorf Wu2010/3 core, and 15 specimens from the Wunstorf Wu2010/4 core.

Occurrence. Very rare at Wunstorf, common to rare at Baddeckenstedt and Söhlde.

Caudammina ovuloides (Grzybowski, 1901)

1901. *Reophax ovuloides* Grzybowski, p. 233, pl. 8, fig. 3.

1988. *Hormosina ovuloides* (Grzybowski); Kaminski et al., p. 186, pl. 2, figs. 3–4.

2005. *Caudammina ovuloides* (Grzybowski); Kaminski and Gradstein, p. 238, pl. 42, figs. 1a–7.

Material. Five specimens from the Baddeckenstedt section, nine specimens from the Wunstorf Wu2010/1 core, and four specimens from the Wunstorf Wu2010/3 core.

Occurrence. Very rare in the Cenomanian.

Caudammina sp.

Material. 24 specimens from the Söhlde section.

Occurrence. Very rare.

Genus *Hormosinella* Stschedrina 1969

Hormosinella fusiformis Kaminski, Cetean, Bălc and Coccioni 2011

2011. *Hormosinella fusiformis* Kaminski, Cetean, Bălc and Coccioni, p. 87, pl. 2, figs. 6–12.

Material. 11 specimens from the Baddeckenstedt section.

Occurrence. Very rare in the lower Cenomanian of the Baddeckenstedt section.

Genus *Subreophax* Saidova 1975

Subreophax scalaris (Grzybowski, 1896)

Figure 3.6k

1896. *Reophax guttifera* (Brady) var. *scalaria* Grzybowski, p. 277, pl. 8, figs. 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.

2011. *Subreophax scalaris* (Grzybowski); Kaminski et al., p. 87, pl. 3, fig. 7.

Material. Three specimens from the Baddeckenstedt section, 41 specimens from the Wunstorf Wu2010/1 core, and six specimens from the Wunstorf Wu2010/3 core.

Occurrence. Common in the uppermost Albian of the Wunstorf cores, very rare in the Cenomanian.

Suborder AMMODISCINA Mikhalevich 1980

Superfamily AMMODISCOIDEA Reuss 1862

Family AMMODISCIDAE Reuss 1862

Subfamily AMMODISCINAE Reuss 1862

Genus *Agathamminoides* Vangerow 1964

Agathamminoides serpens (Grzybowski, 1898)

1898. *Ammodiscus serpens* Grzybowski, p. 285, pl. 10, fig. 31 (not 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. Two specimens from the Baddeckenstedt section, five specimens from the Söhlde section, 14 specimens from the Wunstorf Wu2010/1 core, 12 specimens from the Wunstorf Wu2010/3 core, and two specimens from the Wunstorf Wu2010/4 core.

Occurrence. Very rare.

Genus *Ammodiscus* Reuss 1862

Ammodiscus cretaceus (Reuss, 1845)

Figure 3.6l

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

1934. *Ammodiscus cretacea* (Reuss); Cushman, p. 608, pl. 21, figs. 3a–b.

1990. *Ammodiscus cretaceus* (Reuss); Kuhnt, p. 310, pl. 1, figs. 2–3.

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

2011. *Ammodiscus cretaceus* (Reuss); Kaminski et al., p. 84, pl. 1, fig. 9.

Material. 107 specimens from the Baddeckenstedt section, 100 specimens from the Söhlde section, 52 specimens from the Wunstorf Wu2010/1 core, 88 specimens from the Wunstorf Wu2010/3 core, and 159 specimens from the Wunstorf Wu2010/4 core.

Occurrence. Common to very rare.

Ammodiscus glabratus Cushman and Jarvis, 1928

Figure 3.6m

1928. *Ammodiscus glabratus* Cushman and Jarvis, p. 87, pl. 12, fig. 6a, b.

2005. *Ammodiscus glabratus* Cushman and Jarvis; Kaminski and Gradstein, p.148, pl. 15, figs. 1a–6.

2011. *Ammodiscus glabratus* Cushman and Jarvis; Kaminski et al., p. 85, pl. 1, fig. 10.

Material. 45 specimens from the Baddeckenstedt section, 85 specimens from the Söhlde section, 42 specimens from the Wunstorf Wu2010/1 core, 71 specimens from the Wunstorf Wu2010/3 core, and 166 specimens from the Wunstorf Wu2010/4 core

Occurrence. Common to very rare.

Ammodiscus peruvianus Berry, 1928

Figure 3.6n

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

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

2011. *Ammodiscus peruvianus* Berry; Kaminski et al., p. 85, pl. 1, figs. 11–12.

Material. 18 specimens from the Baddeckenstedt section, 32 specimens from the Söhlde section, 46 specimens from the Wunstorf Wu2010/1 core, 42 specimens from the Wunstorf Wu2010/3 core, and 94 specimens from the Wunstorf Wu2010/4 core.

Occurrence. Common to rare in the Turonian, otherwise very rare.

Ammodiscus tenuissimus Grzybowski, 1898

Figure 3.6o

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. 15 specimens from the Baddeckenstedt section, 16 specimens from the Söhlde section, 71 specimens from the Wunstorf Wu2010/1 core, 61 specimens from the Wunstorf Wu2010/3 core, and 124 specimens from the Wunstorf Wu2010/4 core.

Occurrence. Abundant to common in the Cenomanian¬–Turonian boundary interval at Wunstorf, rare to very rare in other stratigraphical intervals, very rare at Baddeckenstedt and Söhlde.

Ammodiscus spp.

Material. 15 specimens from the Wunstorf Wu2010/1 core, 36 specimens from the Wunstorf Wu2010/3 core, and 43 specimens from the Wunstorf Wu2010/4 core.

Occurrence. Rare to very rare.

Genus *Dolgenia* Kemper 1995

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.

2008. *Dolgenia pennyi* (Cushman and Jarvis); Setoyama et al., 2008, p. 271, pl. 3, figs. 12a–b.

2011. *Dolgenia pennyi* (Cushman and Jarvis); Kaminski et al., p. 85, pl. 1, fig. 13.

Material. Six specimens from the Baddeckenstedt section, 33 specimens from the Söhlde section, 30 specimens from the Wunstorf Wu2010/1 core, 31 specimens from the Wunstorf Wu2010/3 core, and 28 specimens from the Wunstorf Wu2010/4 core.

Occurrence. Rare to very rare

Subfamily TOLYPAMMININAE Cushman 1928

Genus *Tolypammina* Rhumbler 1895

Tolypammina sp.

Material. Material. 15 calculated specimens from the Baddeckenstedt section, eight specimens from the Söhlde section, 40 specimens from the Wunstorf Wu2010/1 core, 42 specimens from the Wunstorf Wu2010/3 core, and 53 specimens from the Wunstorf Wu2010/4 core.

Occurrence. Rare to very rare.

Subfamily USBEKISTANIINAE Vialov 1968

Genus *Glomospira* Rzehak 1885

Glomospira diffundens Cushman and Renz, 1946

Figure 3.6p

1946. *Glomospira gordialis* (Jones and Parker) var. *diffundens* Cushman and Renz, p. 15, pl. 1, fig. 30.

1984. *Glomospira gordialis diffundens* Cushman and Renz.; Hemleben and Troester, p. 519, pl. 1, fig. 21.

2005. *Glomospira diffundens* Cushman and Renz; Kaminski and Gradstein, p. 175, pl. 23, figs. 1–9.

Material. Nine specimens from the Baddeckenstedt section, nine specimens from the Söhlde section, 48 specimens from the Wunstorf Wu2010/1 core, 66 specimens from the Wunstorf Wu2010/3 core, and 55 specimens from the Wunstorf Wu2010/4 core.

Occurrence. Common to very rare at Wunstorf, very rare at Baddeckenstedt and at Söhlde.

Glomospira gordialis (Jones and Parker, 1860)

Figure 3.6q

1860. *Trochammina squamata* (Jones and Parker) var. *gordialis* Jones and Parker, p. 292–307 (no type-figure given).

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.

2011. *Glomospira gordialis* (Jones and Parker); Kaminski et al., p. 85, pl. 1, fig. 14.

Material. 57 specimens from the Baddeckenstedt section, 71 specimens from the Söhlde section, 40 specimens from the Wunstorf Wu2010/1 core, 67 specimens from the Wunstorf Wu2010/3 core, and 97 specimens from the Wunstorf Wu2010/4 core.

Occurrence. Common to very rare.

“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.

2011. *"Glomospira" irregularis* (Grzybowski); Kaminski et al., p. 85, pl. 1, fig. 15.

Material. 14 specimens from the Baddeckenstedt section, 39 specimens from the Söhlde section, 47 specimens from the Wunstorf Wu2010/1 core, 76 specimens from the Wunstorf Wu2010/3 core, and 34 specimens from the Wunstorf Wu2010/4 core.

Occurrence. Common to rare in the Cenomanian at Wunstorf, otherwise rare to very rare.

Glomospira spp.

Material. Six specimens from the Wunstorf Wu2010/1 core, 40 specimens from the Wunstorf Wu2010/3 core, and 48 specimens from the Wunstorf Wu2010/4 core.

Occurrence. Rare to very rare.

Genus *Repmanina* Suleymanov, In Arapova and Suleymanov 1966

Repmanina charoides (Jones and Parker, 1860)

Figure 3.6r

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

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

2001. *Repmanina charoides* (Jones and Parker); Alegret and Thomas, p. 300, pl. 10, fig. 11.

2011. *Repmanina charoides* (Jones and Parker); Kaminski et al., p. 86, pl. 1, figs. 17a–b.

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

Material. 85 specimens from the Baddeckenstedt section, 164 specimens from the Söhlde section, 29 specimens from the Wunstorf Wu2010/1 core, 61 specimens from the Wunstorf Wu2010/3 core, and 262 specimens from the Wunstorf Wu2010/4 core.

Occurrence. Common to very rare in the Cenomanian, abundant to common in the Turonian.

Family LITUOTUBIDAE Loeblich and Tappan 1984

Genus *Lituotuba* Rhumbler 1895

Lituotuba lituiformis (Brady 1879)

Figure 3.6s

1879. *Trochammina lituiformis* Brady, p. 59, pl. 5, fig. 16.

1990. *Lituotuba lituiformis* (Brady); Kuhnt, p. 318, pl. 1, figs. 17, 18.

2005. *Lituotuba lituiformis* (Brady); Kaminski and Gradstein, p. 287, pl. 38, figs. 1–8.

2011. *Lituotuba lituiformis* (Brady); Kaminski et al., p. 88, pl. 3, fig. 12.

Material. 19 specimens from the Baddeckenstedt section, 31 specimens from the Söhlde section, nine specimens from the Wunstorf Wu2010/1 core, 11 specimens from the Wunstorf Wu2010/3 core, and 48 specimens from the Wunstorf Wu2010/4 core.

Occurrence. Rare to very rare.

Family TROCHAMMINOIDAE Haynes and Nwabufo-Ene 1998
Genus *Trochamminoides* Cushman 1910

Trochamminoides spp.

Material. 132 specimens from the Baddeckenstedt section, 125 specimens from the Söhlde section, 23 specimens from the Wunstorf Wu2010/1 core, 36 specimens from the Wunstorf Wu2010/3 core, and 69 specimens from the Wunstorf Wu2010/4 core.

Occurrence. Common.

Suborder SCHLUMBERGERININA Mikhalevich 1980
Superfamily RZEHAKINOIDEA Cushman 1933
Family RZEHAKINIDAE Cushman 1933
Subfamily RZEHAKININAE Cushman 1933
Genus *Rzehakina* Cushman 1927

Rzehakina minima Cushman and Renz, 1946

Figure 3.6t

1946. *Rzehakina epigona* (Rzehak) var. *minima* Cushman and Renz, p. 24, pl. 3, fig. 5.

2005. *Rzehakina minima* Cushman and Renz; Kaminski and Gradstein, p. 215, pl. 35, figs. 1a–10.

2011. *Rzehakina minima* Cushman and Renz; Kaminski et al., p. 86, pl. 1, fig. 19.

Material. Two specimens from the Baddeckenstedt section, one specimen from the Söhlde section, and 15 specimens from the Wunstorf Wu2010/1 core.

Occurrence. Very rare in the uppermost Albian to the upper Cenomanian of Lower Saxony

Subclass GLOBOTHALAMA Pawlowski, Holzmann and Tyszka 2013
Order LITUOLIDA Lankester 1885
Suborder HORMOSININA Mikhalevich 1980
Superfamily HORMOSINOIDEA Haeckel 1894
Family ASCHEMOCELLIDAE, Vialov 1966
Genus *Kalamopsis* De Folin 1883

Kalamopsis grzybowskii (Dylazanka, 1923)
1923. *Hyperammina grzybowskii* Dylazanka, 1923, p. 65.
1995. *Kalamopsis grzybowskii* (Dylazanka); Bubík, pl. 9, fig. 5, cf. 4.
2017. *Kalamopsis grzybowskii* (Dylazanka); Setoyama et al., p. 191, pl. 1, fig. 18.

Material. One specimen from the Baddeckenstedt section.

Occurrence. Very rare in the middle Cenomanian of Baddeckenstedt.

Family REOPHACIDAE Cushman 1927
Genus *Hormosinelloides* Zheng 2001

Hormosinelloides guttifer (Brady, 1884)
1884. *Reophax guttifera* Brady, p. 278.
2011. *Hormosinelloides guttifer* (Brady); Kaminski, p. 87, pl. 2, fig. 13.

Material. Five specimens from the Baddeckenstedt section, one specimen from the Wunstorf Wu2010/1 core, and one specimen from the Wunstorf Wu2010/4 core.

Occurrence. Very rare.

Genus *Reophax* De Montfort 1808

Reophax cf. *globosus* Sliter, 1968

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

Remarks. The reported stratigraphic range of this species spans from the Campanian to the Paleocene (Kaminski and Gradstein, 2005). Beckmann (1994) described it from Cenomanian strata of Trinidad.

Material. 19 specimens from the Baddeckenstedt section.

Occurrence. Very rare in the lower to middle Cenomanian at Baddeckenstedt.

Reophax scorpiurus de Montfort, 1808

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

1971. *Reophax scorpiurus* de Montfort; Fuchs, p. 9, pl. 1, fig. 3.

Material. Four specimens from the Baddeckenstedt section.

Occurrence. Very rare in the lower Cenomanian at Baddeckenstedt.

Reophax subfusiformis (Earland, 1933)

Figure 3.6a

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. 13 specimens from the Baddeckenstedt section, two specimens from the Söhlde section, and 96 specimens from the Wunstorf Wu2010/1 core.

Occurrence. Abundant to common in the uppermost Albian and lowermost Cenomanian at Wunstorf, otherwise very rare.

Family HORMOSINIDAE Haeckel 1894

Subfamily HORMOSININAE Haeckel 1894

Genus *Pseudonodosinella* Saidova 1970

Pseudonodosinella nodulosa (Brady, 1879)

Figure 3.7b

1879. *Reophax nodulosa* Brady, p. 52, pl. 4, figs. 7–8.

2005. *Pseudonodosinella nodulosa* (Brady); Kaminski and Gradstein, p. 259, pl. 49, figs. 1–9.

2017. *Pseudonodosinella nodulosa* (Brady); Setoyama, p. 193, pl. 1, fig. 21.

Material. 48 specimens from the Baddeckenstedt section, 72 specimens from the Söhlde section, 27 specimens from the Wunstorf Wu2010/3 core, and 84 specimens from the Wunstorf Wu2010/4 core.

Occurrence. First occurrence in the lower Cenomanian of Wunstorf above The Rib. Abundant to common in the upper Cenomanian at Baddeckenstedt and Söhlde and in the middle Turonian at Wunstorf, otherwise rare to very rare.

Pseudonodosinella parvula (Huss, 1966)

Figure 3.7c

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.

2011. *Pseudonodosinella parvula* (Huss); Kaminski et al., p. 88, pl. 3, fig. 11.

2017. *Pseudonodosinella parvula* (Huss); Setoyama et al., p. 193, pl. 1, fig. 22.

Material. Nine specimens from the Baddeckenstedt section, 53 specimens from the Söhlde section, 15 specimens from the Wunstorf Wu2010/1 core, 19 specimens from the Wunstorf Wu2010/3 core, and 79 specimens from the Wunstorf Wu2010/4 core.

Occurrence. First occurrence in the lowermost Cenomanian of Wunstorf, common in the lowermost Turonian of Söhlde, otherwise rare to very rare.

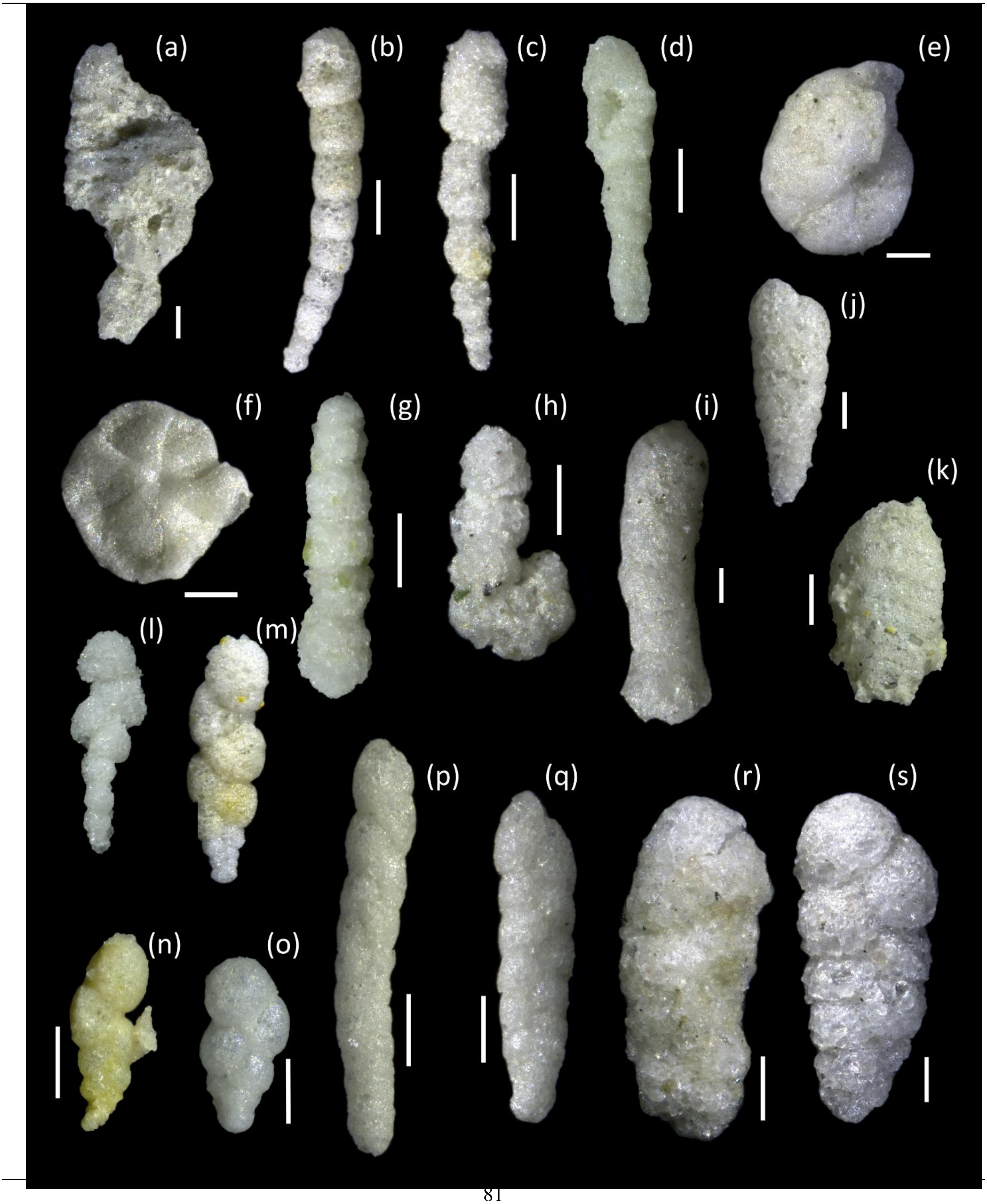

(a)
(b)
(c)
(d)
(e)
(f)
(g)
(h)
(i)
(j)
(k)
(l)
(m)
(n)
(o)
(p)
(q)
(r)
(s)

Figure 3.7. Late Albian to Turonian agglutinated foraminifers from the Lower Saxonian Cretaceous, scale bars are 100 µm. (a) *Reophax subfusiformis*, Wunstorf Wu 2010/1, 54.00 m. (b) *Pseudonodosinella nodulosa*, Wunstorf Wu 2010/4, 48.20 m. (c) *Pseudonodosinella parvula*, Wunstorf Wu 2010/4, 48.20 m. (d) *Pseudonodosinella troyeri*, Baddeckenstedt section, 39.00 m. (e) *Haplophragmoides suborbicularis*, Wunstorf Wu 2010/3, 70.50 m. (f) *Haplophragmoides walteri*, Wunstorf Wu 2010/4, 48.95 m. (g) *Ammobaculites agglutinans*, Söhlde section, 31.00 m. (h) *Ammobaculites wenonahae*, Wunstorf Wu 2010/1, 19.05 m. (i) *Bulbobaculites problematicus*, Wunstorf Wu 2010/1, 24.75 m. (j) *Spiroplectammina navarroana*, Wunstorf Wu 2010/4, 48.20 m. (k) *Spiroplectinella cretosa*, Baddeckenstedt section, 2.00 m. (l) *Bicazammina lagenaria*, Söhlde section, 24.00 m. (m) *Parvigenerina* sp. 3, Wunstorf Wu 2010/4, 48.95 m. (n) *Eobigenerina kuhnti*, Söhlde section, 9.50 m. (o) *Eobigenerina variabilis*, Söhlde section, 1.50 m. (p) *Rectogerochammina eugubina*, Wunstorf Wu 2010/4, 48.95 m. (q) *Gerochammina stanislawi*, Wunstorf Wu 2010/4, 53.15 m. (r) *Plectina cenomana*, Wunstorf Wu 2010/3, 45.00 m. (s) *Plectina mariae*, Wunstorf Wu 2010/3, 84.00 m.

Pseudonodosinella troyeri (Tappan, 1960)

Figure 3.7d

1960. *Reophax troyeri* Tappan, p. 291, pl. 1, figs. 10–12.

1995. *Pseudonodosinella troyeri* (Tappan); Geroch and Kaminski, p. 118, pl. 1, figs. 1,2,4–17.

Material. 35 specimens from the Baddeckenstedt section, nine specimens from the Söhlde section, 20 specimens from the Wunstorf Wu2010/1 core, 24 specimens from the Wunstorf Wu2010/3 core, and ten specimens from the Wunstorf Wu2010/4 core.

Occurrence. Common to very rare in the Cenomanian. Last occurrence in the uppermost Cenomanian at Söhlde, and lowermost Turonian at Wunstorf.

Suborder LITUOLINA Lankester 1885

Superfamily LITUOLIDEA Blainville 1827

Family HAPLOPHRAGMOIDIDAE Maync 1952

Genus *Haplophragmoides* Cushman 1910

Haplophragmoides aff. *bubiki* Setoyama, Kaminski and Tyszka 2008

2008. *Haplophragmoides bubiki*, Setoyama, Kaminski and Tyska p. 273, pl. 6, figs. 12a-b., pl. 7, figs. 9a–c, 10a–c.

Material. 20 specimens from the Söhlde section, 17 specimens from the Wunstorf Wu2010/1 core, five specimens from the Wunstorf Wu2010/3 core, and 31 specimens from the Wunstorf Wu2010/4 core.

Remarks. This species was subsequently recorded from the Campanian to Eocene (Setoyama et al. 2011). Our findings extend the known stratigraphic range to early Cenomanian.

Occurrence. Lower Cenomanian to middle Turonian of Wunstorf. Uppermost Cenomanian (*plenus* Bed) to upper Turonian of Söhlde. Very rare.

Haplophragmoides eggeri Cushman 1926

1926. *Haplophragmoides eggeri* Cushman p. 583, pl. 15, fig. 1a, b.

2005. *Haplophragmoides eggeri* Cushman; Kaminski and Gradstein, p. 342, pl. 75, figs. 1–6.

Material. 37 specimens from the Baddeckenstedt section, 20 specimens from the Söhlde section, 20 specimens from the Wunstorf Wu2010/1 core, 30 specimens from the Wunstorf Wu2010/3 core, and 19 specimens from the Wunstorf Wu2010/4 core.

Occurrence. Rare to very rare.

Haplophragmoides pervagatus Krasheninnikov, 1973

1973. *Haplophragmoides pervagatus* Krasheninnikov, p. 215, pl. 1, fig. 7.

Material. Two specimens from the Wu2010/1 core, four specimens from the Wunstorf Wu2010/3 core.

Occurrence. Very rare in the lower Cenomanian at Wunstorf.

Haplophragmoides porrectus Maslakova, 1955

1955. *Haplophragmoides porrectus* Maslakova, p. 47, pl. 3, figs. 5–6.

1988. *Haplophragmoides porrectus* Maslakova; Kaminski et al., p. 189, pl. 5, figs. 7–8.

2005. *Haplophragmoides porrectus* Maslakova; Kaminski and Gradstein, p. 353, pl. 79, figs. 1a–6.

Material. Two specimens from the Wunstorf Wu2010/4 core.

Occurrence. Very rare in the middle Turonian at Wunstorf.

Haplophragmoides stomatus (Grzybowski, 1898)

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

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

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

Material. Five specimens from the Baddeckenstedt section, four specimens from the Söhlde section, two specimens from the Wunstorf Wu2010/1 core, five specimens from the Wunstorf Wu2010/3 core, and seven specimens from the Wunstorf Wu2010/4 core.

Occurrence. Very rare.

Haplophragmoides suborbicularis (Grzybowski 1896)

Figure 3.6e

1896. *Cyclammina suborbicularis* Grzybowski p. 63, pl. 9, figs. 5–6.

1988. *Haplophragmoides suborbicularis* (Grzybowski); Kaminski et al., p. 189, pl. 5, figs. 12–13.

Material. 22 specimens from the Baddeckenstedt section, four specimens from the Söhlde section, 13 specimens from the Wunstorf Wu2010/1 core, 60 specimens from the Wunstorf Wu2010/3 core, and 32 specimens from the Wunstorf Wu2010/4 core.

Occurrence. Rare.

Haplophragmoides walteri (Grzybowski, 1898)

Figure 3.7f

1898 *Trochammina walteri* p. 290, pl. 11, fig. 31.

1993. *Haplophragmoides walteri* Grzybowski; Kaminski and Geroch, 1993, p. 263, pl. 10, figs. 3a–7c, p. 309, pl. 10, figs. 3a–c.

2005. *Haplophragmoides walteri* Grzybowski; Kaminski and Gradstein, 2005, p. 365, pl. 83, figs. 1–6.

Material. 15 specimens from the Baddeckenstedt section, 17 specimens from the Söhlde section, 46 specimens from the Wunstorf Wu2010/1 core, 53 specimens from the Wunstorf Wu2010/3 core, and 27 specimens from the Wunstorf Wu2010/4 core.

Occurrence. Common to rare in the Cenomanian at Wunstorf, otherwise very rare.

Haplophragmoides spp.

Material. Two specimens from the Baddeckenstedt section, 27 specimens from the Söhlde section, 17 specimens from the Wunstorf Wu2010/1 core, 21 specimens from the Wunstorf Wu2010/3 core, and 15 specimens from the Wunstorf Wu2010/4 core.

Occurrence. Rare to very rare.

Family LITUOLIDAE Blainville 1827
Subfamily AMMOMARGINULININAE Podobina 1978
Genus *Ammobaculites* Cushman 1910

Ammobaculites agglutinans (d'Orbigny, 1846)

Figure 3.7g

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. 45 specimens from the Baddeckenstedt section, 202 specimens from the Söhlde section, six specimens from the Wunstorf Wu2010/1 core, 16 specimens from the Wunstorf Wu2010/3 core, and six specimens from the Wunstorf Wu2010/4 core.

Occurrence. Abundant to common in the Turonian of Söhlde, otherwise common to very rare.

Ammobaculites wenonahae Tappan, 1960

Figure 3.7h

1960. *Ammobaculites wenonahae* Tappan, p. 291, pl. 1, figs. 3¬¬–6.

2010. *Ammobaculites wenonahae* Tappan; Patterson et al., p. 12, figs. 6.18–6.21.

Material. Four specimens from the Wunstorf Wu2010/1 core, six specimens from the Wunstorf Wu2010/3 core, and three specimens from the Wunstorf Wu2010/4 core.

Occurrence. Very rare.

Ammobaculites sp.

Material. Two specimens from the Söhlde section, 12 specimens from the Wunstorf Wu2010/1 core, three specimens from the Wunstorf Wu2010/3 core, and three specimens from the Wunstorf Wu2010/4 core.

Remarks. Mainly fragmented specimens not further determined.

Occurrence. Very rare.

Family AMMOBACULINIDAE Saidova 1981
Subfamily AMMOBACULININAE Saidova 1981
Genus *Bulbobaculites* Maync 1952

Bulbobaculites problematicus (Neagu, 1962)
Figure 3.7i
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.
2011. *Bulbobaculites problematicus* (Neagu); Kaminski et al., p. 92, pl. 5, figs. 5–7.

Material. Three specimens from the Baddeckenstedt section, 746 specimens from the Söhlde section, 270 specimens from the Wunstorf Wu2010/1 core, 22 specimens from the Wunstorf Wu2010/3 core, and 969 specimens from the Wunstorf Wu2010/4 core.

Remarks. *Bulbobaculites problematicus* has a wide range of morphological variety (Kuhnt and Kaminski, 1990). It can be used in the Atlantic realm as a post-Cenomanian marker but already appears in the Cenomanian in the Tethys realm of the Carpathians (Neagu, 1962; Huss, 1966; Geroch and Novak, 1984). Tethyan post-Cenomanian assemblages with increased *B.*

problematicus are documented by Bąk (2000). In Wunstorf, this species is noted already in the Albian.

Occurrence. Very abundant at the Cenomanian–Turonian boundary interval, very abundant to common in the Turonian at Söhlde, common to rare in the Cenomanian at Wunstorf, very rare at Baddeckenstedt.

Family PLACOPSILINIDAE Rhumbler 1913
Subfamily PLACOPSILININAE Rhumbler 1913
Genus *Placopsilina* d'Orbigny 1850

Placopsilina cenomana d'Orbignyi 1850
1850. *Placopsilina cenomana* d'Orbignyi, vol. 2, p. 185, n. 758.
1993. *Placopsilina cenomana* d'Orbignyi; Schmidt and Jäger, p. 153, Fig. 1.
Material. Two specimens from the Baddeckenstedt section.
Occurrence. Very rare.

Placopsilina sp.
Material. One specimen from the Söhlde section.
Occurrence. Very rare.

Genus *Subbdelloidina* Frentzen 1944

Subbdelloidina haeusleri Frentzen 1944
1944. *Subbdelloidina haeusleri* Frentzen, p. 332, pl. 18, figs. 12–22.
1987. *Subbdelloidina haeusleri* Frentzen; Leary, p. 54, pl. 1, fig. 13.
Material. 33 specimens from the Baddeckenstedt section.
Occurrence. Abundant at the sponge beds in the lower Cenomanian at Baddeckenstedt, otherwise rare to very rare at Baddeckenstedt.

Superfamily RECURVOIDOIDEA Alekseychik-Mitskevich 1973

Family AMMOSPHAEROIDINIDAE Cushman 1927

Subfamily AMMOSPHAEROIDININAE Cushman 1927

Genus *Ammosphaeroidina* Cushman 1910

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.

2011. *Ammosphaeroidina pseudopauciloculata* (Mjatliuk); Kaminski et al., p. 91, pl. 4, fig. 16.

Material. 38 specimens from the Söhlde section.

Occurrence. Common to very rare in the middle and upper Turonian at Söhlde.

Genus *Praecystammina* Krasheninnikov 1973

Praecystammina sp.

Material. Two specimens from the Söhlde section.

Occurrence. Very rare in the middle Turonian of Söhlde.

Subfamily RECURVOIDINAE Alekseychik-Mitskevich 1973

Genus *Recurvoides* Earland 1934

Recurvoides sp.

Material. Ten specimens from the Baddeckenstedt section, and five specimens from the Söhlde section.

Occurrence. Very rare.

Suborder SPIROPLECTAMMININA Mikhalevich 1992

Superfamily SPIROPLECTAMMINOIDEA Cushman 1927

Family SPIROPLECTAMMINIDAE Cushman 1927

Subfamily SPIROPLECTAMMININAE Cushman 1927

Genus *Spiroplectammina* Cushman 1927

Spiroplectammina navarroana Cushman, 1932

Figure 3.7j

1932. *Spiroplectammina navarroana* Cushman, p. 96, pl. 11, fig. 14.

1989. *Spiroplectammina navarroana* Cushman; Gradstein and Kaminski, p. 83, pl. 9, figs. 1a–12.

2005. *Spiroplectammina navarroana* Cushman; Kaminski and Gradstein, p. 426, pl. 103, figs. 1a–12.

2017. *Spiroplectammina navarroana* Cushman; Setoyama et al., p. 196, pl. 2, fig. 12.

Material. 70 specimens from the Baddeckenstedt section, 338 specimens from the Söhlde section, eight specimens from the Wunstorf Wu2010/3 core, and 285 specimens from the Wunstorf Wu2010/4 core.

Occurrence. First occurrence in the lower Cenomanian above The Rib. Very abundant in the Cenomanian–Turonian boundary interval at Wunstorf and in the upper Turonian at Söhlde, abundant to common in the upper Cenomanian to Turonian, very rare in the lower to middle Cenomanian.

Spiroplectammina sp.

Material. 8 specimens from the Söhlde section.

Occurrence. Very rare.

Genus *Spiroplectinella* Kisel’man 1972

Spiroplectinella cretosa (Cushman, 1932)

Figure 3.7k

1932. *Spiroplectammina laevis* (Roemer) var. cretosa Cushman, pl. 11, fig. 3.

1972. *Spiroplectammina cretosa* Cushman; Hanzlíková, pl. 10. Fig. 9.

1997. *Spiroplectinella cretosa* (Cushman); Holbourn and Kaminski, p. 136, pl. 2, figs. 4–7.

Material. 29 specimens from the Baddeckenstedt section, four specimens from the Wunstorf Wu2010/1 core, and two specimens from the Wunstorf Wu2010/3 core.

Occurrence. Rare to very rare in the lower and middle Cenomanian of Lower Saxony.

Family TEXTULARIOPSIDAE Loeblich and Tappan 1982

Genus *Bicazammina* Neagu and Neagu 1995

Bicazammina lagenaria (Krasheninnikov, 1974)

Figure 3.7l

1974. *Pseudobolivina lagenaria* Krasheninnikov, p. 639, pl. 5, figs. 1a–b, 2c.

1990. *Pseudobolivina lagenaria* Krasheninnikov; Kuhnt, p. 322, pl. 6, figs. 3¬–6.

2008. *Bicazammina lagenaria* (Krasheninnikov); Cetean et al., p. 24, tab. 1, pl. 1, fig. 17.

2011. *Bicazammina lagenaria* (Krasheninnikov); Kaminski et al, p. 92, pl. 5, figs. 10–11.

Material. Four specimens from the Baddeckenstedt section, 29 specimens from the Söhlde section, two specimens from the Wunstorf Wu2010/3 core, and 40 specimens from the Wunstorf Wu2010/4 core.

Occurrence. Rare to very rare.

Genus *Rashnovammina* Neagu and Neagu 1995

Rashnovammina munda (Krasheninnikov, 1974)

1974. *Pseudobolivina munda* Krasheninnikov, p. 210, pl. 2, figs. 10, 11.

1990. *Pseudobolivina* sp. cf. *munda* (Krasheninnikov); Kuhnt, p. 324, pl. 6, figs. 1, 2.

2008. *Rashnovammina munda* (Krasheninnikov); Cetean et al., p. 138, pl. 1, fig. 14.

2011. *Rashnovammina munda* (Krasheninnikov); Kaminski et al., p. 93, pl. 5, fig. 16.

Material. One specimen from the Wunstorf Wu2010/3 core, and one specimen from the Wunstorf Wu2010/4 core.

Occurrence. Very rare.

Genus *Textulariopsis* Banner and Pereira 1981

Textulariopsis rioensis (Carsey, 1926)

1926. *Textularia rioensis* Carsey, p. 24, pl. 7, fig. 2.

1982. *Textulariopsis rioensis* (Carsey), Loeblich and Tappan, p. 67, pl. 2, figs. 26–28.

Material. One specimen from the Baddeckenstedt, and three specimens from the Wunstorf Wu2010/1 core.

Occurrence. Very rare.

Textulariopsis sp.

Material. One specimen from the Söhlde section.

Occurrence. Very rare.

Family PSEUDOBOLIVINIDAE Wiesner 1931

Genus *Parvigenerina* Vella 1957

Parvigenerina sp. 3 (Kuhnt 1990)

Figure 3.7m

1990. *Pseudobolivina* sp. 3 Kuhnt, p. 324, pl. 6, fig. 5.

2008. *Parvigenerina* sp. 3 (Kuhnt); Cetean et al., p. 23, pl. 1, figs. 20, 21.

2011. *Parvigenerina* sp. 3 (Kuhnt); Kaminski et al., p. 93, pl. 5, figs. 13–14.

Material. Two specimens from the Baddeckenstedt section, 93 specimens from the Söhlde section, seven specimens from the Wunstorf Wu2010/3 core, and 95 specimens from the Wunstorf Wu2010/4 core.

Occurrence. Common to rare in the middle Turonian, otherwise rare to very rare.

Suborder TROCHAMMININA Saidova 1981

Superfamily TROCHAMMINOIDEA Schwager 1877

Family TROCHAMMINIDAE Schwager 1877

Subfamily TROCHAMMININAE Schwager 1877

Genus *Trochammina* Parker and Jones 1859

Trochammina spp.

Material. 39 specimens from the Baddeckenstedt section, 124 specimens from the Söhlde section, 20 specimens from the Wunstorf Wu2010/1 core, 42 specimens from the Wunstorf Wu2010/3 core, and 35 specimens from the Wunstorf Wu2010/4 core.

Occurrence. Common to very rare.

Suborder VERNEUILININA Mikhalevich and Kaminski 2004
Superfamily VERNEUILINOIDEA Cushman 1911
Family PROLIXOPLECTIDAE Loeblich and Tappan 1985
Genus *Eobigenerina* Cetean, Setoyama, Kaminski, Neagu, Bubík, Filipescu and Tyszka 2008

Eobigenerina kuhnti Cetean, Setoyama, Kaminski, Neagu, Bubík, Filipescu and Tyszka 2008

Figure 3.7n

2008. *Eobigenerina kuhnti* Cetean, Setoyama, Kaminski, Neagu, Bubík, Filipescu and Tyszka, p. 22, pl. 1, figs. 13–16.

Material. One specimen from the Baddeckenstedt section, 17 specimens from the Söhlde section, two specimens from the Wunstorf Wu2010/3 core, and five specimens from the Wunstorf Wu2010/4 core.

Occurrence. Very rare.

Eobigenerina variabilis (Vašíček, 1947)

Figure 3.7o

1947. *Bigenerina variabilis* Vašíček, p. 246, pl. 1, figs. 10–12.
1970. *Pseudobolivina variabilis* (Vašíček); Neagu, p. 41, pl. 5, figs. 13–16.
2008. *Eobigenerina variabilis* (Vašíček); Cetean et al., p. 6–7.
2011. *Eobigenerina variabilis* (Vašíček); Kaminski et al., p. 92, pl. 5, figs. 12a–b.

Material. 11 specimens from the Baddeckenstedt section, 101 specimens from the Söhlde section, five specimens from the Wunstorf Wu2010/1 core, six specimens from the Wunstorf Wu2010/3 core, and 278 specimens from the Wunstorf Wu2010/4 core.

Occurrence. Very abundant in the Cenomanian–Turonian boundary interval, abundant to rare in the Turonian, very rare in the Cenomanian.

Genus *Rectogerochammina* Kaminski, Cetean and Neagu 2010

Rectogerochammina eugubina Kaminski, Cetean and Neagu 2010
Figure 3.7p
2010. *Rectogerochammina eugubina* Kaminski, Cetean and Neagu, p. 122, textfigs. 1–2.
2011. *Rectogerochammina eugubina* Kaminski, Cetean and Neagu; Kaminski et al., p. 94, pl. 5, figs. 17a–b.

Material. 55 specimens from the Söhlde section, one specimen from the Wunstorf Wu2010/1 core, one specimen from the Wunstorf Wu2010/3 core, and 80 specimens from the Wunstorf Wu2010/4 core.

Occurrence. Common to rare in the Turonian, very rare in the Cenomanian, absent in Baddeckenstedt.

Genus *Gerochammina* Neagu 1990

Gerochammina stanislawi Neagu, 1990
Figure 3.7q
1990. *Gerochammina stanislawi* Neagu, p. 253, pl. 1, figs 1–26.

Material. 56 specimens from the Baddeckenstedt section, 168 specimens from the Söhlde section, eight specimens from the Wunstorf Wu2010/1 core, ten specimens from the Wunstorf Wu2010/3 core, and 194 specimens from the Wunstorf Wu2010/4 core.

Occurrence. Common to very rare in the Cenomanian up to lower Turonian, abundant to rare in the middle and upper Turonian.

Genus *Kadriayina* Al-Najdi 1975

Kadriayina gradata (Berthelin, 1880)

Figure 3.7t

1880. *Gaudryina gradata* Berthelin, p. 24, pl. 1, figs. 6a–c.

1972. *Dorothia gradata* (Berthelin); Gawor-Biedowa, p. 29, pl. 2, figs. 7a–b.

1997. *Kadriayina gradata* (Berthelin); Holbourn and Kaminski, p. 51.

Material. 86 specimens from the Baddeckenstedt section, four specimens from the Söhlde section, 168 specimens from the Wunstorf Wu2010/1 core, 149 specimens from the Wunstorf Wu2010/3 core, and 12 specimens from the Wunstorf Wu2010/4 core.

Occurrence. Uppermost Albian and Cenomanian, abundant to common in the Cenomanian at Wunstorf, common to rare at Baddeckenstedt.

Genus *Plectina* Marsson 1878

Plectina cenomana Carter and Hart, 1977

Figure 3.7r

1977. *Plectina cenomana* Carter and Hart, p. 12, pl. 2, fig. 9.

1980. *Plectina cenomana* Carter and Hart; Frieg, p. 235, text-fig. 2.4.

Material. 345 specimens from the Baddeckenstedt section, 15 specimens from the Söhlde section, 15 specimens from the Wunstorf Wu2010/1 core, 127 specimens from the Wunstorf Wu2010/3 core, and 17 specimens from the Wunstorf Wu2010/4 core.

Occurrence. Abundant to common in the lower Cenomanian from the *crippsi* Event onwards to the upper Cenomanian below OAE2.

Plectina mariae (Franke, 1928)

Figure 3.7s

1928. *Gaudryina ruthenica* Reuss f. *mariae* Franke, p. 146, pl. 13, figs. 15a, b.

1937. *Plectina ruthenica* Reuss var. *mariae* (Franke); Cushman, p. 106, pl. 11, fig. 15.

1977. *Plectina mariae* (Franke); Carter and Hart, p. 13, pl. 2, fig. 8.

1980. *Plectina mariae* (Franke); Frieg, text-figs. 2.5–6.

Material. 102 specimens from the Baddeckenstedt section, two specimens from the Söhlde section, one specimen from the Wunstorf Wu2010/1 core, 15 specimens from the Wunstorf Wu2010/3 core, and eight specimens from the Wunstorf Wu2010/4 core.

Occurrence. Common to very rare in the lower Cenomanian from the *crippsi* Event onwards to the upper Cenomanian below OAE2.

Family TRITAXIIDAE Plotnikova 1979

Genus *Tritaxia* Reuss 1860

Tritaxia gaultina (Morozowa, 1948)

Figure 3.8a

1948. *Clavulina gaultina* Morozowa, p. 36, pl. 1, fig. 4.

1970. *Tritaxia gaultina* (Morozowa); Neagu.

Material. 123 specimens from the Wunstorf Wu2010/1 core, and one specimen from the Wunstorf Wu2010/4 core.

Occurrence. Abundant to common in the lower Cenomanian at Wunstorf between the *crippsi* Event and The Rib, otherwise very rare.

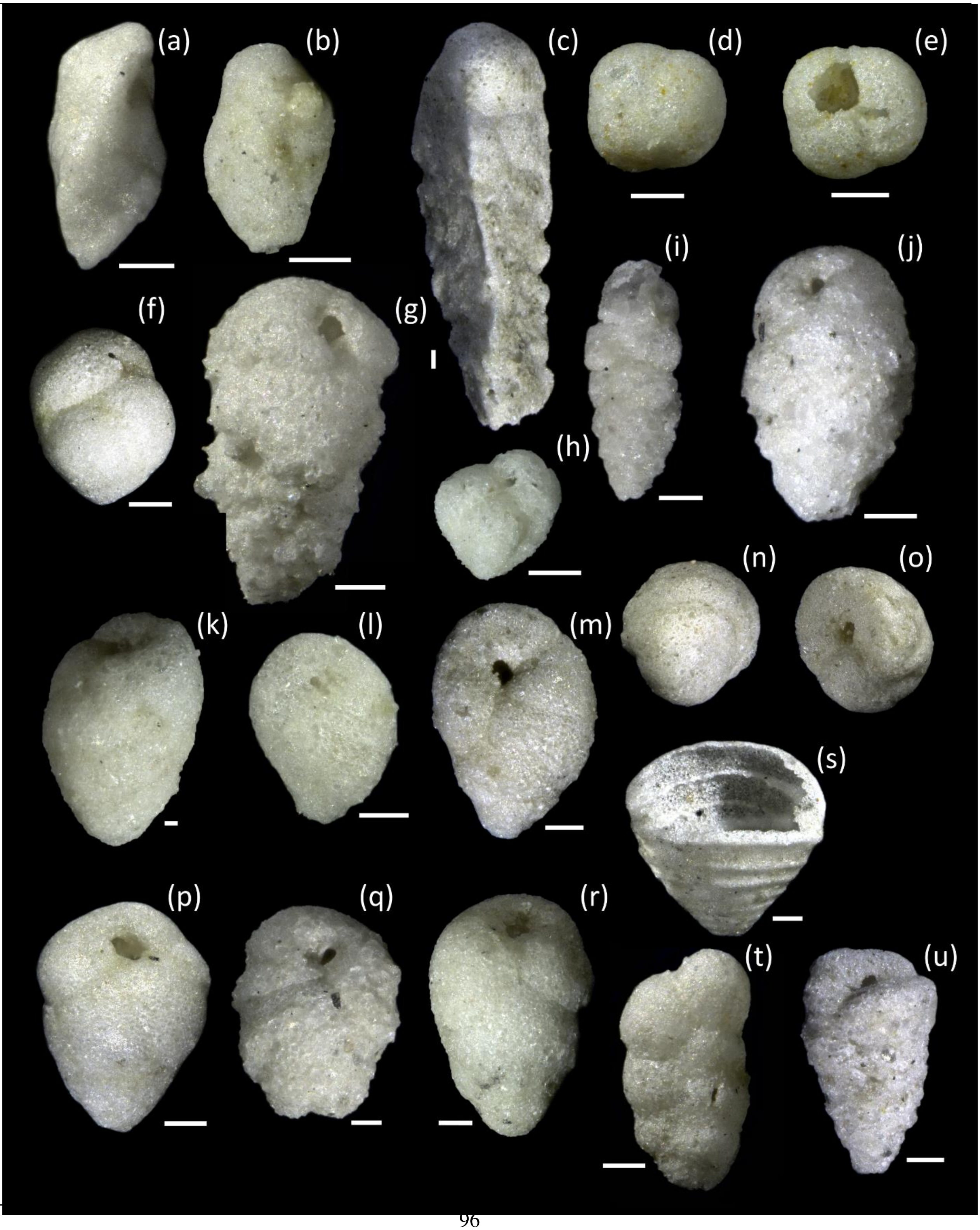

(a)
(b)
(c)
(d)
(e)
(f)
(g)
(h)
(i)
(j)
(k)
(l)
(m)
(n)
(o)
(p)
(q)
(r)
(s)
(t)
(u)

Figure 3.8. Late Albian to Turonian agglutinated foraminifers from the Lower Saxonian Cretaceous, scale bars are 100 µm. (a) *Tritaxia gaultina*, Wunstorf Wu 2010/1, 19.05 m. (b) *Tritaxia tricarinata*, Wunstorf Wu 2010/1, 19.05 m. (c) *Tritaxia macfadyeni*, Wunstorf Wu 2010/1, 34.10 m. (d–e) *Eggerellina brevis*, Baddeckenstedt section, 19.30 m. (f) *Eggerellina mariae*, Wunstorf Wu 2010/3, 30.15 m. (g) *Flourensina intermedia*, Wunstorf Wu 2010/1, 54.80 m. (h) *Gaudryina* sp. 1, Baddeckenstedt section, 39.00 m. (i) *Verneuilinoides* sp., Wunstorf Wu 2010/4, 48.95 m. (j) *Vialovella frankei,* Wunstorf Wu 2010/1, 15.20 m. (k) *Arenobulimina bochumensis*, Baddeckenstedt section, 9.00 m. (l) *Arenobulimina preslii*, Wunstorf Wu 2010/4, 43.30 m. (m) *Arenobulimina truncata*, Wunstorf Wu 2010/4, 43.30 m. (n–o) *Ataxophragmium depressum*, Wunstorf Wu 2010/4, 58.60 m. (p) *Hagenowella elevata*, Wunstorf Wu 2010/4, 58.60 m. (q) *Voloshinoides advenus*, Wunstorf Wu 2010/1, 29.25 m. (r) *Voloshinoides anglicus*, Baddeckenstedt section, 7.00 m. (s) *Pseudotextulariella cretosa*, Wunstorf Wu 2010/1, 19.05 m. (t) *Kadriayina gradata*, Wunstorf Wu 2010/3, 66.05 m. (u) *Marssonella ozawai*, Wunstorf Wu 2010/1, 15.20 m.

Tritaxia macfadyeni Cushman, 1936

Figure 3.8b

1936. *Tritaxia macfadyeni* Cushman, p. 3, pl. 1m figs. 6a, b.

Material. 39 specimens from the Wunstorf Wu2010/1 core, and three specimens from the Wunstorf Wu2010/4 core.

Remarks. Always smaller than *T. tricarinata* and with a much more rounded and smooth cross section.

Occurrence. Mass-occurrence (abundant) in the lower Cenomanian of Wunstorf around the *crippsi* Event, otherwise very rare.

Tritaxia tricarinata (Reuss 1845)

Figure 3.8c

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, p. 34–35, pl. 11, fig. 1.

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

1980. *Tritaxia tricarinata* (Reuss); Frieg, p. 234.

Material. 722 specimens from the Baddeckenstedt section, 14 specimens from the Söhlde section, 387 specimens from the Wunstorf Wu2010/1 core, 371 specimens from the Wunstorf Wu2010/3 core, and 86 specimens from the Wunstorf Wu2010/4 core.

Remarks. Frieg (1980) showed a clear transition of the suture angles between *Tritaxia tricarinata* and *T. pyramidata* (Reuss). *T. pyramidata* must be seen as a junior synonym.

Occurrence. Very abundant to common in the Cenomanian, abundant to very rare in the Turonian at Wunstorf, rare to very rare at Söhlde.

Family VERNEUILINIDAE Cushman 1911
Subfamily VERNEUILINOIDINAE Suleymanov 1973
Genus *Eggerellina* Marie 1941

Eggerellina brevis (d'Orbignyi, 1840)
Figure 3.8d–e
1840. *Bulimina brevis* d'Orbignyi, p. 41, pl. 4, figs. 13–14.
1972. *Eggerellina brevis* (d'Orbignyi); Voloshina, p. 92, pl. 9, figs. 2–3; pl. 21, fig. 2.

Material. 275 specimens from the Baddeckenstedt section, 92 specimens from the Söhlde section, 59 specimens from the Wunstorf Wu2010/1 core, 62 specimens from the Wunstorf Wu2010/3 core, and 46 specimens from the Wunstorf Wu2010/4 core.

Occurrence. Common to very rare at Wunstorf, abundant to common at Baddeckenstedt, common to very rare at Söhlde.

Eggerellina mariae Ten Dam, 1950
Figure 3.8f
1950. *Eggerellina mariae* Ten Dam, p. 15, pl. 1, figs. 17a–e.
1975. *Eggerellina mariae* Ten Dam; Magniez-Jannin, p. 94, pl. 6, figs. 12–21.

Material. 282 specimens from the Baddeckenstedt section, 51 specimens from the Söhlde section, 121 specimens from the Wunstorf Wu2010/1 core, 75 specimens from the Wunstorf Wu2010/3 core, and 14 specimens from the Wunstorf Wu2010/4 core.

Occurrence. Abundant to common in the Cenomanian, rare to very rare in the Turonian.

Genus *Flourensina* Marie 1938

Flourensina intermedia Ten Dam, 1950

Figure 3.8g

1950. *Flourensina intermedia* Ten Dam, p. 15, pl. 1, fig. 16.

Material. 35 specimens from the Baddeckenstedt section, 253 specimens from the Wunstorf Wu2010/1 core, 213 specimens from the Wunstorf Wu2010/3 core, and one specimen from the Wunstorf Wu2010/4 core.

Remarks. The systematic position, occurrence, and palaeogeographical distribution of *Flourensina intermedia* is intensively discussed in Frieg and Kemper (1989). Like observed in the Konrad 101 core, and outcrops in the Münsterland Basin, *Flourensina intermedia* occurs frequently over the whole Cenomanian in Baddeckenstedt.

Occurrence. Abundant to common in the uppermost Albian up to the upper Cenomanian until below the Facies Change at Wunstorf, common to very rare in the Cenomanian at Baddeckenstedt.

Genus *Gaudryinopsis* Podobina 1975

Gaudryinopsis filiformis (Berthelin, 1880)

1880. *Gaudryina filiformis* Berthelin, p. 25, pl. 1, fig. 8a–d.

1937. *Dorothia filiformis* (Berthelin); Cushman, p. 73, pl. 8, figs. 1–2.

1993. *Gaudryinopsis filiformis* (Berthelin); Haig and Lynch, p. 346.

Material. 34 specimens from the Baddeckenstedt section, 13 specimens from the Söhlde section, 25 specimens from the Wunstorf Wu2010/1 core, and seven specimens from the Wunstorf Wu2010/3 core.

Occurrence. Rare to very rare in the uppermost Albian to upper Cenomanian.

Genus *Verneuilinoides* Loeblich and Tappan 1949

Verneuilinoides spp.

Figure 3.8i

Material. 35 specimens from the Baddeckenstedt section, 92 specimens from the Söhlde section, three specimens from the Wunstorf Wu2010/3 core, and 48 specimens from the Wunstorf Wu2010/4 core.

Occurrence. Common to very rare.

Genus *Vialovella* Voloshina 1972

Vialovella frankei (Cushman, 1936)

Figure 3.8j

1936. *Arenobulimina frankei* Cushman, p. 27, pl. 4, figs. 5a–b.

1969. *Arenobulimina frankei* Cushman; Gawor-Biedowa, p. 84, pl. 5, figs. 4, 5, pl. 7, figs. 6–8.

1972. *Vialovella frankei* (Cushman); Voloshina, p. 87, pl. 8, fig. 8.

1977. *Arenobulimina frankei* Cushman; Carter and Hart, p. 15, pl. 1, fig. 1, pl. 2, fig. 5.

1982. *Vialovella praefrankei* (Cushman); Frieg and Price, p. 47, pl. 2.1., figs. a–c.

1989. *Vialovella frankei* (Cushman); Frieg and Kemper, p. 104, pl. 15, figs. 12–20.

Material. 443 specimens from the Baddeckenstedt section, 38 specimens from the Söhlde section, 297 specimens from the Wunstorf Wu2010/1 core, 269 specimens from the Wunstorf Wu2010/3 core, and 19 specimens from the Wunstorf Wu2010/4 core.

Remarks. Initially described as *Arenobulimina frankei* by Cushman (1936), Frieg and Price (1982) and Frieg and Kemper (1989) described the clearly triserial chamber arrangement of this species. Therefore, we follow their classification as *Vialovella frankei*.

Occurrence. Very abundant to common in the uppermost Albian up to the upper Cenomanian. Last occurrence below the Facies Change at Söhlde and Baddeckenstedt, and in the *plenus* Bed at Wunstorf.

Family REOPHACELLIDAE Mikhalevich and Kaminski 2004

Genus *Gaudryina* d'Orbignyi 1839

Gaudryina sp.1

Figure 3.8h

Material. 108 specimens from the Baddeckenstedt section, seven specimens from the Söhlde section, 24 specimens from the Wunstorf Wu2010/1 core, 66 specimens from the Wunstorf Wu2010/3 core, and five specimens from the Wunstorf Wu2010/4 core.

Remarks. Test free, elongate, triserial and triangular in section, biserial part reduced, finely to medium grained agglutinated, chambers are inflated, sutures commonly distinct.

Occurrence. Common to rare in the Cenomanian until below the Facies Change.

Genus *Uvigerinammina* Majzon 1943

Uvigerinammina jankoi Majzon, 1943

1943. *Uvigerinammina jankoi* Majzon, p. 158, pl. 2, fig. 15a, b.

1995. *Uvigerinammina jankoi* Majzon; Bubík, p. 89, pl. 13, fig. 13.

2011. *Uvigerinammina jankoi* Majzon; Kaminski et al., p. 94, pl. 5, fig. 19.

2017. *Uvigerinammina jankoi* Majzon; Setoyama et al., p. 197, pl. 4, figs. 8–9.

Material. 17 specimens from the Söhlde section.

Occurrence. Rare to very rare in the middle and upper Turonian of Söhlde.

Subfamily SPIROPLECTINATINAE Cushman 1928

Genus *Spiroplectinata* Cushman 1927

Spiroplectinata bettenstaedti Grabert, 1959

1959. *Spiroplectinata bettenstaedti* Grabert, p. 15, pl. 1, figs. 14–15; pl. 2, figs. 42–45; pl. 3, figs. 89–90.

Material. One specimen from the Wunstorf Wu2010/3 core.

Occurrence. Very rare in the lower Cenomanian.

Subfamily VERNEUILININAE Cushman 1911

Genus *Gaudryinella* Plummer 1931

Gaudryinella irregularis Tappan, 1943

1943. *Gaudryinella irregularis* Tappan, p. 493, pl. 78, figs. 22–24.

1990. *Gaudryinella irregularis* Tappan; Weidich, p. 104, pl. 9, figs. 10–11; pl. 35, fig. 7.

Material. 39 specimens from the Söhlde section.

Occurrence. Rare to very rare in the middle and upper Turonian of Söhlde.

Order LOFTUSIIDA Kaminski and Mikhalevich 2004
Suborder ATAXOPHRAGMIINA Fursenko 1958
Superfamily ATAXOPHRAGMIOIDEA Schwager 1877
Family ATAXOPHRAGMIIDAE Schwager 1877
Subfamily ATAXOPHRAGMIINAE Schwager 1877
Genus *Arenobulimina* Cushman 1927

Arenobulimina barnardi Frieg and Price, 1982

1982. *Arenobulimina barnardi* Frieg and Price, p. 58, pl. 2.2, fig. f.

1989. *Arenobulimina (Pasternakia) barnardi* (Frieg and Price); Frieg and Kemper, p. 90, pl. 2, figs. 1–5.

Material. 81 specimens from the Baddeckenstedt section, 15 specimens from the Söhlde section, 121 specimens from the Wunstorf Wu2010/1 core, 75 specimens from the Wunstorf Wu2010/3 core, and nine specimens from the Wunstorf Wu2010/4 core.

Occurrence. Common in the uppermost Albian and lower Cenomanian of Wunstorf, otherwise rare to very rare.

Arenobulimina bochumensis Frieg, 1980

Figure 3.8k

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

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

Material. 16 specimens from the Baddeckenstedt section, 75 specimens from the Söhlde section, 16 specimens from the Wunstorf Wu2010/1 core, 25 specimens from the Wunstorf Wu2010/3 core, and 162 specimens from the Wunstorf Wu2010/4 core.

Occurrence. Common to rare in the Turonian, very rare in the Cenomanian.

Arenobulimina improcera Voloshina, 1972

1972. *Arenobulimina improcera* Voloshina, p.71, pl. 4, fig. 2.

1982. *Arenobulimina (Harena) improcera* Voloshina; Frieg and Price, p. 57, pl. 2.1, fig. j.

Material. 18 specimens from the Wunstorf Wu2010/3 core.

Occurrence. Very rare in the lower Cenomanian of Wunstorf above The Rib.

Arenobulimina preslii (Reuss, 1845)

Figure 3.8l

1845. *Bulimina preslii* Reuss, p. 38, pl. 13, fig. 72.

1972. *Arenobulimina preslii* (Reuss); Voloshina, p. 59, pl. 1, figs. 2–3.

1982. *A. (Arenobulimina) preslii* (Reuss); Frieg and Price, p. 52, pl. 2.1., figs. d–h

1989. *A. (Arenobulimina) preslii* (Reuss); Frieg and Kemper, p. 89, pl. 1, figs. 1–22.

Material. 135 specimens from the Baddeckenstedt section, 75 specimens from the Söhlde section, 79 specimens from the Wunstorf Wu2010/1 core, 75 specimens from the Wunstorf Wu2010/3 core, and 345 specimens from the Wunstorf Wu2010/4 core.

Occurrence. Very abundant to common in the Turonian at Wunstorf, otherwise common to very rare. First occurrence between *ultimus/Aucellina* and *crippsi* events.

Arenobulimina truncata (Reuss, 1844)

Figure 3.8m

1844. *Bulimina truncata* Reuss, p. 215, pl. 8, fig. 73.

1937. *Arenobulimina truncata* (Reuss); Cushman, p. 40, pl. 4, figs. 15, 16.

Material. 217 specimens from the Baddeckenstedt section, 132 specimens from the Söhlde section, 314 specimens from the Wunstorf Wu2010/1 core, 162 specimens from the Wunstorf Wu2010/3 core, and 227 specimens from the Wunstorf Wu2010/4 core.

Occurrence. Abundant to common, absent at the Cenomanian–Turonian boundary interval.

Arenobulimina spp.

Material. 113 specimens from the Baddeckenstedt section, 29 specimens from the Söhlde section, 332 specimens from the Wunstorf Wu2010/1 core, 306 specimens from the Wunstorf Wu2010/3 core, and 131 specimens from the Wunstorf Wu2010/4 core.

Remarks. Broken, indeterminable specimens.

Occurrence. Common to very rare.

Genus *Ataxophragmium* Reuss 1860

Ataxophragmium compactum Brotzen, 1936

1936. *Ataxophragmium compactum*, Brotzen, p. 42, pl. 2, figs. 3,10.

Material. Two specimens from the Baddeckenstedt section, and two specimens from the Wunstorf Wu2010/4 core.

Occurrence. Very rare.

Ataxophragmium depressum (Perner, 1892)

Figure 3.8n-o

1882. *Bulimina depressa*, Perner, p. 55, pl. 3, fig. 3.

1937. *Pernerina depressa* (Perner); Cushman, p. 195, pl. 21, figs. 5–9.

1972. *Ataxophragmium* aff. *depressum* (Perner); Voloshina, p. 104, pl. 11, fig. 6.

1980. *Ataxophragmium depressum* (Perner); Frieg, p. 237, text-figs. 2. 9–10.

Material. 51 specimens from the Baddeckenstedt section, four specimens from the Söhlde section, and 13 specimens from the Wunstorf Wu2010/4 core.

Occurrence. Common to very rare.

Ataxophragmium sp.

Material. Three specimens from the Söhlde section.

Remarks. Broken, indeterminable specimens.

Occurrence. Very rare.

Genus *Hagenowella* Cushman 1933

Hagenowella elevata (d'Orbignyi, 1840)

Figure 3.8p

1840. *Globigerina elevata* d'Orbignyi, p. 34, pl. 3, figs. 15–16.

1972. *Arenobulimina* (Novatrix) *elevata* (d'Orbignyi); Voloshina, p. 78, pl. 15, fig. 3, pl. 6, fig. 1, pl. 21, fig. 1.

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

1989. *Hagenowella elevata* (d'Orbignyi); Frieg and Kemper, p. 98, pl. 2, figs. 6–9.

Material. 187 specimens from the Baddeckenstedt section, 88 specimens from the Söhlde section, 33 specimens from the Wunstorf Wu2010/1 core, 61 specimens from the Wunstorf Wu2010/3 core, and 169 specimens from the Wunstorf Wu2010/4 core.

Occurrence. Abundant to common in the Cenomanian of Baddeckenstedt and in the Turonian of Wunstorf, otherwise rare to very rare.

Hagenowella obesa (Reuss, 1851)

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

1937. *Arenobulimina obesa* (Reuss); Cushman, p. 43, pl. 4, figs. 26, 27.

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

Material. 90 specimens from the Baddeckenstedt section, 16 specimens from the Söhlde section, 18 specimens from the Wunstorf Wu2010/1 core, 52 specimens from the Wunstorf Wu2010/3 core, and 31 specimens from the Wunstorf Wu2010/4 core.

Occurrence. Common to very rare in the Cenomanian to the upper Turonian.

Subfamily PERNERININAE Loeblich and Tappan 1984

Genus *Voloshinoides* Barnard and Banner 1980

Voloshinoides advenus (Cushman, 1936)

Figure 3.8q

1936. *Hagenowella advena* Cushman, p. 43, pl. 6, fig. 21.

1969. *Arenobulimina advena* (Cushman); Gawor-Biedowa, p. 86, pl. 8, figs. 1–4.

1977. *Arenobulimina advena* (Cushman); Carter and Hart, p. 14, pl. 2, fig. 4.

1982. *Hagenowina advena* (Cushman); Frieg and Price, p. 68, pl. 2.3, figs. g, h.

1989. *Voloshinoides advena* (Cushman); Frieg and Kemper, p. 94, pl. 5, figs. 5–8, 21–27; pl. 7, fig. 3; pl. 10, figs. 8–15; pl. 11, figs. 10–11.

Material. 216 specimens from the Baddeckenstedt section, 199 specimens from the Wunstorf Wu2010/1 core, and 184 specimens from the Wunstorf Wu2010/3 core.

Remarks. This study follows the intensively discussed generic affiliation of this species by Frieg and Kemper (1989).

Occurrence. Abundant to common in the uppermost Albian to middle Cenomanian, rare to very rare in the upper Cenomanian below the Facies Change.

Voloshinoides anglicus (Cushman, 1936)

Figure 3.8r

1936. *Arenobulimina anglica* Cushman, p. 27, pl. 4, fig. 8.

1982. *Hagenowina anglica* (Cushman); Frieg and Price, p. 68, pl. 2.3, figs. i–m.

1989. *Voloshinoides anglicus* (Cushman); Frieg and Kemper, p. 95, pl. 5, figs. 1–4; pl. 6, figs. 1–6; pl. 7, fig. 8; pl. 8, figs. 2–3, 5-8, 11–12; pl. 9, figs. 1–4; pl. 10, figs. 1–7; pl. 11, figs. 4–9.

Material. 159 specimens from the Baddeckenstedt section, 5 specimens from the Söhlde section, 146 specimens from the Wunstorf Wu2010/1 core, and 88 specimens from the Wunstorf Wu2010/3 core.

Remarks. This study follows the intensively discussed generic affiliation of this species by Frieg and Kemper (1989).

Occurrence. Abundant to common in the lower Cenomanian and middle Cenomanian; rare to very rare in the upper Cenomanian.

Voloshinoides d'orbignyi (Reuss, 1845)

1845. *Bulimina d'orbignyi* Reuss, p. 38, pl. 13, fig. 74.

1937. *Arenobulimina d'orbignyi* (Reuss); Cushman, p. 39, pl. 4, figs. 9–12.

1969. *Arenobulimina polonica* Gawor-Biedowa, p. 90, pl. 6, fig. 3, pl. 8, figs. 5–8.

1982. *Hagenowina d'orbignyi* (Reuss); Frieg and Price, p. 70, pl. 2, 3, figs. n, o.

1989. *Voloshinoides d'orbignyi* (Reuss); Frieg and Kemper, p. 97, pl. 11, figs. 1–3.

Material. Nine specimens from the Baddeckenstedt section, two specimens from the Wunstorf Wu2010/1 core, and seven specimens from the Wunstorf Wu2010/3 core.

Remarks. This study follows the intensively discussed generic affiliation of this species by Frieg and Kemper (1989).

Occurrence. Very rare in the Cenomanian.

Family CUNEOLINIDAE Saidova 1981

Subfamily CUNEOLININAE Saidova 1981

Genus *Pseudotextulariella* Barnard 1953

Pseudotextulariella cretosa (Cushman, 1932)

Figure 3.8s

1932. *Textulariella cretosa* Cushman.

1989. *Pseudotextulariella cretosa* (Cushman); Frieg, p. 362, text-figs. 2 a–h, pl. 1, figs. 1–11.

Material. 139 specimens from the Baddeckenstedt section, one specimen from the Söhlde section, five specimens from the Wunstorf Wu2010/1 core, 35 specimens from the Wunstorf Wu2010/3 core, and four specimens from the Wunstorf Wu2010/4 core.

Remarks. This species is used as index fossil for the Cenomanian of the English chalk (Hart et al. 1989), but Frieg (1989) already proved its existence in the lower part of the Albian. Our findings of four specimens in the middle Turonian of Wunstorf extends the stratigraphical range of this species and supports the idea of Frieg (1989) of a facies related appearance of *Pseudotextulariella cretosa* as it does not appear in the middle Turonian of Söhlde.

Occurrence. Abundant to common in the lower and middle Cenomanian at Baddeckenstedt, rare to very rare in the Cenomanian and Turonian of Wunstorf, absent in the Turonian of Söhlde.

Order TEXTULARIIDA Delage and Hérouard 1896, emended Kaminski 2004

Suborder TEXTULARIINA Delage and Hérouard 1896

Superfamily EGGERELLOIDEA Cushman 1937

Family EGGERELLIDAE Cushman 1937

Subfamily DOROTHIINAE Balakhmatova 1972

Genus *Marssonella* Cushman 1933

Marssonella ozawai Cushman, 1936

Figure 3.8u

1936. *Marssonella ozawai* Cushman, p. 43, pl. 4, figs. 10a, b.

1953. *Marssonella ozawai* Cushman; Barnard and Banner, p. 205, pl. IX, figs. 2A, B.

Material. 42 specimens from the Baddeckenstedt section, 32 specimens from the Wunstorf Wu2010/1 core, and 11 specimens from the Wunstorf Wu2010/3 core.

Occurrence. Lower Cenomanian. Abundant at the sponge beds at Baddeckenstedt and at The Rib at Wunstorf, otherwise very rare.

Marssonella trochus (d'Orbigny, 1840)

1840. *Textularia trochus* d'Orbigny, 1840.

1953. *Marssonella trochus* (d'Orbigny); Barnard and Banner, 1953, p. 204, text-figs. 5o–s.

Material. Three specimens from the Söhlde section.

Remarks. Like suggested by Leary (1987) *M. oxycona* and *M. turris* are varieties of *M. trochus*.

Occurrence. Very rare.

Subfamily PSEUDOGAUDRYINAE Loeblich and Tappan 1985

Genus *Clavulinoides* Cushman 1936

Clavulinoides sp.

Material. 15 specimens from the Baddeckenstedt section, and four specimens from the Söhlde section.

Occurrence. Very rare.

3.5 Distribution of agglutinated foraminifers

3.5.1 Albian–Cenomanian boundary

The Albian–Cenomanian boundary is only accessible in the Wunstorf Wu2010/1 core. It reaches from the base of the core towards the *ultimus/Aucellina* Event (Fig. 3.9). Significant groups are the tubular taxa *Bathysiphon* spp. and *Nothia* spp., coarse grained globular taxa *Psammosphaera fusca* and *Saccammina grzybowskii*, and elongate taxa *Arenobulimina truncata, Bulbobaculites problematicus, Flourensina intermedia, Reophax subfusiformis, Tritaxia tricarinata, Vialovella frankei*, and *Voloshinoides advenus*.

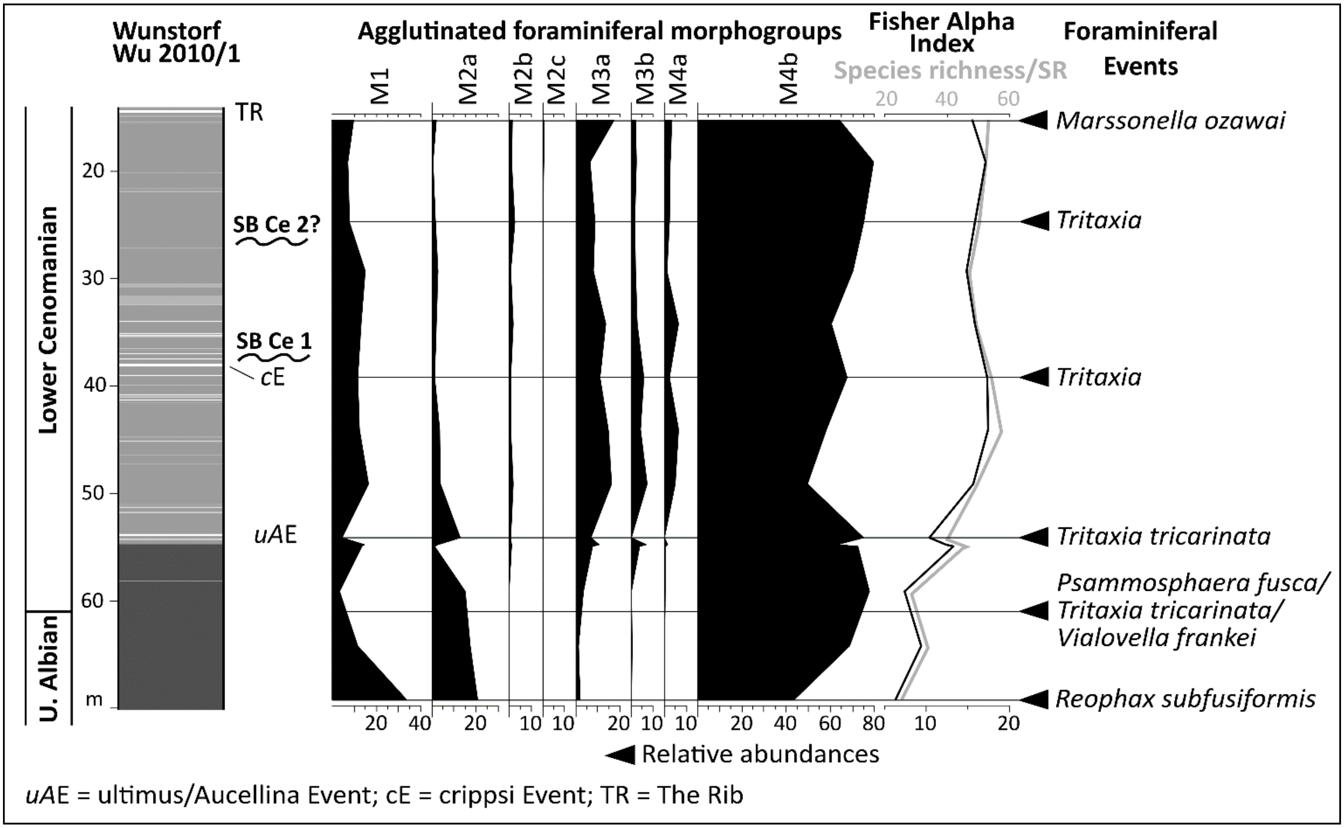


Figure 3.9. Columnar section of the Albian to Cenomanian part of the Wunstorf core Wu 2010/1 with agglutinated foraminiferal morphogroups, Fisher-Alpha Index, species richness, and foraminiferal events (acmes) indicated by arrows. For log legend, see Fig. 3.4.

At a depth of 59.05 m the taxa *Glomospira gordials, Repmanina charoides*, and *Tritaxia gaultina* first occur. Below the *ultimus/Aucellina* Event at 54.8 m core-depth many taxa as *Ammodiscus glabratus, Ammolagena contorta, Gerochammina stanislawi, Glomospira diffundens, G. irregularis, Haplophragmoides eggeri, H. walteri, Pseudonodosinella parvula, P. troyeri*, and *Voloshinoides anglicus* have their first occurrences.

The interval yields an increased proportion of straight tubular taxa, M1: 3.8–33.6 %; shallow infaunal taxa M2a: 14.9–20.6 %; deep infaunal taxa M4b: 43.6–77.7 % (Fig. 3.9). It can be assigned to the Low to mid-Latitude Slope Biofacies proposed by Kuhnt et al. (1989). The diversity is moderate with Fisher-Alpha Index values between 6.3 to 9.4 and SR values between 25 to 33 (Fig. 3.9).

3.5.2 Cenomanian

The Cenomanian agglutinated foraminiferal assemblage occurs from the *ultimus/Aucellina* Event up to the Facies Change below the CTBE (Figs. 3.9 to 3.11). The main faunal elements in the Baddeckenstedt section, Wunstorf Wu2010/1 and Wunstorf Wu2010/3 cores are the elongate taxa *Arenobulimina truncata, Hagenowella elevata, Plectina cenomana, Tritaxia tricarinata, Vialovella frankei,* and *Voloshinoides advenus* and the flattened irregular and attached *Ammolagena clavata*. In the southern Baddeckenstedt section more *Eggerellina brevis* and *E. mariae* occur, while in the Wunstorf cores additionally high numbers of *Kadriayina gradata* and *Flourensina intermedia* are seen.

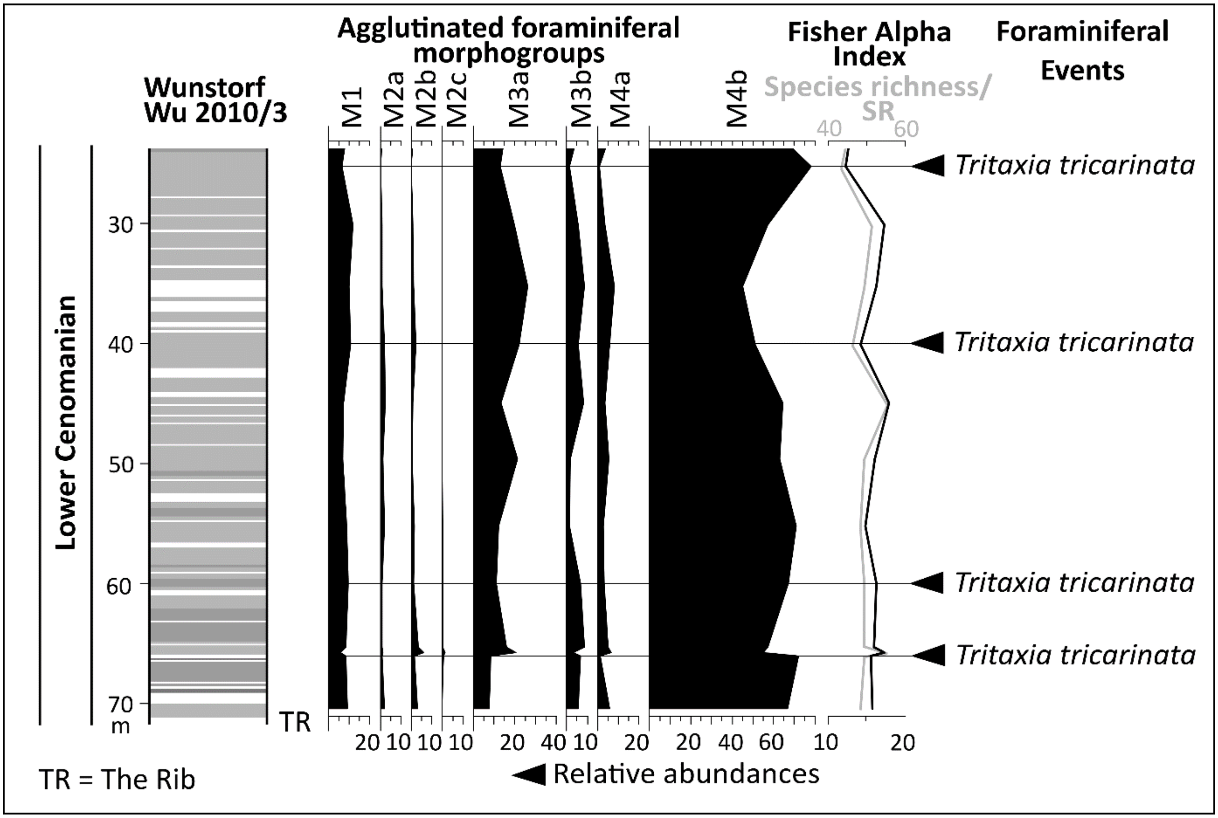
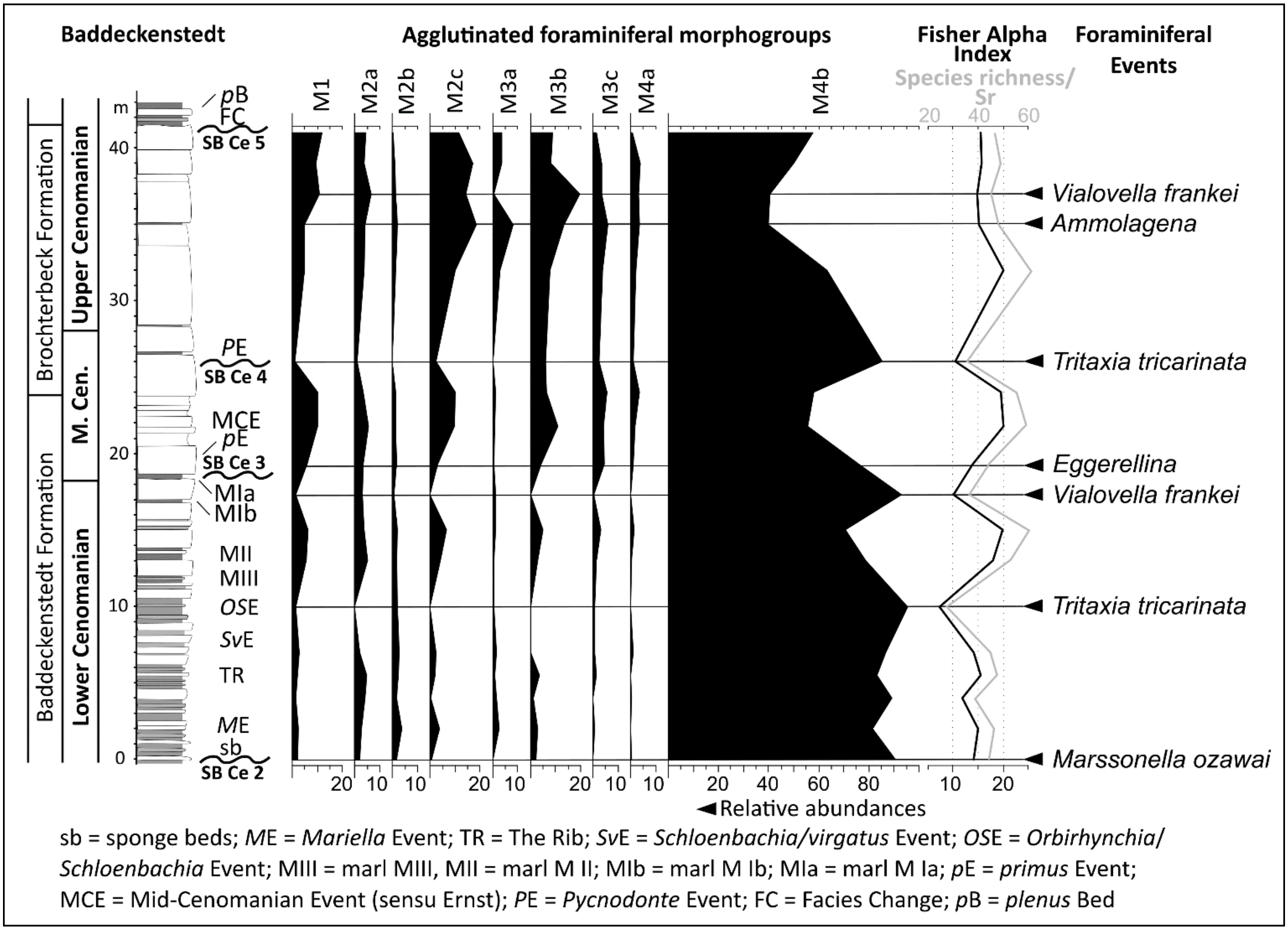


Figure 3.10. Columnar section of the Lower Cenomanian part of the Wunstorf core Wu 2010/3 with agglutinated foraminiferal morphogroups, Fisher-Alpha Index, species richness, and foraminiferal events (acmes) indicated by arrows. For log legend, see Fig. 3.4.

In the Wunstorf Wu2010/1 core, *Hagenowella elevata, H. obesa*, and *Gaudryina* sp. 1 first appear in the *ultimus/Aucellina* Event at a core-depth of 54.65 m. At 49.05 m core-depth, *Voloshinoides d'orbignyi* has its FO. Other FOs are notable at 44 m depth with *Haplophragmoides* aff. *bubiki, H. suborbicularis,* and *Rectogerochammina eugubina*. With the *crippsi* Event at 39m core-depth, *Marssonella ozawai, Plectina cenomana, P. mariae*, and *Tritaxia macfadyeni* occur for the first time in Wunstorf. *Spiroplectammina navarroana* appears and *M. ozawai* vanishes at 65.8 m core-depth in the Wunstorf Wu2010/3 core above the marker limestone The Rib, while similar occurrences are notable in the Baddeckenstedt section shortly above marl M_{II}. Other FOs at Baddeckenstedt are stateable with the appearance of *Pseudonodosinella nodulosa* at the *primus* Event and *Haplophragmoides suborbicularis* around the Mid-Cenomanian Event sensu Ernst et al. (1983). *Pseudotextulariella cretosa* vanishes below the *Pycnodonte* Event and *Voloshinoides anglicus* in the upper Cenomanian at 32 m in the Baddeckenstedt section.



sb = sponge beds; *ME* = *Mariella* Event; TR = The Rib; *SvE* = *Schloenbachia/virgatus* Event; *OSE* = *Orbirhynchia/ Schloenbachia* Event; MIII = marl MIII, MII = marl M II; MIb = marl M Ib; MIa = marl M Ia; *pE* = *primus* Event; MCE = Mid-Cenomanian Event (sensu Ernst); *PE* = *Pycnodonte* Event; FC = Facies Change; *pB* = *plenus* Bed

Figure 3.11. Columnar section of the Cenomanian part of the Baddeckenstedt quarry with agglutinated foraminiferal morphogroups, Fisher-Alpha Index, species richness, and foraminiferal events (acmes) indicated by arrows. For log legend, see Fig. 3.4; log redrawn after Wilmsen (2003: Fig. 8).

In general, the Cenomanian agglutinated foraminiferal assemblages consist of extremely high relative abundances of the morphogroup M4b with values up to 95 % and enhanced abundances of morphogroups M3a and/or M3b of up to 25 % (Figs. 3.9 to 3.11). M1 values range between 10 and 20 %, M2a and M2b values are below 5 % and M3b and M4a values reach up to 10 % (Fig. 3.9 to 3.11). At Baddeckenstedt increased relative abundances of shallow infaunal living taxa (M3b) are noted, while at Wunstorf, numbers of epifaunal living taxa (M3a) are enhanced (Figs. 3.9 to 3.11). Furthermore, the relative abundances of deep infaunal living taxa (M4b) are between 10–20 % higher at Baddeckenstedt than at Wunstorf (Figs. 3.9 to 3.11) The Fisher-Alpha Index of the Cenomanian agglutinated foraminiferal assemblage fluctuates between 7.4 and 20, while SR values are between 39 to 61 (Figs. 3.9 to 3.11).

3.5.3 Cenomanian–Turonian boundary interval

This interval spans from the prominent Facies Change including the *plenus* Bed to above the Cenomanian–Turonian boundary (Figs. 3.12 and 3.13). The dominant taxon is *Bulbobaculites problematicus* with 40–70 % relative abundance. Other common taxa are *Ammodiscus cretaceous, A. tenuissimus, Eobigenerina variabilis*, and *Repmanina charoides*.

Several taxa vanish with the Facies Change. In the Söhlde section as also in the Wunstorf Wu2010/4 core, *Kadriayina gradata, Plectina cenomana*, and *P. mariae* have their last occurrences. While *Pseudonodosinella troyeri, Vialovella frankei, Gaudryina* sp. 1, and *Voloshinoides anglicus* already vanish below the Facies Change at Baddeckenstedt, *V. frankei* and *Gaudryina* sp. 1 have been recorded in the *plenus* Bed at Wunstorf, *P. troyeri* occurs last in the basal lower Turonian; *V. anglicus* vanishes earlier at Wunstorf. The LO of *Gaudryinopsis filiformis* can be observed in the *plenus* Bed of the Söhlde section, while this species was not recorded in the Wunstorf Wu2010/4 core.

Foraminiferal assemblages of this interval yield increased relative abundances of morphogroup M4b with up to 88.8 %. At Wunstorf, increased relative abundances of M2c, e.g., *Spiroplectammina navarroana*, of up to 30.7 % in the *plenus* Bed are recorded. The recorded diversity is low between 4.1–6.2 Fisher-Alpha Index, and a species richness between 18 to 25 (Figs. 3.12 and 3.13).

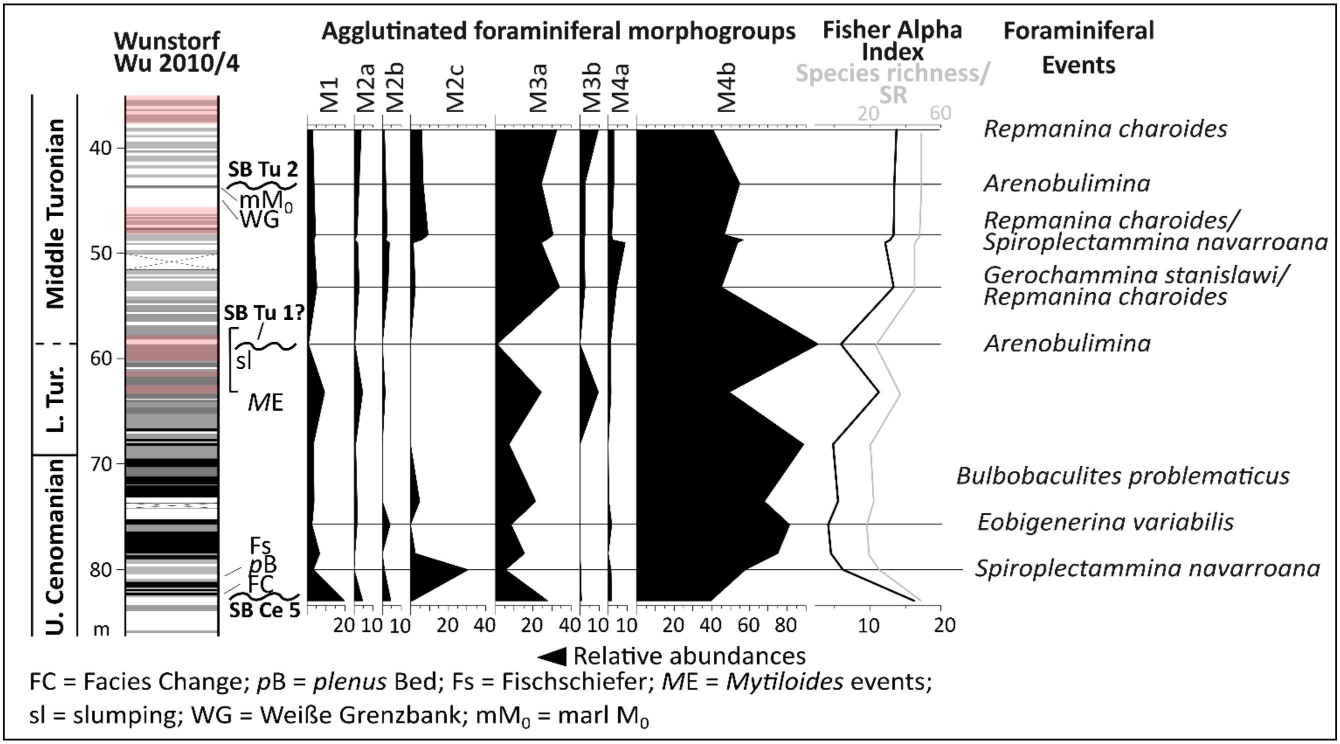


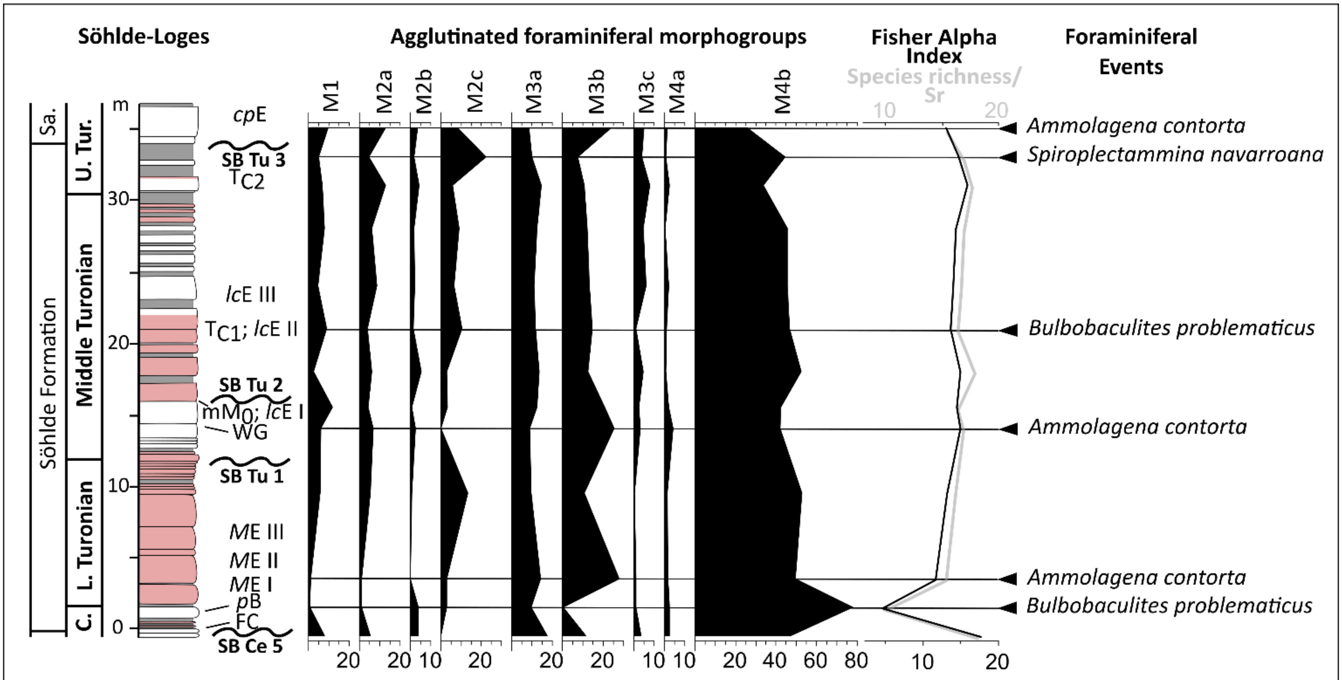
Figure 3.12. Columnar section of the Cenomanian–Turonian boundary and the Lower and Middle Turonian part of the Wunstorf core Wu 2010/4 with agglutinated foraminiferal morphogroups, Fisher-Alpha Index, species richness, and foraminiferal events (acmes) indicated by arrows. For log legend, see Fig. 3.4.

3.5.4 Turonian

In Turonian strata above the black shale/marlstone alternation of the Hesseltal Formation at Wunstorf (Fig. 3.12) and above the Cenomanian–Turonian boundary interval at Söhlde (Fig. 3.13), the species *Ammolagena contorta, Arenobulimina preslii, A. truncata, Bulbobaculites problematicus, Gerochammina stanislawi, Hagenowella elevata, Repmanina charoides*, and *Spiroplectammina navarroana* occur in high numbers (>5 % relative abundances). In the Söhlde additionally the elevated abundances of *Ammobaculites agglutinans, Trochammina* spp., and *Trochamminoides* spp. are notable.

While no FOs or LOs are recorded in the post-CTBE strata in Wunstorf, in Söhlde *Ammosphaeroidina pseudopauciloculata, Gaudryinella irregularis*, and *Uvigerinammina jankoi* occur firstly in the basal middle Turonian.

Above the black shale/marlstone alternation of the Hesseltal Formation, in deposits with slumping structures high relative abundances of morphogroup M4b (96.9 %) are noted at Wunstorf (Fig. 3.12). In strata of the Söhlde Formation, agglutinated foraminiferal assemblages are characterized by a medium high Fisher-Alpha index (12.19–15.94), and high species richness (45–49) at Wunstorf (Fig. 3.12). Relative abundances of the morphogroups M3a range between 24.3–34.1 %, while relative abundances of M4b between 40.7–56.8 % are noticed (Fig. 3.12). Above the CTBE, the Fisher-Alpha Index rises towards 22.5 in the late Turonian of Söhlde, while species richness increases to 52 (Fig. 3.13). Relative abundances are recorded of morphogroups M3a between 8.6–14.5 %, M3b between 7.4–27.8 %, and M4b between 26–52.3 (Fig. 3.13).



Sa. = Salder Formation; FC = Facies Change; *pB* = *plenus* Bed; *ME* I–III = *Mytiloides* Event I–III; WG = Weißе Grenzbank;
*lc*E I–III = *lamarcki/cuvierii* Event I–III; T_{C1} and T_{C2} = bentonite T_{C1} and T_{C2}; *cpE* = *costellatus/plana* Event

Figure 3.13. Columnar section of the Cenomanian–Turonian boundary and the Lower to Upper Turonian part of the Söhlde-Loges quarry with agglutinated foraminiferal morphogroups, Fisher-Alpha Index, species richness, and foraminiferal events (acmes) indicated by arrows. For log legend, see Fig. 3.4; log redrawn after Wiese (2009: Fig. 6).

3.6 Stratigraphy

3.6.1 Litho- and event stratigraphy

The Wunstorf core Wu 2010/1 starts with nine metres of marly claystone (Fig. 3.4), which belong to the uppermost Albian to lowermost Cenomanian Bemerode Member of the Herbram Formation (comp. Hiss et al., 2007a). The observed lithology matches to that found nearby in the Anderten cores, covering the same sedimentation period (Bornemann et al., 2017). In proximal settings of Central Europe, the transgressive *ultimus/Aucellina* Event is used to determine the base of the Cenomanian (e.g., Ernst et al., 1983). However, the succession of Wunstorf is suggested to be more or less continuous due to a more distal position in an intrashelf depression. The following Cenomanian marl–limestone alternations of the Baddeckenstedt Formation (comp. Wilmsen and Hiss, 2007) are comparable to lithology of the Staffhorst shaft (Niebuhr et al., 1999), the Konrad borehole (Niebuhr et al. 2001), Baddeckenstedt section (Wilmsen and Niebuhr, 2002) and Wunstorf quarry section (Wilmsen, 2003).

The basal metres of the core Wunstorf Wu 2010/4 (Fig. 3.5) are built by pure limestones of the Brochterbeck Formation (comp. Hiss et al., 2007c). Above the notable Facies Change, the black shale/marlstone alternation of the Hesseltal Formation (comp. Hiss et al., 2007c; see Voigt et al., 2008b), ranges from 82.5 to 63.5 m depth (Seibertz, 2013; Fig. 3.5). The recorded thickness is surprisingly low compared to other studies (e.g., Erbacher et al., 2007; Voigt et al., 2008b). About 12 m of Turonian strata are completely missing likely induced by a prominent fault at 68 m core-depth (Fig. 3.5). Above the *Mytiloides* events in strata belonging to the Söhlde Formation (comp. Wiese et al., 2007), slumping structures occur in the Wunstorf Wu2010/4 core (Seibertz, 2013; Fig. 3.5). Similar features were not recorded in previous studies on the nearby taken core Wunstorf WK1 (Voigt et. al, 2008b). Consequently, thicknesses can differ in between recorded Wunstorf cores, even in regional scale due to faults and slumping. The Weiße Grenzbank and the overlying marl M_0 in around 44 to 46 m core-depth (Seibertz, 2013; Fig. 3.5) can be correlated to the section Söhlde-Loges of Wiese (2009).

3.6.2 Stable carbon isotopes

The basal part of the studied stratigraphic sequence is expressed through the Albian–Cenomanian boundary interval (ACBI), which yields four distinct peaks of a positive δ^{13}C excursions;

A to D, Fig. 4: A and B are not exposed in these samples, comp. Gale et al. (1996: Fig. 2). The Albian–Cenomanian boundary (ACB), defined by the Last Occurrence (LO) of the planktic foraminifer *Thalmanninella globotruncanoides*, is positioned between the stable carbon isotope excursions C and D (Kennedy et al., 2004; Bornemann et al., 2017). Comparable to the Anderten1 core (Bornemann et al., 2017) and the GSSP site Mont Risou (Gale et al., 1996), both stratigraphically higher excursions, C and D, are visible in the Wunstorf carbon isotope patterns, and thus, can be used to determine the Albian–Cenomanian boundary (Fig. 3.4). The following Lower Cenomanian events (LCE I–III) and the *crippsi* Isotope Event are weakly developed in the cores Wunstorf Wu2010/1, and Wunstorf Wu2010/3, respective (Fig. 3.4). Bornemann et al. (2017) explains this weakly developed isotope events in the Lower Saxony basin with more continuous and only fewer condensed stratigraphical horizons than in the English Chalk.

The strong increase of δ^{13}C values forming the Oceanic Anoxic Event 2 (OAE2) - Isotope Event (-IE; Jenkyns, 1980; Voigt et al., 2008b) is recorded in the Wunstorf Wu2010/4 core (Fig. 3.5). Above the OAE2-IE, a plateau of δ^{13}C values like recorded in other studies can be recognized, but single known peaks are not observable (comp. Jarvis et al., 2006; Voigt et al., 2007; Voigt et al., 2008b). The last peak on the plateau, similar to observations of Voigt et al. (2008b) is Tu 8, or Round Down Event (Jarvis et al., 2006; Fig. 3.5). Afterwards δ^{13}C values decrease (Fig. 3.5). An inflection point, from a slow decrease to a steep one could not be found and thus, the position of the Low-*woolgari* Event of Jarvis et al. (2006) remains questionable.

3.6.3 Agglutinated foraminiferal biostratigraphy

The Albian–Cenomanian boundary at Wunstorf is reflected by the first occurrence (FO) of the species *Glomospira gordialis, Tritaxia gaultina*, and *Repmanina charoides*. However, *Tritaxia gaultina* was reported from the Lower Cretaceous (Melinte-Dobrinescu et al., 2015) and *Repmanina charoides* (Kaminski and Gradstein, 2005; Józsa et al., 2017b, 2018) and *Glomospira gordialis* (Józsa et al., 2017b, 2019) even from Jurassic strata. Many taxa such as some ammodiscids and arenobuliminids occur slightly above the stage boundary or at the facies change marked by the *ultimus/Aucellina* Event at Wunstorf. Reported FOs by Frieg and Kemper (1989) and biozones by Hart et al. (1989) are in most cases not visible in the Wunstorf cores. Thus, *Voloshinoides advenus* already occurs in the latest Albian at Wunstorf while Frieg and Kemper (1989) reported it not until early Cenomanian times in Northwest

Germany (Fig. 3.14). Our observation fits more to those made by Hart et al. (1989; 2020) who reports *V. advenus* already in the latest Albian. *Arenobulimina preslii* occurs with the *ultimus/Aucellina* Event much earlier than usually found in the *dixoni*-Zone in the Northwest Germany (Frieg and Price, 1982; Frieg and Kemper, 1989; Fig. 14). Only some specimens of this species were found in the *mantelli*-Zone in the Münsterland (Frieg and Kemper, 1989). Furthermore, with the *crippsi* Event in Wunstorf or shortly above the taxa *Marssonella ozawai, Plectina cenomana. P. mariae*, and *Pseudotextulariella cretosa* have their FO in Wunstorf (Fig. 3.14). While *M. ozawai* and *P. cretosa* are already known from the Albian (Frieg, 1989; Frieg and Kemper, 1989; Hart et al. 1989), *P. mariae* has been used to define the Albian–Cenomanian boundary in sections of the English Chalk (Hart et al., 1989; Hart and Fox, 2020; Fig. 3.14). *P. cenomana* otherwise reflects the Lower–Middle Cenomanian boundary in sections of the English Chalk (Hart et al., 1989), but occurs earlier in the Wunstorf cores (Fig. 3.14). FOs or Los (first- and last occurrences) commonly used for a stratigraphical division of the Cenomanian substages are not present in Wunstorf and Baddeckenstedt. With the Facies Change at the base of the OAE2 in the Lower Saxony Cretaceous, the LOs of *Kadriayina gradata, Flourensina intermedia, Plectina cenomana*, and *Voloshinoides advenus* take place. Additionally, *Vialovella frankei* becomes extinct above the *plenus* Bed at Wunstorf (Fig. 3.14). This differs slightly from observations made in England, France, and other sections in Germany, in which *F. intermedia* (as *F. mariae*), *P. cenomana, P. mariae,* and *V. advenus* (as *A. advena*) taxa vanish in the *plenus* Bed (Carter and Hart, 1977, Hart et al., 1989; Fig. 3.14). These shorter stratigraphical ranges of some taxa from Lower Saxony could be caused by a stronger peculiarity of the periodical anoxic conditions in the sub-basins, which did not occur in most parts of the European shelf area. This is supported by the prolonged black shale deposition in Wunstorf (Voigt et al. 2008b), which likely affected other parts of the surrounding Lower Saxony Cretaceous sub-basins.

In the overlying Turonian strata, *Ammosphaeroidina pseudopauciloculata, Gaudryinella irregularis*, and *Uvigerinammina jankoi* have their FO in the middle Turonian in the Subhercynian Basin but not in the Wunstorf cores (Fig. 3.14). No comparable biostratigraphical information is available for *G. irregularis* while *A. pseudopauciloculata* does not appear until the Santonian as observed from sections in Italy (Kaminski et al., 2011). *U. jankoi* is the index taxon for the Turonian–Lower Campanian *U. jankoi* biozone in the western Tethys region (Geroch and Nowak, 1984; Coccioni et al., 1995;

Kaminski et al., 2011) and in the Atlantic region (Kuhnt et al., 1989; Kuhnt and Kaminski, 1997). The FO recorded in Söhlde fits more to observations made in the western Tethys region (Fig. 3.14).

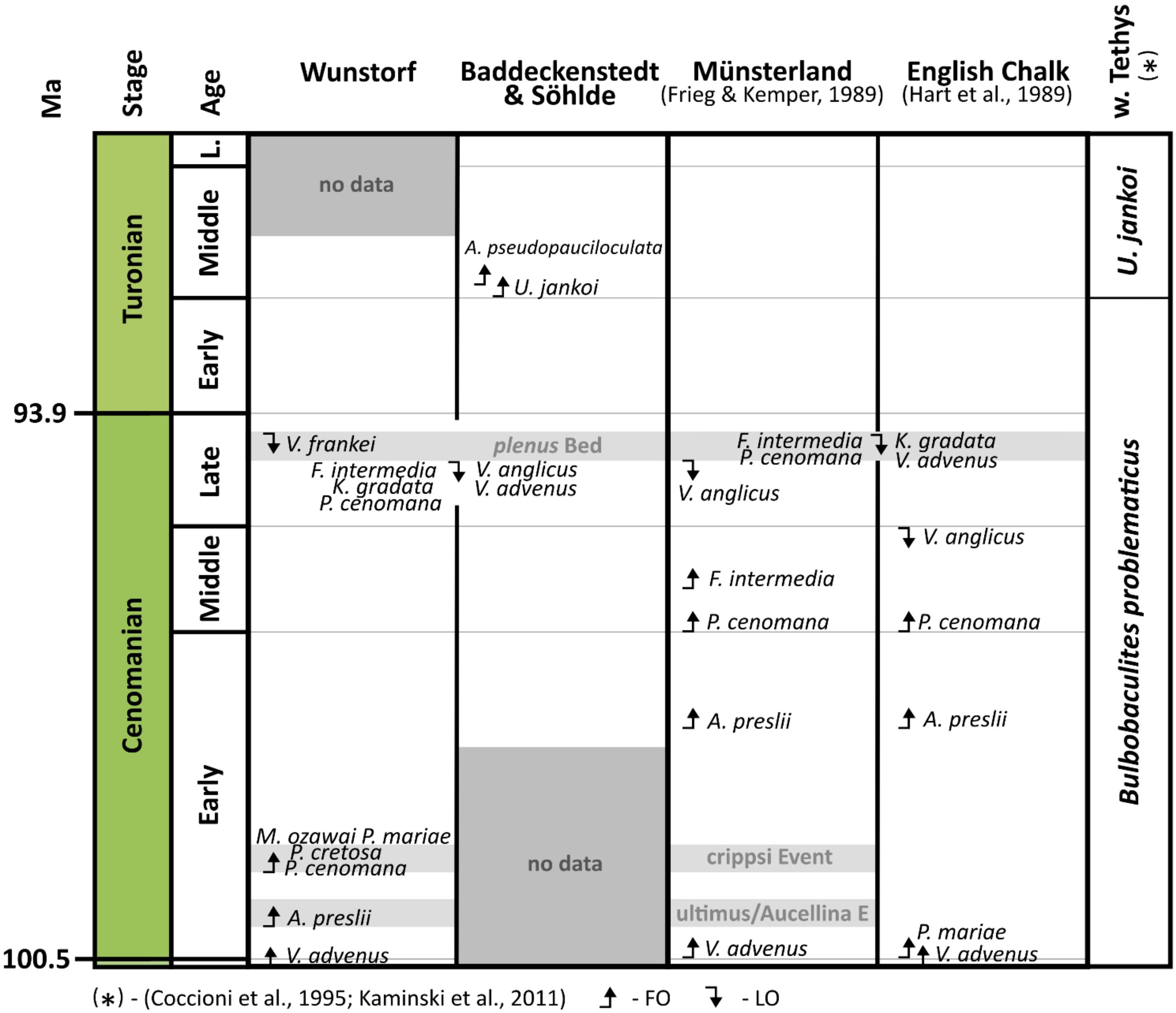


Figure 3.14. Albian, Cenomanian, and Turonian FOs and LOs (first – and last occurrences) of selected agglutinated foraminifers from Lower Saxony (Wunstorf, Baddeckenstedt, Söhlde), the Münsterland (Frieg and Kemper, 1989), and the English Chalk (Hart et al., 1989), and the DWAF (Deep Water Agglutinated Foraminifera) Zonation of the Western Tethys (Coccioni et al., 1995; Kaminski et al., 2011).

Overall, total ranges, FOs and LOs of agglutinated foraminifera are poorly applicable for the Albian to Turonian of Lower Saxony. The potential to correlate this qualitative data with other regions is suggested to be weak. The Deep Water Agglutinated Foraminifera (DWAF) zonation from the North Atlantic and Western Tethys is not fully applicable in all studied sections. *Bulbobaculites problematicus* represents the index taxon for the latest Albian to Cenomanian by Morgiel and Olszewska (1981). This correlates to observations from this study and differs from recorded zones of Geroch and Nowak (1984). The previous *Plectorecurvoides alternans* and latter *Uvigerinammina jankoi* Zone is not distinguishable in Wunstorf due to lack of the index taxa.

3.7 Paleoenvironmental implications

3.7.1 Albian–Cenomanian boundary

Due to a high number of infaunal and deep infaunal specimens (M4b, Fig. 3.9), but also increased relative abundances of filter feeding tubular living specimens (M1, Fig. 3.9), slightly eutrophic bottom water conditions can be assumed (Fig. 3.15) by applying the TROX model after Jorissen et al. (1995), Zwaan et al. (1999) and Setoyama et al. (2017). This is supported by a mass occurrence of the species Psammosphaera fusca, which is commonly occurring in cold, nutrient rich deep-water habitats (Harloff and Mackensen, 1997). An acme of this species can be observed in Tethyan deep marine environments of the same age (Melinte-Dobrinescu et al., 2015). Consequently, this supports the interpretation of Tyszka and Thies (2001) of a deep-water inflow from the Tethyan Ocean towards the North via the Polish Trough during the Albian. A stressed environment, such as through seasonally dysaerobic conditions, possibly have occurred in the latest Albian to earliest Cenomanian at Wunstorf indicated by increased relative abundances of *P. fusca* and *Reophax*. Large proportions of both fast-recolonizing taxa were described under a Recent stressed environment from the Californian Borderland Basin by Kaminski et al. (1995).

3.7.2 Cenomanian

Following the TROX model (Jorissen et al., 1995; Zwaan et al., 1999; Setoyama et al., 2017) bottom water conditions during the lower to middle Cenomanian time were mesotrophic to eutrophic (Fig. 3.15), indicated by a continuous record of morphogroup M1, increased relative abundances of morphogroups M3a/M3b and M4b (Figs. 3.9 to 3.11). Rising relative abundances of shallow infaunal morphogroup M3a and epifaunal morphogroup M3b from below 5 % in the lower Cenomanian to up to 20 % in the upper Cenomanian (Figs. 3.9 to 3.11) are likely explained by a shift from more eutrophic to more mesotrophic conditions during the Cenomanian. This is in accordance with the lithological succession (e.g., rising carbonate content), and proposed sea level fluctuations by Wilmsen (2003) and Janetschke et al. (2015; Fig. 3.3). The food influx during the early to early-middle Cenomanian in the Lower Saxony and Subhercynian sub-basins was mainly controlled by fluvial inlet and so depended on the distance to the shore (Wilmsen, 2003). Higher relative abundances of deep infaunal morphogroup M4b at Baddeckenstedt (Fig. 3.11) are likely induced by the more proximal position of Baddeckenstedt (Fig. 3.1) and therefore a higher food supply.

At Wunstorf, about seven metres above the *ultimus/Aucellina* Event, morphogroup M4b relative abundances rapidly decrease (Fig. 3.9). This likely links to the prominent early Cenomanian transgression belonging to the Depositional Sequence Albian–Cenomanian 1, DS Al–Ce 1, which are in detailed described at sections of the Lower Saxony Basin by Niebuhr et al. (1999, 2001), Wilmsen (2003, 2007), Bornemann et al., (2007) and Erbacher et al. (2020). A minimum of relative abundances of M4b in the Wunstorf Wu2010/1 core at a depth of 49.05 m (Fig. 3.9) likely reflects a low food supply, and therefore, the possible maximum flooding zone of DS Al–Ce 1 (Fig. 3.3). The *crippsi* Event at Wunstorf yields increased relative abundances of M4b (Fig. 3.9). This likely relates to a high food supply during the formation of the *crippsi* Event. Below the prominent limestone bed The Rib relative abundances of M4b are high (Fig. 3.9), which likely reflect high food availability at the SB Ce 2 proposed by Wilmsen (2003). Low relative abundances of deep-infaunal taxa (M4b) at a depth of 35.2 m of the Wunstorf Wu 2010/3 core (Fig. 3.10) likely are induced by low food supply and probably can be correlated to equally lower values above the marl M_{II} of the Baddeckenstedt section (Fig. 3.11). This can not be related to the maximum flooding zone of DS Ce 3, which was proposed to be below at the *Schloenbachia/virgatus* Event (Wilmsen, 2003, 2008). The Lower to Middle Cenomanian boundary at Baddeckenstedt exhibits a higher abundance of the morphogroup M4b (Fig. 3.11). This likely reflects high food availability at the SB Ce 3 proposed by Wilmsen (2003).

For the late-middle to late Cenomanian times, a shift to more oligotrophic conditions in the Lower Saxony basin due to a breakdown of a shelf-front system is proposed (Wilmsen, 2003). Following the paleoceanographical models by Linnert et al. (2010) and Püttmann and Mutterlose (2021), nutrients are mainly delivered by oceanic currents or are provided by mixing processes during stormy seasons (Linnert et al., 2010). Decreased relative abundances of deep infaunal taxa of morphogroup M4b during this time interval are likely induced by this lower food availability. Increased abundances of M4b during this interval likely are affected by regressional trends such as the periodically reinstalment of the shelf-front system or by enhanced vertical and lateral mixing of the water column during stormy seasons. Applying the TROX model on recorded foraminiferal assemblages, mesotrophic bottom water conditions during this interval (Fig. 3.15), but an in general lower food availability than during the early to early-middle Cenomanian are assumed.

The strata, containing the Mid-Cenomanian Event sensu Ernst et al. (1983) yields a distinct decline in M4b relative abundance and high numbers of group M3a/M3b in Baddeckenstedt (Fig. 3.11). Wilmsen (2003) placed the maximum flooding zone of the DS Ce 4 exactly at this level. Decreased food availability during that interval are inferred based on the agglutinated foraminifers applying the TROX model established by Jorissen et al. (1995), Zwaan et al. (1999) and Setoyama et al. (2017).

The strata about one metre below the *Pycnodonte* Event again yields high abundances of group M4b at Baddeckenstedt (Fig. 3.11). High food supply at the SB Ce 4 is likely. About seven metres above the *Pycnodonte* Event at Baddeckenstedt decreased relative abundances of deep infaunal taxa (Fig. 3.11) likely indicate lower food availability. In consideration, the main food source being currents from offshore or mixing due to stormy seasons, increasing water depth, and following lower nutrient influx or less stormy seasons are likely. In case of an increase of water depth, this interval likely reflects the maximum flooding zone of DS Ce 5 (Fig. 3.3).

In general, the discussed time interval is characterized by bottom water conditions changing from eutrophic-mesotrophic to clearly mesotrophic. This likely corresponds to the Cenomanian eustatic sea-level rise (Fig. 3.3) stated by Haq et al. (1987), and Haq (2014).

3.7.3 Cenomanian–Turonian boundary interval

Low diverse agglutinated foraminiferal assemblages from the Cenomanian–Turonian boundary interval at Wunstorf and Söhlde indicate unfavourable living conditions. The dominance of infaunal to deep infaunal taxa and low diversities like recorded at Wunstorf and Söhlde (Fig. 3.12 and 3.13) are indicative for periodically anoxic bottom water conditions (comp. Kaminski et al., 1995). Eutrophic conditions are likely (Fig. 3.15), following the TROX model.

Bulbobaculites problematicus is the most dominant faunal component in this interval with relative abundances up to 70 % (Figs. 3.12 and 3.13). Due to its high relative abundances, this taxon likely represents an opportunistic species, recolonizing after periodically bottom water anoxia or even tolerates lower oxygen concentrations in bottom waters. *Spiroplectammina navarroana*, a species usually known from deeper and thus, colder habitats (Gradstein et al., 1999) occurs in the Wunstorf cores in an acme at the level of the *plenus* Bed with a relative abundance of 30 % (Fig. 3.12). The acme likely represents a southward migration of cool habitat favouring fauna corresponding to findings of similar migration patterns of macrofaunal taxa by Gale and Christensen (1996). A similar acme is absent at Söhlde. This absence is likely explained by the southern migration of *Spiroplectammina navarroana* being limited on deeper habitats like at Wunstorf or by an extended hiatus at Söhlde.

3.7.4 Turonian

The middle Turonian and basal part of the upper Turonian bears relatively low abundances of morphogroup M4b and comparably high abundances of morphogroup M3a and/or M3b, and medium high diversities (Figs. 3.12 and 3.13). This likely supports a shift to more oligotrophic bottom water conditions during the Turonian (Fig. 3.15). Assumptions made for surface water conditions in the Cretaceous shelf sea reflect a similar trend (Wiese et al., 2015).

In all sections, “Lazarus” species from the genera *Ammodiscus, Glomospira*, and *Repmanina* appear above the CTBE, comparable to observations in Tethyan deep water carbonates, made by Coccioni et al. (1995) and Kaminski et al. (2011). The strata with slumping structures at Wunstorf contains high relative abundances of morphogroup M4b (Fig. 3.12), which could reflect high food supply at the SB Tu 1 (Fig. 3.3) applying the TROX model by Jorissen et al. (1995), Zwaan et al. (1999), and Setoyama et al. (2017). Otherwise, these assemblages could be affected by instable environmental conditions due to strong redeposition of strata during this interval. At Söhlde a similar trend is not visible (Fig. 3.13).

Increased relative abundances of morphogroup M4b above the Weiße Grenzbank at Söhlde and Wunstorf (Fig. 3.12 and 3.13) likely reflect higher food availability in the bottom water. It likely corresponds to the SB Tu 2 proposed by Janetschke et al. (2015; Fig. 3.3).

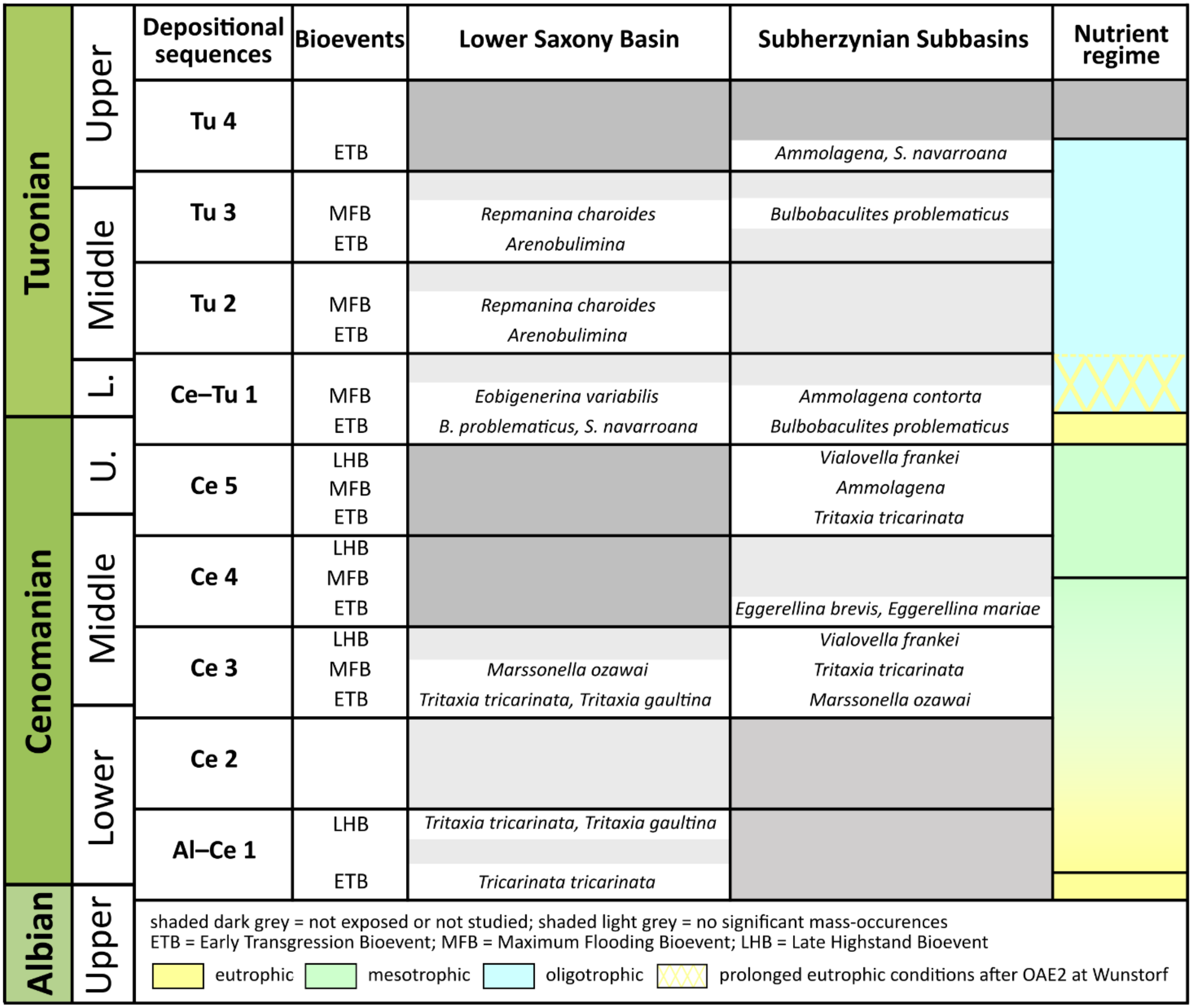
3.8 Agglutinated foraminiferal biofacies

The agglutinated foraminiferal fauna from the Albian–Cenomanian boundary within the Herbram Formation is classified to be the Low to mid-Latitude Slope Biofacies as proposed by Kuhnt et al. (1989). In contrast to this, the recorded Cenomanian to Turonian agglutinated foraminiferal assemblages of the Lower Saxony Cretaceous are different including planktic, calcareous benthic foraminifers, and calcareous-cemented species, such as some *Arenobulimina* species, *Tritaxia*, and *Eggerellina*. Previously described assemblages of such a biofacies from Trinidad (Kaminski et al., 1988) and the Iberian Peninsula (Kuhnt and Kaminski, 1997) are mainly from the lower bathyal environments, whereas the Cenomanian successions from this study were deposited in shallower water depth below 100 m (Wilmsen, 2003). For the late-early Cenomanian, water depths of 20–30 m at Baddeckenstedt and ca. 50 m at Wunstorf are estimated by Wilmsen (2003). During the CTBE, water depths of 100–150 m at Wunstorf are assumed (Wilmsen, 2003). Subsequently, a new biofacies is proposed. The newly named Mid-latitude Shelf Biofacies differs from others by higher relative abundances of up to 30 % of taxa of morphogroups M3a and/or M3b, and up to 95 % of morphogroup M4b, while the diversity is higher with Fisher Alpha Indices usually between 12 and 20 (Figs. 3.9 to 3.13). These assemblages indicate an upper bathyal to inner shelf setting.

3.9 Agglutinated foraminiferal bioevents

In the Cenomanian, three types of macro-bioevents occurred: early transgressive bioevents (ETB), maximum flooding bioevents (MFB) and late highstand bioevents (LHB; Wilmsen, 2003, 2012). These bioevents are in accordance with sea-level driven depositional sequences. ETBs form either due to winnowing fines and thus, accumulation of resistant hard parts, called lag subtype, or due to migration events of uncommon or exotic taxa, called migration subtype. MFBs yield assemblages of taxa adapted to a low water energy, a low food supply and often, soft substrates (Wilmsen, 2003, 2012). LHBs occur as accumulated biogenic hard parts due to a reduced accumulation space at the end of a sea-level highstand (Wilmsen, 2003; 2012). Similar bioevents, expressed through acmes, occur in the foraminiferal record of this research (Fig. 3.15).

Below the *ultimus/Aucellina* Event, two acmes are recorded in the Wu2010/1 core yielding high abundances of *Reophax subfusiformis* at 70 m core-depth and *Psammosphaera fusca, Tritaxia tricarinata*, and *Vialovella frankei* at 62 m core-depth (Figs. 3.9 and 3.15).



		Depositional sequences	Bioevents	Lower Saxony Basin	Subherzynian Subbasins	Nutrient regime
Turonian	Upper	Tu 4	ETB	▓	▓ *Ammolagena, S. navarroana*	▓ 🟦
	Middle	Tu 3	MFB ETB	░ *Repmanina charoides* *Arenobulimina*	░ *Bulbobaculites problematicus* ░	🟦
		Tu 2	MFB ETB	░ *Repmanina charoides* *Arenobulimina*	░	🟦
	L.	Ce–Tu 1	MFB ETB	░ *Eobigenerina variabilis* *B. problematicus, S. navarroana*	░ *Ammolagena contorta* *Bulbobaculites problematicus*	▨ 🟨
Cenomanian	U.	Ce 5	LHB MFB ETB	▓	*Vialovella frankei* *Ammolagena* *Tritaxia tricarinata*	🟩
	Middle	Ce 4	LHB MFB ETB	▓	░ *Eggerellina brevis, Eggerellina mariae*	🟩
		Ce 3	LHB MFB ETB	░ *Marssonella ozawai* *Tritaxia tricarinata, Tritaxia gaultina*	*Vialovella frankei* *Tritaxia tricarinata* *Marssonella ozawai*	🟩 🟨
	Lower	Ce 2		░	▓	🟨
		Al–Ce 1	LHB ETB	*Tritaxia tricarinata, Tritaxia gaultina* ░ *Tricarinata tricarinata*	▓	🟨 🟨
Albian	Upper					

shaded dark grey = not exposed or not studied; shaded light grey = no significant mass-occurences
ETB = Early Transgression Bioevent; MFB = Maximum Flooding Bioevent; LHB = Late Highstand Bioevent
🟨 eutrophic 🟩 mesotrophic 🟦 oligotrophic ▨ prolonged eutrophic conditions after OAE2 at Wunstorf

Figure 3.15. Albian, Cenomanian, and Turonian micro-bioevents, their subtypes defined by agglutinated foraminifers, and interpreted bottom-water nutrient regimes in the Lower Saxony Cretaceous as well as in the Subhercynian subbasins. Micro-bioevent subtypes correlate with one or more acmes of specific agglutinated foraminiferal species. Depositional Sequences and their stratigraphical relations are from Janetschke et al. (2015: Fig. 3.6).

Synchronously to the *ultimus/Aucellina* Event in the Wunstorf 2010/1 core, high relative abundances of *Tritaxia tricarinata* are recorded (Figs. 3.9 and 3.15). This species has a thin test. A lag subtype is not plausible for this bioevent, because thin and fragile test are likely destructed during accumulation of lag subtype bioevents proposed by Wilmsen (2003, 2012). Subsequent, this micro-bioevent is regarded to be a migration subtype ETB.

At the *crippsi* Event in the Wunstorf Wu 2010/1 core, increased relative abundances of *Tritaxia gaultina* and *T. tricarinata* occur. They likely constitute the LHB of DS Al–Ce 1 as proposed for the *crippsi* Event by Wilmsen (2012) and Wilmsen et al. (2021).

A possible ETB of DS Ce 3 with high amounts of the species *Marssonella ozawai* occurs below the *Mariella* Event at Baddeckenstedt (Figs. 3.11 and 3.15). In the Wunstorf Wu 2010/1 core, an acme of the genus *Tritaxia* is observed below The Rib (Figs. 3.9 and 3.15). Fragile tests of the genera *Marssonella* and *Tritaxia*, which commonly break during transgressive reworking, support the interpretation as migration subtype bioevents.

In the Wunstorf Wu 2010/3 core, increased relative abundances of *Marssonella ozawai* and *Pseudonodosinella nodulosa* occur above The Rib; in the Baddeckenstedt section an acme of *Tritaxia tricarinata* is situated at the level of the *Orbirhynchia/Schloenbachia* Event (Figs. 3.10, 3.11, and 3.15). This position represents a maximum flooding interval (Wilmsen 2008). Following the model by Wilmsen (2012), these taxa with acmes are supposed to be specialists for environmental conditions during maximum flooding, e.g., lower food supply and soft substrate.

Increased relative abundances of *Vialovella frankei* in the Baddeckenstedt section above the marl M_{Ib} likely represent a LHB (Figs. 3.11 and 3.15).

Eggerellina has an acme at the level of the *primus* Event in the Baddeckenstedt section (Figs. 3.11 and 3.15). The occurrence of this thin shelled taxon likely indicates a migration subtype ETB of DS Ce 4 as well as proposed for the primus Event by Wilmsen et al. (2007).

Below the *Pycnodonte* Event, an acme of *T. tricarinata* occurs in the Baddeckenstedt section (Fig. 3.11 and 3.15). While the *Pycnodonte* Event is classified as a lag subtype ETB (Wilmsen and Voigt, 2006; Wilmsen, 2012), thin-shelled tests of recorded foraminifer species suggest a migration subtype ETB.

An acme of *Ammolagena* in the Baddeckenstedt section (Figs. 3.11 and 3.15) probably correlates to the *Amphidonte* Event, which is regarded to be the MFB in the DS Ce 5 (Wilmsen, 2012). Thus, encrusting *Ammolagena* likely is adapted to more oligotrophic bottom water conditions.

A possible LHB shortly above the *Amphidonte* Event is expressed by an acme of *V. frankei* at Baddeckenstedt (Figs. 3.11 and 3.15).

During the interval of the CTBE, *Bulbobaculites problematicus* occurs with high relative abundances of usually more than 30 %, and *Spiroplectammina navarroana* has an acme in the *plenus* Bed in the Wunstorf 2010/4 core (Figs. 3.12 and 3.15). These taxa are uncommon for the older strata, thus, are regarded to be exotic taxa. They likely represent migration subtype bioevents.

As a possible MFB, *Eobigenerina variabilis* appears in high numbers in the Wunstorf Wu 2010/4 core and *Ammolagena contorta* at Söhlde (Figs. 3.12, 3.13, and 3.15). These taxa likely prefer more oligotrophic bottom water conditions.

Increased relative abundances of different species of *Arenobulimina* in the Wunstorf Wu 2010/4 core (Figs. 3.12 and 3.15) likely represent the ETB of the DS Tu 2 proposed by Janetschke et al. (2015). As these taxa have relatively robust tests, a lag subtype ETB induced by the accumulation of resistant hard parts during transgressive reworking as proposed by Wilmsen (2012) is likely. Otherwise, the recorded interval at Wunstorf is characterized by strong redeposition of strata, which could have influenced the recorded foraminiferal fauna.

Above this interval, an acme of *Repmanina charoides* with *Gerochammina stanislawi* and *Spiroplectammina navarroana* is observed in the Wunstorf Wu2010/4 core (Figs. 3.12 and 3.15). This acme likely represents the MFB of Ds Tu 2 proposed by Janetschke et al. (2015). *R. charoides* likely prefers more oligotrophic bottom water conditions as observed in the recent Mediterranean by De Rijk et al. (2000) and interpreted for Cretaceous to Paleogene foraminiferal assemblages by Setoyama et al. (2017).

Robust arenobuliminid tests occur in huge amounts slightly above marl M_0 in the Wunstorf Wu 2010/4 core (Figs. 3.12 and 3.15), which is likely to be the ETB of DS Tu 3 by Janetschke et al. (2015).

Another acme of *Repmanina charoides* above the marl M_0 in the Wunstorf Wu2010/4 core (Figs. 3.12 and 3.15) likely represents MFB of DS Tu 3. Again, enhanced relative abundances of *R. charoides* likely indicate more oligotrophic bottom water conditions.

High numbers of *Bulbobaculites problematicus* occur in the Söhlde section around the *lamarcki/cuvierii* Event II (Figs. 3.13 and 3.15). This acme likely represents a MFB of DS Tu 3 by Janetschke et al. (2015). Furthermore, increased relative abundances of *Spiroplectammina navarroana* and *Ammolagena* are recognizable in the basal late Turonian of the Söhlde section (Figs. 3.13 and 3.15) probably marking a migration subtype bioevent likely related to the ETB of DS Tu 4 by Janetschke et al. (2015). Assigned to colder habitats (Gradstein et al., 1999) this acme of *S. navarroana* is possibly referred to the ongoing Late Turonian Cooling Event proposed by Voigt and Wiese (2000) and Wiese and Voigt (2002).

3.10 Conclusions

Agglutinated foraminiferal assemblages have been studied from the Albian to Turonian deposits of the European shelf in northern Germany. With respect to assemblage compositions, we propose a new biofacies called Mid-Latitude Shelf Biofacies, clearly differing in relative abundances from other contemporaneous sections. The main faunal elements of this biofacies are typical shelf related elongate morphogroups such as *Dorothia, Marssonella, Tritaxia*, and arenobuliminids which appear to be the dominant group, epifaunal Deep Water Agglutinated Foraminifera taxa either free living or attached living and tubular forms. Differences in their relative abundances are likely related to oxygen content dissolved in bottom waters which is mostly related to food supply.

1. Increased relative abundances of deep infaunal morphogroups during the latest Albian to early-middle Cenomanian reflect a relatively higher food supply, while decreased ones indicate lower food availability. As the main food source during this time interval being riverine inlet from the coast, maxima of relative abundances of deep infaunal morphogroups likely indicate low relative water depth, and minima probably are related to maximum flooding intervals.

2. Increased relative abundances of deep infaunal morphogroups due to a relatively high food availability during the early-middle Cenomanian to Turonian likely reflect stronger vertical mixing during stormy seasons as the main food source being currents from offshore.

3. In proximal settings the relative abundances of deep infaunal morphogroups are higher than recorded in distal positions, which indicate a higher food supply in proximal settings. Proximal foraminiferal assemblages contain higher numbers of attached epifaunal morphogroups while in distal positions free epifaunal taxa occur more often.

4. Strata deposited during intervals of periodically anoxia at the bottom water layers such as related to the OAE2, or during strong synsedimentary redeposition of sediment mostly linked to tectonic events as recorded in parts of the Turonian at Söhlde and at Wunstorf contain low diverse foraminiferal assemblages. These are composed of mainly deep infaunal taxa such as Bulbobaculites problematicus.

While macro-bioevents are one of the most important features of the often-applied event stratigraphy, these events are also reflected by microfossils such as agglutinated foraminifers.

3.11 Acknowledgements

First, we would like to thank Birgit Niebuhr (Dresden) for a lot of effort in discussing and improving this study. Tobias Püttmann (Krefeld) and Štefan Józsa (Bratislava) provided constructive reviews, that we highly appreciate and substantially improved this manuscript. We appreciate the possibility of access to the Wunstorf cores provided by Bernd-Henning Reupke (Hannover) and the Holcim (Deutschland) GmbH Höver, and access to the working quarry in Söhlde given by the Loges Kalk- und Kreidewerk. We thank Benjamin Besen and Patrick Göhring (both Hildesheim) for their assistance in the field, Edina Merdan (Berlin) for help in core sampling and digital imaging, and Jan Evers (Berlin) to support the photography of foraminifers. Finally, we would like to thank Florian Witzmann (Berlin) for the professional editorial work.

3.12 References

Alegret, L. and Thomas, E. 2001. Upper Cretaceous and lower Paleogene benthic foraminifera from northeastern Mexico. M*icropaleontology*, 47 (4), 269–316.

Akker van den, T.J.H.A., Kaminski, M.A., Gradstein, F.M. and Wood, J. 2000. Campanian to Palaeocene biostratigraphy and palaeoenvironments in the Foula Sub-basin, west of the Shetland Islands, UK. *Journal of Micropalaeontology*, 19 (1), 23–43, https://doi:10.1144/jm.19.1.23.

Badaye, H. 1986. Multistratigraphische Untersuchungen im Cenoman und Turon des Lichtenberger Höhenzuges unter besonderer Berücksichtigung der Kalkbrüche Baddeckenstedt und Groß-Elbe. Diploma thesis, *Freie Universität Berlin*, 117pp. [unpublished].

Bąk, K. 2000. Biostratigraphy of deep-water agglutinated Foraminifera in Scaglia Rossa-type deposits of the Pieniny Klippen Belt, Carpathians, Poland. In: Hart, M.B., Kaminski, M.A. and Smart, C.W. (Eds.) Proceedings of the Fifth International Workshop on Agglutinated Foraminifera. *Grzybowski Foundation Special Publication*, 7, 15–41.

Bąk, K. 2007. Deep-water facies succession around the Cenomanian-Turonian boundary in the Outer Carpathian basin: Sedimentary, biotic and chemical records in the Silesian Nappe, Poland. *Palaeogeographie, Palaeoclimatology, Palaeoecology*, 248, 255–290.

Bąk, K., Bąk, M., Geroch, S. and Manecki, M. 1997. Biostratigraphy and paleoenvironmental analysis of benthic foraminifera and radiolarians in Paleogene variegated shales in the Skole unit, Polish Flysch Carpathians. *Annales Societatis Geologorum Poloniae*, 67, 135–154.

Barnard, T. and Banner, F.T. 1953. Arenaceous Foraminifera from the Upper Cretaceous of England. *The Quarterly Journal of the Geological Society*, 109 (1–4), 173–216.

Bartenstein, H. 1952. Taxonomische Bemerkungen zu den *Ammobaculites*, *Haplophragmium*, *Lituola* und verwandten Gattungen (For.). *Senckenbergiana*, 33, 313–342.

Berggren, W.A. and Kaminski, M.A. 1990. Abyssal Agglutinates: Back to Basics. In: Hemleben, C., Kaminski, M.A., Kuhnt, W. and Scott, D.B. (Eds.) Paleoecology, Biostratigraphy, Paleoceanography and Taxonomy of Agglutinated Foraminifera. NATO ASI Series C327, *Kluwer Academic Publishers*, 53–76.

Berry, E.W. 1928. The smaller foraminifera of the middle *Lobitos* shales of northwestern Peru. *Eclogae Geologae Helvetiae*, 21, 390–405.

Berthelin, M. 1880. Mémoire sur les foraminifères fossiles de l'étage Albien de Montcley (Doubs). *Mémoirs de Société géologique de France*, 3éme Sér, 1, 85 pp.

Blumenberg, M. and Wiese, F. 2012. Imbalanced nutrients as triggers for black shale formation in a shallow shelf setting during the OAE 2 (Wunstorf, Germany). *Biogeosciences*, 9, 4139-4153, https://doi:10.5194/bg-9-4139-2012.

Bornemann, A., Erbacher, J., Heldt, M., Kollaske, T., Wilmsen, M., Lübke, N., Huck, S., Vollmar, N. M. and Wonik, T. 2017. The Albian–Cenomanian transition and Oceanic Anoxic Event 1d – an example from the Boreal Realm. *Sedimentology*, 64, 44–65, https://doi:10.1111/sed.12347.

Brady, H.B. 1871. On *Saccammina Carteri*, a new Foraminifer from the Carboniferous limestone of Northumberland. *Journal of Natural History*, Ser. 4, 7 (21), 177–184.

Brady, H.B. 1879. Notes on some of the reticularian Rhizopoda of the “CHALLENGER” Expedition; Part 1. On new or little known Arenaceous types. *Quarterly Journal of Microscopical Sciences*, 19, 20–67.

Brady, H.B. 1884. Report on the Foraminifera dredged by H.M.S. Challenger during the years 1873 – 1876. *Report on the Scientific Results of the Voyage of the HMS Challenger Zoology*, 9 (22), 814 pp., London.

Brotzen, F. 1936. Foraminifera aus dem schwedischen untersten Senon von Eriksdal in Schonen. *Sverige Geologiska Undersokning*, Ser. C, 396, (30/3), 1–206.

Bubík, M. 1995. Cretaceous to Paleogene agglutinated foraminifera of the Bílé Karpaty unit (West Carpathians, Czech Republic). In: Kaminski, M.A., Geroch, S. and Gasinski, M.A. (Eds.) Proceedings of the Fourth International Workshop on agglutinated Foraminifera. *Grzybowski Foundation Special Publication*, 3, 71–116.

Bubík, M. 2019. Remarks on the quantitative analysis of deep-sea agglutinated foraminiferal taphocoenoses with special attention to tubular astrorhizids. *Micropaleontology*, 65 (1), 63–74.

Carsey, D.O. 1926. Foraminifera of the Cretaceous of central Texas. *University of Texas bulletin*, 2612, 56 pp.

Carter, D.J. and Hart, M.B. 1977. Aspects of mid-Cretaceous stratigraphical micropalaeontology. *Bulletin of the British Museum (Natural History) Geology*, 135 pp.

Cetean, C.G., Bălc, R., Kaminski, M.A. and Filipescu, S. 2011. Integrated biostratigraphy and palaeoenvironments of an upper Santonian–upper Campanian succession from the southern part of the Eastern Carpathians, Romania. *Cretaceous Research*, 32 (5), 575–590, https://doi:10.1016/j.cretres.2010.11.001.

Chapman, F. 1892. 7. – The Foraminifera of the Gault of Folkestone. 2. *Journal of Micropalaeontology*, 12 (3), 319–330.

Charnock, M.A. and Jones, R.W. 1990. Agglutinated foraminifera from the Paleogene of the North Sea. In: Hemleben, C., Kaminski, M.A., Kuhnt, W. and Scott, D.B. (Eds.) Paleoecology, biostratigraphy, paleoceanography and taxonomy of agglutinated foraminifera. NATO ASI Ser. C327, *Kluwer Academic Publishers*, 139–244.

Coccioni, R., Galeotti, S. and Gravili, M. 1995. Latest Albian–earliest Turonian deep-water agglutinated foraminifera in the Bottaccione section (Gubbio, Italy). Biostratigraphic and palaeoecologic implications. *Revista Española de Paleontología*, 10 (3), 135–152.

Cushman, J.A. 1932. *Textularia* and related forms from the Cretaceous. *Contributions from the Cushman Laboratory for Foraminiferal Research*, 8, 86–96.

Cushman, J.A. 1934. The generic position of "*Cornuspira cretacea* Reuss". *Contributions from the Cushman Laboratory for Foraminiferal Research*, 10, 44–47.

Cushman, J.A. 1936. New genera and species of the families Verneuilinidae and Valvulinidae and of the subfamily Virgulininae. *Cushman Laboratory for Foraminiferal Research Special Publication*, 6, 1–71.

Cushman, J.A. 1937. A monograph of the foraminiferal family Verneuilinidae. *Cushman Laboratory for Foraminiferal Research Special Publication*, 8, 1–210.

Cushman, J.A. and Jarvis, P.W. 1928. Cretaceous foraminifera from Trinidad. *Contributions from the Cushman Laboratory for Foraminiferal Research*, 4, 85–103.

Cushman, J.A. and Renz, H.H. 1946. The foraminiferal fauna of the Lizard Springs formation of Trinidad, British West Indies. *Cushman Laboratory for Foraminiferal Research Special Publication*, 18, 1–48.

Deeke, W. 1884. Die Foraminiferenfauna der Zone des *Stephanoceras humphriesianum* im Unter-Elsass. *Abhandlungen zur geologischen Specialkarte von Elsass-Lothringen*, 4, 1–68.

De Rijk, S., Jorissen, F.J., Rohling, E.J. and Troelstra, S.R. 2000. Organic flux control on bathymetric zonation of Mediterranean benthic foraminifera. Marine Micropaleontology, 40 (3), 151–166.

De Montfort, P.D. 1808. Conchyliologie systématique et classification méthodique des coquilles. vol. 1, *Schoell*, Paris, 409 pp.

D'Orbigny, A. 1840. Paléontologie française: Description zoologique et géologique de tous les animaux mollusques et rayonnés fossiles de France. Terrains crétacés. mollusques céphalopodes, *Cosson* Paris, 696 pp.

D'Orbigny, A. 1846. Die fossilien Foraminiferen des tertiären Beckens von Wien, entdeckt von seiner Excellenz Ritter Joseph von Hauer. *Gide et Comp*. Paris, 412 pp.

D'Orbigny, A. 1850–1852. Prodrome de paléontologie stratigraphique universelle des animaux mollusques et rayonnés faisant suite au cours élémentaire de paléontologie et de géologie stratigraphiques. *Masson* Paris. 1, 394 pp.; 2, 427 pp.; 3, 389 pp.

Dylążanka, M. 1923. Warstwy inoceramowe z łomu w Szymbarku koło Gorlic. *Annales Societatis Geologorum Poloniae*, 1, 36–80.

Earland, A. 1933. Foraminifera. Part 2. South Georgia. *Discovery Reports*, 7, 29–138.

Erbacher, J., Mutterlose, J., Wilmsen, M. and Wonik, T. 2007. The Wunstorf Drilling Project: coring a global stratigraphic reference section of the Oceanic Anoxic Event 2. *Scientific Drilling*, 4, 19–21.

Erbacher, J., Bornemann, A., Petrizzo, M.R. and Huck, S. 2020. Chemostratigraphy and stratigraphic distribution of keeled planktonic foraminifera in the Cenomanian of the North German Basin. *Journal of Applied and Regional Geology*, 2, 1–13, https://doi: 10.1127/zdgg/2020/0211.

Ernst, G. and Rehfeld, U. 1997. Transgressive development in the Early Cenomanian of the Salzgitter area (northern Germany) recorded by sea level controlled eco- and litho-events, *Freiberger Forschungshefte* H., 468, 79–107.

Ernst, G. and Rehfeld, U. 1998. Cenomanian-Turonian of Baddeckenstedt. In: Mutterlose, J., Bornemann, A., Rauer, S., Spaeth, C. and Wood, C.J. (Eds.) Key localities of the Northwest European Cretaceous. *Bochumer Geologische und Geotechnische Arbeiten*, 48, 91–94.

Ernst, G. and Wood, C.J. 1995. Die tiefere Oberkreide des subherzynen Niedersachsens. *Terra Nostra*, 5, 41–84.

Ernst, G. and Wood, C.J.: Söhlde quarries, In: Mutterlose, J., Wippich, M.G.E. and Geisen, M. (Eds.) Cretaceous Depositional Environments of NW Germany. *Bochumer Geologische und Geotechnische Arbeiten*, 46, 55–61.

Ernst, G., Schmid, F., Seibertz, E. and Wood, C.J. 1983. Event-Stratigraphie im Cenoman und Turon von NW-Deutschland. *Zitteliana*, 10, 531–554.

Ernst, G., Niebuhr, B., Wiese, F. and Wilmsen, M.1996. Facies development, basin dynamics, event correlation and sedimentary cycles in the Upper Cretaceous of selected areas of Germany and Spain. In: Reitner, J., Neuweiler, F. and Gunkel, F. (Eds.) Global and regional controls on biogenic sedimentation. II. Cretaceous sedimentation, Research Reports. *Göttinger Arbeiten zur Geologie und Paläontologie*, Sb3, 87–100.

Ernst, G., Wood, C.J. and Rehfeld, U. 1998. Cenomanian–Turonian of Söhlde, In: Mutterlose, J., Bornemann, A., Rauer, S., Spaeth, C. and Wood, C.J. (Eds.) Key Localities of the Northwest European Cretaceous. *Bochumer Geologische und Geotechnische Arbeiten*, 48, 102–120.

Fenner, J., Bruns, A., Cepek, P., Köthe, A., Owen, H.G., Prauss, M., Riegel, W., Thies, A., Tyszka, J., Weiß, W. and Wiedmann, J. 1996. Palaeontological results from the Boreal Albian (Cores Kirchrode I and II), biostratigraphy, palaeoenvironment and cycle analysis. In: Reitner, J., Neuweiler, F. and Gunkel, F. (Eds.) Global and regional controls on biogenic sedimentation. *Göttinger Arbeiten zur Geologie und Paläontologie*, Sb3, 5–12.

Fisher, R.A., Corbet, A.S. and Williams, C.B. 1943. The relation between the number of species and the number of individuals in a random sample of an animal population. *The Journal of Animal Ecology*, 42–58.

Franke, A. 1928. Die Foraminiferen der Oberen Kreide Nord-und Mitteldeutschlands. *Abhandlungen der Preußischen Geologischen Landesanstalt*, n. F. 111, 1–207.

Frentzen, K. 1944. Die agglutinierenden Foraminiferen der Birmensdorfer Schichten (Transversarius-Zone in Schwammfazies) des Gebietes um Blumberg in Baden. *Paläontologische Zeitschrift*, 23 (3–4), 317–343.

Frenzel, P. 2000. Die benthischen Foraminiferen der Rügener Schreibkreide (Unter-Maastricht, NE-Deutschland), *Neue Paläontologische Abhandlungen*, 3, pp. 361.

Frieg, C. 1980. Neue Ergebnisse zur Systematik sandschaliger Foraminiferen im Cenoman des südwestlichen Münsterlandes. *Paläontologische Zeitschrift*, 54, (3), 225–240.

Frieg, C. 1989. Über das Auftreten und den Kammerbau der Foraminifere *Pseudotextulariella cretosa* (CUSHMAN) in Nordwestdeutschland, Geologisches Jahrbuch, 113, 359–371.

Frieg, C. and Price, R.J. 1982. The subgeneric classification of *Arenobulimina*, In: Banner, F.T. and Lord, A.R. (Eds.) Aspects of Micropalaeontology. *Springer*, 42–80.

Frieg, C. and Kemper, E. 1989. Mikropaläontologische Gliederung und Abgrenzung von Ober-Alb und Unter-Cenoman in Nordwestdeutschland. *Geologisches Jahrbuch*, 113, 73–193.

Fuchs, W. 1971. Eine alpine Foraminiferenfauna des tieferen Mittel-Barreme aus den Drusbergschichten vom Ranzenberg bei Hohenems in Vorarlberg (Österreich). *Abhandlungen der Geologischen Bundesanstalt*, 27, 1–49.

Gale, A. and Christensen, W.K. 1996. Occurrence of the belemnite *Actinocamax plenus* in the Cenomanian of SE France and its significance. *Bulletin of the Geological Society of Denmark*, 43, 68–77.

Gale, A., Kennedy, W., Burnett, J., Caron, M. and Kidd, B. 1996. The Late Albian to Early Cenomanian succession at Mont Risou near Rosans (Drôme, SE France): an integrated study (ammonites, inoceramids, planktonic foraminifera, nannofossils, oxygen and carbon isotopes). *Cretaceous Research*, 17, 515-606, https//doi:10.1006/cres.1996.0032.

Gawor-Biedowa, E. 1969. The genus *Arenobulimina* Cushman from the Upper Albian and Cenomanian of the Polish lowlands. *Annales Societatis Geologorum Poloniae*, 39 (1–3), 73–102.

Gawor-Biedowa, E. 1972. The Albian, Cenomanian and Turonian foraminifers of Poland and their stratigraphic importance. *Acta Palaeontologica Polonica*, 17, (1), 3–183.

Geroch, S. and Kaminski, M.A. 1995. An emendation of some Cretaceous species of "*Reophax*" (Foraminiferida) from northwest Europe and Poland. In: Kaminski, M.A., Geroch, S. and Gasinski, M.A. (Eds.) Proceedings of the Fourth International Workshop on agglutinated Foraminifera. *Grzybowski Foundation Special Publication*, 3, 117–122.

Geroch, V. S. and Nowak, W. 1984. Proposal of zonation for the Late Tithonian–Late Eocene, based upon arenaceous foraminifera from the Outer Carpathians, Poland. *Benthos*, 83, (2), 225–239.

Grabert, B. 1959. Phylogenetische Untersuchungen an *Gaudryina* und *Spiroplectinata* (Foram.). *Abhandlungen der Senckenbergischen Naturforschenden Gesellschaft*, 498, 1–71.

Gradstein, F.M. and Kaminski, M.A. 1989. Taxonomy and biostratigraphy of new and emended species of Cenozoic deep-water agglutinated foraminifera from the Labrador and North Seas. *Micropaleontology*, 35, 75–92.

Gradstein, F., Kaminski, M.A. and Agterberg, F. 1999. Biostratigraphy and paleoceanography of the Cretaceous seaway between Norway and Greenland. Earth-Science Reviews, 46, (1), 27–98, https://doi:10.1016/S0012-8252(99)00018-5.

Gradstein, F., Ogg, J.G., Schmitz, M. and Ogg, G. 2020. Geologic Time Scale 2020. 2nd Edition, *Elsevier*, pp.

Grzybowski, J. 1896. Otwornice czerwonych ilow z Wadowic. Rozprawy Wydzialu Matematyczno-Przyrodniczego, *Akademia Umiejętności w Krakowie*, serya 2, 30, 261–308, 1896.

Grzybowski, J. 1898. Otwornice pokladow naftonosnych okolicy Krosna. Rozprawy Wydzialu Matematyczno-Przyrodniczego, *Akademia Umiejętności w Krakowie*, serya 2, 33, 257–305.

Grzybowski, J. 1901. Otwornice warstw inoceramowych okolicy Gorlic. Rozprawy Wydzialu Matematyczno-Przyrodniczego, *Akademia Umiejętności w Krakowie*, 41, 201–286.

Haig, D.W. and Lynch, D.A. 1993. A late early Albian marine transgressive pulse over northeastern Australia, precursor to epeiric basin anoxia: Foraminiferal evidence. *Marine Micropaleontology*, 22, 331–362.

Hammer, Ø., Harper, D.A.T. and Ryan, P.D. 2001. PAST: Paleontological Statistics Software Package for Education and Data Analysis, *Palaeontologica Electronica*, 4 (1), 1–9.

Hanzlíková, E. 1972. Carpathian Upper Cretaceous foraminifera from Moravia (Turonian–Maastrichtian). *Rozpravy Ústavu Geologického*, 39, 5–160.

Haq, B.U. 2014. Cretaceous eustasy revisited. *Global Planetary Change*, 113, 44–58, https://doi:10.1016/j.gloplacha.2013.12.007.

Haq, B.U., Hardenbol, J.A.N. and Vail, P.R. 1987. Chronology of fluctuating sea levels since the Triassic. *Science*, 235 (4793), 1156–1167.

Hart, M.B., Fogerty, T. and Smart, C.W. 2020. Foraminifera of the Gault Clay Formation: an update. *Proceedings of the Geological Association*, 131, 3–4, 386–396, https://doi:10.1016/j.pgeola.2019.10.003, 2020.

Harloff, J. and Mackensen, A. 1997. Recent benthic foraminiferal associations and ecology of the Scotia Sea and Argentine Basin. *Marine Micropaleontology*, 31, (1), 1–29, https://doi:10.1016/S0377-8398(96)00059-X.

Helmond, N.A.G.M. van, Sluijs, A., Sinninghe Damste, J.S., Reichart, G.-J., Voigt, S., Erbacher, J., Pross, J. and Brinkhuis, H. 2015. Freshwater discharge controlled deposition of Cenomanian-Turonian black shales on the NW European epicontinental shelf (Wunstorf, northern Germany). *Climate of the Past*, 11, 495–508, https://doi:10.5194/cp-11-495-2015.

Hemleben, C. and Troester, J. 1984. Campanian–Maastrichtian deep-water foraminifers from Hole 543A, Deep Sea Drilling Project. *Initial Reports of the Deep Sea Drilling Project*, 78A, 509–532.

Hercogová, J. and Kriz, J. 1983. New Hemisphaeramminინae (Foraminifera) from the Bohemian Cretaceous basin (Cenomanian). *Věstník Ústředního ústavu geologického*, 58 (4), 205–215.

Hetzel, A., März, C., Vogt, C. and Brumsack, H.-J. 2011. Geochemical environment of Cenomanian–Turonian black shale deposition at Wunstorf (northern Germany). *Cretaceous Research*, 32, 480–494, https://doi:10.1016/j.cretres.2011.03.004.

Hiss, M.: Kreide. In: Geologischer Dienst Nordrhein-Westfalen (Eds.) Geologie im Münsterland, 41–63, 1995.

Hiss, M., Kaplan, U. and Wilmsen, M. 2007a. Herbram-Formation. In: Niebuhr, B., Hiss, M., Kaplan, U., Tröger, K.-A., Voigt, S., Voigt, T., Wiese, F. and Wilmsen, M. (Eds.) Lithostratigraphie der norddeutschen Oberkreide. *Schriftenreihe der Deutschen Gesellschaft für Geowissenschaften*, 55, 30–32.

Hiss, M., Kaplan, U. and Wilmsen, M. 2007b. Brochterbeck-Formation. In: Niebuhr, B., Hiss, M., Kaplan, U., Tröger, K.-A., Voigt, S., Voigt, T., Wiese, F. and Wilmsen, M. (Eds.) Lithostratigraphie der norddeutschen Oberkreide. *Schriftenreihe der Deutschen Gesellschaft für Geowissenschaften*, 55, 34–35.

Hiss, M., Kaplan, U. and Wiese, F. 2007c. Hesseltal-Formation. In: Niebuhr, B., Hiss, M., Kaplan, U., Tröger, K.-A., Voigt, S., Voigt, T., Wiese, F. and Wilmsen, M. (Eds.) Lithostratigraphie der norddeutschen Oberkreide. *Schriftenreihe der Deutschen Gesellschaft für Geowissenschaften*, 55, 37–38.

Holbourn, A.E. and Kaminski, M.A. 1997. Lower Cretaceous deep-water benthic foraminifera of the Indian Ocean: a synthesis of DSDP & ODP material. *Grzybowski Foundation Special Publication*, 4, 172 pp.

Huss, F. 1966. Otwornice aglutynujace serii podslaskiej jednostki roponosnej Weglowki (Polskie Karpaty Fliszowe)(Agglutinated foraminifera of the oil-bearing subsilesian series in Weglowka (Polish Flysch Carpathians). *Prace Geologiczne, Polska Akademia Nauk*, 34, 7–76.

Janetschke, N., Niebuhr, B. and Wilmsen, M. 2015. Inter-regional sequence-stratigraphical synthesis of the Plänerkalk, Elbtal and Danubian Cretaceous groups (Germany): Cenomanian–Turonian correlations around the Mid-European Island. *Cretaceous Research*, 56, 530–549, https://doi:10.1016/j.cretres.2015.04.007.

Jarvis, I., Gale, A.S., Jenkyns, H.C. and Pearce, M.A. 2006. Secular variation in Late Cretaceous carbon isotopes: a new δ13C carbonate reference curve for the Cenomanian–Campanian (99.6–70.6 Ma). *Geological Magazine*, 143, 561–608, https://doi:10.1017/S0016756806002421.

Jenkyns, H. 1980. Cretaceous anoxic events: from continents to oceans. *Journal of the Geological Society*, 137, 171–188, https://doi:10.1144/gsjgs.137.2.0171.

Jones, R.W. and Charnock, M.A. 1985. “Morphogroups” of agglutinated foraminifera. Their life positions and feeding habits and potential applicability in (paleo)ecological studies. *Revue de Paléobiologie*, 4, (2), 311–320.

Jones, T.R. and Parker, W.K. 1860. On the Rhizopodal fauna of the Mediterranean compared with that of the Italian and some other Tertiary deposits. *Quarterly Journal of the Geological Society*, 16, 292–307.

Jorissen, J.J., Stiger, H.C. and Widmark, J.G.V. 1995. A conceptual model explaining benthic foraminiferal microhabitats. *Marine Micropaleontology*, 26, 3-15.

Józsa, Š. 2017a. Field stop 1: Vršatec – Upper Cretaceous microfauna of the oceanic red beds. In: Soták, J., Hudáčková, N. and Michalík, J. (Eds.) Microfauna and biostratigraphy of the Mesozoic and Cenozoic formations of the Western Carpathians: Guidebook of the IWAF-10 field trip to Middle Valley and Malé Karpaty Mts. Bratislava. *Earth Science Institute, Slovak Academy of Sciences; Bratislava*, 41–47.

Józsa, Š. 2017b. Deep water agglutinated foraminifera from the Jurassic/Cretaceous boundary and paleoenvironmental settings of the Maiolica type facies from the Czorstyn ridge (Pieniny Klippen Belt, Western Carpathians). *Rivista Italiana di Paleontologia e Stratigrafia*, 123 (3), 387–398.

Józsa, Š. 2019. Early Tithonian deep-water colonization by benthic foraminifera in the Magura Basin (Pieniny Klippen Belt, Western Carpathians): a clue to the origins of deep-water foraminifera. *Rivista Italiana di Paleontologia e Stratigrafia*, 125 (2), 401–420.

Józsa, Š., Schlögl, J., Meister, C. and Golej, M. 2018. Lower Sinemurian – upper Pliensbachian smaller agglutinated foraminiferal events from the eastern part of the Pieniny Klippen Belt (Transcarpathian Ukraine, Western Carpathians). *Micropaleontology*, 64 (5-6), 493–505.

Kaminski, M.A. and Geroch, S. 1993. A revision of foraminiferal species in the Grzybowski Collection. In: Kaminski, M.A., Geroch, S. and Kaminski, D. (Eds.) The Origins of Applied Micropaleontology: The School of Jozef Grzybowski. *Grzybowski Foundation Special Publication*, 1, 293–323.

Kaminski, M.A. and Gradstein, F.M. 2005. Atlas of Paleogene cosmopolitan deep-water agglutinated foraminifera. *Grzybowski Foundation Special Publication*, 10, 1–547.

Kaminski, M.A., Gradstein, F. and Berggren, W. 1988. Flysch-type agglutinated foraminiferal assemblages from Trinidad: taxonomy, stratigraphy and paleobathymetry. *Abhandlungen der geologischen Bundesanstalt*, 41, 155–227.

Kaminski, M.A., Boersma, E., Tyszka, J. and Holbourn, A.E. 1995. Response of deep-water agglutinated foraminifera to dysoxic conditions in the California Borderland basins. In: Kaminski, M.A., Geroch. S. and Gasinski, M.A. (Eds.) Proceedings of the Fourth International Workshop on agglutinated Foraminifera. *Grzybowski Foundation Special Publication*, 3, 131–140.

Kaminski, M.A., Cetean, C.G. and Neagu, T. 2010. *Rectogerochammina eugubina* nov. gen., nov. sp., a new agglutinated foraminifer from the Upper Cretaceous of Gubbio, Italy. *Revue de micropaléontologie*, 53 (2), 121–124.

Kaminski, M.A., Cetean, C.G., Bălc, R. and Coccioni, R. 2011. Upper Cretaceous deep-water agglutinated foraminifera from the Contessa Highway Section, Umbria-Marche basin, Italy: taxonomy and biostratigraphy. In: Kaminski, M.A. and Filipescu, S. (Eds.) Proceedings of the Eighth International Workshop on agglutinated Foraminifera. *Grzybowski Foundation Special Publication*, 16, 71–106.

Kaminski, M.A., Alegret, L., Hikmahtiar, S. and Waśkowska, A. 2021. The Paleocene of IODP Site U1511, Tasman Sea: A lagerstatte deposit for deep-water agglutinated foraminifera. *Micropaleontology*, 67 (4), 341–364.

Kennedy, W.J., Gale, A., Lees, J. and Caron, M. 2004. The global boundary stratotype section and point (GSSP) for the base of the Cenomanian Stage, Mont Risou, Hautes-Alpes, France. *Episodes*, 27, 21–32.

Krasheninnikov, V. 1973. Cretaceous benthonic foraminifera, Leg 20, Deep Sea Drilling Project. *Initial Reports of the Deep Sea Drilling Project*, 20, 205–221.

Krasheninnikov, V. 1974. Upper Cretaceous benthonic agglutinated foraminifera, Leg 27 of the Deep Sea Drilling Project. *Initial Reports of the Deep Sea Drilling Project*, 27, 631–661.

Kuhnt, W. 1990. Agglutinated foraminifera of western Mediterranean Upper Cretaceous pelagic limestones (Umbrian Apennines, Italy, and Betic Cordillera, Southern Spain). *Micropaleontology*, 36, 297–330.

Kuhnt, W. and Kaminski, M.A. 1990. Paleoecology of Late Cretaceous to Paleocene deep-water agglutinated foraminifera from the North Atlantic and Western Tethys. In: Hemleben, C., Kaminski, M.A., Kuhnt, W. and Scott, D.B. (Eds.) Paleoecology, biostratigraphy, paleoceanography and taxonomy of agglutinated foraminifera. NATO ASI Ser. C327, *Kluwer Academic Publishers*, 433–506.

Kuhnt, W. and Kaminski, M.A. 1997. Cenomanian to lower Eocene deep-water agglutinated foraminifera from the Zumaya section, northern Spain. *Annales Societatis Geologorum Poloniae*, 67 (2–3), 257–270.

Kuhnt, W., Kaminski, M.A. and Moullade, M. 1989. Late Cretaceous deep-water agglutinated foraminiferal assemblages from the North Atlantic and its marginal seas. *Geologische Rundschau* ,78, (3), 1121–1140.

Kuhnt, W., Geroch, S., Kaminski, M.A., Moullade, M. and Neagu, T. 1992. Upper Cretaceous abyssal claystones in the North Atlantic and Western Tethys: current status of biostratigraphical correlation using agglutinated foraminifers and palaeoceanographic events. *Cretaceous Research*, 13, (5–6), 467–478, https://doi:10.1016/0195-6671(92)90011-E.

Leary, P. N. 1987. The Late Cenomanian Anoxic Event; Implications for foraminiferal evolution. PhD thesis, *Plymouth University*, 325 pp.

Linnert, C., Mutterlose, J. and Erbacher, J. 2010. Calcareous nannofossils of the Cenomanian/Turonian boundary interval from the Boreal Realm (Wunstorf, northwest Germany). *Marine Micropaleontology*, 74, 38–58.

Loeblich, A.R. and Tappan, H. 1957. Eleven new genera of foraminifera. *Bulletin of the American Natural History Museum*, 215, 223–232.

Loeblich, A.R. and Tappan, H. 1982. A revision of mid-Cretaceous textularian foraminifers from Texas. *Journal of Micropalaeontology*, 1 (1), 55–69.

Loeblich, A.R. and Tappan, H. 1987. Foraminiferal genera and their classification. *Springer*, New York, 212 pp.

Magniez-Jannin, F. 1975. Les foraminifères de l'Albien de l'Aube: paléontologie, stratigraphie, écologie. *Cahiers de Paléontologie*, 416 pp.

Majzon, L. 1943. Adatok egyes Kárpátaljai flis-rétegekhez, tekintettel a Globotruncanákra (Beitrage zur Kenntniss einiger Flysch Schichten des Karpaten-Vorlandes mit Rücksicht auf die Globotruncanen). A magyar Királyi Földtani Intézet, Évkönyve. *Annales of the Hungarian Geological Institute*, 37 (1), 1–90, 91–169.

Maslakova, N. 1955. Stratigrafiya i fauna melkikh foraminifer paleogenovykh otlozhenii Vostochnykh Karpat. *Materialy po Biostratigrafi zapadnykh oblastii Ukrainskoi SSR*, 5–132.

Melinte-Dobrinescu, M.C., Roban, R.-D. and Stoica, M. 2015. Palaeoenvironmental changes across the Albian-Cenomanian boundary interval of the Eastern Carpathians. *Cretaceous Research*, 54, 68–85, https://doi:10.1016/j.cretres.2014.10.010.

Meyer, T. 1990. Biostratigraphische und sedimentologische Untersuchungen in der Plänerfazies des Cenoman von Nordwestdeutschland. *Mitteilungen aus dem Geologischen Institut der Universität Hannover*, 30, 1–114.

Mjatliuk, E.V. 1966. K vprosu o foraminiferakh c kremnevnym skeletom (On the question of foraminifera with a siliceous skeleton). *Voprosy Mikropaleontologii*, 10, 255–269.

Morozova, V. 1948. Foraminiferi nizhnemelovikh otlozhenii rayona g. sochi (Yugozapadnoi Kavkaz). *Moscov. Obshch. Ispyt. Prirodi, Otdel Geol., Byull*, 23, (3), 23–43, 1948.

Murray, J.W., Alve, E. and Jones, B.W. 2011. A new look at modern agglutinated benthic foraminiferal morphogroups: their value in palaeoecological interpretation. *Palaeogeographie, Palaeoclimatology, Palaeoecology*, 309, (3), 229-241, https://doi:10.1016/j.palaeo.2011.06.006.

Neagu, T. 1962. Studiul foraminiferelor aglutinante din argilele Cretacic superiorare de pe Valea Sadovei (Cimpulung–Moldovenesc) si bazinul superior al vaii Buzauliu. *Studii Cercetari Geologie, Academia Republicii Populare Romine, Sectia de Geologie si Geografie si Istitutul de Geologie si Geografie*, 7, 45–81.

Neagu, T. 1970. Micropaleontological and stratigraphical study of the Upper Cretaceous deposits between the upper valleys of the Buzau and Riul Negru Rivers (Eastern Carpathians). *Memorii, Institutul Geologic*, 12, Bucarest, 7–109.

Neagu, T. 1990. *Gerochammina* n.g. and related genera from the Upper Cretaceous flysch-type benthic foraminiferal fauna, Eastern Carpathians - Romania. In: Hemleben, C., Kaminski, M.A., Kuhnt, W. and Scott, D.B. (Eds.) Paleoecology, biostratigraphy, paleoceanography and taxonomy of agglutinated foraminifera. NATO ASI Ser. C327, *Kluwer Academic Publishers*, 245–265.

Niebuhr, B., Baldschuhn, R., Ernst, G., Walaszczyk, I., Weiss, W., and Wood, C.J. 1999. The Upper Cretaceous succession (Cenomanian–Santonian) of the Staffhorst Shaft, Lower Saxony, northern Germany: integrated biostratigraphic, lithostratigraphic and downhole geophysical log data. *Acta Geologica Polonica*, 49, (3), 175–213.

Niebuhr, B., Wiese, F. and Wilmsen, M. 2001. The cored Konrad 101 borehole (Cenomanian–Lower Coniacian, Lower Saxony): calibration of surface and subsurface log data for the lower Upper Cretaceous of northern Germany. *Cretaceous Research*, 22, 643–674, https://doi:10.1006/cres.2001.0283.

Niebuhr, B., Hiss, M., Kaplan, U., Tröger, K.-A., Voigt, S., Wiese, F. and Wilmsen, M. 2007. Lithostratigraphie der norddeutschen Oberkreide. *Schriftenreihe der Deutschen Gesellschaft für Geowissenschaften*, 55, 136 pp.

Olszewska, B. and Morgiel, J. 1981. Biostratigraphy of the Polish External Carpathians based on agglutinated foraminifera. *Micropaleontology*, 27 (1), 1–24.

Patterson, R.T., Haggart, J.W. and Dalby, A.P. 2010. A guide to Late Albian-Cenomanian (Cretaceous) Foraminifera from the Queen Charlotte Islands, British Columbia, Canada. *Paleontologica Electronica*, 13 (2), 1–28.

Perner, J. 1892. Über die Foraminiferen des böhmischen Cenomans. *Paleontographica Bohemiae*, 1, 65 pp.

Peryt, D., Lahodynsky, R. and Durakiewicz, T. 1997. Deep-water agglutinated foraminiferal changes and stable isotope profiles across the Cretaceous–Paleogene boundary in the Rotwand-graben section, Eastern Alps (Austria). *Palaeogeography, Palaeoclimatology, Palaeoecology*, 132, (1–4), 287–307, https://doi:10.1016/S0031-0182(97)00056-4.

Peryt, D., Alegret, L. and Molina, E. 2004. Agglutinated foraminifers and their response to the Cretaceous/Paleogene (K/P) boundary event at Aïn Settara, Tunisia. In: Bubík, M. and Kaminski, M.A. (Eds.) Proceedings of the Sixth International Workshop on agglutinated Foraminifera. *Grzybowski Foundation Special Publication*, 8, 393–412.

Philip, J. and Floquet, M. 2000. Late Cenomanian (94.7–93.5). In: Dercourt, J., Gaetani, M., Vrielynck, B., Barrier, E., Biju-Duval, B., Brunet, M.F., Cadet, J.P., Crasquin, S. and Sandulescu, M. (Eds.) Atlas Peri-Tethys palaeogeographical maps. *CCGM/CGMW*, Paris, 129–136.

Püttmann, T. and Mutterlose, J. 2021. Paleoecology of Late Cretaceous Coccolithophores: Insights From the Shallow-Marine Record. Paleoceanography and Paleoclimatology, 36, 1–20, https://doi.org/10.1029/2020PA004161.

Reuss, A. E. 1844. Geognostische Skizzen aus Böhmen. Bd. 2: Die Kreidegebilde des westlichen Böhmens, ein monographischer Versuch. Nebst Bemerkungen über die Braunkohlenlager jenseits der Elbe und eine Uebersicht der fossilen Fischreste Böhmens. Medau & Comp., Prag, 304 pp.

Reuss, A. E. 1845. Die Versteinerungen der böhmischen Kreideformation. Mit Abbildungen der neuen oder weniger bekannten Arten, Abt. 1. *Schweizerbart'sohne Verlagsbuchhandlung*, Stuttgart, 58 pp.

Reuss, A. E. 1851. Über die fossilen Foraminiferen und Entomostraceen der Septarianthone der Umgegend von Berlin. Zeitschrift der Deutschen Geologischen Gesellschaft, 3, 49–91.

Reuss, A. E. 1863. Die Foraminiferen der norddeutschen Hils und Gault. *Sitzungsberichte der Kaiserlichen Akademie der Wissenschaften. Mathematisch-Naturwissenschaftliche Classe*, 46, 5–100.

Richardt, N. and Wilmsen, M. 2012. Lower Upper Cretaceous standard section of the southern Münsterland (NW Germany): carbon stable-isotopes and sequence stratigraphy. *Newsletter on Stratigraphy*, 45, 1–24.

Robaszynski, F., Gale, A.S., Juignet, P., Amedro, F. and Hardenbol, J. 1998. Sequence stratigraphy in the Cretaceous series of the Anglo-Paris Basin: exemplified by the Cenomanian stage. In: de Graciansky, P.-C., Hardenbol, J., Jacquin, T., and Vail, P.R. (Eds.) Mesozoic and Cenozoic sequence stratigraphy of European basins. *SEPM Special Publication*, 60, 363–386.

Schmidt, U. and Jäger, R. 1993. Bestimmungstabelle für einige inkrustierende Foraminiferen aus den Unterordnungen Textulariina und Rotaliina. *Zitteliana*. 20, 171–178.

Schubert, R.J. 1902. Neue und interessante Foraminiferen aus dem südtiroler Alttertiär. Beiträge zur Paläontologie und Geologie Österreich-Ungarns und des Orients, 14, 9–26.

Schultze, F.E. 1875. Zoologische Ergebnisse der Nordseefahrt vom 21. Juli bis 9. September 1872: 1. Rhizopoden. *Jahresberichte Kommission zur Untersuchung der Deutschen Meere*, Kiel, 1872–1873, 2–3.

Seibertz, E. 2013. Geologie der Mergelkalk-Lagerstätte Wunstorf (Oberkreide, Niedersachsen), Phase IV. Auswertung der Bohrungen aus den Jahren 2011 und 2012. *Dr. Moll Bericht* 2688/12/11, Isernhagen, 61 pp., https://doi: 10.13140/RG.2.2.29006.77122.

Setoyama, E., Kaminski, MA. and Tyszka, J. 2011. Late Cretaceous agglutinated foraminifera and implications for the biostratigraphy and palaeobiogeography of the southwestern Barents Sea. In: Kaminski, M.A. and Filipescu, S. (Eds.) Proceedings of the Eighth International Workshop on agglutinated Foraminifera. *Grzybowski Foundation Special Publication*, 20, 251–309.

Setoyama, E., Kaminski, M.A. and Tyska, J. 2017. Late Cretaceous–Paleogene foraminiferal morphogroups as palaeoenvironmental tracers of the rifted Labrador margin, northern proto-Atlantic. In: Kaminski, M.A. and Alegret, L. (Eds.) Proceedings of the Ninth International Workshop on agglutinated Foraminifera. *Grzybowski Foundation Special Publication*, 22, 179–220.

Skelton, P.W. 2003. Introduction to the Cretaceous. In: P.W. Skelton (Eds.) The cretaceous world. *Cambridge University Press*, 9–41.

Sliter, W.V. 1968. Upper Cretaceous foraminifera from the southern California and northwestern Baja California, Mexico. *The University of Kansas Paleontological Contributions*, 49 (7), 141 pp.

Tappan, H. 1943. Foraminifera from the Duck Creek formation of Oklahoma and Texas. *Journal of Paleontology*, 17 (5), 467–517.

Tappan, H. 1960. Cretaceous biostratigraphy of northern Alaska. *Bulletin American Association of Petroleum Geologists*, 44, 273–297.

Ten Dam, A. 1950. Les foraminifères de l'Albien des Pays-Bas. *Société géologique de France*, 29 (63), 1–66.

Tyszka, J. 2009. Foraminiferal response to seasonality modulated by orbital cycles in the Cretaceous mid-latitudes: The Albian record from the Lower Saxony Basin. *Palaeogeography, Palaeoclimatology, Palaeecology*, 276, 148–159, https://doi:10.1016/j.palaeo.2009.03.006.

Tyszka, J. and Thies, A. 2001. *Spiroplectinata*, key benthic foraminifer genus for palaeoceanographic reconstruction of the Albian Lower Saxony Basin. *Palaeogeographie, Palaeoclimatology, Palaeecology*, 174, (1), 199–220, https://doi:10.1016/S0031-0182(01)00294-2.

Vašíćek, M. 1947. Poznámky k mikrobiostratigrafii magurského flyše na Moravě. *Věstník Státního Geologického Ústavu Československé Republiky*, 22, 235–256.

Voigt, S. and Hilbrecht, H. 1997. Late Cretaceous carbon isotope stratigraphy in Europe: correlation and relations with sea level and sediment stability. *Palaeogeographie, Palaeoclimatology, Palaeecology*, 134, 39–59, https://doi:10.1016/S0031-0182(96)00156-3.

Voigt, S. and Wiese, F. 2000. Evidence for Late Cretaceous (Late Turonian) climate cooling from oxygen-isotope variations and palaeobiogeographic changes in Western and Central Europe. *Journal of the Geological Society*, 157, 737–743, https://doi:10.1144/jgs.157.4.737.

Voigt, S., Gale, A.S. and Flögel, S. 2004. Midlatitude shelf seas in the Cenomanian–Turonian greenhouse world: Temperature evolution and North Atlantic circulation. *Paleoceanography*, 19, 1–17, https://doi:10.1029/2004PA001015.

Voigt, S., Gale, A.S. and Voigt, T. 2006. Sea-level change, carbon cycling and palaeoclimate during the Late Cenomanian of northwest Europe; an integrated palaeoenvironmental analysis. *Cretaceous Research*, 27, 836–858, https://doi:10.1016/j.cretres.2006.04.005.

Voigt, S., Aurag, A., Leis, F. and Kaplan, U. 2007. Late Cenomanian to Middle Turonian high-resolution carbon isotope stratigraphy: New data from the Münsterland Cretaceous Basin, Germany. *Earth and Planetary Science Letters*, 253, 196-210, https://doi:10.1016/j.epsl.2006.10.026.

Voigt, S., Wagreich, M., Surlyk, F., Walaszczyk, I., Uličný, D. and Čech, S. 2008a. Cretaceous. In: T. McCann (Eds.) Geology of central Europe, vol. 2. London, *The Geological Society*, 923–997.

Voigt, S., Erbacher, J., Mutterlose, J., Weiss, W., Westerhold, T., Wiese, F., Wilmsen, M. and Wonik, T. 2008b. The Cenomanian–Turonian of the Wunstorf section (North Germany): global stratigraphic reference section and new orbital time scale for Oceanic Anoxic Event 2. *Newsletter on Stratigraphy*, 43, 65–89.

Voloshina, A. 1972. Ataxophragmeids from Upper Cretaceous Deposits in the Volyn-Podol Margin of the Russian Platform. *Trudy Ukrainskogo Nauchno-Issledovatelskogo Geologorazvedochnogo Instituta*, 27, 55–130.

Waśkowska, A. 2014. Distribution of the agglutinated foraminifer *Ammolagena clavata* (Jones and Parker) in Western Tethyan Upper Cretaceous and Paleogene deep-water deposits (Outer Carpathians, Poland). *Micropaleontology*, 60 (1), 77–88.

Waters, J.A. 1927. A group of foraminifera from the Dornick Hills Formation of the Ardmore Basin. *Journal of Paleontology*, 1, (2), 129–133.

Weidich, K.F. 1990. Die kalkalpine Unterkreide und ihre Foraminiferenfauna. *Zitteliana*, 17, 1–312.

Wiese, F. 2009. The Söhlde Formation (Cenomanian, Turonian) of NW Germany: Shallow Marine Pelagic Red Beds. In: Hu, X., Wang, C., Scott, R.W., Wagreich, M and Jansa, L. (Eds.) Cretaceous Oceanic Red Beds. *SEPM Special Publication*, 91, 153–170.

Wiese, F. and Voigt, S. 2002. Late Turonian (Cretaceous) climate cooling in Europe: faunal response and possible causes. *Geobios*, 35, 65–77, https://doi:10.1016/S0016-6995(02)00010-4.

Wiese, F., Hiss, M. and Voigt, S. 2007. Söhlde-Formation. In: Niebuhr, B., Hiss, M., Kaplan, U., Tröger, K.-A., Voigt, S., Voigt, T., Wiese, F. and Wilmsen, M. (Eds.) Lithostratigraphie der norddeutschen Oberkreide, *Schriftenreihe der Deutschen Gesellschaft für Geowissenschaften*, 55, 40–41.

Wiese, F., Zobel, K. and Keupp, H. 2015. Calcareous dinoflagellate cysts and the Turonian nutrient crisis – Data from the upper Turonian of the Lower Saxony Basin (northern Germany). *Cretaceous Research*, 56, 673–688, https://doi:10.1016/j.cretres.2015.06.007.

Wiese, F., Zobel, K. and Mortimore, R.N. 2017. Intrinsic processes control late Turonian calcareous dinoflagellate cyst assemblages – A case study from the Sussex chalk (England). *Cretaceous Research*, 56, 1–12, https://doi:10.1016/j.cretres.2017.04.003.

Wiese, R., Renaudie, J. and Lazarus, D.B. 2016. Testing the accuracy of genus-level data to predict species diversity in Cenozoic marine diatoms. *Geology*, 44, (12), 1051–1054, https://doi:10.1130/G38347.1.

Wilmsen, M. 2003. Sequence stratigraphy and palaeoceanography of the Cenomanian Stage in northern Germany. *Cretaceous Research*, 24, 525–568, https://doi:10.1016/S0195-6671(03)00069-7.

Wilmsen, M. 2007. Integrated stratigraphy of the upper Lower–lower Middle Cenomanian of northern Germany and southern England. Acta Geologica Polonica, 57, 263–279.

Wilmsen, M. 2008. An Early Cenomanian (Late Cretaceous) maximum flooding bioevent in NW Europe: Correlation, sedimentology and biofacies. *Palaegeography, Palaeoclimatology, Palaeoecology*, 258, (4), 317–333, https://doi:10.1016/j.palaeo.2007.11.007.

Wilmsen, M. 2012. Origin and significance of Late Cretaceous bioevents: Examples from the Cenomanian. *Acta Palaeontologica Polonica*, 57, (4), 759–771.

Wilmsen, M. and Niebuhr, B. 2002. Stratigraphic revision of the upper Lower and Middle Cenomanian in the Lower Saxony Basin (northern Germany) with special reference to the Salzgitter area. *Cretaceous Research*, 23, 445–460, https://doi:10.1006/cres.2002.1014.

Wilmsen, M. and Voigt, T. 2006. The middle–upper Cenomanian of Zilly (Sachsen-Anhalt, northern Germany) with remarks on the *Pycnodonte* Event. *Acta Geologica Polonica*, 56, 17–31.

Wilmsen, M. and Hiss, M. 2007. Baddeckenstedt-Formation. In: Niebuhr, B., Hiss, M., Kaplan, U., Tröger, K.-A., Voigt, S., Voigt, T., Wiese, F. and Wilmsen, M. (Eds.) Lithostratigraphie der norddeutschen Oberkreide. Schriftenreihe der Deutschen Gesellschaft für Geowissenschaften, 55, 32–33.

Wilmsen, M., Niebuhr, B. and Hiss, M. 2005. The Cenomanian of northern Germany: facies analysis of a transgressive biosedimentary system. *Facies*, 51, 242–263, https://doi:10.1007/s10347-005-0058-5.

Wilmsen, M., Niebuhr, B., Wood, C.J. and Zawischa, D. 2007. Fauna and palaeoecology of the Middle Cenomanian *Praeactinocamax primus* Event at the type locality, Wunstorf quarry, northern Germany. *Cretaceous Research*, 28, (3), 428–460, https://doi:10.1016/j.cretres.2006.07.004,.

Wilmsen, M., Schumacher, D. and Niebuhr, S. 2021. The early Cenomanian *crippsi* Event at Lüneburg (Germany): palaeontological and stratigraphical significance of a widespread Late Cretaceous bioevent. *Palaeobiodiversity and Palaeoenvironments*, 101, 927–946.

Zheng, X.-Y., Jenkyns, H.C., Gale, A.S., Ward, D.J. and Henderson, G.M. 2016. A climatic control on reorganization of ocean circulation during the mid-Cenomanian event and Cenomanian-Turonian oceanic anoxic event (OAE 2): Nd isotope evidence. *Geology*, 44 (2), 151–154, https://doi:10.1130/G37354.1.

Zwaan, G.J. van der, Duijnstee, I.A.P., Dulk, M. den, Ernst, S.R., Jannink, N.T. and Kouwenhoven, T.J. 1999. Benthic foraminifers: proxies or problems? A review of paleocological concepts. Earth-Science Reviews, 46, 213–236.

Chapter 4

Agglutinated foraminifera from the Turonian–Coniacian boundary interval in Europe – an interbasinal correlation.

Submitted to *Journal of Micropalaeontology* as:

Besen, R.M., Schindler, K., Gale, A.S. and Struck, U., 2022. Agglutinated foraminifera from the Turonian–Coniacian boundary interval in Europe – stratigraphy and paleoenvironmental remarks.

Chapter 5

Turonian to Coniacian agglutinated foraminifera from a transitional facies zone – comparing calcareous and agglutinated foraminiferal assemblages.

Published as:

Besen, R.M., Achilles, M., Alivernini, M., Voigt, T., Frenzel, P. and Struck, U., 2022. Stratigraphy and palaeoenvironments in the upper Turonian to lower Coniacian of the Saxonian Cretaceous Basin (Germany) – insights from calcareous and agglutinated foraminifers. *Acta Geologica Polonica*, 72 (2), 159–186, https://doi.org/10.24425/agp.2021.139307.

Abstract

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 Brausnitzbach 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 Brausnitzbach 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 Brausnitzbach Marl deposition was characterized by moderate productivity and a generally shallower water depth.

5.1 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 depositional 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 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 morphogroups, 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).

5.2 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 in the distal regions (Figs. 5.1 and 5.2). 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; Danišík et al., 2010; Käßner et al., 2020; compiled by Voigt et al., 2021).

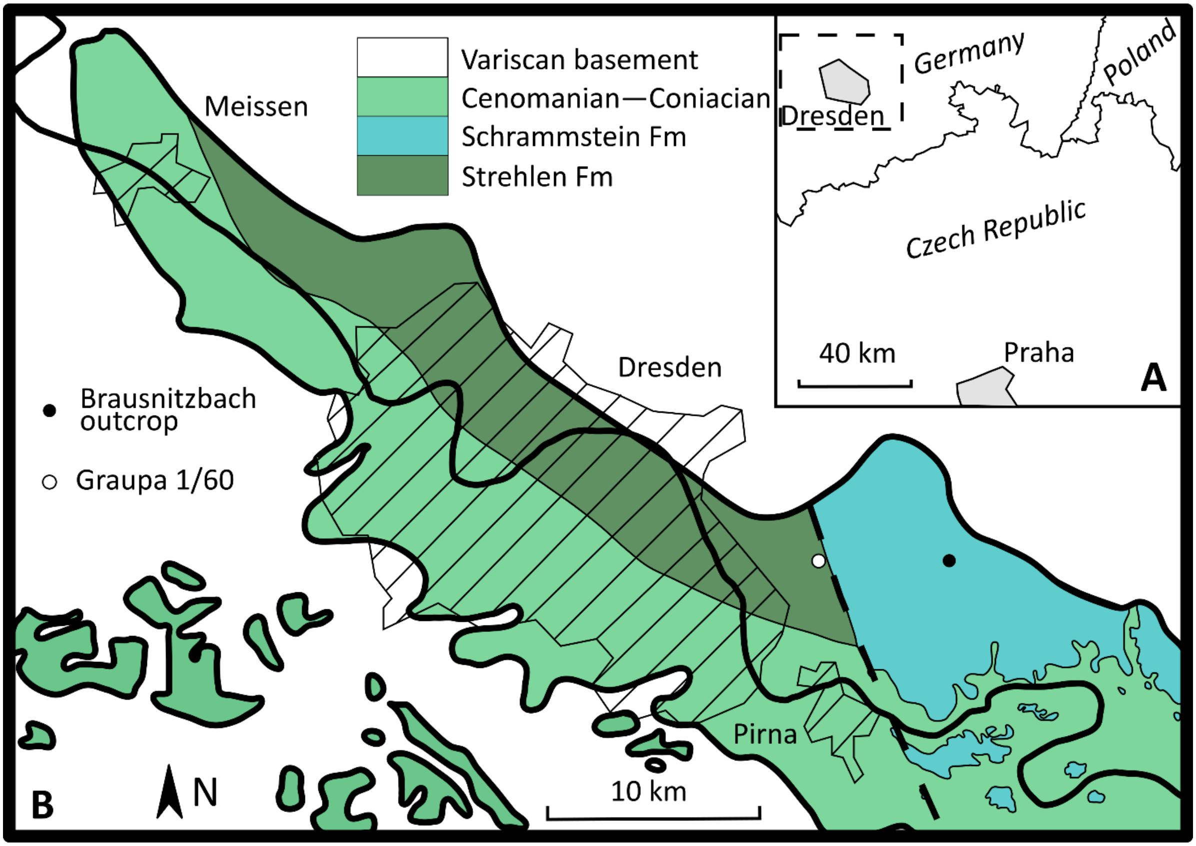


Figure 5.1. Geographical position of the study area (indicated by dashed box). B – Simplified geological map of the Dresden area; shaded areas indicate urban areas, dashed line indicates the tentative boundary between Schrammstein and Strehlen formations; redrawn and modified after Schönfeld and Voigt (2020).

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.

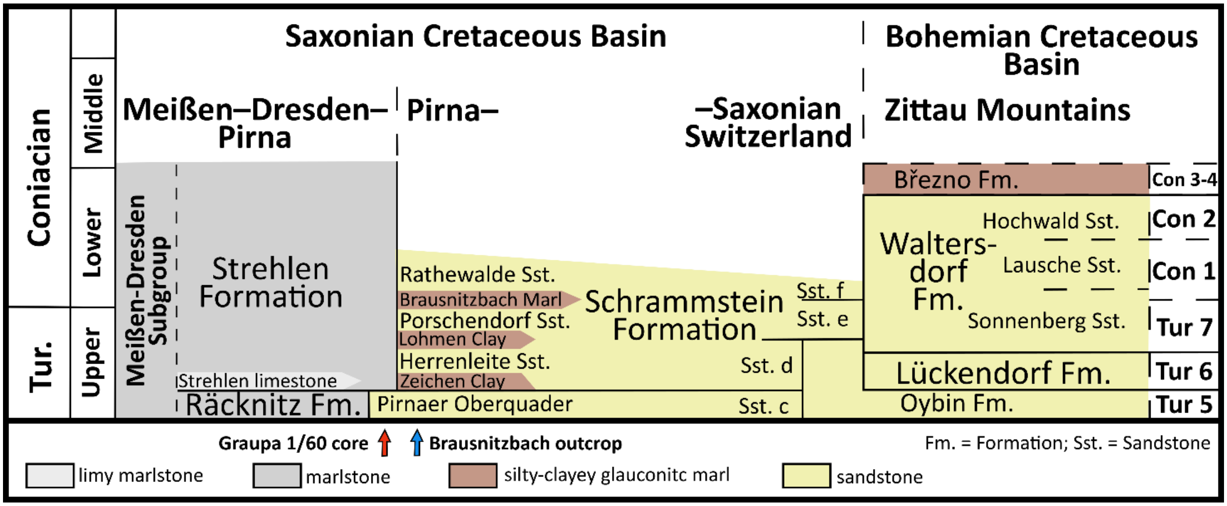


Figure 5.2. Upper Turonian to Coniacian chrono- and lithostratigraphy of the Elbtal Group in the Saxonian Cretaceous and the northwestern Bohemian Cretaceous basins; redrawn and modified after Niebuhr et al. (2020); genetic sequences adapted from Uličný et al. (2009), Nádaskay and Uličný (2014), and Nádaskay et al. (2019).

5.2.1 Graupa 60/1 borehole

The Graupa 60/1 borehole was drilled between Graupa and Hinterjessen, north of Pirna (Fig. 5.1). 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; Fig. 5.2). 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 (Fig. 5.3). The biostratigraphy is based on inoceramids (Tröger et al., 1961; Tröger and Wejda, 1997).

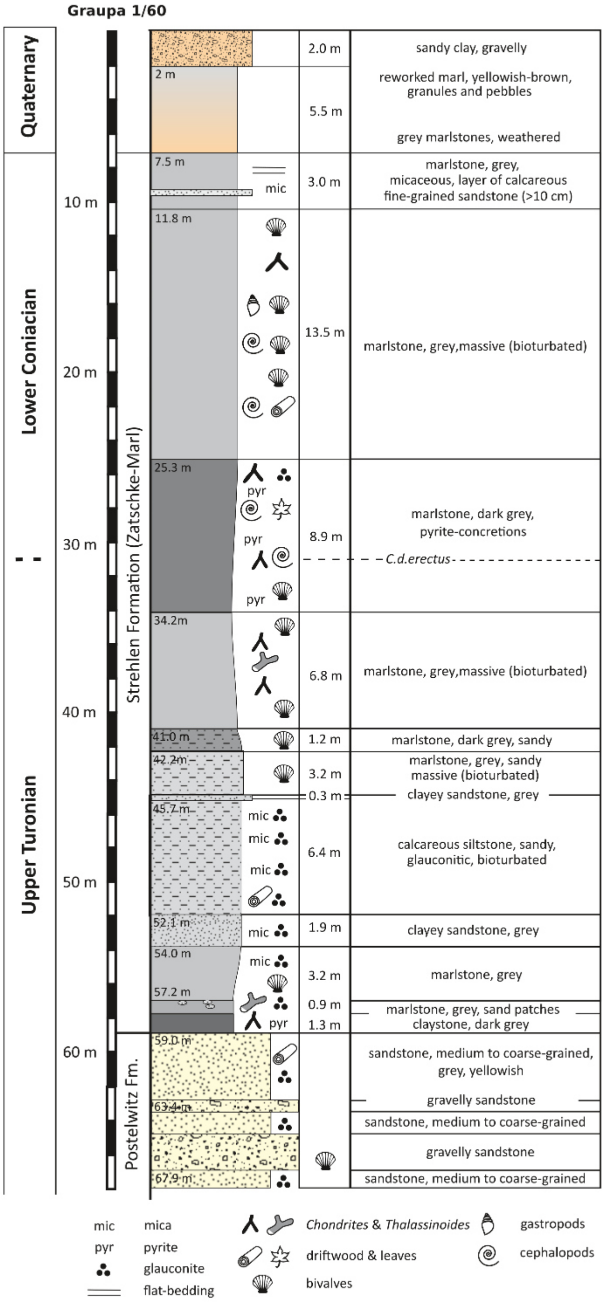


Figure 5.3. Lithological log of the upper part of the Graupa 60/1 core, lithological documentation from Tröger et al. (1961), position of the first occurrence of Cremnoceramus deformis erectus from Tröger and Wejda (1998).

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 (Figs. 5.2 and 5.3). 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 (Fig. 5.3). Dense bioturbation is expressed 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 (Fig. 5.3). Above this unit, massive, structureless grey marlstones without any bedding planes and only rare traces of bioturbation follow (Fig. 5.3). 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 *Cremnoceramus rotundatus* (sensu Tröger, 1967, non Fiege, 1930), which is considered to be a synonym of *Cremnoceramus deformis erectus* (Meek, 1877) (see Walaszczyk and Cobban, 1999, 2000 and Walaszczyk and Wood, 1999; Fig. 5.3). A revision of Cretaceous inoceramid biostratigraphy by Walaszczyk et al. (2010) proposed the base of the Coniacian at the FAD of *Cremnoceramus deformis erectus*, which now defines the Turonian/Coniacian boundary (Walaszczyk et al., 2022). Tröger and Wejda (1998) reported also the inoceramid *Cremnoceramus 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).

5.2.2 Brausnitzbach Marl

The Brausnitzbach 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 (Figs. 5.1 and 5.2). It is bordered by the Porschendorf Sandstone at the base and by the Rathewalde Sandstone at the top (Niebuhr et al. 2020; Fig. 5.2). The Rathewalde Sandstone represents the uppermost sandstone unit in the Saxonian Cretaceous Basin (Fig. 5.2) and reaches a thickness of 50–70 m.

5.3 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 Brausnitzbach Marl were split into two subsamples each and treated both with formic acid and acetic acid in combination of copper-II-sulphate. 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), 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 4.1).

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 analysis of the whole dataset. Samples with low foraminiferal abundance, e.g., Graupa 60/1 49 m and 49.4 m and the Brausnitzbach 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.

Table 5.1. Agglutinated foraminiferal morphogroups and morphotypes. Modified from Cetean et al. (2011) and Setoyama et al. (2017).

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

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.

5.4 Results

5.4.1 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 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 foraminifers 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 ca. 47 and 50 m of core depth, at least 300 specimens per sample treated with formic acid could be identified. The interval between ca. 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.

5.4.2 Distribution of foraminifers

Whiteinella spp. (Fig. 5.4A–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 foraminifers reaching 563.4 individuals per 1 g. Compared to the planktic (hyaline) foraminifers, 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 foraminifers being dominant, representing 73% of the total abundance.

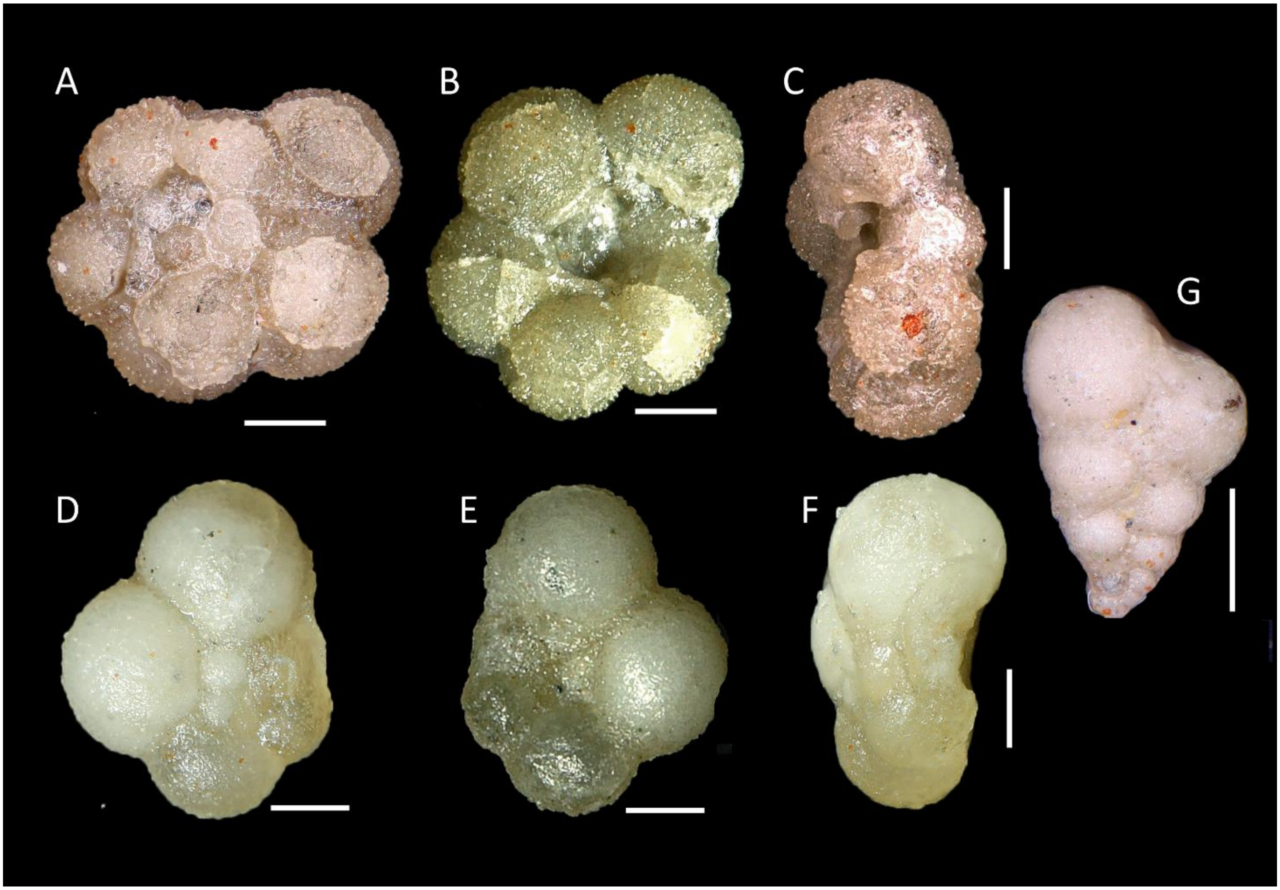
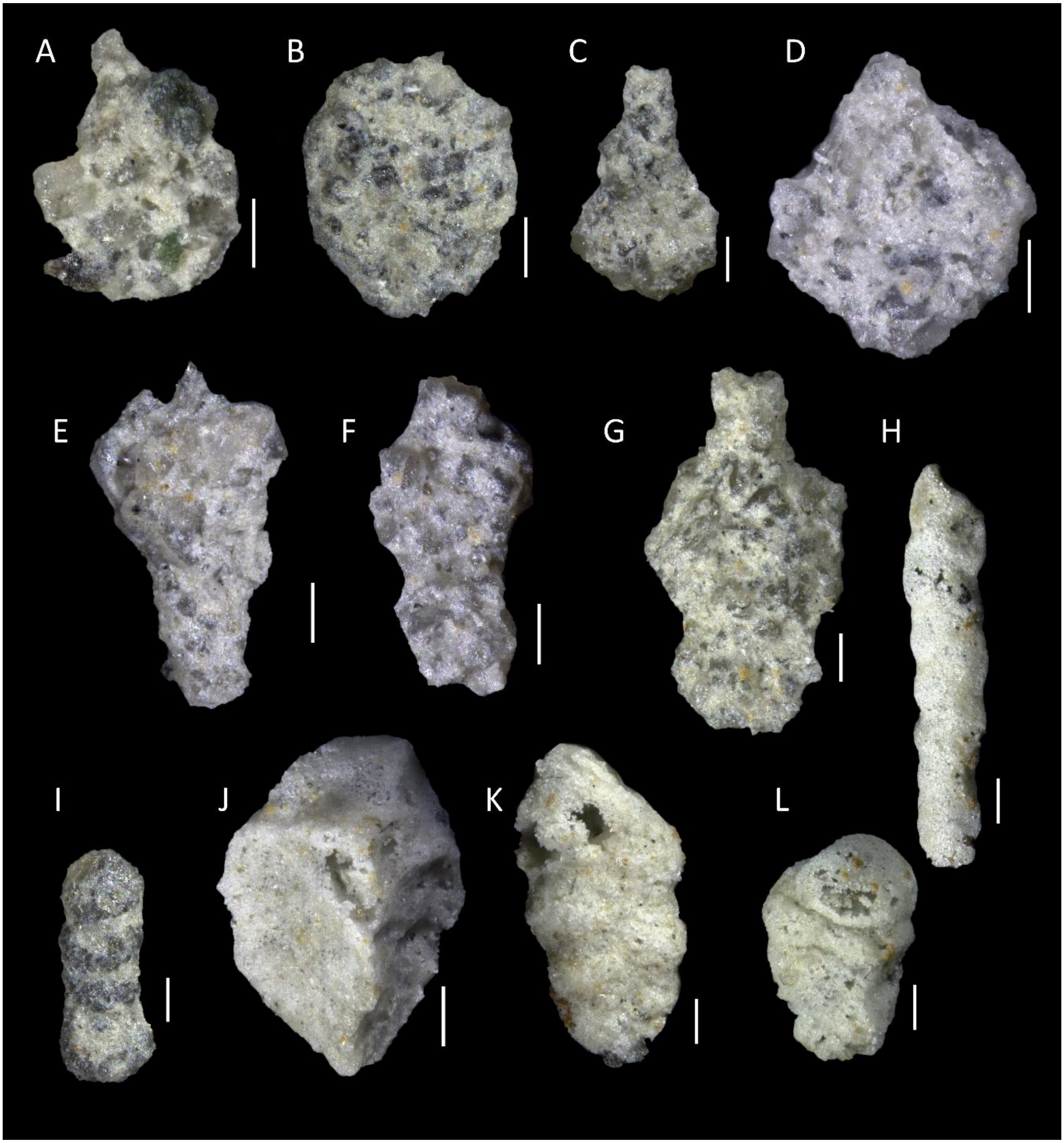


Figure 5.4. Selected planktic foraminifers from the Strehlen Formation of the Graupa 60/1 core. A–C – *Whiteinella aprica* (Loeblich and Tappan, 1961) (41 m core depth). D–F – *Whiteinella baltica* (Douglas and Rankin, 1969) (41 m core depth). G – *Planoheterohelix globulosa* (Ehrenberg, 1840) (41 m core depth). Scale bars 100 µm.

In 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 (Fig. 5.5A) are abundant in high numbers. The first species occurs with 20.5% relative abundance, the second with almost 25%. Other mass occurrences in the latter section are all represented by *Dorothia conula* (Reuss, 1845) (Fig. 5.5K; see Discussion). At the depth of 41 m, the first acme appears with 17% relative abundance, shortly followed by another one ca. 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).

Figure 5.5. Important agglutinated foraminifers from the Strehlen Formation of the Graupa 60/1 core. A – *Psammosphaera fusca* Schultze, 1875 (42.2 m core depth). B – *Psammosphaera irregularis* (Grzybowski, 1896) (38.2 m core depth). C – Lagenammina difflugiformis (Brady, 1879) (34.2 m core depth). D – *Saccammina 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 µm.


A
B
C
D
E
F
G
H
I
J
K
L

5.4.3 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 (Fig. 5.6).

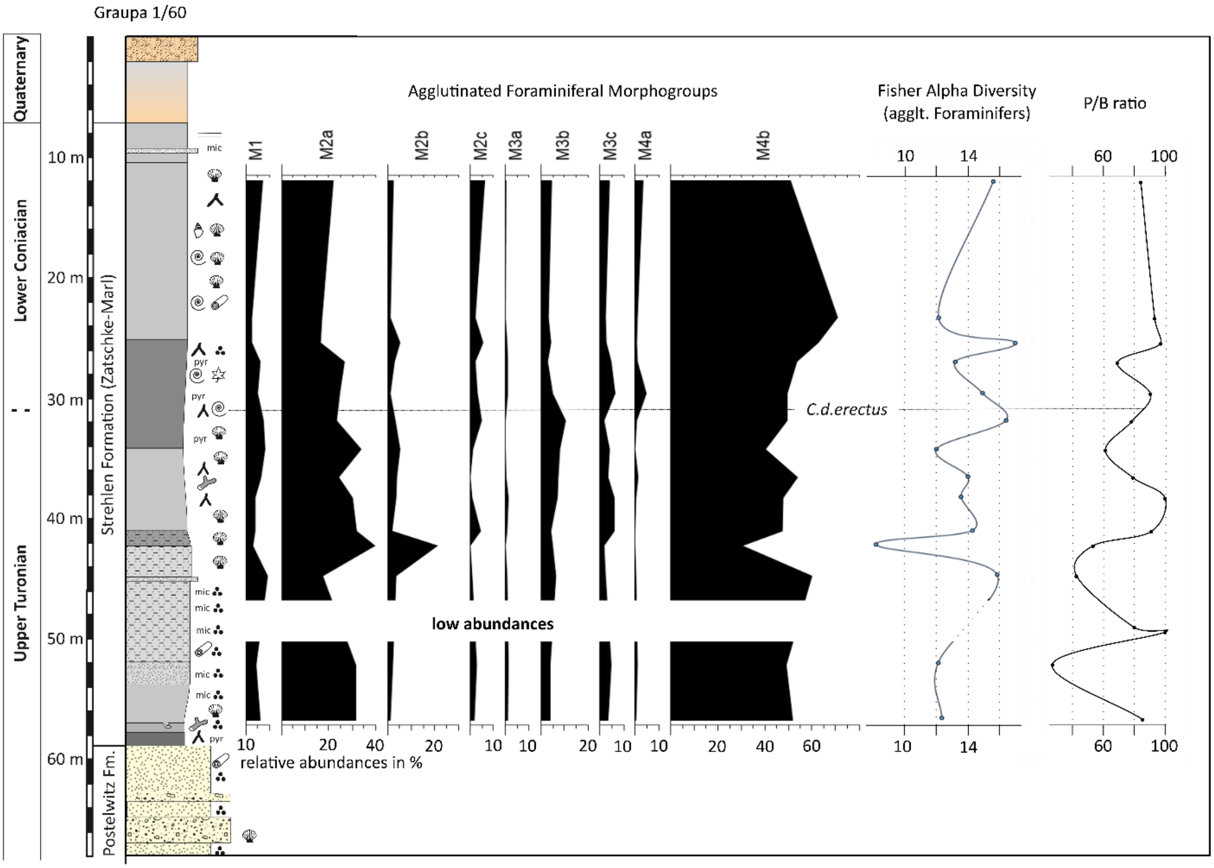


Figure 5.6. Relative abundances of agglutinated foraminiferal morphogroups, Fisher-Alpha diversity, and P/B ratio recorded in the Strehlen Formation of the Graupa 60/1 core. For lithological descriptions see Figure 5.2.

5.4.4 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 Fig. 5.7). Both yield the same taxa, but at different ratios. The most important taxa are *Bulbobaculites problematicus* (Neagu, 1962), *Dorothia conula, Lagenammina difflugiformis* (Brady, 1879), *Psammosphaera fusca*, *Psammosphaera irregularis* (Grzybowski, 1896), *Reophax globosus* Sliter, 1968, *Reophax subfusiformis* (Earland, 1933) and *Saccammina grzybowskii* (Schubert, 1902) (Fig. 5.5). 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 (Fig. 5.5F, G). In contrast, cluster G2 from depth interval 41 to 11.2 m yields higher numbers of *Bulbobaculites problematicus, Dorothia conula*, and *Saccammina grzybowskii* (Fig. 5.5I, K and D, respectively).

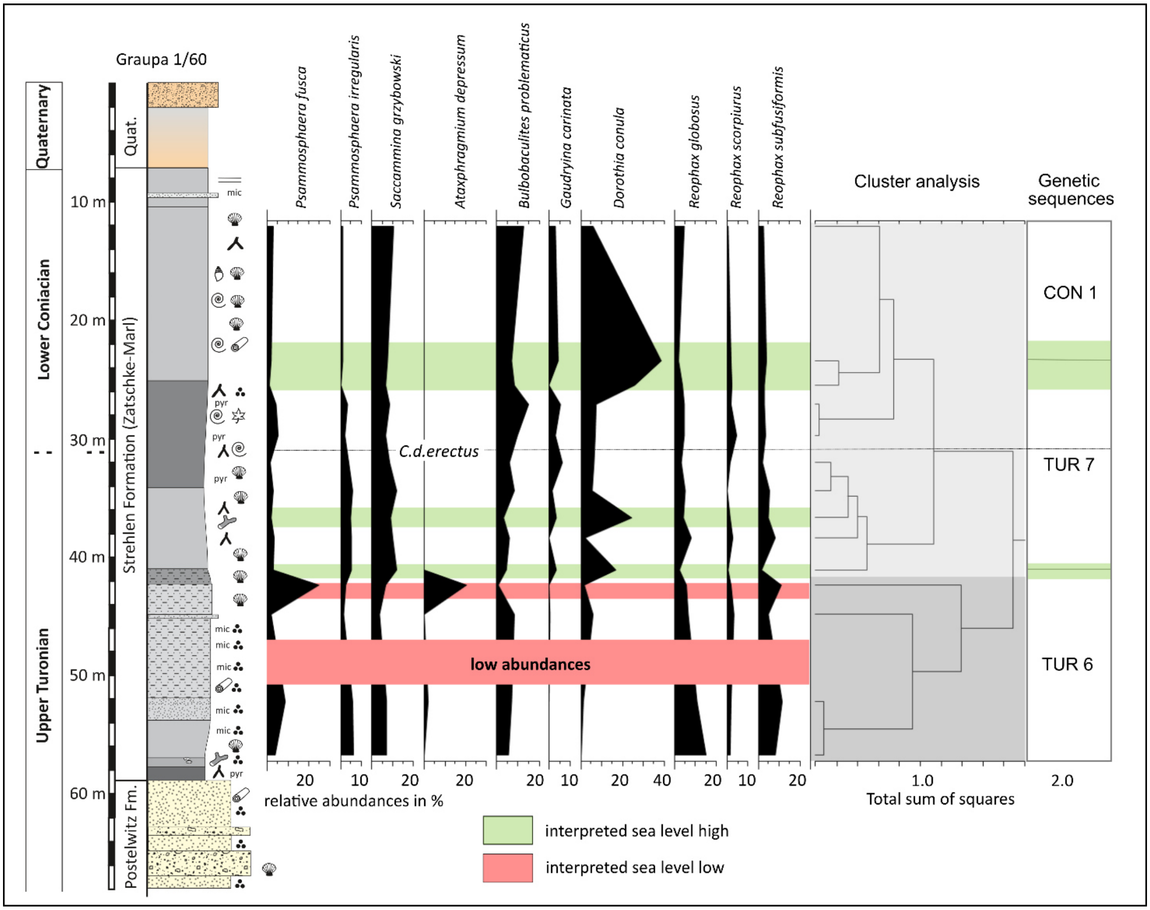


Figure 5.7. Relative abundances of selected agglutinated foraminiferal species, a constrained cluster analysis based on agglutinated foraminiferal abundances, and interpreted genetic sequences (based on maximum flooding surfaces) of the Strehlen Formation of the Graupa 60/1 core. Red bars indicate possible sea level lowstand intervals, green bars mark proposed maximum flooding zones. Different grey areas show both clusters. For more detailed lithological explanations see Figure. 5.2. Genetic sequences after Uličný et al. (2009), Nádaskay et al. (2019) and Niebuhr et al. (2020).

5.4.5 Morphogroups

Tubular agglutinated foraminifers of morphogroup M1 range below 10% (Fig. 5.6). Epifauna from morphogroups M2b, M2c, M3a, M3c and M4a are common in low abundances not exceeding 6% relative abundance, mostly even not that high (Fig. 5.6). Exceptionally, one mass occurrence of *Ataxophragmium depressum* enhances the ratio of yielding M2b up to 21% at the depth of 42.2 m (Fig. 5.6). Attached epifaunal specimens of morphogroup M3b, e.g., *Ammolagena* spp., reach relative abundances up to 10% (Fig. 5.6). 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% (Fig. 5.6). 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% (Fig. 5.6). 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% (Fig. 5.6).

5.4.6 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 (≤10 specimens) were excluded from the analysis. The first 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 Fig. 5.8).

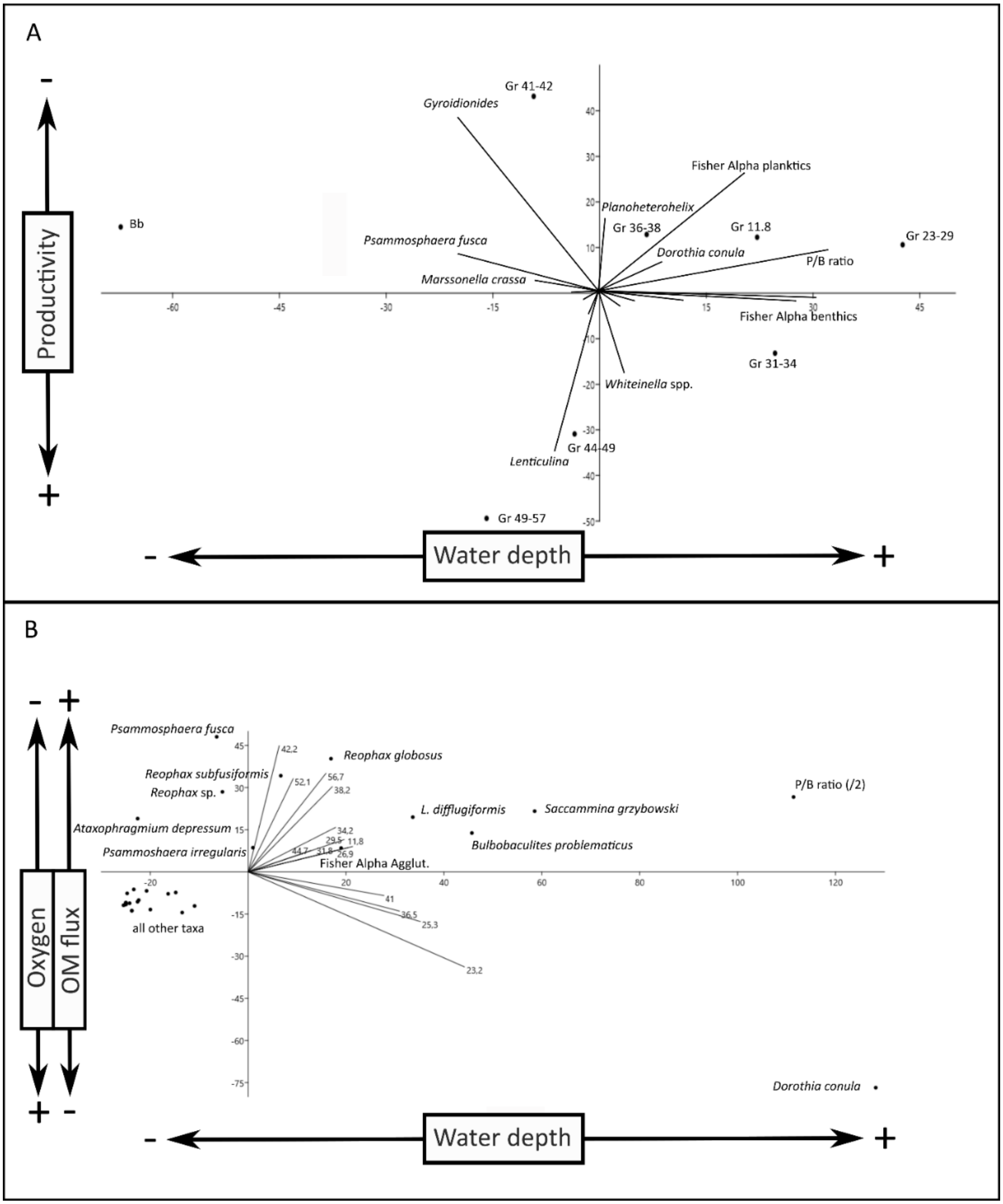


Figure 5.8. Principal component analysis based on: A – the whole dataset including calcareous and agglutinated foraminifers, P/B ratio and diversity indices, variance: PC1 (water depth) 39.2, PC2 (productivity) 30.4; B – agglutinated foraminifers, P/B ratio and Fisher Alpha diversity of agglutinated foraminifers, variance: PC1 (water depth) 56.7, PC2 (oxygen/OM flux) 20.3.

5.5 Discussion

5.5.1 Palaeoenvironmental implications

The recorded foraminiferal fauna in general reflects shelf conditions containing typical shelf associated 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), 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* (Fig. 5.5). 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 (Fig. 5.8) 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 (Fig. 5.6), which could indicate the maximum flooding zone of the Zeichen Clay or Strehlen Kalkstein (Fig. 5.2), 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 (Fig. 5.7), 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 (Fig. 5.7). High abundances of *Ataxophragmium depressum* and *Psammosphaera fusca* indicate relatively low water depth and high organic matter flux (Figs. 5.7 and 5.8).

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 (Figs. 5.7 and 5.8). *Dorothia conula* occurs in high numbers at the depth of 41 m which also yields high P/B ratios (Figs. 5.6 and 5.7). 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; Fig. 5.2) 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 (Figs. 5.6 and 5.7), 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; Fig. 5.2). This stratigraphic interval likely correlates with the Brausnitzbach Marl (Niebuhr et al., 2020; Fig. 5.2).

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 (Fig. 5.6). 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 (Figs. 5.6 and 5.8). The Brausnitzbach Marl was deposited in much shallower conditions than the Strehlen Formation of the Graupa 60/1 core (Fig. 5.8), 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 (Fig. 5.8), followed by a decrease in depth interval 41–42 m (Fig. 5.8) 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 (Fig. 5.8) and not necessarily coupled with relative sea-level changes. The productivity of the Brausnitzbach Marl was comparably moderate (Fig. 5.8).

5.5.2 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 Brausnitzbach Marl (Schrammstein Formation). The studied interval can be assigned to the *Uvigerinammina 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.

5.5.3 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 (Fig. 5.9). A combined application of both methods leads to extended and more complete foraminiferal record and more precise implications on palaeoenvironmental changes.

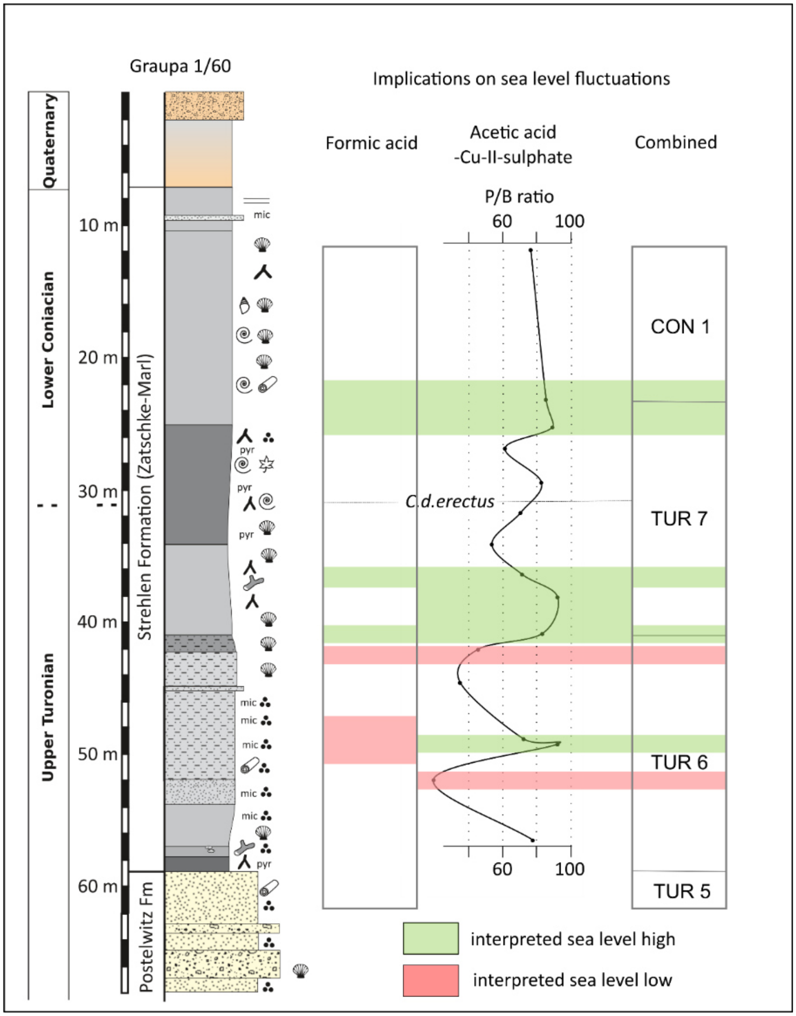


Figure 5.9. Implications on sea-level fluctuations by foraminiferal evidence recorded by the application of different processing methods on the marlstone samples from the Graupa 60/1 core; for more detailed lithological explanations see Figure 5.2. Genetic sequences after Uličný et al. (2009), Nádaskay et al. (2019) and Niebuhr et al. (2020).

5.6 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 Brausnitzbach 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 Brausnitzbach 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/microfossil-bioevents.

1. sea-level lowstand at the depth of 42.2 m, acmes of *Ataxophragmium depressum* and *Psammosphaera fusca*.
2. maximum flooding (TUR6/TUR7) at the depth of 41.0 m, acme of *Dorothia conula*.
3. maximum flooding (lower order) at the depth of 36.5 m, acme of *Dorothia conula*.
4. 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 *Saccammina grzybowskii*, point towards periodical 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 Brausnitzbach Marl was characterized by shallower water depth with relatively moderate productivity.

5.7 Acknowledgements

We are delighted for the opportunity to access the core provided by the Landesamt für Umwelt, Landwirtschaft und Geologie Sachsen. For giving help taking photographs of the foraminifers, we are grateful to Jan Evers. We thank Edina Merdan for useful comments on the manuscript. We highly appreciate the professional editorial effort by Anna Żylińska. Finally, we would like to thank Michael A. Kaminski and Markus Wilmsen for their detailed and substantial reviews that eminently improved this manuscript.

5.8 References

Akker, T.J.H.A. van den, Kaminski, M.A., Gradstein, F.M. and Wood, J. 2000. Campanian to Palaeocene biostratigraphy and palaeoenvironments in the Foula Sub-basin, west of the Shetland Islands, UK. *Journal of Micropalaeontology*, 19, 23–43.

Bąk, K., Bąk, M., Geroch, S. and Manecki, M. 1997. Biostratigraphy and paleoenvironmental analysis of benthic foraminifera and radiolarians in Paleogene variegated shales in the Skole unit, Polish Flysch Carpathians. *Annales Societatis Geologorum Poloniae*, 67, 135–154.

Barnard, T. 1972. Aberrant genera of foraminifera from the Mesozoic (Sub-family Ramulininae Brady 1884). *Revista Española de Micropaleontología*, 4, 387–402.

Barnard, T. and Banner, F.T. 1980. The Ataxophragmiidae of England: Part 1, Albian–Cenomanian *Arenobulimina* and *Crenaverneuilina*. *Revista Española de Micropaleontología*, 12, 383–430.

Bartenstein, H. 1952. Taxonomische Bemerkungen zu den *Ammobaculites, Haplophragmium, Lituola* und verwandten Gattungen (For.). *Senckenbergiana*, 33, 313–342.

Beissel, I. 1891. Die Foraminiferen der Aachener Kreide. *Königliche Preussische Geologische Landesanstalt Abhandlungen*, 3, 1–78.

Berggren, W.A. and Kaminski, M.A. 1990. Abyssal Agglutinates: Back to Basics. In: Hemleben, C., Kaminski, M.A., Kuhnt, W. and Scott, D.B. (Eds.) Paleoecology, Biostratigraphy, Paleoceanography and Taxonomy of Agglutinated Foraminifera. NATO ASI Series C, *Kluwer Academic Publishers*, 327, 53–76.

Berry, E.W. 1928. The smaller foraminifera of the middle *Lobitos* shales of northwestern Peru. *Eclogae Geologae Helvetiae*, 21, 390–405.

Bindui, R., Filipescu, S. and Bălc, R. 2013. Biostratigraphy and paleoenvironment of the Upper Cretaceous deposits in the northern Tarcău Nappe (Eastern Carpathians) based on foraminifera and calcareous nannoplankton. *Geologica Carpathica*, 62, 117–132.

Bolli, H.M. 1959. Planktonic foraminifera from the Cretaceous of Trinidad, B.W.I. *Bulletins of American Paleontology*, 39, 257–277.

Brady, H.B. 1871. On *Saccammina carteri*, a new foraminifer from the Carboniferous limestone of Northumberland. *Annals and Magazine of Natural History*, ser. 4, 7 (21), 177–184.

Brady, H.B. 1879. Notes on some of the reticularian Rhizopoda of the "Challenger" Expedition; Part 1. On new or little known Arenaceous types. *Quarterly Journal of Microscopical Sciences*, 19, 20–67.

Brady, H.B. 1881. Notes on some of the reticularian Rhizopoda of the "Challenger" Expedition; Part 3. *Quarterly Journal of Microscopical Sciences*, 21, 31–71.

Brotzen, F. 1934. Foraminiferen aus dem Senon Palästinas. *Zeitschrift des Deutschen Palästina-Vereins*, 57, 28–72.

Bubík, M. 1995. Cretaceous to Paleogene agglutinated foraminifera of the Bile Karpaty unit (West Carpathians, Czech Republic). In: Kaminski, M.A., Geroch, S. and Gasinski, M.A. (Eds.) Proceedings of the Fourth International Workshop on Agglutinated Foraminifera. *Grzybowski Foundation Special Publication*, 3, 71–116.

Bubík, M. 2019. Remarks on quantitative analysis of deep-sea foraminifer taphocoenosis with special attention to tubular astrorhizids. *Micropaleontology*, 65, 63–74.

Caron, M. 1983a. Cretaceous Planktic Foraminifera. In: Bolli, H.M., Saunders, J.B. and Perch Nielsen, K. (Eds.) Plankton Stratigraphy. *Cambridge University Press*, Cambridge, 17–86.

Caron, M. 1983b. La spéciation chez les foraminifères planctiques: une réponse adaptée aux contraintes de l'environnement. *Zitteliana*, 10, 671–676.

Čech, S. and Uličný, D. 2021. The Turonian-Coniacian stage boundary in an expanded siliciclastic succession: Integrated stratigraphy in deltaic through offshore facies, Bohemian Cretaceous Basin. *Cretaceous Research*, 117, 1–29.

Cetean, C.G., Bălc, R., Kaminski, M.A. and Filipescu, S. 2011a. Integrated biostratigraphy and palaeoenvironments of an upper Santonian–upper Campanian succession from the southern part of the Eastern Carpathians, Romania. *Cretaceous Research*, 32 (5), 575–590.

Cetean, C., Setoyama, E., Kaminski, M.A., Neagu, T., Bubík, M., Filipescu, S. and Tyszka, J. 2011b. *Eobigenerina*, a cosmopolitan deep-water agglutinated foraminifer, and remarks on late Paleozoic to Mesozoic species formerly assigned to Pseudobolivina and Bigenerina. In: Kaminski, M.A. and Filipescu, S. (Eds.) Proceedings of the Eighth International Workshop on Agglutinated Foraminifera. *Grzybowski Foundation Special Publication*, 16, 19–28.

Chapman, F. 1892. 7. – The Foraminifera of the Gault of Folkestone. 2. *Journal of Microscopy*, 12 (3), 319–330.

Charnock, M.A. and Jones, R.W. 1990. Agglutinated foraminifera from the Paleogene of the North Sea. In: Hemleben, C., Kaminski, M.A., Kuhnt, W. and Scott, D.B. (Eds.) Paleoecology, Biostratigraphy, Paleoceanography and Taxonomy of Agglutinated Foraminifera. NATO ASI Series C, *Kluwer Academic Publishers*, 327, 139–244.

Cushman, J.A. 1932. *Textularia* and related forms from the Cretaceous. *Contributions from the Cushman Laboratory for Foraminiferal Research*, 8, 86–96.

Cushman, J.A. 1934. The generic position of "*Cornuspira cretacea* Reuss". *Contributions from the Cushman Laboratory for Foraminiferal Research*, 10, 44–47.

Cushman, J.A. 1937. A monograph of the foraminiferal family Verneuilinidae. *Cushman Laboratory for Foraminiferal Research Special Publications*, 8, 210 pp.

Cushman, J.A. and Jarvis, P.W. 1928. Cretaceous foraminifera from Trinidad. *Contributions from the Cushman Laboratory for Foraminiferal Research*, 4, 85–103.

Danišík, M., Mignon, P., Kuhlemann, J., Evans, N.J., Dunkl, I. and Frisch, W. 2010. Thermochronological constraints on the long-term erosional history of the Karkonosze Mts., Central Europe. *Geomorphology*, 117, 78–89.

Deecke, W. 1884. Die Foraminiferenfauna der Zone des *Stephanoceras humphriesianum* im Unter-Elsass. *Abhandlungen zur geologischen Spezialkarte von Elsass-Lothringen*, 4 (1), 1–68.

Douglas, R.G. and Rankin, C. 1969. Cretaceous planktonic foraminifera from Bornholm and their zoogeographic significance. *Lethaia*, 2, 185–217.

Earland, A. 1933. Foraminifera. Part 2. South Georgia. *Discovery Reports*, 7, 29–138.

Ehrenberg, C.G. 1840. Über die Bildung der Kreidefelsen und des Kreidemergels durch unsichtbare Organismen. *Abhandlungen der Königlichen Akademie der Wissenschaften zu Berlin, Physikalische Klasse*, 1838, 59–147.

Elicki, O., Suhr, P. and Walter, H. 2020. Oberkretazische Foraminiferen aus Reliktvorkommen bei Siebenlehn (Mittelsachsen). *Freiberger Forschungshefte*, C 558 (25), 121–139.

Fiege, K. 1930. Über die Inoceramen des Oberturon mit besonderer Berücksichtigung der im Rheinland und Westfalen vorkommenden Formen. *Palaeontographica*, 73, 31–47.

Fisher, R.A., Corbet, A.S. and Williams, C.B. 1943. The relation between the number of species and the number of individuals in a random sample of an animal population. *The Journal of Animal Ecology*, 12 (1), 42–58.

Franke, A. 1914. Die Foraminiferen und Ostracoden des Emschers, besonders von Obereving und Derne nördlich Dortmund. *Zeitschrift der Deutschen Geologischen Gesellschaft*, 66 (3), 428–443.

Frenzel, P. 2000. Die benthischen Foraminiferen der Rügener Schreibkreide (Unter-Maastricht, NE-Deutschland). *Neue Paläontologische Abhandlungen* Band, 3, 361 pp.

Friedrich, O., Voigt, S., Kuhnt, T. and Koch, M.C. 2011. Repeated bottom-water oxygenation during OAE 2: timing and duration of short-lived benthic foraminiferal repopulation events (Wunstorf, northern Germany). *Journal of Micropalaeontology*, 30, 119–128.

Frieg, C. 1980. Neue Ergebnisse zur Systematik sandschaliger Foraminiferen im Cenoman des südwestlichen Münsterlandes. *Paläontologische Zeitschrift*, 54 (3), 225–240.

Frieg, C. and Price, R.J. 1982. The subgeneric classification of Arenobulimina. In: Banner, F. T. and Lord, A.R. (Eds.) Aspects of Micropalaeontology. *Springer*, Netherlands, 42–80.

Frieg, C., Kemper, E. and Baldschuhn, R. 1989. Mikropaläontologische Gliederung und Abgrenzung von Ober-Alb und Unter-Cenoman in Nordwestdeutschland. *Geologisches Jahrbuch*, 113, 73–193.

Galloway, W.E. 1989. Genetic stratigraphic sequences in basin analysis I: architecture and genesis of flooding-surface bounded depositional units. *AAPG Bulletin*, 73, 125–142.

Gawor-Biedowa, E. 1980. Turonian and Coniacian Foraminifera from the Nysa Trough, Sudetes, Poland. *Acta Paleontologica Polonica*, 25, 3–54.

Geroch, S. and Kaminski, M.A. 1995. An emendation of some Cretaceous species of "Reophax" (Foraminiferida) from northwest Europe and Poland. In: Kaminski, M.A., Geroch, S. and Gasiński, M.A. (Eds.) Proceedings of the Fourth International Workshop on Agglutinated Foraminifera. *Grzybowski Foundation Special Publication*, 3, 117–122.

Geroch, V.S. and Nowak, W. 1984. Proposal of zonation for the Late Tithonian–Late Eocene, based upon arenaceous Foraminifera from the Outer Carpathians, Poland. *Benthos*, 83 (2), 225–239.

Gradstein, F.M. and Kaminski, M.A. 1989. Taxonomy and biostratigraphy of new and emended species of Cenozoic deep-water agglutinated foraminifera from the Labrador and North Seas. *Micropaleontology*, 35, 75–92.

Grimm, E.C. 1987. CONISS: a FORTRAN 77 program for stratigraphically constrained cluster analysis by the method of incremental sum of squares. *Computers & Geosciences*, 13 (1), 13–15.

Grzybowski, J. 1896. Otwornice czerwonych iłów z Wadowic. Rozprawy Wydziału Matematyczno-Przyrodniczego. *Akademia Umiejętności w Krakowie*, serya 2, 30, 261–308.

Grzybowski, J. 1898. Otwornice pokładów naftonośnych okolicy Krosna. Rozprawy Wydziału Matematyczno-Przyrodniczego. *Akademia Umiejętności w Krakowie*, serya 2, 33, 257–305.

Hammer, Ø., Harper, D.A.T. and Ryan, P.D. 2001. PAST: Paleontological Statistics Software Package for Education and Data Analysis. *Palaeontologica Electronica*, 4 (1), 1–9.

Hanzlíková, E. 1972. Carpathian Upper Cretaceous foraminifera from Moravia (Turonian–Maastrichtian). *Rozpravy Ústředního Ústavu Geologického*, 39, 5–160.

Haynes, S.J., Huber, B.T. and MacLeod, K.G. 2015. Evolution and Phylogeny of Mid-Cretaceous (Albian–Coniacian) Biserial Planktic Foraminifera. *Journal of Foraminiferal Research*, 45 (1), 42–81.

Heinz, R. 1932. Zur Gliederung der sächsisch-schlesisch-bömischen Kreide unter Zugrundelegung der norddeutschen Stratigraphie (Beiträge zur Kenntnis der oberkretazischen Inoceramen X). *Jahresbericht des Niedersächsischen Geologischen Vereins zu Hannover*, 24, 23–53.

Hemleben, C. and Troester, J. 1984. Campanian–Maastrichtian deep-water foraminifers from Hole 543A, Deep Sea Drilling Project. *Initial Reports of the Deep Sea Drilling Project*, 78A, 509–532.

Hercogová, J. and Kriz, J. 1983. New Hemisphaeramminae (Foraminifera) from the Bohemian Cretaceous basin (Cenomanian). *Věstník Ústředního ústavu geologického*, 58 (4), 205–215.

Huber, B.T. and Leckie, R.M. 2011. Planktic Foraminiferal Species Turnover across Deep-Sea Aptian/Albian Boundary Sections. *Journal of Foraminiferal Research*, 41 (1), 53–95.

Huss, F. 1966. Agglutinated foraminifera of the oil-bearing subsilesian series in Węglówka (Polish Flysch Carpathians). *Prace Geologiczne, Polska Akademia Nauk*, 34, 7–76.

Janetschke, N. and Wilmsen, M. 2014. Sequence stratigraphy of the lower Upper Cretaceous Elbtal Group (Cenomanian–Turonian of Saxony, Germany). *Zeitschrift der Deutschen Gesellschaft für Geowissenschaften*, 165 (2), 179–208.

Janetschke, N., Niebuhr, B. and Wilmsen, M. 2015. Inter-regional sequence-stratigraphical synthesis of the Plänerkalk, Elbtal and Danubian Cretaceous groups (Germany): Cenomanian–Turonian correlations around the Mid-European Island. *Cretaceous Research*, 56, 530–549.

Jones, R.W. and Charnock, M.A. 1985. "Morphogroups" of agglutinated foraminifera. Their life positions and feeding habits and potential applicability in (paleo)ecological studies. *Revue de Paléobiologie*, 4 (2), 311–320.

Jones, T.R. and Parker, W.K. 1860. On the Rhizopodal fauna of the Mediterranean compared with that of the Italian and some other Tertiary deposits. *Quarterly Journal of the Geological Society of London*, 16, 292–307.

Jorissen, F.J., Stigter, H.C. de and Widmark, J.G.V. 1995. A conceptual model explaining benthic foraminiferal microhabitats. *Marine Micropaleontology*, 26, 3–15.

Józsa, Š. 2017. Field stop 1: Vršatec – Upper Cretaceous microfauna of the oceanic red beds. In: Soták, J., Hudáčková, N. and Michalík, J. (Eds.) Microfauna and biostratigraphy of the Mesozoic and Cenozoic formations of the Western Carpathians: Guidebook of the IWAF-

10 field trip to Middle Valley and Malé Karpaty Mts. Bratislava. *Earth Science Institute, Slovak Academy of Sciences*, Bratislava, pp. 41–47..

Kaminski, M.A. 1985. Evidence for control of abyssal agglutinated foraminiferal community structure by substrate disturbance: Results from the Hebble Area. *Marine Geology*, 66, 113–131.

Kaminski, M.A. and Geroch, S. 1993. A revision of foraminiferal species in the Grzybowski Collection. In: Kaminski, M.A., Geroch, S. and Kaminski, D. (Eds.) The Origins of Applied Micropaleontology: The School of Józef Grzybowski. *Grzybowski Foundation Special Publication*, 1, 293–323.

Kaminski, M.A. and Gradstein, F.M. 2005. Atlas of Paleogene cosmopolitan deep-water agglutinated foraminifera. *Grzybowski Foundation Special Publication*, Kraków, pp. 548.

Kaminski, M.A., Gradstein, F.M., Berggren, W.A., Geroch, S. and Beckmann, J.P. 1988. Flysch-type agglutinated foraminiferal assemblages from Trinidad: Taxonomy, Stratigraphy and Paleobathymetry. In: Proceedings of the Second Workshop on Agglutinated Foraminifera, Vienna 1986. *Abhandlungen der Geologischen Bundesanstalt*, 41, 155–228.

Kaminski, M.A., Boersma, E., Tyszka, J. and Holbourn, A. 1995. Response of deep-water agglutinated foraminifera to dysoxic conditions in the California Borderland basins. In: Kaminski, M.A., Geroch, S. and Gasiński, M.A. (Eds.) Proceedings of the Fourth International Workshop on Agglutinated Foraminifer. *Grzybowski Foundation Special Publication*, 3, 131–140.

Kaminski, M.A., Cetean, C.G. and Neagu, T. 2010. *Rectogerochammina eugubina* nov. gen., nov. sp., a new agglutinated foraminifer from the Upper Cretaceous of Gubbio, Italy. *Revue de micropaléontologie*, 53 (2), 121–124.

Kaminski, M.A., Cetean, C., Bălc, R. and Coccioni, R. 2011. Upper Cretaceous deep-water agglutinated foraminifera from the Contessa Highway Section, Umbria-Marche basin, Italy: taxonomy and biostratigraphy. In: Kaminski, M.A. and Filipescu, S. (Eds.) Proceedings of the Eighth International Workshop on Agglutinated Foraminifera. *Grzybowski Foundation Special Publication*, 16, 71–106.

Kaminski, M.A., Alegret, L., Hikmahtiar, S. and Waśkowska, A. 2021. The Paleocene of IODP Site U1511: A lagerstätte deposit for deep-water agglutinated foraminifera. *Micropaleontology*, 67 (4), 341–364.

Käßner, A., Stanek, K.P. and Lapp, M. 2020. Post-Variscan tectonic and landscape evolution of the Elbe Fault Zone and the Lusatian Block based on apatite fission-track data and geomorphologic constraints. *Geomorphology*, 355, 1–15.

Kuhnt, W. 1990. Agglutinated foraminifera of western Mediterranean Upper Cretaceous pelagic limestones (Umbrian Apennines, Italy, and Betic Cordillera, Southern Spain). Micropaleontology, 36, 297–330.

Kuhnt, W. and Kaminski, M.A. 1990. Paleoecology of Late Cretaceous to Paleocene deep-water agglutinated foraminifera from the North Atlantic and Western Tethys. In: Hemleben, C., Kaminski, M.A., Kuhnt, W. and Scott, D.B. (Eds.) Paleoecology, Biostratigraphy, Paleoceanography and Taxonomy of Agglutinated Foraminifera. NATO ASI Series C, *Kluwer Academic Publishers*, 327, 433–506.

Kuhnt, W. and Kaminski, M.A. 1997. Cenomanian to lower Eocene deep-water agglutinated foraminifera from the Zumaya section, northern Spain. *Annales Societatis Geologorum Poloniae*, 67, 257–270.

Lange, J.-M., Tonk, C. and Wagner, G.A. 2008. Apatitspaltspurdaten zur postvariszischen thermotektonischen Entwicklung des sächsischen Grundgebirges – erste Ergebnisse. *Zeitschrift der deutschen Gesellschaft für Geowissenschaften*, 159, 123–132.

Laurin, J. and Uličný, D. 2004. Controls on a shallow-water hemipelagic carbonate system adjacent to a siliciclatsic margin: example from Late Turonian of Central Europe. *Journal of Sedimentary Research*, 74, 967–717.

Loeblich, A.R. and Tappan, H. 1961. Cretaceous Planktonic Foraminifera: Part I. Cenomanian. *Micropaleontology*, 7 (3), 257–304.

Loeblich, A.R. and Tappan, H. 1987. Foraminiferal genera and their classification. *Springer*; New York, vol. 1, pp. 869; vol. 2, pp. 212.

Magniez-Jannin, F. 1975. Les foraminifères de l’Albien de l’Aube: paléontologie, stratigraphie, écologie. Cahiers de paléontologie. *CNRS*, Paris, pp. 360.

Majzon, L. 1943. Adatok egyes Kárpátaljai flis-rétegekhez, tekintettel a Globotruncanákra (Beitrage zur Kenntniss einiger Flysch Schichten des Karpaten-Vorlandes mit Rücksicht auf die Globotruncanen). *A magyar Királyi Földtani Intézet, Évkönyve*, 37 (1), 1–170.

Marsson, T. 1878. Die Foraminiferen der weissen Schreibkreide der Insel Rügen. *Mitteilungen des Naturwissenschaftlichen Verein für Neu-Vorpommern und Rügen in Greifswald*, 10, 115–196.

Meek, F.B. 1877. Paleontology. Report of the geological exploration of the 40th parallel. *Professional Paper of the Engineer Department of the United States Army*, 184, 142–148.

Meischner, T. and Elicki, O. 2018. Fazielle Analyse einer oberkretazischen Foraminiferen-Mikrofauna im Profil Hoppenstedt (Subherzynes Becken). *Freiberger Forschungshefte*, C553, 79–112.

Mjatliuk, E.V. 1939. Foraminifera of the Upper Jurassic and Lower Cretaceous of the region of the Middle Volga River and the Great Syrte. *Tr. VNIGRI*, 1–75.

Mjatliuk, E.V. 1966. On the question of foraminifera with a siliceous skeleton. *Voprosy Mikropaleontologii*, 10, 255–269.

Montanaro Gallitelli, E. 1955. Foraminiferi cretacei delle marne a fucoidi di Serramazzoni (Appennino modenese). *Accademia di Scienze, Lettere ed Arti di Modena*, 5 (13), 175–204.

Montfort, P.D. de 1808. Conchyliologie systématique et classification méthodique des coquilles. *Schoell*, Paris, vol. 1, 409 pp.

Murray, J.W., Alve, E. and Jones, B.W. 2011. A new look at modern agglutinated benthic foraminiferal morphogroups: their value in palaeoecological interpretation. *Palaeogeography, Palaeoclimatology, Palaeoecology*, 309 (3), 229–241.

Nádaskay, R. and Uličný, D. 2014. Genetic stratigraphy of Coniacian deltaic deposits of the northwestern part of the Bohemian Cretaceous Basin. *Zeitschrift der deutschen Gesellschaft für Geowissenschaften*, 165 (4), 547–575.

Nádaskay, R., Kochergina, Y.V., Čech, S., Švábenická, L., Valečka, J., Erban, V., Halodová, P. and Cejková, B. 2019. Integrated stratigraphy of an offshore succession influenced by intense siliciclastic supply: Implications for Coniacian tectono-sedimentary evolution of the West Sudetic area (NW Bohemian Cretaceous Basin, Czech Republic). *Cretaceous Research*, 102, 127–159.

Neagu, T. 1962. Studiul foraminiferelor aglutinante din argilele Cretacic superiorare de pe Valea Sadovei (Câmpulung Moldovenesc) şi bazinul superior al Văii Buzăuliu. *Studii Cercetari Geologie, Academia Republicii Populare Romine, Sectia de Geologie si Geografie si Istitutul de Geologie si Geografie*, 7 (1), 45–81.

Neagu, T. 1968. Biostratigraphy of Upper Cretaceous deposits in the Southern Eastern Carpathians near Braşov. *Micropaleontology*, 14 (2), 225–241.

Neagu, T. 1970. Micropaleontological and stratigraphical study of the Upper Cretaceous deposits between the upper valleys of the Buzau and Riul Negru Rivers (Eastern Carpathians). *Memorii, Institutul Geologic*, 12, 7–109.

Neagu, T. 1990. *Gerochammina* n.g. and related genera from the Upper Cretaceous flysch-type benthic foraminiferal fauna, Eastern Carpathians - Romania. In: Hemleben, C., Kaminski, M.A., Kuhnt, W. and Scott, D.B. (Eds.) Paleoecology, biostratigraphy, paleoceanography and taxonomy of agglutinated foraminifera, NATO ASI Series C, *Kluwer Academic Publishers*, 327, 245–265.

Neagu, T. 2004. Smaller agglutinated foraminifera from an olistolith of Adneth Limestones, Tipea Valley, Persani Mountains, Romania. In: Bubík, M. and Kaminski, M.A. (Eds.) Proceedings of the Sixth International Workshop on Agglutinated Foraminifera. *Grzybowski Foundation Special Publication*, 8, 381–392.

Neagu, T. 2011. Turonian Marker Foraminifera Associations from the southern part of the eastern Carpathians: Dombovita Valley – Intorsura Buzaului Area. *Acta Paleontologica Romaniae*, 7, 249–255.

Niebuhr, B., Wilmsen, M. and Voigt, T. 2020. Die Oberkreide (Cenomanium–Mittelconiacium) im Zittauer Sandsteingebirge (Deutschland, Tschechien). *Zeitschrift der deutschen Gesellschaft für Geowissenschaften*, 171 (2), 163–197.

Olde, K., Jarvis, I., Uličný, D., Pearce, M.A., Trabucho-Alexandre, J., Čech, S., Gröcke, D.R., Laurin, J., Švábenická, L. and Tocher, B.A. 2015. Geochemical and palynological sea-level proxies in hemipelagic sediments: a critical assessment from the Upper Cretaceous of the Czech Republic. *Palaeogeography, Palaeoclimatology, Palaeoecology*, 435, 222–243.

Orbigny, A. d' 1840. Paléontologie française: description zoologique et géologique de tous les animaux mollusques et rayonnés fossiles de France. Terrains crétacés. Les céphalopodes, *A. Bertrand*, Paris, 696 pp.

Orbigny, A. d' 1846. Die fossilien Foraminiferen des tertiären Bekens von Wien. *Gide et Comp.,* Paris, 312pp.

Perner, J. 1892. Über die Foraminiferen des böhmischen Cenomans. Česká Akademie Císaře Frantiska Josefa, pro Vědy, Slovesnost a Uměni v Praze 2 (*Paleontographica Bohemiae*), 1, 65 pp.

Peryt, D., Lahodynsky, R. and Durakiewicz, T. 1997. Deep-water agglutinated foraminiferal changes and stable isotope profiles across the Cretaceous–Paleogene boundary in the Rotwand-graben section, Eastern Alps (Austria). *Palaeogeography, Palaeoclimatology, Palaeoecology*, 132 (1–4), 287–307.

Peryt, D., Alegret, L. and Molina, E. 2004. Agglutinated foraminifers and their response to the Cretaceous/Paleogene (K/P) boundary event at Aïn Settara, Tunisia. In: Bubík, M. and Kaminski, M.A. (Eds.) Proceedings of the Sixth International Workshop on Agglutinated Foraminifera. *Grzybowski Foundation Special Publication*, 8, 393–412.

Pessagno, E.A. 1967. Upper Cretaceous planktonic foraminifera from the western Gulf Coastal Plain. *Palaeontographica Americana*, 5, 245–445.

Petrascheck, W. 1900. Studien über Faciesbildungen im Gebiete der sächsischen Kreideformation. *Sitzungsberichte und Abhandlungen der Naturwissenschaftlichen Gesellschaft Isis in Dresden*, 1899 (für 1900), 31–84.

Plummer, H.J. 1945. Smaller foraminifera in the Marble Falls, Smithwick, and lower Strawn strata around the Llano uplift in Texas. *University of Texas Bulletin*, 4401, 209–271.

Prokoph, A., Szarek, R., Kłosowska, B. and Kuhnt, W. 1999. Late Albian benthic foraminiferal biofacies and paleogeography of Northeast Germany. *Neues Jahrbuch für Geologie und Paläontologie, Abhandlungen*, 212, 289–334.

Reuss, A.E. 1844. Geognostische Skizzen aus Böhmen. Bd. 2: Die Kreidegebilde des westlichen Böhmens, ein monographischer Versuch. Nebst Bemerkungen über die

Braunkohlenlager jenseits der Elbe und eine Uebersicht der fossilen Fischreste Böhmens. *Medau & Comp.*, Prag, 304 pp.

Reuss, A.E. 1845. Die Versteinerungen der böhmischen Kreideformation. Abtheilung 1. E. *Schweizerbart'sohne Verlagsbuchhandlung*, Stuttgart, 58 pp.

Reuss, A.E. 1851. Über die fossilen Foraminiferen und Entomostraceen der Septarianthone der Umgegend von Berlin. *Zeitschrift der Deutschen Geologischen Gesellschaft*, 3, 49–91.

Reuss, A.E. 1963. Die Foraminiferen der norddeutschen Hils und Gault. *Sitzungsberichte der Kaiserlichen Akademie der Wissenschaften. Mathematisch-Naturwissenschaftliche Classe*, 46, 5–100.

Schönfeld, J. and Voigt, T. 2020. Sediment geometry, facies analysis and palaeobathymetry of the Schrammstein Formation (upper Turonian–lower Coniacian) in southern Saxony, Germany. *Zeitschrift der deutschen Gesellschaft für Geowissenschaften*, 171 (2), 199–209.

Schubert, R.J. 1902. Neue und interessante Foraminiferen aus dem südtiroler Alttertiär. *Beiträge zur Paläontologie und Geologie Österreich-Ungarn und des Orients*, 14, 9–26.

Schultze, F.E. 1875. Zoologische Ergebnisse der Nordseefahrt, vom 21. Juli bis 9. September 1872. I, Rhizopoden. *Jahresberichte Kommission zur Untersuchung der Deutschen Meere*, Kiel, 1872–1873, 99–114.

Seifert, A. 1955. Stratigraphie und Paläogeographie des Cenoman und Turons im sächsischen Elbtalgebiet. *Freiberger Forschungshefte*, C14, 1–218.

Setoyama, E., Kaminski, MA. and Tyszka, J. 2011. Late Cretaceous agglutinated foraminifera and implications for the biostratigraphy and palaeobiogeography of the southwestern Barents Sea. In: Kaminski, M.A. and Filipescu, S. (Eds.) Proceedings of the Eighth International Workshop on Agglutinated Foraminifera. *Grzybowski Foundation Special Publication*, 20, 251–309.

Setoyama, E., Radmacher, W., Kaminski, M.A. and Tyszka, J. 2013. Foraminiferal and palynological biostratigraphy and biofacies from a Santonian-Campanian submarine fan system in the Vøring Basin (offshore Norway). *Marine and Petroleum Geology*, 43, 396–408.

Setoyama, E., Kaminski, M.A. and Tyszka, J. 2017. Late Cretaceous–Paleogene foraminiferal morphogroups as palaeoenvironmental tracers of the rifted Labrador margin, northern proto-Atlantic. In: Kaminski, M.A. and Alegret, L. (Eds.) Proceedings of the Ninth International Workshop on Agglutinated Foraminifera. *Grzybowski Foundation Special Publication*, 22, 179–220.

Sliter, W.V. 1968. Upper Cretaceous foraminifera from southern California and northwestern Baja California, Mexico. *The University of Kansas Paleontological Contributions*, 49 (7), 141 pp.

Ten Dam, A. 1950. Les foraminifères de l'Albien des Pays-Bas. *Société géologique de France*, 29 (63), 66 pp.

Tröger, K.-A. 1964. Zur Ausbildung der Kreide (Cenoman bis Coniac) in der Umrandung des Lausitzer Massivs. *Geologie*, 13, 717–730.

Tröger, K.-A. 1967. Zur Paläontologie, Biostratigraphie und faziellen Ausbildung der unteren Oberkreide (Cenoman bis Turon). Teil I. Paläontologie und Biostratigraphie der Inoceramen des Cenomans bis Turons Mitteleuropas. *Abhandlungen des Staatlichen Museums für Mineralogie und Geologie zu Dresden*, 12, 13–207.

Tröger, K.-A. 2004. Cenomanian through Lower Coniacian events in the Upper Cretaceous of Saxony, Germany. *Acta Geologica Polonica*, 54, 629–638.

Tröger, K.-A. and Voigt, T. 1995. Event- und Sequenzstratigraphie in der sächsichen Kreide. *Berliner Geowissenschaftliche Abhandlungen*, E 16 (Gundolf-Ernst-Festschrift), 255–267.

Tröger, K.-A. and Wejda, M 1997. Biostratigraphie der Strehlener Formation (Ob.-Turon bis Unt.-Coniac) im Gebiet von Dresden. *Freiberger Forschungshefte*, C466, 1–17.

Tröger, K.-A. and Wejda, M. 1998. The Turonian/Coniacian (T/C) boundary in the Upper Cretaceous of the Elbe Valley/Saxony (Germany). *Acta Geologica Polonica*, 48, 387–394.

Tröger, K.-A., Wolf, L. and Uhlig, A. 1961. Schichtenverzeichnis der Kartierungsbohrung Graupa I/60, 61. *Unpublished report of the Staatliche Geologische Kommision. Zentraler Geologischer Dienst*, Freiberg, 47 pp.

Tyszka, J. 2009. Foraminiferal response to seasonality modulated by orbital cycles in the Cretaceous mid-latitudes: The Albian record from the Lower Saxony Basin. *Palaeogeography, Palaeoclimatology, Palaeoecology*, 276, 148–159.

Uličný, D., Laurin, J. and Čech, S. 2009. Controls on clastic sequence geometries in a shallow-marine, transtensional basin: the Bohemian Cretaceous Basin, Czech Republic. *Sedimentology*, 56, 1077–1114.

Vašíćek, M. 1947. Remarks on the microbiostratigraphy of the Magura flysch in Moravia. *Věstník Státního Geologického Ústavu Československé Republiky*, 22, 235–256.

Voigt, T. 2009. Die Lausitz-Riesengebirgs-Antiklinalzone als kreidezeitliche Inversionsstruktur: Geologische Hinweise aus den umgebenden Kreidebecken. *Zeitschrift für Geologische Wissenschaften*, 37, 15–39.

Voigt, T. and Tröger, K.-A. 2007. Elbtal-Gruppe. In: Niebuhr, B., Hiss, M., Kaplan, U., Tröger, K.-A., Voigt, S., Voigt, T., Wiese, F. and Wilmsen, M. (Eds.) Lithostratigraphie der norddeutschen Oberkreide. *Schriftenreihe der Deutschen Gesellschaft für Geowissenschaften*, 55, 136 pp.

Voigt, T., Kley, J. and Voigt, S. 2021. Dawn and dusk of Late Cretaceous basin inversion in central Europe. *Solid Earth*, 12, 1–29.

Voloshina, A. 1972. Ataxophragmeids from Upper Cretaceous Deposits in the Volyn-Podol Margin of the Russian Platform. *Trudy Ukrainskogo Nauchno-Issledovatelskogo Geologorazvedochnogo Instituta*, 27, 55–130.

Walaszczyk, I. and Cobban, W.A. 1999. The Turonian–Coniacian boundary in the United States Western Interior. *Acta Geologica Polonica*, 48, 495–507.

Walaszczyk, I. and Cobban, W.A. 2000. Inoceramid faunas and biostratigraphy of the Upper Turonian–Lower Coniacian of the Western Interior of the United States. *Special Papers in Palaeontology*, 64, 118 pp.

Walaszczyk, I. and Wood, C.J. 1999. Inoceramids and biostratigraphy at the Turonian/Coniacian boundary; based on the Salzgitter-Salder quarry, Lower Saxony, Germany, and the Słupia Nadbrzeżna section, central Poland. *Acta Geologica Polonica*, 48, 395–434.

Walaszczyk, I., Wood, C. J., Lees, J. A., Peryt, D., Voigt, S. and Wiese, F. 2010. The Salzgitter-Salder quarry (Lower Saxony, Germany) and Słupia Nadbrzeżna river cliff section

(Central Poland): a proposed candidate composite global boundary stratotype section and point for the Coniacian stage (upper Cretaceous). *Acta Geologica Polonica*, 60, 445–477.

Walaszczyk, I., Čech, S., Crampton, J.S., Dubicka, Z., Ifrim, C., Jarvis, I., Kennedy, W.J., Lees, J.A., Lodowski, D., Pearce, M., Peryt, D., Sageman, B., Schiøler, P., Todes, J., Uličný, D., Voigt, S. and Wiese, F., With contributions by Linnert, C., Püttmann, T., and Toshimitsu, S. 2022. The Global Boundary Stratotype Section and Point (GSSP) for the base of the Coniacian Stage (Salzgitter-Salder, Germany) and its auxiliary sections (Słupia Nadbrzeżna, central Poland; Střeleč, Czech Republic; and El Rosario, NE Mexico). *Episodes*, 45 (2), 181–220.

Waters, J.A. 1927. A group of foraminifera from the Dornick Hills Formation of the Ardmore Basin. *Journal of Paleontology*, 1, 129–133.

Wiese, R., Renaudie, J. and Lazarus, D.B. 2016. Testing the accuracy of genus-level data to predict species diversity in Cenozoic marine diatoms. *Geology*, 44, 1051–1054.

Wilmsen, M. and Niebuhr, B. 2014. 1. Die Kreide in Sachsen. *Geologica Saxonica*, 60, 3–12.

Wilmsen, M., Niebuhr, B., Fengler, M., Püttmann, T. and Berensmeier, M. 2019. The Late Cretaceous transgression in the Saxonian Cretaceous Basin (Germany): Old story, new data and novel findings. *Bulletin of Geosciences*, 94, 71–100.

Wood, C.J., Ernst, G. and Rasemann, G. 1984. The Turonian-Coniacian stage boundary in Lower Saxony (Germany) and adjacent areas: the Salzgitter-Salder quarry as a proposed international standard section. *Bulletin of the Geological Society of Denmark*, 33, 225–238.

WoRMS. Foraminifera. Accessed at: http://www.marinespecies.org/aphia.php ?p=taxdetails&id=1410 on 28.07.2020.

Zwaan, G.J. van der, Duijnstee, I.A.P., Dulk, M. den, Ernst, S.R., Jannink, N.T. and Kouwenhoven, T.J. 1999. Benthic foraminifers: proxies or problems? A review of paleocological concepts. *Earth-Science Reviews*, 46, 213–236.

Chapter 6

Conclusions and outlook

6.1 Conclusions

Agglutinated foraminifera are classically used to solve biostratigraphical and/or paleoenvironmental issues if no calcareous–shelled microfossils are abundant. Such deposits are usually diagenetically carbonate-depleted flysch or sediments deposited in high latitudes, and deep-sea sediments from below the CCD. As the mid-Cretaceous paleoceanographical configuration with up to 250m higher sea levels than today was completely different, wide-spread warm shelf seas lead to extensive carbonate deposition on the shelfs. These carbonate successions are well accessible today but are not easily comparable to carbonate–depleted deposits named before.

This study reveals the distribution and potential for biostratigraphical and paleoenvironmental purposes of agglutinated foraminifera from shelf related carbonate deposits. Also, it attempts the closure of the gap between deep sea environments and the vast shelf areas in the mid-Cretaceous.

Comparisons of different micropaleontological methods for the disintegration of calcareous rock material have shown not only 1) that dissolving techniques such as the formic acid method are most suitable to obtain diverse agglutinated foraminiferal assemblages but also 2) that most of the agglutinated foraminiferal genera and species are missing in application of different standard micropaleontological methods. A bias of knowledge about the distribution and possible usability of agglutinated foraminifera was proven to exist for calcareous deposits from the mid-Cretaceous.

Albian to Coniacian diverse agglutinated foraminiferal assemblages from carbonate deposits from different European shelf basins were firstly documented and described in detail. A new agglutinated foraminiferal biofacies for these assemblages was proposed: the mid-latitude shelf biofacies. With this extended dataset for agglutinated foraminiferal distribution the regional and interregional biostratigraphical schemes based on agglutinated foraminifera were evaluated. Ranges of regional marker species were either confirmed or refined. In all successions biostratigraphical marker species used for the interregional correlation of deep-sea deposits could be found and were attributed to the widely used biozones of the Atlantic and Tethys.

Comparison of agglutinated foraminiferal assemblages from proximally and distally deposited successions from the Lower Saxony Basin revealed differences in relative abundances of agglutinated foraminiferal morphogroups related to their position inside of the basin. These different distributions of foraminiferal morphogroups are likely related to changes in bottom-water conditions – mainly food availability. While in proximal setting increased numbers of deep infaunal living elongate forms and shallow infaunal globular morphotypes are abundant, distally free epifaunal flattened forms occur more frequently and abundances of deep infaunal forms are relatively smaller. In general, all agglutinated morphogroups occur in the mid-Cretaceous calcareous shelf deposits – even those who are today mainly observed in bathyal to abyssal settings. These findings underline the substantial different conditions in the shallow shelf seas of the studied time interval.

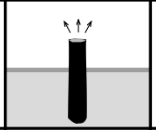
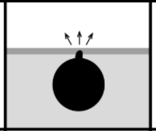
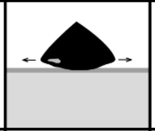
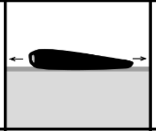
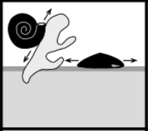
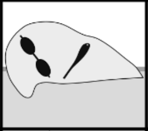
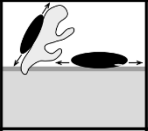
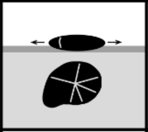
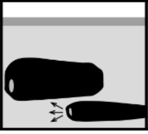
Morphogroup	**Morphotype**	**Test form**	**Life position & feeding habit**	**Environment** (former scheme)	**Environment** (this study)
M1		Tubular	Erect epifauna - suspension	Tranquil bathyal and abyssal	Inner shelf to abyssal
M2a		Globular	Shallow infauna - suspension and/or passive deposit	Common in bathyal and abyssal	Inner shelf to abyssal
M2b		Trochospiral and streptospiral	Surficial epifauna - active deposit	Shelf to deep marine	Shelf to deep marine
M2c		Elongate keeled	Surficial epifauna - active deposit	Shelf to marginal marine	Shelf to marginal marine
M3a		Flattened trochospiral, streptospiral and planispiral	Surficial epifauna - active & passive deposit	Lagoonal to abyssal	Lagoonal to abyssal
M3b		Flattened irregular	Surficial epifauna - suspension	Upper bathyal to abyssal	Inner shelf to abyssal
M3c		Flattened streptospiral	Surficial epifauna - active & passive deposit	Upper bathyal to abyssal	Inner shelf to abyssal
M4a		Rounded planispiral	Surficial epifauna and/ or shallow infaunal - active deposit	Inner shelf to upper bathyal	Inner shelf to upper bathyal
M4b		Elongate-subcylindrical and -tapered	Deep infauna - active deposit	Inner shelf to upper bathyal	Inner shelf to upper bathyal

Figure 6.1. Agglutinated foraminiferal morphogroups, morphotypes/test forms, life position, feeding habit, and environment (former scheme) redrawn and modified after Frenzel (2000), Cetean et al. (2011), and Setoyama et al. (2017). Environment adapted for the Cretaceous (this study: Besen et al. 2021, 2022, in prep).

Acmes (mass occurrences) of agglutinated foraminiferal species (partly also genera) could be linked to classical macro-bioevents which are usually expressed by mass occurrences of inoceramids, ammonites, or belemnites in the mid-Cretaceous deposits. These micro-bioevents are partly usable for stratigraphic correlations as they can be correlated intra- and interbasinally. Furthermore, these acmes but also changes in relative abundances of morphogroups often correspond to specific aspects of depositional sequences such as maximum flooding zones, late highstands, or lowstands. Thus, agglutinated foraminifera reveal potential to differentiate between basin- or interbasin-wide and regional environmental changes.

Agglutinated foraminifera constitute an underestimated tool especially for the reconstruction of paleoenvironmental changes in Cretaceous carbonate successions. Especially, sea level changes and changes in food availability or oxygen concentration in bottom water conditions can be reconstructed by use of agglutinated foraminifera. Easy and fast biostratigraphical attribution of studied rock-material to already published biozonal schemes from the Atlantic and Tethyan realm is possible.

6.2 Outlook

This study firstly documented agglutinated foraminiferal assemblages from the calcareous shelf deposits from the European Boreal shelf sea and gathered information about the utility of these assemblages for biostratigraphical and/or paleoenvironmental issues. Nevertheless, the studied time interval and region are both too short/small to confer the insights of these study to other times and regions. Therefore, further studies on other time intervals with expanded carbonate deposition are reasonable. Possible time intervals to study the distribution and evolution of agglutinated foraminifera on marine shelfs are those with increased sea levels resulting in expanded carbonate deposition (e.g., during the Upper Jurassic, Lower Cretaceous, the not studied remaining Upper Cretaceous (Santonian–Maastrichtian), Paleocene, and Eocene). Despite that, there are still open questions regarding the lateral distribution of agglutinated foraminifera during the Upper Cretaceous, especially on how agglutinated foraminifera thrived and evolved in other shallow shelf seas, particularly in the Tethyan region within vast carbonate platform areas.

In modern times, agglutinated foraminiferal diversity is increasing with water depth (Murray and Alve, 2011). If this scenario holds true for the Cretaceous assemblages is another open question. High diversities of agglutinated foraminiferal assemblages in shelf-related environments as observed in this study are not known to exist in modern times. Therefore, a completely different diversity pattern of agglutinated foraminiferal assemblages could be plausible. Extended research especially considering more different depositional settings from shore to the shelf slope could reveal the actual pattern of agglutinated foraminiferal diversity in the Upper Cretaceous.

6.3 References

Besen, R.M., Struck, U. and Seibertz, E. 2021. Albian to Turonian agglutinated foraminiferal assemblages of the Lower Saxony Cretaceous sub-basins – implications for sequence stratigraphy and paleoenvironmental interpretation. *Fossil Record*. 24, 395–441, https://doi.org/10.5194/fr-24-395-2021.

Besen, R.M., Achilles, M., Alivernini, M., Voigt, T., Frenzel, P. and Struck, U. 2022a. Stratigraphy and palaeoenvironments in the upper Turonian to lower Coniacian of the Saxonian Cretaceous Basin (Germany) – insights from calcareous and agglutinated foraminifers. *Acta Geologica Polonica*. 72, (2), 159–186, https://doi.org/10.24425/agp.2021.139307.

Besen, R.M., Schindler, K., Gale, A.S. and Struck, U. in prep. Agglutinated foraminifera from the Turonian–Coniacian boundary interval in Europe – stratigraphy and paleoenvironmental remarks. Submitted to *Journal of Micropaleontology* 17.01.2023, (currently under revision, 08.05.2023).

Cetean, C.G., Bălc, R., Kaminski, M.A. and Filipescu, S. 2011. Integrated biostratigraphy and palaeoenvironments of an upper Santonian–upper Campanian succession from the southern part of the Eastern Carpathians, Romania. *Cretaceous Research*, 32 (5), 575–590.

Frenzel, P. 2000. Die benthischen Foraminiferen der Rügener Schreibkreide (Unter-Maastricht, NE-Deutschland). *Neue Paläontologische Abhandlungen* Band, 3, 361 pp.

Murray, J.W. and Alve, E. 2011. The distribution of agglutinated foraminifera in NW European seas: Baseline data for the interpretation of fossil assemblages. Palaeontologia Electronica, 14 (2), 1–41.

Setoyama, E., Kaminski, M.A. and Tyszka, J. 2017. Late Cretaceous–Paleogene foraminiferal morphogroups as palaeoenvironmental tracers of the rifted Labrador margin, northern proto-Atlantic. In: Kaminski, M.A. and Alegret, L. (Eds.) Proceedings of the Ninth International Workshop on Agglutinated Foraminifera. *Grzybowski Foundation Special Publication*, 22, 179–220.

Appendix A

Related publications

In Appendix A all thesis related publications are listed.

Peer-reviewed publications:

Besen, R.M., Struck, U. and Seibertz, E. 2021. Albian to Turonian agglutinated foraminiferal assemblages of the Lower Saxony Cretaceous sub-basins – implications for sequence stratigraphy and paleoenvironmental interpretation. *Fossil Record*. 24, 395–441, https://doi.org/10.5194/fr-24-395-2021.

Besen, R.M., Achilles, M., Alivernini, M., Voigt, T., Frenzel, P. and Struck, U. 2022. Stratigraphy and palaeoenvironments in the upper Turonian to lower Coniacian of the Saxonian Cretaceous Basin (Germany) – insights from calcareous and agglutinated foraminifers. *Acta Geologica Polonica*. 72, (2), 159–186, https://doi.org/10.24425/agp.2021.139307.

Besen, R.M., Hegert, J. and Struck, U. 2022. The hidden agglutinated foraminifera of the mid-Cretaceous hemipelagic carbonate deposits: A method–derived bias? *Marine Micropaleontology*, 176, 102168, https://doi.org/10.1016/j.marmicro.2022.102168.

Conference contributions:

Besen, R.M., 2017. An old method newly applied - Agglutinated foraminifera from the Albian to Turonian from Wunstorf (NW -Germany). - *10th International Workshop on Agglutinated Foraminifera*, Smolenice Castle, Slovakia, 19-23 April 2017. (prelimary work before project application)

Besen, R.M., Achilles, M., Alivernini, M., Voigt, T., Frenzel, P. and Struck, U., 2022. Stratigraphy and palaeoenvironments in the upper Turonian to lower Coniacian of the Saxonian Cretaceous Basin (Germany) – insights from calcareous and agglutinated foraminifers. - *11th International Cretaceous Symposium*, Warsaw, Poland, 22-26 August 2022.

Besen, R.M., Hegert, J. and Struck, U., 2022. The hidden agglutinated foraminifera of the mid-Cretaceous hemipelagic carbonate deposits: A method–derived bias? - *The Micropalaeontological Society Annual Conference*, Bremen, Germany, 9-11 November 2022.

Besen, R.M. and Struck, U., 2023. Agglutinated foraminifera from the European boreal shelf sea during the Turonian nutrient crisis – preliminary results. – *11th International Workshop on Agglutinated Foraminifera*, Krakow, 19–22 April 2023.

Appendix B

Supporting information for Chapter 2:

The supporting information is not available in the online version due to copyright restrictions.

Appendix C

Supporting information for Chapter 3:

All supporting information for chapter 3 is included on a USB hard drive (printed version) or as supplementary tables in the supplement files (online version).

Appendix D

Supporting information for Chapter 4:

The supporting information is not available in the online version due to copyright restrictions.

Appendix E

Supporting information for Chapter 5:

Appendix E.1. 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; not figured.

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 sphericoidal. Last whorl with five to six 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)

(Fig. 5.5I)

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.

Caudammina 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. *Caudammina ovula* (Grzybowski); Kaminski and Gradstein, p. 233, pl. 41, figs. 1a–8.

Material. 9 specimens (in formic acid treated samples).

Caudammina sp.

Remarks. Fragmented specimen from the genus *Caudammina* Montanaro Gallitelli, 1955, most likely belonging to *Caudammina ovula*.

Clavulinoides sp.

Material. 42 specimens (in formic acid treated samples).

Cribrostomoides sp.

Material. 33 specimens (in formic acid treated samples).

Dicarinella cf. *concavata* (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)

(Fig. 5.5K)

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 Tyszka, 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

(Fig. 5.5L)

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 (no type figure given).

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, figs. 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).

Kechenotiske 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 *Kechenotiske 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)
(Fig. 5.5C)
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)

(Fig. 5.4G)

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

2015. *Planoheterohelix globulosa* (Ehrenberg); Haynes et al., p. 55, figs. 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

(Fig. 5.5A)

1875. *Psammosphaera fusca* Schultze, p. 113, pl. 2, figs. 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)

(Fig. 5.5B)

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

(Fig. 5.5F)

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)

(Fig. 5.5G)

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).

Saccammina grzybowskii (Schubert, 1902)

(Fig. 5.5D)

1902. *Reophax grzybowskii* Schubert, p. 20, pl. 1, fig. 13a–b.

1993. *Saccammina grzybowskii* (Schubert); Kaminski and Geroch, p. 248, pl. 2, figs. 1a–4b.

2005. *Saccammina 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.

Saccammina sphaerica Brady, 1871

1871. *Saccammina 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).

Spiroplectammina navarroana Cushman, 1932

1932. *Spiroplectammina navarroana* Cushman, p. 96, pl. 11, fig. 14.

1989. *Spiroplectammina navarroana* Cushman; Gradstein and Kaminski, p. 83, pl. 9, figs. 1a–12.

2005. *Spiroplectammina navarroana* Cushman; Kaminski and Gradstein, p. 426, pl. 103, figs. 1a–12.

Material. 9 specimens (in formic acid treated samples).

Spiroplectammina praelonga (Reuss, 1845)

(Fig. 5.5H)

1845. *Textularia praelonga* Reuss, p. 72, pl. 26, fig. 8

1970. *Spiroplectammina praelonga* (Reuss); Neagu, p. 40, pl. 5, fig. 4–6.

Material. 40 specimens (in formic acid treated samples).

Spiroplectammina 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)

(Fig. 5.5E)

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)

(Fig. 5.5J)

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).

Verneuilinoides sp.

Material. 87 specimens (in formic acid treated samples).

Remarks. This species group includes different species of the genus *Verneuilinoides* Mjatliuk, 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.

(Fig. 5.4A–F)

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

Curriculum Vitae

The curriculum vitae is not available in the online version due to personal data protection.

Danksagungen

Zuallererst möchte ich mich bei Ulrich Struck bedanken, der mir als Betreuer dieser Arbeit immer mit Rat und Tat zur Seite stand. Besonders danke ich dir für alle die Unterstützung und die vielen Freiheiten, die du mir gewährt hast.

Für alle die vielen hilfreiche Tipps und deine kontinuierliche Unterstützung über die Jahre hinweg bedanke ich mich herzlich bei Frank Riedel. Besonders hervorheben möchte ich die Unterstützung von Eki Seibertz, der mich initial in die Kreide geführt hat und allzeit Ideengeber sowie ein guter Gesprächspartner ist. Danke auch für die tollen Exkursionen in die Kreide!

Des Weiteren danke ich den vielen Co-Autoren der einzelnen Publikationen dieser Arbeit: Mareike Achilles, Mauro Alivernini, Thomas Voigt, Peter Frenzel, Jasmin Hegert, Kathleen Schindler, Andy Gale, Ulrich Struck und Ekbert Seibertz. Vielen Dank für die angenehme Zusammenarbeit!

Auch viele weitere Personen haben ihren Anteil an dieser Arbeit und ihnen wird gedankt: Jan Evers leiste technischen Support beim Fotografieren und bearbeitete die Bilder der agglutinierenden Foraminiferen; Maike Glos und Marc Barlage unterstützten bei Laborarbeiten und fertigten Dünnschliffe an; Patrick Göhring, Benjamin Besen, Ekbert Seibertz und Edina Merdan halfen bei der Beprobung von Kernen sowie Aufschlüssen im Gelände; Sascha Zertani las so einige Zeilen dieser Arbeit und korrigierte diese, aber stand auch mit Rat und Tat in Fragen der Ausgestaltung, formaler Abläufe sowie mit Tipps zu Publikationen zur Seite.

Nun möchte ich ganz besonders meinem engsten Kreise danken, ohne eure Unterstützung hätte das niemals geklappt: Oscar, Patrick, Hanna, Bruno, Benni und Alisa, aber ganz besonders natürlich: Danke an euch, Mama und Papa! Danke, dass ihr ihr das möglich gemacht habt! Und zuletzt danke ich Edi für das unerschütterliches Vertrauen in mich, dass du immer ein Ohr für mich hast, deine unglaubliche Unterstützung bei dieser Arbeit und natürlich für das größte Geschenk: Uma.