



The early Cenomanian *crippsi* Event at Lüneburg (Germany): palaeontological and stratigraphical significance of a widespread Late Cretaceous bioevent

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Abstract

The early Cenomanian *crippsi* Event comprises a 1–3-m-thick interval characterised by mass occurrences of the early Cenomanian inoceramid *Gnesioceramus crippsi*, identified in the uppermost *Sharpeiceras schlueteri* Subzone (lower lower Cenomanian *Mantelliceras mantelli* Zone), below an interregional sequence boundary (SB Ce 1). At Lüneburg, the event is characterised by densely packed, very large, disc-like valves of *G. crippsi*. Taphonomy as well as bio- and microfacies suggest an event formation in a deeper shelf setting below the storm-wave base as primary biogenic concentration, the inoceramids living as recumbent forms on a soft substrate in dense populations. When tracked between basins, the stratigraphic pattern of the *crippsi* Event suggests a moderately prolonged phase (< 100 kyr) of increased shell production with rapid deposition aiding in preserving the shell-rich event strata. Towards the basin margins, it grades into storm wave-reworked bioclastic concentrations. The *crippsi* Event formed by an interregional population bloom and provides, as an proliferation epibole, an important marker for intra- and interbasinal correlation. The first record of *G. mowriensis* within the *crippsi* Event at Lüneburg, hitherto endemic to the US Western Interior Seaway, and the occurrence of the ammonite *Metengonoceras teigenense*, likewise an endemic North American faunal element, from the level of the *crippsi* Event in northern France indicate faunal exchange between the New and Old worlds during the early Cenomanian. This faunal dispersal and contemporaneous occurrence of warm-water biofacies in Western Europe during the early Cenomanian is explained by the existence of a perpetual NE-directed current transporting warm surface waters from the Gulf of Mexico towards Europe. The occurrence of short-lived *M. teigenense* in France allows for the calibration of the uppermost *schlueteri* Subzone of the *mantelli* Zone in Europe to the lowermost *Neogastrolites muelleri* Zone in North America and to assign an age of ~98.6–98.7 Ma to the *crippsi* Event.

Keywords Upper Cretaceous · Proliferation epibole · Taphonomy · Palaeo(bio)geography · Correlation

Introduction

Widespread beds or thin packages of strata that either characterised by unusual fossils or concentrations of usually

common faunal elements are a specific feature of Upper Cretaceous epicontinental strata in NW Europe and beyond (e.g. Ernst et al. 1983, 1996; Dahmer and Ernst 1986; Lehmann 1999; Wiese et al. 2004; Wilmsen and Voigt 2006; Wilmsen et al. 2007; Wilmsen 2008; Wiese et al. 2009; Amédro et al. 2012; Nagm 2019). Such palaeontological events, termed bioevents by Ernst et al. (1983), form important marker beds that have widely been used for correlation (e.g. Bower and Farmery 1910) even if the processes that governed their formation often remained obscure. However, it was not before the end of the last century that bioevents became the focus of more detailed and integrated research (Ernst et al. 1983; Kauffman and Hart 1995; Brett and Baird 1997). Bioevents were recognised to occur at local, regional, and global scales and are inferred to reflect short- to intermediate-term (hours to tens-of-thousands of years) ecological, evolutionary, and/or palaeo(bio)geographic responses

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of biota to fluctuations of environmental parameters. Sea-level changes influence a number of important (abiotic) environmental factors in a predictable way (e.g. water depth and energy, sedimentation rate, temperature, light availability) and have been demonstrated to be an important part of bioevent formation (e.g. Brett 1995; Ernst et al. 1996; Holland 2000, 2001; Wilmsen 2012). Preferential positions for bioevent formation in a depositional sequence are the early transgressive, maximum flooding and late highstand phases (Wilmsen 2012). Late Cretaceous early transgressive (e.g. Wilmsen and Voigt 2006; Wilmsen et al. 2007) and maximum flooding bioevents (e.g. Wilmsen 2008; Nagm 2019) have already been detailed but a late highstand bioevent still awaits comprehensive palaeontologic, sedimentologic, and taphonomic dissection. Thus, the *crippsi* Event is studied herein based on excellently preserved inoceramid material from Lüneburg (northern Germany). Unfortunately, no detailed section exists from this locality and the site is not accessible anymore. However, the finds from Lüneburg can be integrated into the detailed stratigraphic framework of the lower Cenomanian and (inter-)regional correlations based on bio- and event stratigraphic considerations.

Geological and stratigraphic setting

The Triassic–Cenozoic succession brought to surface in Lüneburg due to halokinetic movements of Zechstein evaporites around the so-called Kalkberg (a central gypsum caprock of the Lüneburg salt dome) is a classical site for Cretaceous palaeontology and stratigraphy (e.g. von Strombeck 1863; Stolley 1896; Wollemann 1902; Heinz 1926; Schmid 1962, 1963). The Cretaceous succession is ca. 450 m thick, starting with a thin (ca. 23 m) middle-upper Albian argillaceous-marly unit (“upper Gault” of Lüneburg; Ernst 1921) overlying Upper Triassic “Steinmergelkeuper” (Arnstadt Formation), followed by an Upper Cretaceous succession comprising all substages up to the lower Maastrichtian (Schmid 1962). However, due to complex halokinetic faulting, the succession is strongly tectonized (e.g. Stümke 1905), and this is the main reason for the lack of detailed measured sections from this locality. After centuries of salt, gypsum, and chalk mining, the extensive quarries were abandoned in the mid-twentieth century and the Zeltberg site (from which the finds reported in this study derive) was transformed into a recreational area including a lake (the so-called Kreidebergsee; for more information on the Kalkberg in Lüneburg, see Stein 1992).

Palaeogeography

The former Zeltberg quarry in Lüneburg (Fig. 1a, c) is located north of the centre of the town of Lüneburg, ca. 40 km

southeast of Hamburg (northern Germany). During Cenomanian times, it occupied a rather distal position on the north German shelf that was characterised by a general transgression from north to south/southeast. In the course of transgression, sediments of the roughly coast-parallel facies belts (inner shelf greensands and marls, mid-shelf marl-limestone alternations and outer shelf chalk-like limestone) were superimposed, reflecting the overall retrogradational stratigraphic stacking patterns (Wilmsen et al. 2005). In the early Cenomanian, the coastline was already far south of Lüneburg and hemipelagic to pelagic deposition of marl-limestone alternations of the Baddeckenstedt Formation and chalky limestones of the Brochterbeck Formation prevailed over much of the middle and outer shelf (Fig. 1a, b). Based on the chalky nature of the rocks and the near-absence of marly interbeds (Fig. 2), the strata containing the *crippsi* Event in Lüneburg are assigned to the Brochterbeck Formation. This is the stratigraphically deepest record of this formation in northern Germany (cf. Niebuhr et al. 2007) and highlights the time-transgressive character of the lithostratigraphic units.

Stratigraphy

The Cenomanian strata of northern Germany have been stratigraphically dated and correlated with an integrated approach since many decades (e.g. Ernst et al. 1979). Of utmost importance are macrofossil biostratigraphy, bioevents, and sequence stratigraphy (cf. Fig. 1b).

Macrofossil biostratigraphy

The key groups for macrofossil biostratigraphy in lower Cenomanian strata of northwest Europe are ammonites and inoceramid bivalves. The substage is commonly subdivided into two ammonite biozones, i.e. a lower (lowest occurrence) interval zone of *Mantelliceras mantelli* and an upper total range zone of *M. dixoni* (see recent synopsis by Wright and Kennedy 2017; Fig. 1b). These two zones correspond to the interval zones of *Gnesioceramus crippsi* and *Inoceramus virgatus*, respectively (e.g. Tröger 1989). The *M. mantelli* Zone can be further subdivided into three subzones, i.e. in ascending order, the *Neostlingoceras carcitanense*, *Sharpeiceras schlueteri*, and *M. saxbii* subzones (Gale and Friedrich 1989; Gale 1995; Wright and Kennedy 2017; Fig. 1b). The stratigraphic level in question falls into the upper part of the mid-*M. mantelli* zonal *Sharpeiceras schlueteri* Subzone which is equivalent to a mid-*Gnesioceramus crippsi* zonal position.

Early Cenomanian bioevents

Ultimus/Aucellina Event: This event is characterised by in places abundant specimens of the belemnite *Neohibolites ultimus* (d’Orbigny) and the small bivalve *Aucellina* associated with

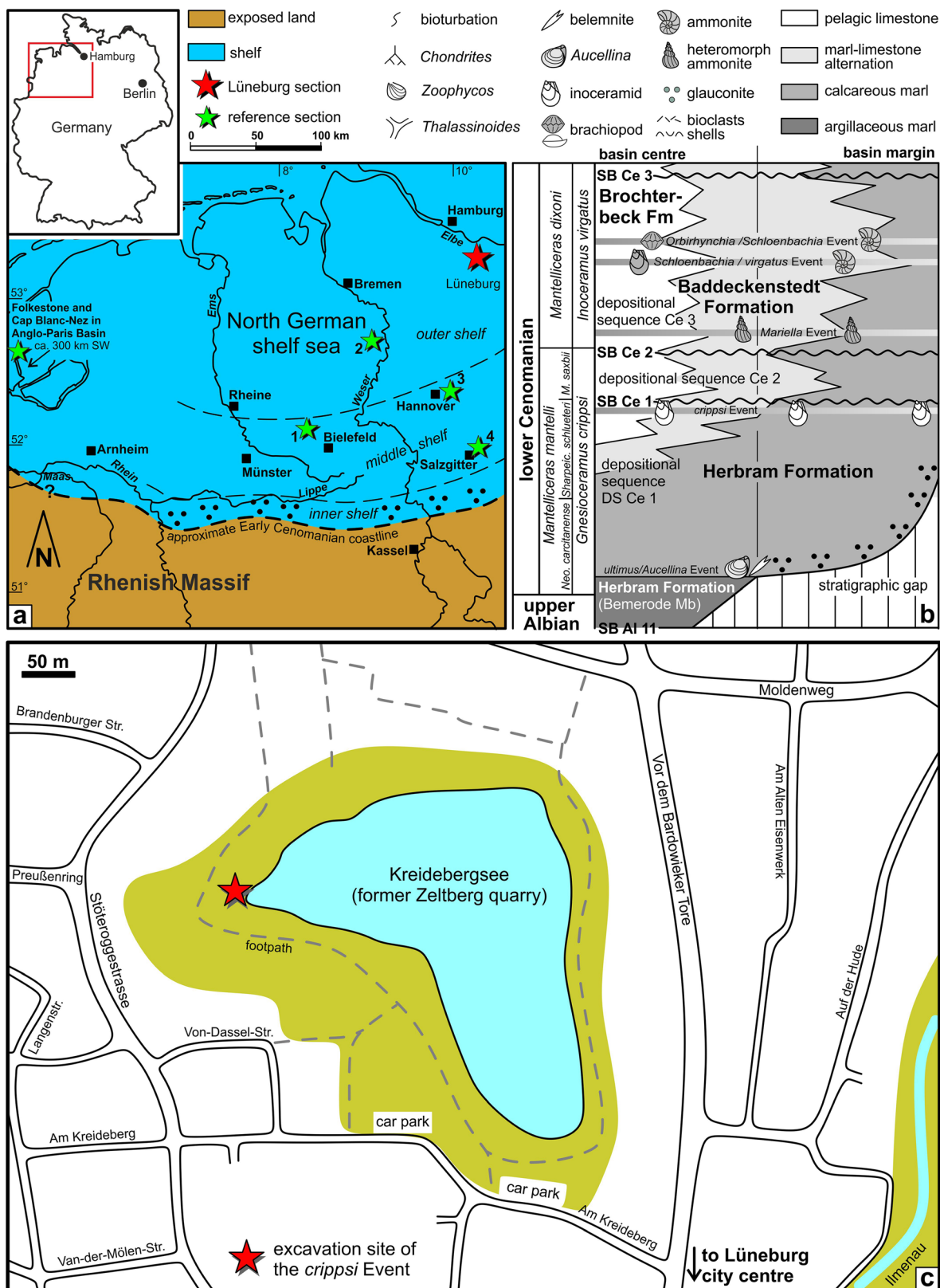


Fig. 1 Geological setting and locality details. **a** Palaeogeography of the north German shelf (base map modified from Hiss 1995) during the early Cenomanian with indication of the principal shelf facies zones and the location of Lüneburg (red asterisk). Reference sections (green asterisks): 1 Halle-Ascheloh; 2 Staffhorst shaft; 3 Hannover-Anderten; 4 Konrad-101 borehole. **b** Integrated stratigraphic framework of the lower

Cenomanian in northern Germany showing litho-, bio-, event, and sequence stratigraphic details (compiled after Ernst et al. 1983; Wilmsen 2003, 2012; Wright and Kennedy 2017). **c** Locality details of the *crippsi* Event in the former Zeltberg quarry in Lüneburg (now Kreidebergsee recreational area)



Fig. 2 Outcrop situation in the Zeltberg quarry (Lüneburg, northern Germany) in 1963 (photo archive of DS, Brietlingen). The position of the early Cenomanian *crippsi* Event is indicated by an arrow

phosphorite and glauconite concentrations (Ernst et al. 1983). Its stratigraphic position is in the lower part of the *Mantelliceras mantelli* Zone (*Neostlingoceras carcitanense* Subzone). The event marks the onset of the Cenomanian transgression (*ultimus/Aucellina* transgression) and thus corresponds to an early transgressive bioevent (Fig. 1b). It often rests unconformably with a basal hiatus on upper Albian strata; only in central basinal positions, it overlies argillaceous lowstand deposits (the Bemerode Member of the Herbram Formation) that straddle the Albian–Cenomanian boundary (Bornemann et al. 2017; Fig. 1b).

***Crippsi* Event:** This event, introduced by Tröger (1995) for a stratigraphic interval in the middle part of the *Mantelliceras mantelli* Zone (upper *Sharpeiceras schlueteri* Subzone; Fig. 1b), is rich in inoceramid bivalves of *G. ex gr. crippsi* (Mantell) (see also Gale and Friedrich 1989 and Gale 1995). In Lüneburg, it is characterised by densely packed shell accumulations (float- to rudstones) predominantly consisting of large, often isolated inoceramid valves. The *crippsi* Event is interpreted as a late highstand bioevent (Wilmsen 2012), based on its taphonomic signature and position below sequence boundary SB Ce 1 in all sections studied so far (Fig. 1a, b and see below).

***Mariella* Event:** This event, broadly corresponding to an acme of large turrilitid ammonites (*Hypoturrilites* and *Mariella*) in the lowermost part of the *M. dixoni* Zone (Kaplan and Best 1985), was detailed by Ernst and Rehfeld (1997) in the Baddeckenstedt section near Salzgitter, comprising two fairly coarse-grained limestone beds rich in siliceous sponges, often fragmentary inoceramid valves, and ammonites (their sponge bed/*Mariella* Event). Taphonomic phenomena such as corrosion and glauconitization suggest condensation during the formation of the event bed (Ernst and Wood 1995), and its position shortly above sequence boundary SB Ce 2 characterises it as an early transgressive bioevent (Wilmsen 2012; Fig. 1b).

***Schloenbachia/virgatus* Event:** (Ernst et al. 1983) This event comprises an interval of five marl-limestone couplets with high carbonate content in the mid-*M. dixoni* Zone, characterised by an abundance of commonly double-valved *Inoceramus ex gr. virgatus* Schlüter and *Schloenbachia varians* (J. Sowerby) (see Wilmsen 2008). The accompanying fauna is of low diversity and consists of rare sponges, small brachiopods, and irregular echinoids. It is a typical example of a maximum flooding bioevent (Wilmsen 2008, 2012; Fig. 1b).

Orbirhynchia/Schloenbachia Event: (Ernst et al. 1983) This mid-*M. dixonii* zonal event (Fig. 1b) is characterised by the common occurrence of the small rhynchonellid brachiopod *Orbirhynchia mantelliana* (J. de C. Sowerby) accompanied by likewise common *S. varians* and a moderately diverse assemblage of terebratulid brachiopods, sponges, heteromorph ammonites, gastropods as well as inoceramid and non-inoceramid bivalves. It can be correlated from the northern German across the Anglo-Paris Basin into the Cleveland Basin (“lower *Orbirhynchia* band” of Jeans 1980; e.g. Gale 1995) and is regarded as a maximum flooding bioevent (Wilmsen 2012).

Sequence stratigraphy

The early Cenomanian was a strongly transgressive time interval characterised by three onlap pulses that led to the retrogradational stacking of three depositional sequences (e.g. Robaszynski et al. 1998; Wilmsen 2003; Janetschke et al. 2015). The bounding unconformities are sequence boundaries SB Ce 1 to SB Ce 3 (Fig. 1b). SB Ce 1 and SB Ce 2 have been identified in the middle and at the summit of the *M. mantelli* Zone, SB Ce 2 corresponding to the “Subdixonii Erosional Surface” (SdES) of Wright and Kennedy (2017), while SB Ce 3 is placed close to the top of the *M. dixonii* Zone, slightly below the base of the middle Cenomanian (e.g. Wilmsen 2007; Fig. 1b). In northern Germany, the *crippsi* Event has been documented to occur in the upper (late highstand) part of Cenomanian depositional sequence DS Ce 1, just below SB Ce 1 (e.g. Niebuhr et al. 2001; Wilmsen 2003, 2012; Richardt 2010; cf. Fig. 1b). In Lüneburg, the sequence stratigraphic position of the *crippsi* Event cannot be specified due to the absence of a detailed log and the inaccessibility of the strata today.

Material and methods

The material studied herein is stored in the palaeozoological collection of the Senckenberg Naturhistorische Sammlungen Dresden (SNSD), Department Museum für Mineralogie und Geologie (MMG, repository prefix number MMG: NsK), and the collection of DS in Brietlingen (repository number: DSB plus running number). The latter material will be transferred to the collections of the SNSD-MMG at a later stage. The material was collected from a shallow (maximum 30-cm-deep) excavation of ca. 2 × 1.8-m size conducted discontinuously in winter months during 1980–1994. Biometric standard measurements of inoceramid bivalves, taken with a Vernier caliper, comprise height (h) and length (l) of the shell as well as observations on the sculpture (number, size, and form of ribs) and the course of the growth axis (for terminology and measured parameters, see Fig. 3). For the higher rank systematics

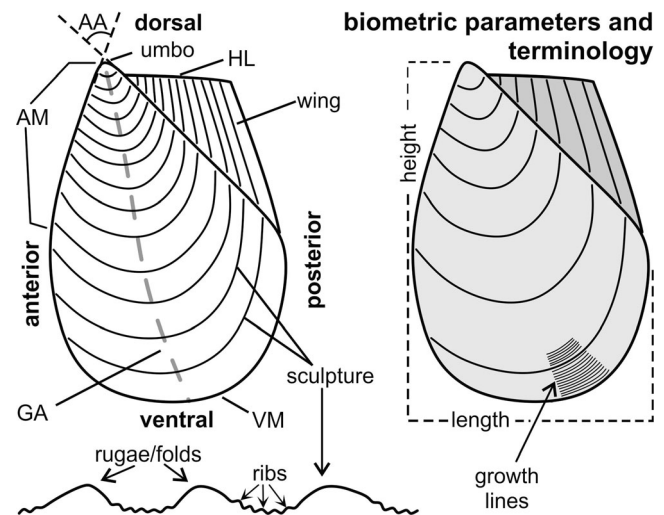


Fig. 3 Terminology and biometric parameters of the inoceramid shell (AA, apical angle; AM, anterior margin; GA, growth axis; HL, hinge line; VM, ventral margin)

of the Bivalvia, we refer to Carter et al. (2011). A thin section of the host strata was prepared on a Logitech preparation line using a LP50 lapping and polishing jig with a PLJ7 lapping jig and a GTS-1 thin-section saw. Microfacies was observed with a Leica M125 stereo-microscope equipped with a Leica DFC 420 digital camera placed in the optical path.

Results

Observations on litho- and biofacies as well as palaeontological analyses (taphonomy and systematic descriptions) form the data basis of this study.

Lithofacies

The lithofacies of the event bed in Lüneburg is dominated by fine-grained, light-grey chalky limestones (Fig. 2) which form the matrix for the fine-to-coarse-grained shell material (predominantly inoceramid valves and debris, up to 160 mm/100 mm in height/length, respectively). Thin-section analyses characterise the matrix as fine-grained calcisphere-bearing wackestone with subordinate content of predominantly non-keeled planktic foraminifers and microbioclasts (mainly isolated prisms of disintegrated inoceramid shells; Fig. 4a). Nevertheless, due to the variably high content of inoceramid shell material larger than 2 mm and the density of packing, the rocks of the event partly have to be classified as bioclastic inoceramid float- to rudstones (Fig. 4c, e). Chambers of calcispheres (calcareous cysts of dinoflagellates, i.e. c-dinocysts) and planktic foraminifera are partly filled with pyrite; framboidal pyrite of variable size also occurs scattered in the matrix (Fig. 4b).

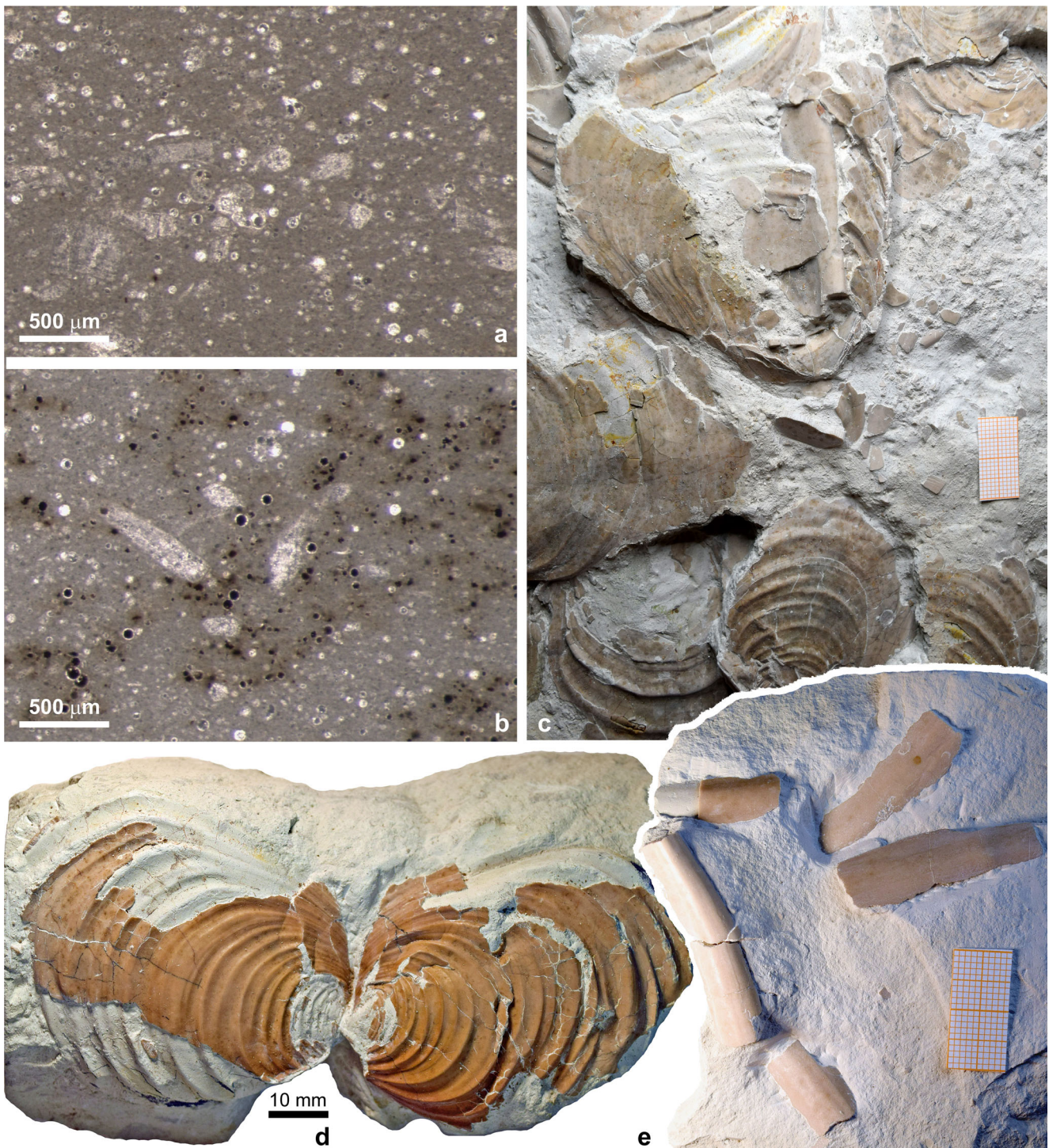


Fig. 4 Microfacies and taphonomy of the early Cenomanian *crippsi* Event at the former Zeltberg quarry, Lüneburg. **a** Microbioclastic calcisphere wackestone with planktic foraminifers and isolated incceramid prisms (thin section prepared from the matrix of MMG: NsK 1274). **b** Calcisphere wackestone with rare incceramid prisms; note the dark pyritic filling of calcispheres and the dispersed framboidal pyrite in the matrix (thin section prepared from the matrix of MMG: NsK 1274). **c**

Shell pavement of large *Gnesioceramus crippsi* (Mantell, 1822), mostly in convex-up position; note the coarse-grained bioclastic fabric between the shells, the disarticulated hinge in upper centre, and the overall very thin shell thickness (sample DSB-1, scale in mm). **d** Double-valved specimen of *Gnesioceramus crippsi* (Mantell, 1822) in butterfly position (sample DSB-2). **e** Concentration of isolated hinges on a limestone slab (sample DSB-3, scale in mm)

Biofacies

The faunal assemblage of the *crippsi* Event in Lüneburg is in abundance completely dominated by inoceramid bivalves, i.e. *Gnesioceramus crippsi*, accompanied by a few specimens of *G. mowriensis*. However, apart from the ubiquitous inoceramids, the following invertebrate and vertebrate taxa have been identified (the number of the benthic taxa is given in [square brackets]):

Ammonites: *Mantelliceras mantelli* (J. Sowerby), *Mantelliceras* cf. *cantianum* Spath, *Mantelliceras* sp., large *Austiniceras austeni* (Sharpe), *Schloenbachia varians* (J. Sowerby), *Hypoturrites tuberculatus* (Bosc) and large *Mariella* sp.

Bivalves: *Euthymipecten beaveri* (J. Sowerby), *Limea granulata* (Nilsson), *Limaria elongata* (J. de C. Sowerby), *Teredina amphibaena* (Goldfuss), *Plicatula inflata* J. de C. Sowerby and small oysters (*Hyotissa* sp.) [ca. 60 specimens]

Gastropods: *Bathrotomaria* sp. [a single specimen]

Echinoids: *Cardiaster granulatus* (Goldfuss), *Holaster* sp., *Salenia* sp. [19 specimens]

Arthropods: claws of decapod crustaceans (*Protocallianassa* sp. and an unidentified taxon) [two specimens] and *Palaega carteri* (Woodward) [four specimens]

Shark teeth: *Hexanchus gracilis* (Davis), *Cretalamna appendiculata* (Agassiz), *Scapanorhynchus raphiodon* (Agassiz)

Additionally, brachiopods (three taxa, 22 specimens), serpulids (*Rotulispira?* sp., 21 specimens), bryozoans (five taxa, 22 specimens), starfish ossicles, and the trace fossil *Lepidenteron mantelli* (Geinitz) have been recorded.

Taphonomy

The taphonomic observations are focused on the inoceramids within the *crippsi* Event. A brief account on the large *G. crippsi* show that most valves are disarticulated and that the large, discoidal shells are often imbricated, forming true inoceramid pavements (Fig. 4c). Most valves have been found to occur in convex-up position (ca. 80%, $n = 56$) albeit the flat, sparsely domed shape of the shell certainly restricted overturning into the stable position. Fragments of variable size occur scattered or are concentrated in lenses between the shells (Fig. 4c). The thick and stable ligament ridges may have been concentrated, too (Fig. 4e). On the other hand, a few specimens occur in butterfly position with the right and left valves associated and facing each other with the two umbos (Fig. 4d).

Systematic palaeontology

Class Bivalvia Linnaeus, 1758

Subclass Pteriomorpha Beurlen, 1944

Order Pterioida Newell, 1965

Family Inoceramidae Giebel, 1852

Genus *Gnesioceramus* Heinz, 1932

Type species: *Inoceramus anglicus* Woods, 1911 (p. 264, pl. 45, figs. 8–10, text-fig. 29), by subsequent designation of Pokhialainen (1985a, p. 32; note that the genus is erroneously spelled “*Gneisioeramus*” therein).

Remarks: This genus, originally proposed by Heinz (1932, p. 6) for the common Cenomanian species *Inoceramus crippsi* Mantell characterised by coarse commarginal growth folds (“Anwachsreifen”), was long-time neglected until Pokhialainen (1985a, b) described the generic characteristics in more detail and formally designated *I. anglicus* as the type species of the genus (see Walaszczyk and Cobban 2016 for additional information).

Gnesioceramus crippsi (Mantell, 1822)

(Figures 4c, d; 5, 6, and 7)

- *1822 *Inoceramus crippsii*, Mantell, p. 133, pl. 27, fig. 11
- 1863 *Inoceramus striatus* Mant. – von Strombeck, p. 108
- 1902 *Inoceramus orbicularis* Münster – Wolleemann, p. 65
- 1909 *Inoceramus crippsi* Mantell – Boehm, p. 41, pls 9, 10, pl. 11, fig. 1 [with early synonymy]
- 1911 *Inoceramus crippsi* Mantell, 1822 – Woods, p. 273, pl. 48, figs. 2 and 3, text-figs. 33 and 34
- non 1956 *Inoceramus Crippsi*, Mantell – Kilpady and Kulkarni, p. 2, pl. 1 figs. 1 and 2
- 1962 *Inoceramus crippsi* Mantell, 1822 – Bräutigam, p. 188, pl. 1, figs. 1 and 2
- 1967 *Inoceramus crippsi crippsi* Mant., 1822 – Tröger, p. 24, pl. 2, figs. 4 and 5
- 1982 *Inoceramus crippsi crippsi* Mantell, 1822 – Keller, p. 44, pl. 1, fig. 5 [see for additional synonymy]
- 1987 *Inoceramus crippsi crippsi* Mantell, 1822 – Cieśliński, p. 37, text-fig. 19a–c
- 1987 *Inoceramus crippsi orbicularis* Münster, 1836 – Cieśliński, p. 39, text-fig. 20a, b
- 1987 *Inoceramus crippsi mogilensis* subsp. n., Cieśliński, p. 42, text-fig. 25
- 2001 “*Inoceramus*” *crippsi* Mantell, 1822 – Wilmsen et al., p. 129, pl. 1, fig. 1 [with additional synonymy]
- 2002 “*Inoceramus*” ex gr. *crippsi* Mantell – Wilmsen and Niebuhr, text-fig. 5
- 2009 *Inoceramus crippsi crippsi* Mantell, 1822 – Tröger et al., p. 62, figs. 3a–c and 4a
- 2010 *Inoceramus crippsi crippsi* Mantell – Wilmsen and Niebuhr, p. 275, figs. 4h and 5
- 2010 “*Inoceramus*” *crippsi* Mantell, 1822 – Richardt, p. 51, pl. 1, fig. 1, text-fig. 11

Fig. 5 More than ten valves of *Gnesioceramus crippsi* (Mantell, 1822), scattered on a large limestone slab (largest diameter 365 mm) from the early Cenomanian *crippsi* Event of Lüneburg (sample MMG: NsK 1273)



- 2012 “*Inoceramus*” *crippsi* – Wilmsen, text-fig. 6d
 2012 *Inoceramus crippsi crippsi* Mantell, 1822 – Amédéo et al., pl. 1, pl. 2, figs. 1–3
 2013 *Inoceramus crippsi crippsi* Mantell, 1822 – Schneider et al., p. 570, text-fig. 10d [with further synonymy]
 2019 *Inoceramus crippsi* – Püttmann et al., text-fig. 3n
 2019 *Inoceramus crippsi* Mantell, 1822 – Kaplan et al., p. 29, text-fig. 4

Material: 155 specimens, either isolated or scattered on a several rock slabs of variable size (retrieved from a shallow excavation of 2 × 1.8 m size)

Description: The shells are equivalved, inequilateral, subcircular in outline, and only weakly inflated. Maximum length and height are 152 mm and ~105 mm, respectively. The umbo is not extending above the hinge line, and the ligamental area is relatively wide. Well-rounded small rugae

Fig. 6 The largest specimen of *Gnesioceramus crippsi* (Mantell, 1822) from the early Cenomanian *crippsi* Event of the former Zeltberg quarry in Lüneburg has a shell height > 155 mm (sample MMG: NsK 1272, left valve)



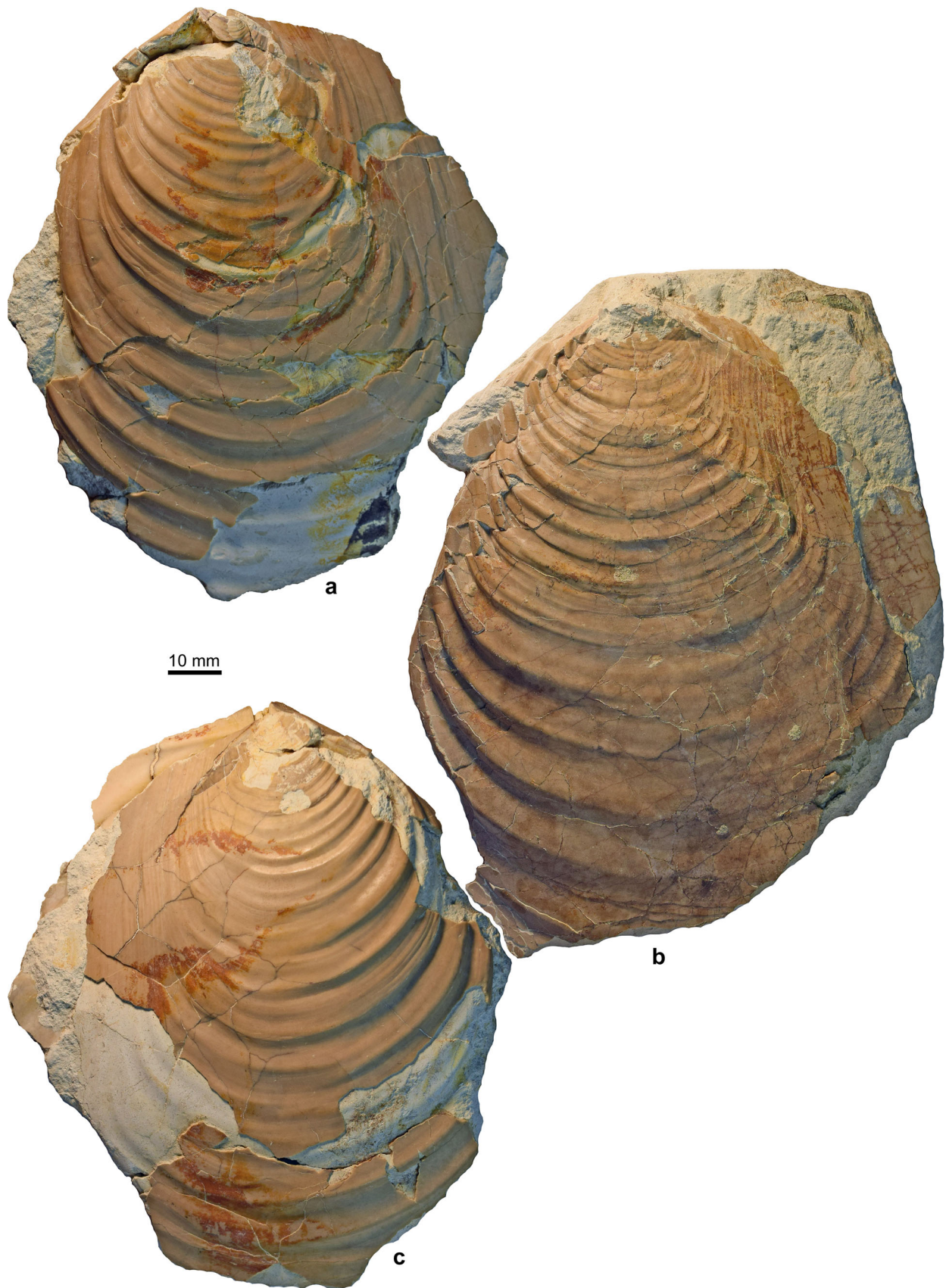


Fig. 7 *Gnesioceramus crippsi* (Mantell, 1822) from the early Cenomanian *crippsi* Event of the former Zeltberg quarry in Lüneburg. **a** Specimen DSB-4 (left valve). **b** Specimen DSB-5 (left valve). **c** Specimen DSB-6 (right valve)

appear a few millimeters from the umbo and develop into coarse, sharp-edged concentric rugae in adults. The rugae are up to 3 mm high and asymmetric, i.e. the slope directed to the umbo is shallower compared with the ventrally directed one. The inter-rugae spaces are ca. 3 mm wide on the juvenile and 10 mm wide on the adult part of the shell. Up to a height of ca. 75 mm, 2–4 secondary ribs may be developed in the depressions between the rugae. The ligament is long and massive, with smooth transition to the posterior margin. Compared with the relatively large size of many specimens, the thickness of the shell is quite low (≤ 1 mm).

Remarks: *Gnesioceramus crippsi* is a well-known early Cenomanian inoceramid taxon that ranges, as a rarity, up into the middle Cenomanian (e.g. Tröger 1989; Wiedmann et al. 1989). It is readily characterised by a subcircular growth trace, regularly developed rugae, an oblique and slightly convex growth axis, and a weakly inflated shell with a massive ligamental plate (e.g. Wilmsen et al. 2001). The rugae continue across the shell without weakening, except on the posterior wing. Extraordinary is the in part very large size of the specimens compared with other records of *G. crippsi*, reaching > 150 mm in height and > 100 mm in length. In conjunction with the near-absence of shell convexity, the specimens tend to have a disc-like appearance. This feature, along with the flange-like anterior margin and the distinctively triangular ligament plate with its closely spaced and vertically elongated ligamental pits cause a certain resemblance of *Gnesioceramus crippsi* to the much younger (mid-to-late Late Cretaceous) genus *Platyceramus* (Wilmsen et al., 2001). Similarly, Kauffman and Powell in Kauffman et al. (1977, pp. 84–86) discussed a relationship to the genus *Mytiloides* and provisionally referred this species to *Mytiloides? crippsi*. Contemporaneous *Gnesioceramus hoppenstedtensis* have a dorsoventrally elongate shell, a more or less straight growth axis, a much thinner shell, and more irregularly developed rugae (see below). Several of the subspecies of *I. crippsi* described by Cieřliński (1987) can be accommodated in *G. crippsi*. However, the giant specimen assigned to *Inoceramus crippsi* by Kilpady and Kulkarni (1956) from the Cretaceous of Trichinopoly (India) is doubtful as it is very large (> 0.5 m in height), has strongly inflated, convex shells and only very few (five to seven) and very coarse concentric folds. Its exact stratigraphic position is also unclear, and it may rather be a representative of the Turonian *lamarcki* group or an even younger species. *G. crippsi* has been noted from the lower Cenomanian (= *varians* Pläner) of Lüneburg already in early studies (von Strombeck 1863; Wollemann 1902), albeit under species names that have subsequently been synonymized with Mantell's species (cf. Boehm 1909).

Occurrence: *Gnesioceramus crippsi* is a very widespread form that ranges from the lower Cenomanian into the lower middle Cenomanian (Keller 1982; Kaplan et al. 1984; Wiedmann et al. 1989; Tröger 1989, 2009). In the type area

in southern England, this taxon characterises the *Sharpeiceras schlueteri* Subzone of the *Mantelliceras mantelli* Zone, in which it is very common, dominating the inoceramid assemblage.

Gnesioceramus mowriensis Walaszczyk and Cobban, 2016 (Fig. 8)

2016 *Gnesioceramus mowriensis* sp. nov., Walaszczyk and Cobban, p. 53, text-figs. 17–19

Material: Eight specimens, mostly isolated and partly fragmentary valves

Description: Small-to-medium-sized form with equivalved and inequilateral, only weakly inflated shells, higher than long (maximum measured height 53 mm, length ~ 42 mm; Fig. 8). The apical angle measures ca. 70°; the growth axis is almost straight. The anterior margin is straight to slightly convex, and the ventral margin broadly rounded; posterior margin long and straight. The ligamental area is poorly preserved but shows a thickened hinge line; otherwise, the shell is very thin. The regularly developed ornament consists of evenly spaced, symmetric, and rounded commarginal ribs and narrow interspaces (ca. 50 ribs at a height of 50 mm, rib distance 1.8 mm on the adult shell). Following a faint, regular increase of rib and interspace dimensions in the juvenile stage, the ornament remains almost constant during the later ontogeny.

Remarks: Introduced by Walaszczyk and Cobban (2016), *G. mowriensis* is very similar to the late Albian *G. anglicus* (Woods). It differs from Woods' species in a more subtrapezoidal outline, a finer ornament, and a shorter length of the anterior margin. *Inoceramus tenuis* Mantell has a straight to slightly concave anterior margin, a concave growth axis, is much more inflated, and is less regularly ribbed (see Woods 1911, p. 271, pl. 48, fig. 1, text-figs. 31, 32).

Occurrence: *Gnesioceramus mowriensis* is so far only known from the mid-lower Cenomanian of the US Western Interior Seaway (Utah, Colorado, Wyoming, and Montana) where it ranges from the *Neogastropylites cornutus* up to the *N. americanus* ammonite Zone (Walaszczyk and Cobban 2016). The stratigraphic position is equivalent to the specimens from the *crippsi* Event at Lüneburg. This is the first record of *G. mowriensis* from outside northern America.

Discussion

Even if no detailed measured section exists for the (lower) Cenomanian of Lüneburg and the material was retrieved from a shallow excavation, the stratigraphic position of the strata with super-abundant *G. crippsi* can be precisely calibrated. In its type area in southern England, this taxon particularly characterises the *Sharpeiceras schlueteri* Subzone in the

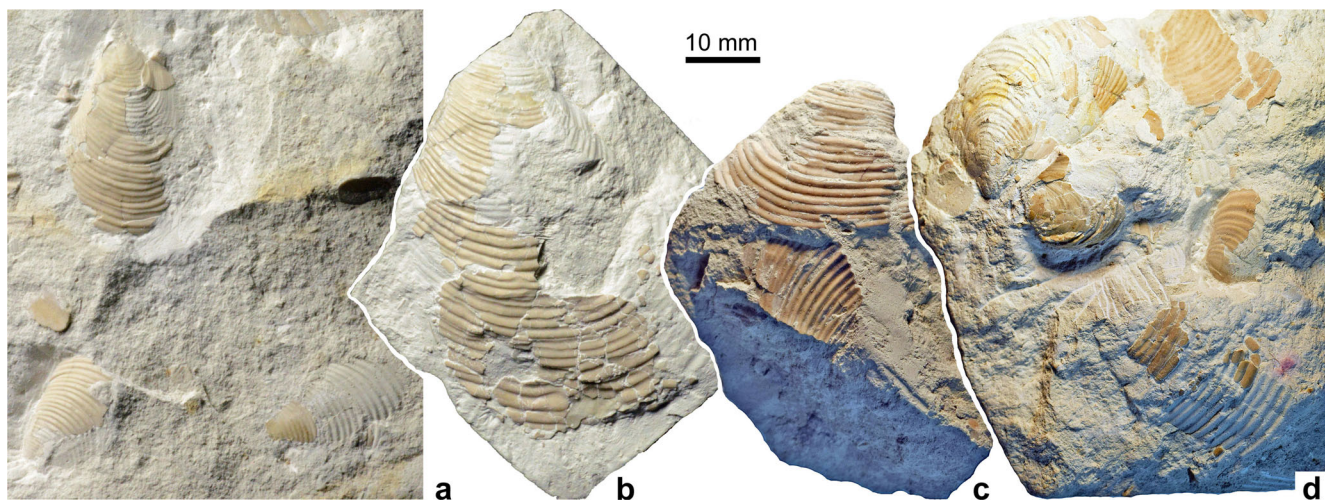


Fig. 8 *Gnesioceramus mowriensis* Walaszczyk and Cobban, 2016 from the early Cenomanian *crippsi* Event of the former Zeltberg quarry in Lüneburg. **a** Several isolated valves scattered on a limestone slab

(sample MMG: NsK 1274). **b** Specimen MMG: NsK 1275 (left valve). **c** Specimen DSB-7 (right valve). **d** Several isolated valves scattered on a limestone slab (sample DSB-8)

middle of the *Mantelliceras mantelli* Zone (cf. Wright and Kennedy 2017), in which it is very common, dominating the inoceramid assemblage (Wilmsen et al. 2001; see also Gale and Friedrich 1989 for Folkstone). A position within the lower lower Cenomanian *M. mantelli* Zone is ascertained by the index species from the layers with super-abundant *G. crippsi* at Lüneburg. The co-occurrence of (rather inflated) *M. mantelli* and *M. cantianum* with common *Hypoturrites* more specifically supports a classification into the *S. schlueteri* Subzone (see Gale and Friedrich 1989; Gale 1995). *Gnesioceramus mowriensis*, so far only known from the mid-lower Cenomanian of the US Western Interior Seaway, ranges from the *Neogastrolites cornutus* up to the *N. americanus* ammonite Zone (Walaszczyk and Cobban 2016), corresponding to the middle and upper *M. mantelli* Zone as well as the lower *M. dixoni* Zone; its sole occurrence can thus not specify the age of the beds with *G. crippsi* at Lüneburg (but see discussion on faunal migrations from the Western Interior Seaway below). However, the event-like occurrence of common large *G. crippsi* is a unique stratigraphic feature of the upper *S. schlueteri* Subzone (Gale 1995; Wilmsen 2012). Based on the biofacies and the biostratigraphic data, the excavated layer at Lüneburg definitely corresponds to this acme occurrence. In a sequence stratigraphic context, the beds with common *G. crippsi* are always capped by the first intra-Cenomanian sequence boundary (SB Ce 1; Robaszynski et al. 1998; Wilmsen 2003) but this stratigraphic superposition cannot be deduced from Lüneburg section.

Palaeontological events (cf. Brett and Baird 1997), termed bioevents by Ernst et al. (1983) in their seminal paper on early Late Cretaceous stratigraphic events in northern Germany, are a specific character of Cretaceous epicontinental strata in Europe, forming important marker beds that have widely been used for intra- and interbasinal correlation (e.g. Kauffman and Hart 1995).

They comprise widespread single beds or thin bundles of strata that are either characterized by “exotic” fossils or unusual concentrations of rather common faunal elements (e.g. Ernst et al. 1983; Dahmer and Ernst 1986; Küchler 1998; Lehmann 1999; Wiese et al. 2004, 2009; Wilmsen and Voigt 2006; Wilmsen et al. 2007; Wilmsen 2008; Amédéo et al. 2012; Nagm 2019). Some of the Late Cretaceous bioevents identified in the pioneering study of Ernst et al. (1983) have already been related to sea-level fluctuations (“Eustato-Events”), but a more general relationship between Cretaceous sequence stratigraphy and bioevent formation has been suggested somewhat later (Ernst et al. 1996; Wilmsen 2003, 2012; see also Brett 1995 for a more general approach on stratigraphic palaeontology and sequence stratigraphy).

Late highstand bioevents (LHB) commonly comprise hard-part accumulations formed as a result of winnowing of fines and concentration of biotic remains by storm currents and/or ground-touching waves (Wilmsen 2012). Their formation is related to shallowing (normal regression) and filling of accommodation during the late highstands of 3rd-order depositional sequences and 4th-order high-frequency sequences. LHBs in 3rd-order sequences correspond to toplap shell beds sensu Kidwell (1991) and the “top-highstand concentrations” of Fürsich and Pandey (2003). In high-frequency sequences, they find their equivalents in the top-of-parasequence shell beds of Banerjee and Kidwell (1991) and the toplap shell bed of Naish and Kamp (1997).

There are only a few well-documented examples of Cretaceous LHBs so far as most of the widespread and correlatable Cretaceous bioevents formed during initial rise (early transgressive bioevents, ETB) and sea-level maxima (maximum flooding bioevents, MFB; e.g. Ernst et al. 1996; Wilmsen 2003, 2008, 2012; Wilmsen et al. 2007). In northern Germany, Late Cretaceous LHBs are often associated with relatively carbonate-rich strata and coarse-grained bioclastic

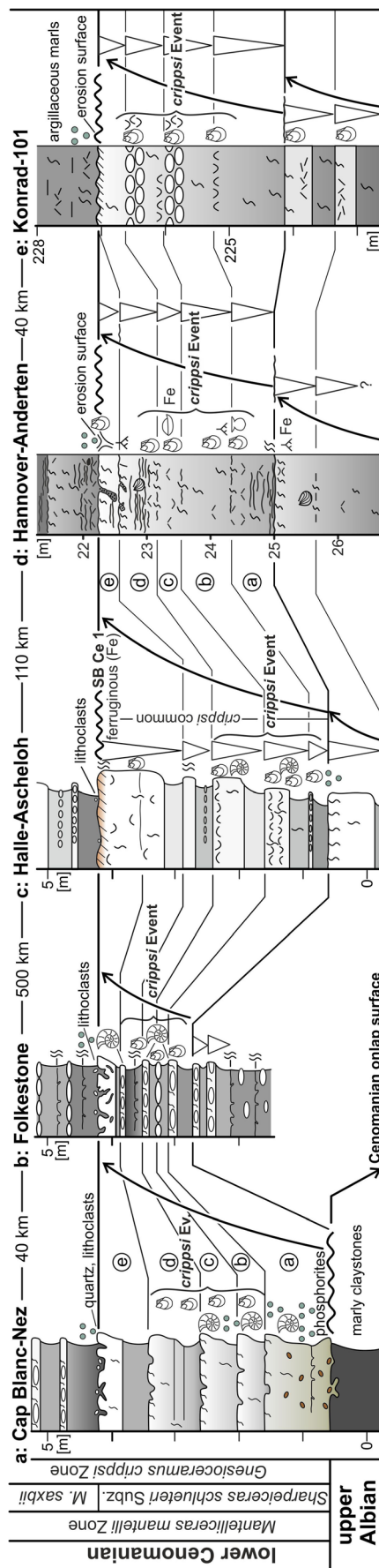
fabrics and commonly consist of pauci- or even monospecific skeletal concentrations with a considerable degree of fragmentation and convex-up orientation of shells (Fig. 4c, e). Single-event (i.e. tempestites) and multiple-event concentrations have been differentiated (Wilmsen 2012), but even for the latter subtype, the absence of significant taphonomic alteration (bor-ing, encrusting) argues against substantial time-averaging (Brett 1995 also mentions relatively high sedimentation rates during this phase of a sequence, augmenting the dilution effect). Overall, the significance of LHBs for interbasinal correlation is rather low because their formation may be predominantly controlled by local to regional processes (such as storms or localized winnowing across a limited submarine topography); furthermore, their preservation potential is low because of common erosion at the sequence boundary capping the highstand deposits (Wilmsen 2012).

The *crippsi* Event from Lüneburg deviates in some aspects from the abovementioned propositions. The large size and thin shell of the numerous complete valves of *G. crippsi* suggest little transport and overall low energy albeit some fragmentation and the predominant convex-up orientation of valves suggest episodically elevated water energy (e.g. Fürsich and Oschmann 1993; Fürsich 1995). The microfacies analysis reveals a fine-grained mud- to wackestone fabric dominated by planktonic components (c-dinocysts, planktic foraminifers), suggesting a predominantly low-energy, open shelf environment dominated by vertical accretion of fine-grained particles (planktonic rain; cf. Turner 2002). Based on the sedimentary facies and bioturbation pattern, the sea-bottom was evidently a softground on which epibenthic organisms such as inoceramids would benefit from a large resting surface and low weight. From the perspective of functional morphology, the flat, disc-like form and thin shell of *G. crippsi* are thus most likely an adaption to a recumbent lifestyle (see also Kauffman et al. 2007 for *Platyceramus*). Some groups of (inferred chemosymbiotic) inoceramid bivalves are well-known to occur in oxygen-deficient environments where they may predominate the benthic assemblages (Hilbrecht and Dahmer 1991; MacLeod and Hoppe 1992; Kauffman et al. 2007). Weak support for this hypothesis comes from the presence of framboidal pyrites observed in thin section (Fig. 4b) that may reflect oxygen deficiency in the upper sediment pile during early diagenesis (e.g. Kauffman et al. 2007; Mozer 2010). However, the broad size distribution and occurrence of large pyrite specimens (> 10 µm) indicates only modest oxygen depletion, i.e. upper dysaerobic conditions (e.g. Wignall and Newton 1998), and the presence of a moderately diverse and abundant assemblage of other benthic taxa than the inoceramids (ca. 15–20 species and ca. 150 specimens, see results on biofacies above) also argue against significant oxygen depletion [oxygen-restricted biofacies (ORB) 6 of the upper dysaerobic zone sensu Wignall (1994)]. On the other hand, deep infaunal biota are completely missing from the benthic assemblage of the *crippsi* Event at Lüneburg and also shallow-infaunal

taxa are rare (i.e. *Palaega carteri* or *Cardiaster granulosus*). However, such a predominance of epibenthic taxa in macrobenthic offshore assemblages from Upper Cretaceous chalks has also been demonstrated by Engelke et al. (2016), without any palaeoecological (Engelke et al. 2017) or geochemical (Engelke et al. 2018) evidence for oxygen restriction.

When tracked on an interbasinal scale, conspicuous stratigraphic patterns can be identified from the strata containing the *crippsi* Event (Fig. 9). In all sections, the event interval consists of five asymmetric bedding couplets grading from more marly/argillaceous sediments below to more calcareous sediments at the top (labeled a–e in Fig. 9). The thickness of the individual basic cycles varies from 0.2 to 1.3 m. Together, they form a bundle of couplets that gets more calcareous up-section and is terminated by a conspicuous unconformity surface interpreted as oldest intra-Cenomanian sequence boundary (SB Ce 1) capping depositional sequence DS Ce 1 (Gale 1995; Robaszynski et al. 1998; Wilmsen 2003; Janetschke et al. 2015). This depositional sequence started at a terminal Albian sequence boundary (SB Al 11) and, on the wide NW European epicontinental shelf, subsequent lowstand deposits straddling the Albian–Cenomanian boundary are only developed in deep intra-shelf basins due to the widespread lack of accommodation in up-dip settings (e.g. Bornemann et al. 2017). The transgressive systems tract started with the *ultimus/Aucellina* Event in the earliest Cenomanian and costal onlap continued into the late highstand of DS Ce 1 as shown by the unconformable superposition of the *crippsi* Event bundle onto upper Albian claystones in Cap-Blanc-Nez (Robaszynski et al. 1998; Amédéo et al. 2002; Fig. 9). The main occurrence of the *crippsi* Event relates to the lower four couplets a–d of the bundle and may vary between the sections (Fig. 9). The uppermost couplet (e) of the *crippsi* Event bundle is commonly rather poor in inoceramids. Its terminal surface (SB Ce 1) is a burrowed unconformity that has been reworked by the subsequent transgression; a lag of small rounded lithoclasts derived from the substrate suggests that the surface has been lithified before the deposition of the early transgressive sandy to argillaceous, glauconite-bearing strata above took place.

Striking is the in part very dense packing of the inoceramid shells within the *crippsi* Event which can be seen in many places [e.g. Lüneburg as demonstrated herein and already mentioned by von Strombeck 1863, p. 108: “..., wo in einzelnen Bänken die Schalen dicht angehäuft sind.”; but see also Richardt (2010) for the Halle-Ascheloh, and Amédéo et al. (2012) for the Cap-Blanc-Nez sections; Fig. 9]. The distribution of the shells across three to four marl-limestone bedding couplets rules out single or even several storm events for the concentration of shell but rather suggests a moderately prolonged phase of increased shell production and/or preservation, favoured by the late highstand conditions (e.g. relatively rapid burial). Temporal constraints can be



◀ **Fig. 9** Interbasinal correlation of the early Cenomanian *crippsi* Event. **a** Cap-Blanc-Nez modified after Amédéo et al. (2012). **b** Folkestone modified after Gale and Friedrich (1989). **c** Halle-Ascheloh modified after Richardt (2010) and Wilmsen (2012). **d** Hannover-Anderten (Wilmsen, unpubl.). **e** Konrad-101 modified after Niebuhr et al. (2001). See Fig. 1 for key to symbols and for location of the sections (the Lüneburg section is situated approximately 80 km to the north-northeast of Hannover)

derived from the couplet stratigraphy developed for the Cenomanian of the Anglo-Paris Basin (and beyond) by Gale (1990, 1995) and Gale et al. (1999) who suggested an orbital control for the cyclic bedding patterns. The authors convincingly argued that a marlimestone couplet can be assigned to the precession cycle of the Milankovitch frequency band, comprising ca. 21 kyr in the Cenomanian. The bedding couplets are commonly bundled into sets of five, reflecting the precession–(short) eccentricity syndrome (Gale 1990; Wilmsen 2003). The bundle containing the *crippsi* Event comprises such a short-eccentricity cycle (ca. 105 kyr), the event duration, thus amounting to 60–85 kyr. We thus propose a geologically short (< 100 kyr) inoceramid bloom in the early part of the early Cenomanian (mid-*Mantelliceras mantelli* Zone) that resulted in relatively dense populations on the seafloor across large shelf areas. This acme distribution of *G. crippsi* can thus also be interpreted as a proliferation bioevent (epibole) sensu Brett and Baird (1997), triggered by an inter-regional population bloom. Concentration by storm amalgamation (but also physical destruction) of the shells increased towards the basin margins where sand- and glaucony-bearing, marly shell-detrital facies prevailed (e.g. Konrad-101 borehole; Niebuhr et al. 2001). However, as shown by the limited taphonomic alteration of the *crippsi* Event assemblage in Lüneburg, the seafloor must have partly really been paved by inoceramids, also in the deeper part of the basin where physical concentration of shells played a subordinate role. These observations indicate a formation as a primary biogenic concentration with relatively high shell density grading into storm wave-reworked concentrations towards the proximal areas (cf. Fürsich and Oschmann 1993).

Of particular importance is the occurrence of *Gnesioceramus mowriensis* within the *crippsi* Event at Lüneburg, known so far only from lower Cenomanian strata of the US Western Interior Seaway (Walaszczyk and Cobban 2016; see Fig. 10a). The presence of the species in northwestern Europe suggests faunal exchange between North America and the Old World during the mid-early Cenomanian. North American immigration is also supported by the occurrence of the ammonite *Metengonoceras teigenense* Cobban and Kennedy, 1989, endemic to the Western Interior Seaway, in exactly the same stratigraphic horizon (i.e. the *crippsi* Event level) in Basse-Normandie (France; see Amédéo et al. 2002; Fig. 10a, b). *G. crippsi* was not specifically mentioned from the Boécé section but the characteristic

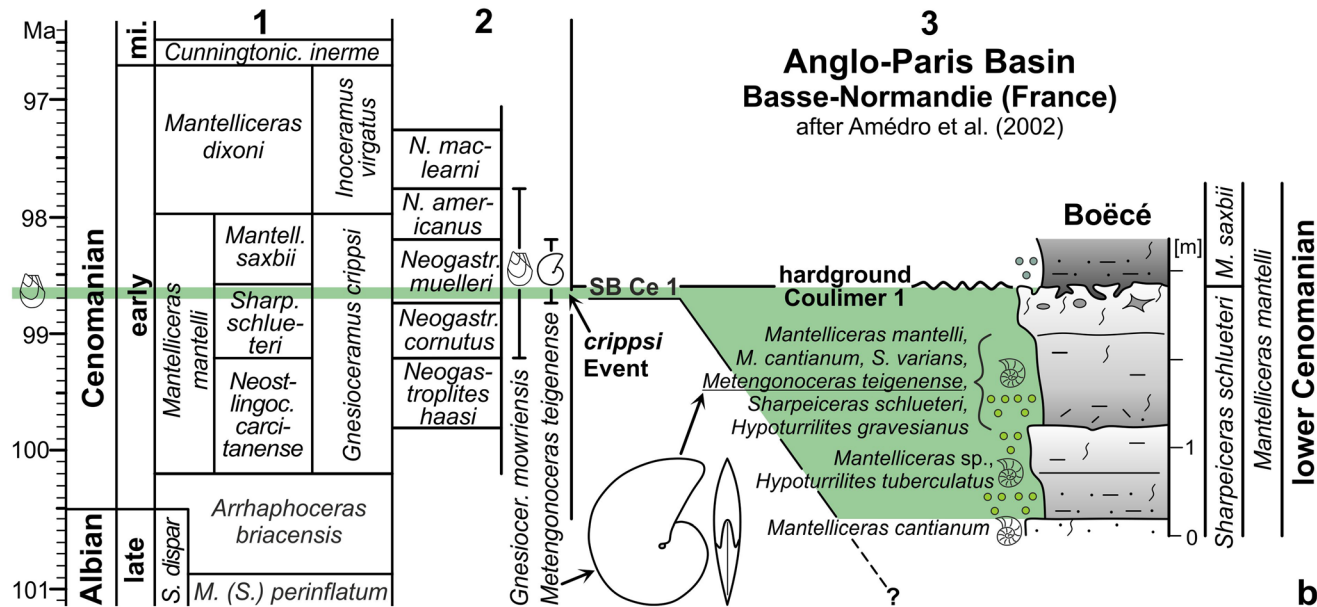
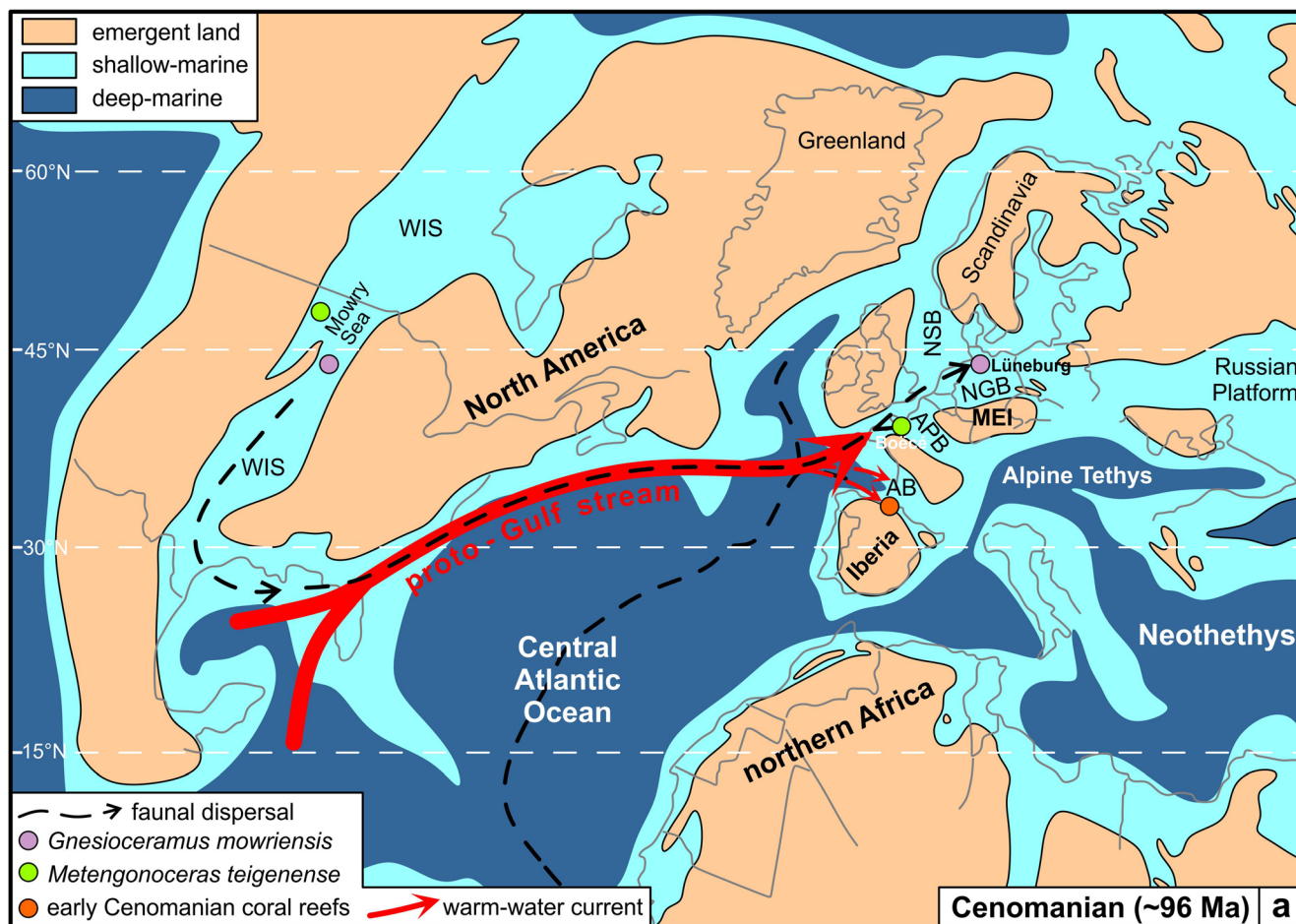


Fig. 10 Palaeogeographic and stratigraphic framework of faunal migrations associated with the *crippsi* Event. **a** Cenomanian palaeogeography (after Scotese 2014, sea level + 80 m, Mollweide projection) showing the occurrences of *G. mowriensis* and *M. teigenense* as well as the diverse early Cenomanian coral reefs in northern Cantabria (AB, Aquitaine Basin; APB, Anglo-Paris Basin; MEI, Mid-European Island; NSB, North Sea Basin; NGB, North German basins; WIS, Western Interior Seaway; see text for

discussion). **b** Geochronological framework of the *crippsi* Event related to the NW European standard biozonation (1, modified and supplemented after Wright and Kennedy 2017) and correlated to the North American ammonite record (ammonite biozonation and ages from Ogg and Hinnov 2012, faunal ranges after Cobban and Kennedy 1989; Walaszczyk and Cobban 2016) as well as the Boëcé section in Basse-Normandie (where *M. teigenense* was recorded) by Amédéo et al. (2002)

ammonite assemblage (cf. Gale and Friedrich 1989), the terminal *S. schlueteri* subzonal age, and the superposition by sequence boundary SB Ce 1 provide firm support for the correlation of the French site with the *crippsi* Event (Fig. 10b). Dispersal of marine Cretaceous faunas often occurred during the transgressive and maximum flooding intervals of sequences (e.g. the belemnite Events in the Cenomanian; Gale and Christensen 1996; Mitchell 2005; Wilmsen et al. 2007, 2010; Wilmsen 2012), but in this case, a late highstand position of both *G. mowriensis* and *M. teigenense* can be ascertained as the *crippsi* Event bundle is capped by the interregional sequence boundary Cenomanian 1 (Robaszynski et al. 1998; Wilmsen 2003; Janetschke et al. 2015; see discussion above). However, common immigration events during highstands have been proposed by Brett (1998) based on altered water mass properties and open migration pathways following the transgressive reorganisation of the shelf seas. We speculate that the stability of the water masses and oceanic currents during the highstand acted as a driver of faunal dispersal. Amédéo et al. (2002) assume a migration of *M. teigenense* from the Mowry Sea of the Western Interior Seaway via a southern route across the Gulf of Mexico and along the northwestern margin of the Central Atlantic Ocean to Europe, also considering postmortem drift of empty shells. However, the oxycone shell form of *M. teigenense* is not appropriate for prolonged floating (Yacobucci 2018). Furthermore, the contemporaneous dispersal of benthic inoceramids (*G. mowriensis*) suggests the existence of appropriate (NE-directed) surface currents for the distribution of their planktotrophic larvae (cf. Kauffman 1975; Knight and Morris 1996 and Tanoue 2003 demonstrated the existence of planktotrophic larvae in inoceramids). Scheltema (1977) showed that the planktic stages of different mollusk groups last up to one year and that planktic larvae can easily be spread across oceans in a few months based on temporal constraints of modern trans-ocean surface currents. Consequently, a dispersal of planktotrophic inoceramid larvae from the Western Interior to Europe by means of a NE-directed surface current seems a plausible explanation. This current may have distributed warm surface waters from the Gulf of Mexico towards Europe (Fig. 10a) in the form of a proto-Gulf stream (see also Amédéo et al. 2002, fig. 4). Considering the warm-water preference of many engonoceratid ammonites, being latitudinally restricted to warm-temperate to tropical zones of the Cretaceous oceans (e.g. Kennedy and Cobban 1976; Kennedy et al. 2009; see also Ifrim et al. 2015 and Lehmann et al. 2015), a northerly dispersal route of the Western Interior faunas via the Arctic Ocean towards Europe (Fig. 10a) is much less likely. The presence of *M. teigenense* in western France (Amédéo et al. 2002) thus supports the existence of a warm proto-Gulf stream in early Cenomanian times. Further support for this interpretation comes from the development of relatively large and diverse coral reefs in Cantabria, northern Spain, in relatively high palaeolatitudes during the early Cenomanian (Wilmsen 1996, 2000), and the

prevalence of contemporaneous warm-water biofacies in the Aquitaine Basin of western France (e.g. Masse and Philip 1981; Francis 1984), forming potential fingerprints of this warm-water current on its way to the northeast (Fig. 10a).

The early Cenomanian species *Gnesioceramus mowriensis* appeared in the Western Interior Seaway during the *Neogastrolites cornutus* ammonite Zone (Walaszczyk and Cobban 2016; zone base at ca. 99.20 Ma according to Ogg and Hinnov 2012) and ranges through the *N. muelleri* Zone (base at 98.75 Ma, top at 98.20 Ma) up to the *N. americanus* Zone (top at 97.80 Ma); the maximum duration of the species is thus ca. 1.4 myr (Fig. 10b). Its brief appearance in Europe, documented herein, comprises a short interval from the middle part of its North American range as can be demonstrated by the occurrence of *M. teigenense* in the correlative level of the *crippsi* Event in the Boécé section, Basse-Normandie, just below sequence boundary SB Ce 1 (= hardground Coulimer 1; Amédéo et al. 2002): the ammonite species is known only from the *N. muelleri* Zone of Montana (Cobban and Kennedy 1989). When the North American ammonite zones are plotted against the European standard zonation (cf. Wright and Kennedy 2017), it can be shown that the uppermost *Sharpeiceras schlueteri* Subzone of the *Mantelliceras mantelli* Zone in Europe must correlate to the lowermost *N. muelleri* Zone in North America (Fig. 10b). Accepting this tie point, the absolute age of the *crippsi* Event may be defined as ca. 98.6–98.7 Ma.

Conclusions

Palaeontological events (or bioevents) are a specific feature of Cretaceous epicontinental strata in Europe, forming important marker beds for intra- and interbasinal correlation. The lower Cenomanian *crippsi* Event comprises a thin interval of strata (1–3 m) characterised by the mass occurrence of valves of the early Cenomanian inoceramid bivalve *Gnesioceramus crippsi* (Mantell, 1822), identified in the uppermost part of the *Sharpeiceras schlueteri* Subzone of the lower lower Cenomanian *Mantelliceras mantelli* ammonite Zone, below an interregional sedimentary unconformity (sequence boundary SB Ce 1). At Lüneburg, the event beds are characterised by a dense packing of mostly complete, disc-like valves of *G. crippsi* with limited taphonomic alteration. Bio- and microfacies data suggest an event formation in a deeper shelf setting on a soft substrate below the storm-wave base as a primary biogenic concentration with the inoceramid bivalves living as inferred recumbent forms in relatively dense populations. When tracked on an interbasinal scale across the North German shelf into the Anglo-Paris Basin, the distribution of the *crippsi* Event across three to four marl-limestone bedding couplets of a couplet bundle, reflecting

orbital forcing by the precession/short-eccentricity syndrome, suggests a moderately prolonged phase (< 105 kyr) of increased shell production. Rapid deposition during the late highstand phase of depositional sequence Cenomanian 1 aided in preserving the shell-rich event strata. The *crippsi* Event can thus be interpreted as a proliferation bioevent (epibole) sensu Brett and Baird (1997), triggered by an interregional population bloom. Towards the basin margin, it grades into storm wave-reworked shell concentrations.

Of particular importance is the occurrence of *Gnesioceramus mowriensis* Walaszczyk and Cobban, 2016 within the *crippsi* Event at Lüneburg, formerly only known from lower Cenomanian strata of the US Western Interior Seaway. Together with the ammonite *Metengonoceras teigenense* Cobban and Kennedy, 1989, likewise an endemic North American mid-early Cenomanian faunal element known as a single find from the level of the *crippsi* Event in northern France, these taxa indicate faunal exchange between North America and Europe during the early Cenomanian. Albeit post-mortem drift of an empty ammonite shell cannot completely be excluded for *M. teigenense*, the contemporaneous dispersal of benthic inoceramids (*G. mowriensis*) rather suggests the existence of a perpetual NE-directed surface current for the distribution of their planktotrophic larvae. This inferred proto-Gulf stream transported warm surface waters from the Gulf of Mexico towards Europe, supported by the existence of warm-water biofacies in Western Europe during the early Cenomanian. Furthermore, the disjunct occurrence of the short-lived species *M. teigenense* in France allows for the calibration of the uppermost *schlueteri* Subzone of the *mantelli* Zone in Europe to the lowermost *Neogastropilites muelleri* Zone in North America, assigning an absolute age of ca. 98.6–98.7 Ma to the *crippsi* Event.

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Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

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