Chemostratigraphy and stratigraphic distribution of keeled planktonic foraminifera in the Cenomanian of the North German Basin

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Abstract

The record of keeled planktonic foraminifera during the Cenomanian in boreal epicontinental basins is discontinuous. Micropalaeontologic and bulk carbonate carbon and oxygen isotope investigations from two cores in the center of the North German Basin (NGB, Wunstorf, Lower Saxony) showed keeled praeglobotruncanids and rotaliporids to exclusively appear during three stratigraphic intervals of varying duration in the lower and middle Cenomanian. Our new high-resolution carbon isotope ($\delta^{13}C_{carb}$) composite curve shows that keeled foraminifera are absent during the Mid Cenomanian Event (MCE) I. In the aftermath of MCE I, keeled planktonic foraminifera are present throughout. The data are correlated to previously published sequence stratigraphic models for the NGB. The presence/absence of keeled planktonic foraminifera in the epicontinental NGB is believed to be controlled by sea level and according environmental conditions in the epicontinental basin.

Kurzfassung

In den Cenoman-zeitlichen Abfolgen der epikontinentalen Becken der borealen Kreide lassen sich gekielte planktonische Foraminiferen nicht durchgehend nachweisen. Neue Untersuchungen an zwei Bohrungen aus dem Norddeutschen Becken bei Wunstorf in Niedersachsen zeigen, dass sich die Vorkommen von gekielten Praeglobotruncanen und Rotaliporiden auf drei stratigraphisch klar abtrennbare Intervalle des Untercenomaniums und Mittelcenomaniums beschränken. Die hier präsentierte neue und hochauflösende Kohlenstoffisotopenkurve ($\delta^{13}C_{carb}$) belegt außerdem, ein Fehlen gekielter planktonischer Foraminiferen während der positiven C-Isotopen-Exkursion des Mid Cenomanian Event (MCE) I. Oberhalb des MCE I ist das Vorkommen gekielter planktonischer Foraminiferen kontinuierlich. Die Korrelation unserer Daten mit etablierten sequenzstratigraphischen

Untergliederungen für das Cenomanium Norddeutschlands weist auf einen Zusammenhang zwischen Meeresspiegelschwankungen und dem Vorkommen gekielter Formen hin. Offensichtlich ermöglichten die Umweltbedingungen während hoher Meeresspiegelstände das Leben gekielter Formen in den Randbecken.

1. Introduction

In the Cretaceous Tethyan and Atlantic oceans, some of the Late Albian to Cenomanian planktonic foraminiferal species are excellent stratigraphic marker fossils, often present throughout long intervals of successions, resulting in frequently applied biostratigraphical zonations (e.g. Robaszynski and Caron, 1979; Caron, 1985; Robaszynski and Caron, 1995; Coccioni and Premoli Silva, 2015). Over the years however, taxonomic revisions of planktonic foraminiferal taxa, especially of the polyphyletic *Rotalipora* group (*Rotalipora,* Brotzen 1942*; Thalmanninella,* Sigal, 1948*; Pseudothamanninella*, Wonders, 1978; *Parathalmanninella*, Lipson-Benitah, 2008), have resulted in the re-interpretation of the morphologic plasticity and species variation within the lineages (Robaszynski et al., 1994; Petrizzo and Huber, 2006; Gonzales-Donoso et al., 2007; Lipson-Benitah, 2008), which of course, has influences on the classic planktonic foraminiferal biozonations (e.g. discussions in Ando et al., 2010; Petrizzo et al., 2015; Falzoni et al., 2018). In contrast to the Tethys, unkeeled and globular forms, predominately muricohedbergellids (Huber and Leckie, 2011) dominate the lower to lowermost Upper Cretaceous of the Boreal epicontinental basins (Hecht, 1938; Carter and Hart, 1977; Weiss, 1997; Rückheim et al., 2006; Weiss, 2012). First keeled rotaliporids appear in the latest Albian, but mostly as single specimen or in low numbers (Weiss, 1997). Stratigraphic patchiness of keeled planktonic rotaliporids and praeglobotruncanids continues in the lower to middle Cenomanian (Carter and Hart, 1977; Koch, 1977; Weiss, 1982; Premoli Silva and Sliter, 1999). This changes in the upper Cenomanian following the so-called "P/B break" in Boreal successions, a level marking a sudden increase in total number of planktonic foraminifera versus benthic foraminifera above the "mid-Cenomanian non-sequence" first described by Carter and Hart (1977) (see also Dahmer and Ernst, 1986). As potential factors controlling the stratigraphic patchiness, palaeotemperatures (Carter and Hart, 1977), ingressions of Tethyan water masses (Carter and Hart, 1977; Weiss, 1997), sea-level variations (Hart and Bailey, 1979, Dahmer and Ernst, 1986), the presence of a layered water column versus vertical mixing (Mitchell and Carr, 1998) and changes in nutrient supply have been discussed. In the light of this patchiness, an application of the standard Tethyan planktonic foraminiferal zonation is obviously difficult, especially in the lower to middle Cenomanian (comp. Carter and Hart, 1977; Weiss, 1982; Bornemann et al., 2017).

The North German Basin as part of the Southern Permian Basin is one of the southernmost epicontinental basins of the Cretaceous Boreal realm with varying connections to the Tethys via potential gateways in the West and Southeast (summary in Voigt et al. 2008b; Fig. 1). In the central Lower Saxony Basin (LSB), a sub-basin of the North German Basin, the Cenomanian is represented by an up to 170-m-thick succession of hemipelagic marly claystones and marly limestones. For details on the palaeogeographic evolution and depositional environment of the Cenomanian North German Basin see Voigt et al. (2008b) and Wilmsen (2003, 2012).

Over the past 15 years, detailed $\delta^{13}C$ records have allowed for a comprehensive chemostratigraphic correlation of upper Albian to upper Cenomanian successions between

Tethyan basins, the Central Atlantic, and the Boreal realm (e.g. Jarvis et al., 2006, Petrizzo et al., 2008; Gambacorta et al., 2015; Giorgioni et al., 2015; Bornemann et al., 2017; Gyawali et al., 2017). Positive and negative excursions of carbon isotope records in the upper Albian to Turonian are frequently used to correlate sedimentary successions and have been interpreted as global carbon cycle perturbations (e.g. Jenkyns et al., 1994; Erbacher et al., 1996; Jarvis et al., 2006). For the upper Albian to middle Cenomanian, however, the resolution of the Boreal records from England (Mitchell et al., 1996; Jarvis et al., 2006) and Northern Germany (Mitchell et al., 1996; Wilmsen, 2007) are rather low, hampering a detailed correlation to sections elsewhere. While the high-resolution record of Bornemann et al. (2017) focused on the Albian-Cenomanian transition, our study presents the first high-resolution $\delta^{13}C_{carb}$ record for the lower to upper Cenomanian of the Boreal realm. Globally or supra-regionally occurring carbon isotope excursions during the stratigraphic interval investigated herein are: the lower Cenomanian excursions belonging to LCE 1 to 3 (Jarvis et al., 2006); the Mid Cenomanian Event (MCE) I (Paul et al., 1994; Mitchell et al., 1996; Jarvis et al., 2006) and Oceanic Anoxic Event 2 (Arthur et al., 1985; Tsikos et al., 2004; Erbacher et al., 2005; Voigt et al. 2008a; Jenkyns, 2010, among many others).

Our dataset includes a new composite record documenting the carbon and oxygen isotopes as well as the presence/absence of keeled planktonic foraminifera, spanning large parts of the Cenomanian. This is based on two recently cored commercial boreholes that have been drilled close to Wunstorf, 25 km west of Hanover, Germany (Cores Wunstorf 11/8 and 11/2, Fig. 1). Our record is stratigraphically correlated and partly stratigraphically overlapping with core Anderten 1, east of Hanover, yielding an upper Albian to lower Cenomanian succession (see Bornemann et al., 2017) and with core WK1, close to Wunstorf and stratigraphically covering the upper Cenomanian to lower Turonian (Voigt et al., 2008a) (Figs. 1 and 2). Our data is complemented with published data from the upper Cenomanian of Wunstorf (Weiss, 1982: planktonic foraminifera; Voigt et al., 2008a: carbon and oxygen isotopes).

The upper part (uppermost Lower Cenomanian to Cenomanian-Turonian Boundary Interval) of the herein studied succession has been described by several authors based on a 110-m-thick succession cropping out in the Wunstorf quarry (Weiss, 1982; Meyer 1990; Zügel, 1994; Mitchell et al., 1996; Wilmsen, 2007; Wilmsen et al., 2007) and the scientific drill-core WK1 (Fig. 1) (Erbacher et al., 2007; Voigt et al., 2008a; Blumenberg and Wiese, 2012; van Helmond et al., 2015). Wilmsen (2003) and Wilmsen and Niebuhr (2002) established a well-documented multi-stratigraphic, sedimentological and sequence-stratigraphic scheme of the succession. According to them, the succession in Wunstorf was situated on the outer shelf with high sedimentation rates of up to 100 m/my in the lower and middle Cenomanian and 4 to 6 times lower sedimentation rates in the upper Cenomanian. Regardless of the expanded character of the section, hiatuses of potentially limited extend might be present at the sequence boundaries.

The aim of this paper is to document and investigate the stratigraphic patchiness of keeled planktonic foraminifera in the lower to middle Cenomanian of the North German Basin. Potential reasons responsible for this patchiness are discussed and the first high-resolution carbonate carbon isotope record spanning the entire Cenomanian of the North German Basin is presented. Planktonic foraminiferal events in the North German Basin are stratigraphically constrained by this detailed chemostratigraphic record.

2. Material and methods

Cores Wunstorf 2011/2 and Wunstorf 2011/8 are located 1 km south of Wunstorf (approx. 25 km west of Hannover, Germany) near a semi-active quarry, owned by Lafarge-HOLCIM, north of the Autobahn A2. The two holes are situated ca. 800 m apart (Wunstorf 2011/2: UTM 32532994.75 E, 5805234.25 N; Wunstorf 2011/8: UTM 32532837.55 E, 5806131.47 N, Fig. 1). Each core covers a 100-m-thick succession spanning the lower Turonian to upper part of the lower Cenomanian (Wunstorf 2011/2) and upper part of the lower Cenomanian to the lower part of the lower Cenomanian (Wunstorf 2011/8). Lithostratigraphically, the two cores comprise the uppermost Herbram- (Bemerode Member), Baddeckenstedt- and Brochterbeck-Formations. The upper part of the cored succession, including the Cenomanian-Turonian Boundary Event (CTBE) is intensively discussed in Voigt et al. (2008a), Wilmsen (2003) and Weiss (1982). Therefore, we focus on the lower 57 m of core Wunstorf 2011/2 and the lowermost 80 m succession of Wunstorf 2011/8, i.e. the lower part of the upper Cenomanian to lower Cenomanian (Figure 2) herein. Our data, however, is complemented with the datasets from Voigt et al. (2008a) and Weiss (1982). See Figures 3 and 4.

Micropalaeontology sample spacing ranges from 5 to 100 cm. All samples were crushed into small pieces (1 to 2 cm in diameter), dried, gently disaggregated using an 85% water, 15% hydrogen peroxide solution and soaked in a solution of 80% acetic acid and water modified after the method suggested by Lirer (2000). After soaking, the samples were washed with warm water over a 63 µm mesh sieve and dried at 50°C. The fraction >63 µm was then dry-sieved into fractions >315 µm, 315 to 200 µm, 200 to 125 µm and 125 to 63 µm. From each fraction, planktonic foraminifera and ostracods were picked in slides. Planktonic foraminifera and the ostracod *Physocythere steghausi* were qualitatively (present/absent) and semi-quantitatively documented for biostratigraphic purposes. Keeled planktic foraminifera and *P. steghausi* were only retrieved from fractions >125 µm. Taxonomic concepts for planktonic foraminiferal genera and species identification follow their original descriptions and illustrations, the taxonomies by Caron and Spezzaferri (2006), Petrizzo and Huber (2006), Ando and Huber (2007), Gonzales Donoso et al (2007); Huber and Leckie (2011), Petrizzo et al. (2015), and the online taxonomic database for Mesozoic Planktonic Foraminifera available at http://www.mikrotax.org/pforams/index html (Huber et al. 2016). Type material is stored in the Collection of Micropalaeontology (Micro-Unimi) of the Department of Earth Sciences, University of Milan.As mentioned above, we used data documented and described by Weiss (1982) to complement our dataset by correlating his data from the nearby Wunstorf quarry to our dataset (see Fig. 5). Weiss (1982), focused on the middle to upper Cenomanian part of the succession, leading us to sample the lower part of the section at higher resolution.

For carbon and oxygen isotope the two drill cores were sampled at a spacing between 20 and 100 cm resulting in a total of 319 samples that were analysed for $CaCO_3$ and total organic carbon (TOC) using a LECO device (LECO Corporation, St Joseph, MI, USA) at the BGR in Hanover. Analyses for bulk-rock stable isotopes ($\delta^{13}C$, $\delta^{18}O$) were conducted using a Thermo Scientific GasBench II carbonate device connected to a Thermo Scientific Delta 5 Advantage IRMS (Thermo Fisher Scientific, Waltham, MA, USA) at the Institute of Geology, Leibniz University of Hanover. The GasBench uses viscous water-free (98 g mol^{-1}) orthophosphoric acid at 72°C to release CO_2 of the calcite 1 h before the start of the measurement. Values are expressed in the delta notation relative to Vienna Pee Dee Belemnite (VPDB) in per mill. Repeated analyses of certified carbonate standards (NBS 19, IAEA CO-1 and CO-8) show an external reproducibility of <0.06‰ for $\delta^{13}C$ and <0.08‰ for $\delta^{18}O$. As mentioned above, we used data documented and described by Voigt et al. (2008a) to complement our dataset by correlating their data from the nearby core WK 1 to our dataset (see Fig. 3).

3. Results

3.1 Stable isotope stratigraphy and $CaCO_3$ values

$\delta^{13}C$ values of cores Wunstorf 11/2 and 11/8 are remarkably stable and vary around 2 per mill between 145 and 45 mcd (meter composite depth, Fig.3). A 1.5‰ positive excursion with maximum values of up to 3‰ is evident between 49 and 30 mcd, followed by a short trough and another increase between 20 and 14 mcd. $\delta^{18}O$ values are more variable than the $\delta^{13}C$ data. Most negative excursions are documented between 145 and 130 mcd (around -3.8‰). Upsection, the oxygen isotope record shows a long-term cyclicity between 2 and 3‰ and whereas $CaCO_3$ values show a gradual long-term increase from 60 to 90 wt% between the base of the succession and the top. However, a step in $CaCO_3$ content is observed at 70 mcd, values below this level show a meter-scale high variability of 15 wt% reflecting marl and limestone alternations, values above 70 m are more uniform.

3.2 Planktonic foraminifera (Fig. 4)

Planktonic foraminifera, mostly muricohedbergellids, are present in all samples in varying abundances (see also Weiss et al., 1982). Below 117 mcd of the composite section, planktonic foraminiferal faunas are dominated by muricohedbergellids. *Globigerinelloides* is present but rare throughout this lower part of the succession. Favusellids only occur in very few samples. At 116.20 mcd and 1.18 m above the HO (highest occurrence) of *P. steghausi*, lies the LO (lowest occurrence) of rotaliporids in core Wunstorf 11/8, which are represented by *Thalmanninella globotruncanoides* and *Thalmanninella* cf. *reicheli*. Strikingly large forms (> 200 µm) dominate these faunas. Rotaliporids disappear above 114.2 mcd and reappear in low numbers between 105 and 104 mcd. Specimens in the latter interval are small and mainly represented by the species *Thalmanninella globotruncanoides* and *Thalmanninella brotzeni*. Weiss (1982) documented praeglobotruncanids in the same stratigraphic level of the nearby Wunstorf quarry. No keeled planktonic foraminifera (with exception of one single *Praeglobotruncana delrioensis* specimen at 97.11 mcd) occur until 87,88 mcd. Between 87,88 and 75 mcd keeled planktonic foraminifera belonging to the species *Th. globotruncanoides*, *Th. brotzeni*, *Thalmanninella gandolfi* are present albeit usually in small numbers. The assemblages in this interval are composed by abundant muricohedbergellids (*Muricohedbergella delrioensis*, *Clavihedbergella amabilis*, *Clavihedbergella simplicissima*, *Muricohedbergella portsdownensis*) characterized by a high variability in the arrangement of the chambers. Rare *Rotalipora montsalvensis* are identified at 79 mcd. No keeled forms are present between 70 and 74 mcd. Between 70 and 45 mcd keeled planktonic foraminifera such as *Th. globotruncanoides*, *Th. gandolfi, R. montsalvensis* and *Praeglobotruncana delrioensis* are mostly present. Rare specimens resembling *Thalmanninella reicheli* and *Thalmanninella greenhornensis* are recorded at 49.52 mcd. Few meters above, at 45.95 mcd, *Thalmanninella deeckei* and *Whiteinella archaeocretacea* are recorded although very rare. Muricohedbergellids and especially the species *M. delrioensis* and *M. portsdownensis* are common in this interval. A striking lack of keeled forms is evident between 44 and 32 mcd. Weiss (1982) documented one single sample at approx. 38 mcd from this interval with a few praeglobtruncanids. Above 30 mcd, keeled planktonic foraminifera are present and usually common in all samples investigated. Remarkable are the occurrence of common *R. montsalvensis*, which shows a high morphologic variability in the shape and number of chambers in the last whorl, and the presence of many specimens transitional to *Rotalipora cushmani*.

A detailed and taxonomic study/review on the planktonic foraminifera observed will be the focus of another study (Petrizzo and Erbacher in prep.).

3.3 Stratigraphy and correlation of the sections investigated

The base of our composite succession lies in the lowermost lower Cenomanian. The uppermost positive excursions of Albian-Cenomanian Boundary Event, well documented in core Anderten 1 (see Bornemann et al., 2017), is not reached, which gives us a good estimate for the maximum age of our succession.

The highest occurrence (HO) of the ostracod species *Physocythere steghausi* is regarded as a useful stratigraphic marker in the North German Basin (Frieg et al., 1989; Witte et al., 1992). The HO of *P. steghausi* in core Wunstorf 11/8 at 73.38 m (117.38 mcd) is very close to the lowest occurrence (LO) of rotaliporids at 72.69 m (116.2 mcd, Fig. 5). Bornemann et al. (2017) described the same succession of biostratigraphic events, which we call the "*steghausi*-*Thalmanninella*-Event", and even the same vertical distance between these events from core Anderten 1. This suggests similar sedimentation rates in both successions and underlines the solid applicability of the *steghausi*-*Thalmanninella*-Event at least in the North German Basin. Bornemann et al. (2017) related a pronounced positive δ^{13}C excursion immediately below this event to one of the Lower Cenomanian Events (LCEs) sensu Jarvis et al. (2006). Although sampled at high resolution, this carbon isotope peak cannot be identified in Wunstorf 11/8. Whether this questions the completeness of Wunstorf 11/8 or interpretation in Bornemann et al. (2017) remains open.

Above approx. 105 mcd, the succession recovered in Wunstorf 11/8 overlaps with the record formerly cropping out in the Wunstorf quarry, which was described in detail by Wilmsen (2003). This allows for a correlation of the recently developed and well-established bio- and lithostratigraphic scheme for the North German Cenomanian (e.g. Wilmsen, 2003; Wilmsen et al., 2005; Wilmsen, 2007; Wilmsen, 2008) with the succession discussed herein (Figs. 2 and 3).

We interpret the pronounced positive carbon isotope excursion between 49 and 30 mcd to be the local expression of the MCE I. Mitchell et al., (1996) and Wilmsen (2007) both described the presence of the MCE I at Wunstorf. As described in Mitchell et al., (1996), MCE I may be subdivided in two distinct positive peaks, MCE 1a and MCE 1b (Fig. 3). Above approx. 30 mcd, the succession recovered in Wunstorf 11/2 overlaps with the succession described by Erbacher et al. (2007) and Voigt et al. (2008a) (core WK1, Figs. 1 and 2). This allows us to tying our data to a stable isotope record reaching up to the lower Turonian, including the positive carbon isotope excursion related to the Cenomanian-Turonian Boundary Event (Fig. 3).

4. (Sequence-) Stratigraphic distribution of keeled planktonic praeglobotruncanids and rotaliporids in the North German Basin

Figure 4 shows the stratigraphic distribution of intervals yielding keeled planktonic foraminifera. Four of these intervals (Intervals I to IV) may be discriminated. Interval I, in the lower part of the lower Cenomanian was first described in core Anderten 1 (Bornemann et al., 2017). It is the first, albeit stratigraphically short interval, with abundant and diverse keeled planktonic foraminifer faunas in the North German Basin. Stratigraphically older findings are confined to single and mostly rare specimen of *Th. appeninica* in upper Albian successions (Koch, 1977, Weiss, 1997). A comparison with the relative sea-level curve and sequence stratigraphic scheme for the North German Basin by Wilmsen (2012) shows Interval I lying above Sequence Boundary Ce1 and correlating with the according transgressive systems tract (TST).

Interval II in the middle lower Cenomanian is not as pronounced as Interval I, as keeled planktonic foraminifera do occur but are not as common as in Interval I. It is striking, however, that the interval lies once again above a sequence boundary (SB Ce2) and, thus, falls into a TST.

In contrast to Intervals I and II, the upper lower Cenomanian Interval III is of much longer duration. As Interval II, it belongs to depositional sequence Ce III (Wilmsen, 2003). While Interval II correlates with the lower part of the TST, Interval III comprises the maximum flooding zone as defined by Wilmsen (2003).

Interval IV begins at the end of the MCE I and its base correlates with the “P/B break” (sensu Carter and Hart, 1977). The upper limit of this interval is not defined, as keeled planktonic foraminifera are present throughout the mid middle to upper Cenomanian succession in Northern Germany (Koch, 1977; Weiss et al., 1982; Dahmer and Ernst, 1986).

5. Planktonic foraminiferal intervals and controlling factors – a discussion

Based on the results presented above, the occurrence of keeled planktonic foraminifera in the North German Basin seems to be related to sea level. A rising sea level would allow keeled planktonic foraminifera to migrate into the Cenomanian North German Basin via gateways potentially existing in the northwest (North Sea) and southeast (Polish Basin) (Voigt et al. 2008b, Fig. 2). Several authors already suggested this being a potential cause for the base of Interval IV (Carter and Hart, 1977; Dahmer and Ernst, 1986), but for the earlier Intervals I to III, this observation has not been documented yet.

The classic model for depth habitats of Cretaceous planktonic foraminifera goes back to a modern analogue model, where species with small, simple and globular tests would be shallow dwellers and large, complex tests often disc-shaped with keels would be deep dwellers. Accordingly, muricohedbergellids are interpreted as shallow dwellers and keeled species, such as rotaliporids, as deep dwellers resulting in a dominance of muricohedbergellids in epicontinental basins (e.g. Hart and Bailey, 1979; Hart, 1980; Caron and Homewood, 1983; Leckie, 1987; Premoli Silva and Sliter, 1999). Modern depth-habitat reconstructions based on carbon and oxygen isotope investigations of diagenetically uncompromised tests, however, demonstrated that such models are too simplistic (e.g., Hart, 1999; Abramovich et al., 2003; Bornemann and Norris, 2007; Ando et al., 2009, 2010; Falzoni et al., 2013, 2016). Planktonic foraminifera seem to be far more adaptive to varying environmental conditions than formerly expected and water-depth seems to be only one potential factor controlling the presence or absence in ecological niches. Other ecological factors are the thickness of the mixed-layer, position and stability of the thermocline, trophic conditions and salinity, as well as surface water circulation (see Hart, 1999; Abramovich et al., 2003; Ando et al., 2009, 2010; Falzoni et al., 2013, 2016; Petrizzo et al., 2017 and discussions therein).

The spatial distribution of planktonic organisms in epicontinental seas is mainly depending on ocean circulation patterns (e.g. currents) and boundaries between different water masses (Schiebel and Hemleben, 2017). For the case of the North German Basin this means Tethyan or Atlantic water-masses needed to have flown into or through the basin in order to enable planktonic foraminifera to invade. An increase of sea level alone would not bring e.g. Tethyan planktonic foraminifera to the North German Basin. This sounds trivial but needs to be taken into account when discussing the factors responsible for the presence or absence of keeled planktonics in an epicontinental basin.

Intervals I to IV: While a correlation of Intervals III and IV with high sea level is obvious as both of these Intervals correlate perfectly with the maximum flooding zones defined by Wilmsen (2003, 2008), the correlation of Intervals I and II is not as straight forward. Both of these events are much shorter in duration and rather correlate with phases of rising but not highest sea level (Fig. 5). This might be explained by a sample resolution too low to document the presence/absence of foraminifera sophisticatedly. Another possible explanation is a lack of precision of Wilmsen's sea-level curve for the lower lower Cenomanian part of the succession. Certainly, his observations for this stratigraphic interval are based on a rather limited number of sections, leaving space for a re-interpretation of the sea-level curve for this stratigraphic part (see question mark behind the position of SB Ce2 in e.g. Wilmsen, 2003). A third possibility could be, ocean currents connecting the North German Basin during the initial transgression, only and being redirected, elsewhere, during further sea level rise. This interpretation is supported by the presence of large rotaliporid tests in Interval I and a lack of small, potentially juvenile forms. One potential explanation for this interpretation was given by Retailleau et al. (2009). These authors have observed a lack of small tests in planktonic foraminifer cohorts on the modern continental shelf in the Bay of Biscay. The authors interpreted theses faunas as being expatriated from the open ocean. Environmental conditions on the shelf (river discharge affecting salinity and trophic conditions) allowed a further growth of the foraminifer individuals but no reproduction.

Keeled planktonic foraminifera in the Cenomanian of southern England: A comparison with the planktonic foraminiferal record of the Cenomanian in southern England shows a rather comparable evolution, although continuous records are lacking. Apparently, keeled species are present from the base of the Lower Cenomanian onward (*Thalmanninella appenninica* and *Praeglobotruncana stephani*) (Carter and Hart, 1977) but their stratigraphic appearance seems to be patchy and a continuous presence of keeled forms is not observed before the late Lower Cenomanian, i.e. during our late Interval III (Carter and Hart, 1977; Paul et al., 1994; Hart and Harris, 2012).

<u>*MCE 1*</u>: In contrast to Wunstorf and Baddeckenstedt, a more proximal section to the southeast of Wunstorf (Bartels, unpubl.), keeled planktonic foraminifera are present in southern England during the MCE 1 positive carbon isotope excursion (Paul et al., 1994; Mitchell and Carr, 1998). Mitchell and Carr (1998) explained the occurrence of *Th. reicheli* in Folkestone to be controlled by the 100 ky eccentricity cycle with *Th. reicheli* only being present during the transgressive phase of a cycle and disappearing thereafter and *R. montsalvensis* and praeglobotruncanids being present throughout the MCE. Generally, however, MCE 1 is paralleled by a low sea level (Wilmsen, 2012; Gebhardt et al., 2004) and a potential ingression of cool water masses from the Boreal Sea (e.g. Zheng et al., 2016). The environmental conditions during MCE 1, obviously did not allow keeled planktonic species to survive in the North German Basin. As they were described from southern England, however, temperature can be ruled out as a factor controlling the absence. Other factors such as water-depth, salinity, the availability of prey or the connection of the North German Basin by open ocean currents thus have to be considered. Batenburg et al. (2016), based on astronomical age models for sections from the Western Interior Seaway, dated the base of the MCE 1 excursion to 96.57+/-0,12 Ma and the end of the excursion to 96.36 +/-0,12 Ma, resulting in a duration of 200 ky for MCE 1 and the absence of keeled planktonic foraminifera in Northern Germany, respectively.

6. Summary

Micropalaeontologic and carbon and oxygen isotope investigations from two new cores in the center of the North German Basin (Wunstorf, Lower Saxony) showed keeled praeglobotruncanids and rotaliporids to appear during three stratigraphic intervals of varying duration in the Lower and Middle Cenomanian. The last interval without keeled planktic foraminifera is during the Mid Cenomanian Event (MCE 1). Above MCE 1 and starting with the "P/B-break" (Carter and Hart, 1977), keeled planktonic foraminifera are present throughout. Our new high-resolution stable carbon isotope record allowed tying the micropalaeontologic record to sequence stratigraphic models and sea level curves for the North German Basin published by Wilmsen (2012). Obviously, high sea level connected the North German Basin to Tethyan and/or Atlantic water masses during the intervals yielding keeled planktonic foraminifera. Planktonic foraminifera were able to adapt to the environmental conditions in the North German Basin. Whether or not they were thriving in the same ecological niches as in their "original" habitat remains open.

7. Acknowledgments

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Figure Captions

Fig 1: (A1) locality map of the Wunstorf quarry near Hanover with position of cores Wunstorf 2001-2 and Wunstorf 2011-8 as well as core WK1; (A2) locality map of Northern Germany with position of Wunstorf and cores Anderten 1 and 2 near Hanover. (B) Palaeogeographic map of northern Germany during Albian and Cenomanian times with position of locations discussed herein (modified after Hiss, 1995).

Fig 2: Palaeogeographic map of Europe for the Upper Cretaceous, modified after Vejbaek et al. (2010).

Fig. 3: Composed section for Wunstorf cores (WK1, Wunstorf 2011-2 and Wunstorf 2011-8) and Wunstorf quarry (Wilmsen, 2003, Erbacher et al., 2007, Voigt et al., 2008a) showing schematic lithology, stable carbon and oxygen isotope records and $CaCO_3$ values. Names indicate key chemostratigraphic events following the terminology of Jarvis et al. (2006). $\delta^{13}C$ record: light green line from core Wunstorf 2011-8, dark green line from core Wunstorf 2011-2, black line from core WK 1 (Voigt et al., 2008a). $\delta^{18}O$ record: red line from core Wunstorf 2011-8, brown line from core Wunstorf 2011-2, black line from core WK 1 (Voigt et al., 2008a). $CaCO_3$ values: red line from core Wunstorf 2011-8, brown line from core Wunstorf 2011-2. The "facies change", which marks the lithologic base of the Cenomanian Turonian Boundary Event (CTBE), has been taken as 0 m on the depth scale.

Fig. 4. 1a-c, *Thalmanninella gandolfi*, sample 11/8-31.00-31.05; 2a-c, *Muricohedbergella delrioensis*, sample 11/8-31.00-31.05; 3a-c, *Clavihedbergella simplicissima*, sample 11/8-31.00-31.05; 4a-c, *Praeglobotruncana delrioensis*, sample 11/8-56.10-56.15; 5a-c, *Thalmanninella globotruncanoides*, sample 11/2-57.44-57.50; 6a-c, *Rotalipora montsalvensis*, sample 11/2-50.00-50.05; 7a-c, *Rotalipora* cf. *cushmani*, sample 11/2-50.00-53.05; 8a-c, *Whiteinella archaeocretacea*, sample 11/2-76.22-76.78; 9a-c, *Thalmanninella reicheli*, sample 11/2-50.00-53.05; 10a-c, *Muricohedbergella portsdownensis*, sample 11/2-50.00-50.05. Scale bars 100 μm. SEM images acquired at the Department of Earth Sciences, University of Milan using Jeol JSM-IT500.

Fig. 5. Composed section for Wunstorf cores (WK1, Wunstorf 2011-2 and Wunstorf 2011-8) and Wunstorf quarry showing schematic lithology and $\delta^{13}C$ record (see figure caption 4). Dots indicate microplaeontologic results from this study (left column) and Weiss (1982) (right column). Sequence boundaries (SB Ce) are from Wilmsen (2003) and Bornemann et al. (2017).

Sea level curve from Wilmsen (2012). Grey shaded horizons mark intervals with keeled planktonic foraminifera.

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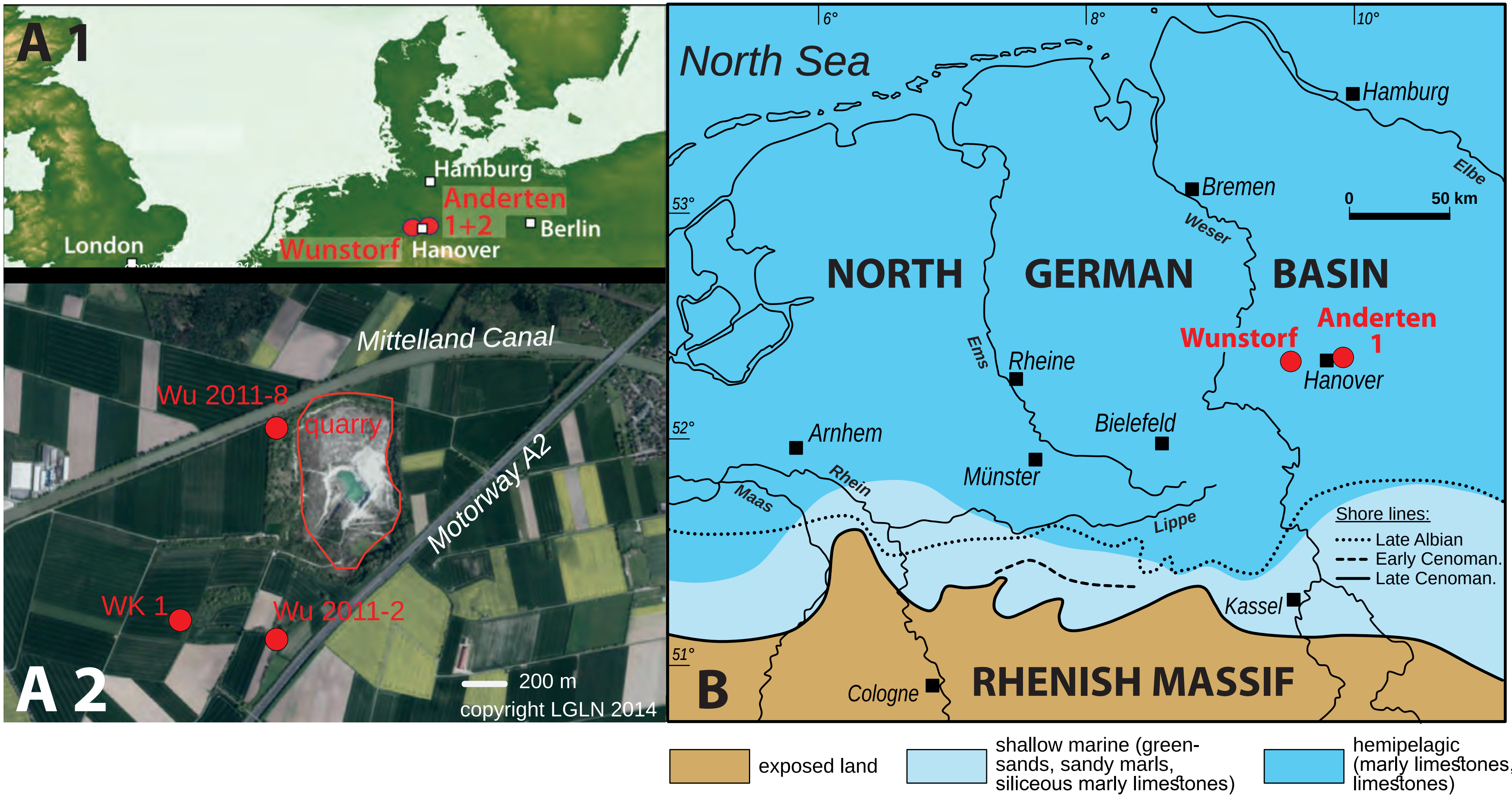
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Hanover
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Shore lines:
Late Albian
Early Cenoman.
Late Cenoman.
Kassel
51°
Cologne
RHENISH MASSIF
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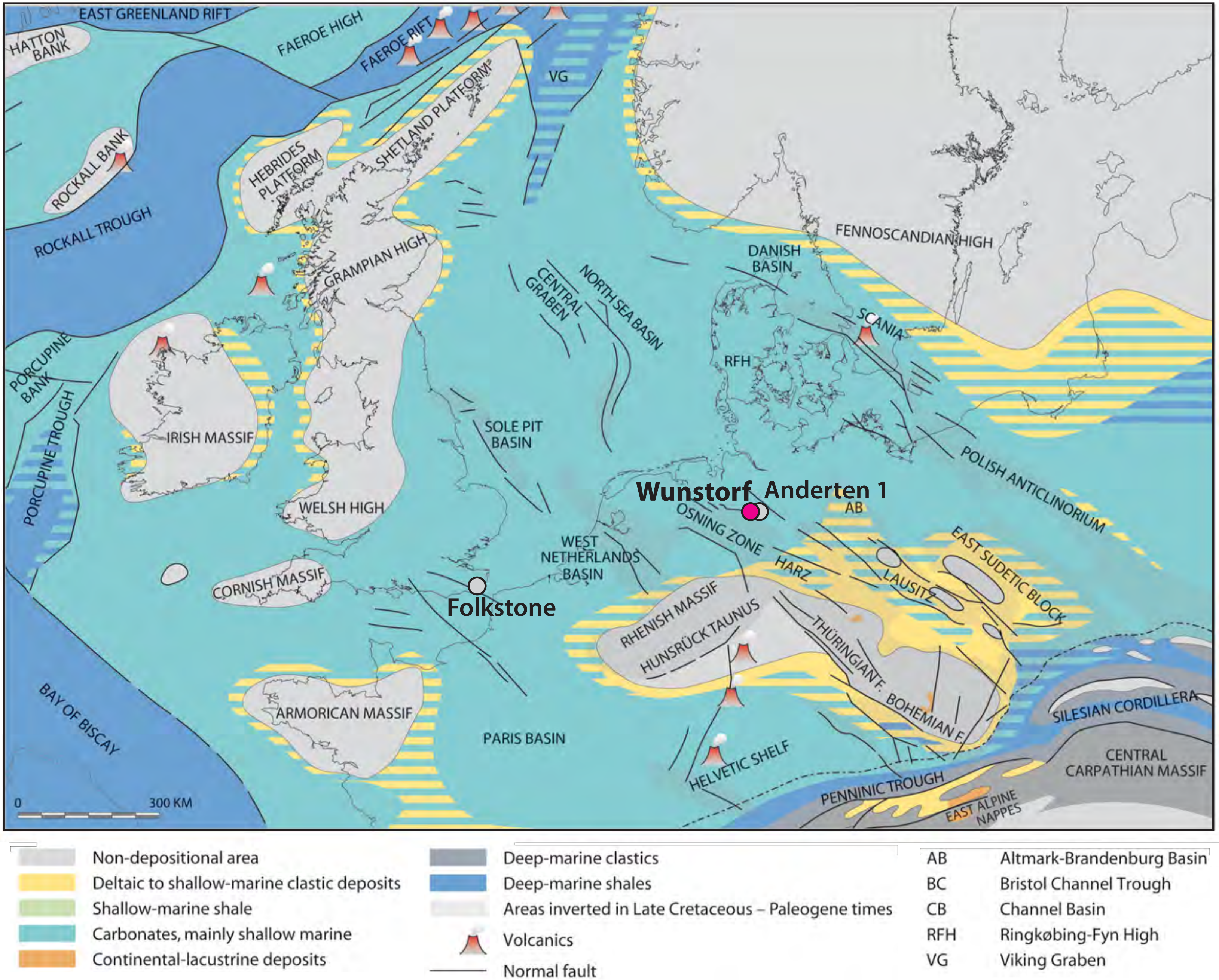
shallow marine (green-
sands, sandy marls,
siliceous marly limestones)
hemipelagic
(marly limestones,
limestones)

Fig. 1


EAST GREENLAND RIFT
HATTON BANK
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FAEROE RIFT
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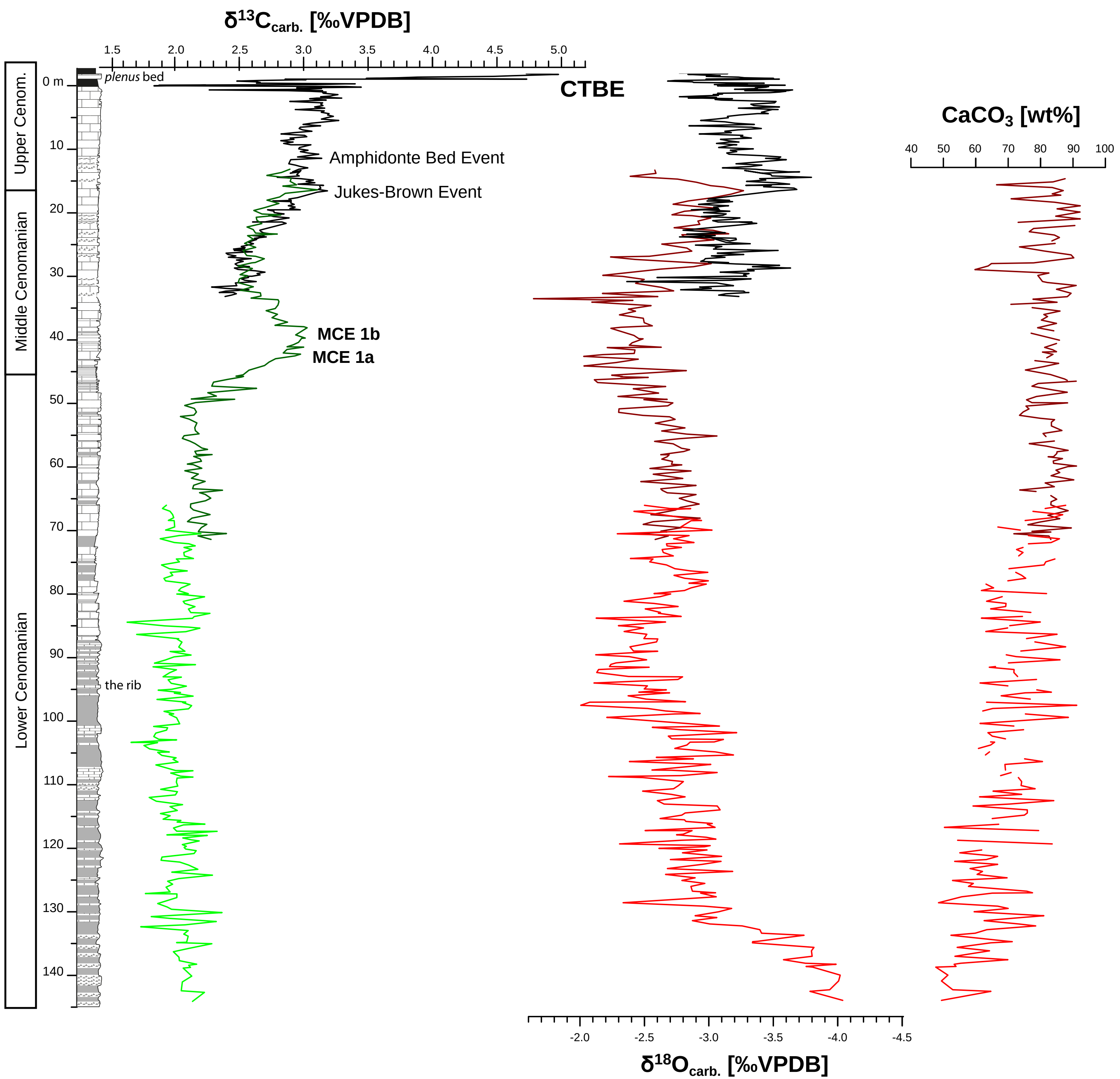
SHETLAND PLATFORM
ROCKALL BANK
HEBRIDES PLATFORM
ROCKALL TROUGH
GRAMPIAN HIGH
FENNOSCANDIAN HIGH
DANISH BASIN
CENTRAL GRABEN
NORTH SEA BASIN
SCANIA
PORCUPINE BANK
RFH
IRISH MASSIF
PORCUPINE TROUGH
SOLE PIT BASIN
POLISH ANTICLINORIUM
Wunstorf
Anderten 1
AB
WELSH HIGH
OSNING ZONE
WEST NETHERLANDS BASIN
HARZ
EAST SUDETIC BLOCK
LAUSITZ
CORNISH MASSIF
Folkstone
RHENISH MASSIF
HUNSRÜCK TAUNUS
THÜRINGIAN F.
BAY OF BISCAY
ARMORICAN MASSIF
BOHEMIAN F.
SILESIAN CORDILLERA
PARIS BASIN
HELVETIC SHELF
CENTRAL CARPATHIAN MASSIF
PENNINIC TROUGH
EAST ALPINE NAPPES
0
300 KM
Non-depositional area
Deltaic to shallow-marine clastic deposits
Shallow-marine shale
Carbonates, mainly shallow marine
Continental-lacustrine deposits
Deep-marine clastics
Deep-marine shales
Areas inverted in Late Cretaceous – Paleogene times
Volcanics
Normal fault
AB Altmark-Brandenburg Basin
BC Bristol Channel Trough
CB Channel Basin
RFH Ringkøbing-Fyn High
VG Viking Graben



δ13Ccarb. [‰VPDB]
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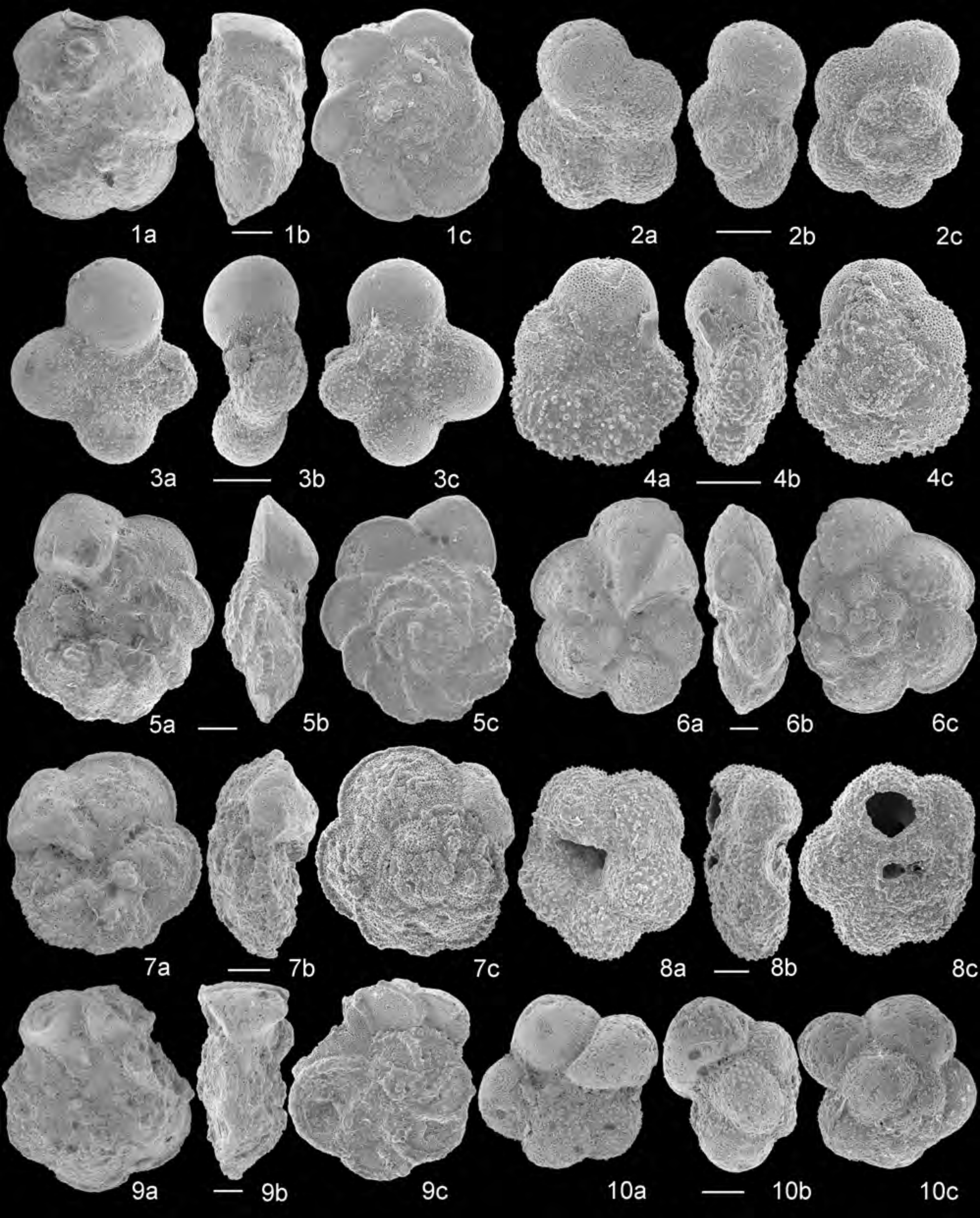
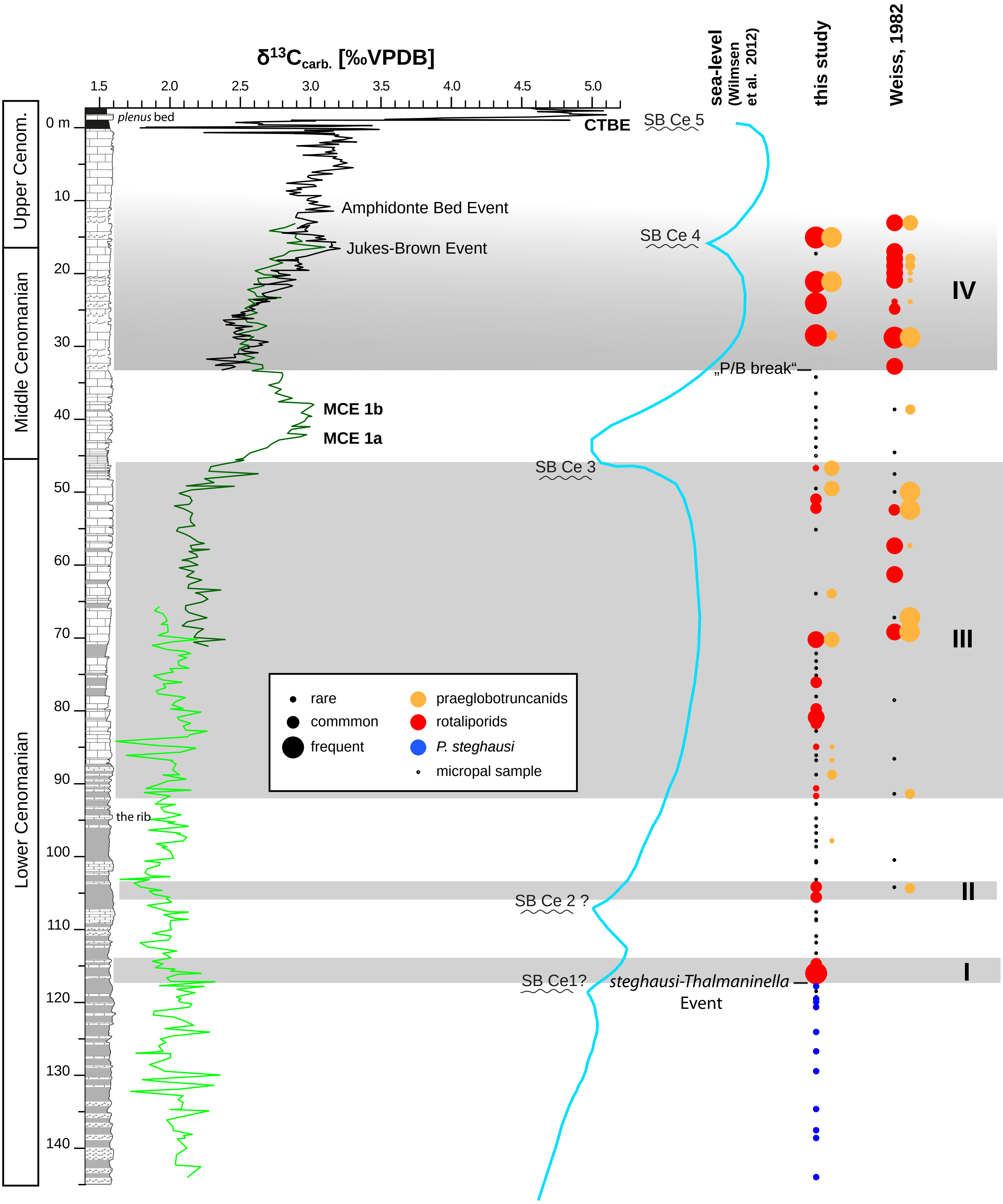
5.0
plenus bed
CTBE
0 m
10
20
30
40
50
60
70
80
90
100
110
120
130
140
Upper Cenom.
Middle Cenomanian
Lower Cenomanian
Amphidonte Bed Event
Jukes-Brown Event
MCE 1b
MCE 1a
the rib
CaCO3 [wt%]
40
50
60
70
80
90
100
-2.0
-2.5
-3.0
-3.5
-4.0
-4.5
δ18Ocarb. [‰VPDB]


1a
1b
1c
2a
2b
2c
3a
3b
3c
4a
4b
4c
5a
5b
5c
6a
6b
6c
7a
7b
7c
8a
8b
8c
9a
9b
9c
10a
10b
10c



δ13Ccarb. [‰VPDB]
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
sea-level (Wilmsen et al. 2012)
this study
Weiss, 1982
Upper Cenom.
Middle Cenomanian
Lower Cenomanian
0 m
10
20
30
40
50
60
70
80
90
100
110
120
130
140
plenus bed
CTBE
SB Ce 5
Amphidonte Bed Event
Jukes-Brown Event
SB Ce 4
IV
„P/B break“
MCE 1b
MCE 1a
SB Ce 3
III
rare
commmon
frequent
praeglobotruncanids
rotaliporids
P. steghausi
micropal sample
the rib
SB Ce 2 ?
II
SB Ce1?
steghausi-Thalmaninella Event
I