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20 years of event stratigraphy in NW Germany; advances and open questions

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"*The being determines consciousness*" *(Karl Marx)*
For Gundolf

ABSTRACT:

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The application of event stratigraphy in the Cenomanian to Lower Coniacian (Upper Cretaceous) Plänerkalk Gruppe of northwestern Germany has advanced stratigraphic resolution considerably. For a short interval in the Upper Turonian, various genetically variable events (bioevents, tephroevents, stable isotope marker, eustatoevents) are reviewed and new data are partly added. In addition, the lateral litho and biofacies changes within individual events are discussed and provide a basis for a tentative high-resolution correlation between distal and proximal settings. The dense sequence of events permits a stratigraphic resolution of 50 – 100ky for some intervals. Beyond stratigraphic purposes, the alternation of fossil barren intervals with thin fossil beds still demands explanations. As taphonomic processes are considered to be play only a minor role, other explanations are required. It appears that trophic aspects and a calibration of planktic and benthic faunal assemblages may result in a better understanding of this biosedimentary system and its faunal characteristics.

Key words: Events, Event stratigraphy, Upper Cretaceous, Upper Turonian, Germany, Correlation.

INTRODUCTION

In 2003, the classic work of Gundolf ERNST and his co-authors on the event stratigraphy of the Cenomanian and Turonian in the Lower Saxony Basin of NW Germany ("Event-Stratigraphie im Cenoman und Turon von NW-Deutschland") had its 20th anniversary. Since then, this stratigraphic framework has been continually added to and refined. In the course of these later studies additional correlations of individual events outside the Lower Saxony Basin (LSB) into the Subhercynian Cretaceous Basin (SCB) and the Münsterland Cretaceous Basin (MCB), the Anglo-Paris Basin (APB) of England/France, to northern Spain and to Poland have successfully been attempted. The event stratigraphic concept has been a large advance in subdividing the apparently monotonous grey to white limestone of the "Plänerkalk Gruppe" (Pläner Limestone Group). In the 1990s, event stratigraphy was progressively combined with sequence stratigraphy, leading to a more dynamic understanding of sedimentation processes in the

Pläner Limestones and a better understanding of lateral facies changes, including biofacies changes within event beds (ERNST & *al*. 1996). The same authors presented a catalogue of criteria for sequence and event stratigraphy in Boreal pelagic systems, giving an overview of work in progress. More recently – as the stratigraphic framework had already been established – event stratigraphic investigations began to concentrate on the refinement of sequence stratigraphic subdivisions in the Plänerkalk Group and the reasons for the occurrence of distinct fossil beds. In this contribution, we want to review the current event stratigraphic subdivision within a sequence stratigraphic context, exemplified by a case study (lower Upper Turonian). As working progress is best in Lower Saxony and Saxony-Anhalt, we specifically refer to these areas (Text-fig. 1). Where possible, we also consider localities from the Münsterland Cretaceous Basin. It must be emphasised that the sequence stratigraphic framework and genetic event interpretations presented in this paper is not to be taken as a definitive statement. We explicitly want to make clear that this is to be regarded rather as a topic for discussion by the Cretaceous community in the spirit of Gundolf ERNST's own work.

GEOLOGICAL FRAMEWORK AND HISTORICAL ACCOUNT

The so-called Pläner (Unterer Pläner, Obere Pläner; VON STROMBECK 1857) of northern Germany (Lower Cenomanian to Lower Coniacian) forms a well mappable lithounit in Westphalia, Lower Saxony and Saxony-Anhalt,

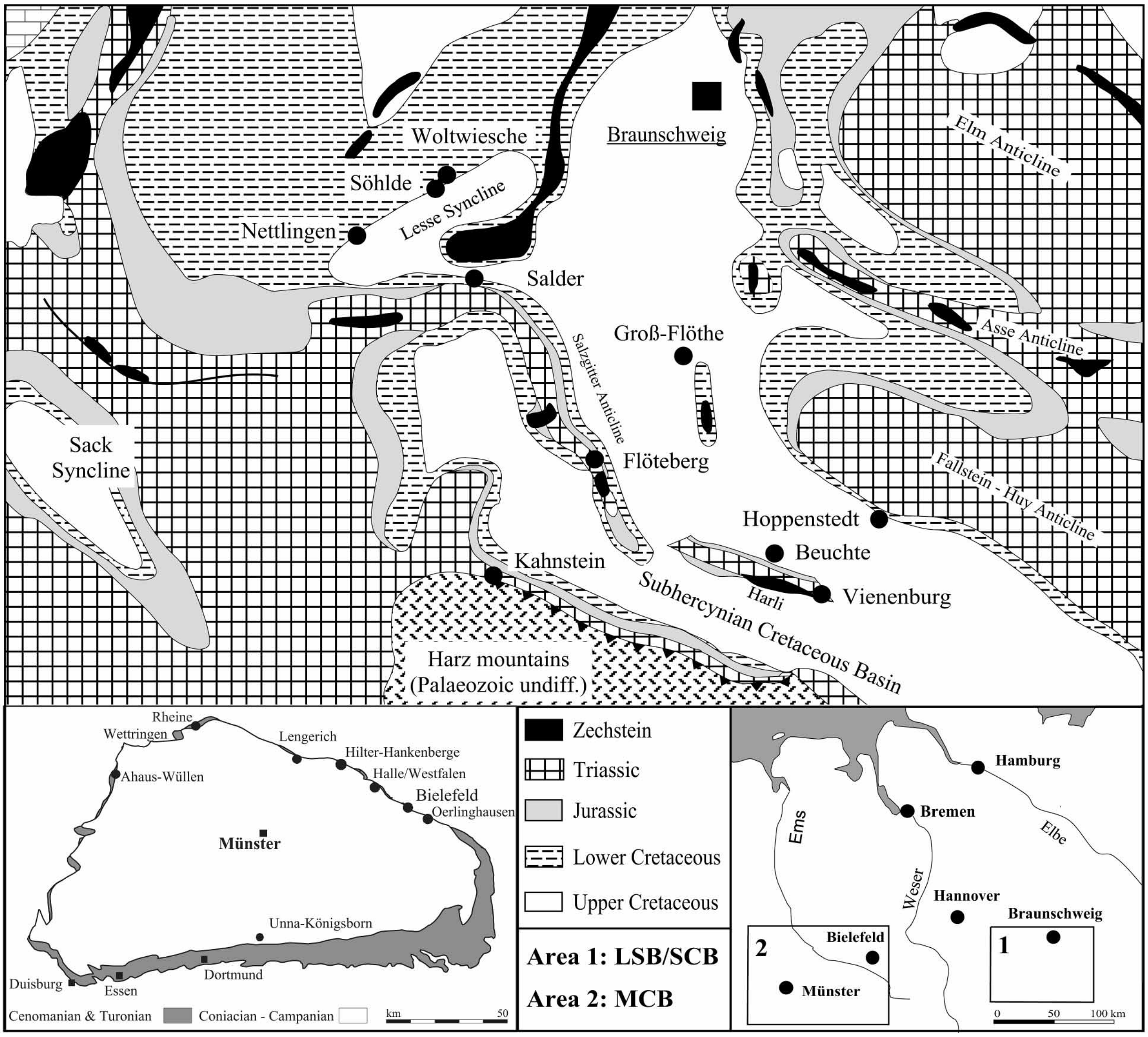

Fig. 1. Working area of the former Ernst Working Group. Area 1: Lower Saxony Cretaceous Basin (LSB) and Subhercynian Cretaceous Basin (SCB), Area 2: Münsterland Cretaceous Basin (MCB)

with an extent of several 100 km^2. In the text, we will refer to it informally as “Pläner Gruppe” (Pläner Group). It ranges in thickness from tens metres to a maximum thickness of at least 500 m (Lengerich area, Westphalia). Lithologically, the succession of marl/limestone alternations and white and red bedded to nodular limestones represents Boreal pelagic limestones [mainly composed of coccolithophorids (matrix); calcareous dinoflagellate cysts (here referred to as calcispheres), planktonic foraminifera and bioclasts (mainly inoceramid bivalves, echinoderms)]. The base of the Pläner Gruppe is taken at a facies change in the context of the global Cenomanian transgression, accompanied by a change from (glauconitic) siliciclastic-dominated sedimentation to progressively distal, pelagic marl/limestone alternations, monotonous, massively bedded, white and red limestone bodies and red marls. The uniform Cenomanian sedimentation occurred on a tectonically poorly structured shelf (WILMSEN 2003). From the terminal Cenomanian to the earliest Turonian on, local movements of salt pillows occurred in Lower Saxony and Saxony-Anhalt. This resulted in a narrowly differentiated shelf into more subsiding areas (here referred to as “basinal”) and off-shore, pelagic swells with water depth periodically above storm wave base (tempestites with hummocky cross stratification). The top of the Pläner Group is marked by a fundamental turnover from pelagic limestones towards dark marls (Emscherian Marls), the base of which can be characterized by sand layers, glauconite and phosphatic nodules. A particularly characteristic feature of the Turonian part of the Pläner Group is the occurrence of (typically relatively thin) fossiliferous strata separated by thick intervals with very scarce fossil records. The fine-grained white splintery limestones mostly provide no macroscopic information regarding grain-size and sedimentary structure/texture and are, therefore, difficult to interpret by means of conventional sequence stratigraphic analysis. Formerly, only lateral faunal changes were considered to distinguish between near-swell and more basinal settings. Therefore, early stratigraphic subdivision of the Plänerkalk Group was based mainly on fossil contents (where present) and then on lithological characteristics (where visible) (ROEMER 1850; STROMBECK 1857, 1859). This resulted in an incoherent mixture of lithostratigraphic and biostratigraphic terminology, and fossil names have been used (incorrectly) to designate mapped lithostratigraphic units. However, many of these units have never been properly defined (notably the Lamarcki-Schichten, Scaphiten-Schichten, Schloenbachi-Schichten), and their supposed limits do not in any meaningful way correspond to the ranges of the eponymous taxa. This framework has repeatedly been emended (e.g. STILLE 1904, SCHULTE 1937, SEIBERTZ 1979, CLAUSEN 1984, SKUPIN 1985, FRIEG & *al.* 1989). In addition, there has been a continual mixing of different lithostratigraphic terms established for the same lithounits. There is clearly an urgent need for the lithostratigraphic nomenclature of the Plänerkalk Group to be rationalised in the sense of the International Stratigraphic Guide (SALVADOR 1994) (a definition and formalization process is currently undertaken by the German Subcommission on Cretaceous Stratigraphy). The first purely biostratigraphic zonal schemes, based on inoceramid bivalves and ammonites, were developed in the second part of the last century (e.g. BRÄUTIGAM 1962, TRÖGER 1967, KELLER 1982, KAPLAN & *al.* 1985, KAPLAN 1986). The first event stratigraphic approaches were presented by ERNST & *al.* (1979) and the key paper was done by ERNST & *al.* (1983) followed by a large number of studies progressively elaborating and updating the event framework in north Germany (WOOD & *al.* 1984, ERNST & WOOD 1995, ERNST & WOOD 1997, WRAY & *al.* 1995, WRAY 1999)

A CASE STUDY: THE LOWER UPPER TURONIAN

In the lower Upper Turonian of north Germany, numerous events of different origins provide a comparatively high frequency of stratigraphic markers (see also Text-fig. 2a). A possible relation between events and sequences has already been proposed (ERNST & *al.* 1996, WILMSEN 2003). Within the biostratigraphic and lithostratigraphic framework (Text-figs 2-3), we present first a sequential subdivision, in part with new data. Events will be described and discussed with reference to depositional sequences.

Biostratigraphic framework

Biostratigraphic subdivision of the north German Turonian is based on ammonite and inoceramid bivalve (assemblage/concurrent range) zones. The various zonal schemes and their progressive elaboration are discussed in the literature at length (e.g. KELLER 1982, WOOD & *al.* 1984, ERNST & WOOD 1995, KAPLAN & KENNEDY 1996, WALASZCZYK & WOOD 1999, WIESE & *al.* 2000). The reader is referred to Text-fig. 2a, which provides an overview of the currently accepted zonal framework for the interval considered.

Sequential framework: Eustatoevents *sensu* ERNST & *al.* 1983

ERNST & *al.* (1983) applied the term eustatoevent to define a relative sea level fall and the succeeding transgression. As they pointed out, a clear distinction between rocks representing regression and rocks representing transgression was not always possible due to the often monotonous lithology of the Pläner Limestones. In addition to some lithological features (erosional surfaces,

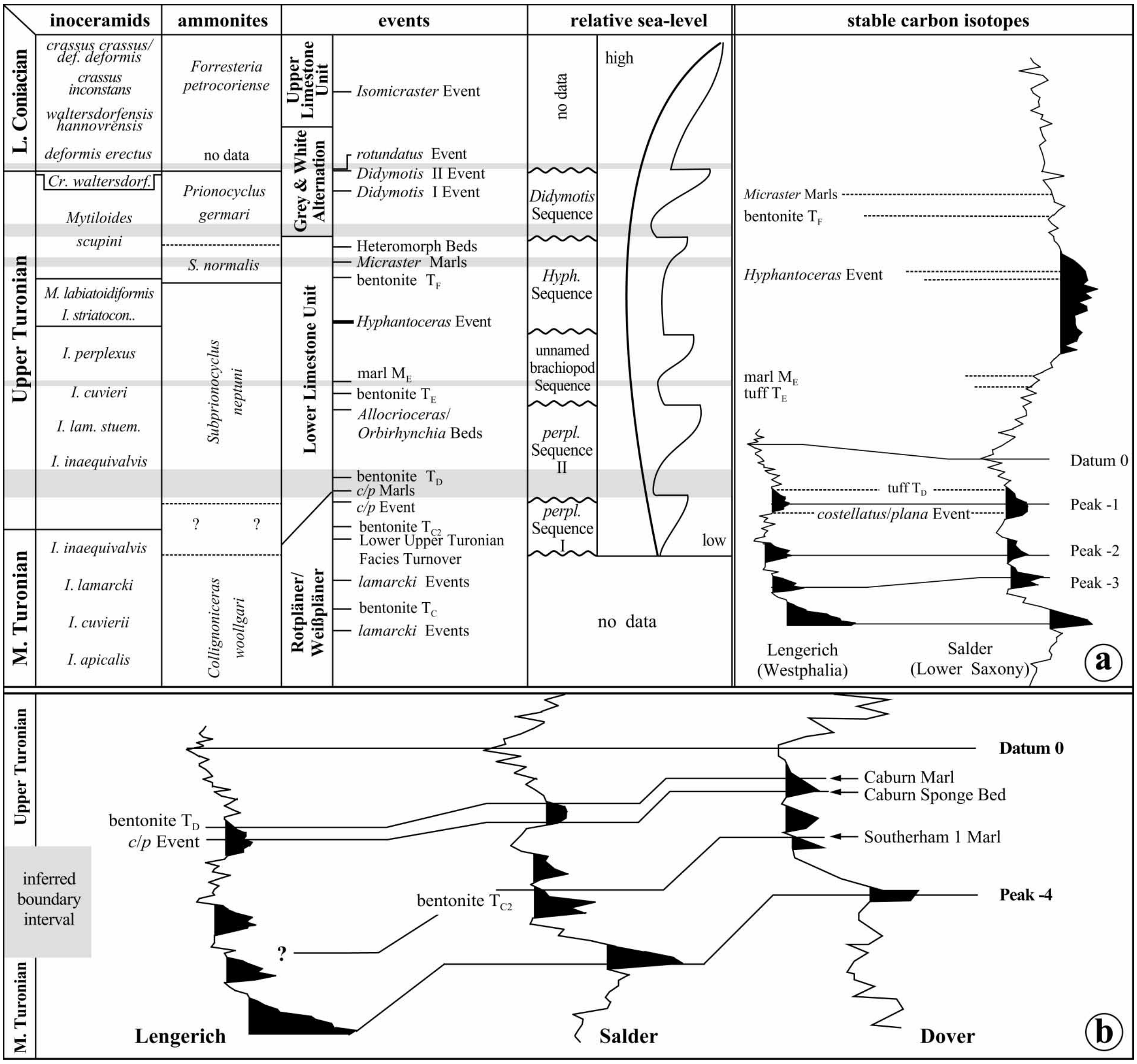

Fig. 2. **A**. Integrated stratigraphic framework for the Middle Turonian to Lower Coniacian of northwest Germany. Biostratigraphy compiled from the literature (see text). Stable carbon isotopes after VOIGT & HILBRECHT (1997) and WIESE & KAPLAN (2001). Sequence stratigraphy: own field data. **B.** Interbasinal $\delta^{13}C$ correlation of the potential Middle/Upper Turonian boundary interval between the Salder (LSB, data after VOIGT & HILBRECHT 1997), Lengerich (MCB, data after WIESE & KAPLAN 2001) and Dover (Anglo-Paris Basin, data after GALE 1996). Bentonites and the *costellatus/plana* Event/Caburn Sponge Bed aid interbasinal calibration of the boundary interval

hardgrounds and hiatuses, glauconite occurrences, nodular limestone, abrupt facies changes and fossil accumulations), fossils/fossil assemblages of mainly of oysters and echinoids were used to indicate a regressive-transgressive event. They also made the important observation that fossil accumulations associated with sea level events have potentially a diachronous character (see below).

Owing to its often monotonous lithology, shallowing/sequence boundaries in the Pläner limestones must also be inferred from faunal development (e.g. *Conulus* Facies: LÖSCHER 1912, ERNST & *al*. 1979, WIESE & KRÖGER 1998) and stratigraphic gaps ("Lückenstratigraphie" – gap stratigraphy of ERNST & *al*. 1996). While the lateral relations of litho- and biofacies in the Turonian of Lower Saxony have been elaborated in detail in the past (ERNST & WOOD 1995, see also NIEBUHR & *al*. 2001), it has always been problematic to evaluate the exact timing and duration of hiatuses and thus the stratigraphic completeness in on-swell settings. The classic bioevents of the basinal areas (where ERNST & *al*. 1983 recognized most of their bioevents) change both lithologically and faunistically (disappearance of biostratigraphically significant taxa, occurrence of biostratigraphically insignificant shallow water assemblages) towards swells (Text-fig. 3).

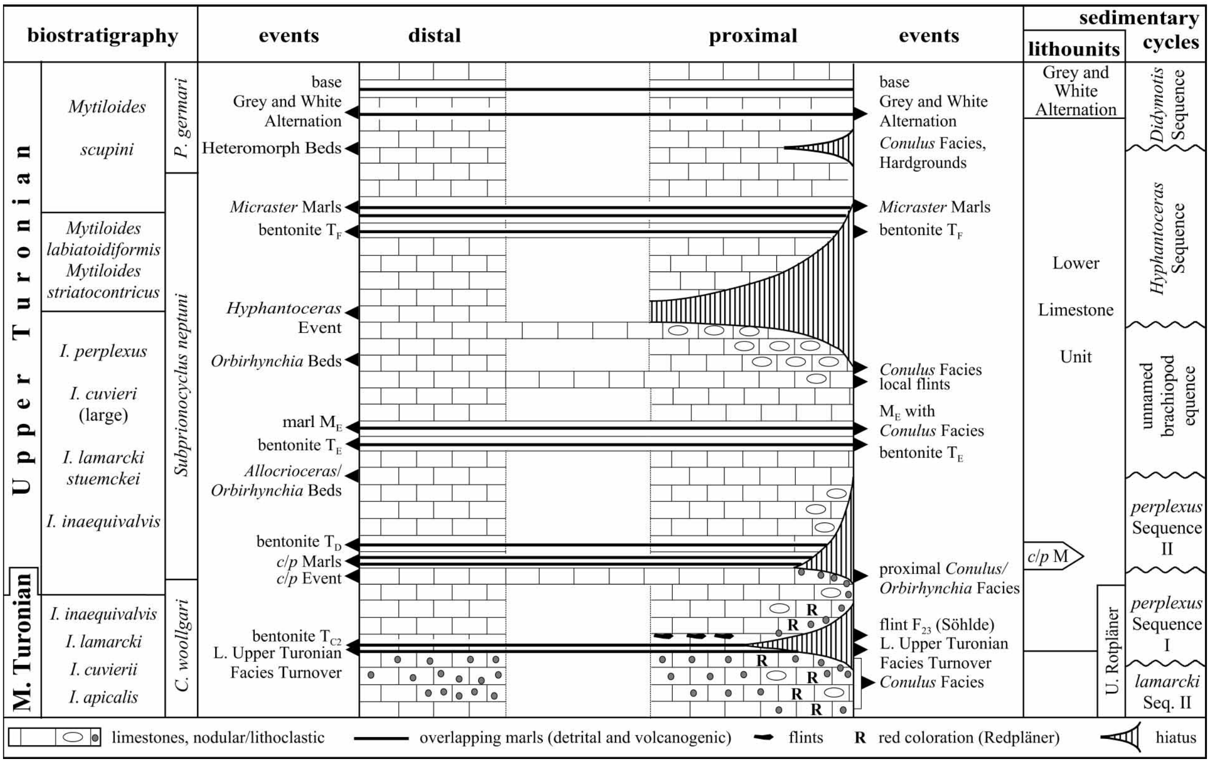

Fig. 3. Revised Middle to Upper Turonian facies framework in a swell-basin transect with event stratigraphic marker. Compiled after Ernst & Wood (1995) and Niebuhr & *al.* (2000)

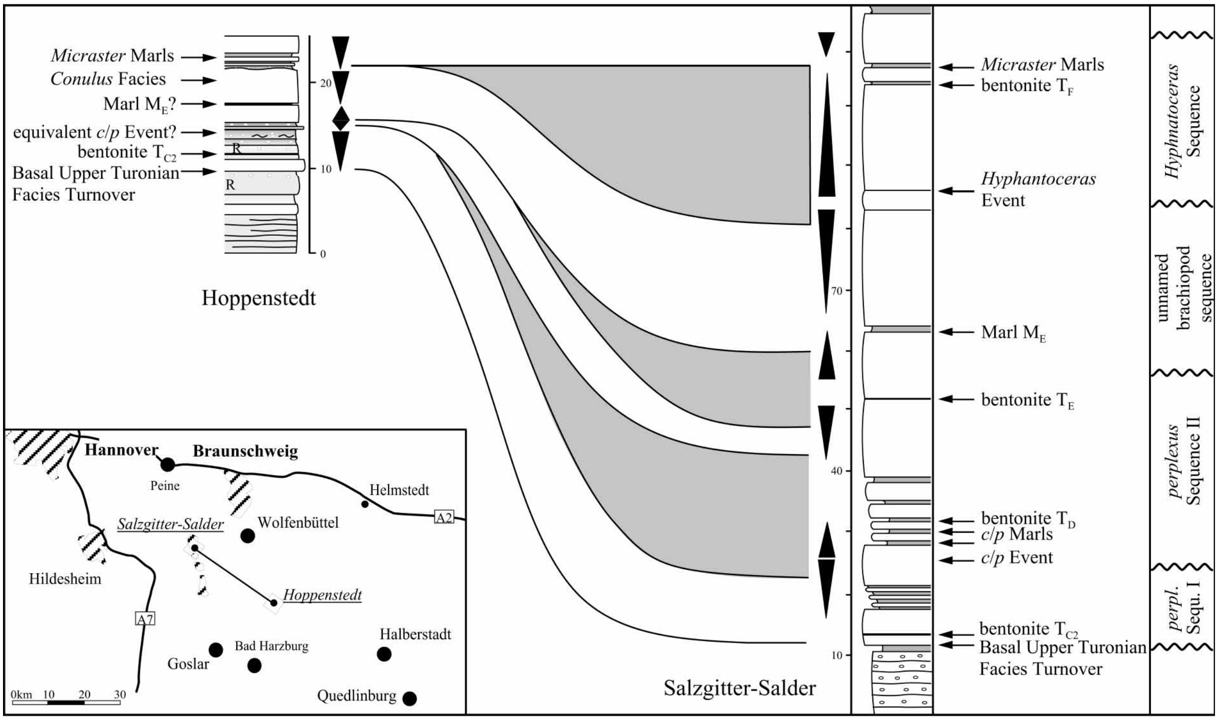

Fig. 4. Putative lithostratigraphic/sequence stratigraphic correlation from a basinal (Salzgitter-Salder) onto a pelagic swell (Hoppenstedt). Shaded correlation intervals: potentially not preserved; white correlation intervals: Potentially preserved. R: Rotpläner (Red coloured limestones). Black triangles: deepening and shallowing, respectively

The resulting lack of stratigraphic control prevented, on the one hand, a precise correlation with basinal sections and an understanding of the sedimentary dynamics and, on the other hand, a prediction as to which parts of the sea level cycle were potentially preserved on swells.

The occurrence of bentonites within the Pläner Limestones succession enable the establishment of isochronous time lines, thereby permitting the understanding of lateral lithofacies relationships within small-scale lithofacies units. This then aids a tentative calibration of the stacking patterns in basinal and swell areas, resulting in a conceptually dynamic interpretation of potentially preserved – not preserved/not deposited parts of sedimentary sequences (Text-fig. 4) see also WIESE & *al*., this volume). A tentative correlation diagram between the Upper Turonian of the Hoppenstedt section (HORNA 1996) and Salzgitter-Salder (HORNA & WIESE 1997) shows how individual sequences can either pinch out completely or be reduced to only tens of centimetres. Assuming the sequential interpretations presented here to be correct, the lateral litho/biofacies diagram of ERNST & WOOD (1995) needs some minor revision, since red and pink coloured limestones (Rotpläner) range stratigraphically well above the so-called Basal Upper Turonian Facies Turnover (see Text-figs 3, 4), a sudden development of a unit of white massive limestones, which has an excellent lithostratigraphic correlation potential within Lower Saxony and Saxony-Anhalt.

Owing – to some extent – the monotony of the lithology, the precise stratigraphic/lithostratigraphic positioning of sequence boundaries is sometimes difficult to recognize, and our tentative interpretations given in Text-figs 3-4 are therefore open to discussion. Easier to recognize than the sequence boundaries, and less open to question, are the maximum flooding intervals, which are mostly well developed and aid interbasinal correlation within north Germany (for more details see ERNST & *al*. 1996, WILMSEN 2003).

The lateral position of the Pläner Limestones within a proximal/distal transect is located between the siliciclastic and/or glauconitic near-shore successions in the vicinity of ancient massifs (Sudetic Islands, Bohemian Massif, Rhenish Massif; see ZIEGLER 1988) and the coccolithic white chalk sediments (Schreibkreide) of the fully pelagic settings (TRÖGER 2000). The Pläner limestones form a highly productive carbonate belt, where calcispheres in particular can occur in abundance (NEUWEILER & BOLLMANN 1991, NEUMANN 1999, WILMSEN 2003). In the context of relative sea level changes two main features can be observed: slight lateral facies migration and an abrupt breakdown in calcareous bioproductivity in association with transgressions. Thus, the carbonate belt is most strongly developed (thickly bedded limestones, no marl seams) – in association with peak occurrences of invertebrate faunas – during shallowing phases or in near-swell settings (NEUWEILER & BOLLMANN 1991; ERNST & *al*. 1998, NEUMANN 1999). In the depositional system considered here, we observe a decrease in planktonic calcareous bioproductivity (calcispheres) during transgression in context with marl-dominated intervals intercalated with foraminiferal wackestone/mudstones. Relative sea level trends can, consequently, be recognized (similar to the case of siliciclastic systems) by coarsening-up and – if sufficient accommodation space is available – thickening-up developments. Such depositional features are found during regression. In contrast, thinning-up sequences can occur both during transgression or, if accommodation space progressively decreases, during regression. The latter trend however, is always associated with the development of griotte-like sediments (flasery undulating limestones, marls with abundant lithoclasts) and is easily distinguishable from the first.

The lateral facies relations and the facies successions within the lithologic column and relations of litho- and biofacies were summarized and figured by ERNST & WOOD (1995, p. 47, text-fig. 1.4), revised by NIEBUHR & *al*. (2000, p. 104, text-fig. 36; here in part reproduced and emended in Text-fig. 3). In addition, biostratigraphic gaps were used to detect and correlate intervals of non-deposition/erosion. However, sequence boundaries in the Pläner Limestones are often impossible to detect as a definite surface. On the other hand, the maximum flooding intervals are not only well developed and readily identifiable, but they can be used for can be used for intrabasinal correlation within north Germany and for the recognition of sequence numbers (genetic sequence model: GALLOWAY 1989; see also ERNST & *al*. 1996, WILMSEN 2003).

In this paper, a transgression is expressed by the classic Transgressive Systems Tract (TST); for maximum flooding, the term "maximum flooding zone" (mfz) is used; and progradational/shallowing sediments are termed regressive systems tracts (RST). Following the recommendation by HANCOCK (2000), we favor the designation of sequences by names rather than by numbers. In total, four Upper Turonian sedimentary sequences can be recognized, in ascending order *Inoceramus perplexus* Sequence I, *Inoceramus perplexus* Sequence II, un-named small brachiopod Sequence; *Hyphantoceras* Sequence. These sequences reflect fluctuating but comparatively constant water depths, with the lowest sea level (estimated ca. 50 m to slightly above storm wave base) at the base of the *Hyphantoceras* Sequence (see explanations below, Text-figs 2a, 3). The succeeding *Didymotis* Sequence (not considered here; Text-figs 2a, 3) marks the turnover towards a major late Late Turonian transgressive pulse. Judging from absolute time plotted against biostratigraphy, the investigated interval represents an approximate time of ca. 800 ky to 1 my (VOIGT 2000), resulting in sequences between of a duration of ca. 250 ky. In this context, the sequences observed here reflect high-frequency sequences, which will, in the following parts, be briefly described.

***Inoceramus perplexus* Sequence I.** This sequence, named after the inoceramid bivalve *Inoceramus perplexus* WHITFIELD, can best be demonstrated in the basinal setting of the Lengerich area of Westphalia (Hohne working quarry of Dyckerhoff cement work, see Text-fig. 5). Its mfz is characterized here by thinly laminated and black marls, whereas in the LSB a marl/limestone sequence occurs in basinal sections (Salzgitter-Salder, Flöteberg). The RST is associated with the main part of the *costellatus*/*plana* Event, an abundance peak of a rich invertebrate assemblage in an otherwise poorly fossiliferous interval (see below). In Westphalia, it is developed as the top of a well developed progradationally stacked marl/limestone alternation, representing the RST. The uppermost part of the event reflects renewed deepening (Text-fig. 5). In the LSB (e.g. Salzgitter-Salder, Flöteberg, Söhlde), the event is less distinctively developed as a thin fossil bed and is difficult to discern within a thick limestone package. As a consequence, the inflection point towards a renewed transgression (*perplexus* II Sequence) falls into the *c*/*p* Event. In Lower Saxony, a clearly-defined sequence boundary (erosional unconformity) cannot be recognized. The cryptic sequence boundary is tentatively taken with the thin *c*/*p* Event. Rare occurrences of tempestites at Lengerich and Hilter-Hankenberge (Westphalia) below the event (*costellatus*/*plana* calcarenite; NEUWEILER 1989, WIESE & KAPLAN 2001) suggest water depths at least temporarily above storm wave base.

***Inoceramus perplexus* Sequence II.** In Westphalia, excellent exposures in this sequence exist at Lengerich. In Lower Saxony, the *perplexus* Sequence II is ideally exposed

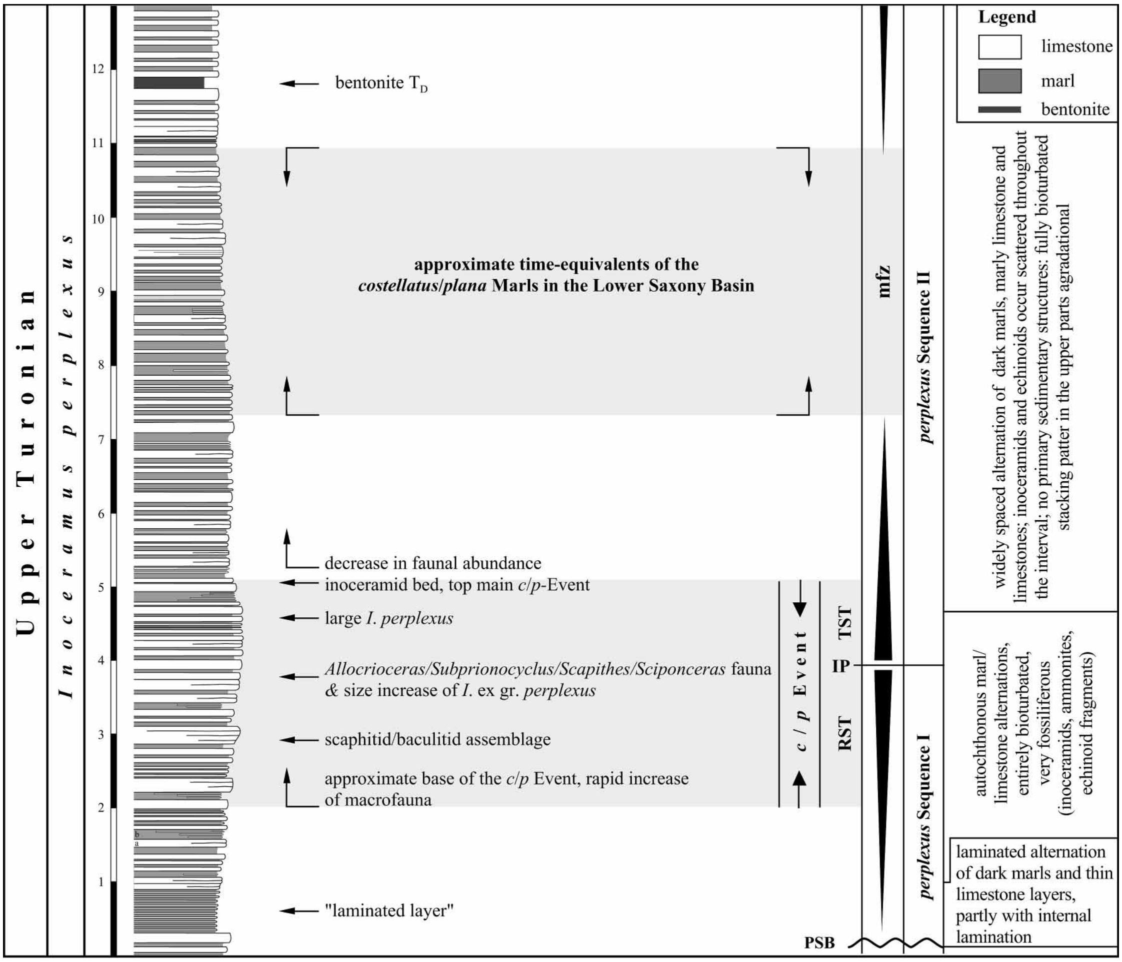

Fig. 5. Detailed litho-log of the lower Upper Turonian of the Lengerich area (MCB), combined section abandoned Wicking II and Hohne working quarries. The *costellatus*/*plana* Event is well developed and shows clear lithologic and faunal changes during the regressive-transgressive inflection point (IP). RST: Regressive Systems Tract, HST: Highstand Systems Tract, mfz: maximum flooding zone, PSB: Parasequence Boundary. Black triangles indicate shallowing and deepening, respectively

in the Salgitter-Salder, Flöteberg and Söhlde sections; for localities see Text-fig. 1). As at Lengerich, the *c/p* Event incorporates an inflection point towards progressive deepening, indicated by retrogradational stacking patterns. The mfz is represented by a well developed marl/limestone alternation which includes the *costellatus/plana* Marls and marl/limestone alternations some tens of cm above (ERNST & WOOD 1995; Text-fig. 2a). Within the mfz, the bentonite T_D (Text-fig. 3) is located. After some meters of aggradationally stacked marl/limestone alternations, the RST (massively bedded limestone) shows a progressive but weak increase in macrofauna (brachiopods, sponges) in basinal settings, while shallower water and thus thinner, more condensed sections are characterized by the so-called *Conulus* Facies (see discussion in ERNST & WOOD 1995, p. 47, Text-fig. 1.4; WIESE & WOOD 2001). A clear sequence boundary in the form of an erosional surface is not visible, and a possible boundary interval can only be estimated from faunal criteria (increase of macrofauna) ca. 10 m below T_E, where a fossil bed (*Allocrioceras/Orbirhynchia* Event) occurs both in Westphalia and Lower Saxony. Time-equivalent sections in condensed swell settings are characterized by very nodular limestones with abundant lithoclasts and partly red coloration. In relation to the basin position, the interval from the *c/p* Event to the inferred level of the succeeding sequence boundary is highly variable. In basinal areas, it reaches ca. 18 m (Halle, Westphalia) to 20 m (Salzgitter-Salder, Lower Saxony) and only a maximum of 0.5 on swells (Hoppenstedt) (compare Text-fig. 4).

unnamed brachiopod Sequence. The sequence starts some distance below T_E presumably around the level of the *Allocrioceras/Orbirhynchia* Event (see above). The mfz incorporates marl M_E and M_{Echen} and is specifically characterized by an abundance peak of two irregular echinoids, *Infulaster excentricus* (WOODWARD) and *Plesiocorys* [formerly *Sternotaxis*] *plana* (MANTELL). Small rhynchonellid and terebratulid brachiopods of uncertain systematic status are very common particularly above M_E in all localities exposing this interval irrespective of their position within the basin (e.g. Salzgitter-Salder, Flöteberg: basinal settings; Beuchte, Hoppenstedt: swell settings) and have been used to name this sequence. The RST is indicated by a progressive increase in macrofauna, especially sponges and brachiopods. The terminating sequence boundary cannot be recognized in subsiding areas such as Salzgitter-Salder, although VOIGT & HILBRECHT (1997) have suggested a sequence boundary based on microfacies changes. In accordance with the latter authors it is suggested that the sequence boundary is located well below the succeeding *Hyphantoceras* Event (see discussion below). In more condensed/incomplete sections (Hoppenstedt section; HORNA & WIESE 1997), shallowing is indicated by a *Conulus* Facies with *Micraster* ex gr. *leskei* DESMOULINS, large brachiopods [*Cretirhynchia cuneiformis* (PETTITT)] and a low diverse hexactinellid sponge assemblage, including *Cystispongia bursa* (QUENSTEDT) indicative of comparatively shallow settings (WIESE & WOOD 2001). At Hoppenstedt, the terminating sequence boundary is expressed by an erosion surface, overlain with major hiatus by the mfz of the succeeding *Hyphantoceras* Sequence (*Micraster* Marls; see Text-fig. 3). This is likewise the case at Söhlde (WOOD & ERNST 1997), where shallowing in the calcisphere chalk facies is indicated by the progressive establishment of a weakly developed sponge/brachiopod fauna. Stable isotope curves show that this cryptic sequence boundary is associated with a massive hiatus, comprising an interval from well below the *Hyphantoceras* Event to correlatives of the *Micraster* Marls, i.e. the mfz of the succeeding *Hyphantoceras* Sequence (VOIGT & HILBRECHT 1997) As in the LSB, shallowing is indicated by an increase in faunal abundance and diversity, an increase in the development of limestones and by renewed occurrences of tempestites in the MCB.

***Hyphantoceras* Sequence**. Originally introduced as the *Hyphantoceras flexuosum* Sequence by WIESE & KRÖGER (1998), we now refer to this sequence as the *Hyphantoceras* Sequence, as it comprises the main occurrence of the nostoceratid ammonite genus *Hyphantoceras* in NW Germany. In basinal areas, the *Hyphantoceras* Event, a peak occurrence of a diverse invertebrate fauna, shows a transgressive character, lithologically indicated by an overall fining-up trend. Progressive deepening is also shown by the succession of ammonite morphotypes (KAPLAN 1991). In more positive areas of the LSB and the SCB, the *Hyphantoceras* Event is not developed (e. g. Söhlde, Hoppenstedt), and the mfz (*Micraster* Marls) onlaps regional erosional unconformities, sealing an existing relief (see above). In proximal settings of the southwestern MCB, the upper sequence boundary of the *Hyphantoceras* Sequence is associated with a large hiatus, overlain with a sharp boundary by a greensand tongue (lowstand/regressive sediments of the succeeding *Didymotis* Sequence) prograding from near-shore settings close the Rhenish Massif into the MCB ("Untere Werksteinbänke" of the Soest Greensand; see sections in WRAY & al. 1995). In the Teutoburger Wald, in the northeastern margin of the MCB, the Rothenfelde Greensand (debris flows, turbidites) was shed contemporaneously from the NE into the basin (ELBERT 1901, KAPLAN & BEST 1984, KAPLAN 1994) representing distal tongues, analogous to a Lowstand Fan in sequence stratigraphic terminology, but here shed from a swell (nordwestfälische -Lippische Schwelle; HAACK 1925) into an intra-shelf depression. In Lower Saxony, the terminating boundary is characterized either by reworking, hardground development (e. g. Flöthe; WIESE & KRÖGER 1998) or by slumping possibly associated with minor hiatuses (e.g. Salzgitter-Salder; WIESE 1999).

Events (excluding tephro events)

In the original concept of ERNST & *al*. (1983), the eco-events were characterized by a sudden and stratigraphically short-termed abundance peak of fossils and/or the establishment of a distinctive faunal assemblage. Some of these events have received much attention in the past due to the faunal abundance; moreover, their faunal developments are well known and documented in the extensive literature (e.g. WOOD et al. 1984, DAHMER & ERNST 1986, KAPLAN 1992, METZDORF 1992, ERNST & WOOD 1995, WOOD & ERNST 1997, ERNST & *al*. 1998, WIESE & KAPLAN 2001, WILMSEN 2003). Ecoevents as understood here are often not well-defined beds but reflect acme occurrences of a distinct faunal assemblage. In most cases, these events begin rapidly (however without a sharply defined base) and end gradually. The concept of ecoevents applied by ERNST & *al*. (1983) equates roughly with the proliferation epibole concept of BRETT & BAIRD (1997a) and the ecological diversification bioevent as introduced by SAGEMAN et al. (1997) for the Cenomanian/Turonian of the Western Interior of the USA. Beside ecoevents, ERNST & *al*. (1983) also distinguished lithoevents, of which only one with regional correlation potential will be considered (*c/p* Marls, see below).

***costellatus/plana* Event (*c/p* Event).** The *c/p* Event marks an acme occurrence of *Inoceramus perplexus* and *Plesiocorys plana* together with a diverse ammonite assemblage; it also marks the approximate FO of the Upper Turonian index ammonite *Subprionocyclus neptuni* (GEINITZ) (faunal details are given by KAPLAN 1992, WOOD & ERNST 1998, KAPLAN & KENNEDY 1996, WIESE & KAPLAN 2001). As discussed elsewhere (WIESE & KAPLAN 2001), a re-naming of the event in the light of inoceramid taxonomic advances (the eponymous *Inoceramus costellatus* is a synonym of *I. perplexus*; see discussion in WALASZCZYK & WOOD 1999) as the *perplexus/plana* Event (e.g. NIEBUHR & *al*. 2000) appears – for the sake of coherent stratigraphic nomenclature – unwise.

Little attention has been paid so far to the lithological/palaeontological development of the *costellatus/plana* Event. In the MCB, the *c/p* Event – ca. 280 cm in thickness – is characterized by marl/limestone alternations exhibiting thickening-up development in the lower part but a thinning-up trend in its upper parts. The inflection point is located in the main event body. Thus, the lower part of the event appears to fall into the upper part of the RST of the *perplexus* Sequence I, while the upper part may well already be the transgressive part of the succeeding *perplexus* II Sequence (Text-fig. 5). In Lower Saxony the situation is less clear. The *c/p* Event is only developed as a few cm thin abundance peak of the index taxa, and stacking patterns are not recognizable. However, with/above the event, retrogradation starts, indicated by the progressive intercalation of marl seams terminating in the *costellatus/plana* Marls (mfz).

Although the fauna of the event is well-known, little, however, is known of its possible lateral and vertical faunal changes as a response to sea level changes or shifting environmental conditions. In Westphalia (Lengerich area), the *c/p* event exhibits a clear faunal succession within a 280 cm interval (Text-fig. 5). After an abrupt increase in inoceramid abundance but with a low diversity, scaphitid and baculitid ammonites become frequent one metre higher in the lower part of the main event. Only a short distance above, allocrioceratid and collignoniceratid ammonites enter. Higher up-section, inoceramids are still very frequent; however, ammonites, become significantly rarer. According to the model of TANABE (1979), the ammonite morphotype succession observed in the event shows shifting from a more distal to a more proximal fauna, indicative of a regressive development (see also KAPLAN 1991, WIESE & KRÖGER 1998). No such successions have been reported so far from the LSB, but this may be due either to sampling failure or to a weaker development of the event in the area.

Lateral facies variations within the *c/p* Event are difficult to evaluate. In condensed sections (e.g. Hoppenstedt), the tentatively identified stratigraphic equivalents of the *c/p* Event are located well above bentonite T_{C2}, here developed as griotte in Redpläner Facies. However, in this shallow water setting stratigraphic control is poor, and correlation with other sections can only be based on event bed correlation and assumptions derived from sedimentary geometry (see tentative correlation between Salzgitter-Salder and Hoppenstedt in Text-fig. 4). If this tentative lateral correlation should prove to be correct, the Redpläner Facies extends – contrary to previous interpretations – as high as the lowermost Upper Turonian in Saxony-Anhalt.

***costellatus/plana* Marls.** The *c/p* Marls are a lithomarker, distinctively developed only in Lower Saxony and the eastern MCB, where limestone deposition clearly dominates over marl deposition. Two distinct marly beds in Lower Saxony and their correlatives in the MCB that can be correlated with confidence into any section with "normal accumulation rates" (e.g. Söhlde, Salzgitter-Salder, Flöteberg, Kahnstein, Sack Syncline in Lower Saxony, Halle and Oerlinghausen in Westphalia). Only few centimetres above, the bentonite T_D is located, thus forming a good recognizable triple marl sequence. Lithologically, the *c/p* Marls develop rapidly but progressively from the top of the *c/p* Event by an increase of marls and a decrease of bed thickness of the limestones, thus suggesting retrogradation. The *c/p* Marls are interpreted to reflect the lower part of the mfz of the *perplexus* II Sequence (see above). Consequently, only in very condensed sections are the marls missing (Hoppenstedt, Woltwiesche). In contrast to other maximum flooding zones (see discussion below), no distinctive fauna has been collected, although this may be due to collection failure, rather than an absence of fauna. In basinal parts of Westphalia, the *c/p* Marls are not developed because the distal setting is in any case dominated by marl/limestone alternations

***Orbirhynchia*/*Allocrioceras* Event**. A minor fossil event occurs between the *c/p* marls and the Marl M_E/*Infulaster* acme, ca. 10 m below M_E both in the MCB (Halle quarry; KAPLAN 1991) and Salzgitter-Salder (WOOD & *al*. 1984; Text-fig. 2). It is represented by a short interval only few cm in thickness with an increase of fauna, specifically inoceramids, *Allocrioceras* and *Orbirhynchia*. This event has not yet been investigated in detail. Sequence stratigraphically, it may be associated with the sequence boundary between the *perplexus* II and the unnamed brachiopod Sequence

Marl M_E/*Infulaster* acme. M_E is considered to reflect the mfz of the unnamed brachiopod Sequence. It has an overlapping character and can, in accordance with this interpretation, be correlated in virtually all sections exposing this interval in NW Germany, irrespective of the position within the swell/basin transect. Even at Hoppenstedt, the shallowest section exhibiting this interval, a thin marl can tentatively be identified as M_E based on the characteristic small brachiopod assemblage that occurs in abundance in the immediately overlying limestones. In the MCB, the level represents the highest marl contents. Previously, M_E has only been regarded as a lithomarker. However, in the marls and limestones immediately above and below, an abundance peak of the irregular echinoid *Infulaster excentricus* together with *Plesiocorys plana* occurs in the LSB (e. g. Salzgitter-Salder, Flöteberg) and parts of the MCB (Halle-Westfalen, Bielefeld-Senne). We interpret the unique abundance peak of *Infulaster* as an ecological response to changing environmental conditions due to maximum flooding conditions. In the strongly subsident Lengerich area of the MCB, which represents the deepest part of the basin for the interval in question (WIESE & KAPLAN 2001), *Infulaster* shows, accordingly, no short-term, event-like occurrence but is fairly common throughout the entire interval from the *perplexus* I Sequence to the *Hyphantoceras* Sequence. The reason for the abundance of *Infulaster* remains open to discussion. It lived presumably infaunal with the apex below/just above the sediment surface and its morphological specialisation concerns mainly burial strategies and feeding efficiency (GALE & SMITH 1982), which may suggests a better exploration potential for food in basinal settings. Within this context it may be argued that it is not only the dominance of *Infulaster* itself, but also the almost exclusive absence of any other irregular echinoids which may provide a base for future discussion.

***Hyphantoceras* Event.** The *Hyphantoceras* Event is an abundance peak of a diverse and abundant invertebrate fauna. It can be correlated between N Germany and England with some confidence, and comparable faunal assemblages are also known from Saxony (limestones of Weinböhla and Strehlen), Bohemia, Czech Republic (WIESE & al. 2004) and Poland (TARKOWSKI 1991). Where data exist, it is isotope stratigraphically positioned in the uppermost part of a distinct positive $\delta^{13}C$ peak (GALE 1996, VOIGT & HILBRECHT 1997; Peak +1 of WIESE 1999; Text-fig. 2b). Its faunal characters have been adequately described in the literature, key references being DAHMER & ERNST (1986), METZDORF (1992) and WOOD & ERNST (1997). In a sequence stratigraphic context, it is interpreted to reflect a transgressive trend, indicated by the ammonite assemblage (see discussion in KAPLAN 1991). The event itself shows lateral differentiation of biofacies: with progressively shallower settings, ammonites become rarer and brachiopods begin to dominate. This is also the case towards distal settings, where ammonite get less abundant and diverse. In consequence, the main *Hyphantoceras* Event represents a kind of biofacies belt changing in its faunal composition within a swell-basin transect considerably. It must be emphasized that, due to the strong succeeding sea level fall and associated erosion, the event is not preserved everywhere. For example, in swell settings localities like Söhlde (VOIGT & HILBRECHT 1997) and Hoppenstedt (HORNA 1996) the event falls within a hiatus.

Micraster* Event *(=* *Micraster* Marls*). The *Micraster* Event was first recognized by FÖRSTER (1876), mentioned by BESCHOREN (1927) and later used as a marker by BRÄUTIGAM (1962: *Micraster*-Schicht) or *Micraster*-Lage (ERNST & *al*. 1979, KELLER 1982). From 1983 (ERNST & *al*. 1983, *Micraster* Marl, M_G) to 1984, in the spirit of the event stratigraphic concept, the *Micraster* Bed finally mutated to *Micraster* Ecoevent in the literature (WOOD & *al*. 1984). There is a repeated mixing of the terms *Micraster* Event and *Micraster* Marls. In sections like Salzgitter-Salder, Flöteberg or Nettlingen, *Micraster* occurs in fact in a distinct marl. In sections of the northeastern MCB, the event is characterized by a succession of marl seams and thin limestone beds (comp. Text-fig. 6), and *Micraster* occurs scattered throughout this entire interval. Thus, the term *Micraster* Marls is favoured here.

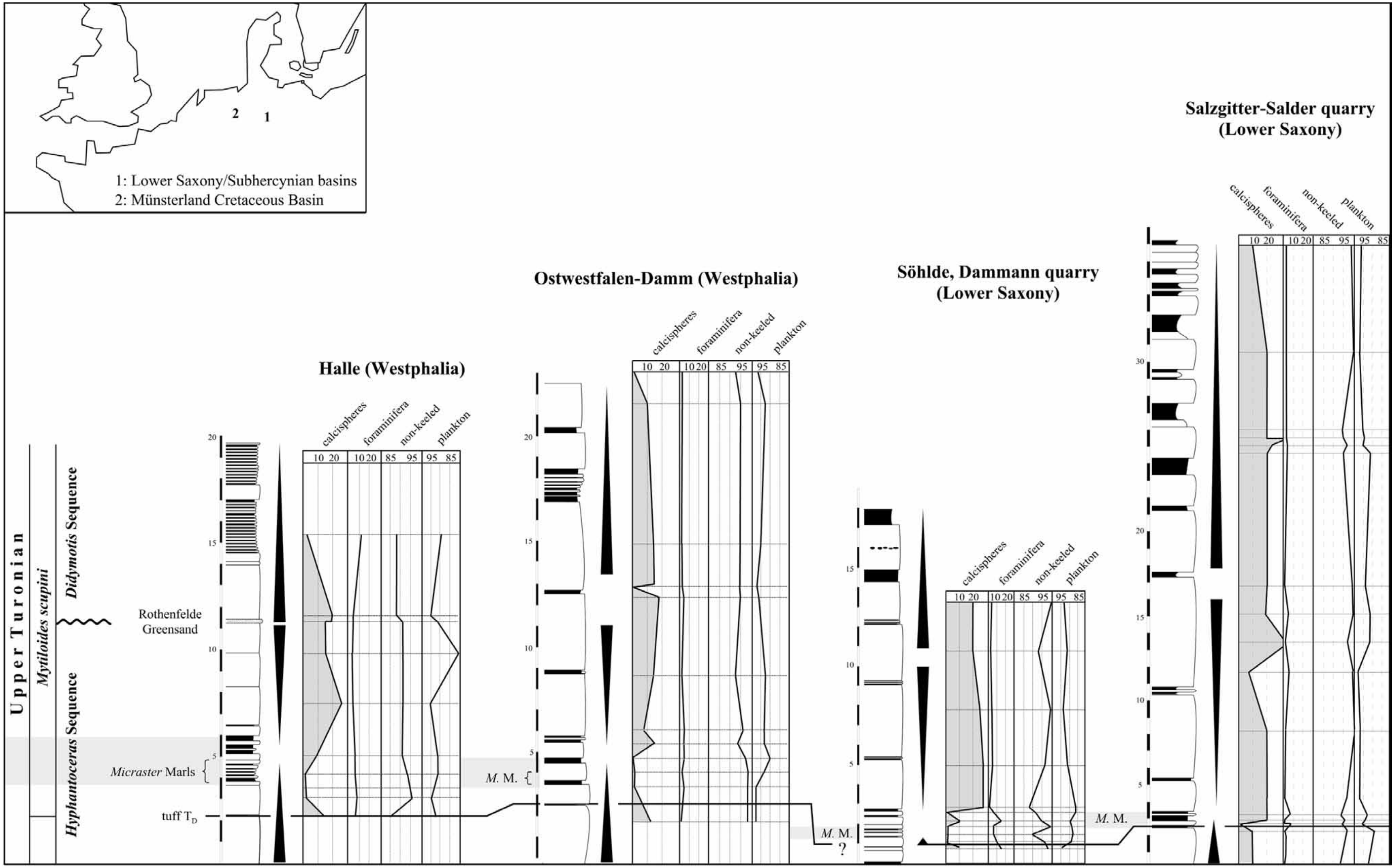

Fig. 6. Correlation of the mfz (*Micraster* Marls), the RST of the *Hyphantoceras* Sequence and the TST of the succeeding *Didymotis* Sequence between the MCB and the LSB. Quantitative microfaunal data (in %: Calcispheres, bulk foraminifera, non-keeled/keeld ratio, bulk plankton) are plotted against the lithological column. While bulk foraminifera and non-keeled/keeled ratio show minor fluctuations, specifically clacisphere abundance shows a strong relation to relative sea level fluctuation; data compiled from diploma thesises of the former ERNST Working Group (BÖTTCHER 1996, JÖRDENS-MÜLLER 1996, KRÖGER 1996). Shaded box: approximate extension of the mfz (*Hyphantoceras* Sequence); *M*. M.: *Micraster* Marls

The *Micraster* Marls represent a mfz with – as in the case of M_E – a clear overlapping character. As can be seen from Text-fig. 6, the relative increase in the marl content may be in part the response of the biosedimentary system to a transgressive pulse, expressed by a significant decrease in calcispheres and thus calcareous bioproductivity.

Palaeontologically, the *Micraster* Marls mark a first abundance peak of the *M.* ex gr. *precursor/normanniae* lineage together with large *Plesiocorys* ex gr. *plana/placenta*. It represents a new branch of *Micraster* – in the literature often referred to as "modern" or "advanced" forms – that succeeds the "primitive" group of *M. leskei/borchardi*. Seen in an interbasinal context (Germany, England/France, Spain), the turnover towards the new *Micraster* occurs – where well dated – isochronously in both Boreal chalk and Pläner limestones as well as in temperate ramp settings (WIESE 1999). In Lower Saxony and Saxony-Anhalt, it is associated with the mfz of the *Hyphantoceras* Sequence in more basinal settings. In sections representing presumably deepest settings (Lengerich area of Westphalia), *M.* ex gr. *precursor/normanniae* is absent. It is noteworthy that – as in the case of M_E/*Infulaster* Acme – again a mfz is characterized by a specific irregular echinoid assemblage.

Heteromorph Beds. The Heteromorph Beds (HORNA & WIESE 1997) form a second, albeit brief and poorly differentiated peak occurrence of heteromorph ammonites of the genus *Hyphantoceras* (*H. ernsti* WIESE) together with scaphitids, baculitids and *Subprionocyclus* cf. *branneri* (ANDERSON). This event is much more weakly developed than the *Hyphantoceras* Event both with respect to faunal abundance and diversity. It is situated well above the *Micraster* Marls and represents the RST of the *Hyphantoceras* Sequence. There is only limited knowledge regarding its potential for regional correlation, but it is known from several localities in the SCB (Hoppenstedt), the LSB (Größ-Flöthe: well developed, Nettlingen, Dorstadt; WIESE & KRÖGER 1998) and the MCB (Halle). Although WIESE (1999) suggested a hiatus in this interval based on an interbasinal $\delta^{13}C$ correlation at Salzgitter-Salder, an ammonite-rich layer with scaphitids, baculitids and *H. ernsti* was found in the correct stratigraphic position (Bed MK 15, comp WOOD & ERNST 1997, p. 96, text-fig. 55), expanding the range of the event also into distal settings.

Tephroevents

Bentonites are well known from northern Germany since DORN & BRÄUTIGAM (1959) and treated partly in great detail (BRÄUTIGAM 1962, ERNST & *al.* 1979, ERNST & *al.* 1983, WRAY & *al.* 1995, WRAY & WOOD 2002; see also this volume). At the moment, five Turonian bentonites can be correlated between north Germany and England with great confidence (WRAY 1999; see also discussion in this volume) and correlation with French volcanogenic marl seams is possible (DECONINCK & *al.* 1991; VANDERAVEROET & *al.* 2000). As bentonites are strictly isochronous markers, their value for calibrating the bioevents and evaluating possible diachronous developments in the sequence stratigraphic development is of outstanding relevance (see below). Preservation of bentonites in particular is controlled by subsidence *versus* relative sea level: they are best and most thickly developed in subsiding, basinal areas and tend to be eroded after deposition in shallower settings. High sea level and sufficient accommodation space also favour the preservation of bentonites. In this context is becomes clear that the best preservation potential of bentonites occurs during late transgression (TST) or maximum flooding (mfz). As a result, all of the (Middle and Upper) Turonian bentonites identified so far fall into such a setting. However, in view of the fact that evidence for volcanic activity without any well defined bentonites may be derived from magnetic minerals, as shown by HAMBACH (1987) for the Lower Turonian, it may also be worth considering whether or not the bentonites identified in the European Turonian really represent the total number of ash falls.

DIACHRONEITY *VERSUS* ISOCHRONEITY

As shown above, ecoevents and several lithomarkers (the mfz) show a clear relation to sea level. Considering the theoretical background of the sequence stratigraphic model, at least some of the markers may potentially be diachronous. The bentonites, in combination with the peaks of the carbon isotope curves, provide unequivocal isochronous time-lines that permit an estimation of a possible diachroneity. Taking the lower Upper Turonian as an example, it can be shown by the relationship between the bentonite T_D and isotope peak Peak-1 that the *c/p* Event is virtually isochronous in a geological sense. The Caburn Sponge Bed of southern England (APB) can also be unequivocally correlated with the *c/p* Event using this method (WIESE & KAPLAN 2001). A comparable good interbasinal calibration of ecoevents such as the *Hyphantoceras* Event also appears to be possible (VOIGT & HILBRECHT 1997). Of particular interest is the position of the maximum flooding zones, as they show also comparatively constant stratigraphic positions within the integrated stratigraphic column. The entire integrated event framework is thus demonstrably broadly isochronous in a geological sense and any possible diachroneity, which may theoretically be inferred from sedimentological assumptions, is below the level of stratigraphic resolution (see summary in ERNST & *al.* 1996). Stable isotope correlation, furthermore, suggest that the mfz of the *Micraster* Marls is located in comparable stratigraphic positions in both northern Spain and Bohemia (WIESE 1999, WIESE & *al*. 2004), suggesting a true eustatic nature for the observed sea level change.

DISCUSSION

Going back to MARX's approach "*the being determines consciousness*", it may well be argued that the specific litho-logical/palaeontological characteristics of the Pläner Limestones resulted inevitably in a particular view of the successions: the occurrence of (highly) fossiliferous beds or thin intervals intercalating with fossil-depleted rocks in an otherwise monotonous sedimentary setting almost without macroscopic features of necessity shifted attention to the fossiliferous strata. For stratigraphers to realize that these fossil beds can be recognized in neighbouring sections must have resulted in the insight that these beds might be of value for regional correlation in an otherwise poorly differentiated succession. It can be argued that the geological setting created a specific consciousness that inevitably resulted in event stratigraphic thinking. Although event stratigraphy is well-established and applied virtually in all settings and all systems (e.g. in the Devonian; WALLISER 1996; see also BRETT & BAIRED 1997b for further data) the high resolution subdivision of a Mesozoic lithogroup by genetically different short-termed events of quasi-isochronous character within an integrated stratigraphic framework is specifically advanced in northern Germany, and – to some extent – also in the Cenomanian/Turonian of the Western Interior Seaway of the USA (KAUFFMAN & HART 1996, SAGEMAN & *al*. 1997). This event stratigraphic concept and its application to the Cretaceous in north Germany, has advanced regional stratigraphic resolution considerably. Using stratigraphic markers of different disciplines (lithostratigraphy, sequence stratigraphy, stable isotope stratigraphy, event stratigraphy including tephro events and bioevents), a closely-spaced succession of isochronous or near-isochronous markers has been established. From the base of the Upper Turonian to the base of the so-called Grey and White Alternation (basal part of the upper Upper Turonian), 12 markers (four bentonite layers, three detrital marls and five bioevents) plus five $\delta^{13}C$ time-lines with varying relevance for interregional but invariably good potential for regional correlation are recognized (Text-fig. 2). Given a very rough estimate of ca. 750 – 800 ky for the lower part of the Upper Turonian (based on an approximate duration of 1.5 my for the late Turonian; GRADSTEIN & *al*. 1995, VOIGT 2000), a relative resolution between 50 and 100 ky appears to be possible in some intervals. This resolution is not attainable by means of conventional stratigraphic methods alone, and it provides a good basis for any further palaeontological (e. g. palaeoecological/palaeobiogeographic) investigation also in an interbasinal context (ERNST & *al*. 1996, KÜCHLER 1998).

But what are the reasons for the alternations of frustrating thick fossil-barren intervals and short-term fossil abundance peaks? ERNST & *al*. (1996) and WILMSEN (2003; with detailed discussion) demonstrated a relationship between ecoevents and relative sea level cycles for the Cenomanian of the LSB and the SCB. They observed clustering of events at the base of a sequence in a transgressive setting (onlapping bioevent), at the mfz (maximum flooding bioevent of WILMSEN 2003) and at the top of the RST (Late Highstand Bioevent of WILMSEN 2003). In the case of the Upper Turonian, the *Hyphantoceras* Event and possibly parts of the Heteromorph Beds may reflect onlapping events in a transgressive setting; the complex Marl M_E/*Infulaster* acme and the *Micraster* Marls can be shown to represent maximum flooding bioevents; and the *c/p* Event occurs in the upper part of the RST (or late Highstand Systems Tract in traditional terminology). Judging from the literature, the formation of shell-beds or shell accumulations are conventionally interpreted to be triggered by physical parameters: water turbulence results in a variety of taphonomic processes (e. g. corrosion, erosion, winnowing, relative enrichment, current-induced accumulations, time-averaging, imbrication, amalgamation), and fossil beds are explained mainly to be result of these processes (e.g. BANERJEE & KIDWELL 1991, FÜRSICH & OSCHMANN 1993, DI CELMA & *al*. 2002). However, none of the Turonian ecoevents discussed above shows any significant sedimentological characteristics indicative of short-term shedding and winnowing-derived accumulations (see discussion in BRETT & BAIRD 1997a). Although slight winnowing and some current induced enrichment of shell debris cannot be excluded, the faunal development and the entry of entirely new faunal assemblages point at other factors than simple enrichment due to physical parameters. Microfacies analyses of the Pläner Limestones show that the macrofossil debris is mainly floating within the matrix (calcisphere/foraminiferal wackestones, bioclastics wackestones), and faunal abundance never reaches that of classic coquinas or Fossillagerstätten. In addition, the base and top of the beds show always gradational contacts, and the development of the events reflects a progressive increase in fauna, as ideally developed in the case of the *costellatus/plana* Event at Lengerich (MCB; Text-fig. 5). In addition, the development of the events is not only accompanied by a faunal increase in terms of abundance but also by a diversity increase or significant faunal change compared to the underlying strata. This trend is associated with a shallowing pulse, while the contrary situation (faunal and abundance decrease) occurs during transgression. Thus, the development of bioevents and the establishment of distinct faunas show a relationship to sea level. Strong lateral differentiation of biofacies is well known from the Turonian, suggesting, at first sight, a highly sensitive relationship between bathymetry and faunal characteristics. However, the relationship to bathymetry can at best be a passive one, as already discussed for trace fossil assemblages (FREY & *al*. 1990). In extant shelf seas with normal aerobic conditions, faunal abundance and faunal compositions are controlled primarily by food availability (ROSENBERG 1995), which – from an actualistic point of view – is also a reasonable assumption for the Pläner Limestone seas. Thus, the alternation of ecoevents with macrofossil-barren intervals may – excluding taphonomic implications – be explained by food web responses to trophic changes (WILMSEN 2003, WIESE & *al*. 2004).

As bioproductivity of the main planktic carbonate constituents in Boreal pelagic systems (e.g. coccolithophorids, calcispheres) is controlled mainly by nutrient supply, relative water depth and temperature (BRAND 1994, ZÜGEL 1994, ROTH 1994, ZONNEVELD & *al*. 1999, GALE & *al*. 2000, PRAUSS 2000, VINK & *al*. 2002, WENDLER & *al*. 2002), quantitative compositional changes may indicate shifting environmental conditions. Recently, WENDLER & *al*. (2002) suggested trophic changes – from oligotrophic to eutrophic – as a possible triggering mechanism for the alternation of calcisphere-rich calcareous beds and calcisphere-poor marls in Cenomanian marl/limestone cycles of NW Germany and France. This has also been also confirmed by WILMSEN (2003) for the Cenomanian of NW Germany. However, in other areas (e.g. Bohemia; WIESE & *al*. 2004), calcisphere packstones and, thus, abundance peaks of calcispheres, are associated with faunas of low diversity and abundance, which are suggested to reflect rather oligotrophic instead of mesotrophic or even eutrophic conditions. As shown by quantitative analyses of calcisphere and foraminiferal content (counting in thin-sections; planktonic *vs.* benthic, keeled-non-keeled ratio) in several diploma theses of the former working group of Gundolf Ernst (BÖTTCHER 1996, JÖRDENS-MÜLLER 1996, KRÖGER 1996), foraminifera and especially calcispheres appear to show a sensitive response to relative sea level fluctuation (Text-fig. 6), even though the available data set is still comparatively crude. In particular, the interbasinal observable and repeated breakdown in calcisphere bioproductivity in the context of maximum flooding events and a recovery during shallowing (Text-fig. 6), strongly suggests a relationship of some kind between nutrient fluxes in surface waters and sea level fluctuations. This also suggests that lithological and specifically macrofaunal characteristics must be seen in the entire context of the biosedimentary system, the main carbonate constituents of which were generated by *in situ* planktonic bioproductivity. Consequently, the explanation of ecoevents in the Pläner Limestones may be found by more detailed palaeoecologic understanding of the depositional system and the complex interaction of planktonic *versus* benthic biotic developments.

CONCLUSION AND PERSPECTIVES

In 20 years of event stratigraphy in N Germany, a stratigraphic framework has been established that provides an excellent framework of isochronous events, reaching in parts a time resolution around 100 ky. Most of these events show a clear relation to sea level fluctuations, either by faunal responses to deepening or shallowing and related environmental changes or, as in the case of bentonites, by variations in their preservation potential. As the stratigraphic framework is now well established and works extremely well even in an interbasinal context, investigation of the biosedimentary system of the Pläner Limestone touches increasingly on palaeoecological questions in an attempt to decipher at least parts of the feedback systems between fauna and environmental changes. Still inexplicable are the dramatic changes from highly fossiliferous beds to (typically) thick barren intervals with apparently identical litho- and taphofacies. As diversity and composition of recent faunas are controlled mainly by food availability, more work needs to be done to resolve the trophic conditions and their changes within the Pläner Limestone Facies. It is important to accept that the planktonic calcareous bioproductivity is difficult to interpret by means of trophic conditions if there is no control on possible benthic feedback as observed in modern day seas. If we interpret calcisphere abundance to reflect eutrophic or mesotrophic conditions, why is benthos abundance and diversity so low during Turonian times? Clearly, in order to understand the biodynamics better, we need to consider data from both surface primary producers and from those organisms dependent on them. Consequently, a synthesis of environmental changes, planktonic calcareous productivity and benthic microfaunal and macrofaunal responses in context with a reconstruction of the C_{org} flux needs to be established for a better understanding of bioevents in the Pläner Limestones.

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