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Evidence for a shallowing event in the Upper Turonian (Cretaceous) *Mytiloides scupini* Zone of northern Germany

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ABSTRACT:

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Based on the evidence of a regression in the Late Turonian (Cretaceous) *scupini* Zone of the Münsterland Cretaceous Basin (Westphalia), the exposures Nettlingen and Groß-Flöthe are investigated in order to discover whether or not a comparable event can be observed in Lower Saxony. The lithological and faunal investigation of the two localities show this to be the case. This regressive event is interpreted to be the expression of a sequence boundary, separating two 3rd order sea-level cycles. The lower sequence, the base of which is located above the main *Hyphantoceras* Event in the middle Late Turonian of northern Germany, is termed the "*flexuosum* Sequence". The sequence above the sequence boundary, which ranges into the Lower Coniacian *Cremnoceramus deformis* Zone, spans approximately the reported range of *Didymotis costatus*. It is, therefore, named the "*Didymotis* Sequence". It can be shown that the observed sequence boundary can also be recognized in Spain, southern England, Poland and the Czech Republic.

Dedicated to the 65th birthday of Prof. Dr. E. HERRIG

INTRODUCTION

In the Upper Turonian of the Münsterland Cretaceous Basin (Westphalia, northern Germany), the glauconitic greensands of Soest (Soester Grünsand; BÄRTLING 1921, SEIBERTZ 1977, 1979; KAPLAN 1994), in the south, and the greensands of Rothenfelde and Timmeregge as well as the conglomeratic iron-ores of Borgholzhausen, in the north (SCHLOENBACH 1869, ELBERT 1902, BÄRTLING 1921, KAPLAN & BEST 1984), mark a significant change of facies: Pläner-limestones, representing a more distal environment, locally glauconitic, are overlain with a comparatively sharp contact by sediments that represent a shallower environment. The Soest Greensand comprises autochthonous/parauthochthonous sediments of a shallow marine setting north of the Rhenish massiv. The greensands grade progressively up into distal, monotonous marl-limestone alternations (Grau-Weiße-Wechselfolge: **G**rey and **W**hite **A**lternation, GWA; FRIEG & *al.* 1989) that can be readily correlated between the Münsterland and the Lower Saxony Basin (ERNST & *al.* 1983) and reflect, therefore, a period of high relative sea-level with widespread uniform sedimentation. The allochthonous greensands of Timmeregge and Rothenfelde (debrites/turbidites) were shed as apron-like bodies from a palaeohigh in the north (VOIGT & HÄNTZSCHEL 1964), the Nordwestfälisch-Lippische Schwelle of HAACK (1925), located close to the present-day Teutoburger Wald. Their microfacies represent a shallow marine environment that is not preserved due to erosion of the source area (MESTWERDT 1930, VOIGT & HÄNTZSCHEL 1964). Of the same age are lenticular accumulations of clay iron-stones (iron-ores of Borgholzhausen) that erosively cut deep into the underlying Pläner limestones and, locally, interfinger with greensands time-equivalent to that of Rothenfelde. These clay-ironstones may derive secondarily from conglomeratic Neocomian sandstones that yield clay-ironstone geodes reworked from the Lias, or may even derive directly from the Lias (BÄRTLING 1921). In any case, the lithological composition of these iron deposits indicates deep erosion that cuts at least as far down as into the Lower Cretaceous. These deposits are also overlain by the GWA, indicating a transgressive development.

BÄRTLING (1921) noted already that the greensands reflected a major regression and the interpretation of the greensands as shallow marine in origin ("Seichtwasserbildungen") can also be found in STILLE (1908) and MESTWERDT (1930). Interpreting the comparatively rapid facies change from the more distal Pläner limestones below and the transgressive greensands above in terms of sedimentology, the contact between these two lithologies can be considered to indicate a sequence boundary between two 3rd order cycles *sensu* VAN WAGONER & *al.* (1988).

The first dating of the greensands was done by SCHLOENBACH (1869), who could prove that they fell stratigraphically into the so-called "Scaphiten-Schichten" (*Scaphites* beds) of the late Late Turonian (for a discussion of the stratigraphic significance of the Scaphiten-Schichten see PRESCHER 1963). KAPLAN & BEST (1984), KAPLAN (1994) and KAPLAN & KENNEDY (1996) demonstrated that the greensand occurrences of Soest in the south and of Rothenfelde/Timmeregge in the north fall into the late Late Turonian *Mytiloides scupini* inoceramid Zone (the former *Inoceramus* aff. *frechi* Zone of German workers, *e.g.* WOOD & *al.* 1984), or into the lowermost part of the *Prionocyclus germari* ammonite Zone, respectively. They are, therefore, of the same age.

No evidence for a similar regression has so far been reported in time-equivalent strata in Lower Saxony and Saxony-Anhalt. This interval appears to be characterized here by monotonous Pläner limestones without any significant lithological and sedimentological features. Therefore the question arises, whether this regressive event is restricted to the Münsterland Basin, or whether it can also be identified in other areas of northern Germany or, perhaps, elsewhere in Europe.

AIMS AND METHODS

Since no direct evidence for a late Late Turonian sequence boundary in Lower Saxony and Saxony-Anhalt can be obtained from the literature, the scope of this paper will be to investigate the time-equivalent strata of the Westphalian greensand occurrences (basal *Mytiloides scupini* Zone, Late Turonian) by means of lithology, sedimentology and faunal development. Unfortunately, strongly glauconitic sediments and/or conglomeratic deposits that might indicate the occurrence of a shallower environment and a corresponding regressive event, are not known in Lower Saxony and Saxony-Anhalt in Late Turonian times. There, most exposures exhibit the typical Upper Turonian Pläner limestone facies, consisting of apparently little diversified marl/limestone alternations of white to greyish limestones with intercalated dark marl seams. Sedimentary features, suggestive of shallower water environments, such as channel-fills or reworking horizons are of only local occurrence. (ERNST & WOOD 1995). To recognise a shallowing in such environments, VOIGT (1959), HANCOCK (1989), ERNST & *al.* (1996) and GALE (1996) suggested that hardgrounds, nodular limestones and lag-deposits, in particular, could be used to recognize regressive developments in Pläner limestone and chalk environments. Allochthonous deposits as predicted by the sequence stratigraphic model (VAN WAGONER & *al.* 1988) can also occur. ERNST & *al.* (1996) presented a list of criteria that are inferred to occur within a sea-level cycle in Boreal and pelagic shelf carbonates. Based on their model (ERNST & *al.* 1996, p. 90, Fig. 4), the following features are inferred to be indicative of a regressive development:

i) hardgrounds,
ii) nodular limestones,
iii) calcarenites ["Grobkreide"],
iv) increased content of macrofauna [fossil accumulations, bio-events],

v) allochthonous deposits,
vi) low keeled/unkeeled planktonic foraminifera ratio,
vii) low ratio of benthic *versus* planktonic foraminifera,
viii) glauconite.

Microfacies analyses can also aid the recognition of environmental changes in these Pläner limestones as has been shown by NEUWEILER & BOLLMAN (1991) and HORNA & *al.* (1994).

Using all these features listed above, an attempt is made to provide an analyses of facies and faunal development in the investigated interval. The question of a possible sequence boundary in this interval is additionally discussed.

PREVIOUS WORK ON SEDIMENTARY SEQUENCES IN THE TURONIAN OF NORTHERN GERMANY

In the Upper Turonian of northern Germany, data on sequence stratigraphy are limited. ERNST & WOOD (1995) presented a cycle chart for Lower Saxony. Those authors, however, did not report a high Turonian sequence boundary in the investigated interval. In the comparative cycle chart between Spain and northern Germany of ERNST & *al.* (1996, p. 89, Fig. 3), a sequence boundary in the *scupini* Zone was recognized but no horizon or locality data were given. WIESE (1997) tried to compare his cycle chart for Turonian and Lower Coniacian strata of northern Spain (Santander area, Cantabria) with data from Westphalia and equated his sequence boundary in the *Mytiloides scupini/Prionocyclus germari* Assemblage Zone (*Mytiloides scupini* Zone of northern Germany) with that below the Westphalian Soest and Rothenfelde greensands. Based on the succession of macrofaunas in the limestone quarry of Hoppenstedt (Saxony-Anhalt), HORNA & WIESE (1997) suggested that there may be evidence to support shallowing in the early *scupini* Zone.

The sequence stratigraphic subdivision, presented in the figures to this text, are based on literature and our own unpublished field data.

GEOLOGICAL FRAMEWORK AND CHOICE OF THE LOCALITIES

The study area lies within the Lower Saxony Basin (ZIEGLER 1988). The best researched

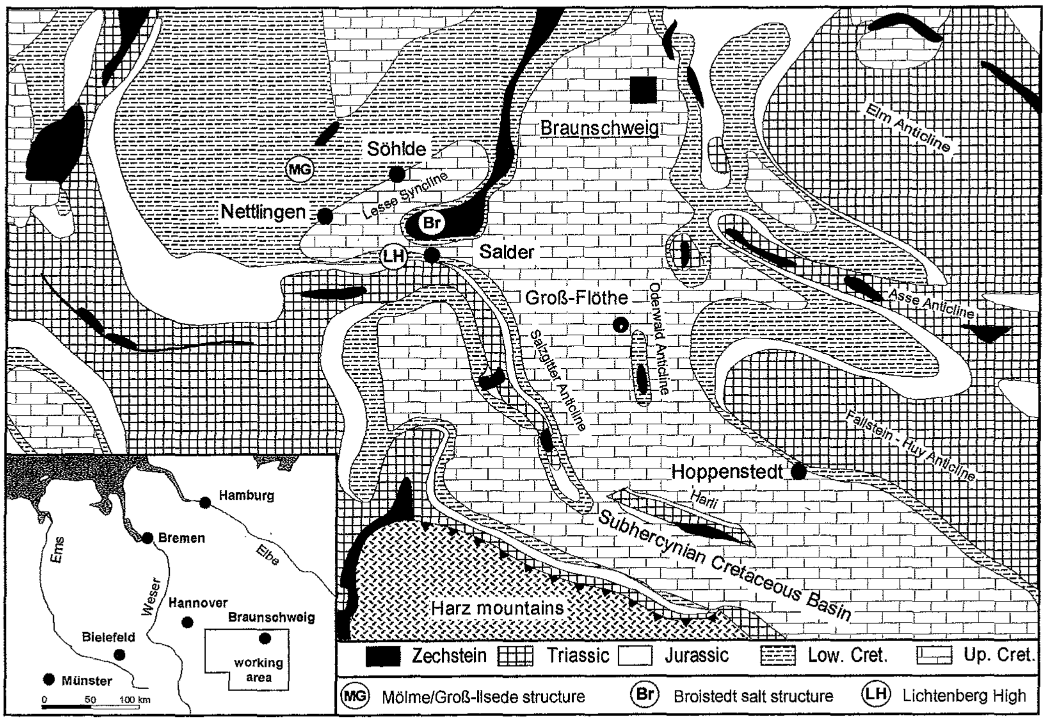

Fig. 1. Simplified geological sketch-map of the study area in Lower Saxony

sections exhibiting Upper Turonian strata are the sections in the limestone quarries of Salzgitter-Salder and Söhlde in the the Lesse Syncline (Text-fig. 1; WOOD & *al.* 1984, ERNST & WOOD 1995, WOOD & ERNST 1997, KAUFFMAN & *al.* 1996). Salzgitter-Salder is located within a structurally complex depositional area, being influenced both by the rim syncline of the uprising Broistedt salt structure in the north and the marginal trough of the Lichtenberg High in the south. It is characterized by high accumulation rates. The exposures around Söhlde are positioned close to the salt-structure of Broistedt and show, presumably due to a migrating rim syncline, strongly differing rates in subsidence over time: Although the interval around the *Hyphantoceras* Event (*Subprionocyclus neptuni* Zone, Text-fig. 2) falls within an hiatus (VOIGT & HILBRECHT 1997), the exposed part of the *Mytiloides scupini* Zone shows in the Grey and White Alternation accumulation rates comparable to those of Salder (ERNST & WOOD 1995), indicating renewed accelerated subsidence. Due to the comparatively high accumulation rates, these two localities, at first sight, do not exhibit any significant facies changes that might permit the detection of a sequence boundary. Therefore, the sections of Nettlingen (close to the Mölme/Groß Ilsede salt structure) and Groß-Flöthe (Oderwald structure) were selected for this investigation (Text-fig. 1). Their inferred position close to or over positive structures seem to be more appropriate for the recognition of a possible sequence boundary because a relative sea-level change and its resulting impact on the sedimentary record should be easier to recognize in shallower environments. In fact, the investigated localities do actually exhibit shallower environments as indicated, to some extent, by the lower accumulation rates and the presences of distinct faunal assemblages. These points will be discussed in detail below.

The exposures of Nettlingen and Groß-Flöthe are abandoned limestone quarries, and the sections are already covered to a large extent by talus. The work on these sections presented here serves to preserve information on successions that would otherwise be lost.

STRATIGRAPHY

Biostratigraphy

Biostratigraphic subdivision in Lower Saxony and Saxony-Anhalt is based on inoceramids. In this paper, the subdivision of the Upper Turonian into three inoceramid (assemblage) zones of WOOD & *al.* (1984) is, with slight modifications, adopted [in ascending order: *Inoceramus*

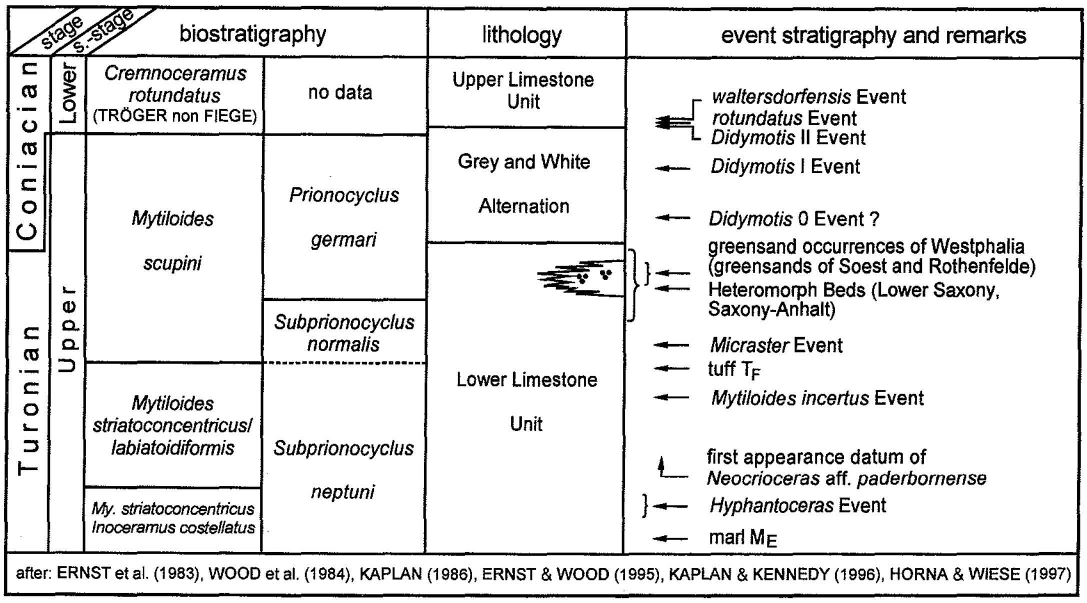

Fig. 2. Generalized multistratigraphic subdivision of the upper Upper Turonian in northern Germany (Saxony-Anhalt, Lower Saxony, Westphalia)

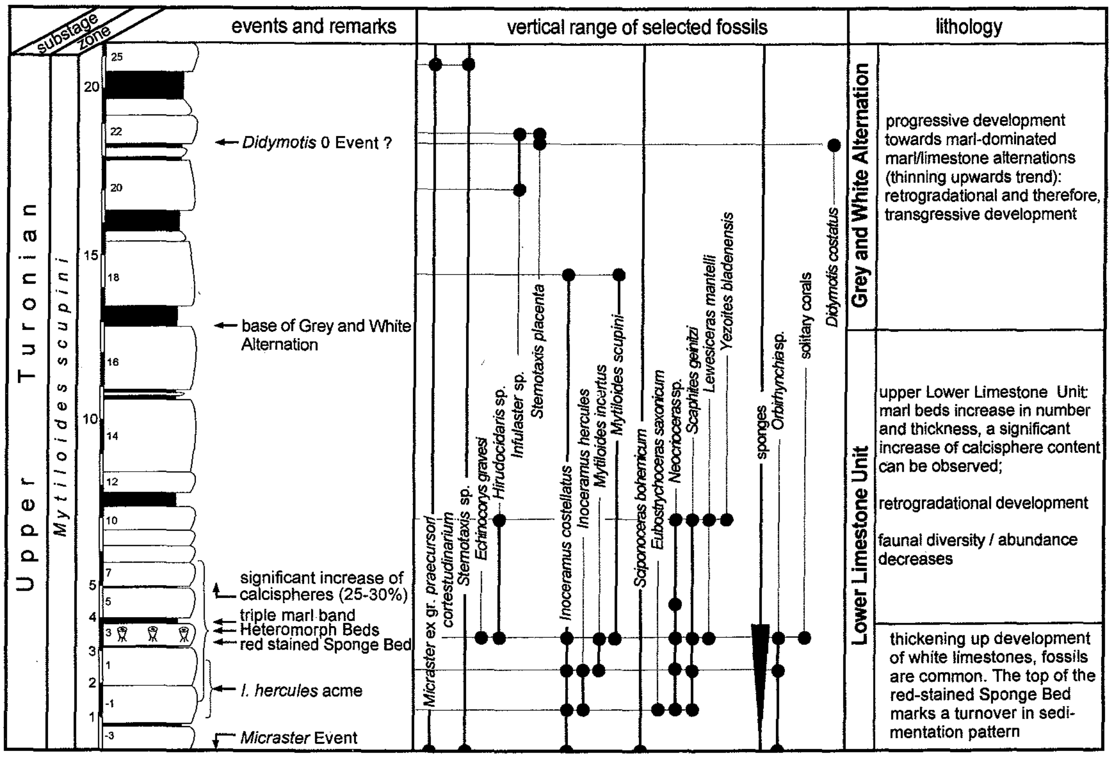

Fig. 3. Lithology and vertical range of selected fossils in the lower *Mytiloides scupini* Zone at Nettlingen

inaequivalvis/stuemckei/cuvierii/costellatus Assemblage Zone, *Mytiloides striatoconcentricus/labiatoidiformis* Assemblage Zone, *Mytiloides scupini* Zone (that is the *Inoceramus* aff. *frechi* Zone of WOOD & *al.* 1984; for discussion see WALASZCZYK & TRÖGER 1997)]. KAPLAN (1986) and KAPLAN & KENNEDY (1996) presented an ammonite zonation for the Upper Turonian of Westphalia and applied it to the inoceramid zonation.

Within this stratigraphic framework, the investigated interval can be shown to fall, respectively, into the late Late Turonian *Mytiloides scupini* Zone or into the lowermost part of the *Prionocyclus germari* Zone (Text-fig. 2). In Westphalia, the base of the latter zone lies just below the greensand occurrences of Rothenfelde and Soest (KAPLAN & KENNEDY 1996). HORNA & WIESE (1997) discussed the possibility that the **f**irst **a**ppearance **d**atum (FAD) of a heteromorph ammonite resembling *Neocrioceras* sp. could be used to define the base of the *germari* Zone in Lower Saxony. As shown below (Text-figs 2-3), this is not the case. However, the base of the first peak occurrence of this genus may well approximate the base of the *germari* Zone and, therefore, aid in recognizing the time-equivalent strata to the Westphalian greensands in Lower Saxony (Text-fig. 2).

It should be mentioned here that KAPLAN (1986) established a *Subprionocyclus normalis* Zone in Westphalia, the base of which equates with that of the inoceramid zone of *Mytiloides scupini*. The *normalis* Zone was abandoned later (KAPLAN & KENNEDY 1994) in favour of a *Prionocyclus germari* Zone with its base located in the lowest part of the *scupini* Zone. Finds of *Subprionocyclus normalis* (ANDERSON) from the lowermost *scupini* Zone (approximately 50 cm above the *Micraster* Event, Text-figs 2-3; Pl. 2, Fig. 5) at Groß-Flöthe fit the data from Westphalia and provide, therefore, additional stratigraphic information.

Event stratigraphy

In order to delimit the investigated interval more accurately, the event-stratigraphic framework of ERNST & *al.* (1983) will be applied (Text-fig. 2). Based on this work, the interval starts with a so-called "event-bundle". This consists of two marker horizons of different origin, namely the tuff layer T_F and the *Micraster* Event. The latter is characterized by the first flood occurrence of "modern" *Micraster* of the *praecursor/cortestudinarium* lineage and serves as an excellent marker between Saxony-Anhalt, Lower Saxony and Westphalia (BRÄUTIGAM 1962, WOOD & *al.* 1984, HORNA 1996). T_F can be recognized in Westphalia and Lower Saxony (WRAY 1995, WRAY & WOOD 1995, WRAY & *al.* 1995, WRAY & *al.* 1996), and marks the base of the *scupini* Zone. In this context, the base of the interval studied is taken at the *Micraster* Event and falls, therefore, into the early Late Turonian *scupini* Zone.

The Heteromorph Beds of HORNA & WIESE (1997) in the lower *scupini* Zone (Text-fig. 2) may have event-like character. They are characterized by an abundance-peak of a nostoceratid ammonite assemblage, consisting mostly of *Neocrioceras* sp. aff. *paderbornense* (SCHLÜTER) (this species will provisionally be referred to exclusively as *Neocrioceras* sp. in this text and the figures; it is currently under investigation by WIESE, *in prep.*), *Hyphantoceras flexuosum* (SCHLÜTER), *Scaphites geinitzi* (D'ORBIGNY) and *Sciponoceras bohemicum* (FRITSCH). They are inferred to define a stratigraphic interval around the Westphalian greensand occurrences and can be shown to occur in Lower Saxony and Saxony-Anhalt (HORNA & WIESE 1997). Furthermore, the two specimen of *Neocrioceras* sp. from the Dresden/Blasewitz borehole (Saxony, Germany), figured and mistakenly identified as *Hyphantoceras reussianum* (D'ORBIGNY) by TRÖGER (1968) and TRÖGER & VOIGT (1995), prove the presence of these beds in Saxony.

The top of the investigated interval is taken at the first abundance peak of *Didymotis costatus* (FRITSCH), which is referred to provisionally as the *Didymotis* 0 Event (JÖRDENS-MÜLLER 1996, WOOD & ERNST 1997) in this text. This possible marker bed has only recently been discovered and its stratigraphic value is still under investigation. Loose finds of *Didymotis costatus* at Söhlde and Hoppenstedt (Text-fig. 1) in Saxony-Anhalt (HORNA & WIESE 1997) suggest the event to be also present there.

Lithostratigraphy

Based on event stratigraphic correlation, the strata can be shown to belong to the Upper Turonian "Untere Kalkstein-Einheit" (Lower Limestone Unit) and the lower part of the "Grauweiße Wechselfolge" (Grey and White Alternation) of ERNST & *al.* (1983). As informally proposed by HORNA & WIESE (1997), the Lower Limestone Unit can be, by means of the *Micraster* Event, lithologically subdivided into a lower part and an upper part. In this context, the base of the studied strata, therefore, corresponds to the base of the upper Lower Limestone Unit (Text-fig. 2). In Lower Saxony, the interval above the *Micraster* Event is, generally speaking, characterized by a succession of thickly bedded white to greyish limestones with intercalated marl beds. It is overlain by the Grey and White Alternation. The GWA as a whole exhibits a thickening upwards development that is terminated by thickly bedded limestones (Upper Limestone Unit, WOOD & *al.* 1984). The lower part of the GWA, which falls within the studied interval, is characterized by the predominance of marlier sediments. The transition between these two litho-units is a gradual one and the definition of a boundary is necessarily somewhat arbitrary. At Salder, it is taken at the first thick marl bed above an interval with thickly bedded limestones (Bed 14 of WOOD & ERNST 1997; Text-fig. 5 of this paper). Based on lithostratigraphic correlation within the working area, this bed is inferred to correspond to bed 17 at Nettlingen and bed 16 at Groß-Flöthe (Text-figs 3-5).

NETTLINGEN: LITHOLOGY AND FAUNA

Grid reference: GK 25: 3827 Lesse; R: 358030, H: 577990
Locality: Abandoned small limestone quarry near the Nettlingen-Berel road
References: MENZEL (1902), WOLLEMANN (1902a, 1902b, 1905), SCHRAMMEN (1910), WOLSTEDT (1933), BRÄUTIGAM (1962), ERNST & *al.* (1979), KRÖGER (1996a)

The locality Nettlingen is structurally located at the western border of the Lesse Syncline, close to the salt structures of Mölme/Groß Ilsede (Text-fig. 1). Formerly, there were many quarries around Nettlingen but these are now back-filled. They exposed Cenomanian to Upper Turonian strata, up to the *Micraster* Event, and were mentioned in WOLLEMANN (1902a, b), MENZEL

(1902) and SCHRAMMEN (1910). A detailed investigation was presented by BRÄUTIGAM (1962). The studied quarry is the only Nettlingen exposure at the moment and it was not studied by BRÄUTIGAM (1962).

The exposed section covers an interval from immediately above the *Micraster* Event (upper Lower Limestone Unit) to the lower GWA (Text-fig. 3, for key see Text-fig. 5). The *Micraster* Event itself is not exposed. However, finds of several fragments of "modern" *Micraster* ex gr. *praecursor/cortestudinarium* in grey-weathering, marly sediments from the bottom of the quarry suggest the event to be only tens of centimetres below the quarry floor. As in Salder and Groß-Flöthe, a *Didymotis* 0 Event is recognized, delimiting the upper boundary of the investigated interval (Text-fig. 3).

Upper Lower Limestone Unit (approx. 13.0 m exposed)

The upper Lower Limestone Unit above the *Micraster* Event in the quarry shows a conspicuous two-fold subdivision: The lower part consists of white, more massively bedded limestones and subordinate marl seams. The higher part is characterized by a widely-spaced marl/limestone alternations of greyish limestones and dark marls. The boundary between these two lithologies is marked by an interval rich in limonitic and strongly altered sponges (Sponge Bed), giving the sediment a reddish/brownish colouration, immediately followed by a triplet of closely spaced marl beds.

Micraster Event to the Sponge Bed (approx. 3.5-4.0 m)

Lithology: As mentioned above, the *Micraster* Event is inferred to lie just below the quarry floor. The only locally exposed marls at the base of the quarry are, therefore, the last marl seams of the marl-dominated interval around the *Micraster* Event. Further up-section, a thickening upwards trend can be recognized. It is terminated by the Sponge Bed. The latter is characterized by the abundant occurrence of pyritized and altered sponges (Pl. 2, Fig. 1), giving this layer a partially red colouration. Compared with the thickly bedded limestones below, the Sponge Bed exhibits a more flasery character. It seems to be the end-member of a thickening upwards cycle, because a facies change towards marlier sediments can be observed immediately above.

Even though the strata appear macroscopically to become coarser towards the top of this cycle, microfacies analyses show the rocks to be almost monotonous and only a small increase of bioclastics towards (bioclastic) calcisphere wackestones (Pl. 1, Fig. 1) at the top of this unit can be observed. The succession consists generally of wackestones containing calcispheres, planktonic foraminifera and, to a minor degree, inoceramid debris. Spicules of hexactinellid sponges also occur, as do scattered grains of glauconite.

Macrofauna: From the base of the quarry, some specimen of *Micraster* ex gr. *praecursor/cortestudinarium* were collected. In contrast to the microfacies, the macrofauna shows a readily recognizable, positive correlation with the thickening upwards development: While the basal exposed sediments are still poor in macrofossils, beds 2 and 3 (Text-fig. 3) yielded a rich invertebrate macrofauna. It consists of inoceramids: *Mytiloides incertus* (JIMBO), *Inoceramus costellatus* WOODS, *Inoceramus hercules* (HEINZ); ammonites: *Lewesiceras mantelli* WRIGHT & WRIGHT, *Eubostrychoceras saxonicum* (SCHLÜTER), *Scaphites geinitzi*, *Sciponoceras bohemicum*, *Neocrioceras* sp. (Pl. 2, Fig. 7); echinoids: *Echinocorys gravesi* (DESOR), *Sternotaxis* sp. (an intermediate form between *Sternotaxis plana* and *Sternotaxis placenta*), *Hirudocidaris* sp. (Pl. 2, Fig. 4); brachiopods: *Orbirhynchia* sp.; solitary corals and a diverse sponge fauna. Based on field observations by one of the authors (KRÖGER), the acme of large *Inoceramus hercules* is of special interest for regional comparison because it can also be observed in the Salder and Söhlde sections, as well as in Groß-Flöthe (Text-fig. 4). It is also of importance to note that the occurrence of *Mytiloides incertus* well above the *Micraster* Event both at this locality and Groß-Flöthe is the first evidence of the species from this interval in Lower Saxony.

Top of the Sponge Bed to the base of the Grey and White Alternation (approx. 9.0 m)

Lithology: Above the Sponge Bed, a significant change in lithofacies can be observed. Even though thickly bedded limestone bundles prevail, the colour changes from white to grey. Furthermore, marl seams begin to intercalate successively, foreshadowing the GWA. The uppermost part of the Lower Limestone Unit exhibits in this interval a considerable change from weakly bioclastic wackestones towards calcisphere wackestones (up to 25 % calcispheres; Text-fig. 3).

Macrofauna: Above the Sponge Bed, the amount of macrofauna decreases considerably. However, ammonites [*Neocrioceras* sp., *Scaphites geinitzi*, *Sciponoceras bohemicum, Yezoites bladenensis* (SCHLÜTER)], *Hirudocidaris* sp. and *Sternotaxis* sp. are still common. A sudden decrease of the macrofauna around beds 5 to 7 marks the upper limit of the Heteromorph Beds.

Grey and White Alternation

Lithology: The base of the GWA is taken here at bed 17. It represents an alternation of greyish limstones and dark marl beds. It develops gradually out of the Lower Limestone Unit and marks the further shift towards marlier sediments.The microfacies varies from (calcisphere) wackestones to bioclastic wackestones, containing common planktonic foraminifera (hedbergellids, heterohelicids, globotruncanids), inoceramid and echinoid debris and spicules of hexactinellid sponges. Towards the top of the section, above the *Didymotis* 0 Event, the first mudstones occur.

Macrofauna: With the GWA, a further decrease in abundance and diversity can be observed. The fauna is dominated by irregular echinoids (*Sternotaxis* sp., *Micraster* ex gr. *praecursor/cortestudinarium*, *Infulaster* sp.) and inoceramids, including *Inoceramus costellatus* and *Mytiloides scupini*. The *Didymotis* 0 Event in bed 22 marks the FAD of *Didymotis costatus* in this section. This interval also yielded very large specimen of *Sternotaxis* referred here to *Sternotaxis* cf. *placenta* (AGASSIZ). *Sciponoceras bohemicum* occurs scattered throughout the entire section.

Additional fauna

In the papers of WOLLEMANN (1902a, b), MENZEL (1902) and SCHRAMMEN (1910), additional lists with Upper Turonian fossils from Nettlingen were presented, including *Hyphantoceras flexuosum* (SCHLÜTER). As this species enters well above the *Hyphantoceras* event (KAPLAN 1986), it can be, also based on the associated fauna, assumed that these authors collected in the same stratigraphic interval as described above. Within this context, it is important to note that SCHRAMMEN (1910) collected a diverse sponge fauna from this interval at Nettlingen, now housed and registered at the British Museum of Natural History, London. These specimen are all three-dimensionally preserved and limonitized, as are the specimen from the Sponge Bed. Based on this information, it is highly possible that SCHRAMMEN's Nettlingen material, in fact, derived from the Sponge Bed described here.

Conulus subrotundus (MANTELL), very large *Gibbythyris subrotunda* (SOWERBY) and *Puzosia* sp. are also listed.

GROß-FLÖTHE: LITHOLOGY AND FAUNA

Grid reference: GK 3928 Salzgitter, R: 3601100, H: 5773250

Locality: Abandoned limestone quarry beside the motorway BAB 395 (Braunschweig-Bad Harzburg).

References: WOLLEMANN (1901), SCHRÖDER (1912), CARLÉ (1938), ERNST & *al.* (1979), JÖRDENS-MÜLLER (1996)

The two abandoned quarries at Groß-Flöthe are located on the western side of the N – S-trending Oderwald structure (Text-fig. 1). They exhibit an almost complete composite section from the Upper Turonian *Hyphantoceras* Event (*Subprionocyclus neptuni* Zone) to the Lower Coniacian with a minor gap in exposure of few metres in the upper *Hyphantoceras* Event. The beds dip gently at 20° to 25° to the WNW (260°).

In the north-eastern quarry, an interval from the marl layer M_E (Text-fig. 2) up to the upper part of the *Hyphantoceras* Event ist still exposed and readily accessible. In the southern quarry, an interval from the top of the *Hyphantoceras* Event to the basal Coniacian is exposed, the latter being indicated by the abundance of a typical Lower Coniacian fauna (e.g. *Cremnoceramus waltersdorfensis*, *Cremnoceramus erectus*, *Cremnoceramus deformis, Neocrioceras paderbornense*).

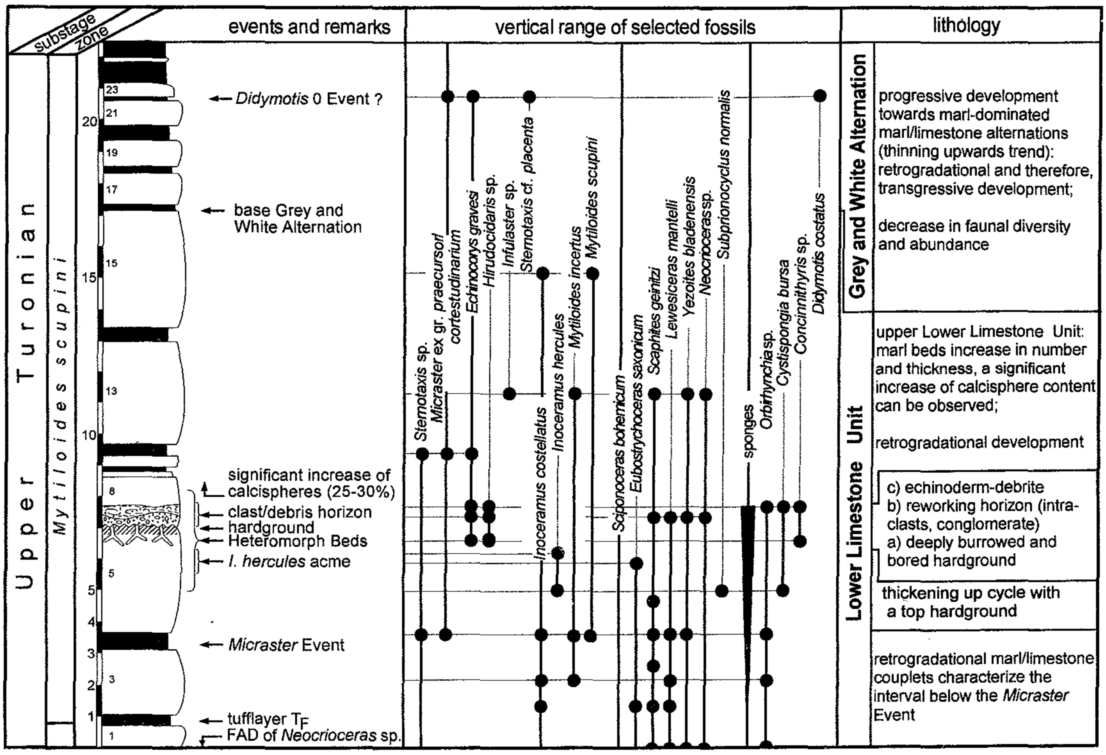

Fig. 4. Lithology and vertical range of selected fossils in the lower *Mytiloides scupini* Zone at Groß-Flöthe

The lowermost strata of the southern quarry are characterized by the common occurrence of *Lewesiceras mantelli* (Pl. 2, Fig. 6). *Hyphantoceras flexuosum* (SCHLÜTER) (Pl. 2, Fig. 8) and *Neocrioceras* sp. were also found. This fauna belongs presumably to the top of the *Hyphantoceras* Event (desmoceratid ammonite association *sensu* KAPLAN 1991). Several specimen of *Mytiloides incertus* were collected, indicating the presence of the *Mytiloides incertus* Event (KAPLAN 1991, ERNST & WOOD 1995; Text-fig. 2 of this paper). Two distinct marl seams, the higher of which contains "modern" *Micraster*, are interpreted as tuff T^F and the *Micraster* Event, respectively (Text-fig. 4). The presence of these index-markers permits good dating and a reliable correlation of the section with other localities. A short distance above the *Micraster* Event, an interval rich in *Neocrioceras* sp. occurs in the upper Lower Limestone Unit. Within this interval, there is a well developed hardground with conglomerates and debrites. The upper Lower Limestone Unit is overlain by the Grey-White Alternation.

Above the *Micraster* Event, a distinct sequence of lithologies can distinguished and described. These are (in ascending order): i) the *Micraster* Event, ii) thickly bedded limestones of the Lower Limestone Unit terminating in a hardground, iii) a conglomerate/debrite complex, iv) thickly bedded limestones of the Lower Limestone Unit and v) the Grey-White Alternation. As the section is already partly covered by talus, bed-by-bed logging is not possible in the lower parts. A detailed bed-by-bed sampling and fossil collecting as in the case of Nettlingen was not feasible, and a continous fossil documentation was, therefore, not always possible.

Micraster Event

Lithology: As in all other sections of Lower Saxony, the *Micraster* Event represents a short interval that is characterized by the predominance of marly sediments (BRÄUTIGAM 1962, WOOD & *al.* 1984). In those sections where detailed microfacies studies have been carried out, the interval around the *Micraster* Event is characterized by a significant decrease in calcispheres and planktonic foraminifera. Keeled forms of the planktonic foraminiferal component can reach up to 90% (KRÖGER 1996b, ERNST & WOOD 1997, WOOD & ERNST 1997). This can also be observed at Groß-Flöthe. The thin limestone beds within this interval are wackestones, in part on the boundary to mudstones. Coarse bioclastics are scarce. Only foraminifera and calcispheres occur in significant amounts.

Macrofauna: The *Micraster* Event is characterized by the first abundance peak of modern *Micraster* of the *praecursor/cortestudinarium* lineage. *Sternotaxis* sp. and *Micraster leskei* (DESMOULINS) occur as subordinate elements. The beds are otherwise poor in macrofossils with the exception of inoceramids. The taxonomic position of the inoceramids, as at Nettlingen, is unclear but they seem to characterize the stratigraphic interval well above tufflayer T_F (C. J. WOOD, *pers. comm.*), and can be compared with the fauna at Nettlingen.

Upper part of the Lower Limestone Unit (approx. 17.0 m exposed)

As mentioned above, a major hardground with conglomerates and debrites is intercalated into this interval, separating these beds into three individual parts. Therefore, the individual lithologies (Text-fig. 4) will be seperately described.

Micraster Event to the hardground (approx. 4.0 m)

Lithology: As at Nettlingen, a thickening upwards development can be recognized from the *Micraster* Event on. Even though the sediment appears to become coarser and the faunal content increases up-section, the microfacies shows only the slightest variation. The sediment consists of bioclastic wackestones (Pl. 1, Fig. 2) with fragments of calcispheres, planktonic foraminifera (hedbergellids, heterohelicids and globotruncanids). Debris of inoceramids or echinoids, as well as benthic foraminifera such as *Lenticulina* sp. are of subordinate importance. Spicules of hexactinellid sponges are common. In comparison to time-equivalent strata at Nettlingen (Pl. 1, Fig. 1), the strata yield significantly less calcispheres here.

This facies is abruptly terminated by a hardground (Text-fig. 4; Pl. 1, Fig. 4). Its surface is slightly iron-stained and strongly bioturbated by *Thalassinoides*. Bioturbation can pipe sediment down up to 30 cm. The three-dimensional preservation of the burrows and the sharp contact of burrow-walls with the infilled sediments indicate early diagenetic lithification. This is also proved by *Trypanites*-like borings (Pl. 1, Fig. 3) and fragmented areas of the hardgrounds, where sharp, angular hardground clasts are preserved in formerly open cavities.

Macrofauna: Above the *Micraster* Event, the macrofauna progressively increases up-section. *Sternotaxis* sp. and fragments of *Micraster leskei* are common. *Eubostrychoceras saxonicum*, *Hyphantoceras flexuosum*, *Scaphites geinitzi*, *Sciponoceras bohemicum* and *Subprionocyclus normalis* (Pl. 2, Fig. 5) also occur. The latter species is known to have its FAD well above the *Hyphantoceras* Event in Westphalia (KAPLAN 1986). This fits the situation as observed at Groß-Flöthe. A first peak-occurrence of *Neocrioceras* sp. about 10 to 50 cm below the hardground indicates the presence of the Heteromorph Beds at this locality. The inoceramid fauna yielded forms that resemble *Inoceramus costellatus longealatus* TRÖGER, *Mytiloides scupini* and *Mytiloides incertus*. Fragments of very large inoceramids (*Inoceramus hercules,* Pl. 2, Fig. 9) are common in this interval. It is noteworthy that at Nettlingen an accumulation of these large inoceramids can also be observed in the same stratigraphic position. The interval below the hardground is particularly characterized by *Cystispongia bursa* QUENSTEDT (Pl. 2, Fig. 2). Its occurrence may be of certain interest, because this species seems to be comparatively common both in England (*e.g.* HINDE 1883, WOOD 1992) and in Germany (*e.g.* QUENSTEDT 1877, SCHRÖDER & DAHLGRÜN 1927) in Upper Turonian strata. Where it occurs, it is linked to condensed sedimentation in shallow environments and it may, therefore, be indicative for regressive developments. The hardground surface is poor in macrofauna.

It appears that the increase of the total amount of macrofauna correlates positively with the thickening up trend.

Conglomerate/debris complex (0.10-0.45 m)

Lithology: A well developed conglomerate bed overlies the hardground with a sharp basal contact. It exhibits a red colouration and is, therefore, easy to recognize. The pebbles are mostly well rounded and reach a diameter up to 6-10 cm. Pebbles with a more angular shape also occur. They consist of different facies types, from mud/wackestones to slightly bioclastic wackestones with fragments of inoceramids, echinoids, planktonic foraminifera and calcispheres. Differences between these lithologies are only small. The composition of the matrix, however, reflects a major facies change towards a shallower environment: It consists of a bioclastic packstone that is rich in inoceramid- and echinoderm-debris (spines of *Hirudocidaris* sp., asteroid ossicles, echinoids), calcispheres, non-keeled planktonic foraminifera (hedbergellids, heterohelicids). Ostracods, bryozoans, serpulids, ostreid bivalves, spicules and *Lenticulina* sp. are common (Pl. 1, Fig. 6). The conglomerate shows lataral variation in thickness (5-30 cm), possibly reflecting an undulating erosion surface on top of the hardground that can be regarded as a primary relief. The conglomerate is overlain by a partly laminated, echinoderm wacke- to packstone of varying thickness (5 to 15 cm; Pl. 1, Fig. 7). Filling up the residual relief, it terminates this allochthonous interval, and is itself covered by "normal" autochthonous limestones that show no change in thickness within the quarry.

Macrofauna: The conglomerate is very rich in macrofossils. Inoceramids debris, large *Echinocorys gravesi*, *Concinnithyris* sp., *Orbirhynchia* sp., *Spondylus* sp. and spines of *Hirudocidaris* sp. are particularly common. Associated fragments of asteroids are scarce; however, the local superabundance of isolated asteroid ossicles confirm that asteroids (*Metopaster* sp.?; Pl. 2, Fig. 3) were an important element of the fauna. Serpulids, hexactinellid sponges and solitary corals also occur.

Uppermost Lower Limestone Unit
(approx. 9.5 m)

Lithology: Immediately above the hardground, the microfacies grades back into bioclastic wackestones with decreasing amount of coarse bioclastics (Pl. 1, Fig. 8). There is an increasing intercalation of marl beds, and the limestones turn from white to a slightly greyish colour.

Macrofauna: The beds immediately above the hardgrounds are rich in ammonites (*Neocrioceras* sp., *Yezoites bladenensis*, *Sciponoceras bohemicum*, *Scaphites geinitzi*, *Eubostrychoceras saxonicum*). Inoceramids, including large *Mytiloides incertus*, also occur. After only tens of centimetres, the macrofossil content decreases. Only *Sternotaxis* sp. and small inoceramids are common.

Grey and White Alternation

Lithology: The base of the GWA is taken at the base of bed 16, which is a marl seam (Text-fig. 4). As already described from Nettlingen, the base of the GWA marks an increase of marl beds and a decrease of macrofauna. The limestone beds are of a light grey colour and are penetrated by dark-coloured *Zoophycos* and *Chondrites*. Lithologically, the limestones can be best described as wackestones with varying amount of bioclastics (echinoids, inoceramids, planktonic foraminifera). In addition, the calcisphere content increases significantly (approx. 25 %), as already observed at Nettlingen at the same level.

Macrofauna: The Turonian part of the GWA is generally poorer in macrofauna as the strata below. However, echinoids (*Sternotaxis* cf. *placenta*, *Echinocorys gravesi*, *Infulaster* sp., *Micraster* ex gr. *praecursor*/*cortestudinarium*) as well as scaphitids, *Sciponoceras bohemicum* and small mytiloid inoceramids of uncertain taxonomic position occur scattered throughout the section

DISCUSSION

Lithology and microfacies

The *Micraster* Event was interpreted as a maximum flooding zone by KRÖGER (1996a). At Salder and Söhlde, it is particularly characterized by thinly bedded limestones with a very high content of keeled planktonic foraminifera (up to 90%). Above the *Micraster* Event, a short-term thickening upwards development in the upper part of the Lower Limestone Unit can be recognized both at Nettlingen and Groß-Flöthe. It is characterized by a successive decrease of marl beds and an increase in bed thickness of the limestones. Furthermore, the amount of macrofossils

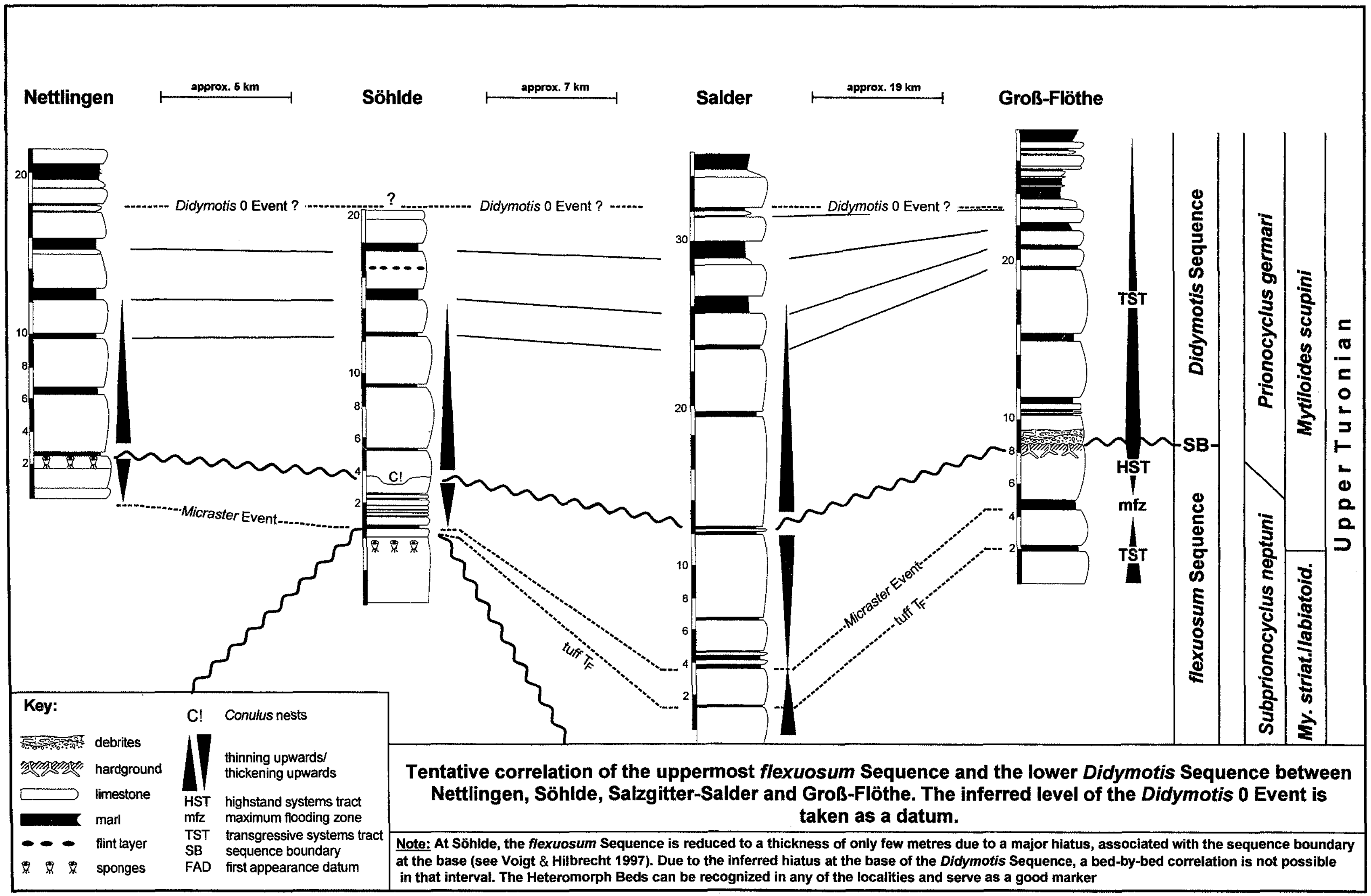

Fig. 5. Tentative, lateral correlation of the early *Mytiloides scupini* Zone between Nettlingen, Söhlde, Salder and Groß-Flöthe within a sequence stratigraphic framework

increases considerably. This is also reflected by the microfacies, which exhibits change from wackestones towards slightly bioclastic wackestones. At Nettlingen, this trend is terminated by the flasery Sponge Bed (bioclastic calcisphere wackestone, Pl. 1, Fig. 1). At Groß-Flöthe, a hardground is developed at the same level, terminating a succession of wackestones (Pl. 1, Fig. 2). Based on the data from ERNST & *al.* (1996), these features can be interpreted as marking a regressive event. Correlation and a comparison of lithological/sedimentological features between Groß-Flöthe, Salder, Söhlde and Nettlingen (Text-fig. 5) suggest that Groß-Flöthe represents the shallowest section with the hardground incorporating a small hiatus. This gives further evidence for a relative sea-level fall. It is important to note that the comparatively more distal section at Nettlingen yielded more calcispheres in time-equivalent strata than at Groß-Flöthe. At Salder, the corresponding strata of this thickening upwards cycle are characterized by thickly-bedded calcisphere-wackestones with a calcisphere content of approximately 25 % (ERNST & WOOD 1995).

Interpreting the microfacies data presented by KRÖGER (1996a, 1996b), JÖRDENS-MÜLLER (1996) and in this paper, a facies zonation from proximal [hardground, (bioclastic) wackestone] to distal (foraminiferal wackestones, *e.g.* the interval around the *Micraster* Event) can be inferred. The calcisphere-maximum (calcisphere wackestones) possibly reflects a medial position close to swell margins between the proximal (bioclastic) wackestones and the distal foraminiferal wackestones. A comparable observation was also reported by NEUWEILER & BOLLMANN (1991) from the Turonian of Westphalia. This indicates that the maximum occurrence of calcispheres is restricted to a distinct calcisphere facies belt. The comparatively higher accumulation rates within this calcisphere belt are reflected by a generally higher bed thickness. Within a sea-level change, the stacking pattern of the strata, *e.g.* a thickening upwards development, can, therefore, indicate either a shallowing development (facies change from distal foraminiferal wackestones to medial calcisphere wackestones) or a deepening development [facies change from proximal (bioclastic) wackestones to medial calcisphere wackestones].

Following WALTHER'S law of facies, an increase of calcispheres should, therefore, be expected during transgression in a position more proximal to the calcisphere belt, when it shifts up-swell. In fact, this can be observed at Nettlingen and Groß-Flöthe. Above the Sponge Bed (Nettlingen) and the hardground (Groß-Flöthe), respectively, a significant increase of calcispheres can be recognized, accompanied by an increase of bed thickness of the limestones (Text-figs 3-5). Higher up-section the thicknesses of individual limestone beds decrease and those of marl seams increase. This may be regarded as representing a transgressive development. The lithostratigraphic boundary between the Lower Limsestone Unit and the GWA, therefore, is purely arbitrary, representing only a moment within an overall transgressive trend.

Macrofauna

Above the *Micraster* Event, the fauna is increasingly dominated, amongst others, by *Echinocorys gravesi*, *Sternotaxis* sp., brachiopods and, to some extent, by *Micraster leskei* in both Nettlingen and Söhlde. These faunal elements are part of what ERNST & *al.* (1979) called the *Conulus* Facies. This term is derived from the old-fashioned "Galeriten-Pläner" (*e.g.* VON STROMBECK 1857), Galeritenschichten (*e.g.* LÖSCHER 1910) or "Galeriten-Fazies" (*e.g.* BÄRTLING 1913) of Westphalia, interpreting the holectypoid echinoid genus *Conulus* as *Galerites*, and was used to describe a significant occurrence of *Conulus subrotundus* (MANTELL). The *Conulus* Facies is indicative of shallower environments (LÖSCHER 1912) and it is, where it occurs within otherwise normally developed Pläner limestones, interpreted as a regressive event (ERNST & *al.* 1979). In other localities where the *Conulus* Facies is developed (*e.g.* Wüllen in Westphalia, ERNST 1967; Vienenburg in Lower Saxony, ERNST & WOOD 1995; Steinberg in Lower Saxony, ERNST & SCHMID 1984), *Echinocorys* is an invariable element of the facies. In the strongly condensed Wüllen section, *Conulus* occurs abundantly, *Echinocorys* is common, while *Micraster* is rare (ERNST 1967). In the Vienenburg section, where the GWA is condensed but without hardgrounds, *Echinocorys*, *Conulus* and *Sternotaxis* occur in approximately equal numbers, and *Micraster* is rare (ERNST & *al.* 1997). ERNST & WOOD (1995) showed that, beside the eponymous *Conulus* an assemblage of *Echinocorys gravesi*, *Sternotaxis* sp., *Orbirhynchia* and other brachiopods characterize this facies. Additionally, the hexactinellid sponge *Cystispongia bursa* is common in regressive phases, as observed in other localities in Lower Saxony. With or without *Conulus*, the association of *Echinocorys*, *Sternotaxis*, *Cystispongia* and brachiopods and the absence of *Micraster* ex. gr. *praecursor/cortestudinarium* fits the observations from other localities. In this paper, we apply the term "incipient *Conulus* Facies" to the latter faunal assemblage associated with lithologies suggestive of shallower environments and/or reduced accumulation rates.

At Salder, no evidence for a *Conulus* Facies can be recognized at the investigated level, suggesting continuous sedimentation. However, brachiopods (*Naidinothyris* sp., *Gibbithyris* sp.), and inoceramids (C.J. WOOD, *pers. comm.*), including fragments of large specimen of *Inoceramus hercules*, occur commonly in an interval approximately 4 m above the *Micraster* Event. At Söhlde, the presence of *Conulus* 'nests' (locally developed, weak *Conulus* Facies) and sedimentary anomalies (ERNST & WOOD 1995), approx. 50 cm above the *Micraster* Event, indicates condensation and a possible hiatus and may be the expression of the regressive event observed in the investigated localities.

With the renewed transgression in the uppermost part of the Lower Limestone Unit, the incipient *Conulus* Facies dissappears, and the faunal content decreases significantly. The echinoid association changes towards an assemblage that is dominated by *Sternotaxis* cf. *placenta*, *Infulaster* sp. and *Micraster* ex. gr. *praecursor/cortestudinarium*, indicating the more distal settings suggested by the lithological development.

Further faunal support for relative bathymetric reconstructions may be provided by the ammonite fauna. In Westphalia, KAPLAN (1991) demonstrated a threefold subdivision of the *Hyphantoceras* Event into three distinct, successive ammonite associations. The basal association fauna is characterized by a collignoniceratid/allocrioceratid association. It is followed by a nostoceratid and a desmoceratid association. The latter fauna reflects already advanced transgression, and its presence in the working area can be demonstrated in the northern part of the Groß--Flöthe quarry. There, the desmoceratid association is characterized by the common occurrence of *Lewesiceras mantelli* together with *Hyphantoceras flexuosum* and *Neocrioceras* sp. The interval around the *Micraster* Event marks peak transgression (KRÖGER 1996a), and it is accompanied by a low-diversity fauna of sporadic *Sciponoceras bohemicum* and *Scaphites* sp. As these genera are ubiquitous in the Upper Turonian of northern Germany, it is the absence of any other significant ammonites, rather than the presence of these genera, that indicates a period of relative high sea-level.

Within the thickening-upwards development towards the incipient *Conulus* Facies in the upper Lower Limestone Unit, the macrofaunal content increases. Concomitantly with the observed regressive development, the ammonite fauna shifts back into a nostoceratid association, consisting of *Hyphantoceras flexuosum*, *Neocrioceras* sp. and *Eubostrychoceras saxonicum*. A similar fauna in the same stratigraphic position was described by HORNA & WIESE (1997) from Hoppenstedt (Saxony-Anhalt) and by KAPLAN (1991) from the Anneliese quarry at Bad Laer (Westphalia). The FAD of the collignoniceratid ammonite *Prionocyclus germari* is located in this interval at the latter locality. It should also be noted that at Groß-Flöthe (interpreted here, based on lithology and fauna, as the shallowest section of this interval in the working area) several fragments of *Subprionocyclus normalis* were collected (Pl. 2, Fig. 5). This fits the distribution of collignoniceratid ammonites in general (TANABE & *al.* 1978, TANABE 1979, WESTERMANN 1996) and is specifically reported from the Turonian of the Münsterland Cretaceous Basin, where *Subprionocyclus normalis* and *Subprionocyclus branneri* (ANDERSON) occur preferentially in proximal settings (KAPLAN 1988). Furthermore, no other section in Lower Saxony has so far yielded collignoniceratid ammonites in this interval with the exception of a single, loose fragment from the *scupini* Zone of Hoppenstedt in Saxony-Anhalt (HORNA & WIESE 1997). Therefore, it may well be possible that the finds from Groß-Flöthe can be interpreted as indicating a shallow environment, which agrees well with the data presented above.

On the other hand, the sudden collapse of the nostoceratid ammonite assemblage and the occurrences of *Sciponoceras* sp. and *Scaphites* sp. in the uppermost Lower Limestone Unit and the GWA may indicate renewed transgression, with an ammonite assemblage similar to that around the *Micraster* Event. This interpretation is supported by the development of lithology and the other macrofauna.

Sequential interpretation

Bringing the lithological and macrofaunal data together, a statement on the change of the relative sea-level appears possible (Text-fig. 5). The short interval from the *Micraster* Event to the top of the thickening up cycle may well be interpreted as a late highstand systems tract (HST) *sensu* VAN WAGONER & *al.* (1988). As only a progradational development can be observed, no early, aggradational highstand is documented. The *Micraster* Event is inferred to reflect the maximum flooding zone as already proposed by KRÖGER (1996a). Based on data from HORNA & WIESE (1997) and VOIGT & HILBRECHT (1997), who show a major hiatus below the *Micraster* Event, and our own field data, it is suggested that the HST above the *Micraster* Event belongs to a sequence that is interpreted here to start within the *Hyphantoceras* Event, above the main *Hyphantoceras* occurrence. In order to avoid confusion by numbering individual sequences (as done *e.g.* by HORNA & WIESE 1997), this sequence is named here the "*flexuosum* Sequence", after the ammonite *Hyphantoceras flexuosum* that is characteristic of this interval. The *flexuosum* Sequence is terminated in the proximal section of Groß-Flöthe by a hardground that is taken as a third order cycle sequence boundary. Lithostratigraphic correlation with adjacent areas suggest an hiatus which is lithologically confirmed by the occurrence of reworking above the sequence boundary. Down-swell, the time-equivalent strata of the hiatus are characterized by an (incipient) *Conulus* Facies (Nettlingen, Söhlde) or even by an apparently continuous succession with a significant increase in faunal diversity that can be observed 4 m above the *Micraster* event at Salder. The latter interval at Salder, around the marl bed 9c of WOOD & ERNST (1997), however, is characterized by laminated and slightly convoluted bedding, suggesting minor sedifluction structures. This points to the possibility of a small hiatus, and might be interpreted as the expression of the sequence boundary in the distal setting of Salder. Within this context, it is interesting to note that, based on a comparison of the stable carbon isotope curve from Salder with that from northern Spain (WIESE, *in press*), the interval above marl bed 9c is inferred to be characterized by an expanded hiatus because part of the Spanish isotope curve is missing from the Salder. Based on this information, a detailed correlation of the lowermost part of the *Didymotis* Sequence is not possible.

The uppermost part of the Lower Limestone Unit exhibits a slow thinning upwards development, with an increase of marl beds, that grades continuously into the GWA. Both lithological and faunal parameters suggest a progressive deepening. This interval is, therefore, regarded as representing a TST of a third order cycle. Based on the literature, it appears that this sequence may extend up into the Lower Coniacian Upper Limestone Unit of ERNST & *al.* (1983). The latter shows a progradational stacking pattern and may, therefore, be regarded as a HST. As the sequence largely corresponds to the reported range of *Didymotis*, we suggest the name "*Didymotis* Sequence" for this sequence.

Interbasinal correlation

The data presented in this paper show a third order sequence boundary (SB) to occur within the Late Turonian *Mytiloides scupini* Zone of Lower Saxony. Taking the faunal data into consideration, it appears that this SB is located in the lowermost *Prionocyclus germari* Zone. These data suggest this regressive event to be the same as the one that generated the facies change towards the shallow water greensand facies in the lowermost *germari* Zone of the Münsterland Cretaceous Basin. It must be concluded that this SB, therefore, is not a local phenomenon but can be recognized at least in Westphalia, Lower Saxony and Saxony-Anhalt. Cycle charts from other regions (Saxony: TRÖGER & VOIGT 1995; England: GALE 1996; northern Spain: GRÄFE 1994; Tunisia: ROBASZYNSKI & *al.* 1990) or at the "global" cycle chart of HAQ & *al.* (1988), do not recognize a SB in this stratigraphic position.

In the North Cantabrian Basin (northern Spain), however, WIESE & WILMSEN (*in press*) report a SB in the lower part of their late Turonian *Mytiloides scupini/Prionocyclus germari* Assemblage Zone that equates with the *scupini* Zone as recognized in northern Germany.

Therefore, this SB is inferred to correlate with that observed in the working area.

In the Úpohlavy section in the Bohemian Cretaceous Basin (Czech Republic), a sequence boundary can be recognized in the Late Turonian, indicated by channels that incise deeply into the underlying strata (ČECH & *al.* 1996). Based on the stratigraphic data, this SB lies within the Teplice Formation, which falls within a *Mytiloides striatoconcentricus* Zone. In Bohemia, this zone spans roughly the interval from the equivalent of the German *Hyphantoceras* event to the base of the Lower Coniacian. As this SB still lies well below the *Didymotis* I Event in the litho unit Xb (ČECH 1989), it is highly possible that it can be correlated with the *scupini* Zone SB discussed in this paper. Biostratigraphic data from boreholes and exposures elsewhere in the Bohemian Cretaceous Basin are also relevant to the discussion. ČECH (1989) could demonstrate that the top of litho-unit Xb ranged almost to the base of the *germari* Zone, which likewise marks the base of the succeeding litho-unit Xc. The channel fill is interpreted as belonging still to litho-unit Xb by ČECH & *al.* (1996), without giving any biostratigraphic or lithostratigraphic reasons. It therefore may be worth discussing, whether the channel cuts down from the unit Xc into the underlying strata of Xb. If this were the case, the SB recognized in the Úpohlavy section would also fall into the basal *germari* Zone and would, therefore, equate exactly with the position of the SB recognized in Westphalia and Lower Saxony.

In southern England (Lewes), the *Micraster* Event cannot be recognized. A thick marl with abundant large *Micraster leskei*, the Lewes Marl, however, may be a correlative event of either the tuff T_F or the marl bed M_F (Text-fig. 2, *see* WRAY & *al.* 1996). Based on a bio- and event stratigraphic correlation between northern Spain, northern Germany and southern England, WIESE (1997) discussed whether the Lewes Marl may equate the tuff T_F [investigations on the origin (detrital *versus* volcanic) of Turonian marl beds are currently being carried out by D. WRAY; University of Greenwich]. In any case, the FAD of the "modern" *Micraster* ex gr. *praecursor/cortestudinarium* immediately above the Lewes Marl indicates that this interval equates with the base of the strata investigated in this paper. Above the Lewes Marl, a progressive development towards nodular chalks (Lewes Nodular Chalk), locally flinty chalk (Upper Lewes Flints) and cemented surfaces (Lewes Hardground) can be observed (MORTIMORE 1986, MORTIMORE 1987, MORTIMORE 1997). Based on HANCOCK (1989) and ERNST & *al.* (1996), this is inferred to indicate a shallowing development. Above the Lewes Nodular Chalk, the facies changes rapidly towards a soft white chalk (Cuilfail Bänderkreide/*Zoophycos* beds). It correlates positively with a turnover in the ichnofacies from a *Thalassinoides/Spongeliomorpha* association in the Lewes Nodular Chalk towards a *Zoophycos/Chondrites* association in the Cuilfail Bänderkreide. Following ichnofacies models of *e.g.* EKDALE & BROMLEY (1984), FREY & PEMBERTON (1984) and SAVRDA & *al.* (1991), this turnover can be interpreted as indicating a deepening and, therefore, as a transgressive development (MORTIMORE & POMEROL 1991). Based on these data, it can be shown that a regressive/transgressive event can be observed in southern England in a stratigraphic position that demands a correlation with that observed in northern Germany.

In the Upper Turonian *Mytiloides incertus* Zone [which spans the interval from the north German *Mytiloides incertus* Event (Text-fig. 2) to the Turonian/Coniacian boundary interval, WALASZCZYK 1992] of the Folwark quarry (Opole Trough, Poland), passively back-filled, synsedimentary depressions were observed during field work of the working group G. ERNST (Berlin). These are located well above the top of the *Hyphantoceras* Event and significantly below the Turonian/Coniacian boundary. Stratigraphically, these features equate the position of the SB terminating the *flexuosum* sequence.

CONCLUSION

The investigation of the abandoned limestone quarries of Nettlingen and Groß-Flöthe shows that, based on fauna and lithology, the lower part of the upper Lower Limestone Unit (*Mytiloides scupini* Zone, Upper Turonian) above the *Micraster* Event exhibits a progradational and, therefore, a shallowing development. These strata are interpreted as a HST. The *Micraster* Event marks the maximum flooding Zone. Based on the data obtained from literature, it is assumed that the strata treated here are part of a third order cycle that starts above the *Hyphantoceras* Event. For this sequence the name *flexuosum* Sequence is proposed.

The succeeding sequence boundary is located in the lower part of the *Prionocyclus germari* Zone. In Groß-Flöthe, it is characterized by a hardground and reworking. Based on lithostratigraphic correlation within a bio/event stratigraphic framework it can be shown that the Groß-Flöthe section is the shallowest known section exhibiting this stratigraphic interval in Lower Saxony. In Nettlingen and Söhlde, the interval around the SB is characterized by an (incipient) *Conulus* Facies. This development can be tentatively recognized at Salder by an abundance and diversity peak of the macrofauna.

The following succession (uppermost Lower Limestone Unit and Grey and White Alternation) exhibits a retrogradational development. It is, therefore, interpreted as a TST. For this sequence, which presumably terminates in the Upper Limestone Unit, the name *Didymotis* Sequence is proposed.

Interbasinal correlation shows that the SB recognized here equates with that below the Westphalian greensand occurrence. Further evidence for a sequence boundary in the high Turonian can be recognized in Spain, southern England, Poland and the Czech Republic. It therefore seems that this event can be recognized over a wide area and that it may be of importance, at least in Europe, for a reconstruction of a relative sea-level curve.

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PLATES 1 – 2

PLATE 1

1 – Weakly bioclastic (calcisphere) wackestone (bed 1 at Nettlingen, HST of the *Hyphantoceras* Sequence) with calcispheres, spicules and debris of heterohelicid and hedbergellid planktonic foraminifera Based upon the above presented facies interpretation, the comparatively high calcisphere content suggests a more distal setting close to or within the calcisphere belt (width of picture: 2,1 cm)

2 – Weakly bioclastic wackestone (bed 5 at Groß-Flöthe) with fragments of heterohelicid and hedbergellid planktonic foraminifera, lateral equivalent of bed 1 at Nettlingen (Pl. 1, Fig. 1). In context with the above presented facies model, this microfacies is inferred to reflect more proximal environments as the calcisphere wackestones (HST of the *Hyphantoceras* Sequence) (width of picture: 2.7 cm)

3 – Borings grade from the cemented hardground (3rd order cycles sequence boundary) into bed 5 at Groß-Flöthe. The open cavities are infilled with calcareous muds. The infill exhibits sometimes (left side of the picture) graded bedding (width of picture: 6.5 cm)

4 – Contact between the hardground (wackestone of the uppermost *flexuosum* Sequence) and the overlying debrite/conglomerate complex (bioclastic wacke/packstone of the basal *Didymotis* Sequence) at Groß-Flöthe (width of picture: 2.7 cm)

5 – Conglomeratic layer at Groß-Flöthe (bioclastic wackestone), consisting of echinoderm debris, planktonic and benthonic foraminifera, calcispheres and spicules (width of picture: 2.7 cm)

6 – Same as Fig. 5, here with calcispheres, 1) spines or regular echinoids, 2) asteroid ossicles, 3) heterohelicids, 4) hedbergellids, 5) spicules (width of picture: 4.1 cm)

7 – Echinoderm debris at Groß-Flöthe (bioclastic wackestone) with abundant echinoderm fragments [spines of regular echinoids, thick-shelled echinoderm debris of *Echinocorys* (?), thin shelled debris of irregular echinoids (*Sternotaxis*?), asteroid ossicles], inoceramid-debris, shells of *Spondylus* sp. (1), *Lenticulina* sp., biserial textulariid foraminifera, planktonic foraminifera, calcispheres and spicules. of subordinate importance Ostracodes (width of picture: 7 cm)

8 – Bioclastic calcisphere wackestone above the echinoderm debrite at Groß-Flöthe (bed 8), indicating renewed authochthonous sedimentation (TST of the *Didymotis* Sequence) (width of picture: 4.9 cm)

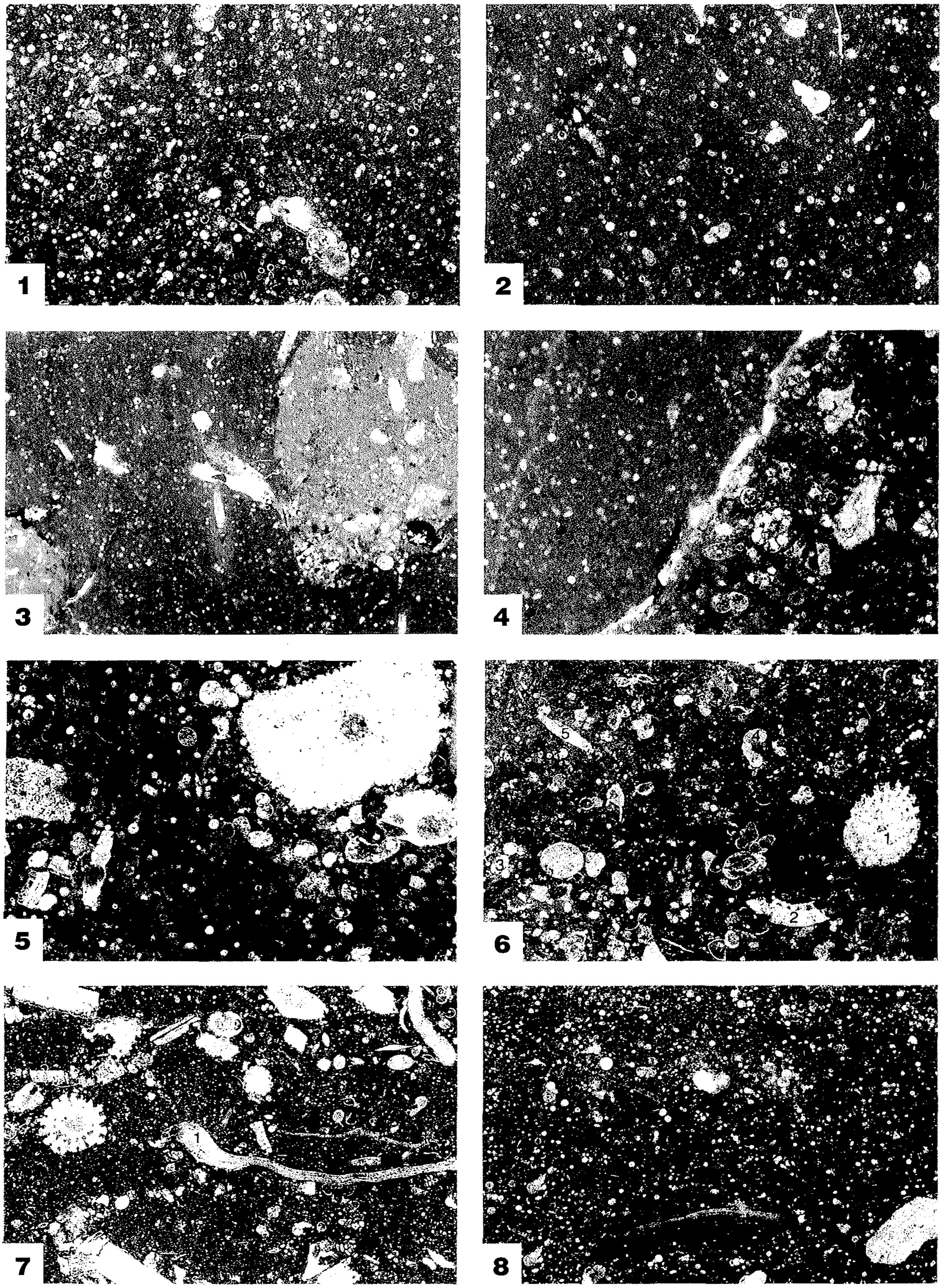
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PLATE 2

1 – Limonitized sponge from the Sponge Bed of Nettlingen, late HST of the *Hyphantoceras* Sequence (× 1).

2 – *Cystispongia bursa* (QUENSTEDT), Heteromorph Beds of Groß-Flöthe (bed 5), HST of the *flexuosum* Sequence (× 1).

3 – Associated ossicles of *Metopaster* sp. (?), Heteromorph Beds at Groß-Flöthe (bed 5), HST of the *flexuosum* Sequence (× 1)

4 – *Hirudocidaris* sp., bed 5 at Nettlingen, TST of the *Didymotis* Sequence (× 1)

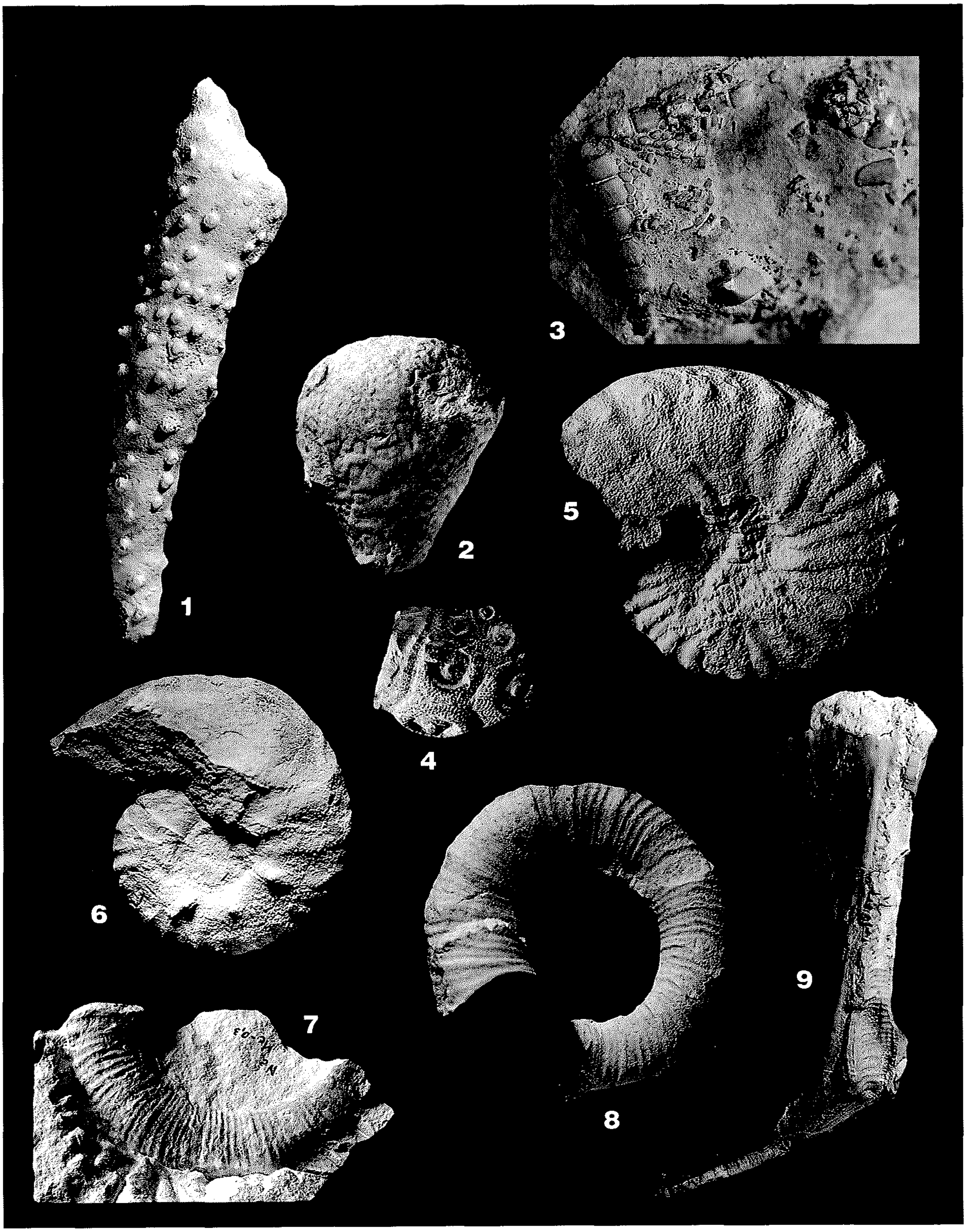
5 – *Subprionocyclus normalis* (ANDERSON), loose from the lower Heteromorph Beds (approximately base of bed 5) at Groß-Flöthe, HST of the *flexuosum* Sequence (× 1)

6 – *Lewesiceras mantelli* WRIGHT & WRIGHT, base of the exposed strata at Groß-Flöthe. It belongs to the desmoceratid ammonite assemblage of the *Hyphantoceras* Event *sensu* KAPLAN (1991), TST of the *flexuosum* Sequence (× 1)

7 – *Neocrioceras* sp. aff. *paderbornense* (SCHLÜTER), Heteromorph Beds (bed 1) at Nettlingen, uppermost *flexuosum* Sequence (× 1)

8 – *Hyphantoceras flexuosum* (SCHLÜTER), base of the exposed strata at Groß-Flöthe. It occurs together with *Lewesiceras mantelli* in the desmoceratid ammonite assemblage of the *Hyphantoceras* Event *sensu* KAPLAN (1991), TST of the *flexuosum* Sequence (× 1)

9 – Large hinge of *Inoceramus hercules* HEINZ from the Heteromorph Beds (bed 5) at Groß-Flöthe, uppermost *flexuosum* Sequence. Original size: 20 × 9 cm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