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The middle–upper Cenomanian of Zilly (Sachsen-Anhalt, northern Germany) with remarks on the *Pycnodonte* Event

MARKUS WILMSEN[1] & THOMAS VOIGT[2]

[1]*Institut für Paläontologie, Bayerische Julius-Maximilians-Universität, Pleicherwall 1, D–97070 Würzburg, Germany. E-mail: m.wilmsen@mail.uni-wuerzburg.de*

[2]*Institut für Geowissenschaften der Friedrich-Schiller-Universität, Burgweg 11, D–07749 Jena, Germany. E-mail: Thomas.Voigt@uni-jena.de*

ABSTRACT

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A detailed stratigraphic log of the 28 m thick Cenomanian succession at Zilly (Sachsen-Anhalt) is presented. The succession is composed of 11 m of middle Cenomanian hemi-pelagic marl–limestone alternations (‘Pläner Limestones’) grading into 15 m of upper Cenomanian calcareous pelagites (‘Poor *rhotomagense* Limestones’) unconformably overlain by 1.5 m of red-coloured marly clays and limestones (‘Rotpläner’). The proof of the interregional marker beds of the *Pycnodonte* Event at the 11 m level, the Facies Change at 26 m, and the base of the *plenus* Bed at 26.9 m allow a bio-/chronostratigraphic correlation of these levels with the middle/upper *Acanthoceras jukesbrownei* Zone (upper middle Cenomanian), the *Calycoceras* (*Proeucalycoceras*) *guerangeri*/*Metoicoceras geslinianum* Zone transition, and the lower *Metoicoceras geslinianum* Zone, respectively (middle upper Cenomanian). Litho-/microfacies and sequence stratigraphic analyses indicate an overall increase of pelagic influence up to the Facies Change. This retrogradational trend was shortly interrupted by the *Pycnodonte* Event, the base of which correlates with the late middle Cenomanian sequence boundary SB Ce IV and the succeeding transgressive surface. The Facies Change indicates a significant mid-late Cenomanian sea-level fall (sequence boundary SB Ce V), followed by more shallow water Rotpläner deposition. The *Pycnodonte* Event is very thick and proximal in character at Zilly. Its monospecific oyster fauna consists of small pycnodonteines assigned to *Pycnodonte* (*Phygraea*) *vesicularis* (LAMARCK) *vesiculosa* (J. SOWERBY), a secondarily free-lying oyster which lived as a ‘cup-shaped recliner’. The patchy occurrence of the oysters, the sorting and partial damage of valves prior to final burial along with significant supply of terrigenous materials suggest episodically elevated water energy and strong environmental stress during deposition of the *Pycnodonte* Event. This situation promoted colonization of the sea-floor by, and reproductive success of the inferred eurytopic oyster. The *Pycnodonte* Event is a classic example of an ‘onlapping bioevent’, the formation of which was controlled by different factors such as sea-level rise, terrigenous influx, environmental stress, and preferential preservation.

Key words: Cretaceous, Cenomanian, Subhercynian Basin, Event stratigraphy, Microfacies, *Pycnodonte* Event, Correlation.

INTRODUCTION

Exposures of Cenomanian strata are limited in the area north of the Harz Mountains, i.e., the so-called Subhercynian area, with the most important sections being located near Hoppenstedt and Langenstein (Text-fig. 1). The abandoned limestone quarry at Zilly (Text-fig. 1) exposes a c. 28 m thick succession of marine marls, marly limestones and limestones of Cenomanian age. However, the section is virtually unknown and was

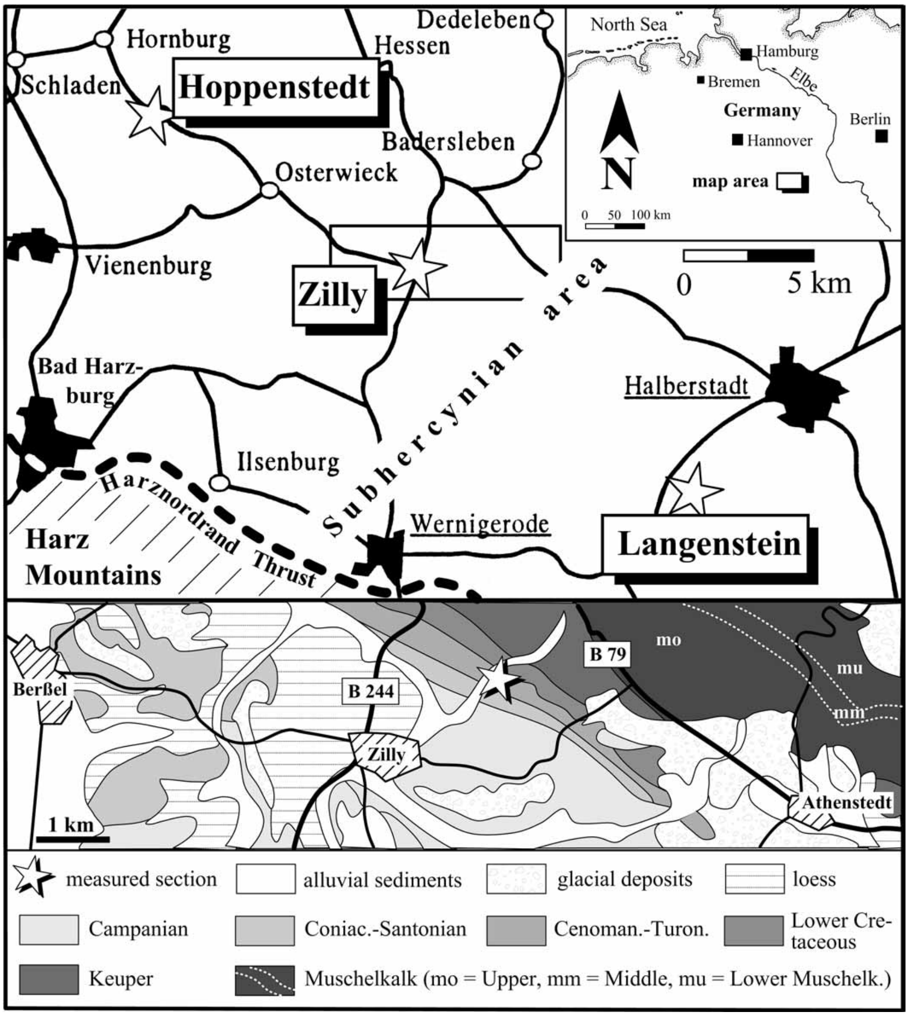


Fig. 1. Geographical and geological details of the Zilly section. Above: Locality map with indication of the Hoppenstedt and Langenstein sections mentioned in the text. Below: Geological situation of the Zilly section (asterisk)

not described yet in the literature. Here we present a detailed stratigraphic log of the Cenomanian succession at Zilly from the lower middle Cenomanian up the upper Cenomanian *plenus* Bed, compare it to the integrated stratigraphic framework of the Cenomanian Stage, suggest a correlation to the Subhercynian Cenomanian standard section at Hoppenstedt, ca. 12 km to the WNW, and discuss the genesis and lateral change of the late middle Cenomanian *Pycnodonte* Event, an important interbasinal marker bed of Cenomanian event stratigraphy. In order to obtain these goals, we measured the section bed-by-bed, analyzed the microfacies using hand lens and 20 thin sections, and collected macrofossils *in situ*. The Zilly section was then calibrated against the Cenomanian standard of the Subherynian area, the Hoppenstedt section, and the interval of the *Pycnodonte* Event was correlated along a ca. 100 km proximal-distal (i.e., SE–NW) transect.

GEOLOGICAL FRAMEWORK

The Zilly section is located in the central part of the Subhercynian Basin (SHB, TRÖGER 1995) which comprises the area between the Harz Mountains and the Flechtingen High. The exposed strata are lithologically similar to those of the middle and upper Cenomanian of the Hoppenstedt section in the western part of the Subhercynian Basin as well as sections from the south-eastern Lower Saxony Basin (LSB, i.e., the area east of the NNW/SSE Steinhude Lineament; see BALDSCHUHN & *al*. 1991) such as Baddeckenstedt. Important papers dealing with the facies and stratigraphy of the Cenomanian in the Lower Saxony and Subhercynian basins are TRÖGER (1969, 1995, 2000), ERNST & *al*. (1983), HILBRECHT & DAHMER (1994), ERNST & WOOD (1995), HORNA (1996, 1997), ERNST & REHFELD (1997), NIEBUHR & *al*. (2000, 2001), WILMSEN & NIEBUHR

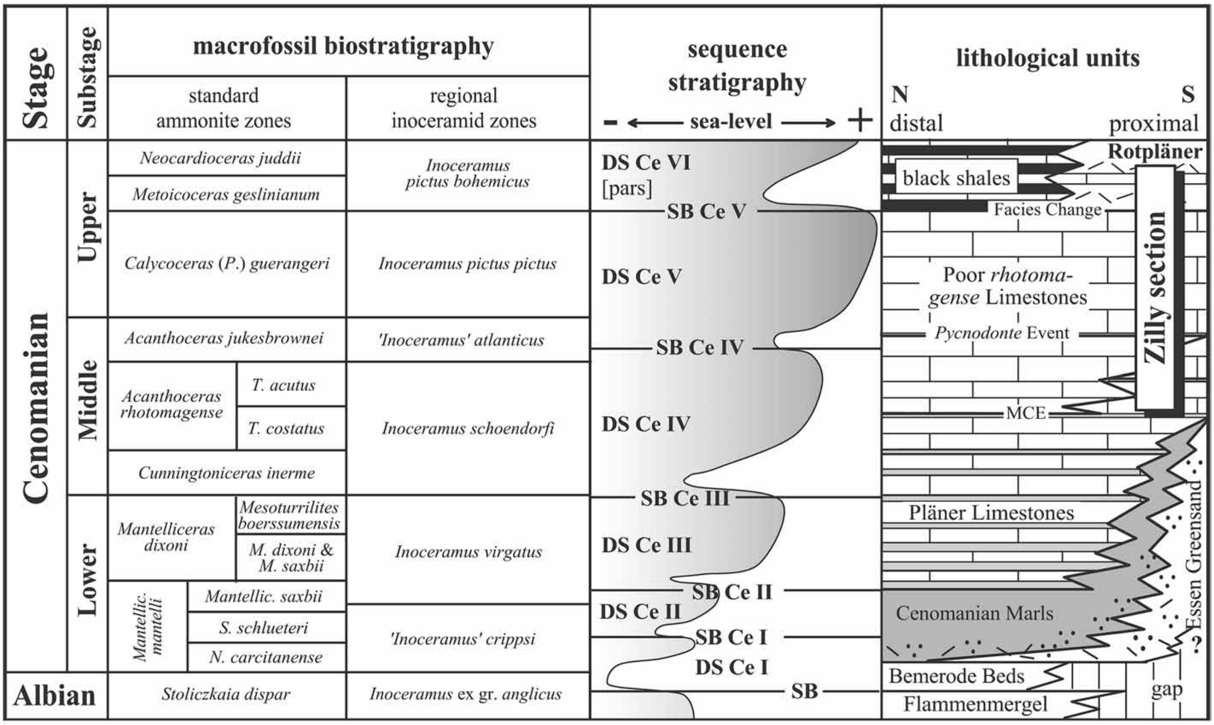


Fig. 2. Integrated stratigraphic framework of the Cenomanian Stage in northern Germany (modified after WILMSEN & *al.* 2005). The stratigraphic interval of the Zilly section is indicated. Abbreviations: DS = depositional sequence; Ce = Cenomanian; SB = sequence boundary

(2002), WILMSEN (2003), WILMSEN & WIESE (2004), WILMSEN & WOOD (2004), VOIGT & *al*. (2004) and WILMSEN & *al*. (2005).

Following a pronounced sea-level lowstand across the Albian–Cenomanian boundary, the Cenomanian was characterized by a general transgressive facies development as shown by an increase in carbonate content and a decrease in siliciclastic input. After nearshore deposition of condensed, phosphorite-bearing greensands ('Essen Greensand', see Text-fig. 2) and sandy-silty marls ('Cenomanian Marls') during the early early Cenomanian, the late early to middle late Cenomanian were characterized by deposition of hemipelagic, fossiliferous marl–limestone alternations ('Pläner Limestones') and pelagic nannofossil ooze ('Poor *rhotomagense* Limestones'; Text-fig. 2; see WILMSEN 2003 and WILMSEN & *al*. 2005, for synopsis). The overall transgressive development was terminated in the middle part of the upper Cenomanian at a stratigraphic level known as the 'Facies Change' ('Faziesgrenze' of ERNST & *al*. 1983). Above that level, which indicates an important regressive event, variegated marls and marly limestones ('Rotpläner') or black shales of latest Cenomanian to Early Turonian age were deposited in northern Germany.

The high-resolution integrated stratigraphy of the Cenomanian Stage is based on several independent approaches such as bio-, cyclo-, event, and sequence stratigraphy. In northern Germany, Cenomanian macrofossil biostratigraphy is mainly based on ammonites and inoceramid bivalves (Text-fig. 2, e.g., KAPLAN & *al*. 1984, 1998). Stratigraphic events were established by ERNST & *al*. (1983), and WILMSEN (2003) presented a detailed sequence stratigraphic framework (cf. Text-fig. 2).

THE ZILLY SECTION

LOCALITY: The section is located ca. 1.5 km NE of the village of Zilly in a small abandoned quarry (Text-fig. 1). It can be reached via a track leading to a NE–SW oriented valley cut into the southwestern flank of the Huy Anticline by a small creek. The exposed thickness is 28 m and the beds dip with ca. 40° towards the SSW. The Huy Anticline is a WNW–ESE trending structure with Lower Triassic sediments (Lower Buntsandstein) in its core. It is the eastern extension of the Fallstein and the Zilly section, thus, occupies a comparable structural position within the Subhercynian Basin as that of Hoppenstedt (which is located on the southwestern flank of the Fallstein).

LITHOFACIES: The section starts with an intercalation of decimetric marls and slightly thicker (marly) lime-

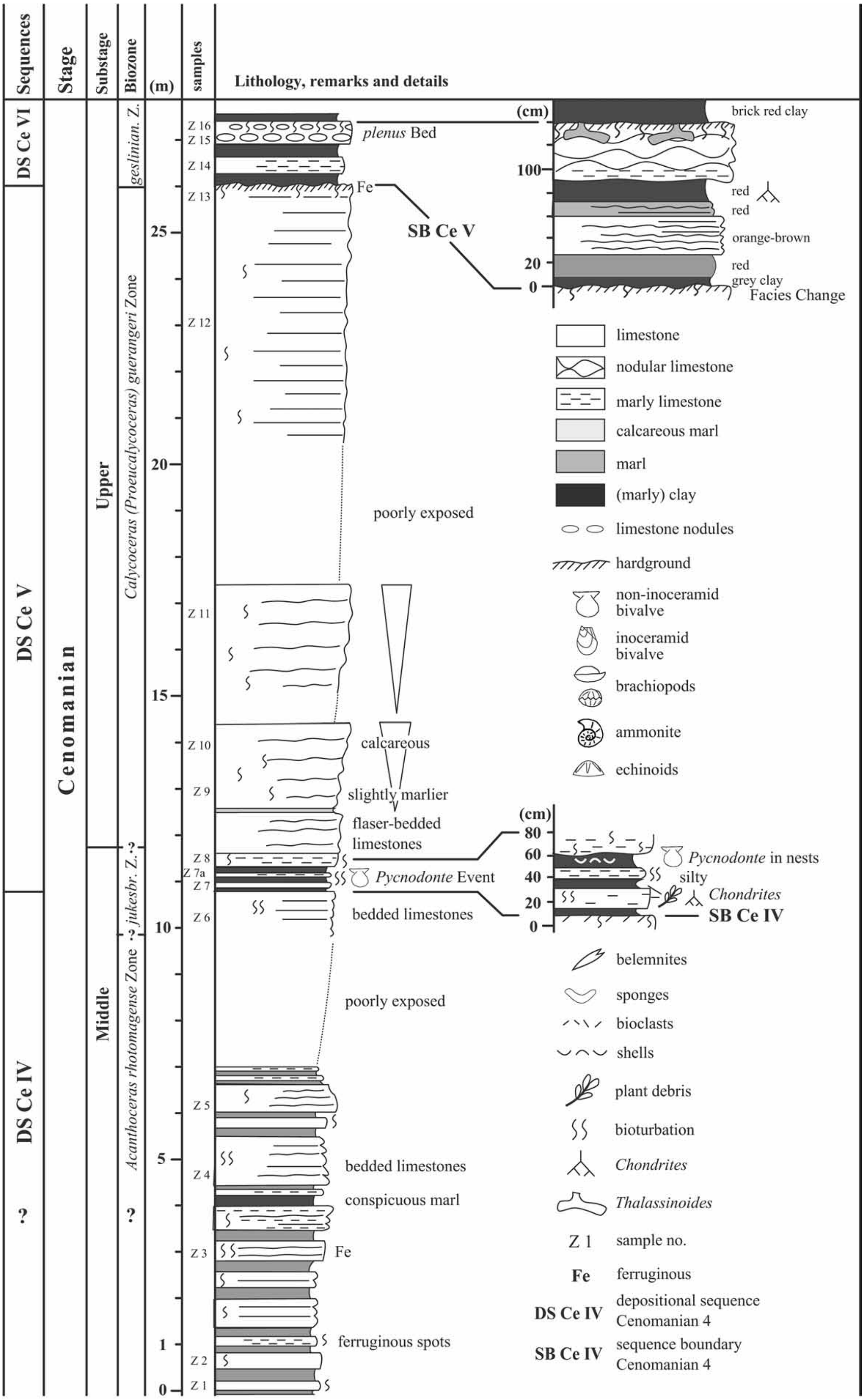


Fig. 3. Stratigraphic log of the Zilly section. Legend applies also for Text-figs 6 and 8. Abbreviations: *jukesbr*. Z.= *Acanthoceras jukesbrownei* Zone; *geslinian*. Z.= *Metoicoceras geslinianum* Zone; DS Ce IV/V/VI = depositional sequence Cenomanian 4/5/6; SB Ce IV/V = sequence boundary Cenomanian 4/5

stones which are often internally stratified (Text-fig. 3). Apart from indeterminate bioturbation, the beds are poorly fossiliferous. At 4 m, a conspicuous marl bed occurs, and between 7–10 m, the succession is only poorly exposed. Between 10.8–11.3 m, a conspicuous marly interval is intercalated into light-grey bedded limestones (Text-figs 3, 4). It contains marly limestone interbeds with *Chondrites*, plant debris, silt-sized quartz grains, and, in its upper part, lenticular, matrix-supported accumulations of small pycnodonteine oysters (Text-fig. 4C–G). Above that level, marls disappear from the succession and white, fine-grained bedded limestones predominate up to the 26 m mark of the section. In the lower part of this interval, two 2–3 m thick cycles occur

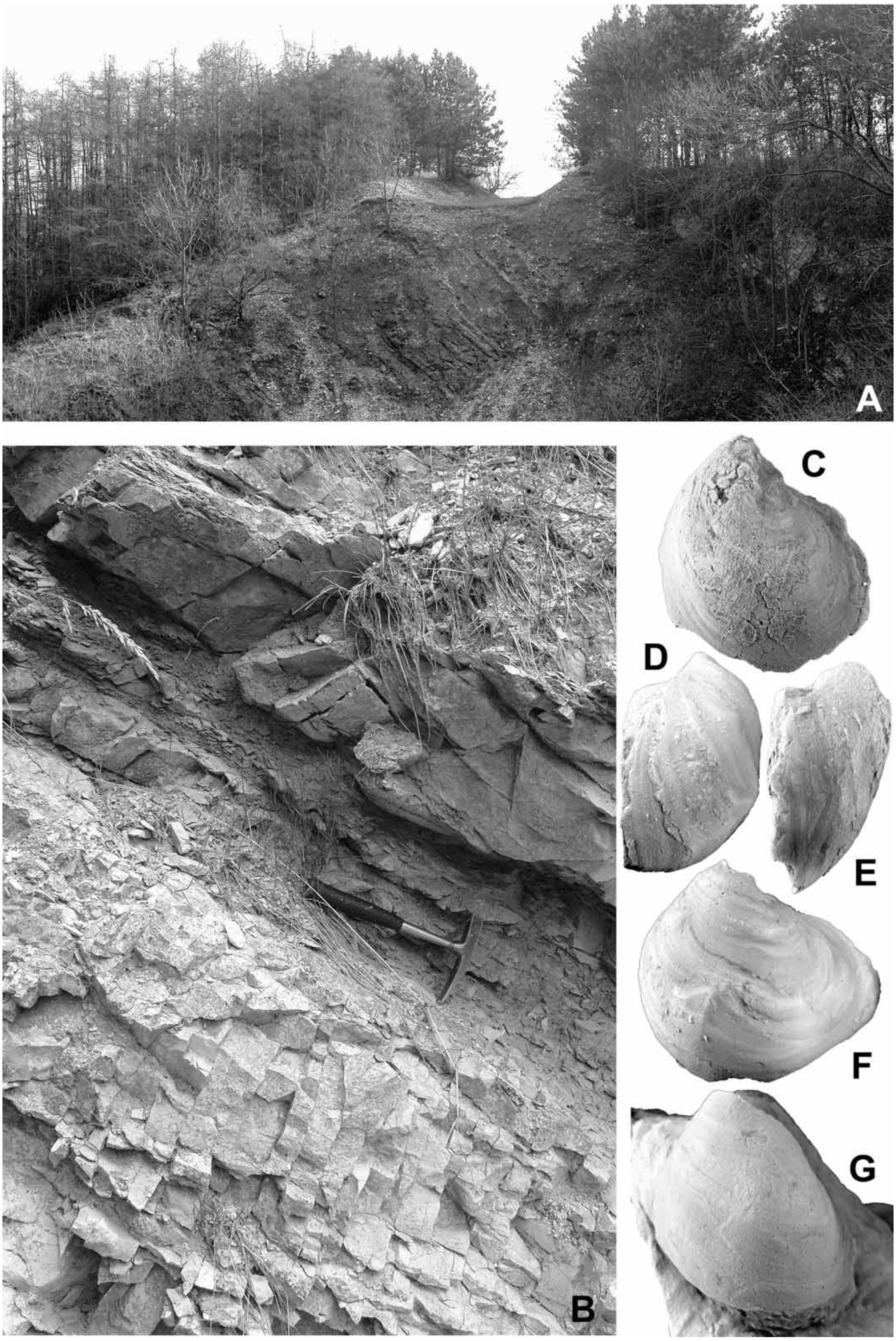


Fig. 4. Field aspects and fossils of the Zilly section. A, Overview of the section, seen from the west. B, Detail of the *Pycnodonte* Event. C–G, *Pycnodonte* (*Phygraea*) *vesicularis* (LAMARCK) *vesiculosa* (J. SOWERBY) (all figures × 2.0). C, E, specimen PIW2005IV-1. D, F, specimen PIW2005IV-2. G, specimen PIW2005IV-3

in which beds thicken upwards and carbonate contents slightly increase. The 26 m level of the section marks an important lithological boundary, the so-called 'Facies Change' ('Faziesgrenze' of ERNST & *al*. 1983), followed by reddish marly clays and marly limestones with an intercalated, 50 cm thick nodular limestone bed with a bioturbated omission surface at its top (27.3 m level). Above that bed, which corresponds to the *plenus* Bed of authors [due to the occasional occurrence of the belemnite *Praeactinocamax plenus* (BLAINVILLE) in this bed; see, e.g., ERNST & *al*. 1983; HILBRECHT & DAHMER 1994], brick red (marly) clays terminate the section.

MICROFACIES: The microfacies of the lower part of the section (samples Z1–Z6) is dominated by fine-bioclastic wackestones with calcispheres, ostracodes, and occasional non-keeled planktic foraminifera (Text-fig. 5A, B). The bioclasts are mainly fragments and isolated prisms of inoceramid shells as well as subordinate echinoid debris. Bioturbation is indicated by inhomogenous distribution of components. The prominent marly interval around 11 m consists of silty bioclastic oyster floatstones and clayey–silty inoceramid prism wacke- to packstones (Text-fig. 5C, D). Irregular distribution of bioclasts is common and related to bioturbation (*Chondrites* isp.). Fine plant debris may occur. Up-section, silt/clay and bioclast content rapidly decreases (samples Z8–Z10) and microbioclastic wacke- and mudstones (Text-fig. 5E) and planktic foraminifera mudstones prevail (samples Z11–Z15). The Facies Change at 26 m is also a prominent microfacies boundary: an undulating erosion surface is overlain by soft, grey and (brick) red clayey sediments, orange–brown marly limestones (bioturbated planktic foraminifera wacke- to packstones; Text-fig. 5F) and a sharp-based, nodular, bioturbated limestone bed (i.e., the *plenus* Bed). This prominent limestone bed is a calcisphere packstone at its base (Text-fig. 5G) and an inoceramid prism–calcisphere packstone at the top (Text-fig. 5H). Burrows at the top are filled with the overlying (marly) brick-red clay.

MACROFOSSILS: The section is only poorly (macro-) fossiliferous. Small pycnodonteine oysters [*Pycnodonte* (*Phygraea*) *vesicularis* (LAMARCK) *vesiculosa* (J. SOWERBY)] occur abundantly in one layer at ca. 11 m of the section (Text-fig. 4). From this interval, also rare inoceramids were collected in the scree, which can be referred to '*Inoceramus*' *atlanticus* (HEINZ) with some doubt due to poor preservation. The oysters characterize the *Pycnodonte* Event of ERNST & *al*. (1983), an important interbasinal marker bed which is discussed below. Since the oysters of the *Pycnodonte* Event were rarely documented they are briefly described below.

SYSTEMATIC PALAEONTOLOGY

Suborder Ostreina FÉRUSSAC, 1822
Superfamily Ostreoidea RAFINESQUE, 1815
Family Gryphaeidae VIALOV, 1936
Subfamily Pycnodonteinae STENZEL, 1959
Genus *Pycnodonte* FISCHER DE WALDHEIM, 1835
Subgenus *Phygraea* VIALOV, 1936

REMARKS: Although some authors regard *Phygraea* VIALOV as an independent genus (e.g., COOPER 1992; PACAUD & *al.* 2000), most authors (e.g., MALCHUS 1990; DHONDT 1993; MALCHUS & *al.* 1994; FRENEIX 1994; SEELING & BENGTSON 1999; WEN 2000; KASSAB & ZAKHERA 2002; MACHALSKI & ROBASZEWSKA 2003; EL QOT 2006) follow the traditional view of STENZEL (1971), placing *Phygraea* VIALOV as a subgenus of *Pycnodonte* FISCHER DE WALDHEIM.

Pycnodonte (*Phygraea*) *vesicularis* (LAMARCK, 1806)
vesiculosa (J. SOWERBY, 1823)
(Fig. 4C-G)

*1823. *Gryphaea vesiculosa* J. SOWERBY, p. 93, pl. 369 (7 figs).
1972. *Pycnodonte* (*Pycnodonte*) *vesicularis* (LAMARCK, 1806) *vesiculosa* (J. SOWERBY, 1813); FRENEIX, p. 102, pl. 10, figs 1-3, text-figs 11, 12.
2006. *Pycnodonte* (*Phygraea*) *vesicularis* (LAMARCK, 1806) *vesiculosa* (J. SOWERBY, 1823); EL-QOT, pl. 5, figs 10a, b, 11a, b, text-fig. 29A. (with extensive synonymy)

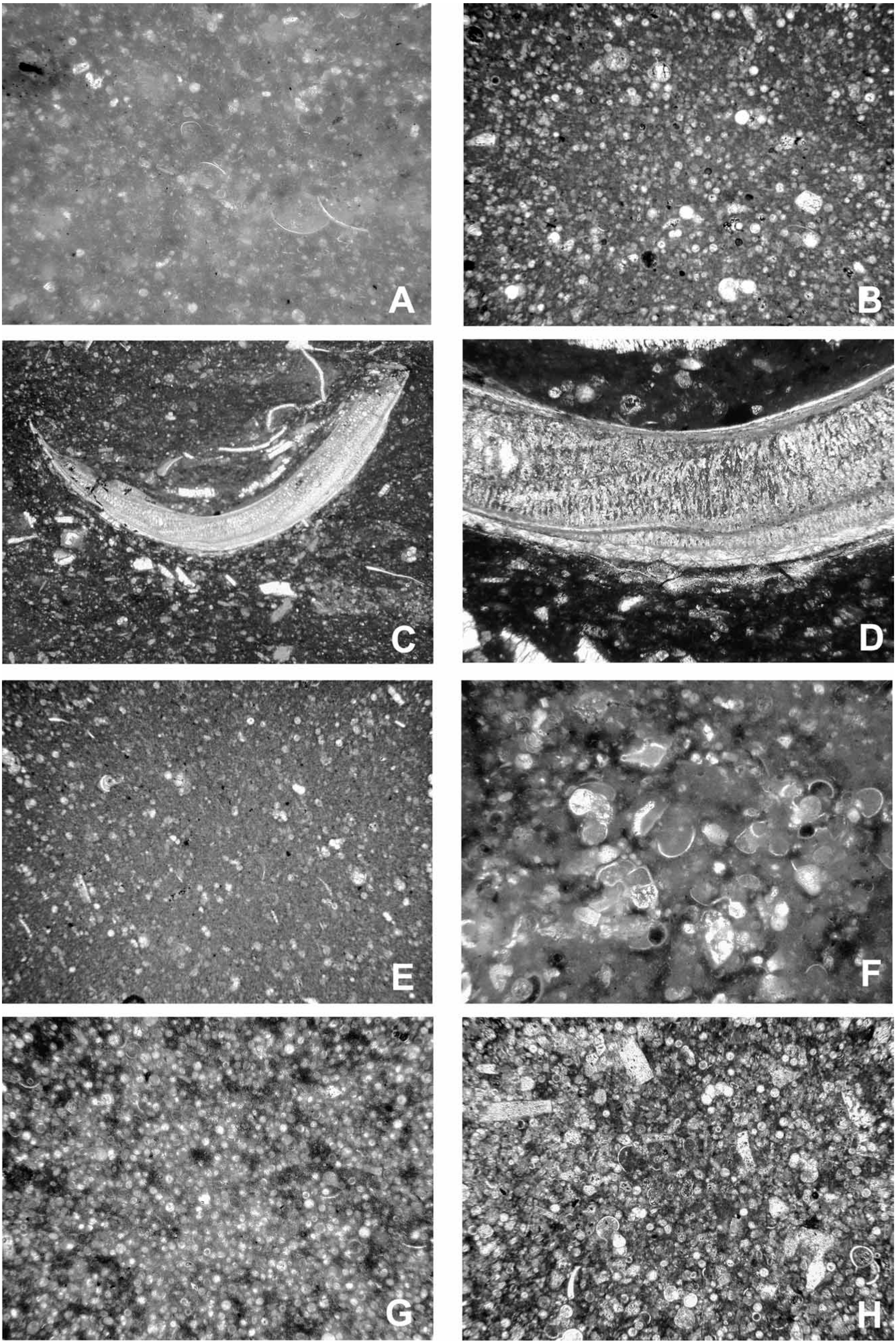
MATERIAL AND METHODS: Eight isolated left valves (PIW2005IV-1 to -8, stored in the collection of the Institute of Palaeontology of Würzburg University). The oysters were cleaned, mechanically prepared and treated with black ink and magnesium oxide prior to photography. Descriptive terminology follows STENZEL (1971) and MALCHUS (1990).

DESCRIPTION: Small pycnodonteine oyster with a maximum height of 16 mm (minimum 11 mm), length about the same (maximum 17 mm, minimum 10 mm). Most specimens are slightly higher than long but commonly very close to a height–length ratio of one. Left valves are strongly convex (up to 8 mm deep), with suboval to subcircular outline and a weak posterior sulcus. The outer shell surface is almost smooth with faint growth lines and occasional stronger growth lamellae. The umbo is small and opisthogyrate, with a small umbonal attachment area (1-3 mm wide). Some of the collected specimens were damaged prior to final deposition as shown by shell loss, especially at the umbo and at the shell margins. The oysters occur predominantly in the upper part of the *Pycnodonte* Event bed at Zilly and appear to be concentrated in small lenses.

TAXONOMIC REMARKS: There is a lot of confusion in the taxonomy of small pycnodonteine oysters from the upper Albian–Cenomanian. On the one hand, the small Cenomanian oysters from the *Pycnodonte* Event are commonly assigned to *Pycnodonte* (*Phygraea*) *vesicularis* (LAMARCK) (e.g., LEHMANN 1999), a normally larger species assigned by some authors exclusively to the upper Upper Cretaceous (Coniacian–Maastrichtian; MALCHUS 1990; SEELING & BENGTSON 1999). On the other hand, there is the very similar *P.* (*Ph.*) *vesiculosa* (J. SOWERBY), a likewise rather small Albian–Cenomanian pycnodonteine oyster, originally described from the upper Albian of southern England, for which MALCHUS (1990, p. 147) stressed the general similarity to *P.* (*Ph.*) *vesicularis*. Correspondingly, small Cenomanian pycnodonteines are also often included in *P.* (*Ph.*) *vesiculosa*, especially in northern Africa (e.g., AQRABAWI 1993; DHONDT & *al.* 1999), or classified as *P.* (*Ph.*) *vesicularis* (LAMARCK) *vesiculosa* (J. SOWERBY) (e.g., FRENEIX 1972, see below). Furthermore, some authors (e.g., OWEN 1996) have used the name *Pycnodonte baylei* (GUÉRANGER) for the small Cenomanian forms from the *Pycnodonte* Event.

In the first half of the twentieth century, several authors regarded *P.* (*Ph.*) *vesiculosa* as a subspecies or form of *P.* (*Ph.*) *vesicularis* (see discussion in EL QOT 2006). FRENEIX (1972, p. 102-104) thoroughly discussed this problem based on upper Albian–Campanian oyster populations from the Tarfaya Basin, Morocco, and concluded that there were three chronological subspecies of *P.* (*Ph.*) *vesicularis*, i.e., *P.* (*Ph.*) *vesicularis vesiculosa* (late Albian–Cenomanian), *P.* (*Ph.*) *vesicularis subvesiculosa* (?Turonian–Coniacian), and *P.* (*Ph.*) *vesicularis vesicularis* ('Senonian'–Danian; '*P. vesicularis* sensu stricto'). Later, FRENEIX & VIAUD (1986) placed *P.* (*Ph.*) *vesicularis subvesiculosa* in the synonymy of *P.* (*Ph.*) *vesicularis vesicularis* and described two more Cenomanian–Turonian subspecies of *P.* (*Ph.*) *vesicularis*: For a generally small middle Cenomanian–Turonian form (less than 30 mm high, mean ~10 mm), they erected *P.* (*Ph.*) *vesicularis parvula* FRENEIX & VIAUD. Their late Cenomanian *P.* (*Ph.*) *vesicularis pseudovesiculosa* COUFFON is medium-sized (height up to 40 mm, mean height ~24 mm) and includes the small pycnodonteines described by COQUAND (1869, p. 124, pl. 48) as *Ostrea baylei* GUÉRANGER. However, both subspecies appear to be very poorly differentiated from each other and also from *P.* (*Ph.*) *vesiculosa* (which was then again regarded as a separate species; FRENEIX & VIAUD 1986, p. 27). *P.* (*Ph.*) *vesiculosa* is usually higher than long to rounded, has a well developed posterior sulcus and a pointed umbo without any or only a very small attachment area (J. SOWERBY 1823, p. 93, pl. 369; WOODS 1913, p. 374, pl. 55, figs 10–14, pl. 56, fig. 1). However, shell form and size of attachment area are strongly dependent on ecologic factors and mode of life/duration of fixation during ontogeny (e.g., MACHALSKI 1998). In southern England, *P.* (*Ph.*) *vesiculosa* occurs only in upper Albian arenaceous sediments (Upper Greensand), and it thus may represent only one form of a polymorphic species. This interpretation is corroborated by the co-occurrence of morphologically variable small oysters of the *vesiculosa* or small-*vesicularis* type in the lower Cenomanian of Morocco (FRENEIX 1972). Furthermore, in the upper Cenomanian of Egypt EL QOT (2006) documented not only the two main morphs but also transitional forms from the same beds; these clearly represent a polymorphic population, and not allopatric or chronologic subspecies or species. Also the numerous variants, forms or subspecies recognized for the often larger Coniacian – Danian '*P.* (*Ph.*) *vesicularis* sensu stricto' merely represent ecophenotypes (see MALCHUS 1990; DHONDT 1993; MALCHUS & *al.* 1994; ABDEL-AAL & EL-HEDENY 1998). Thus, the view of EL QOT (2006) is followed, in which *P.* (*Ph.*) *vesicularis* is subdivided into two chronologic, morphologically variable subspecies, i.e. the (late) Albian-Turonian *P.* (*Ph.*) *vesicularis vesiculosa* and the Coniacian–Danian *P.* (*Ph.*) *vesicularis vesicularis.*

In terms of shell size, length–height ratio, convexity of the left valve, size and position of the attachment area, and general shell form, the specimens described herein as *P.* (*Ph.*) *vesicularis* (LAMARCK) *vesiculosa* (J. SOWERBY) are close to the small pycnodonteines from the middle – upper Cenomanian of the Anglo-Paris Basin figured by FRENEIX & VIAUD (1986) as *P.* (*Ph.*) *vesicularis* '*parvula*' or '*pseudovesiculosa*'. WOODS (1913, pl. 55, figs 8, 9) figured some small forms as '*Ostrea vesicularis*' from Blue Bell Hill, Burham, England, which are also very similar to the Zilly specimens and come from inferred stratigraphically equivalent beds (i.e., uppermost middle Cenomanian). Comparable small pycnodonteine oysters occur commonly also in the equivalent of the *Pycnodonte* event in eastern England [the so-called '*Gryphaea* Band' of BOWER & FARMERY (1910), the Nettleton *Pycnodonte* Marl of modern UK usage; see MORTIMORE & *al.* (2001) for stratigraphic details]. The small size of the oysters may have something to do with their occurrences in marl-rich sediments (see below). However, most of the Albian–Turonian species and subspecies of *Pycnodonte* (*Phygraea*) are rather small (MALCHUS 1990), followed by a marked increase in size and shell thickness, especially from the Campanian into the Maastrichtian (pers. commun. C.J. WOOD, 12/2005).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DISCUSSION

FACIES DEVELOPMENT: The facies development displayed by the Cenomanian strata of the Zilly section indicates an overall decrease of terrigenous and an increase of pelagic influence up to the Facies Change, well known from many (middle–upper) Cenomanian sections across northern Germany (WILMSEN 2003; WILMSEN & *al*. 2005). In the lower part, hemi-pelagic marl–limestone alternations prevail (mainly fine-bioclastic calcisphre wackestones), grading into pure, light-coloured, fine-grained limestones (microbioclastic, planktic foraminifera-bearing mudstones). This general transgressive trend was briefly interrupted by the silty-marly interval of the *Pycnodonte* Event around the 11 m level of the section. The Facies Change, however, indicates a significant sea-level fall followed by a change in the depositional pattern: the widespread pelagic facies was replaced by a small-scale mosaic of shallow water Rotpläner swells and deeper water black shale basins (see HILBRECHT & DAHMER 1994; WILMSEN & WIESE 2004). In Zilly, a mingling of terrigenous influence (red clays) and pelagic signals such as planktic foraminifera- and calcisphere-rich sediments resulted in the deposition of a variegated intercalation of (marly) clays and (marly) limestones.

STRATIGRAPHIC INTERPRETATION: Only an integrated stratigraphic approach enabled the integration of the Zilly section into the Cenomanian stratigraphic framework (Text-fig. 6). From a lithostratigraphic viewpoint, the succession is similar to many middle–upper Cenomanian successions such as Hoppenstedt and Baddeckenstedt. The marl–limestone intercalation up to the 11 m level is equivalent to the Pläner Limestones, the light-coloured limestones up to the 26 m level are the Poor *rhotomagense* Limestones, and the sediments above the Facies Change correspond to the Rotpläner. As many of the Cenomanian lithounits are strongly diachronous, this does not help much in improving the chronostratigraphy of the succession. The *ex situ* finds of *Inoceramus atlanticus* (HEINZ) from around the 11 m level suggests a late middle Cenomanian age for that interval. The keys for the stratigraphic interpretation, however, are provided by event and sequence stratigraphic analyses: the proof of the *Pycnodonte* Event at the 11 m level, the Facies Change at 26 m, and the base of the *plenus* Bed at 26.9 m assign these levels to the middle/upper *Acanthoceras jukesbrownei* Zone, the *Calycoceras* (*Proeucalycoceras*) *guerangeri*/*Metoicoceras geslinianum* Zone transition, and the lower *Metoicoceras geslinianum* Zone, respectively (see ERNST & *al.* 1983). Likewise, the recognition of sequence boundaries SB Ce IV below the *Pycnodonte* Event and SB Ce V at the Facies Change suggests that the strata below the 10.8 m level belong to Cenomanian depositional sequence DS Ce IV (middle Cenomanian; see WILMSEN 2003). The beds between 10.8–26 m compose DS Ce V (latest middle to middle late Cenomanian), and the beds above the Facies Change comprise the lower part of DS Ce VI/Tu I (late late Cenomanian–Early Turonian; see WILMSEN & WIESE 2004). Text-fig. 6 suggests a correlation to the stratigraphically fine-tuned Hoppenstedt section (HORNA 1996; WILMSEN & WOOD 2004), the lower Upper Cretaceous standard section of the Subhercynian area, ca. 12 km to the WNW. The correlation documents the slighty reduced thicknesses of the interval from the *Pycnodonte* Event up to the Facies Change and the more proximal character of coeval middle Cenomanian strata at Zilly, including the relatively thick marl of the *Pycnodonte* Event (see below).

The observed thickness and facies variations can well be integrated into a regional facies pattern of Cenomanian strata. KARPE (1973) correlated Cenomanian and Turonian deposits of the Subhercynian Createceous Basin on the basis of 24 boreholes (lithology, gamma ray, SP and resistivity logs). He observed a distinct trend to marlier deposits from west to east in the lower and middle Cenomanian, accompanied by decreasing thicknesses (20–15 m). In the southeastern part of the basin (Ermsleben), this tendency culminates in an only 13 m thick lower to middle Cenomanian succession which is completely composed of monotonous sandy marls, thus indicating proximity of the basin margin. Unfortunately, this part of the basin is only poorly exposed, contains only a few diagnostic fossils and the existence of marker beds, erosion surfaces and hiatuses is hitherto unknown. However, according to the published log correlations (KARPE 1973), the upper Cenomanian pelagic limestones (Poor *rhotomagense* Limestones) cover the marly succession without significant changes in facies and thickness in comparison to the more western sections, stressing the magnitude of this extraordinary facies levelling event (WILMSEN 2003).

Fig. 5. Microfacies of the Zilly section (width of photomicrographs is 2.5 mm except in 5C where it is 10 mm). A, Ostracode-bearing fine-bioclastic wackestone (Pläner Limestones, sample Z2). B, Calcisphere wackestone with non-keeled planktic foraminifera (Pläner Limestones, sample Z6). C, Pycnodonteine oyster shell floating in a quartz silty-bioclastic matrix (*Pycnodonte* Event, sample Z7a). D, Close-up of the oyster shell of Text-fig. 5C; note typical pycnodonteine shell structure (*Pycnodonte* Event, sample Z7a). E, Fine-bioclastic wackestone from the Poor *rhotomagense* Limestones (sample Z11). F, Marly, microbioclastic wackestone with packed planktonic foramonifera in a burrow (sample Z14, Rotpläner below *plenus* Bed). G, Calcisphere packstone (lower *plenus* Bed, sample Z15). H, Inoceramid prism packstone with planktic foraminifera (top *plenus* Bed, sample Z16)

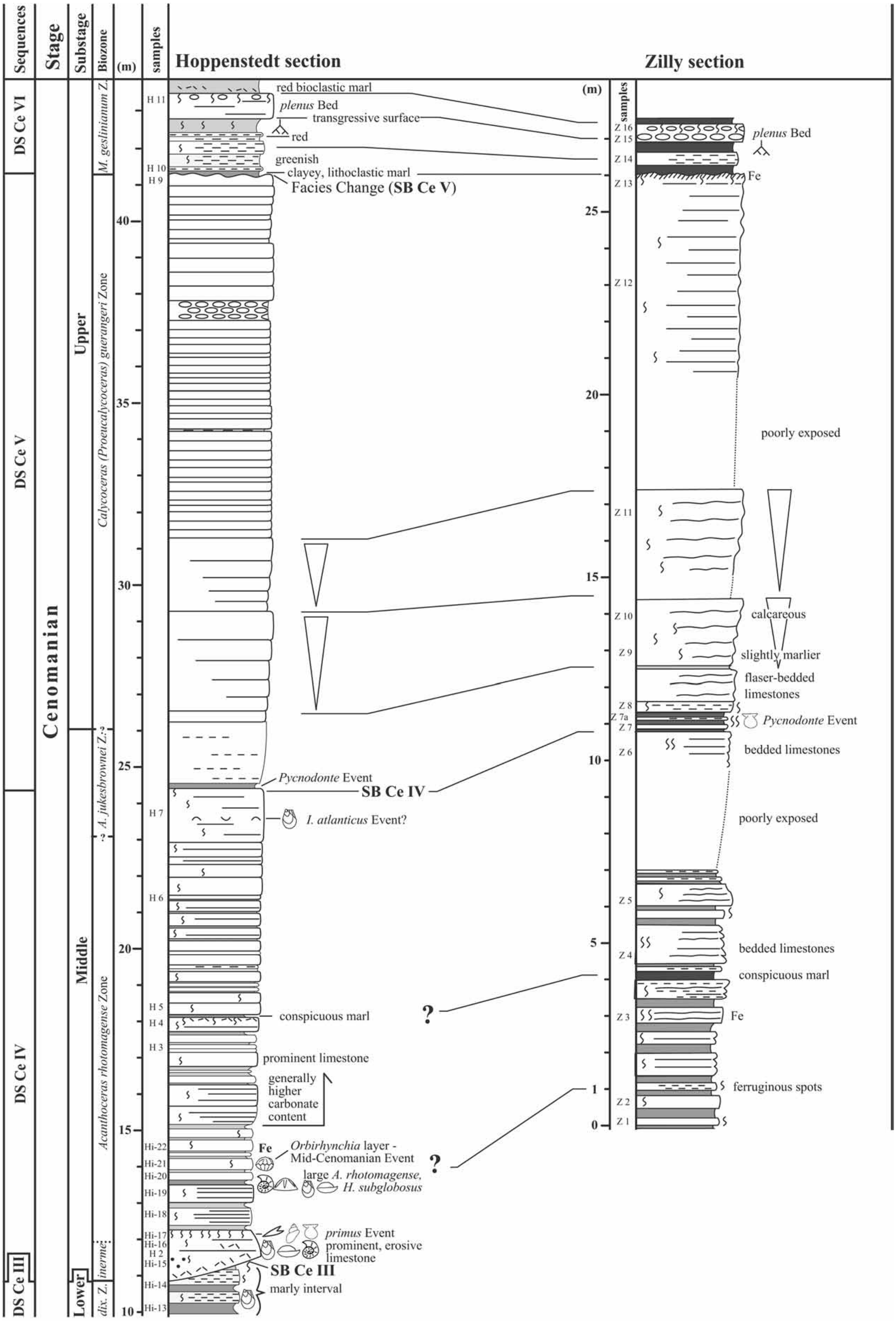

Fig. 6. Correlation of the middle–upper Cenomanian of the Zilly and Hoppenstedt sections (Hoppenstedt section after WILMSEN & WOOD 2004; for location see Text-fig. 1, for key of symbols Text-fig. 3). Abbreviations: *dix*. Z.= *Mantelliceras dixoni* Zone; *A*.= *Acanthoceras*; *M*.= *Metoicoceras*; DS Ce III/IV/V/VI= depositional sequence Cenomanian 3/4/5/6; SB Ce III/IV/V= sequence boundary Cenomanian 3/4/5

THE *PYCNODONTE* EVENT: The *Pycnodonte* Event (ERNST & *al*. 1983) is the lower of two so-called oyster events of the upper middle Cenomanian *A. jukesbrownei* Zone and the lower upper Cenomanian *Calycoceras* (*Proeucalycoceras*) *guerangeri* Zone (*Amphidonte* Event). The *Pycnodonte* concentration was first identified by BOWER & FARMERY (1910) in England (termed '*Gryphaea* Band'). It is characterized by a silty marl layer or a thin marly interval within predominantly calcareous upper middle Cenomanian strata yielding small oysters of the genus *Pycnodonte* FISCHER DE WALDHEIM. Local fossil concentrations and scouring are reported (e.g., LEHMANN 1999), and the base of the event is clearly erosional in the Konrad 101 borehole (NIEBUHR & *al*. 2001; Text-fig. 7). Its base represents a transgressive surface of Cenomanian depositional sequence DS Ce V and often fuses with the underlying sequence boundary SB Ce IV (e.g., OWEN 1996; MITCHELL & *al*. 1996; WILMSEN 2003). The event is an excellent marker bed that can be correlated across northern Germany to southern England and the Cleveland Basin, eastern England (ERNST & *al*. 1983; OWEN 1996; MITCHELL & *al*. 1996; LEHMANN 1999; MORTIMORE & *al*. 2001; WILMSEN 2003). The upper oyster event, i.e., the *Amphidonte* Event (characterized by the small ostreid *Amphidonte*), could not be recognized at Zilly.

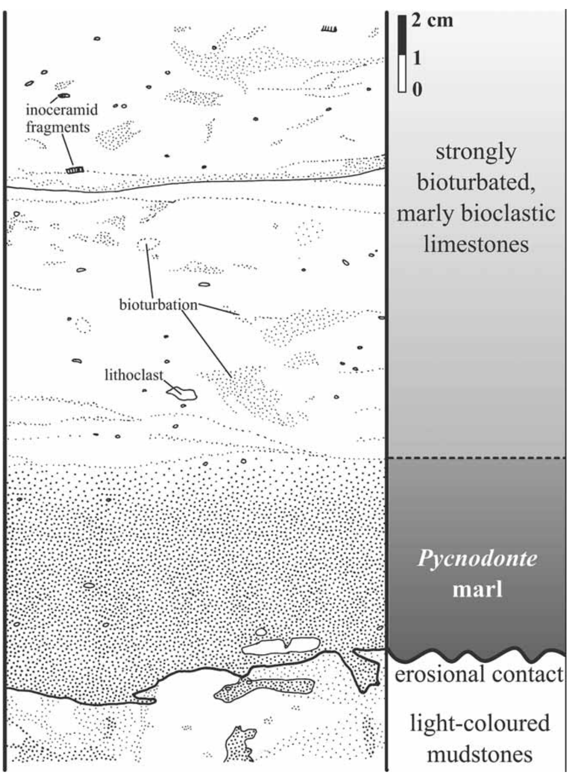

Fig. 7. Detailed graphic representation of the *Pycnodonte* Event in the Konrad 101 cored borehole (see NIEBUHR et al. 2001 for details). Note the erosional base of the *Pycnodonte* Event (drawn after a polished slab)

The sedimentology and genesis of the *Pycnodonte* Event were discussed by MEYER (1990), OWEN (1996), and LEHMANN (1999). Whereas MEYER (1990, pp. 73-74) assumed episodic rapid deposition for the marls of the *Pycnodonte* Event (evidenced by internal bedding features and escape burrows), OWEN (1996, p. 278) explained the fossil concentration by condensation associated with winnowing and scouring. LEHMANN (1999) termed the *Pycnodonte* Event a 'concentration deposit' (using the Fossillagerstätten classification of SEILACHER 1990) and also assumed episodic obrution.

At Zilly, the *Pycnodonte* Event is considerably thicker compared to the approximately 5–10 cm thick occurrences at Hoppenstedt, the Baddeckenstedt quarry, the Konrad 101 cored borehole of the Salzgitter area (Text-fig. 7), and the HPCF II quarry east of Hannover (Text-fig. 8; see also NIEBUHR & *al*. 2001; WILMSEN & NIEBUHR 2002; WILMSEN & WOOD 2004). Furthermore, it yields a relatively large number of oysters in relation to the small outcrop area. The thick, siliciclastic character and the presence of fine plant debris suggests a rather proximal position, close to an emergent source area (which probably was located in the SE; cf. KARPE 1973). Also the microfacies analysis showed rather coarse-grained sedimentary fabrics, indicating elevated water energy during deposition of the event bed, an observation which can also be obtained from the Langenstein section (Text-fig. 8). The interval of the *Pycnodonte* Event at Langenstein (Text-fig. 8) is similar in thickness to Zilly but even more bioclastic and thicker, with considerable terrigenous influence also in the lower part of the Poor *rhotomagense* Limestones. Towards the NW, into the open shelf area of the northern Geman shelf sea, the thickness and terrigenous influence of the *Pycnodonte* Event is gradually reduced. Thus, a clear proximal–distal trend within the *Pycnodonte* Event from SE–NW can be established (Text-fig. 8).

In its mode of life, the small *P.* (*Ph.*) *vesicularis vesiculosa* from the *Pycnodonte* Event most likely was like a variant of *Gryphaea*, the classical secondarily free-lying oyster obtaining stability on a soft substrate with its large, convex and thickened left valve ('cup-shaped recliner'; see HALLAM 1968; SEILACHER 1984; ABDEL-AAL & EL-HEDENY 1998; MACHALSKI 1998; NORI & LATHUILIÈRE 2003). Attachment areas are usually small in pycnodonteine oysters from the *Pycnodonte* Event, indicating a fixosessile mode of life for juveniles only. The patchy occurrence, sorting and enrichment of the (heavier and thicker) left valves, and the partial damaged prior to final deposition suggest some transport and episodically elevated water energy during the deposition of the *Pycnodonte* Event, in accordance with its interpretation

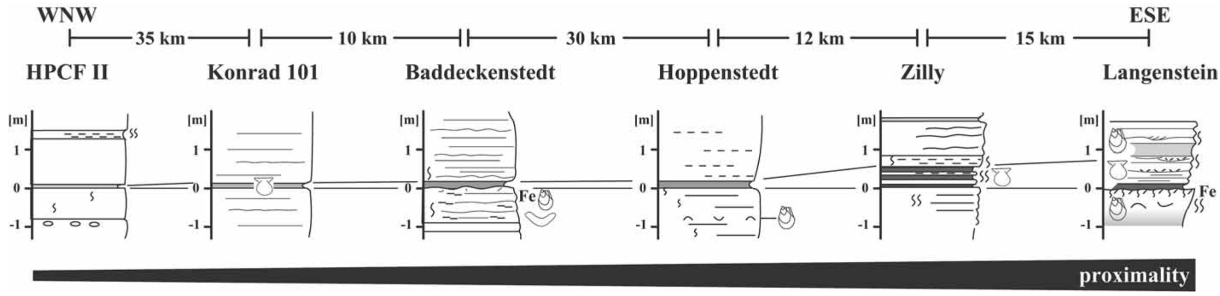

Fig. 8. Proximal–distal correlation of the *Pycnodonte* Event from Langenstein via Zilly, Hoppenstedt (see Text-fig. 1), Baddeckenstedt and the Konrad 101 cored borehole (Salzgitter area) to the HPCF II quarry near Hannover

as an early transgressive deposit. This situation was accompanied by significant supply of terrigenous materials (silt, clay, plant debris), suggesting strongly fluctuating environmental conditions (including possible short-term salinity changes), also indicated by the monospecific character of the fauna of the event bed and the small size of the oysters. This situation promoted colonization by eurytopic oysters, well adapted to withstand prolonged environmental stress (e.g., YONGE 1966; STENZEL 1971). The genesis of the *Pycnodonte* Event can, thus, be related to a combination of different geodynamic (sea-level rise), ecologic (environmental stress) and taphonomic factors (winnowing, condensation, preferential preservation of durable shells). It is an example of an 'onlapping bioevent' *sensu* WILMSEN (2003), related to early transgressive conditions. This bioevent type, however, bears the potential danger of diachronism due to its time-transgressive (onlapping) nature, and a slight diachronism for the *Pycnodonte* Event was discussed by MITCHELL & *al*. (1996) based on a carbon stable isotope correlation of the stratigraphic interval between England and northern Germany. Nevertheless, it is an excellent and easily recognizable stratigraphic marker.

CONCLUSIONS

A detailed stratigraphic log of the Cenomanian succession at Zilly is presented. The succession is nearly 28 m thick and starts with 11 m of middle Cenomanian hemi-pelagic marl–limestone alternations (so-called 'Pläner Limestones') grading into 15 m of upper Cenomanian pelagic fine-grained limestones ('Poor *rhotomagense* Limestones'), unconformably overlain by 1.5 m of red-coloured marly clays and limestones (so-called 'Rotpläner'). The key for the bio-/chronostratigraphic interpretation of the section comes from event stratigraphy: the proof of the interregional marker beds of the *Pycnodonte* Event at the 11 m level, the Facies Change at 26 m, and the base of the *plenus* Bed at 26.9 m assign these levels to the middle/upper *Acanthoceras jukesbrownei* Zone, the *Calycoceras* (*Proeucalycoceras*) *guerangeri*/*Metoicoceras geslinianum* Zone transition, and the lower *Metoicoceras geslinianum* Zone, respectively. This also allows a detailed correlation to the Hoppenstedt section, the lower Upper Cretaceous standard section of the Subhercynian area, ca. 12 km to the WNW.

Litho- and microfacies as well as sequence stratigraphic analyses indicate an overall decrease of terrigenous and an increase of pelagic influence up to the Facies Change at Zilly, a development well known from many (middle–upper) Cenomanian sections across northern Germany. This general retrogradational (transgressive) trend was shortly interrupted by the *Pycnodonte* Event, its base correlating with late middle Cenomanian sequence boundary SB Ce IV (capping Cenomanian depositional sequence DS Ce IV) and the succeeding transgressive surface of DS Ce V. The Facies Change, however, indicates a significant middle late Cenomanian sea-level fall (sequence boundary SB Ce V) followed by more shallow water Rotpläner deposition.

The late middle Cenomanian *Pycnodonte* Event is very thick, strongly siliciclastic and contains fine plant debris at Zilly, suggesting a rather proximal character. It yielded several small oysters assigned to *Pycnodonte* (*Phygraea*) *vesicularis* (LAMARCK) *vesiculosa* (J. SOWERBY). This secondarily free-lying oyster lived as a 'cup-shaped recliner' on soft substrates. The patchy occurrence of the oyster shells, their sorting (only left valves were collected) and partial damage prior to final burial suggest episodic elevated water energy during the deposition of the *Pycnodonte* Event. Combined with significant supply of terrigenous materials (silt, clay, plant debris) and the nearly monospecific character of the fauna, strong environmental stress is suggested. This situation promoted colonization of the sea-floor by, and reproductive success of the inferred eurytopic oysters during the deposition of the *Pycnodonte* Event. The *Pycnodonte*

Event is an example of an 'onlapping bioevent', the formation of which was controlled by different factors such as sea-level rise, terrigenous influx, environmental stress, and preferential preservation of durable shells.

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