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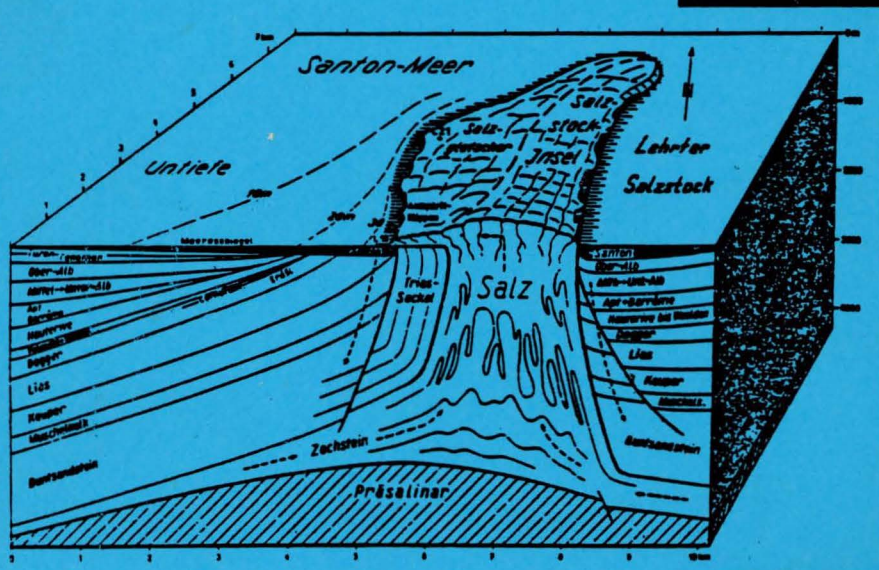
GEOLOGISCHE UND GEOTECHNISCHE

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HEFT 46 (1997)

J. MUTTERLOSE,
M. G. E. WIPPICH
& M. GEISEN (EDS.)

CRETACEOUS DEPOSITIONAL ENVIRONMENTS OF NW GERMANY



Bochumer geologische und geotechnische Arbeiten

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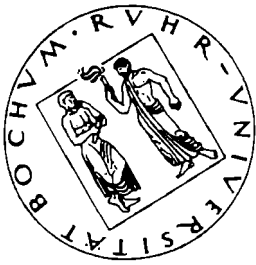
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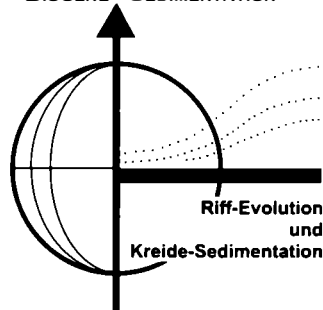
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HEFT 46 (1997)

**J. MUTTERLOSE,
M. G. E. WIPPICH
& M. GEISEN (EDS.)**

**CRETACEOUS
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ENVIRONMENTS
OF NW GERMANY**

DFG-Schwerpunkt
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Abstract

15 outcrops exposing sediments of Early and Late Cretaceous age (Berriasian-Campanian) are described from the Subhercynian Basin (Quedlinburg-Blankenburg area) and the eastern part of Lower Saxony (Salzgitter-Hannover area). Apart from the bio- and lithostratigraphy, the fauna, flora, sedimentology, the palaeoenvironment and the regional position of these outcrops is discussed. New data and results going back to research performed from 1990 to 1996 are presented and sequence-stratigraphic models are proposed for some outcrops. Some of the microfauna and -flora and the macrofauna is documented by plates.

The following outcrops exposing sediments of Early Cretaceous age are described: the Obernkirchen Sandstone (Berriasian) at Münchehagen (No. 15), mid-Hauterivian sediments rich in ammonites near Resse (No. 13), pale-dark bedding rhythms of Late Hauterivian age near Frielingen (No. 14), Hauterivian iron ores of the Glockenberg section (No. 5) and clays of Barremian and Aptian age near Sarstedt (No. 9). Outcrops of sediments of Late Cretaceous age are: Hoppenstedt (No. 3), Vienenburg (No. 4), Baddeckenstedt (No. 6), and the HPCF II quarry at Misburg (No. 10), exposing the Cenomanian and Lower Turonian; the sediments exposed in the Salzgitter-Salder quarry (No. 7) are of mid-Turonian to Early Coniacian age, the Lehofsberg section near Quedlinburg (No. 1) is of mid-Coniacian age; shallow marine clastics of early Campanian age of the Subhercynian Basin are described from near Blankenburg (No. 2), marly and calcareous Campanian basinal sediments are exposed in the HPCF II (No. 10), Germania IV (No. 11) and Teutonia I (No. 12) quarries at Misburg.

Zusammenfassung

Aus dem nördlichen Harzvorland (Raum Quedlinburg-Blankenburg) und dem östlichen Niedersachsen (Großraum Salzgitter-Hannover) werden 15 Tagesaufschlüsse beschrieben, in denen Sedimente der Unter- und Oberkreide (Berrias-Campan) anstehen. Neben der Bio- und Lithostratigraphie, werden Fauna, Flora, Sedimentologie, das Ablagerungsmilieu und die regionalgeologische Stellung dieser Aufschlüsse dargestellt. Es werden neue Forschungsergebnisse aus den Jahren 1990 bis 1996 vorgestellt und für einige Aufschlüsse werden sequenzstratigraphische Modelle diskutiert. Ein Teil der Mikrofauna und -flora sowie der Makrofauna ist auf Fototafeln dokumentiert.

Der berriaszeitliche Obernkirchener Sandstein wird in einem Aufschluß in Münchehagen (Nr. 15) behandelt, ammonitenreiche Sedimente des mittleren Hauterive in Resse (Nr. 13), hell-dunkel gebankte Sedimente des höheren Hauterive in Frielingen (Nr. 14), hauterivezeitliche Trümmereisenerze der Randfazies im Glockenberg-Profil (Nr. 5) und Tonsteine des Barrême und Apt in Sarstedt (Nr. 9). Oberkretazische Sedimente des Cenoman und tiefen Turon sind in Hoppenstedt (Nr. 3), in Vienenburg (Nr. 4), in Baddeckenstedt (Nr. 6) und in der Grube HPCF II in Misburg (Nr. 10) erschlossen. Das Profil Salzgitter-Salder (Nr. 7) umfaßt das mittlere Turon bis mittlere Coniac, das Profil am Lehofsberg bei Quedlinburg (Nr. 1) das mittlere Coniac in seiner Randfazies. Frühcampanzeitliche, flachmarine Klastika des Subherzyn werden am Beispiel eines Aufschlusses bei Blankenburg (Nr. 2) beschrieben, während die mergelig-kalkige Beckenfazies des Campan durch die drei Mergelgruben HPCF II (Nr. 10), Germania IV (Nr. 11) und Teutonia I (Nr. 12) in Misburg abgedeckt wird.

1. Introduction (Figs. 1-3)

(by J. Mutterlose)

In the context of the "Fifth International Cretaceous Symposium" at Freiberg from 16. 9. to 24. 9. 1996, several field trips were organized. Field trip B2 entitled "Cretaceous Depositional Environments of the Eastern Part of the NW German Basin (Quedlinburg-Salzgitter-Hannover)" covered outcrops of Cretaceous age in the Subhercynian Basin and in Lower Saxony. The present field guide, developed from this symposium field trip, describes sections of both Early and Late Cretaceous age. From 1990 to 1996 various research projects dealing with the German Cretaceous have been funded by the German Science Foundation (DFG). A research programme entitled "Global and Regional Processes of Biogenic Sedimentation" allowed the funding of several PhD-theses covering palaeontologic, geologic and geochemic aspects. Apart from sequence-stratigraphy, the analyses of sedimentary bedding

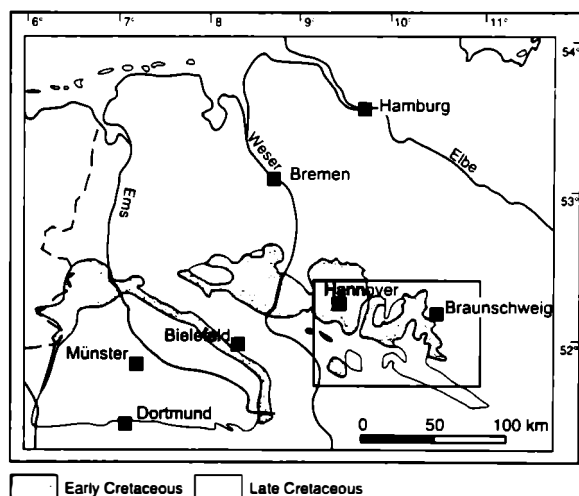


Fig. 1. Regional distribution of Cretaceous rocks in northern Germany. The area covered by this field guide is indicated.

rhythms, Cretaceous black shales and palaeoclimatic aspects played an important role within this programme. It is the objective of this field guide to demonstrate the results of this most recent research in the

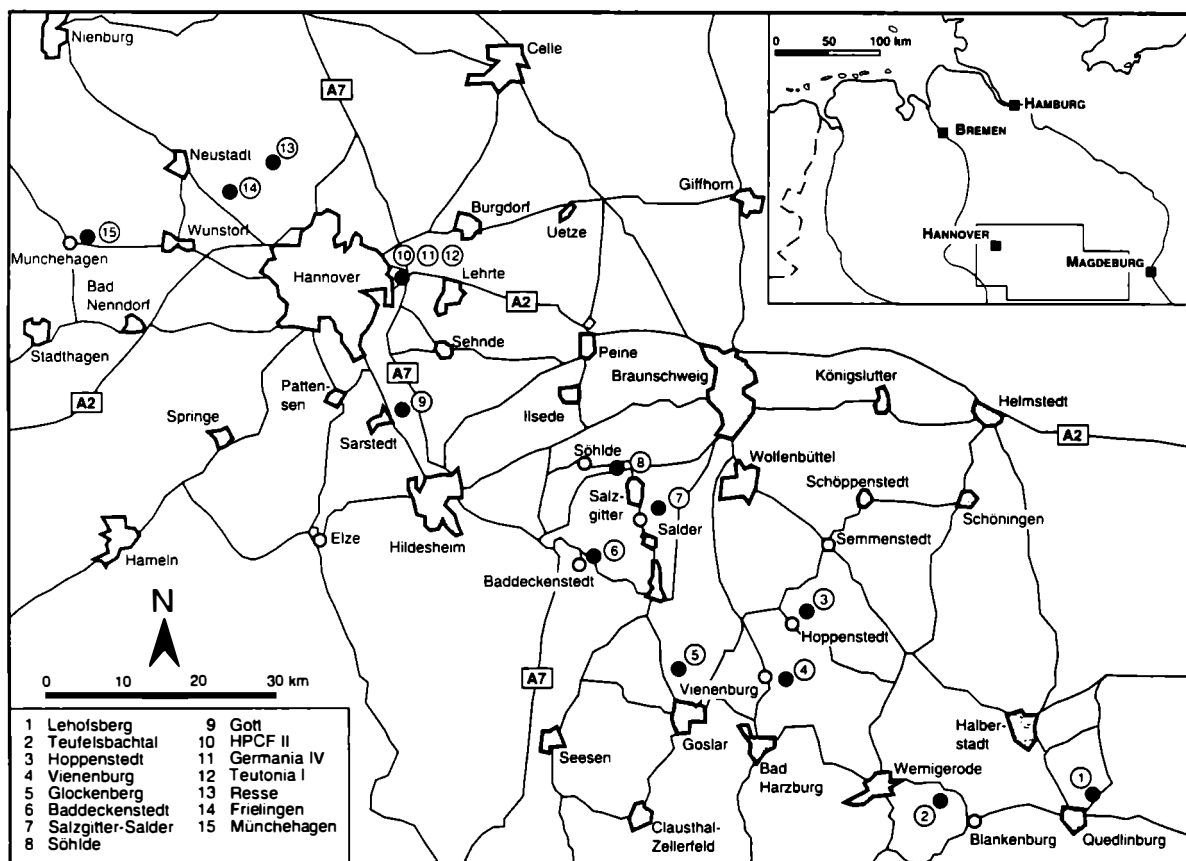


Fig. 2. Overview of the geographic position of the exposures described in this field guide.

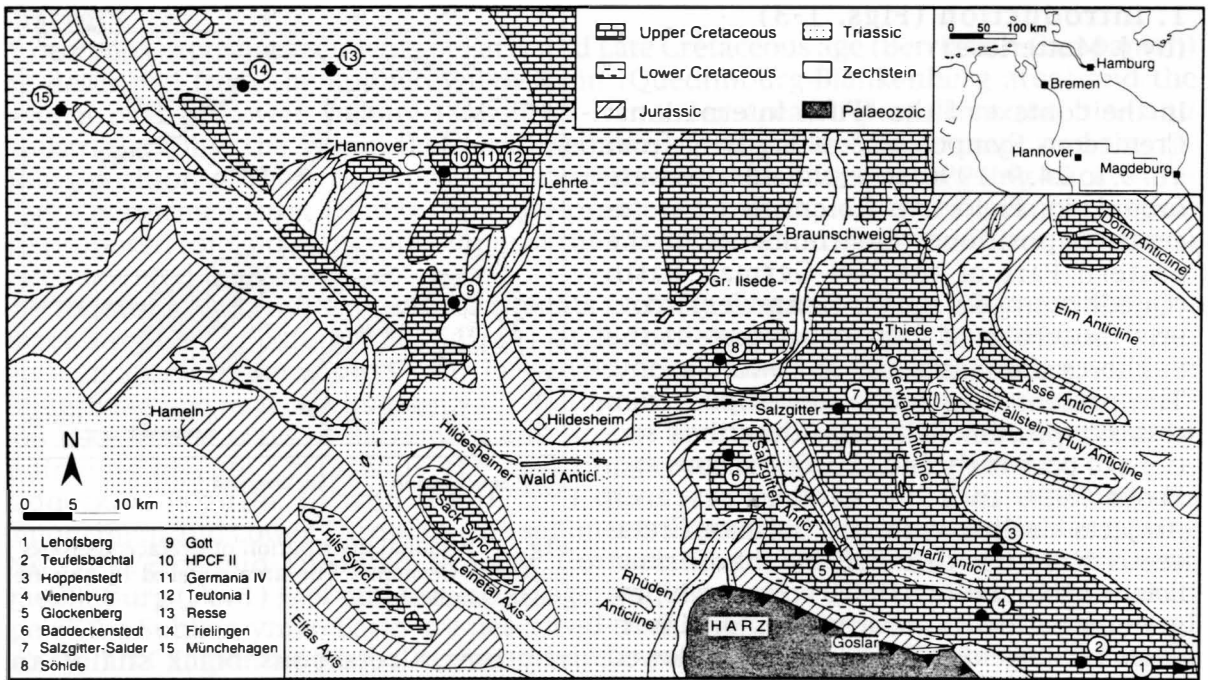


Fig. 3. Generalized geologic map and the Central Lower Saxony. The sections described in this guide are indicated, for section No. 1 see Fig. 14.

field. Additional details are to be found in the volume “Cretaceous Biogenic Sedimentation and Stratigraphy” soon to be published by Springer, synthesizing all the results.

In N Germany sediments of Cretaceous age occur, from west to east, in the following areas:

- Maastrichtian of the Aachen area,
- Berriasian-Albian of the Emsland,
- Cenomanian-Campanian of the Münsterland,
- Berriasian-Albian of the Teutoburger Wald and Egge Gebirge,
- Berriasian-Hauterivian north of the Wiehengebirge,
- Berriasian-Albian of the Minden-Hannover-Braunschweig-Salzgitter area,
- Cenomanian-Campanian of the Hannover-Braunschweig-Salzgitter area,
- Barremian-Campanian of the Subhercynian Basin,
- Maastrichtian of the Rügen area,
- Cenomanian-Santonian of the Elbsandsteingebirge.

The regional distribution of Cretaceous

rocks in N Germany is shown in Fig. 1, the area covered by this field guide is indicated. This guide book describes exposures from three of the regions mentioned above. Lehofsberg near Quedlinburg (No. 1), Teufelsbachtal near Blankenburg (No. 2), Hoppenstedt (No. 3), Vienenburg (No. 4) and Glockenberg (No. 5) are situated in the Subhercynian Basin. Baddeckenstedt (No. 6), Salzgitter-Salder (No. 7), Söhlde (No. 8), the HPCF II (No. 10), Germania IV (No. 11) and Teutonia I (No. 12) quarries near Misburg represent the Cenomanian-Campanian of the the Hannover-Braunschweig-Salzgitter area. Sarstedt (No. 9), Resse (No. 13), Frielingen (No. 14) and Munchenhagen (No. 15) are exposures of the Berriasian-Albian of the Minden-Hannover-Braunschweig-Salzgitter area.

Fig. 2 gives an overview of the geographic position of the 15 exposures described in this volume, Fig. 3 shows the geologic setting. The numbers used in both maps correspond to the numbers used in Chapter 2 to describe the exposures.

1.1 Lower Cretaceous (Figs. 4-11) (by J. Mutterlose)

Overview: Marine sediments of Berriasian-Barremian age are widespread in NW Germany and, to a certain extent, in NE England, where they have been studied for over a hundred years. Aptian-Albian strata are mainly exposed in southern England and NW Germany. In addition, Early Cretaceous sediments are present in the North Sea area, though the information on these is relatively scarce and patchy.

During the Early Cretaceous the NW Euro-

pean area was composed of a number of basins. These formed the southernmost extension of the Boreal-Arctic sea further to the north. There also existed sea-ways towards the Tethys to the south. Due to the palaeogeographic position of the NW European area between the Boreal and the Tethyan Realm, palaeoceanographic changes become more obvious in this area than elsewhere. Marginal epicontinental seas like this were extremely sensitive to changes of sea-level, palaeogeography and palaeoclimate.

The NW German Basin, which formed the

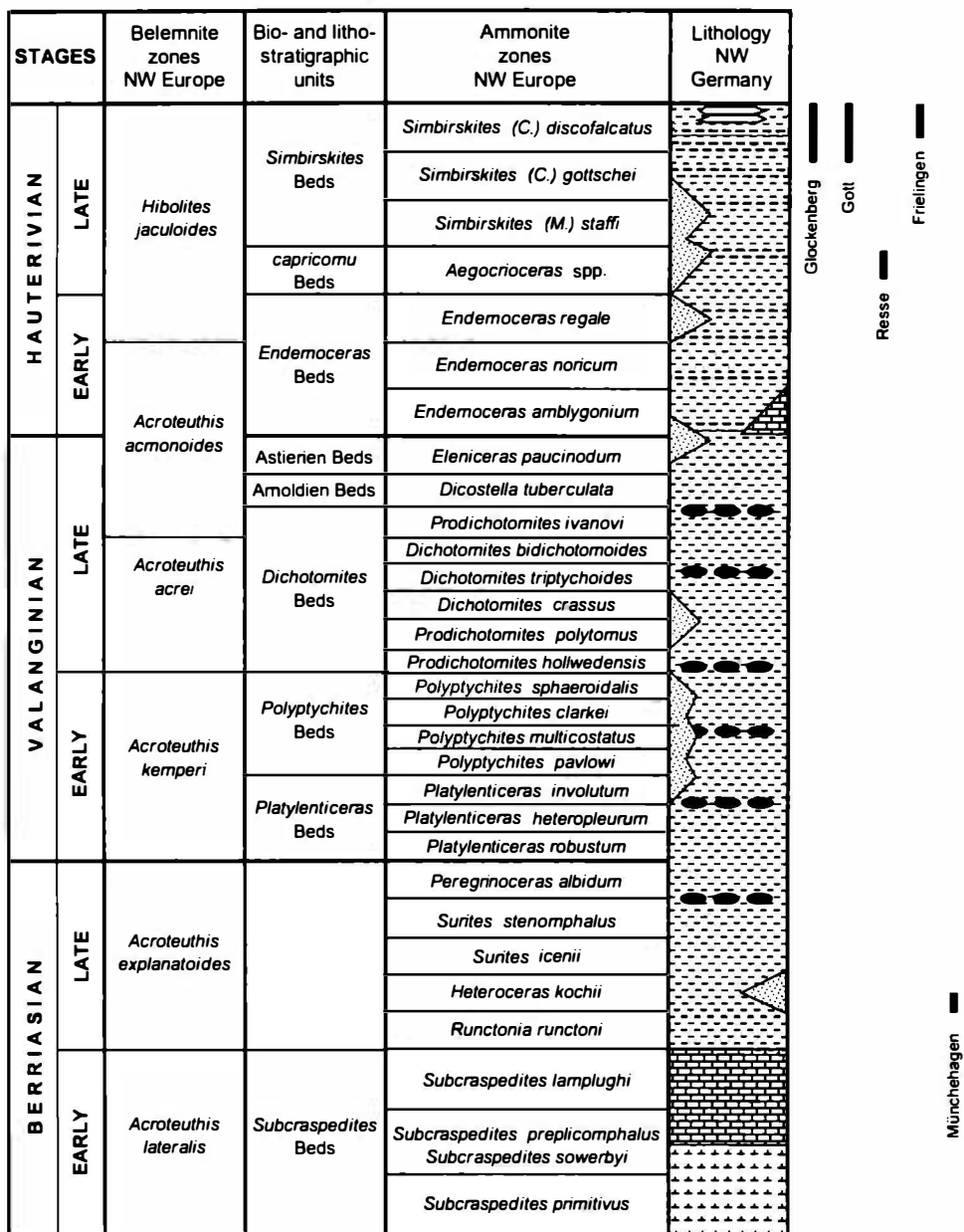


Fig. 4. Lithology and biostratigraphy of the Berriasian to Hauterivian interval of NW Germany. The stratigraphic ranges of the Lower Cretaceous sections described in this field guide are indicated.

southernmost extension of the North Sea Basin, had a length of about 280 km and a width of about 80 km. More than 2000 m of Lower Cretaceous sediments accumulated in this epirogenic basin. The central parts of the basin are characterized by continuous subsidence and great thicknesses of shales and mudstones (Figs. 4, 5). Along the margins, however, shallow water sediments including sand- and ironstones were deposited. Due to lithologic variation within the basin, it is possible to differenti-

ate a western part (Rheine-Bentheim-Meppen-Groningen area), a central part (Osnabrück-Bielefeld-Minden-Vechta area) and an eastern part (Hannover-Braunschweig-Salzgitter area) (SCHOTT et al. 1967, 1969). The sections described in this field guide are situated in the eastern part of the basin. Detailed descriptions of the evolution of the basin have been given by SCHOTT et al. (1967, 1969), MICHAEL (1974, 1979), KEMPER (1979) and MUTTERLOSE (1992). This field guide aims to demonstrate the

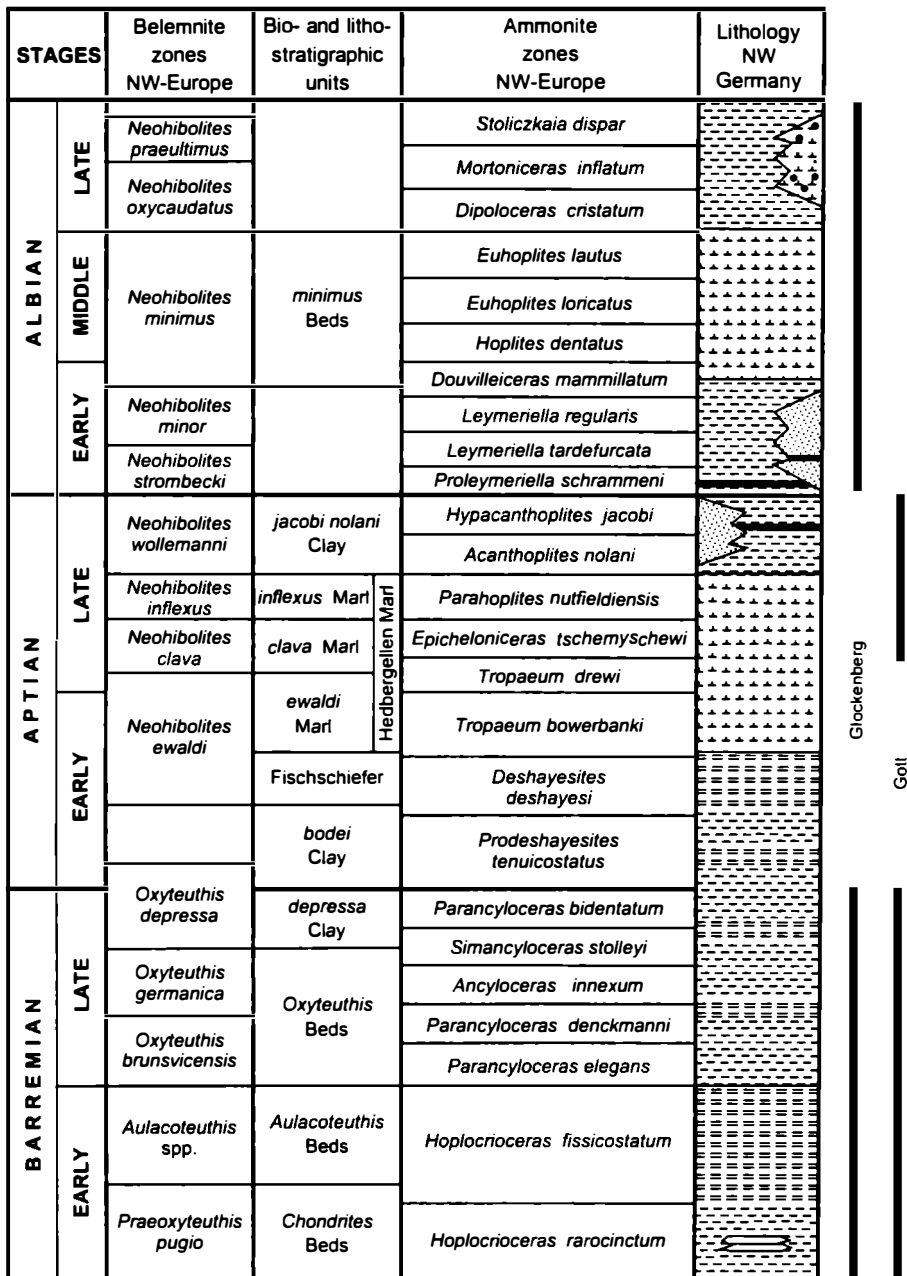


Fig. 5. Lithology and biostratigraphy of the Barremian to Albian interval of NW Germany. The stratigraphic ranges of the Lower Cretaceous sections described in this field guide are indicated.

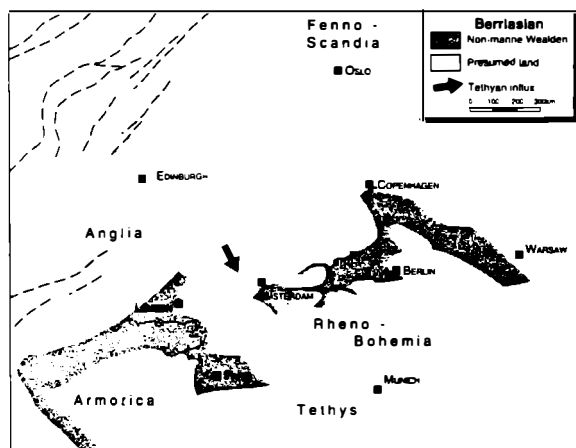


Fig. 6. Palaeogeographic setting of the Berriasian of NW Europe.

palaeoceanographic changes occurring within the Early Cretaceous of NW Europe by integrating sedimentologic and palaeontologic observations. The distribution of sediments and biota clearly reflect palaeoceanographic changes throughout the Early Cretaceous. These data are based on most recent studies of the lithology, geochemistry and palaeoecology of the Berriasian-Albian interval.

Evolution of the NW German Basin:

The Berriasian is represented by non-marine Wealden sediments, deposited under brackish-lacustrine conditions (Figs. 6, 10). However, several short-lived marine incursions occurred, allowing marine biota (including foraminifera) to spread into the basin from the northwest via the Netherlands. The base of the Valanginian is marked by a major transgression and the return of marine conditions in NW Ger-

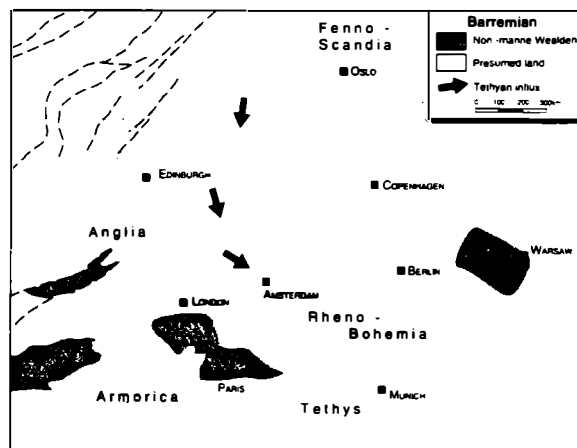


Fig. 8. Palaeogeographic setting of the Barremian of NW Europe.

many (Figs. 7, 10). These are represented by the fully marine *Platylenticeras* Beds. During the Early Valanginian transgression, the Carpathian sea-way opened towards the Tethys via Poland. This sea-way, which existed throughout the Valanginian, enabled an exchange of Tethyan and Boreal nannofloras and faunas. The Gifhorn Channel, the Hoya Channel and the Ems Channel linked the NW German Basin to the southern North Sea via the Pompeckj Block. The marine floras and faunas of the Early Valanginian of NW Germany have a Boreal character, Tethyan elements being largely absent from the Boreal Realm at this time. A widespread transgression is evident for the early Late Valanginian over much of Europe. This caused an expansion of the NW German Basin, in many places Late Valanginian sediments rest with a non-sequence on Berriasian strata. In the western part of the basin the Lower Valanginian

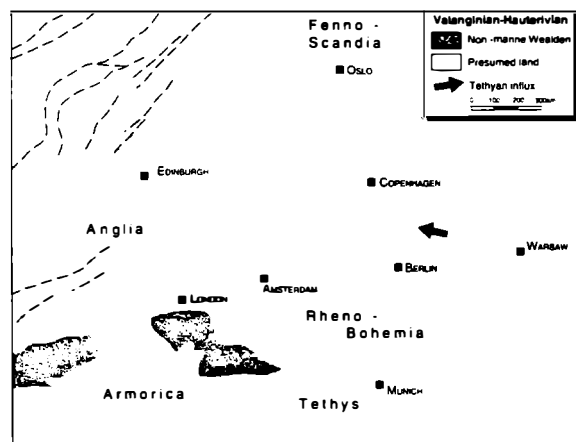


Fig. 7. Palaeogeographic setting of the Valanginian-Hauterivian of NW Europe.

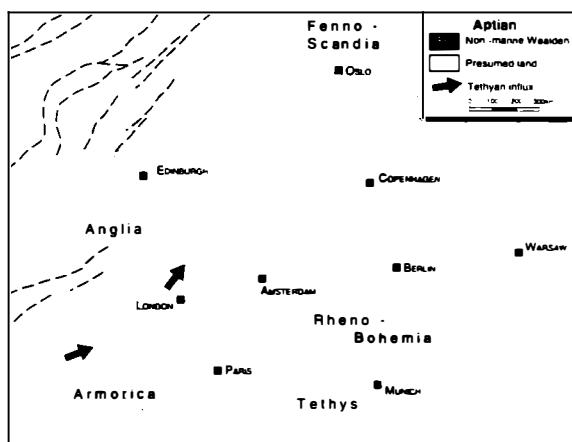


Fig. 9. Palaeogeographic setting of the Aptian of NW Europe.

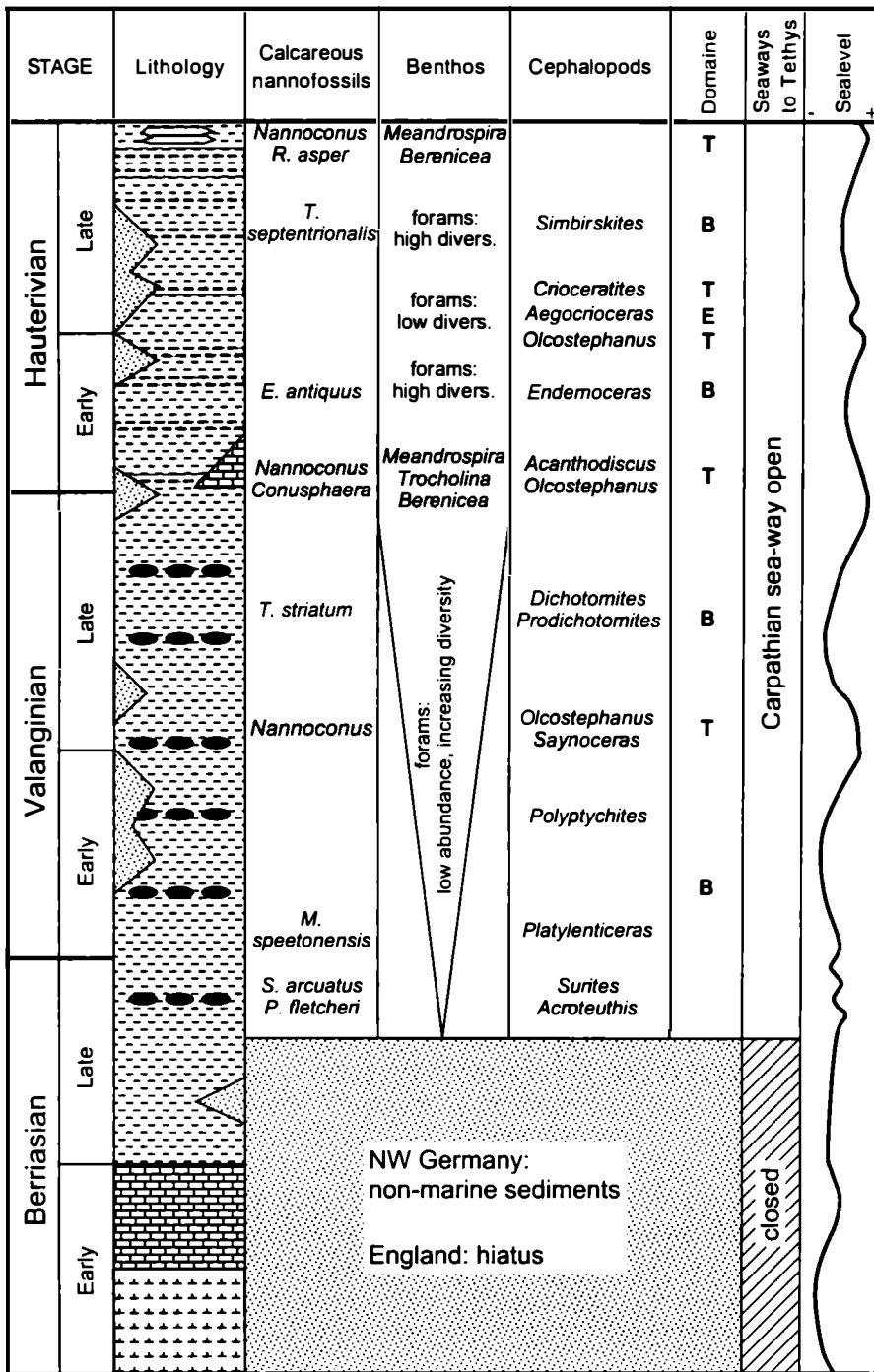


Fig. 10. Distributions of nannofloras and faunas, sea-ways and assumed sea-level curve for the Berriasian-Hauterivian interval in NW Europe (modified after MUTTERLOSE 1992). Sea-level curve according to observations in NW Europe.

Bentheim Sandstone is overlain by clays. The mid-Late Valanginian Dichotomiten Sandstone of NW Germany may record a subsequent minor regression, followed by the transgressive Arnoldien- and Astierien Beds. Overall, Boreal nannofloras and faunas dominate most of the Late Valanginian of NW Europe. During two periods, in the early Late Valanginian and in the latest

Valanginian (=Astierien- and Arnoldien Beds), there were extensive influxes of both Tethyan nannofloras and faunas via the Carpathian sea-way (Fig. 7). For the Hauterivian, the general outline of the palaeogeography is similar to that of the Valanginian. In NW Germany marine strata of Hauterivian age are widespread and, in the basin facies, they are repre-

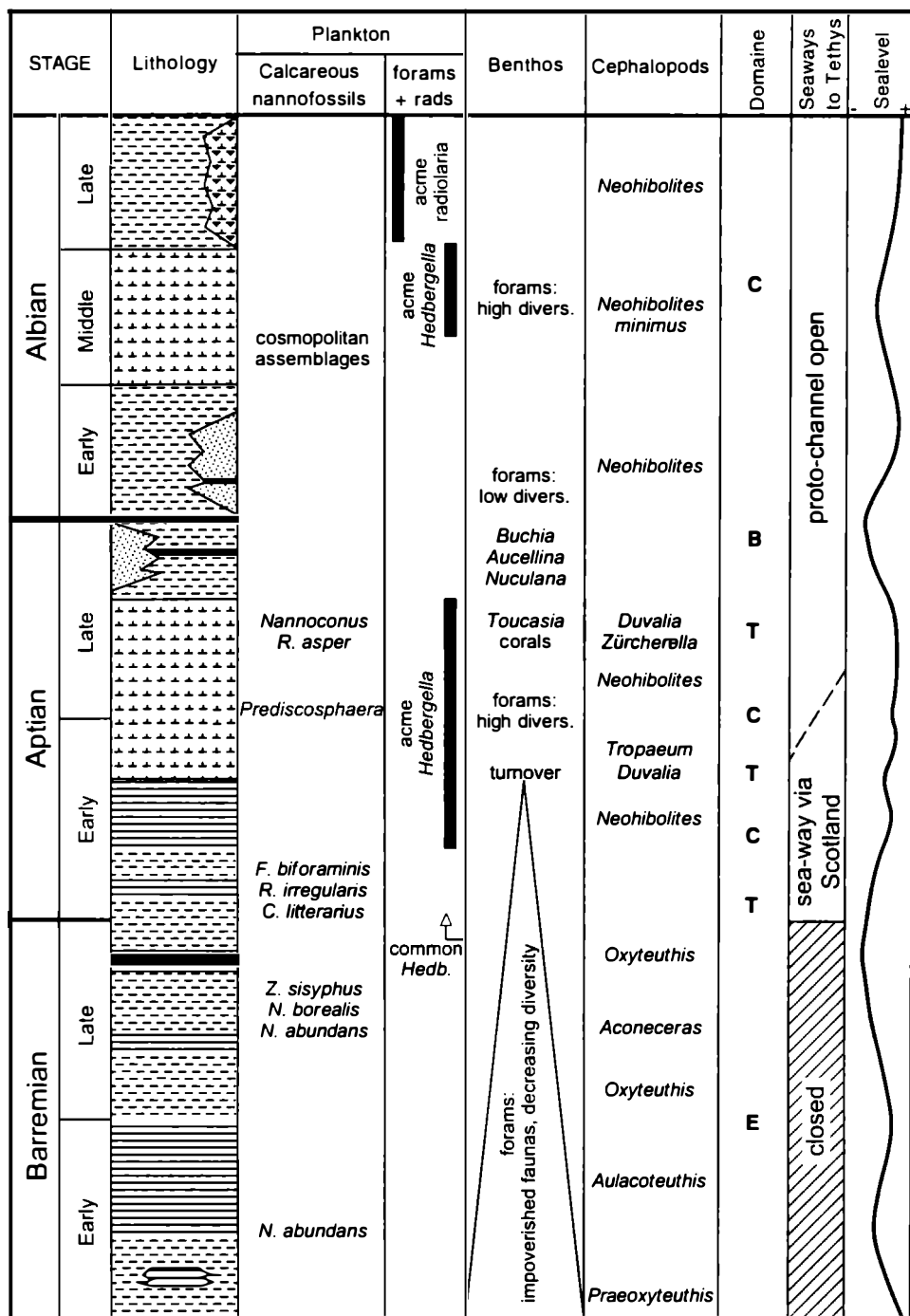


Fig. 11. Distributions of nannofloras and faunas, sea-ways and assumed sea-level curve for the Barremian-Aptian interval in NW Europe (modified after MUTTERLOSE 1992). Sea-level curve according to observations in NW Europe.

sented by more than 400 m of clays. In the marginal areas, thicknesses are reduced and the clay is partly replaced by sandstones or ironstones. Early in the Hauterivian a major transgression further expanded the NW German Basin (Fig. 7). This transgression began in the latest Valanginian (Arnoldien Beds) and reached its maximum in the Early Hauterivian

Endemoceras amblygonium ammonite Zone. The Grenz Sandstone at the Valanginian/Hauterivian boundary in NW Germany records a minor regression within this transgressive sequence. A subsequent regression of late Early Hauterivian age is marked by the *norcium* Sandstone. The latest Valanginian (Arnoldien- and Astierien Beds) and the earliest Hauterivian are char-

acterized by a strong influx of Tethyan nanofloras and faunas, which must have used the Carpathian sea-way. The regression of the late Early Hauterivian (*Endemoceras regale* ammonite Zone) was followed by an extensive mid-Hauterivian transgression (*Aegocrioceras* ammonite Beds and lower *Simbirskites (M.) staffi* ammonite Zone). After a regression in the mid-Late Hauterivian (upper *S. (M.) staffi* ammonite Zone and *Simbirskites (C.) gottschei* ammonite Zone), recorded by the Gildehaus Sandstone, another transgressive peak is to be observed in the latest Hauterivian (*Simbirskites (C.) discofalcatus* ammonite Zone).

Nannofloras and microfauas of low diversity and abundance are present in the lowermost Upper Hauterivian (= *Aegocrioceras* Beds), the ammonites being of Boreal, Tethyan and endemic provenance. This level correlates with the widespread mid-Hauterivian transgression. The middle part of the Upper Hauterivian yields Boreal and endemic nanofloras and faunas, with brief influxes of Tethyan ammonites (*Crioceratites*). The biota indicate a regressive phase, Tethyan nannoconids being absent from this interval. Finally, Tethyan influxes of nanofloras and faunas again become obvious in the uppermost Hauterivian. This is supported by recent finds of foraminifera of warm water affinities and bryozoans in the *discofalcatus* Zone.

Significant palaeogeographic and palaeoceanographic changes occurred at the Hauterivian/Barremian boundary; the overall regressive nature of the Barremian is often cited. A regression at the base of the Barremian caused brackish-lacustrine conditions in central and southern Poland. In NW Germany, the entire Barremian reaches a thickness of more than 200 m. The sediments, nanofloras and faunas in both areas are uniform throughout. Finely laminated sediments, known as "Blättertton" horizons, are typical of the Barremian of NW Germany (Figs. 8, 9). While the "Hauptblättertton" (main Blättertton) is of late Early Barremian age, thin Blättertton horizons are common in the early Late Barremian. Towards the centre of the basin the number of Blättertton horizons in-

creases. These sediments are enriched in organic matter (6 to 8% TOC) and were deposited under anoxic conditions. The Barremian was a period of restricted conditions, allowing the deposition of these organic-rich sediments. The palaeogeographic and palaeoceanographic configuration favoured the evolution of endemic species from Tethyan ancestors at the Hauterivian/Barremian boundary. Within both nanofloras and faunas, endemic species evolved simultaneously and became quite abundant. These are associated with Boreal elements, while Tethyan forms are extremely rare or absent.

Several transgressions, with intervals of shallowing and regression in between, through the Aptian and Albian enlarged the depositional areas in NW Europe (Figs. 9, 11). The Early Aptian transgression caused significant changes in the palaeogeography. New sea-ways between the Tethys and the Boreal Realm opened via northern France and southern England, while brackish-lacustrine deposition prevailed in Poland. In NW Germany, the Aptian comprises at least 200 m of clays and marls. Dark clays (*bodei* Clay) are overlain by the Fischschiefer, a finely laminated sediment rich in organic matter (Figs. 5, 11). Above this horizon follow dark clays and three marly horizons rich in carbonate: the *ewaldi* Marl, the *clava* Marl and the *inflexus* Marl. The uppermost Aptian consists of dark clays. Cosmopolitan elements dominated in NW Europe and the endemic forms of the Barremian became extinct. The fluctuations of the calcareous nannofossils, in particular the distribution of nannoconids, indicate three periods of Tethyan influxes: 1) lowermost Aptian, 2) *ewaldi* Marl, 3) *inflexus* Marl. On the other hand, three periods without or with only few nannoconids can be recognized: 1) black clays below the Fischschiefer, 2) the *clava* Marl, 3) the black *nolani-jacobi* Clays. Sediments of earliest Albian age resemble the black *nolani-jacobi* Clays. It is only in the mid Early Albian and mid-Albian that a major transgression changes the depositional environment significantly.

References: KEMPER (1979); MICHAEL (1974, 1979); MUTTERLOSE (1992); SCHOTT et al. (1967, 1969).

1.2 Upper Cretaceous (Figs. 12, 13) (by C. J. Wood & G. Ernst)

Overview: The localities to be described belong to the eastern sub-basin of the Hercynian (WNW-ESE) trending Lower Saxony Basin (LSB), i.e. the area E of the NNW-SSE Steinhude Lineament (BALDSCHUHN et al. 1991). The LSB graben underwent subsidence from early Portlandian to late Aptian times, after which there was reduced tectonic activity until the late Turonian. Inversion began in the early Coniacian, reached its peak during the Santonian and continued into Campanian times. Further inversion took place in the latest Cretaceous and early Tertiary. The cumulative inversion converted the former graben into the present tectonically stable Lower Saxony tectogene.

Since Upper Cretaceous deposition in the area and the extent to which the sediments have been subsequently preserved are strongly controlled by the structural setting, it is necessary to describe this aspect before considering the stratigraphy. Three major structural units can be distinguished, comprising, from E to W: 1) the Hercynian-trending Subhercynian Basin, 2) the Rhenish zone, 3) the Hercynian zone S and W of Hannover.

The Subhercynian Basin (SHB): The SHB is bounded to the SW by the Harz block and to the NE by the Flechtingen High. It is differentiated into a succession of Hercynian-trending broad symmetrical salt pillows (Fallstein and Elm) and narrow asymmetrical, salt-injected anticlines (Harli-Berg or Vienenburg and Asse). Reflection seismic work (BRÜNING et al. 1987) has shown that the Harli-Berg Anticline, like the Quedlinburg Anticline, is a salt-injected thrust structure resulting from inversion of the Fallstein. The Asse and Elm form an analogous structural pair. The SSW-directed Harli-Berg thrust opposes the NNW-directed Harz northern boundary thrust. The Dorm Anticline is a narrow salt structure with diapirs. The Upper Cretaceous is preserved in the intervening synclines (Subhercynian Cretaceous Syncline, Beiwende Syncline, Schöppenstedt Syncline and the Beienrode Basin) either as largely complete successions or as isolated relicts. In the Subhercynian Cretaceous Syncline, situated parallel to the steeply inclined (40°-50°

SSW) Harz northern boundary thrust, the Upper Cretaceous (Cenomanian-Lower Campanian) attains considerable thicknesses, locally more than 2000 m. This is the classic example of sedimentation in a subsiding marginal trough in front of an inverting massif (VOIGT 1963). During the early part of the Late Cretaceous, the sea actually extended far to the south and the area occupied today by the Harz formed part of the original basin. The discovery in the Cenomanian at Baddeckenstedt, ca. 35 km from the Harz, of a group of gastroliths comprising lithologies of probable Harz massif provenance suggests that at least part of the massif must have been emergent as an island at this time (ERNST et al. 1996). However, following uplift, the massif formed the coastline of the Cretaceous sea, as demonstrated by the occurrence of marginal facies.

In the northern synclines, the Upper Cretaceous is much thinner and includes larger sedimentary hiatuses resulting from Subhercynian tectonism. In the Beiwende Syncline, S of the Asse Anticline, higher Santonian or Lower Campanian rests on Middle Turonian, while in the Schöppenstedt Syncline to the N, the Upper Cretaceous succession ends low in the Turonian. In the Beienrode Basin, Cretaceous sedimentation began with the latest Early Campanian *mucronata* transgression: here glauconitic sediments rest on Middle Keuper (NIEBUHR & ERNST 1991).

Uplift of the Harz massif during the late Cretaceous resulted in steeply inclined to overturned (85° SSW) Mesozoic strata in the narrow zone ("Aufrichtungszone") parallel to the northern boundary thrust. There were two main (so-called "Subhercynian") inversion phases, the Ilsede and Wernigerode Phases, the latter being structurally the more significant. Each uplift phase was followed by a phase of renewed transgression, so that in the Aufrichtungszone there is repeated onlap of later strata over the earlier upturned strata. The Subhercynian inversion phases (tectoevents) are expressed in the sedimentary record by significant lithofacies changes (e.g. the change from Pläner carbonate facies to Emscher argillaceous facies) and/or major hiatuses. They also caused or accentuated uplift of pre-existing salt structures throughout the area, creating submarine swells or even island

chains, with resultant facies differentiation of Cretaceous sedimentation. To varying degrees, the effects of these phases can also be recognized throughout Europe.

The onset of the Ilsede Phase is seen in Vienenburg (No. 4), where Early Coniacian marl-limestone alternations with inoceramids are interrupted by glauconitic turbidites. The Wernigerode Phase can be accurately dated to within a single macrofossil zone, indicating very rapid uplift: in the Subhercynian Syncline, late Santonian Heimburg Beds rest discordantly on the Teufelsmauer Sandstone, both yielding *Marsupites* (VOIGT 1929).

The zone of Rhenish structures: The SHB is truncated to the W by a zone of Rhenish (NNE-SSW) structures, which follows the Rhine Graben-Gifhorn Trough Lineament (see NIEBUHR 1995). This zone strongly overprints the Hercynian structural trend and includes most of the area between Braunschweig and Hannover. It is characterized by several subparallel elongate Rhenish salt structures associated with complex fault-zones, which represent a continuation of the swarms of similar structures to the north. These salt structures comprise, from E to W, the Broistedt salt structure, the salt structures in the Stederdorf Graben, the Lehrte-Sarstedt salt structure and the Benthe salt structure (Fig. 54).

The Upper Cretaceous is preserved on the flanks of the salt structures and in the intervening broad synclines (Meine-, Peine-, Lehrte West- and Pattensen Synclines). Typically, only the higher stages (Santonian-Campanian or just Campanian) are found here (NIEBUHR 1995). However, in the Kronsberg Syncline adjacent to the Lehrte West Syncline, as well as in the Pattensen Syncline, Cenomanian and Lower Turonian are preserved beneath transgressive Santonian, most of the Turonian and all the Coniacian being missing as a result of the Ilsede tectoevent. The thickest and most complete Campanian successions are found in the Lehrte West Syncline, where several quarries (Höver, Misburg; Nos. 11, 12) and gas pipeline sections (Ahlten) have provided a composite section up to the higher part of the Upper Campanian. A small tectonic unit of Upper Maastrichtian is preserved as field brash at Ilten to the E of these sections (VOIGT 1951).

There is an area of structural complexity N of the Harz where three major structures intersect. The Rhenish Wendeburg fault-zone with the Broistedt salt structure at its southern end comes into juxtaposition with the oblique-Hercynian (NNW-SSE), salt-injected, Salzgitter Anticline and the adjacent E-W Lichtenberg-Hohenassel structure, both of which are northward-directed asymmetrical inversion structures. Movement of these structures and uplift of the salt structure controlled sedimentation in the area to the N (Lesse Syncline). Here, the subsequently steeply uptilted thick limestone-marl successions (Salder quarry; No. 7) developed in the foredeep or marginal trough between the salt structure and the inverting Lichtenberg structure contrast with thinner, chalk facies successions (Söhle quarry; No. 8) deposited on the shelf only a few kilometres away on the N flank of the syncline. These quarries and the Baddeckenstedt quarry (No. 6; Cenomanian-Middle Turonian) in the Innerste Syncline to the S will be described below.

The Santonian iron-ores formerly worked in the Groß-Ilsede area and near Broistedt represent the marginal basal conglomerates of a Santonian transgression following the Subhercynian Ilsede tectoevent and uplift phase. The conglomerates, which are composed of ironstone geodes and phosphates reworked from the Albian, rest with erosive contact either on Albian (Groß-Ilsede) or Middle Turonian (Broistedt), in each case in proximity to a salt structure. It is this major hiatus at Groß-Ilsede that gives its name to the first Subhercynian uplift phase and its associated regression.

Zone of Hercynian structures: S and W of Hannover, the Rhenish zone abuts against a zone dominated again by Hercynian structures. The main occurrences of Upper Cretaceous are in the Hils Syncline (Cenomanian), Sack Syncline (Cenomanian-basal Coniacian), Wunstorff Cretaceous Syncline (Cenomanian-Turonian in the Wunstorff quarry) and the Gehrden Graben. In the graben, Santonian calcarenites with a basal ironstone conglomerate rest on Barremian to Aptian mudstones.

Stratigraphy: The stratigraphic diagrams (Figs. 12, 13) are intended to be largely

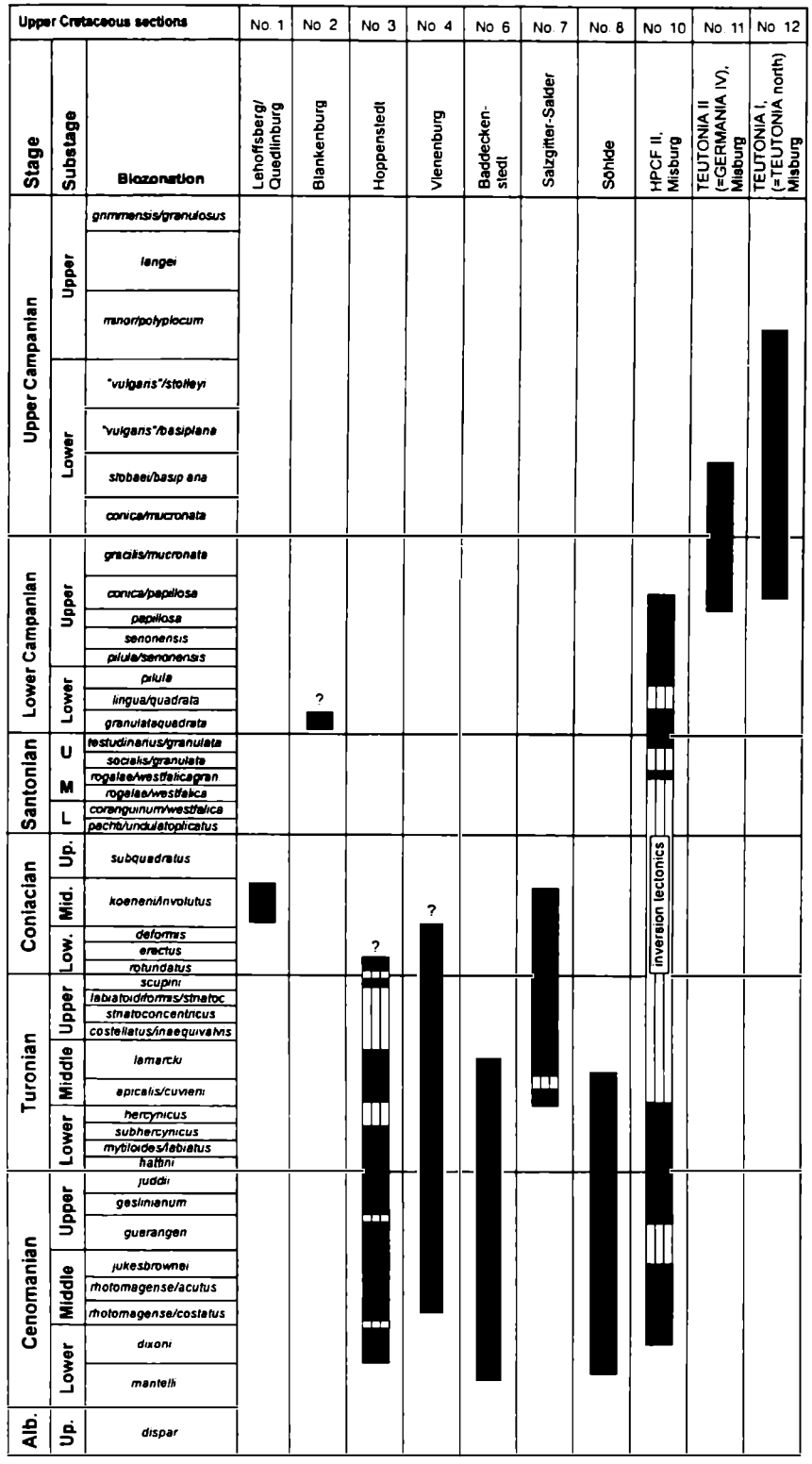


Fig. 12. Stratigraphic ranges of the described Upper Cretaceous sections.

self-explanatory, to avoid duplication of information given under the descriptions of the localities. The event stratigraphic scheme for the Cenomanian-Coniacian succession, which comprises over 30 events of

various types (ERNST et al. 1983), was originally developed in this area and the component events are documented in greater detail elsewhere in this guide. It is now known that some of the events first tenta-

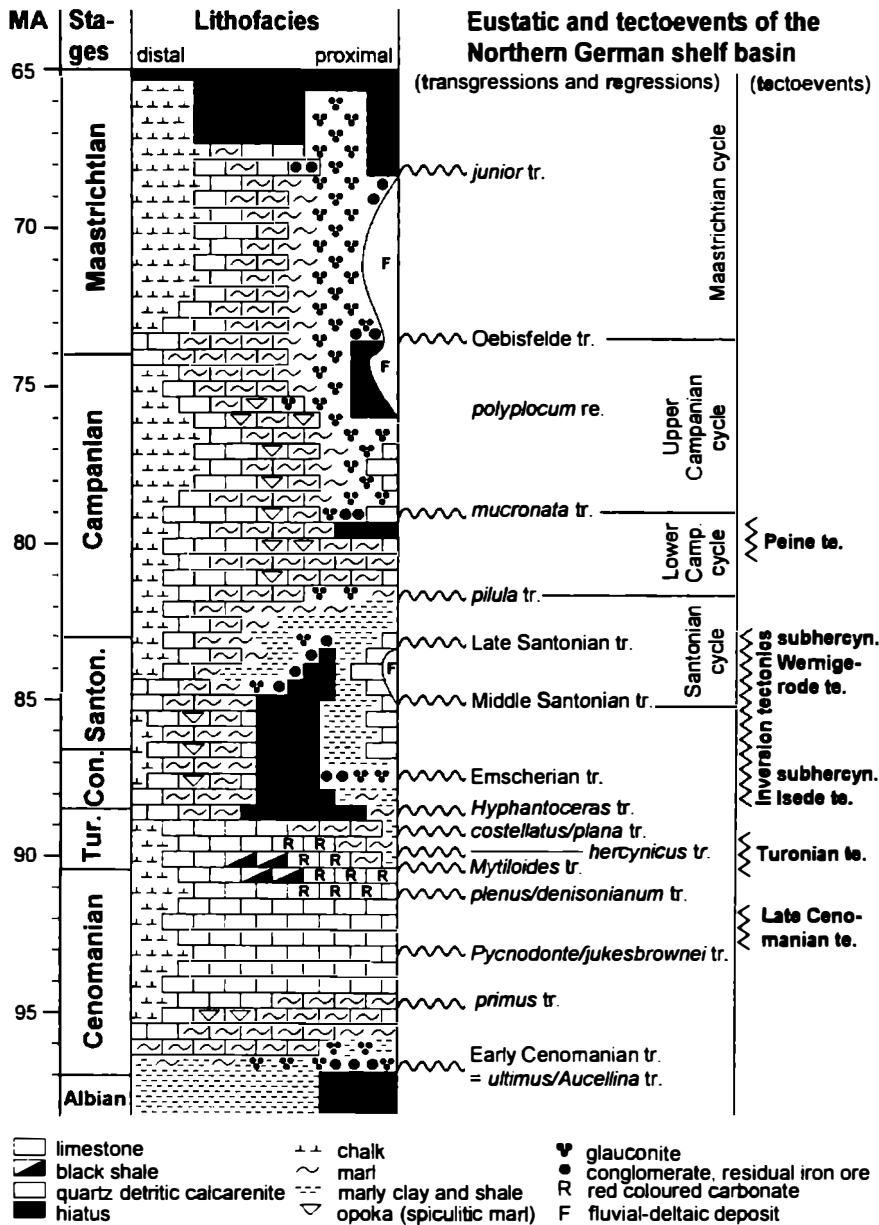


Fig. 13. Upper Cretaceous lithofacies, eustatic and tectonic events of the North German Basin (after NIEBUHR & PROKOPH in press).

tively identified here are of inter-regional lateral extent. The generalized lithostratigraphic succession is shown graphically in Fig. 13. Four major lithounits can be recognized as follows: 1) the Plänerkalk (Cenomanian-Lower Coniacian), 2) the Emscher Marl (Lower Coniacian-lower Lower Campanian), 3) the Mergelkalk (upper Lower Campanian-lower Upper Campanian), 4) the spongiolitic "Opoka" facies (upper Upper Campanian). Above the last unit, calcarenites of early Maastrichtian age are known from deep boreholes to the N of the area.

The Plänerkalk can be further subdivided into five lithological subunits. Beginning with a basal transgression, marked by glauconitic marls with phosphatized pebbles (seen in the Flöteberg road-cutting), the Cenomanian is developed as initially argillaceous (Cenoman-Mergel) and later increasingly calcareous sediments (Cenoman-Kalk). There is a major facies change near the top of the Cenomanian from white, pure limestones to variegated argillaceous sediments. These are developed as thin successions of red limestones and marls (the so-called "Rotpläner" facies)

in the oxygenated environments over swells and platforms, while in the adjoining basins are found thick successions of organic carbon-rich dark grey marls alternating with very pale limestones, constituting the Black Shale or "Schwarzweiße Wechselfolge" facies. The latter represents the Oceanic Anoxic Event II in the Cenomanian/Turonian boundary succession.

The Black Shales end in the Lower Turonian, but the Rotpläner continues to near the top of the Middle Turonian. These units are followed by the Weißpläner, developed as argillaceous limestones in basins and as chalk facies over swells. The Weißpläner includes several vulcanogenic marls (tuffs), which constitute isochronous tephroevents that have been used to correlate Turonian successions throughout Germany. The thick ME marl-seam used here as a datum-plane can even be traced to northern England. The Weißpläner is succeeded by the Grauweisse Wechselfolge, which is characterized by laterally correlatable conspicuous limestone-marl alternations of uncertain origin and includes the Turonian/Coniacian boundary event-bundle (Fig. 31). The top of this unit is marked by the Ilse tectoevent, which is reflected by a major facies change from carbonates to the argillaceous and somewhat monotonous Emscher Marl.

In the basinal areas, the marl facies continues into the Lower Campanian and there is little evidence of the pre-Hercynian inversion phases. In some marginal areas (Groß-Ilse, Broistedt, Gehrden), the (post-Ilse) transgressive Lower to Middle Santonian develops a ferruginous basal conglomerate. The overlying beds are calcarenitic and highly fossiliferous, yielding a fauna (particularly echinoids) that is totally different from that of the correlative marl facies (references in ERNST 1968). In other areas that have been uplifted as a result of

Subhercynian Ilse tectonism and salt movement, the Emscher Marl facies begins even later, with the post-Wernigerode tectoevent Marsupites transgression, e.g. near Misburg. Here, Turonian Pläner is overlain by a glauconitic marl with abundant *Goniatites*.

The overlying Mergelkalk comprises inconspicuously developed argillaceous marl-limestone alternations with, locally, a basal glauconitic transgression horizon enriched in *Goniatites* marking the *pilula* transgression. Reflecting the *polyplacum* regression eustatic event, the marl-limestone alternations are replaced upwards by spongiferous, spiculitic marls ("Opoka" facies) with a rich fauna dominated by large oysters, together with and moulds of aragonitic bivalves and gastropods (NIEBUHR 1995, 1996a).

In the Peine Syncline and elsewhere, a further tectoevent, the Peine Phase (RIEDEL 1940) and subsequent mucronata transgression, is found near the top of the Lower Campanian.

In the Beienrode Basin, the Cretaceous succession begins with the *mucronata* transgression. Here the lower Upper Campanian is developed in marginal glauconitic facies, with the *polyplacum* regression being marked by a change to continental quartz sands which continue into the Upper Maastrichtian (NIEBUHR & ERNST 1991). The Ilten Maastrichtian occurrence (VOIGT 1951) with its basal conglomerate marks the Upper Maastrichtian *junior* transgression: in the Beienrode Basin, this event is suggested by increasing indications of marine influence towards the top of the continental quartz sands.

References: BALDSCHUHN et al. (1991); BRÜNING et al. (1987); ERNST (1968); ERNST et al. (1983, 1996); NIEBUHR & ERNST (1991); NIEBUHR (1995, 1996); RIEDEL (1940); VOIGT (1929, 1951, 1963).

2. Locality descriptions

2.1 Lehofsberg near Quedlinburg (Figs. 14-16)

(by T. Voigt & F. Horna)

Location and grid reference: TK 25, 4133 Wegeleben, R: 4442250, H: 5742150. The Lehofsberg sections, an abandoned and a working sand pit, are situated 2 km north of Quedlinburg by the old road to Ditfurt (Figs. 2, 14).

Tectonic setting: Southern flank of the Halberstadt Syncline (Fig. 14). This NW-SE structure is 4.5 km wide and about 14 km long.

Coniacian: The Coniacian of the Subhercynian Basin is divided into 5 units. The Lower Coniacian (Unit 1) consists of an alternation of marls and limestones—the so-called “Grauweisse Wechselfolge”—yielding *Cremnoceramus rotundatus*, *C. erectus* and *C. crassus*.

Unit 1 is overlain by the Emscher Marl Formation (Unit 2), which consists of homogeneous marls and silty marlstones with common glauconite at the base. In the eastern part of the basin a stratigraphic gap of considerable duration is developed: the Grauweisse Wechselfolge is missing, and the

Emscher Marl rests unconformably on Middle Turonian or Upper Turonian coccolith limestones. This unconformity is inferred to be connected with activity of the Quedlinburg salt structure (VOIGT 1929; TRÖGER & ULBRICH 1971), or it may be the expression of the marginal position of these localities (northeastern basin margin).

The overlying Formsand Formation (Unit 3) marks the beginning of sand progradation from the northeast (demonstrated by the granulometry), a sedimentation pattern which persisted from the mid-Coniacian to the Late Santonian. *Volviceramus koeneni*, *Inoceramus sublabiatus*, *I. kleini* and *I. percostatus* and members of the *Platyceramus mantelli* group establish the early mid-Coniacian age of the silty, fine-grained sands.

The top part of Unit 3 is characterized by increasing glauconite content, which continues in the overlying Unit 4 (*involutus* Sandstone Formation). The distinct coarsening upward trend is expressed by a transition from fine- to medium-grained sandstones with siliceous cementation. Common cross-bedding and increasing density of event-beds (probably storm-layers) indicate a change from a lower shoreface environment to a current-influenced setting. Unfortunately, the high en-

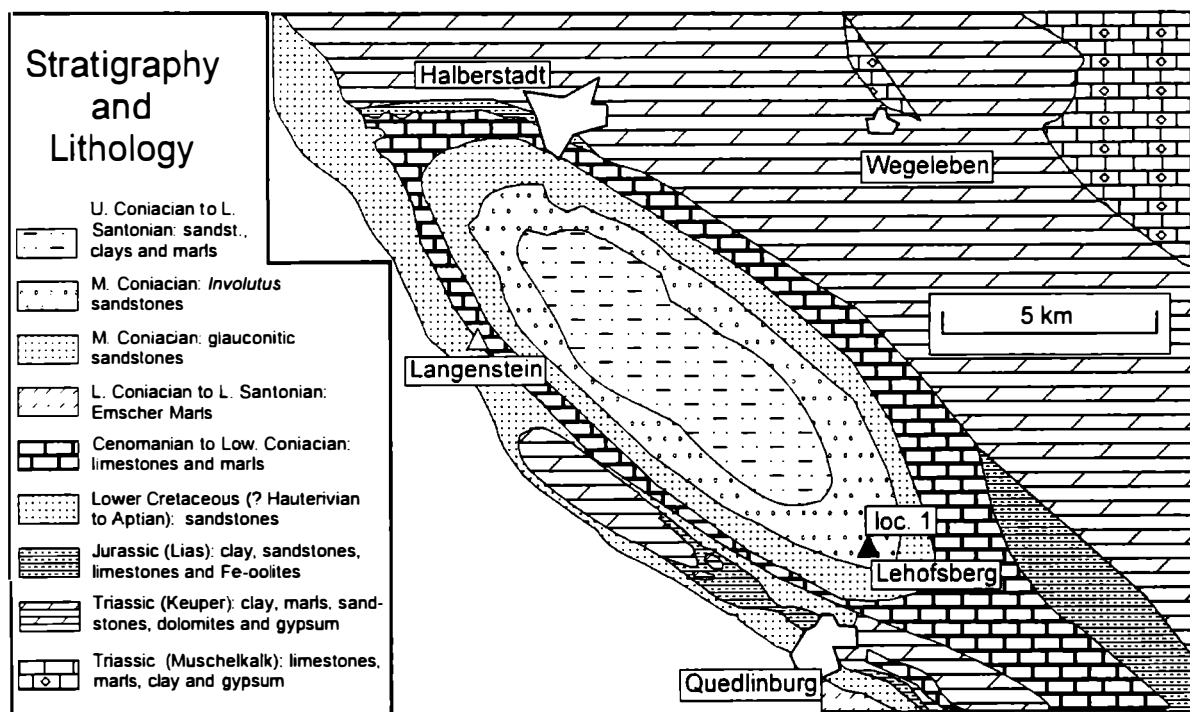


Fig. 14. Geologic sketch map of the Halberstadt Syncline (after TRÖGER & KURZE 1980).

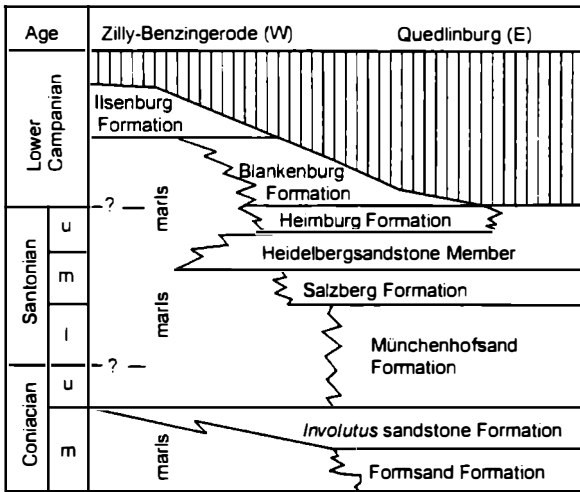


Fig. 15. Lithostratigraphic scheme of the higher Upper Cretaceous in the eastern Subhercynian basin. (after TIWARI & ROY, 1973).

ergy also prevented the preservation of fossils, so that it is difficult to place exactly the biostratigraphic boundary between the zone of *V. koeneni* and the overlying zone of *V. involutus*, which has been recognized at some localities in the up to 50 m thick succession.

Pebbles of phosphorite and coccolith limestones within the *involutus* Sandstone are particularly important. They reflect reworking of Cenomanian and/or Turonian deposits in the source area (VOIGT 1929).

The late Coniacian is represented by the Münchenhof Sand Formation (Unit 5) which consists of fine-grained sandstones reflecting the transition to marl sedimentation in the southeastern part of the Subhercynian Basin. These marls yield *Magadiceramus subquadratus* which indicates a late Coniacian age.

Stratigraphy and lithology: The localities west of Quedlinburg expose middle Coniacian sandstones (*involutus* Sandstone; Figs. 15, 16). These sandstones are composed of quartz which was probably derived from Buntsandstein (Triassic) and Early Cretaceous sandstones. This provenance is inferred from the high maturity of the heavy mineral association. Furthermore, the quartz surfaces and present relict cements indicate a fluvial environment. In the large sand pit south of Lehofsberg, the transition from greenish, clay-rich

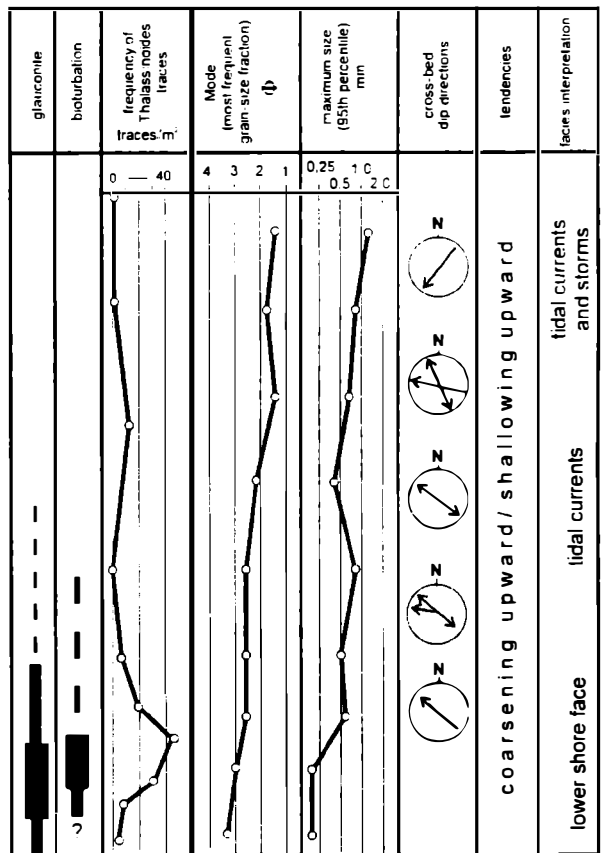
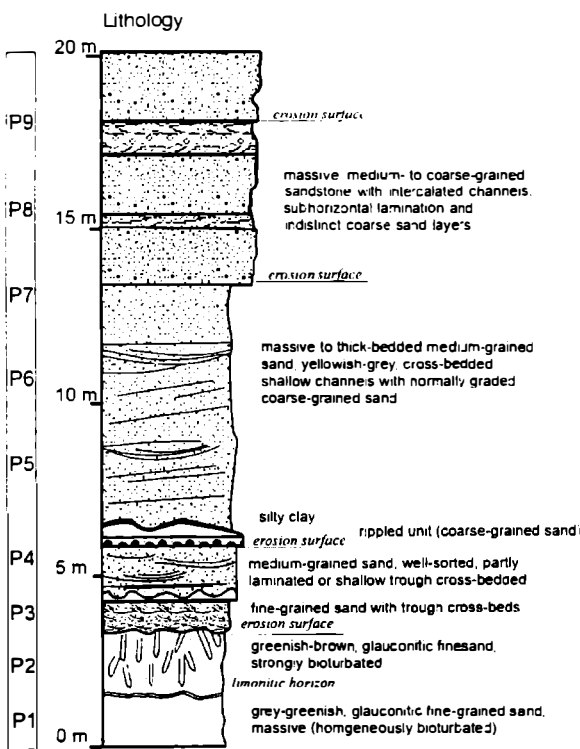


Fig. 16. Lithology and sedimentologic patterns of the Middle Coniacian of the Lehofsberg sand-pit.

sandstones to medium-grained cross-bedded sandstones is accompanied by increasing grain size and decreasing glauconite content. Fossils are very rare, only some bivalve fragments including *Volviceramus involutus* have been reported from the sandstones. The upper parts of the succession form a steep rock massif which is traceable around the Halberstadt Syncline, composed of thick-bedded sandstones. In the lower part of this unit, silty and marly interbeds with rippled surfaces, mud drapes and graded bedding may indicate tidal currents, while intercalated conglomerate beds in the higher parts of the succession reflect high energy events with scouring and rapid deposition. These con-

glomerate beds, up to 0.4 m thick, consist of well-rounded quartz pebbles. They become more closely spaced and thicker up-section and are interpreted as proximal tempestites.

Heavy-mineral assemblage (after Tiwari & Roy 1973):

- zircon: 77% (sedimentary >> magmatic),
- tourmaline: 11%,
- rutile: 6%,
- others (staurolite, kyanite, garnet, pyroxene...): 6%.

References: TIWARI & ROY (1973); TRÖGER & ULBRICH (1971); TRÖGER (1967); VOIGT (1929).

2.2 Teufelsbachtal section near Blankenburg (Fig. 17)

(by K.-A. Tröger & F. Horna)

Location and grid reference: TK 25, 4131 Derenburg, R: 4425450, H: 5742730. The outcrop is situated 3 km northwest of Blankenburg adjacent to the road to Heimbürg (Fig. 2).

Tectonic setting: Flexure zone north of the Harz block. An angular unconformity between the Blankenburg Formation (lowermost Campanian) and the Hauptmuschelkalk (Middle Triassic) is exposed (Fig. 17). Type locality of the Wernigerode Phase (Subhercynian tectonic movements at the Santonian/Campanian

boundary). The Middle Triassic beds are overturned. Both the Blankenburg Formation and the Middle Triassic sediments are deformed by post-Early Campanian movements.

Palaeogeography: The shoreline of the Early Campanian sea was just in front of the uplifted Harz block. During the Campanian, the flexure zone north of the Harz probably represented an archipelago formed by island chains consisting of Lower and Middle Triassic limestones.

Stratigraphy and lithology: The basal part of the Blankenburg Formation (?lowermost Campanian) is composed of calcareous siltstones and fine-grained

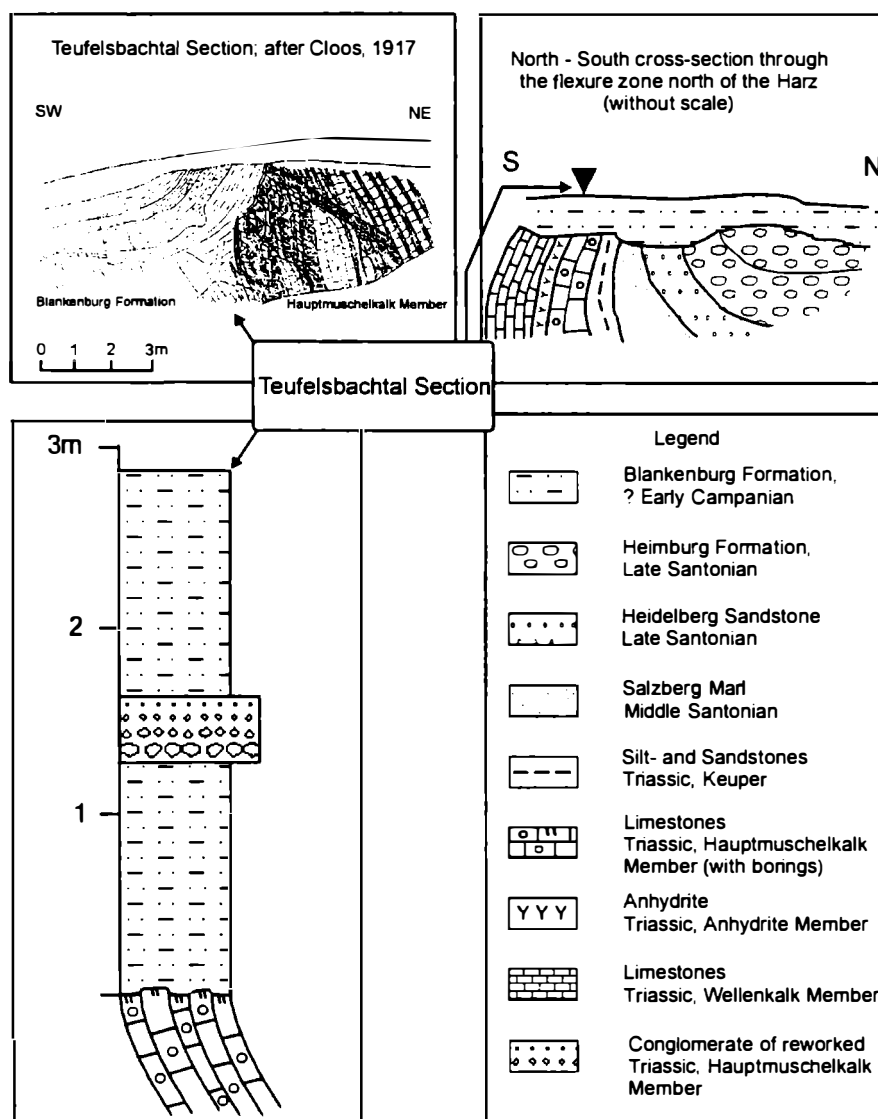


Fig. 17. Lithostratigraphy of the Teufelsbachtal section.

sandstones.

The angular unconformity surface between the Blankenburg Formation and the Triassic basement is irregularly shaped and wavy. This irregularity reflects differences in resistance to weathering of the alternating hard limestones and softer marls comprising the Triassic (Hauptmuschelkalk) succession.

The Triassic limestones are intensively bored. A conglomerate consisting of middle Triassic limestones is found 1.2 m above the unconformity. The pebbles are irregular in shape, poorly rounded and show traces of boring.

Fauna: The sediments of the Blankenburg Formation are not particularly fossiliferous. The macrofauna mainly consists of fragments of oysters and belemnites. Complete belemnite guards (*Goniotheuthis*) are very rare and are reworked. They belong to the phyletic lineage *G. granulata*-*G. granulataquadrata*-*G. quadrata* at the Santonian/Campanian boundary. Because all of them are reworked, an Early Campanian age is assumed. The microfauna is characterized by low abundance and diversity. Benthic foraminifera belonging to the genera *Psammosphaera*, *Marssonella*, and *Lenticulina* have been recorded.

References: Cloos (1917).

2.3 Hoppenstedt quarry (Figs. 18, 19)

(by F. Horna)

Location and grid reference: TK 25, 4029 Vienenburg, R: 4408000, H: 5763350. The abandoned quarry "Kalkwerk Nordharz" is situated 4 km west of Osterwieck at the northern edge of the village of Hoppenstedt (Figs. 2, 11). The quarry was worked until the early sixties of this century.

Tectonic setting: Southern flank of the Fallstein salt structure. The NW-SE Fallstein Anticline is 2 to 3 km wide and about 7.5 km long. Its core is formed by Triassic sediments (Muschelkalk). The Upper Cretaceous deposits dip at 30-40° SSW.

General remarks: The upper Cretaceous succession of Hoppenstedt (Cenomanian to basal Coniacian) was subdivided by HORN (1996) into four sedimentary units (Fig. 19):

- Unit A (limestone-marlstone-alternation),
- Unit B (bedded limestone member),
- Unit C (Rotpläner),
- Unit D (thin-bedded marly limestone member).

These units differ in their carbonate content as well as in their microfacies and character of sedimentation.

Unit A (limestone-marlstone-alternation): Because of the monotonous A-B rhythms of unit A, a continuous sedimentation with rhythmic changes of terrigenous input and/or planktic productivity is inferred. These rhythms are interrupted by coarser-grained beds rich in inoceramid debris and with typical post-event bioturbation (sensu SEILACHER 1982). Consequently, they are considered to represent event-beds deposited from suspensions. The base of the Middle Cenomanian, corresponding to the *Cunningtoniceras inermis* Zone which is known from complete sections in Lower Saxony (Wunstorf) and southern England (Lewes, Dover-Folkestone) is missing at Hoppenstedt. Besides biostratigraphic premises this is also supported by well documented periods of resedimentation at the level of the *primus* Event.

Unit A comprises the *primus* Event and the Mid-Cenomanian Event, which are de-

scribed in detail in Chapter 2.6 (Baddeckenstedt quarry, No. 6).

Unit B (bedded limestone member):

Unit B shows significant higher carbonate contents than Unit A. It can be subdivided into 8 to 10 m thick cycles with increasing carbonate content towards the top of each cycle. The microfacies is characterized by calcisphere and foraminiferal mudstones and wackestones. The clay mineral composition changes from predominantly montmorillonitic in the lower part to kaolinitic in the highest beds. A progressive shallowing of the depositional environment can be inferred. At the top of Unit B, there is an abrupt lithologic change (the so-called "Fazieswechsel") from pure white coccolith limestones, traditionally termed "Arme rothomagense-Schichten", to reddish and brownish coloured marls and marly limestones, collectively known as Rotpläner at the base of the overlying Unit C. This facies change reflects an hiatus that is traceable throughout Europe (e.g. sub-*plenuserosion* surface, the change from the Regensburg Greensand to the Eibrunn Marls, and the Antifer 1 Hardground in northern France).

Within the massive limestone beds, an up to 0.05 m thick marl-seam (bed T-24, Fig. 19) yields abundant fragments of small pycnodontine oysters, constituting the *Pycnodonte* Event. Owing to the lack of stratigraphically relevant ammonites the base of the Upper Cenomanian is drawn above the *Pycnodonte* Event horizon.

The *Amphidonte* Event is marked by the occurrence of small exogyrine oyster fragments within a limestone bed otherwise devoid of macrofossils (bed T-17), 7 m above the *Pycnodonte* Event.

Unit C (Rotpläner): The basal part of Unit C consists of reddish and brownish, bioturbated, flaser-bedded marls and marly limestones, and is distinguished by a significantly lower carbonate content (55 to 65%) than Unit B as well as by lateral thickness variations. Sharp contacts between the marls and lateral variations of thickness indicate an episodic sedimentation (mud flows) of the marls (inoceramid wackestones). The pelagic background sediments (autochthonous calcisphere-foraminiferal wackestones and packstones), represented in the overlying *plenus* Bed

(named after the belemnite *Actinocamax plenus*), are restricted to infilled burrows. The *plenus* Bed is a conspicuous, massive white limestone bed with a pink mottled upper part characterized by anastomosing stylolites. The carbonate content increases from 77 to 82% from the base to the top of the 0.6 m thick limestone bed. The microfacies of the *plenus* Bed is dominated by calcispheres, which comprise more than 50 % of the biogenic component. The mottled and, in some cases, nodular appearance of the upper part of the *plenus* Bed is caused by bioturbation. The numerous *Thalassinoides* burrows (omission-suite *Thalassinoides*) are filled with reddish sediment identical to the overlying marly limestones during sedimentation of the so-called Lower Rotpläner.

Within the level of the *Mytiloides* Event (see below), apart from inoceramid wackestones, inoceramid floatstones (rudstones) occur, which are interpreted to represent tempestites. Furthermore, increasing fragmentation of the inoceramid shells, caused by increasing erosion at the base of the tempestites, indicates a shift of the depositional area into a more proximal environment. Infilled *Thalassinoides* burrows, described by WANLESS et al. (1988) as tubular tempestites, show a depositional environment dominated by storm events. The succession above the *Mytiloides* Event is formed by several 0.2 to 0.8 m thick distinct limestone beds within the marls. These limestones represent a more autochthonous pelagic sedimentation.

The coincidence of a mass occurrence of *Mytiloides hercynicus* and the first appearance of *Collignonicerias woollgari* has been reported at several localities in NW Germany (ERNST et al. 1984; KAPLAN 1992). The *hercynicus* Event therefore provides a good marker horizon for the base of the Middle Turonian. The *hercynicus* Event has so far not been recorded from Hoppenstedt or from the Söhlde and Baddeckenstedt sections. Consequently, a hiatus around the Lower/Middle Turonian boundary can be inferred for these localities.

The Middle Rotpläner, separated from the Lower Rotpläner by a conspicuous limestone bed ("Weiße Grenzbank" or White Boundary Bed), is characterized by increasing carbonate contents between 83 to 90% and a microfacies that consists almost exclusively of calcispheres. The clay-mineral

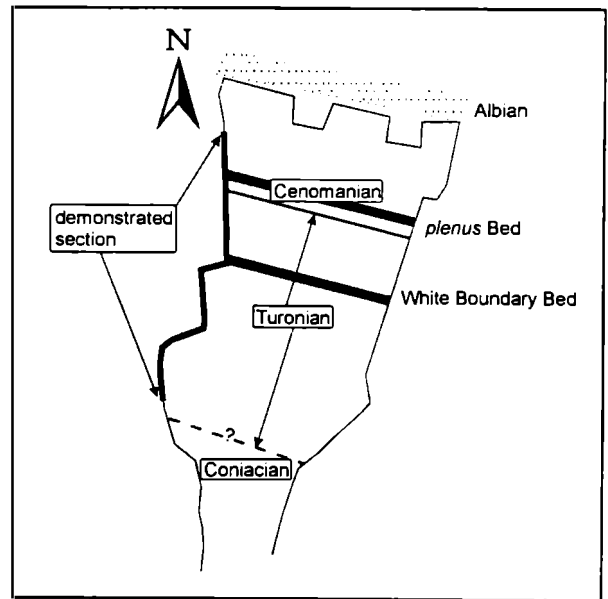


Fig. 18. Sketch map of the Hoppenstedt quarry, showing the two main marker beds.

composition within Unit C is characterized by the dominance of montmorillonite, as in the lower part of Unit B. The Upper Rotpläner above the tuff TC, which usually reaches a thickness of more than 10 m in other localities, is completely absent from the Hoppenstedt section.

Unit C includes several events, providing distinctive stratigraphic markers: 1) the *Chondrites* Event, 2) the *Gastrochaena* Horizon, 3) the *hattini* Event, 4) the *Mytiloides* Event, 5) the White Boundary Bed (Weiße Grenzbank), 6) the tuff horizon TC.

The *Chondrites* Event, underlying the *plenus* Bed, is an horizon remarkably enriched in *Chondrites* at two separate levels. The *Chondrites* bioturbation of the upper level originated from the base of the *plenus* Bed, indicated by the paler and more calcareous burrow infill. The facies change, the *Chondrites* Event and the *plenus* Bed provide excellent marker horizons within this unit and facilitate correlation.

The *Gastrochaena* Horizon comprises a flood occurrence of *Gastrochaenolites* in a marly, greenish coloured bed (T 5/6). *Gastrochaenolites* borings are inferred to be connected with erosional boundaries (KRAWINKEL & SEYFRIED 1996) and are used as an indicator of short-term bioerosion (BROMLEY & ASGAARD 1993). This horizon has so far not been reported from the correlative sections in Lower Saxony.

The *hattini* Event is marked by the sudden

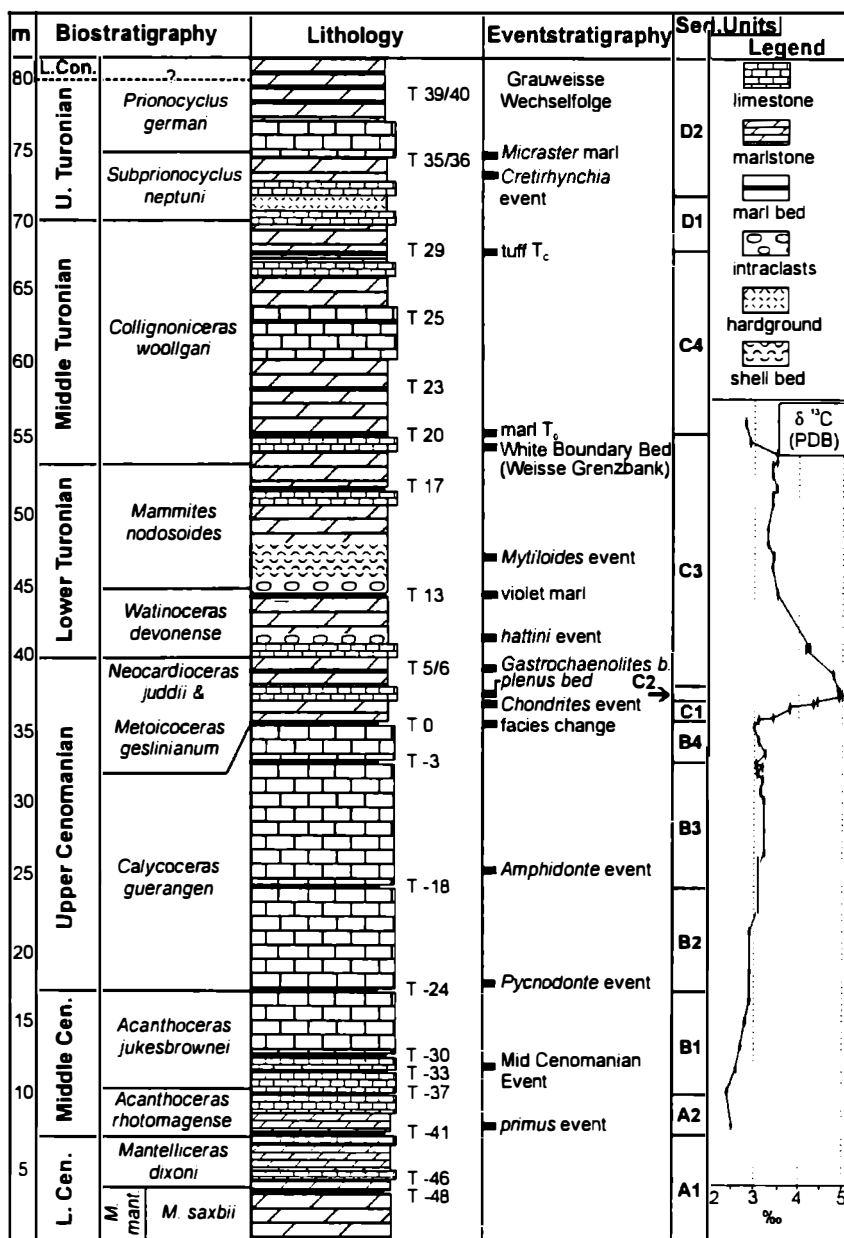


Fig. 19. Bio- and event stratigraphy of the Cenomanian, Turonian and basal Coniacian of the Hoppenstedt quarry.

appearance of *Mytiloides hattini* 3.5 m above the top of the *plenus* Bed. A subdivision into two separate *hattini* Events, as reported by ERNST & WOOD (1995) from Baddeckenstedt, cannot be observed at Hoppenstedt.

Mytiloides mytiloides appears in abundance 7 m above the top of the *plenus* Bed. This horizon is herein taken to mark the base of the widespread Lower Turonian *Mytiloides* Event.

The White Boundary Bed (Weiße Grenzbank) is a conspicuous hard, splintery limestone bed 17.5 m above the top of

the *plenus* Bed (Fig. 19). Both the bottom and top of the bed are strongly undulated and show a stylolitic overprint.

An excellent inter-regional correlation is provided by the tuff layer TC, 12.5 m above the top of the White Boundary Bed (HORN 1995). This tuff layer has been recognized in the Söhlde sections and also in Westphalia (WRAY & WOOD 1995; WRAY et al. 1995).

Unit D (thin-bedded marly limestone member): Unit D begins with an incipient hardground. These nodular, flaser bedded

limestones are rendered conspicuous by glauconitic pigmentation, yellowish colour, and increased cementation. Their microfacies pattern is characterized by foraminiferal wackestones and packstones, calcispheres are less frequent. Glauconite and phosphatic bioclasts are present. The *costellatus/plana* Event (ERNST et al. 1983) which is taken to mark the base of the Upper Turonian elsewhere in Germany, is absent from Hoppenstedt because of a hiatus resulting from the hardground sedimentation. Furthermore, the entire event succession comprising flint F₂₃, T_{D1}, T_{D2}, T_E, M_E up to the *Hyphantoceras* Event is not represented at Hoppenstedt. An horizon (bed 34) with abundant brachiopods (*Cretirhynchia cuneiformis*, *Kingena elegans*, *Gibbithyris subrotunda*, and *Orbirhynchia* cf. *reedensis*) occurs 5.5 m above the tuff layer T_C.

Above the nodular limestones thin, platy, greyish-white limestone beds with intercalated diagenetic marl seams appear. The *Micraster* Event (see below) is the first Upper Turonian marker horizon which has been identified within the Hoppenstedt section. 3 m above the *Micraster* Marl, there is a change to a rhythmically bedded marl-limestone succession with a thickening upward of the marls. This corresponds to the Grauweisse Wechselfolge of WOOD et al. (1984), which can be seen in the Salzgitter-Salder section (No. 7). The carbonate content fluctuates between 80 and 95% with a decreasing trend up-section.

Two events provide marker horizons within Unit D: 1) the *Cretirhynchia* Event, 2) the *Micraster* Event.

There is no ammonite evidence for the existence of the *Hyphantoceras* Event at Hoppenstedt. The *Cretirhynchia* Event may represent the same stratigraphic interval, since in condensed platform sections of southern England *C. cuneiformis* occurs commonly in a hardground (Chalk Rock) which yields the ammonite fauna of the *Hyphantoceras* Event.

The *Micraster* Event is characterized by the sudden appearance of advanced *Micraster* (*cortestudinarium* group) above the marl seam T35/36 (Fig. 19).

$\delta^{13}\text{C}$ values: In the basal part of Unit C, the $\delta^{13}\text{C}$ values rise continuously from 3.1 to 4.99‰ in the *plenus* Bed, reflecting the global Cenomanian/Turonian boundary excursion (Fig. 19). The increase in values agrees with published data relating to this excursion in other areas (SCHOLLE & ARTHUR 1980; HILBRECHT 1991; SCHÖNFELD et al. 1991; ULICNY et al. 1993). In the uppermost part of the *plenus* Bed, the values already start to decrease, but the decrease of the values is more gradual than the previous increase. In the Lower Rotpläner $\delta^{13}\text{C}$ values decrease to 3.5‰. In the Middle Rotpläner the $\delta^{13}\text{C}$ values drop to 2.5 to 3‰ and are here as low as beneath the Cenomanian/Turonian boundary excursion in Unit B.

References: BROMLEY & ASGAARD (1993); ERNST & WOOD (1995); ERNST et al. (1983, 1984); HILBRECHT (1991); HORNA (1995, 1996); KAPLAN (1992); KRAWINKEL & SEYFRIED (1996); SCHOLLE & ARTHUR (1980); SCHÖNFELD et al. (1991); SEILACHER (1982); ULICNY et al. (1993); WANLESS et al. (1988); WOOD et al. (1984); WRAY & WOOD (1995); WRAY et al. (1995).

2. 4 Road-cuttings near Vienenburg (Figs. 20, 21)

(by G. Ernst, U. Rehfeld & C. J. Wood)

Location and grid reference: TK 25, 4029 Vienenburg, R: 360230, H: 575955 to R: 360220, H: 575980. Road-cuttings of the A 395 Bad Harzburg-Vienenburg-Braunschweig and west side of the B4.

Stratigraphy: The B4 section described comprises the hardground facies from the Lower/Middle Turonian boundary to the allochthonites of the Lower to ?basal Middle Coniacian. A thrust mass of Cenomanian age is intercalated within the Upper Turonian.

General remarks: The Autobahn cutting was made in 1972, before the event stratigraphical framework of the Cenomanian-Coniacian interval was developed. The section is now much degraded in many parts and access is not normally permitted. The historic section in the river cliff forming the eastern truncation of the Harli (SCHLOENBACH 1868; SCHRÖDER 1912), paralleling the B4, seemed to be virtually forgotten. The two closely adjacent sections provide an useful composite section from low in the Cenomanian to the middle part of the Coniacian.

In comparison to other exposures in the lower part of the Upper Cretaceous, the Vienenburg section exhibits some special features. The Turonian here is represented by a very much reduced succession, which is consequently, particularly in the lower and middle part, characterized by hardgrounds and the development of the so-called *Conulus* facies. A thick series of allochthonous sediments is intercalated into the higher Lower Coniacian autochthonous succession, providing evidence of one of the main (Ilsede) phases of Subhercynian tectonic activities. Another noteworthy feature is a large olistolith of Cenomanian sediments situated within and interrupting the Turonian succession. This is interpreted as a slide mass, which probably became detached towards the end of the Early Coniacian. All the strata are overturned.

The Upper Cretaceous of the Vienenburg Anticline is currently the subject of investigations by I. MAUSA, T. WAGNER-DOUGLAS and F. WIESE (Berlin working group), who kindly

provided their field data.

Stratigraphy and facies: 58 m of Cenomanian beds were formerly accessible on the west side of the Autobahn cutting. The marl facies of the basal Cenomanian is exposed some 4 km away in the Wedde-Bach section on the southern flank of the anticline, and exhibits the normal fossiliferous character. The boundary to the Upper Albian is marked, as usual, by a glauconitic marl horizon, which indicates the position of the sequence boundary and the transgressive systems tract of the subsequent Cenomanian transgression.

In the B4 road section, an olistolithic block of Cenomanian material, previously described by SCHLOENBACH (1868) and SCHRÖDER (1912) as the so-called "Cenoman-Keil" (Cenomanian wedge), is incorporated in the Upper Turonian succession. This constitutes a slipped mass (ERNST & WOOD 1995) which became detached from the roof of the Vienenburg diapir in the course of the upward movement of the Vienenburg halokinetic structure. The individual components of this complex slide mass are delimited by marls, which acted as slide planes. As typically found with slide masses, "Scheiterkalk" (limestone with a lath-like structure) and phacoidal bodies are also associated. The fauna collected by T. WAGNER-DOUGLAS and ourselves indicates both Lower Cenomanian (*Schloenbachia*, *Inoceramus virgatus*) and Middle Cenomanian (*Acanthoceras rhotomagense*) components. The Middle Cenomanian fossils include elements from the *primus* fauna (*Hemiaster griepenkerli*) as well as from the time range of the Mid-Cenomanian Event (*Holaster subglobosus*) and the vicinity of the *Pycnodonte* Event.

The "Cenoman-Keil" was formerly considered to be restricted in its lateral extent to the B4 section, with only incipient indications of disturbed sediments in the adjacent Autobahn section. However, the recent discovery of a large limestone phacoid with *Acanthoceras* cf. *jukesbrownei* and *Inoceramus* cf. *atlanticus*, situated either within or underlain by debrites on the west side of the Autobahn cutting, indicates that the Cenomanian olistolith may have formerly extended much farther to the west, perhaps even beyond the cutting into the area of the Harliberg itself.

The Cenomanian/Turonian boundary suc-

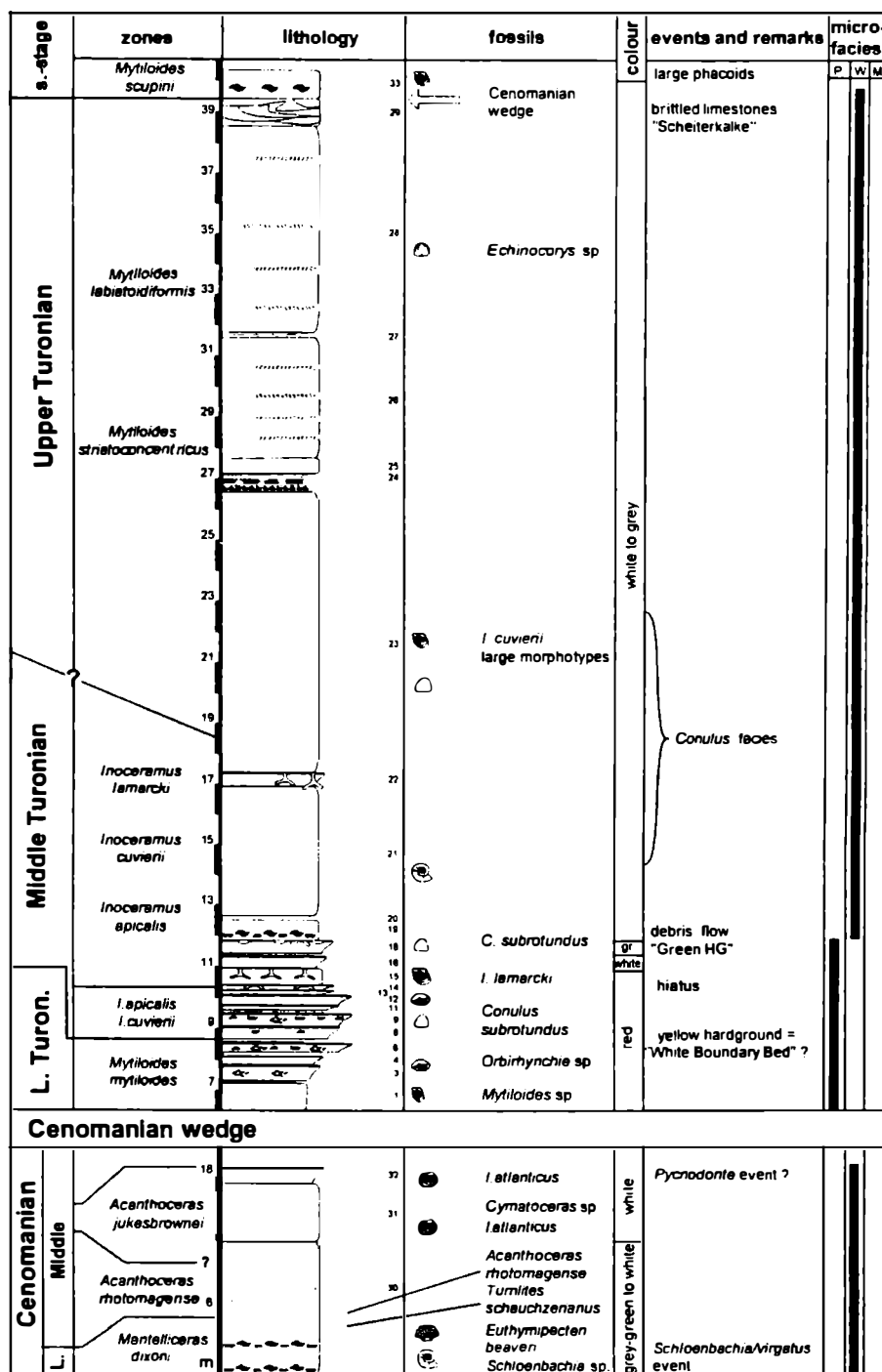


Fig. 20. Turonian section of the B4 road cut, Vienenburg structure (after WAGNER-DOUGLAS 1996)

cession was documented in detail on the east side of the Autobahn cutting (HILBRECHT 1988; HILBRECHT & DAHNER 1994). It is characterized by an extremely condensed succession developed in Rotpläner facies. The pre-plenus sequence and the *plenus* Bed together total only 0.5 m, but nevertheless exhibit the characteristic *Chondrites* Event and the tripartite subdivision of the *plenus* Bed. The *plenus* Bed is overlain with a

marked hiatus by deep red, then followed by variegated marls. These marls are of tempestitic origin exhibiting a bioclastic matrix mainly composed of inoceramid fragments, gutter casts and, slightly higher up-section, grade into lenticular tempestites. Rising energy levels are documented by an increase in the size of the channels and in the number of intra- and extraclasts. This facies is typical of a car-

bonate ramp. The first *Mytiloides* Event is found only 0.5 m above the *plenus* Bed: the morphotypes here are closer to *M. labiatus* than to the more common *M. mytiloides*, a fact which HILBRECHT & DAHMER (1994) attributed to possible ecomorphic factors. It is noteworthy that the tempestite facies has a greater vertical extent than in the nearby comparative sections. Both the early establishment of carbonate ramp sedimentation and the small thickness of sediment indicate a significantly shallower bathymetric position than in the case of other Rotpläner sections.

The stratigraphic condensation characterized by hardgrounds and the *Conulus* facies continued into the early Late Turonian (Fig. 20). In the B4 road section, the succession begins with the Cenomanian/Turonian boundary interval. At the base of the section, Lower Turonian red marls with *Mytiloides* are exposed. These are overlain by a complex tripartite unit of hard beds, about 3 m thick, which form a conspicuous projecting ridge. This unit is composed of hard, white, pink and ochre-coloured limestones within which there are several hardgrounds, as well as marl seams and marl partings. It is not known whether or not any of these marls are of vulcanogenic (tuff) character, rather than merely detrital marls. Analyses for rare earth elements by D.S. WRAY (University of Greenwich) indicate a detrital origin. It is likewise unclear where the White Boundary Bed with its overlying M_0 marl is situated within this complex. From the very limited inoceramid evidence, we assume that the entire unit comprises a reduced equivalent of the *apicalis/cuvieri* Zone. The hardgrounds are penetrated by post-depositional glauconitized *Thalassinoides* burrows, and the surfaces exhibit irregularly developed shallow grooves reminiscent of shrinkage or desiccation cracks.

The shallower water environment, indicated by the hardgrounds, is further demonstrated by the typical echinoid faunal elements such as *Conulus subrotundus* and a single *Cardiaster truncatus*. The facies and its associated fauna is closely comparable to that found at Wüllen in Westphalia (ERNST et al. 1992). The hardground complex is overlain non-sequentially by pale marly limestones with *Inoceramus lamarcki*. Some additional hardgrounds are found in the lower part of this interval, one of which is

overlain by a marly debrite. The marly limestones are succeeded by the nodular and splintery so-called *Conulus* facies, which was described, among other workers, by SCHRÖDER (1912) from the east side of the Vienenburg structure. Apart from the typical echinoids (*C. subrotundus*, *Sternotaxis plana*, *Echinocorys gravesi*), the fauna comprises mainly *Orbirhynchia* and other brachiopods. According to the inoceramid biostratigraphy, the *Conulus* fauna may well be situated close to the Middle/Upper Turonian boundary, in that Middle Turonian index taxa (*Inoceramus lamarcki* and related forms) are associated with rare Upper Turonian elements.

In the Upper Turonian, above the *Conulus* facies, the sedimentation pattern “normalizes” to some extent. Marly limestones with sporadic marls are typical. It has not yet been possible to correlate the marl seams of the B4 section with those logged by SEIBERTZ (1972, unpublished) in the Autobahn section. It remains unclear whether or not the event bundle in the vicinity of Marl M_E or the *Hyphantoceras* Events are developed in these sections. A similar situation may be found in the Hoppenstedt section on the Fallstein east of the Vienenburg structure, where these events are represented by a non-sequence (HORNA 1995). In the Beuchte quarry, situated on the northern margin of the Vienenburg structure, some 4 km WNW of the B4 section, the Upper Turonian is largely reduced in thickness, but here both the M_E event-bundle and the *Didymotis* I Event can be recognized. However, the *Hyphantoceras* Events have so far not been identified, although the underlying condensed brachiopod acme-occurrence, which normally underlies these events, is well represented.

Between the “Cenoman-Keil” and the allochthonous Middle Coniacian in the B4 section a some 15 m thick succession is found, comprising an alternation of marls and marly limestones with sporadic minor allochthonite intercalations, including debris flows. On the basis of the inoceramid fauna, this part of the succession must belong to the Grauweisse Wechselfolge sensu WOOD et al. (1984). At the base of the section the higher of the two *Didymotis* Events is found, which approximates the Turonian/Coniacian boundary. Two beds, respectively 1.5 and 2 m above the base,

yielded typical *Cremnoceramus* of the *waltersdorfensis* and *rotundatus-erectus* lineages, associated with *Conulus subrotundus*, *Echinocorys gravesi*, *Sternotaxis* sp. and *Micraster* ex gr. *cortestudinarium*. The occurrence of *Conulus* is of particular palaeoecologic interest, since this genus is absent from correlative sections elsewhere in Lower Saxony. As this species is exclusively known to occur in context with shallower water environment, reduced sedimentation, incipient and true hardgrounds as well as reworking, its occurrence here points to a continuous shallow water environment and, to some degree, to condensation. The succession ends with a sponge horizon, in which numerous hexactinellid sponges are found in a coarse inoceramid shell debris wackestone. Close above the sponge horizon, a bed with large fragments of *Cremnoceramus* ex gr. *crassus* provides evidence for the higher part of the Lower Coniacian. This bed yielded part of a guard of *Praeactinocamax*-an extreme rarity at this level throughout Germany-which on stratigraphic grounds could well belong to *P. paderbornensis*.

Above the sponge horizon, the facies changes rapidly into a succession of glauconitic calciturbidites. Intercalated are approximately 13 very distinct beds that contain abundant phosphorite clasts. The turbidites are often stacked in thickening-up/thinning-up cycles. In some cases, only the thickening-up or the thinning-up part was recorded. Thickly bedded, glauconitic calcarenites show a multiphase depositional history with repeated phases of deposition and erosion, indicating a long-lasting development and a persisting distributary fan system for this period. As thinning-up or thickening-up, respectively, corresponds to fining-up or coarsening-up developments, each sequence can best be interpreted as recording the sedimentation history of one individual fan. A bed by bed correlation from the old road cutting to the Autobahn is not possible. Therefore, the individual beds are thought to be of only very limited extension. Each of these cycles is separated by a sedimentary unit that is rather dominated by either autochthonous deposits or the Bouma D and E sequences of a turbidite.

In its basal parts, the turbidite sequences show comparatively high frequencies of

event beds, that decreases in the middle part. Towards the top, the facies changes rapidly into coarse-grained event beds (Fig. 21; phosphorite 10-12), which yield abundant phosphorite pebbles as well as limestone clasts and phosphatized sandstones. Additionally, well rounded quartz grains up to 7 mm in diameter occur. Overlying the allochthonous succession with a sharp contact, glauconitic, decalcified and crossbedded siltstones represent autochthonous lowstand sediments that rapidly grades transgressively into the Emscher Marls.

The fauna of these strata is poor. Only shark teeth, so far 16 different species, were found in larger numbers (J. KRIVET, Berlin, pers comm.). Poorly preserved sponges are scattered throughout the section but may be enriched in distinct horizons that show characters of incipient hardgrounds. Sparse fragments of definite *Cremnoceramus* sp. were found up to 1.5 m below the top of the turbidites. Within the turbidites, sponge-remains, remnants of a thin-shelled, ostreid bivalve fauna as well as fragments of thick-shelled cremnoceramids can be found. Important is the fragment of a doubtful *Volviceramus* sp. from the uppermost phosphorite bed, which may indicate the base of the Middle Coniacian.

For the interpretation of the allochthonites, it is particularly necessary to establish their original age and provenance. Isotopic data, provided by KREUZER (BGR Hannover) of glauconite grains in samples from the Autobahn section give a range of ages from 88-91 million years (ERNST et al. 1979), indicating that the glauconites were derived from reworked Cenomanian sediments. The radiometric results were confirmed by micropalaeontological analyses carried out by KOCH (BGR Hannover), who found reworked Cenomanian foraminifera in some of the samples. This gives evidence that the allochthonites have also been derived from significantly older formations. In addition, the presence of reworked Upper Cenomanian and Turonian limestones is documented by foraminifera within the clasts, such as the Upper Cenomanian *Rotalipora cushmani* and the Turonian *Dicarinella hagni*, *Marginotruncana pseudolinneiana* and *M. marginata*. In phosphorite beds 11 and 12, Aptian-Albian sandstone clasts as well as phosphatized pebbles of the Albian "Flammenmergel"

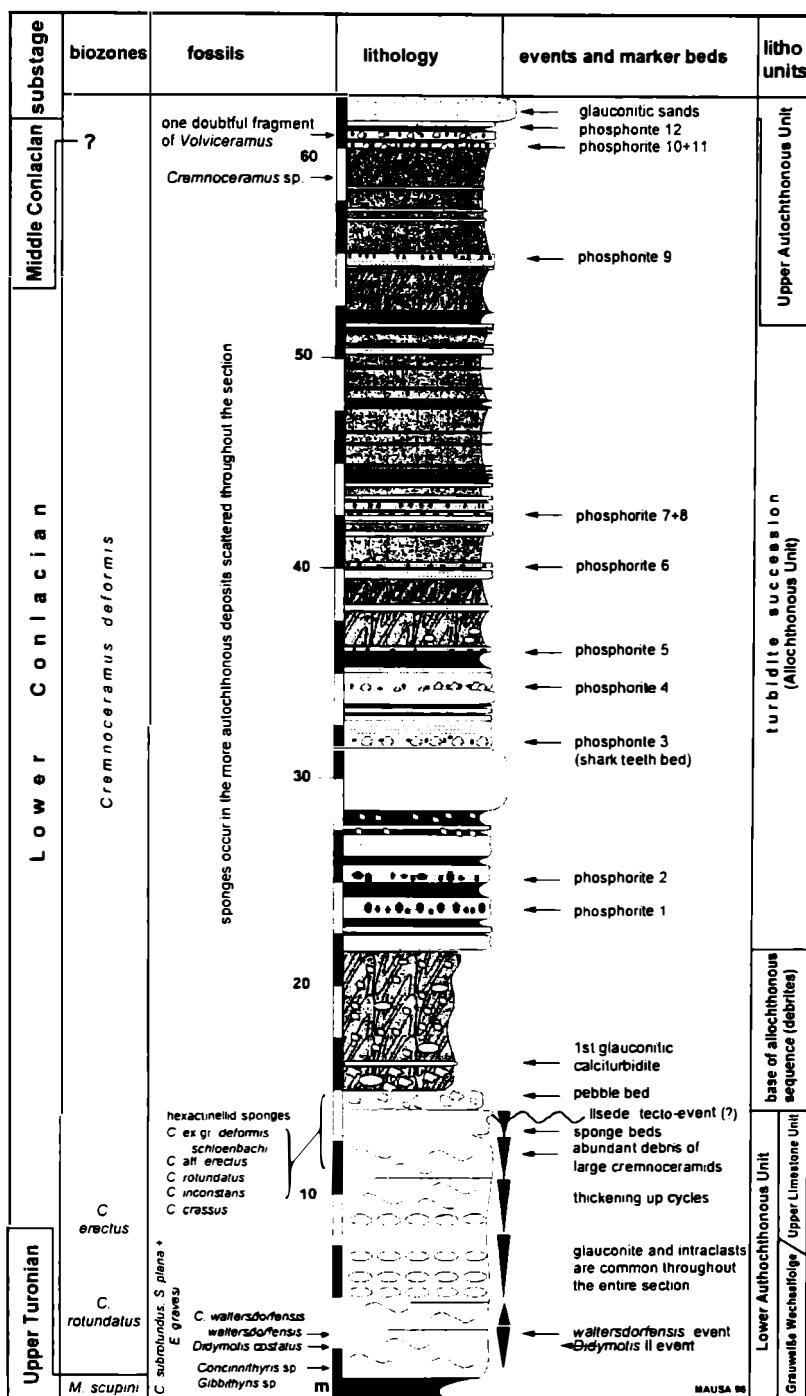


Fig. 21. Upper Turonian to Middle (?) Coniacian section of B4 road cutting, Vienenburg structure (after MAUSA 1996).

were found together with one phosphatized mould of *Aucellina gryphaeoides*, which is presumably derived from the Flammenmergel (F. WIESE, Berlin, pers comm.). The coarse quartz grains might also originate from Neocomian sandstones. The abundant phosphorites could all have their provenance in the Lower Cenomanian, as is the case in the Zilly section (ESE of Osterwieck). Phosphorite clasts are also

known from the basal Cenomanian of the Flöteberg section (Salzgitter Anticline) as well as from the nearby Weddebach section. However, diagnostic phosphatized remanie fossils have not been found so far. The abundant shark teeth associated with the phosphorites are in all probability primary fossils of Coniacian age. Comparing these lithologic data with those of the Cenomanian olistolith, it can be in-

ferred that during Cenomanian times, glauconite- and phosphate-rich sediments were still restricted to the source area and were only later reworked to produce the early Coniacian allochthonites. The interpretation of these allochthonites is controversial. Our original interpretation (ERNST et al. 1986) was that the Vienenburg structure itself functioned as the source area, and that the allochthonites moved from the roof of the diapir in the course of the Illsede Subhercynian tectonic phase. In our view, this hypothesis is supported by the fact that the allochthonites were obviously restricted to the eastern flank of the Vienenburg structure. In contrast, KOCKEL (in BRÜNING et al. 1987: Fig. 29) has reinterpreted the entire Vienenburg "Anticline" as representing a pile of Mesozoic sediments that had slid south west from the roof of the rising Fallstein basement block and had come to rest in its present position, where it became subsequently modified and uplifted by salt injection. KOCKEL argued that typical features of a halokinetic structure, such as primary and secondary marginal troughs ("Randsenken"), are not developed in the Vienenburg "Anticline". In his view, this and other gravitational slide structures are of Santonian age. However, the existence of Lower Coniacian allochthonites in the B4 section presupposes the existence of a

foredeep associated with a halokinetic structure, which contradicts KOCKEL's interpretation. Though the facies for the interval from latest Cenomanian to Early Coniacian in the Vienenburg succession points to a shallow water depositional environment of a swell, this area could equally well have been the rising Vienenburg halokinetic structure, rather than the Fallstein block.

The old clay pit adjoining the northern end of the B4 section is used as a waste disposal site today, but it probably exposed autochthonous Middle Coniacian in Emscher Marl facies. This interpretation is supported by the record of an involute inoceramid (SCHRÖDER 1912), probably a *Volviceramus*. A few hundred metres NNE of this Coniacian clay pit, dark marls with a sparse marofauna were temporarily exposed in the floor of the Oker valley between the B4 and the railway. The index fossils *Goniot euthis westfalicagranulata*, *G. granulata* and *Actinocamax verus* prove a Mid- and Late Santonian age for these sediments.

References: BRÜNING et al. (1987); ERNST & WOOD (1995); ERNST et al. (1979, 1986, 1992); HILBRECHT & DAHMER (1994); HILBRECHT (1988); HORNA (1995); MAUSA (1996); SCHLOENBACH (1868); SCHRÖDER (1912); SEIBERTZ (1972, unpublished); WAGNER-DOUGLAS (1996); WOOD et al. (1984).

2.5 Glockenberg section (Figs. 22-26) (by J. Mutterlose)

Location and grid reference: TK 25, 4028 Goslar, R: 3598500, H: 5761237. The abandoned mine "Georg-Friedrich" is situated about 10 km northeast of Goslar, about 2 km east of Dörnten (Fig. 22). The shaft was operated until 1968 and subsequently filled in. The disused iron ore pit "Glockenberg" is situated about 100 m north of the mine.

Tectonic setting: Western flank of the Salzgitter Anticline. The NW-SE striking salt structure is 2 to 3 km wide and about 20 km long (Fig. 22). The axis of the salt-induced anticline, which is here about 200 m farther east, is marked by Triassic sediments (Buntsandstein). Early Cretaceous iron ores rest with an angular unconformity of up to 20° on Toarcian shales and Aalenian clays, indicating pre-Cretaceous movements.

Palaeogeography: Eastern part of the NW German Basin, a few kilometres north off the former coast-line. The palaeogeography

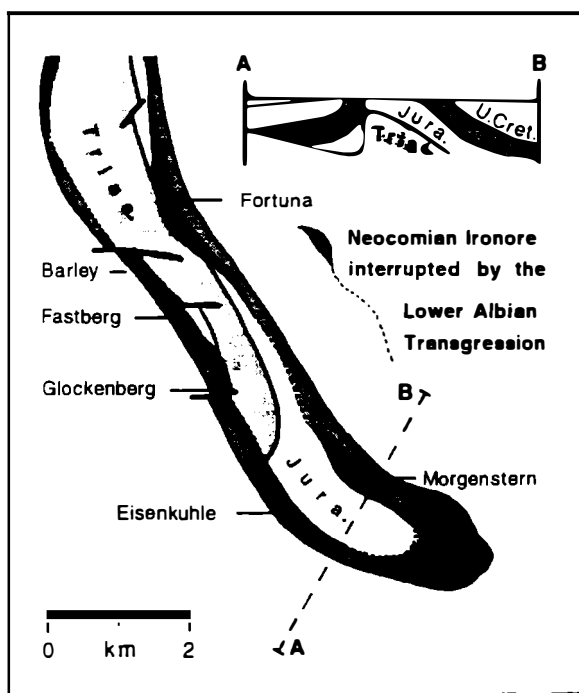


Fig. 22. Geologic sketch map of the southern part of the Salzgitter anticline, showing the outcrop of early Cretaceous sediments and locations of former ore mines.

of the Salzgitter-Goslar area was highly variable during the Valanginian-Aptian interval. The Harz massif, less than 10 km to the south, was probably not covered by sea in Early Cretaceous times. From here, elongated SW-NE striking swells extended up to 15 km into the NW German basin to the north. The deposition of the iron ores of Salzgitter was controlled by these peninsulas, causing abrupt lithologic changes in a shallow marine nearshore environment. Up to 100 m of iron ores accumulated in synsedimentary Y-shaped graben structures, aligned parallel to the strike of the strata (KOLBE 1962, 1970).

Facies and Stratigraphy: The north face of the pit exposes in its easternmost part dark bituminous shales (Lower Toarcian, Posidonienschiefer; Fig. 24). The Posidonienschiefer, which yields *Inoceramus dubius*, was deposited under anoxic conditions and reflects a widespread oceanic anoxic event (OAE). More than 5 m of black clays and marls of late Toarcian and Aalenian age follow above the Posidonienschiefer (Dörntener Schichten). About 7 m of coarse clastic ironstones of Early Cretaceous age rest with an angular unconformity on the Aalenian clays (Figs. 23, 24). The iron ores consist of reworked limonitic fragments of formerly sideritic nodules. The surfaces of the fragments are smooth and have been polished due to reworking in a nearshore shallow marine environment. Reworked ammonite fragments indicate that the coarse clastic fragments originated from Early and early Mid-Jurassic sediments exposed nearby. Fragments of Triassic origin are extremely rare. Iron ooids are less common, but occur in the lower part of the section (beds 99, 100). The iron content in the Glockenberg section reaches up to 40%. The clastic ironstone is embedded in a fine-grained clay-marl matrix. Intercalated are several limestone beds varying from 0.6 m to 0.2 m in thickness. These horizons are less rich in limonitic clasts than the clays and marls. Further to the west the iron ore is overlain by glauconitic, sandy clays of Early Albian age. This 40 m thick succession correlates with the Hilssandstein, which was formerly exposed in the Morgenstern section about 2 km further southeast. Strata of mid-Albian age consist of 10 to 15 m of clay, yielding the belemnite *Neohibolites*

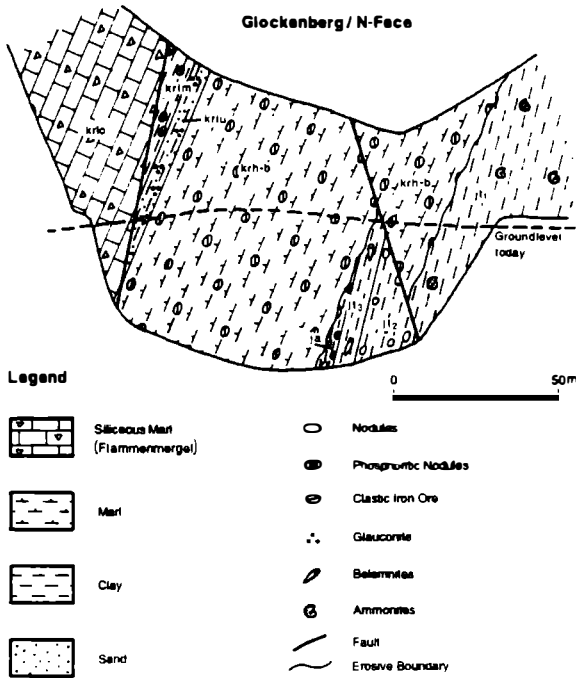


Fig. 23. Sketch of the north face of the Glockenberg section (modified after KOLBE et al. 1984).

minus (*minus* Clay). The Late Albian is represented by 80 m of siliceous marls (Flammenmergel).

Stratigraphy of the iron ores: The exact age assignment of the Early Cretaceous ironstone formations in the Salzgitter area is still debatable. Due to differences in lithology and age it is possible to differentiate between a northern and a southern area of sedimentation. The village of Liebenburg marks the boundary. In the northern area, ammonites and belemnites provided a solid biostratigraphic framework for dating the different iron ore lenses. Belemnites, in particular, have proved to be extremely useful (Figs. 25, 26). Iron ore sedimentation in the Salzgitter area possibly started in the Late Valanginian, the Late Hauterivian is characterized by oolitic ores, which are present only in the north. The main ore accumulation occurred in the Barremian, when conglomeratic ores were deposited. The Aptian is characterized by sandy and partly oolitic iron ores.

KOLBE (1962) suggested an Hauterivian age for the basal part of the succession exposed in Glockenberg. This part is enriched in carbonate. Most of the 60 m section comprises sediments of Barremian age. More recently KOLBE et al. (1984) assigned a Barremian age

to all of the ironstone succession in Glockenberg. These stratigraphic interpretations are based on the following observations: Oolitic iron ores are common in the Upper Hauterivian, they are, however, absent in the Barremian. Since most of the iron ores south of Liebenburg are clastic in their origin, KOLBE et al. (1984) inferred a Barremian age for the ore deposits in the southern part.

Due to the high carbonate content a Hauterivian age is tentatively assigned to the lowermost part of the Glockenberg section, which directly overlies the Aalenian clay. RODIGER (1932: 291) mentions two

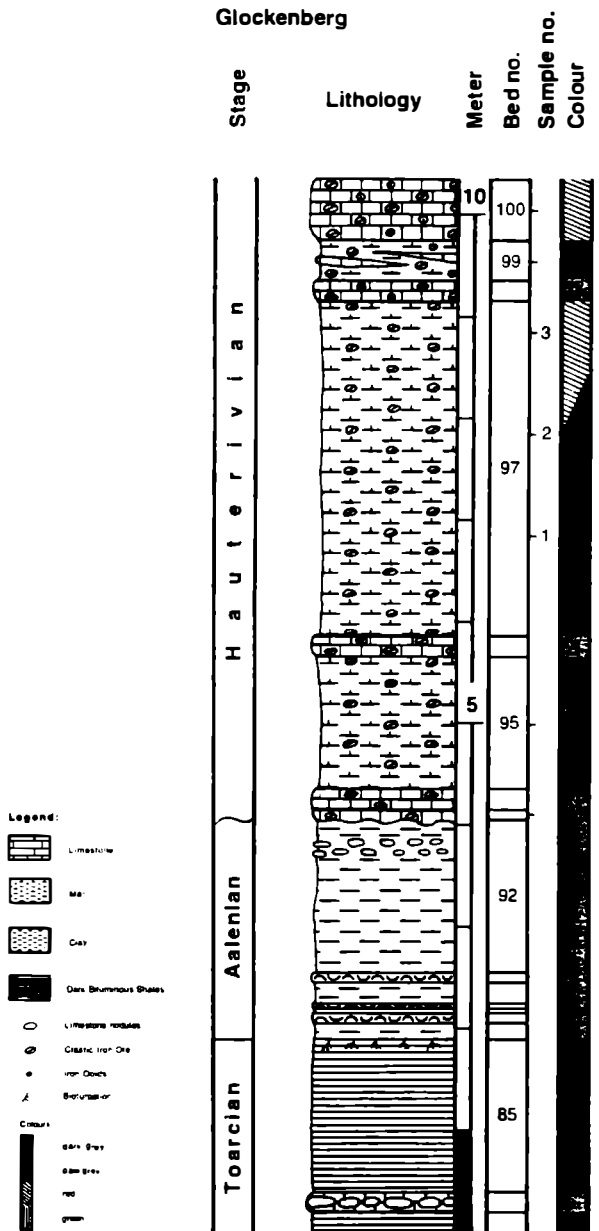


Fig. 24. Stratigraphy and lithology of the Glockenberg section.

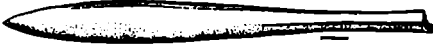

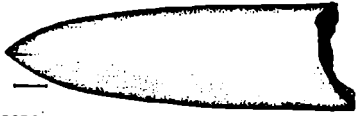


| STAGES | | Ammonite zones NW Europe | Belemnite zones | Iron ore deposits |
|-------------|--------------------------------------|--|--|--|
| HAUTERIVIAN | LATE | <i>Simbirskites (C.) discofalcatus</i> |  <i>Hibolites jaculoides</i> | Braunes und Schwarzes Lager (oxiditic ironores 15-30m) |
| | | <i>Simbirskites (C.) gottschei</i> | | |
| | | <i>Simbirskites (M.) staffi</i> | | |
| | | <i>Aegocrioceras</i> spp. | | |
| | EARLY | <i>Endemoceras regale</i> |  <i>Acroteuthis acmonoides</i> | Kalkiges Lager (5-20m) |
| | | <i>Endemoceras noricum</i> | | |
| | | <i>Endemoceras amblygonium</i> | | |
| | | <i>Eleniceras paucinodum</i> | | |
| VALANGINIAN | LATE | <i>Dicostella tuberculata</i> |  <i>Acroteuthis acrei</i> | |
| | | <i>Prodichotomoides ivanovi</i> | | |
| | | <i>Dichotomites bidichotomoides</i> | | |
| | | <i>Dichotomites triprychoides</i> | | |
| | | <i>Dichotomites crassus</i> | | |
| | | <i>Prodichotomites polytomus</i> | | |
| | | <i>Prodichotomites hollwedensis</i> | | |
| | | EARLY | | |
| | <i>Polyprychites clarkei</i> | | | |
| | <i>Polyprychites multicostatus</i> | | | |
| | <i>Polyprychites pavlowi</i> | | | |
| | <i>Platylenticeras involutum</i> | | | |
| | <i>Platylenticeras heteropleurum</i> | | | |
| | <i>Platylenticeras robustum</i> | | | |
| BERRIASIAN | LATE | <i>Peregrinoceras albidum</i> |  <i>Acroteuthis explanoides</i> | |
| | | <i>Surites sienomphalus</i> | | |
| | | <i>Surites icenii</i> | | |
| | | <i>Heteroceras kochii</i> | | |
| | | <i>Runctonia runctoni</i> | | |
| | EARLY | <i>Subcraspedites lamplughii</i> |  <i>Acroteuthis lateralis</i> | |
| | | <i>Subcraspedites preplicomphalus</i> | | |
| | | <i>Subcraspedites sowerbyi</i> | | |
| | | <i>Subcraspedites primitivus</i> | | |
| | | | | |

Fig. 25. Bio- and lithostratigraphy of the Berriasian-Hauterivian interval, showing belemnite species most significant for biostratigraphy.

Simbirskites from the lowermost part of the section, supporting a Late Hauterivian age. Future finds of belemnites might provide a definite age assignment.

Genesis of the iron ores: The Early Cretaceous iron ores of the Salzgitter area have been economically important from about 1940 to 1960, when they were mined extensively. Today all mines and pits are

closed down and abandoned.

The iron ores are preserved in lenticular bodies of 1 to 2 km length and up to 100 m thickness. The lenses are aligned along the western and eastern shoulder of the Salzgitter Anticline over a distance of 20 km. The sedimentation of the iron ores was controlled by epeirogenic factors, in particular by a highly variable palaeogeography. The ores were deposited

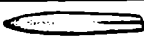

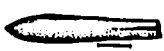
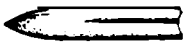

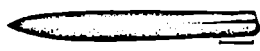
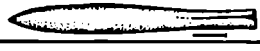
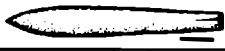
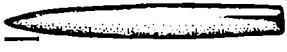

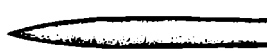

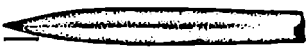

| STAGES | | Ammonite zones NW-Europe | Belemnite zones | Litho- facies | |
|-----------|--------|--------------------------------------|--|--|--|
| ALBIAN | LATE | <i>Stoliczkaia dispar</i> | <i>Neohibolites praeultimus</i>  I | Flammen- inregel (60-130m) | |
| | | <i>Mortoniceras inflatum</i> | <i>Neohibolites oxycaudatus</i>  | | |
| | | <i>Diploceras cristatum</i> | | | |
| | MIDDLE | <i>Euhoplites lautus</i> | <i>Neohibolites minimus</i>  | minimus-Beds (20-130m) | |
| | | <i>Euhoplites loricatus</i> | | | |
| | | <i>Hoplites dentatus</i> | | | |
| | EARLY | <i>Douvilleiceras mammillatum</i> | <i>Neohibolites minor</i>  | Hilssand- stein (10- 160m) | |
| | | <i>Leymeriella regularis</i> | | | |
| | | <i>Leymeriella tardefurcata</i> | | | |
| APTIAN | LATE | <i>Proleymeriella schrammeni</i> | <i>Neohibolites strombecki</i>  | Rotes Lager clastic iron ores (3-6.5m) | |
| | | <i>Hypacanthoplites jacobi</i> | <i>Neohibolites wollemanni</i>  | | |
| | | <i>Acanthoplites nolani</i> | <i>Neohibolites inflexus</i>  | | |
| | | <i>Parahoplites nutfieldiensis</i> | <i>Neohibolites clava</i>  | | |
| | EARLY | <i>Tropaeum drewi</i> | <i>Neohibolites ewaldi</i>  | | FS |
| | | <i>Tropaeum bowerbanki</i> | | | |
| | | <i>Deshayesites deshayesi</i> | | | |
| BARREMIAN | LATE | <i>Prodeshayesites tenuicostatus</i> | <i>Oxyteuthis depressa</i>  | Graues Lager (≤ 22m) clastic iron ores | |
| | | <i>Parancycloceras bidentatum</i> | | | |
| | | <i>Simancycloceras stolleyi</i> | | | <i>Oxyteuthis germanica</i>  |
| | | <i>Ancycloceras innexum</i> | | | |
| | EARLY | <i>Parancycloceras denckmanni</i> | <i>Oxyteuthis brunsvicensis</i>  | | Gelbes Lager (≤ 17m) |
| | | <i>Parancycloceras elegans</i> | <i>Aulacoteuthis</i> spp.  | | |
| | | <i>Hoplocrioceras fissicostatum</i> | | | |
| | | <i>Hoplocrioceras rarocinctum</i> | <i>Praeoxyteuthis puigio</i>  | | |

Fig. 26. Bio- and lithostratigraphy of the Barremian-Albian interval., showing belemnite species most significant for biostratigraphy.

in synsedimentary Y-shaped grabens and halfgrabens. The greatest thicknesses of ore deposits can be observed next to the fault. Ore deposition and subsidence of the graben occurred simultaneously. First, oolitic ores were deposited in the Late Hauterivian, while subsequently thick clastic ores accumulated in the Barremian and

Aptian. Aptian ores or Albian sediments cover the ore lenses. The strike of the iron ore lenses corresponds to the axis of the Salzgitter Anticline, subsequent movements caused the steep inclination of the ore lenses.

References: KOLBE (1962, 1970); KOLBE et al. (1984); RÖDIGER (1932).

2.6 Baddeckenstedt quarry (Figs. 27-29)

(by C. J. Wood, G. Ernst & U. Rehfeld)

Location and grid reference: TK 25, 3927 Ringelheim, R: 3584000, H: 5774000. The abandoned limestone quarry lies NW of Baddeckenstedt east of the B6 between Hildesheim and Goslar.

Stratigraphy: Lower Cenomanian limestone-marl rhythmite facies to the "Weiße Grenzbank" between the Lower and Middle Turonian Rotpläner.

Tectonic setting: The quarry is cut into the side of the Rasterberg on the S flank of the Lichtenberg Höhenzug at the point where it curves round to join the Hainberg structure in the tectonically disturbed NW corner of the Ringelheim (or Innerste) Syncline. The position of the quarry at the intersection of two major structures is expressed in complex tectonics with several fault systems (BADAYE 1986). Of particular importance are the stepped tension faults, typically throwing down SE towards the centre of the syncline. The displacements on these faults can reach ca. 6 m. The complex tectonics probably resulted from inversion of the Lichtenberg Höhenzug during the Subhercynian Illsede Phase. The faults are inferred to have developed as sediment masses slid gravitationally from the rising and tilting massif into the basin to the south (BRÜNING et al. 1987).

Lithology and lithostratigraphy: The ca. 70 m succession can be subdivided into the following three formations:

- Cenomanian Marl-Limestone Rhythmites and Transitional Beds (almost 20 m): Lower Cenomanian to lowest Middle Cenomanian. This unit is divided into a lower, rhythmically bedded succession, and a higher, less conspicuously, or even non-rhythmic succession (Transitional Beds), which includes several, some 0.25 m-thick, dark marls (M_{II} - M_{Ia}) in ascending order. For descriptive purposes, these two successions are treated separately.
- Cenomanian Limestones (ca. 22 m): higher Middle Cenomanian to lower Upper Cenomanian.
- Rotpläner (ca. 23 m): uppermost Upper Cenomanian to Middle Turonian.

Marl-Limestone Rhythmites: This unit (ca. 20 m) comprises alternations of thinner, marl-rich beds and thicker marly limestones up to and including M_{III} and the overlying limestone. The marls typically have a sharp basal contact and grade up into the overlying limestones. The sediment is composed of calcispheres, foraminifera, coccoliths, inoceramid prisms and, at some horizons, a significant amount of sponge spicules. The marl-limestone couplets vary in thickness and degree of lithification. The sequence of couplets can be matched in detail with the cyclostratigraphy of the correlative succession in the Anglo-Paris Basin. There, the rhythmicity is interpreted to be orbitally controlled, corresponding to the 20 ka cycle (precession) of the Milankovitch band (GALE 1995). Stable isotope evidence shows that the limestones represent warmer sea water temperatures than the marls, with a maximum difference of 4°C (ERNST et al. 1979; DITCHFIELD & MARSHALL 1989). Bundles of five couplets terminating in a more strongly developed limestone, indicating the effect of the eccentricity cycle (100 ka), cannot be recognized at Baddeckenstedt. The underlying argillaceous Cenomanian marl and the Albian/Cenomanian boundary succession are not exposed in Baddeckenstedt, but the basal Cenomanian transgression surface may lie some 10 metres below the floor of the quarry.

The Marl-Limestone Rhythmites contain two distinctive event-bundles, which are described in detail below: 1) Sponge Beds and *Mariella* Event, 2) "The Rib", *Inoceramus virgatus* acme, *Orbirhynchia* Event, and "The Double Limestone".

Near the base of the Baddeckenstedt section, the lowermost parts of a some 20 m thick rhythmically bedded marl-limestone succession are distinguished by at least two conspicuously lithified coarse arenitic limestone beds rich in inoceramid and echinoid debris which alternate with marlier limestones and marls, respectively. These limestone beds are often enriched in the anastomosing lychniscosan sponge *Becksia*, which lead to their designation as "Sponge Beds". The upper, main Sponge Bed also yields poorly preserved moulds of ammonites including *Schloenbachia*, *Mantelliceras*, *Austiniceras*, and *Mariella*. This is believed to be the level at which several *Neohibolites ultimus* were found

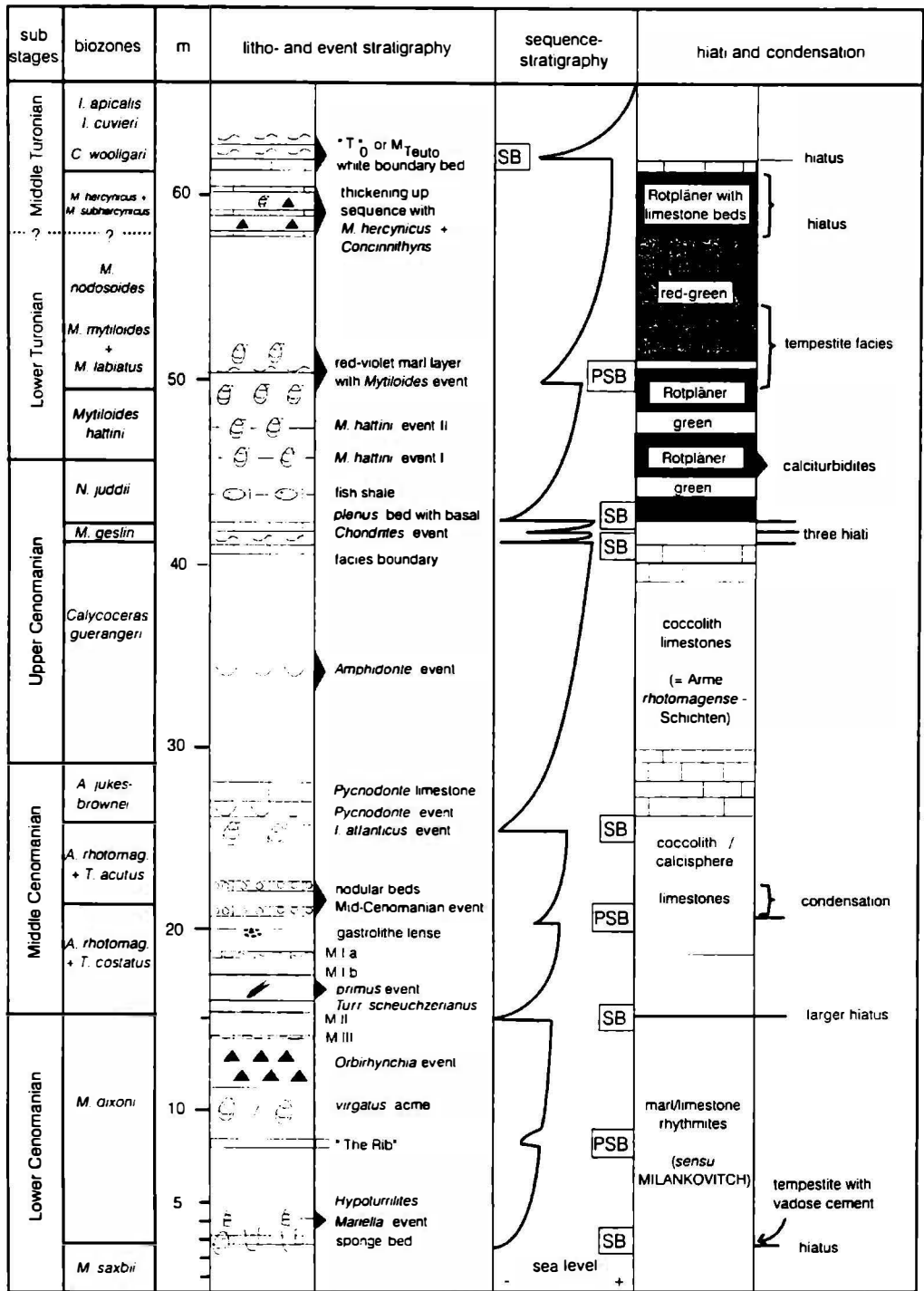


Fig. 27. Lower Cenomanian to Middle Turonian lithology and stratigraphy of the Baddeckenstedt quarry .

inside cemented sponges. The thicknesses of both beds are not constant in the quarry but swell and thin laterally between 0.2 and 0.4 m. They are marked by sharp contacts against the subjacent marly layers; their transition into the superjacent marl layer, instead, is more gradual. Gradation can often be recognized. Densely clustered, often double-valved large inoceramid

bivalves tend to form the base of both marker beds. These beds were mentioned from the Hoppenstedt area as well (HORNA 1996).

Biostratigraphically, the arenitic beds belong to the base of the *dixoni* ammonite Zone, which follow the argillaceous Lower Cenomanian marls of the subjacent *mantelli* ammonite Zone.

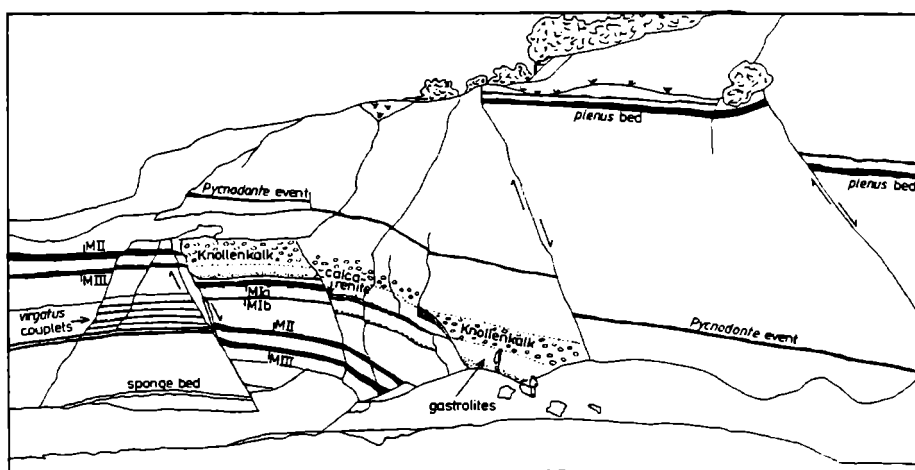


Fig. 28. Sketch, drawn from photographs, of the NE corner of the Baddeckenstedt quarry, showing the most important Cenomanian events.

The limestones comprise inoceramid-echinoid packstones to grainstones with a patchily well winnowed mud fraction.

The bioclasts of the matrix average 1 mm. They are rounded and almost completely micritized. Many of the echinoid fragments exhibit syntaxial rim cements.

The packstones and grainstone microfacies of the arenitic limestone beds indicate shallower, more agitated water environments. Micritization of the bioclasts and homoaxial rim cements around echinoderm fragments even hint at vadose diagenesis. Shallow water conditions are likewise supported by the occurrences of charophyte gyrogonites and dasycladacean fragments (ERNST & REHFELD in press). The sharp contacts against the sub- and superjacent marly calcisphere-foraminifera wackestone, the sudden facies change and the gradation suggest an allochthonous origin with a probably tempestite character from a shallower water source.

The large inoceramid valves at the base of these beds are autochthonous, being interpreted to form some kind of "Obrution Lagerstätte" (see BRETT & SEILACHER 1991). The fast entombment by the tempestitic sediment favoured their good, even double-valved preservation.

A well-marked acme-occurrence of commonly large turrilitid ammonites associated with *Inoceramus crippsi*, found in a marl about 1 m above the Sponge Beds comprise the *Mariella* Event. Omission is indicated by erosion of the upper surfaces of the ammonites. The event is also found at Hoppenstedt and it can apparently be traced to Westphalia (KAPLAN & BEST 1985).

It may well equate with the horizon of large, poorly preserved, glauconitized turrilitids in the Second *Inoceramus* Bed in eastern England (the so-called "Turrilitid Plane" of JEANS 1968).

"The Rib" is a conspicuous, 0.2 m thick limestone situated some 6 m below M_{III} and tending to weather proud. It is a key element of the Cenomanian cyclostratigraphy (the limestone of couplet B11 of GALE 1995: Fig. 4), and can be traced from England as far as Hoppenstedt. At Baddeckenstedt it yields well preserved *Mantelliceras dixonii* and *Inoceramus virgatus*. The immediately overlying couplets are particularly rich in ammonites, notably *Schloenbachia* and *Mariella*, associated with *Inoceramus crippsi*. This constitutes the *Schloenbachia/crippsi* Event of BADAYE (1986).

In bed 121 of BADAYE (1986) and in the underlying marl bed 122, there is an acme occurrence of bivalved *Inoceramus virgatus* associated with common *Schloenbachia*, *Inoceramus crippsi* and *Mantelliceras dixonii*. This corresponds to the *virgatus* acme in the likewise carbonate-rich couplets above "The Rib" in southern England. *Orbirhynchia mantelliana* ranges over some 2 to 3 m, with an acme occurrence in limestone-bed 119 of BADAYE (1986). *Acompsoceras*, *Forbesiceras* and *Austiniceras* are also recorded. This *Orbirhynchia* Event corresponds to the lowest of the three *Orbirhynchia* Beds in the Anglo-Paris Basin.

The massive, prominent "Double Limestone" (although here only inconspicuously bipartite) with its underlying *Orbirhynchia* Event is another key element of the

Cenomanian cyclostratigraphy and constitutes a combination of couplets B23 and B24. The top of this limestone at Baddeckenstedt is extensively burrowed by *Thalassinoides*, and GALE (1995) reported that there was a significant hiatus at this level, involving ca. 27 m of the highest *dixoni* Zone succession developed at Wunstorf, west of Hannover. The bed is very fossiliferous, yielding many ammonites including *Schloenbachia*, *Austiniceras* and *Acompsoceras renevieri*.

The rhythmites are generally very fossiliferous, quite apart from the previously discussed event occurrences, and *Plagiostoma globosum*, *Plicatula inflata* and *Euthymipecten beaveri* are common in the lower part of the section. Brachiopods include *Monticlarella rectifrons* and *Grasirhynchia grasiana*. Most beds are extensively bioturbated by *Thalassinoides*, *Planolites* and *Chondrites*. BARTELS (1993) provided quantitative data for the foraminifera (including plankton/benthos ratios), ostracods and bryozoa (see Fig. 29). The rhythmites and the basal part of the overlying succession were assigned to the *Rotalipora appenninica* planktonic foraminiferal zone.

The allochthonous coarse-grained arenitic Sponge Beds mark the "proximity" of a sequence boundary, probably representing lowstand sediments which were shed from a shallower swell area into the Baddeckenstedt area. Since the subjacent beds are not exposed at Baddeckenstedt, its distinct position cannot be defined. This sequence boundary probably equals the base of Sequence 2 of GALE (1995) and of Sequence 3 of ROBASZYNSKI et al. (in press). It is unclear whether or not "The Rib" corresponds to a maximum flooding surface at the top of the transgressive systems tract of the sequence, with the overlying carbonate-rich couplets containing the *virgatus* acme representing a highstand systems tract. Evidence of a major hiatus at the top of the burrowed limestone below M_{II} shows this to be probably a sequence boundary which, from its stratigraphic position, would correspond to the base of GALE'S (1995) Sequence 3.

The Transitional Beds: This unit comprises the succession from the second of the four conspicuous marls (M_{II}) up to the Mid-Cenomanian Event and beginning of

the Cenomanian Limestones. As noted above, there is a major hiatus and inferred sequence boundary at the base of these beds. At this level (1.25 m above M_{II}) there is a some 0.4 m thick horizon exhibiting at least three calciturbidites (ERNST & REHFELD in press). BARTELS (1993) reported a significant increase in grain size of the sediment ca. 1 m above M_{II} . He also recorded an increase in the percentage of keeled planktonic foraminifera in and above M_{II} . Minimum carbonate values were found in the highest marl (M_{Ia}). M_{Ia} is darker compared with the other marls. It rests on a highly irregular surface and fills pockets and burrows in the top of the underlying bed. Approximately 1 m above M_{Ia} , there is an abrupt change to a unit of relatively coarse-grained sediment, which includes the gastrolith lens (see below). These sediments rest with sharp basal contact on the underlying bed, and small pale brown to buff phosphatic clasts are concentrated just above the base. Above M_{Ia} , the succession becomes in general massively bedded and arhythmic. Carbonate values increase towards the top, where rather coarse-grained limestones composed of inoceramid and echinoid debris develop a marked nodularity at the level of the Mid-Cenomanian Events.

Three distinctive marker horizons can be recognized within the Transitional Beds: 1) the *Turrilites scheuchzerianus* Event, 2) the Gastrolith horizon, 3) the Mid-Cenomanian Event.

The *Turrilites scheuchzerianus* Event is an acme occurrence of large *T. scheuchzerianus* associated with *Schloenbachia*, *Acompsoceras*, *Austiniceras*, *Euthymipecten beaveri*, *Grasirhynchia grasiana* and inoceramids including *Inoceramus* cf. *reachensis*, *I.* cf. *schoendorfi* and *I.* ? ex. gr. *tenuis* 0.3 m above M_{II} . *T. scheuchzerianus* is long-ranging, first appearing in the higher part of the Early Cenomanian *dixoni* ammonite Zone, but the inoceramids appear to constitute an early Mid-Cenomanian assemblage.

About 1.5 m above M_{Ia} at least 350 gastroliths associated with reptilian bones have been found in a lenticular occurrence up to 1 m wide. The inferred provenance of some of these pebbles from the region of the Harz points to a possible Mid-Cenomanian uplift phase preceding the

early Coniacian Ilse Subhercynian inversion phase (ERNST et al. 1996). The surrounding sediment contains *Entolium orbiculare* and *Ostrea incurva*. The coarse-grained underlying sediment is similar to that of the main primus horizon with *Actinocamax primus* as developed in England.

The nodular arenitic limestones of the Mid-Cenomanian Event at the top of the Transitional Beds is characterized by the occurrence of *Holaster subglobosus* and large fragments of *Acanthoceras rhotomagense* with subordinate *Austinoceras* and *Turrilites costatus* (BADAYE 1986). Compared to other localities, e.g. Wunstorf, where a marked *Austinoceras* Event can be observed, *Acanthoceras* appear to predominate here over *Austinoceras*. Apart from isolated reports of *Orbirhynchia*, there is no evidence of the *Orbirhynchia mantelliana* occurrence and the *Sciponoceras baculoides* acme that characterizes this event elsewhere. The nodularity of these coarse-grained limestones points to omission and incipient hardground formation (ERNST & REHFELD, in press). These beds are time-equivalent with

the formation of the hardgrounds recorded by tubular tempestites at Misburg (HPCF II quarry). The conspicuous shift in the ratio of planktonic to benthonic foraminifera (second P/B break between M_{II} and M_{Ib} in BARTELS 1993) is inferred to occur on top of the nodular limestones.

The macrofauna evidence from the *scheuchzerianus* Event points to an early Mid-Cenomanian date, although no unequivocally diagnostic Middle Cenomanian ammonites such as *Cunningtoniceras* or *Acanthoceras* have so far been found. However, the identification by BARTELS (1993: Fig. 8) of the key planktonic foraminiferal zonal index *Rotalipora reicheli* from midway between M_{II} and M_{Ia} and above, suggests that the succession above the *scheuchzerianus* Event belongs to the narrow *reicheli* Zone. This zone is interpreted by German micropalaeontologists as marking the base of the Middle Cenomanian, although elsewhere (e.g. Folkestone) it appears to mark the top of the *dixonii* Zone and may extend (English Channel, French sector) into the Middle Cenomanian.

The position of the *primus* Event(s) remains

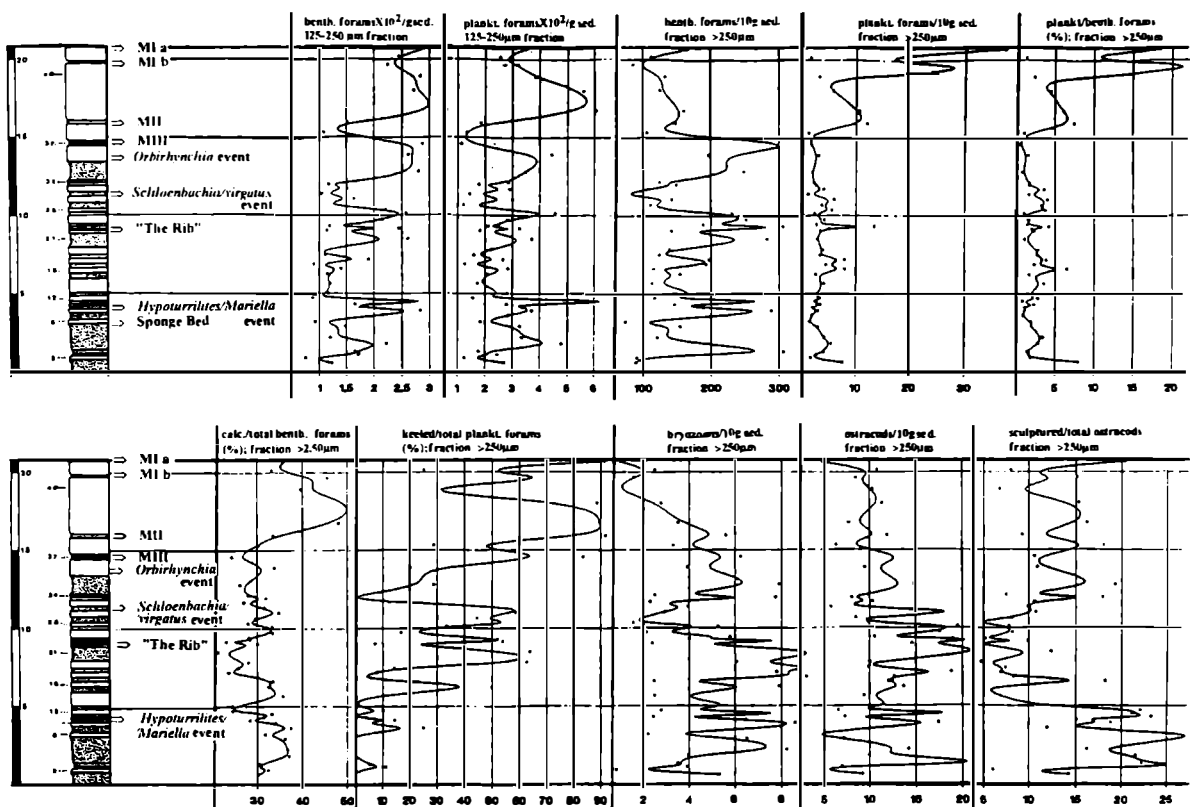


Fig. 29. Distribution of foraminifera, bryozoans and ostracods in the 125-63 μ m fraction of the Lower Cenomanian at Baddeckenstedt (data compiled after BARTELS 1993).

problematic. On the planktonic foraminiferal evidence these events should lie above the *scheuchzerianus* Event. A specimen of *A. primus* collected loose was assigned on the basis of its matrix to bed 111, i.e. the bed between M_{1a} and the nodular chalks (BADAYE 1986). It must be emphasized that the critical succession is at present inaccessible. However, the succession which includes M_{1a} and the bed with the gastroliths is strongly reminiscent of the (dark) *arlesiensis* Bed and the calcarenitic Cast Bed in the Anglo-Paris Basin succession, i.e., the two main *primus* Event beds. The gastrolith Bed is also comparable with the Totternhoe Stone, which is likewise an horizon in which reptilian bones are found.

A sequence boundary can be placed at the hiatus between the top of the "Double Limestone" and the overlying M_{11} . In the absence of definite evidence for the main *primus* Event, the flooding surface and the transgressive systems tract cannot be identified at present. In analogy with interpretations of correlative sections elsewhere (OWEN 1996), the Mid-Cenomanian Events may correspond to a maximum flooding surface.

Cenomanian limestones: Above the Mid-Cenomanian Events, there is a significant microfacies change from calcisphere dominated sediments to coccolith micrites with only a small foraminiferal content. Carbonate values range from 96 to 98%. These generally poorly fossiliferous beds constitute the so-called "Armerhotomagense-Schichten". They display a rather inconspicuous rhythmicity expressed as an alternation of thick, massively bedded limestones and very thin marls.

Two event occurrences of oysters within this succession constitute 1) the *Pycnodonte* Event, 2) the *Amphidonte* Event.

The *Pycnodonte* Event comprises a marl rich in small pycnodonteine oysters, some with valves associated. At this horizon elsewhere are found *Inoceramus pictus*, *I. atlanticus* and the top Middle Cenomanian zonal index *Acanthoceras jukesbrownei*. The marl grades up into a massive limestone bed which correlates with the Nettleton Stone of eastern England and the "Rauhe Bank" of Büren in Westphalia (see OWEN 1996). At Wunstorf and Langenstein, the event is underlain by an interval with

several event beds of *Inoceramus atlanticus*, but only sparse occurrences of the eponymous inoceramid have so far been found at Baddeckenstedt.

In marked contrast to the relative abundance of the eponymous oysters in the *Pycnodonte* Event, the *Amphidonte* Event comprises a relatively inconspicuous, sparse event occurrence in three closely spaced marly beds, of small exogyrine oysters (*Amphidonte*) and subordinate small pycnodonteine oysters.

Apart from the event occurrences of oysters, these beds are almost barren of macrofossils with the exception of *Inoceramus pictus*. By analogy with other areas, the interval is placed in the *Calycoceras guerangeri* Zone, but no ammonites have been found at Baddeckenstedt.

The relatively coarse-grained bioclastic sediments of the *Pycnodonte* Events are interpreted as a condensed transgressive lag superimposed on a sequence boundary. This is variously taken to mark the base of the fourth (GALE 1995), or the fifth (OWEN 1996; ROBASZYNSKI et al., in press) Cenomanian sequence. The maximum flooding surface is considered to lie a short distance above the massive limestone. OWEN (1996) interpreted the *Amphidonte* Event as a shallowing episode within the subsequent highstand. KAPLAN & GALE (in prep.) can demonstrate, on the basis of bed stratigraphy, that the highest parts of these highstand deposits are missing due to the erosive phase at the sequence boundary marked by the facies change.

Rotpläner: The Rotpläner succession is thicker than the correlative successions in the Lesse Syncline, but the same subdivision into the pre-*plenus*, *plenus* and post-*plenus* sequences can be recognized. The succession includes thin intercalations of black shales, carbonaceous marls with fish debris known as the "Fischschiefer" and two event beds with inoceramids including *Mytiloides hattini* and inoceramids belonging to the *pictus* group. These inoceramid events indicate the approximate position of the Cenomanian/Turonian boundary. The Violet Marl marker horizon probably corresponds to the acme occurrence of *Mytiloides* in the middle of the *Mammites nodosoides* Zone in the Anglo-Paris Basin. *Mytiloides* valves encrusted by serpulids

(*Filograna avita*), recorded from just above the Violet Marl at Söhlde but not from here, provide a link to the Anglo-Paris Basin.

The upper unit of the tripartite *plenus* Bed has yielded several specimens of *Actinocamax plenus* and a large *Pachydesmoceras denisonianum* is inferred to have come from the lower part of the bed (see DIEDRICH 1996). WOOD & MORTIMORE (1995) have discussed the correlation of the *plenus* Bed with beds 3 and 4 of the *plenus* Marls of southern England. The correlations presented by SCHÖNFELD et al. (1991) are incorrect. There is a significant non-sequence on top of the *plenus* Bed.

There is a thickening-up sequence (highstand systems tract?) of calcisphere limestones below the White Boundary Bed, which is itself a coccolith limestone. There is a major hiatus at the base of the White Boundary Bed, which includes the *hercynicus* Event of Westphalia. The White Boundary Bed contains small *Inoceramus*

cuvierii and *I. apicalis* and it has yielded a single specimen of *Collignonicerias woollgari*. In contrast to other localities, the overlying M_0 (or M_{Teuto} of the Teutoburger Wald), is represented by two brick-red marl layers.

Finally, it should be mentioned that the find of one loose specimen (presumably from the facies change Rotpläner to red/green alternation; Fig. 27) of *Mammites nodosoides* (coll. JUDENHAGEN) is of considerable importance as it proves the presence of the *nodosoides* ammonite Zone at this locality.

References: BADAYE (1986); BARTELS (1993); BRETT & SEILACHER (1991); BRÜNING et al. (1987); DIEDRICH (1996); DITCHFIELD & MARSHALL (1989); ERNST & REHFELD (in press); ERNST et al. (1979); ERNST et al. (1996); GALE (1995); HORNA (1996); JEANS (1968); KAPLAN & BEST (1985); KAPLAN & GALE (in prep.); OWEN (1996); ROBASYNSKI et al. (in press); SCHÖNFELD et al. (1991); WOOD & MORTIMORE (1995).

2.7 Salzgitter-Salder quarry

(Figs. 30-33)

(by C.J. Wood & G. Ernst)

Location and grid reference: TK 25, 3827 Lebenstedt-West, R: 3591000, H: 577775. To the south of the Autobahn 39 between Braunschweig and the Autobahn junction Salzgitter near the exit to Salzgitter-Salder, on the NE flank of the Lichtenberg Höhenzug.

Stratigraphy: *lamarcki* Zone of the Middle Turonian up to the contact with the Emscher Marl in the *deformis* Zone of the Lower Coniacian (Fig. 30).

Tectonic setting: The tectonic setting is complex and its interpretation is controversial. The quarry is situated in the area of intersection of three major inversion structures, the NW-SE trending Salzgitter Höhenzug, the Rhenish-trending Wendenburg fault-zone with the Broistedt salt structure at its southern termination and the E-W trending Lichtenberg Höhenzug (Hohenassel) structure. All three structures may have influenced the degree of subsidence in the Salder area and the resultant thick Turonian and Lower Coniacian sediments. It can be inferred that a marginal trough developed in front of the Lichtenberg block and its extension into the Salzgitter Höhenzug structure and that additional salt migration from the Broistedt saltplug took place.

The strata in the quarry are steeply inclined as a result of the uplift of the Lichtenberg block and dip at ca. 70° NNE. There are numerous, mainly antithetic faults, but displacements on these are small and do not hinder correlation of the beds. The time of the inversion coincides with Subhercynian tectonism, in particular the Early Coniacian Ilse Phase. 2.5 km to the W of Salder, in the Autobahn section N of Salzgitter-Lichtenberg, the Cretaceous strata are vertical or even slightly overturned.

General remarks: The 750 m long limestone quarry of Fels-Werke Peine Salzgitter GmbH lies parallel to the strike and exposes a ca. 220 m thick well-bedded succession of carbonate rocks. The thicknesses of virtually all the stratal units are significantly greater than in most other correlative sec-

tions in Lower Saxony. Because of the fully exposed succession and, particularly in the higher Turonian and Lower Coniacian, the enormous richness in inoceramids and other macrofossils, the Salder quarry provides a key section in the development of a biostratigraphic framework. The succession can be subdivided by means of numerous litho-, tephro- and ecoevents, which together permit excellent correlation with other European localities. The highly fossiliferous Turonian/Coniacian boundary succession with its closely-spaced event-bundles appears to have no obvious hiatuses or condensation and is unusual in this respect in comparison with all other European sections, except for the Vistula valley section in Poland. In view of this, the Salder quarry was proposed as an international stratotype section for the lower boundary of the Coniacian stage by KAUFFMANN et al. (1996).

Lithofacies and lithostratigraphic classification: On the basis of carbonate content, RASEMANN (1984) distinguished six different lithologies from limestone (K) to marl clay (MT). In the Middle and lower Upper Turonian, the more calcareous categories predominate, while the more clay-rich categories take on an increasing importance in the higher Turonian and Lower Coniacian (Grauweiße Wechselfolge). No analyses are available for the lower Middle Turonian, but this part of the succession is also more argillaceous. The microfacies has hitherto been investigated only on the basis of spot samples, or in limited parts of the succession (SIEHL in LANGHEINRICH & PLESSMANN 1968; RASEMANN 1984; KRÖGER 1996). Calcispheres constitute a relatively high proportion of the rock throughout, reaching 20% on average in the higher Upper Turonian, while the foraminifera and other bioclasts represent only a small percentage (calcisphere packstones). The micritic matrix is largely composed of coccoliths.

The argillaceous limestones and marls are highly bioturbated, with complex, secondarily extremely compacted ichnofabrics. The compaction rate was estimated by LANGHEINRICH & PLESSMANN (1968) to have resulted in a volumetric loss of 25%. They attributed this loss to pressure solution, which caused the original pore spaces to be completely filled. This compaction is also

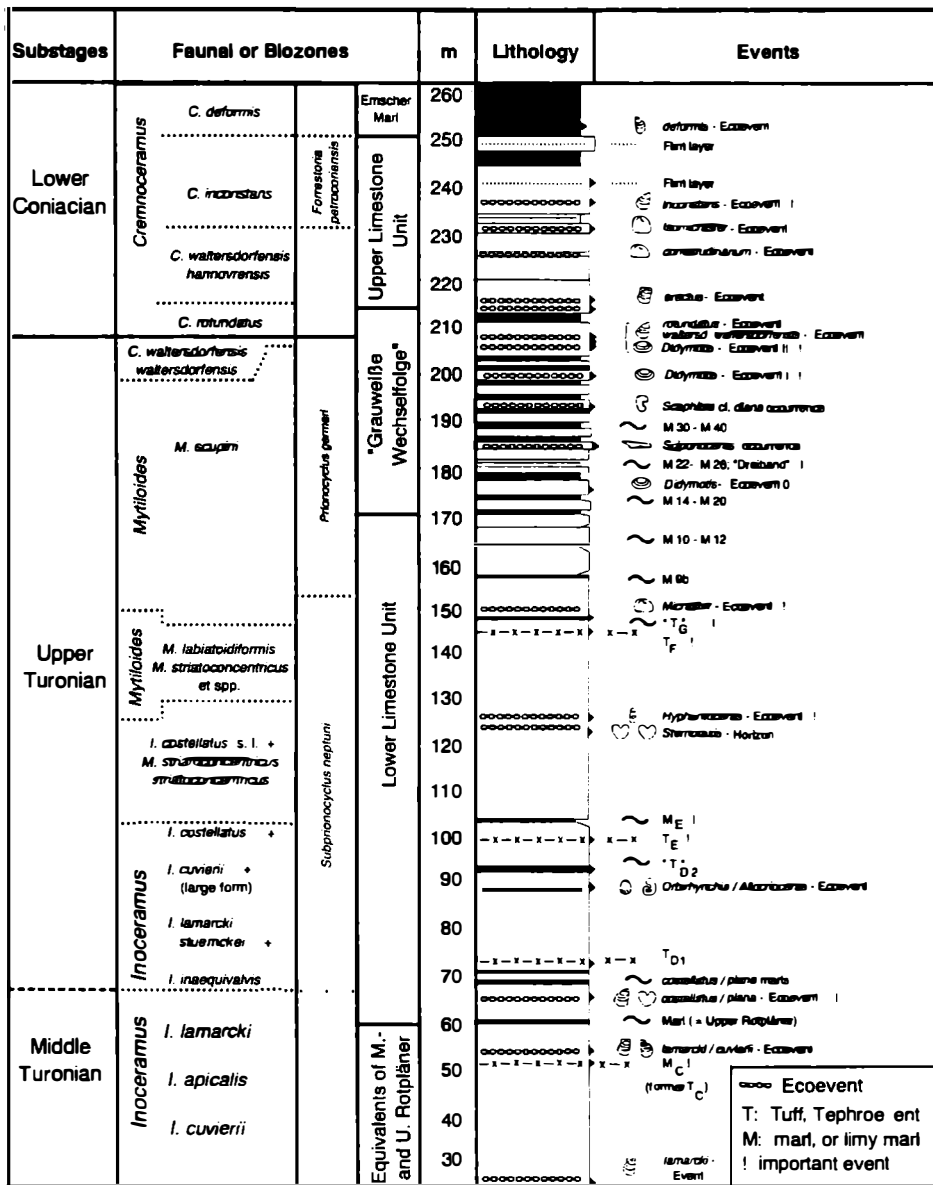


Fig. 30. Bio- and event stratigraphy of the Turonian and Lower Coniacian of the Salzgitter-Salder quarry.

demonstrated by a greater or lesser degree of distortion of the macrofossils. The succession can be subdivided into 5 main lithostratigraphic units, two of which are additionally discussed below.

Unit 1 (equivalent of the higher Rotpläner): This unit is developed as Middle and Upper Rotpläner on the NW margin of the Lesse Syncline, only 10 km distant. However, at Salder, a special structural situation was obtained during the Middle Turonian. Here, rapid sedimentation took place in a narrow subsiding foredeep/marginal trough, protected from the influence of upwelling cold northern currents. Salder was consequently an area of reducing con-

ditions at this time, so that the iron minerals linked to the clay fraction were not oxidized. In consequence, thick pale grey marly limestones and calcareous marls were deposited rather than thin Rotpläner. However, Rotpläner facies was proved ca. 250 m NNW of the quarry, in the Salder II borehole between 609 and 635 m. This is probably Lower Rotpläner, because this unit has the greatest regional lateral extent. High resolution correlation between the Rotpläner and the "Graupläner" facies is not possible at present. Only some events (inoceramid beds, limestone beds) permit a broad correlation. The equivalent of the Upper Rotpläner in Salder is, as elsewhere, characterized by slump structures.

Unit 3 (Grauweisse Wechselfolge):

This unit was established on the basis of the more or less rhythmic alternation of limestones and marls (ERNST et al. 1979) and was more precisely delimited in an event-stratigraphic framework by WOOD et al. (1984). Salder is the type locality for this unit. On account of its wide lateral extent in Lower Saxony and Westphalia, this rhythmic unit provides the key to the approximate localisation of the Turonian/Coniacian boundary in poorly recorded or former, now obliterated, sections, as well as in records of shaft successions and wireline logs of boreholes. The rhythms display a distinct thickening-upward pattern. It remains unclear whether or not the rhythmicity is orbitally controlled. These questions and other problems relating to the Grauweisse Wechselfolge should be shortly clarified from the results of current research by the Diploma students B. KRÖGER and T. JÖRDENS-MÜLLER (FU Berlin; Figs. 32, 34).

Event stratigraphy and fauna: The Salder succession can be readily subdivided by means of numerous litho-, tephro- and ecoevents (Fig. 30, 31). The tephro- and some of the litho- and ecoevents, in particular, permit an exact correlation with coeval successions elsewhere. With only a few exceptions, all the events included in the general NW German event scheme (ERNST et al. 1983) for this part of the succession are recognizable at Salder.

The closely-spaced event framework and the detailed lithostratigraphic section allow accurately horizoned, bed-by-bed collections to be made throughout the succession. Near the Turonian/Coniacian boundary, there are extensive bedding-planes exposed from which faunal assemblages and populations of individual species can readily be collected. From this level up to the beginning of the Emscher Marl, macrofossils are extremely abundant and taxonomically relatively diverse. This applies particularly to the inoceramids and, to a lesser extent, to the irregular echinoids and the brachiopods. In the Turonian/Coniacian boundary succession there are two beds with the interregionally important index bivalve *Didymotis*. Ammonites, mostly heteromorphs, are relatively uncommon. They tend to be restricted to particular beds, e.g. the *Hyphantoceras* Event.

The echinoids also tend to be concentrated at particular horizons. In addition to the regionally correlatable *Micraster* Bed overlying tuffs T_F and T_C (*Micraster* Event), there are event-occurrences of *Sternotaxis*, *Micraster cortestudinarium* and of an undescribed species of *Micraster* (*Isomicraster*) sp. The predominance of particular echinoid taxa in these events is of biostratonomical interest.

Middle Turonian: Only the higher part of this substage, comprising ca. 40 m, is exposed at present. The greater part of the Middle Turonian succession below a marly layer, until recently incorrectly considered to be the tephroevent tuff T_C , was not yet accessible at the time of the investigations by RASEMANN (1984) and by WOOD et al. (1984), but was exposed only later as the quarry was extended to the south. Consequently, only limited and poorly horizoned macrofossil data are available for this interval. The inoceramid assemblage exhibits an increasing proportion down-section of small to medium-sized, weakly sculptured *Inoceramus cuvieri* with *Inoceramus apicalis*. However, at the base of the section, there is an event with inoceramids exhibiting strong tendencies towards *Inoceramus lamarcki* so that it remains unclear whether or not the boundary with the underlying *apicalis/cuvieri* Zone has been reached. The basal beds certainly still lie significantly above the level of the Weiße Grenzbank which, in condensed sections, marks the boundary with the lower part of the Turonian and the Lower Rotpläner. The succession can be subdivided into several sequences on the basis of differing carbonate content and varying bed thicknesses (the beds are predominantly thin-bedded). The equivalent of the Upper Rotpläner is characterized by a ca. 3.5 m thick calcareous marl with slump structures.

Upper Turonian: The Upper Turonian at Salder is extremely thick (140 m). The great diversity of inoceramids permits the subdivision of the Upper Turonian substage into at least four inoceramid assemblage zones. The limits and faunal characteristics of these zones were documented by ERNST et al. (1983) in general terms and, in the specific context of Salder, by RASEMANN (1984) and by WOOD et al. (1984). However, recent as yet unpublished work on critical

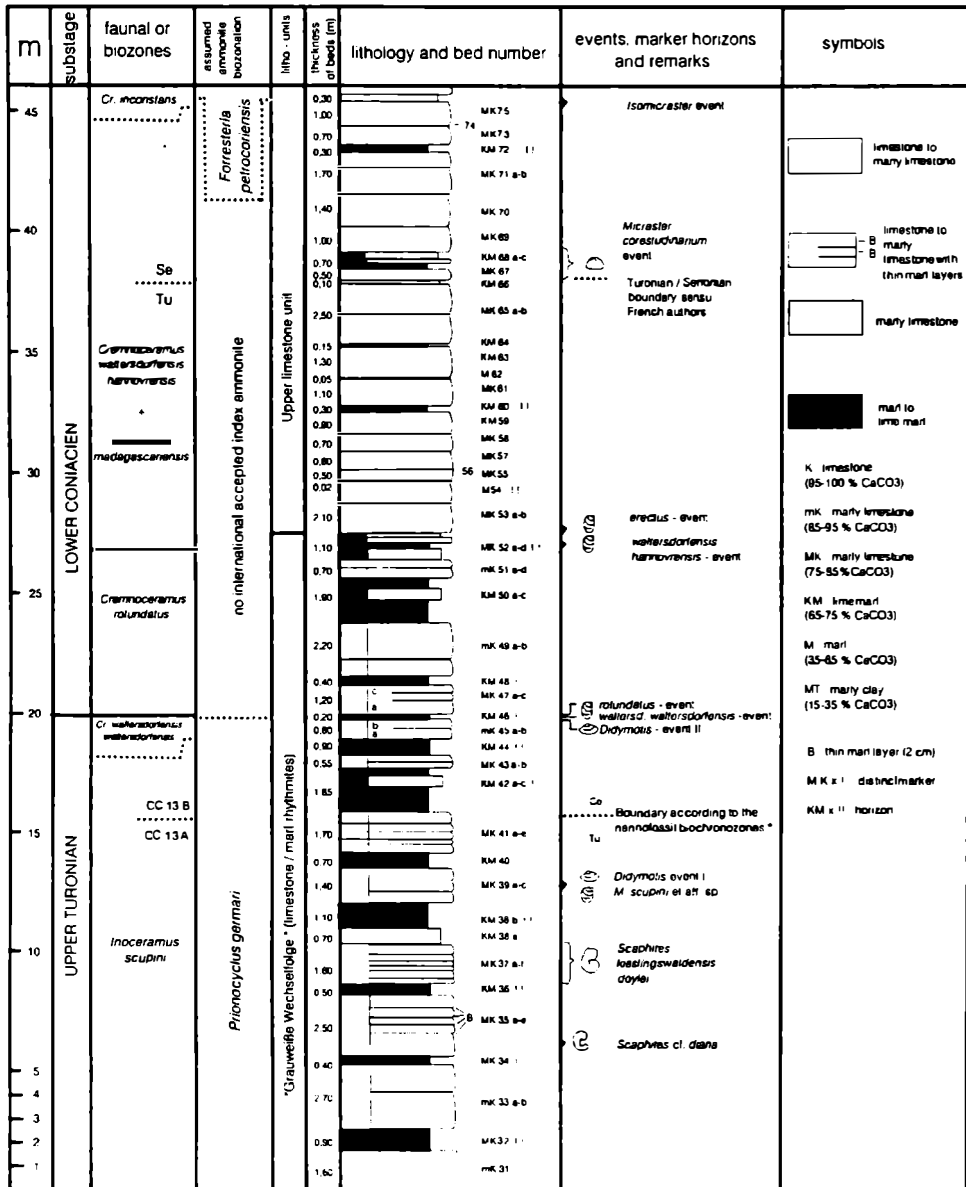


Fig. 31. Detailed litho- and event stratigraphy of the Turonian/Coniacian boundary succession of the proposed international standard section at Salzgitter-Salder (after WOOD, ERNST & RASENIANN 1984).

inoceramid assemblages from eastern Europe has necessitated significant modification of the inoceramid zonation then used. The numerous eco-, tephro- and lithoevents in this substage provide a relatively simple key to the location of the approximate positions of the zonal boundaries in the field. The *Mytiloides scupini* (formerly *Inoceramus aff. frechi*) Zone comprises a ca. 50 m succession within which a significant lithofacies change takes place from massive limestones to the rhythmic marl-limestone alternations of the *Grauweiße Wechselfolge*. The inoceramid fauna of this zone is relatively sparse. The two co-occurring inoceramid morphotypes that collectively characterize this zone, provisionally

assigned by Wood et al. (1984) to the single broad species concept of *Inoceramus aff. frechi*, are now considered by Tröger & Walaszczyk (in press) to be unrelated to the true (highest Lower Coniacian) *I. frechi*. In their view, the two morphotypes should be referred to *Mytiloides scupini* and *M. herbichi* respectively. The *M. scupini* Zone begins at T_f and extends up to just below the *Didymotis* II Event. It is thus approximately co-extensive with the uppermost Turonian *Prionocyclus germari* ammonite Zone of Kaplan & Kennedy (1994), which begins 2 to 3 m above the *Micraster* Marl and terminates just below the Turonian/Coniacian boundary. Only the stratigraphically most significant

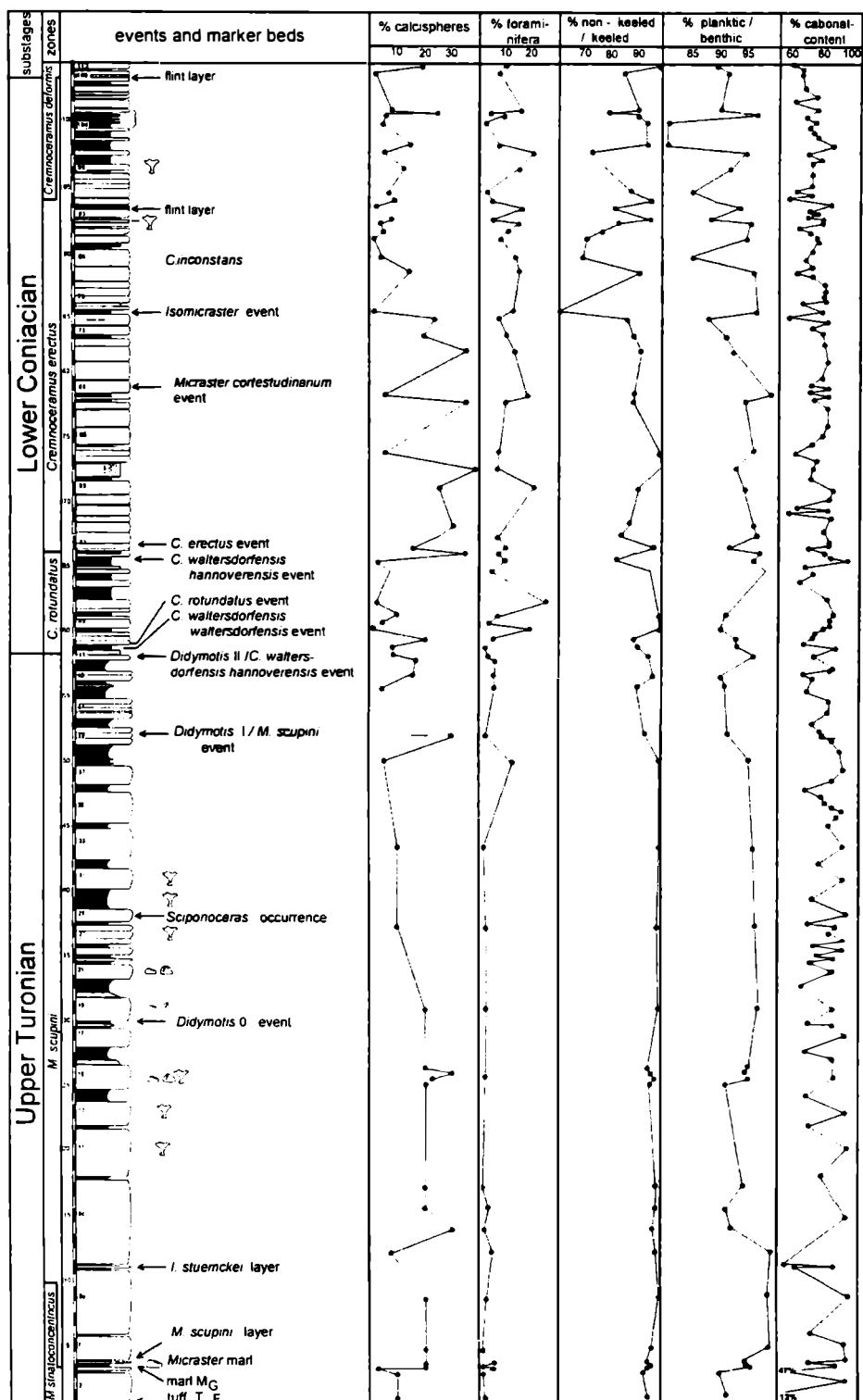


Fig. 32. Carbonate content and semi-quantitative analysis of foraminifera and calcispheres in the Upper Turonian-Lower Coniacian succession of Salzgitter-Salder (after KROGER 1996 and JORDENS-MULLER 1996).

events in the Upper Turonian are discussed here: 1) *costellatus/plana* Event, 2) M_E event-bundle, 3) *Hyphantoceras* Event, 4) *Mytiloides incertus* Event, 5) event-bundle tuff T_F , marl M_G and *Micraster* Marl, 6) lower

Didymotis Event. Further details of these and the other events as developed at Salder are to be found in Wood et al. (1984). The *costellatus/plana* Event is characterized by the mass co-occurrence of thin-

shelled inoceramids of uncertain affinities (including the eponymous group of *Inoceramus costellatus*) together with *Sternotaxis plana*. Associated with the guide-fossils are sparse *Allocrioceras*, *Sciponoceras* and *Scaphites* cf. *diana*, as well as *Infulaster excentricus*. Following its first appearance in this event, *I. costellatus* does not reappear until the overlying zone. The event is restricted to a thin, clearly delimited bed intercalated between otherwise relatively poorly fossiliferous limestones; it can be readily located by its position some 6 m beneath tuff T_{D1}.

The M_E event-bundle comprising the conspicuous 0.3 m thick marl M_E with its associated underlying tuff (T_E) and overlying thin marl M_{E-chen} can be traced throughout Germany and is the key to the correlation between thick, clay-rich successions such as Salder and relatively thin, carbonate-rich platform equivalents as in the Söhlede quarries in the nearby Lesse Syncline.

The *Hyphantoceras* Event (ERNST et al. 1983; DAHMER & ERNST 1986) has a thickness of about 6.5 m at Salder, with its base approximately 17 m above marl M_E. The event is named after the occurrence of the heteromorph ammonite *Hyphantoceras reussianum*. The base of the event is typically marked by a 2 m fining-upward sequence of coarse-grained, bioclastic sediment containing inoceramid shell fragments, smooth-shelled brachiopods and ammonite fragments. Immediately above the top of this basal unit the first *Hyphantoceras* fragments appear (first *Hyphantoceras-acme*). The second *Hyphantoceras-acme* lies ca. 2 m above the first one and has a thickness of ca. 3 m. The development of the *Hyphantoceras* Event in Salder does not correspond to the "normal development" (DAHMER & ERNST 1986), since the thicknesses found here are three to four times those usually attained. This is probably connected with the greater degree of subsidence and the intercalation of allochthonous sedimentation.

The *Mytiloides incertus* Event has not yet been proved in Salder, but its apparent absence is perhaps more due to collection failure than to an actual non-sequence.

The bundle of the three closely-spaced events tuff T_F, marl M_G and the *Micraster* Marl (M_G) comprises an excellent marker with wide regional extent (WOOD et al. 1984). On the basis of rare earth geochemistry,

marl M_G, previously considered to be a tuff comparable with T_F, has now been shown to be a detrital marl (WRAY 1995; WRAY & WOOD 1995). Work in progress suggests that tuff T_F is the highest tuff in the Turonian tephrostratigraphic scheme. The *Micraster* Marl event is characterized by the occurrence of advanced *Micraster* of the *bucailli* lineage near to the marl with a distinct concentration in the marl itself.

The lower *Didymotis* Event (DI) is characterized by the common occurrence of the thin-shelled bivalve *Didymotis* in a 0.45 m marly limestone (MK 39) associated with *Inoceramus lusatae*, *Mytiloides herbichi* and *M. scupini*. *Didymotis* has a virtually worldwide distribution and is of great biostratigraphic importance for long-range correlation. A lower *Didymotis* occurrence (designated D₀) has now been recognized in bed 19 (KRÖGER 1996), this occurrence may correlate with an event bed with rare *Didymotis* sp. in the lower part of the Grauweisse Wechselfolge at Hoppenstedt, which was formerly believed to be equivalent to one of the main *Hyphantoceras* Events on the basis of its ammonite and inoceramid fauna.

Turonian/Coniacian boundary succession: This comprises an event-bundle of three very closely-spaced bioevents within less than 0.5 m, which spans the stage boundary: 1) *Didymotis* II Event, 2) *C. waltersdorfensis waltersdorfensis* Event, 3) *Cremnoceramus rotundatus* Event.

The *Didymotis* II Event (bed 45) comprises a near-monospecific assemblage in limestone preservation of small inoceramids referred by WOOD et al. (1984) to small *Cremnoceramus waltersdorfensis hannoverensis*, but now considered (WALASZCZYK & WOOD in prep.) to be conspecific with *C. waltersdorfensis waltersdorfensis*. The inoceramids are associated with common *Didymotis* cf. *costatus*.

The *C. waltersdorfensis waltersdorfensis* Event (bed 46) is a near-monospecific assemblage of the eponymous inoceramid associated with rare large *Didymotis*. The inoceramids are preserved in marl with the shell and the two valves in association, but are predominantly considerably compressed.

The *Cremnoceramus rotundatus* (sensu TRÖGER non FIEGE) Event (bed 47) is a near-

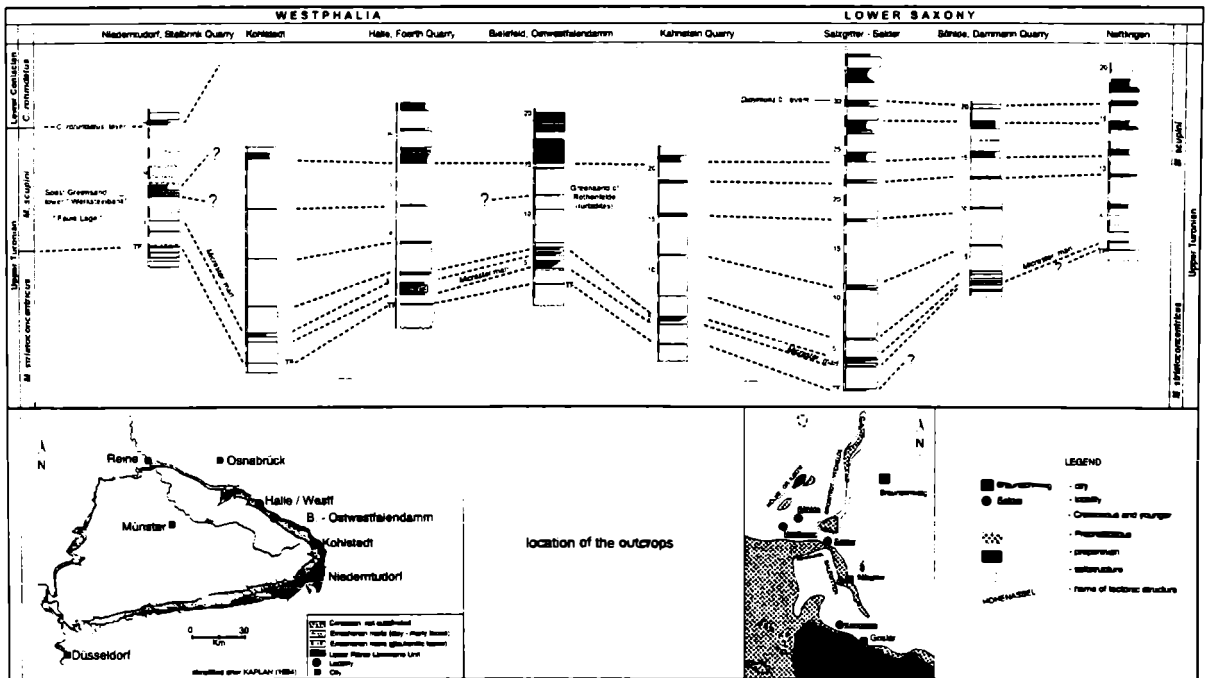


Fig. 3.3. Correlation of the Upper Turonian *M. scupini* Zone between Lower Saxony and Westphalia.

monospecific assemblage of the eponymous inoceramid in limestone preservation. This marks the first appearance of *C. rotundatus*, which, following the recommendation of the Brussels Symposium 1995, is the unique boundary marker for the base of the Coniacian stage. The base of the stage is consequently shifted upwards from the *Didymotis* II Event to the *rotundatus* Event, from which it follows that the two main *Didymotis* Events belong to the terminal Turonian.

This sudden appearance of Coniacian inoceramids in closely-spaced event-beds is one of the most striking features of the Salder succession. *Forresteria* (*Harleites*) *petrocoriensis*, the index of the base of the Coniacian for ammonite stratigraphers, has never been found in Salder, or anywhere else in Lower Saxony, but occurs significantly above the base of the stage in Westphalia (KAPLAN & KENNEDY 1994). An unequivocal Lower Coniacian ammonite fauna (*Scalarites turoniense*, *Neocrioceras paderbornense* and *Scaphites kieslingswaldensis kieslingswaldensis*) first appears in Salder at or a little below the *Isomicraster* Event (bed 75).

Lower Coniacian: At present only 50 m of Lower Coniacian are exposed. Previously, a further 65 m of the overlying succession

were accessible, and were cursorily documented by BRÄUTIGAM (1962). The highest 40 m fell in the *Volviceramus koeneni* Zone, i.e. basal Middle Coniacian in the sense of inoceramid stratigraphers.

The part of this succession that is still available can be readily subdivided lithostratigraphically using the numerous marl-seams and the two flint beds at the top of the section. The succession can also be readily subdivided using event stratigraphy. In addition to some inoceramid flood-occurrences, two echinoid events, the *Micraster cortestudinarium* and the *Isomicraster* Events, can be distinguished. The biostratigraphic significance of the *Didymotis* II, *waltersdorfensis* *waltersdorfensis* and *rotundatus* Events have already been noted. Other inoceramid events here comprise the *waltersdorfensis hannoverensis*, *inconstans* and *deformis* ecoevents. The *hannoverensis* Event marks a level of significant increase in inoceramid diversity and speciation, as does the *Isomicraster* Event (WALASZCZYK & WOOD in prep.). The latter is named from the common occurrence in bed MK75 of a relatively large, rounded *Micraster* (*Isomicraster*) sp. and likewise appears to offer good correlation potential within a relatively restricted area (e.g. Flöteberg section).

References: BRÄUTIGAM (1962); DAHMER & ERNST (1986); ERNST et al. (1979, 1983); JÖRDENS-MÜLLER (1996); KAPLAN & KENNEDY (1994); KAUFFMANN et al. (1996); KRÖGER (1996); LANGHEINRICH & PLESSMANN (1968); RASEMANN (1984); TRÖGER & WALASZCZYK (in press); WALASZCZYK & WOOD (in prep.); WOOD et al. (1984); WRAY & WOOD (1995); WRAY (1995).

2.8 Söhlde quarries (Figs. 34-36)

(by G. Ernst & C. J. Wood)

Location and grid reference: TK 25, 3827 Lebenstedt-West, R: 3585400, H: 5783935. From some 15 quarries situated south of Söhlde and along the road between Söhlde and Barbecke, three (the Loges and Damman quarries) are described in detail. Together they provide a more or less complete composite section through the Söhlde chalk.

Stratigraphy: Middle Cenomanian *primus* Event in the Witt quarry (also known as “Söhlde 1000”) to the Upper Turonian Grauweiße Wechselfolge.

Tectonic setting: The Lesse Syncline lies at the southern margin of the Gifhorn Trough. Its structural history was largely influenced by salt movement of the Broistedt saltplug and of the Luttrum and Westerlinde salt horsts in the Lichtenberg-Hohenassel structure (BAUERLE 1980). According to VINKEN (1971), halokinetic activity of the Mölme and Groß-Ilse salt structures to the north may also have played a role. The Luttrum and Westerlinde salt plugs already exhibited some degree of activity during the Early Cretaceous, but their influence on Cenomanian and Turonian sedimentation was quite minor (slight reductions in thicknesses towards the salt structures). A similar development is seen in the case of the complicated structural history of the Broistedt salt plug (BAUERLE 1980; RAUFUSS 1985). The thicknesses of the lower part of the Upper Cretaceous in the foredeep situated in front of the Broistedt salt structure are significantly greater than those in the Söhlde area of the Lesse Syncline. This provides evidence for strong syndepositional control of the depositional area, which is reflected to a limited extent by lateral thickness variations and the development of hiatuses in the Söhlde chalk.

Syn depositional tectonism, expressed by intraformational slides, rotational slumps and related phenomena, were described by HILBRECHT (1988) from the lower part of the Turonian of some of the Söhlde quarries. One year later, HILBRECHT (1989) attempted, without applying tectonism, to explain the same phenomena by invoking pore-water over-pressure resulting from eustatic sea-

level fall. These sedimentary disturbances were thought to terminate at one of the more important sequence boundaries, UZA 2.6/UZA 2.7, which is marked by the base of the Weiße Grenzbank (White Boundary Bed). However, we consider that these phenomena do not result from a single cause, particularly as comparable processes at other sequence boundaries are either not observed or are represented only to a limited degree. In our view, these can be attributed to tectonic pulses during the mid-Turonian, forerunners of the later main Subhercynian tectonic phases, which initiated possible tectoeustatic processes. A new working quarry in the vicinity of the Damman plant actually shows that the Weiße Grenzbank itself has been fragmented into blocks by sliding processes, which contradicts HILBRECHT'S model. The culmination of these activities must also be placed at a stratigraphically higher level than hitherto thought, somewhere between tuff T_c and the *costellatus/plana* Event, since-particularly at the level of the Upper Rotpläner-comparable submarine sedimentary anomalies are to be found not only in the Söhlde area, but also in some other comparative sections.

Lithofacies, lithostratigraphy and events: The succession exposed by the Damman and Loges quarries can be subdivided into four main lithostratigraphic units (Fig. 34):

- Upper Cenomanian Limestones (“Armerhotomagens-Schichten”), ca. 16 m to the base of the Loges quarry,
- Rotpläner (ca. 32m),
- Weißpläner (or Lower Limestone Unit; 50m),
- Grauweiße Wechselfolge (ca. 15 m up to the top of the Damman quarry).

Cenomanian limestones: The upper Middle Cenomanian with the *Pycnodonte* Event is accessible only in some of the western quarries of the Söhlde chain of quarries. As the result of the establishment of a dump for construction rubbish in the most westerly Witt quarry (= “Söhlde 1000” of HILBRECHT & DAHMER 1994), the lower Middle Cenomanian *primus* and Mid-Cenomanian Events, which were formerly exposed alongside a fault, are becoming progressively covered. The succession here was documented in detail by DAHMER (1986) and also

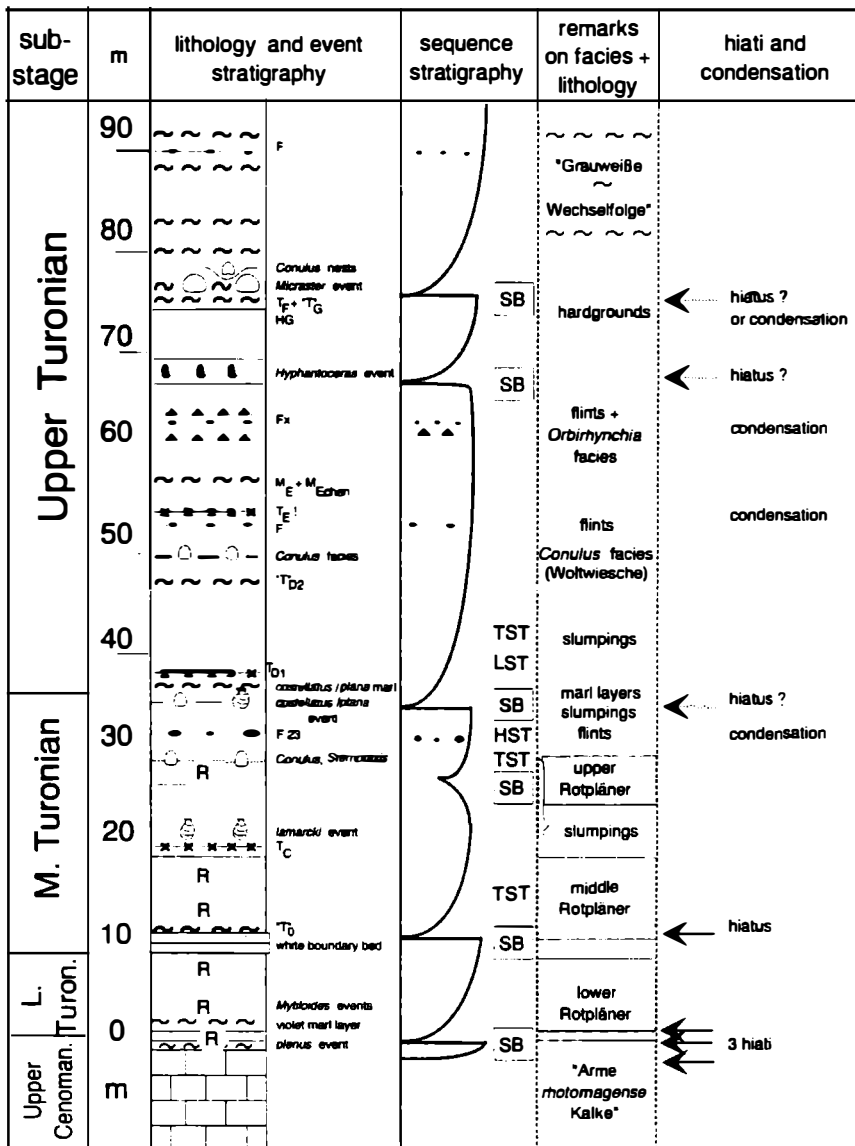


Fig. 34. Generalized standard section of the Upper Cenomanian to Upper Turonian of the Söhlde area.

treated by ERNST et al. (1992). The *Pycnodonte* Event, i.e. the boundary event at the base of the Upper Cenomanian, is developed here as a marl bed rich in the oyster *Pycnodonte* within rather uniform white limestones. It has also yielded rare *Inoceramus ex gr. pictus* and a whorl fragment of *Acanthoceras jukesbrownei*. The traditionally named "Arme (poor) rhotomagense-Schichten" (so-called from their extremely poorly fossiliferous character), overlying the *Pycnodonte* Event in the Loges quarry, do not differ in any way from those exposed at the Baddeckenstedt quarry. The microfacies comprises a rather pure coccolith rock with a subordinate con-

tent of calcispheres and foraminifera. About 3 m above the *Pycnodonte* Event another oyster event occurs, the lower *Amphidonte* Event. The extent of the hiatus in the vicinity of the facies boundary at the top of this succession has not yet been calculated in the context of the bed stratigraphy developed by KAPLAN (unpublished) in the Teutoburger Wald.

Rotpläner: The Rotpläner succession in Söhlde can be subdivided into three units, the Lower, Middle and Upper Rotpläner (Fig. 34). The Lower and Middle Rotpläner are separated by a conspicuous, ca. 2.5 m thick bed of white limestone, the so-called

Weißer Grenzbank. Söhlde is the type locality for this widely traceable event. The Weißer Grenzbank is overlain by a conspicuous red marl bed (the so-called T_0), which was originally interpreted by BRAUTIGAM (1962) as a tuff, and was consequently given the symbol T. It is probably a lag deposit and represents a significant hiatus. The Weißer Grenzbank and the T_0 together constitute a conspicuous marker sequence, which is represented in the Teutoburger Wald by a comparable bed of limestone overlain by a thick marl, the so-called M_{TEUTO} sensu KAPLAN. Both the T_0 and M_{TEUTO} have been shown on the basis of rare earth element analysis to be detrital rather than vulcanogenic marls (WRAY & WOOD 1995; WRAY et al. 1996). The Middle and Upper Rotpläner are likewise separated by a pale coloured bed of marly limestone (bed 17). In comparison to Baddeckenstedt (ca. 24 m), the Lower Rotpläner at Söhlde is markedly condensed (ca. 11 m). It comprises three sub-units, the pre-plenus succession, the *plenus* Bed and the post-plenus succession. Despite condensation, the pre-plenus succession together with the *plenus* Bed can be satisfactorily correlated with the same beds at Baddeckenstedt, although there are some differences in detail. In the Söhlde quarries, the pre-*plenus* succession exhibits lateral variation in both thickness and development, and shows evidence of occasional re-sedimentation (HILBRECHT & DAHMER 1994). Two *Chondrites* event-beds are present, the lower corresponding to the extinction datum of *Rotalipora greenhornensis* and the higher to the (local?) last appearance datum of *Rotalipora cushmanni* (ERNST et al. 1984). The upper event represents the original *Chondrites* Bed of ERNST et al. (1983) and is situated at the boundary with the *plenus* Bed. The *plenus* Bed at Söhlde and neighbouring localities is a complex, tripartite bed with three highly bioturbated separation planes (HILBRECHT & DAHMER 1994). At the top and, less distinctly, at the base of the bed, there is an hiatus marked, among other features, by reworked nodules with a greenish-grey coating (see also SCHÖNFELD et al. 1991). The eponymous belemnite *Actinocamax plenus* is extremely rare, a single specimen found so far probably coming from the top part of the bed. The remaining fauna comprises small pycnodontine oysters (abundant in the lower part of the bed), *Inoceramus*

pictus bohemicus and small brachiopods such as *Orbirhynchia wiestii* and *Monticlairella jefferiesi*. The complex *plenus* Bed with its underlying upper *Chondrites* Event constitutes an outstanding inter-regional event, which can be correlated in detail as far as Westphalia (ERNST et al. 1992) and even to England (see discussion by WOOD & MORTIMORE 1995).

The post-*plenus* succession is more completely developed in the western quarries of the Söhlde chain than it is in the eastern quarries. This is documented by the intercalation of a basal green succession, including the "Fischschiefer" (Fish-shale) event, which can be correlated to Baddeckenstedt and other localities (ERNST et al. 1984), and falls in the uppermost Cenomanian. The first really overlapping event of this sequence on the north-western margin of the Lesse Syncline is the so-called Bunte (variegated) Mergellage (DAHMER 1986; HILBRECHT & DAHMER 1994). This event marks the entry of shell detritus from the inoceramids *Mytiloides* ex gr. *mytiloides/labiatus*. The overlying thin limestone bed at the Söhlde 1000 quarry yielded a single specimen of the basal Turonian zonal index ammonite *Watinoceras devonense*. The Bunte Mergellage can therefore be used as a marker to identify the approximate position of the base of the Turonian in the Söhlde area. However, the true stage boundary lies significantly lower in less condensed successions.

Above this bed, there is a marked change in style of sedimentation, characterized by repeated reworking during high-energy episodes. Winnowing resulted in an increase in the proportion of shell debris and calcispheres. The microfacies changes from wackestones to packstones. Guttercasts, calcisphere-filled scour channels and green-coloured (reduced) high-angle shell debris document a distal tempestite facies. The gutters and scours contain well preserved, complete valves of *Mytiloides labiatus*, typically in "convex-downward" position. This depositional pattern terminates at the so-called Violette (violet) Mergellage, an event only a few centimetres thick, but nevertheless widely traceable in many N German localities. This event marks the first mass-occurrence of *Mytiloides mytiloides* (the lower facies-overlapping *Mytiloides* Event). The *Mytiloides* shells ca. 0.1 m above the Violette Mergellage are encrusted by

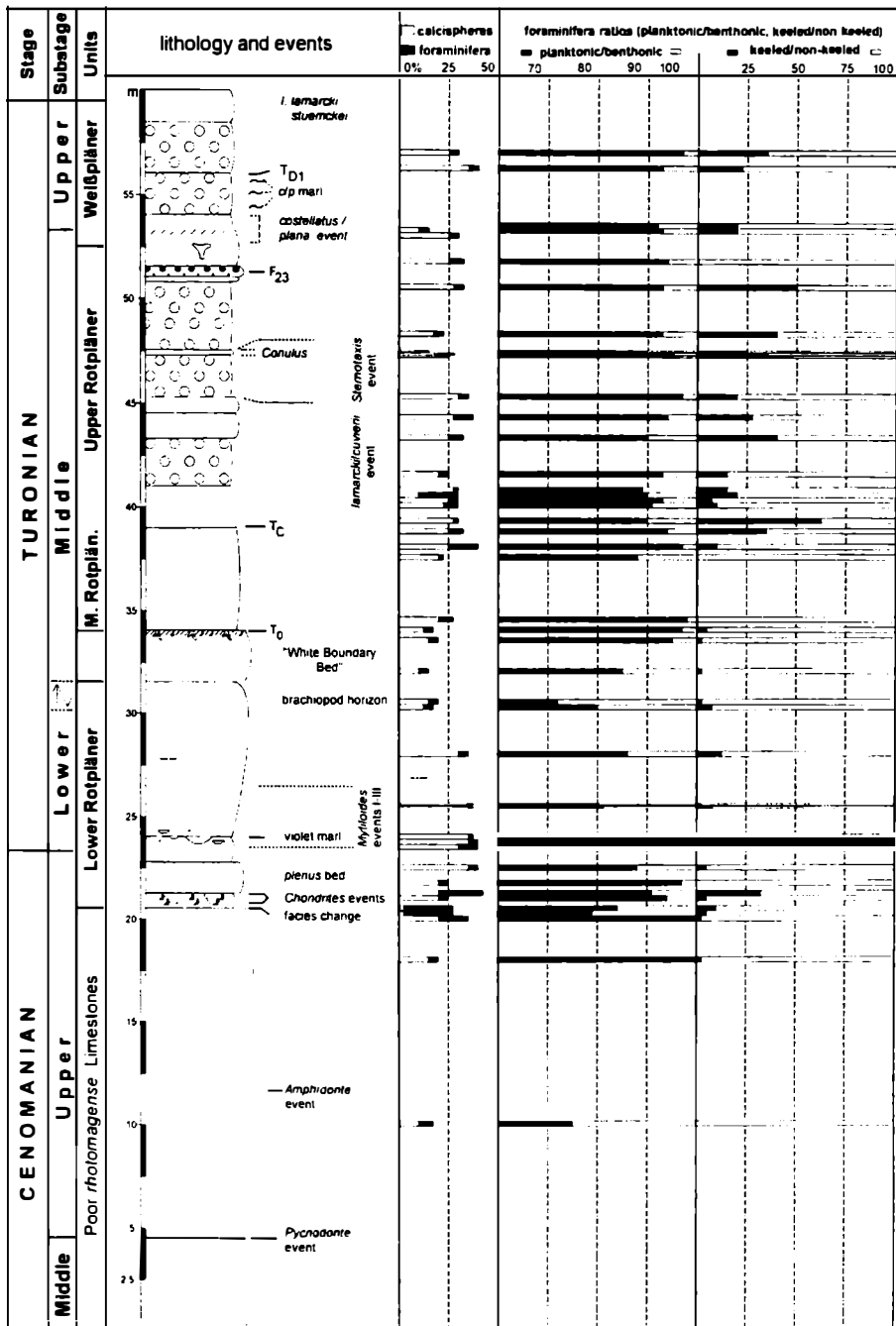


Fig. 35. Middle Cenomanian to lower Upper Turonian lithology and stratigraphy in the Söhlde area with semi-quantitative analyses of foraminifera and calcispheres (after BOTTCHEER 1996).

serpulids. This event probably corresponds to the *Filograna avita* horizon described by GALE et al. (1993) from an equivalent level in the Anglo-Paris Basin.

The Middle Rotpläner is usually pink rather than red-coloured, and it exhibits extensive bioturbation (*Thalassinoides*). The colour is predominantly restricted to the *Thalassinoides* burrow-fills, which possibly document tubular tempestites sensu TEDESCO & WANLESS (1991). It is also possible

that secondary oxidation took place in the relatively porous sediments of the burrow-fills. The upper boundary of the Middle Rotpläner at Söhlde and many other localities is marked by the first tuff bed (T_c). However, the red coloration may extend a little bit higher. The succession around T_c is additionally characterized by a geographically widespread *Inoceramus lamarki/cuvierii* Event.

The Upper Rotpläner is red-coloured in

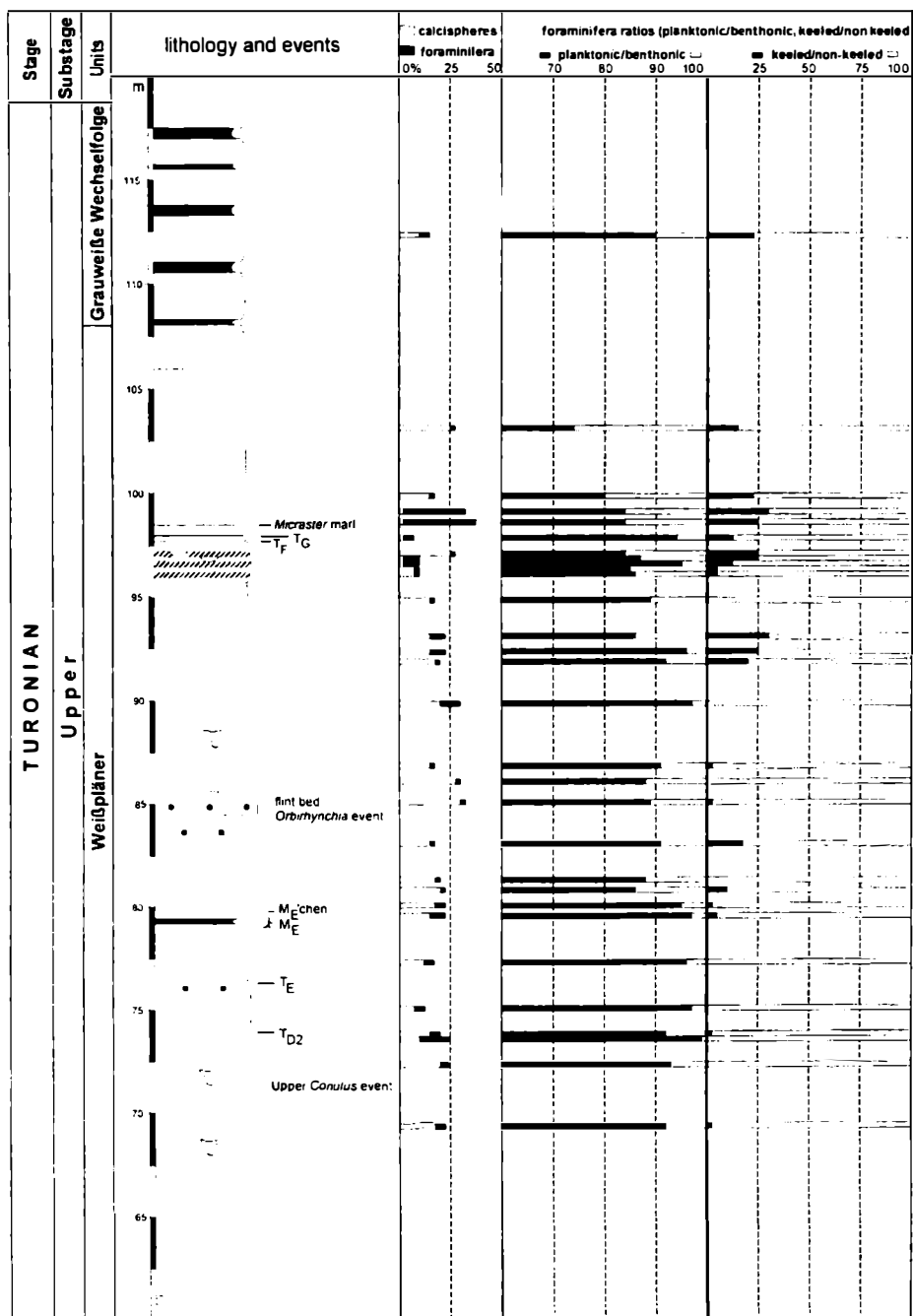


Fig. 36. Upper Turonian lithology and stratigraphy in the Söhlde area with semi-quantitative analyses of foraminifera and calcispheres (after BOTTCHER 1996)

only a few of the Söhlde quarries, which clearly reflect the shallowest parts of the depositional area. The red-coloured beds are mostly replaced by grey marls of varying abundance. At the top of this unit and at the base of the overlying Weißpläner, an event with *Sternotaxis plana* and *Conulus subrotundus* marks the first echinoid event following a long interval without such events and even virtually without echinoids in general.

Weißpläner: This Upper Turonian succession is significantly more calcareous than the beds below and is preferentially exploited by the quarry companies for this reason. The microfacies comprises a rather monotonous white calcisphere-rich coccolith micrite. Four event-bundles in the lowest, middle and uppermost part allow the unit to be subdivided and permit wide-ranging correlation: 1) flint horizon F₂₃ to tuff T_{D1}, 2) marl-bed T_{D2} to marl-bed M_E, 3)

flint horizon Fx and *Hyphantoceras* Event, 4) tuff T_F to *Micraster* Marl.

In sequence stratigraphic terms, the event-bundle F₂₃ to T_{D1} corresponds to the late highstand of one sequence and the lowstand and transgressive systems tract of the following sequence. The late highstand includes the flint horizon F₂₃, which is situated near the base of the Weißpläner and for which Söhlde is the type locality. It consists of several layers of thin, commonly white-striped tabular flints, in addition to sporadic vertical elements, in a unit of thin-bedded limestones about 1 m thick. This flint event can be traced to the eastern Teutoburger Wald (WRAY & WOOD 1995) and is in all probability represented in eastern England by the so-called Ferruginous Flint (see WOOD et al. 1984). It is absent in the marly foredeep sediments of the Salzgitter-Salder quarry, although its position can be easily identified at a thin-bedded limestone horizon. In the condensed vicinity of the sequence boundary is found the *costellatus/plana* Event, which marks the base of the Upper Turonian. The position of the event can be readily identified by a marked increase in limonitized sponges at the same level. The commonest fossils are the eponymous thin-shelled *Inoceramus costellatus* and related species, together with *Sternotaxis plana*; the only ammonite from here is a poorly preserved *Lewesiceras* sp.

The event is overlain by a thin slump horizon (movement to the south), which is followed by two marl beds, which may well belong to the transgressive systems tract. The event-bundle terminates upwards at the conspicuous tuff bed T_{D1}, which is one of the original tuff layers (then designated Tuff A) described by DORN & BRÄUTIGAM (1959) from the Söhlde area (see WRAY & WOOD 1995). This ca. 0.05 m thick tuff bed is divided into a lower barren part composed of greenish-yellow montmorillonitic clay, and an upper grey part which becomes more calcareous upwards and again yields some nanno- and microfossils.

The event-bundle T_{D2} to M_E comprises a combination of various litho-events: marl beds, a tuff and a flint bed. T_{D2} has been shown to be a detrital marl (WRAY & WOOD 1995) and consequently has been redesignated M_p. Particularly conspicuous and most readily correlatable is the succession T_E, M_E and M_{E-chen}. Tuff_E is similar

to Tuff T_{D1} and represents the second of the tuffs described by DORN & BRÄUTIGAM (1959; their Tuff B). The 0.3 m thick marl bed M_E is the most striking and perhaps the geographically most widespread marker horizon of the lower part of the Upper Turonian. M_E is usually followed, 0.3 m higher, by a thin marl bed known as the M_{E-chen}. Both these marls have been likewise shown on the basis of their rare earth elements to be detrital rather than vulcanogenic marls (WRAY & WOOD 1995). The interval between the marls contains an echinoid event comprising thin-tested forms such as *Infulaster* and/or *Sternotaxis*. In some comparative sections in Lower Saxony and Westphalia (e.g. Flöteberg, Bielefeld etc.), *Infulaster* occurs predominantly or exclusively at this level. An additional, rather scattered, echinoid occurrence lies in the region of T_E or below the tuff. In the Woltwiesche quarry, ca. 2.5 km north-east of the Dammann quarry, the relatively common occurrence of *Conulus* below T_E, in an interval several metres thick, represents the initial development of a *Conulus* facies.

The event-pair Fx and *Hyphantoceras* Event falls again in the vicinity of a sequence boundary. The only very weakly developed flint bed (Fx) lies within a condensed and relatively conspicuous brachiopod horizon which yields *Orbirhynchia* and small smooth terebratulids of uncertain affinity. This horizon is traceable at least in eastern Lower Saxony (e.g. Salder, Flöteberg, etc.). On the other hand, the *Hyphantoceras* Event some distance higher, is extremely poorly represented in the chalk facies of the Söhlde quarries and is difficult to locate. Its development here is quite atypical, consisting of an horizon with limonitised sponges, thin-shelled inoceramids, small brachiopods and rare *Scaphites geinitzii*. *Hyphantoceras* appears to be completely absent. Either the event in Söhlde falls within a succession with many hiatuses, or the sparse development here corresponds to a pelagic version of the highly fossiliferous event found elsewhere in different depositional situations (see DAHMER & ERNST 1986).

Once again, the event-bundle T_F to *Micraster* Marl falls in the vicinity of a sequence or parasequence boundary. It is underlain by a succession of one or more hard- or firmgrounds associated with thin

debrites. The last appearance datum of *Inoceramus* ex gr. *inaequivalvis* is found at this level. The event-bundle itself comprises two thin and one 0.05 m thick marl bed in an interval of only 0.5 m, constituting the so-called "Dreiband" (triple band). The thicker upper marl yields advanced *Micraster* of the *bucailli* lineage and therefore unequivocally represents the *Micraster* Event of other localities (e.g. Salder). The two lower marls were formerly identified as tuff T_F and the supposed tuff "T"_G respectively, but rare earth element analyses (WRAY & WOOD 1995) have shown that they are both detrital marls. The absence of the widely distributed marker tuff T_F from the triple band of the Söhlde chalk is puzzling. It is suggested that either this tuff was not deposited in the Söhlde area or that after deposition it was rapidly eroded (WRAY et al. in press). Above the *Micraster* Marl there is a minor facies change to slightly more clay-rich sediments. The calcisphere content increases suddenly at this level and there is a concomitant decrease in the foraminiferal content (KRÖGER 1996). Sporadic clusters of *Conulus* occur ca. 0.5 m above the *Micraster* Marl. All these characteristics support the hypothesis that there is a sequence boundary in the vicinity of the *Micraster* Marl. There is also a significant change in the ammonite assemblages some 2 to 3 m above the marl, marked by the occurrence in a quarry near Nettlingen in the western part of the Lesse Syncline of *Hyphantoceras flexuosum*, a characteristic

element of the topmost Turonian *Prionocyclus germari* ammonite Zone.

Grauweiße Wechselfolge: This litho-unit is relatively inaccessible at Söhlde and poor in macrofossils. In comparison to Salder, the marls are thinner, paler and not so clearly defined. However, they all appear to be present and show the same thickening-upward pattern (WOOD et al. 1984; KRÖGER 1996). As in the case of the lower litho-units, the Grauweiße Wechselfolge is 50% thinner in Söhlde compared to Salder. Only the lower part of the unit is exposed in the Söhlde quarries and the Turonian/Coniacian boundary interval is nowhere exposed. However, in the now backfilled former quarry near Barbecke, ca. 2 km east of the Dammann quarry, a well preserved low (but not basal) Lower Coniacian inoceramid assemblage dominated by large *Cremnoceramus waltersdorfensis hannovrensis* was collected from sediments in unexpectedly chalky facies.

References: BAUERLE (1980); BÖTTCHER 1996; BRÄUTIGAM (1962); DAHMER & ERNST (1986); DAHMER (1986); DORN & BRÄUTIGAM (1959); ERNST et al. (1983, 1984, 1992); GALE et al. (1993); HILBRECHT & DAHMER (1994); HILBRECHT (1988, 1989); KRÖGER (1996); RAUFUSS (1985); SCHÖNFELD et al. (1991); TEDESCO & WANLESS (1991); VINKEN (1971); WOOD & MORTIMORE (1995); WOOD et al. (1984); WRAY & WOOD (1995); WRAY et al. (1996).

2.9 Gott clay-pit near Sarstedt (Figs. 37-53)

(by J. Mutterlose)

Location and grid reference: TK 25, 3725 Sarstedt, R: 3560400, H: 5790650. The clay pit is situated about 30 km south of Hannover (Fig. 2). In 1993 the pit, which is a key section for the study of sediments of Early Cretaceous age, was closed down. Currently claystones of Barremian and Aptian age are being quarried in a new section directly north of the Gott section.

Tectonic setting: Northwest flank of the Sarstedt-Lehrte salt structure, about 1 km from the salt dome (Fig. 37). The beds dip at 25° towards WNW. There are several minor faults, each with a displacement of about a metre.

Palaeogeography: Eastern part of the NW German Basin, about 20 km north of the Hildesheim Peninsula. The palaeogeography varied considerably during the interval under discussion. In Hauterivian times a sea-way existed towards the Tethys via Poland (Carpathian sea-way) allowing floral and faunal exchanges. The Barremian is characterized by a major regression causing restricted conditions. No direct sea-way existed towards the Tethys, and the entire North Sea formed a marginal restricted basin. This palaeogeographic configuration allowed for the deposition of anoxic sediments (Blättertorn, Fischschiefer) and the evolution of endemic floras and faunas. The overall transgressive Aptian is marked by a change of the palaeoceanographic setting. A new sea-way opened to-

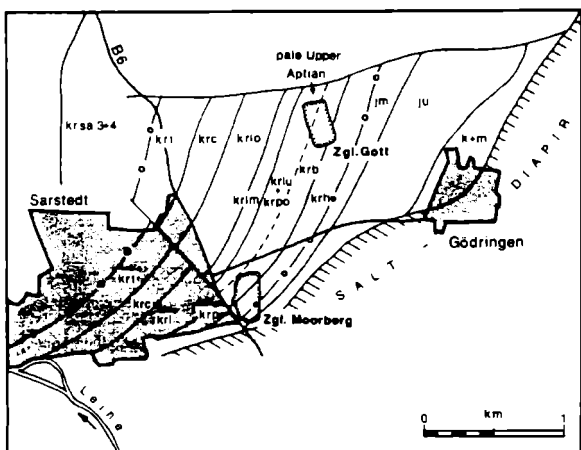


Fig. 37. Geologic map of the NW shoulder of the Lehrte-Sarstedt anticline.

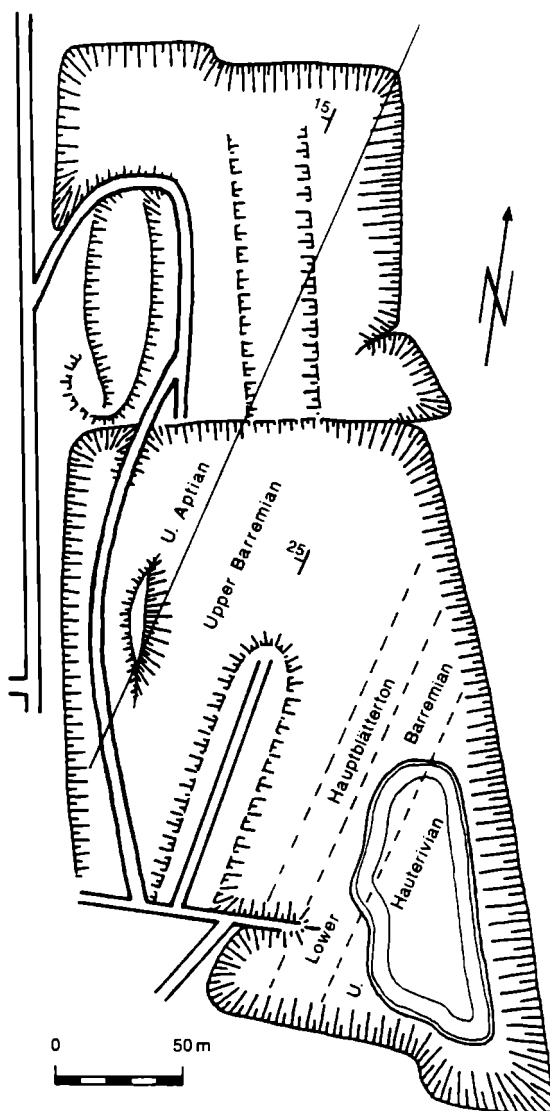


Fig. 38. Sketch map of the Gott clay-pit.

wards the west via a Proto-Channel and Tethyan floras and faunas invaded the basin from the west.

Stratigraphy and lithology: About 85 m of clays and marly clays are exposed (Figs. 38, 39). Strata of latest Hauterivian age (*Simbirskites gottschei* ammonite Zone) and Barremian age (*Praeoxyteuthis pugio* to *Oxyteuthis depressa* belemnite Zones) are unconformably overlain by mid- to late Aptian strata (*Parahoplites nutfieldiensis* to *Nolaniceras nolani* ammonite Zones). This pit exposes the most complete section of Early Cretaceous sediments in NW Germany (MUTTERLOSE 1984, 1995; Fig. 39).

About 12 m of fossiliferous clays of Hauterivian age (*gottschei* and *discofalcatus* ammonite Zones) are exposed (Fig. 39). These show typical bedding

Gott / Sarstedt

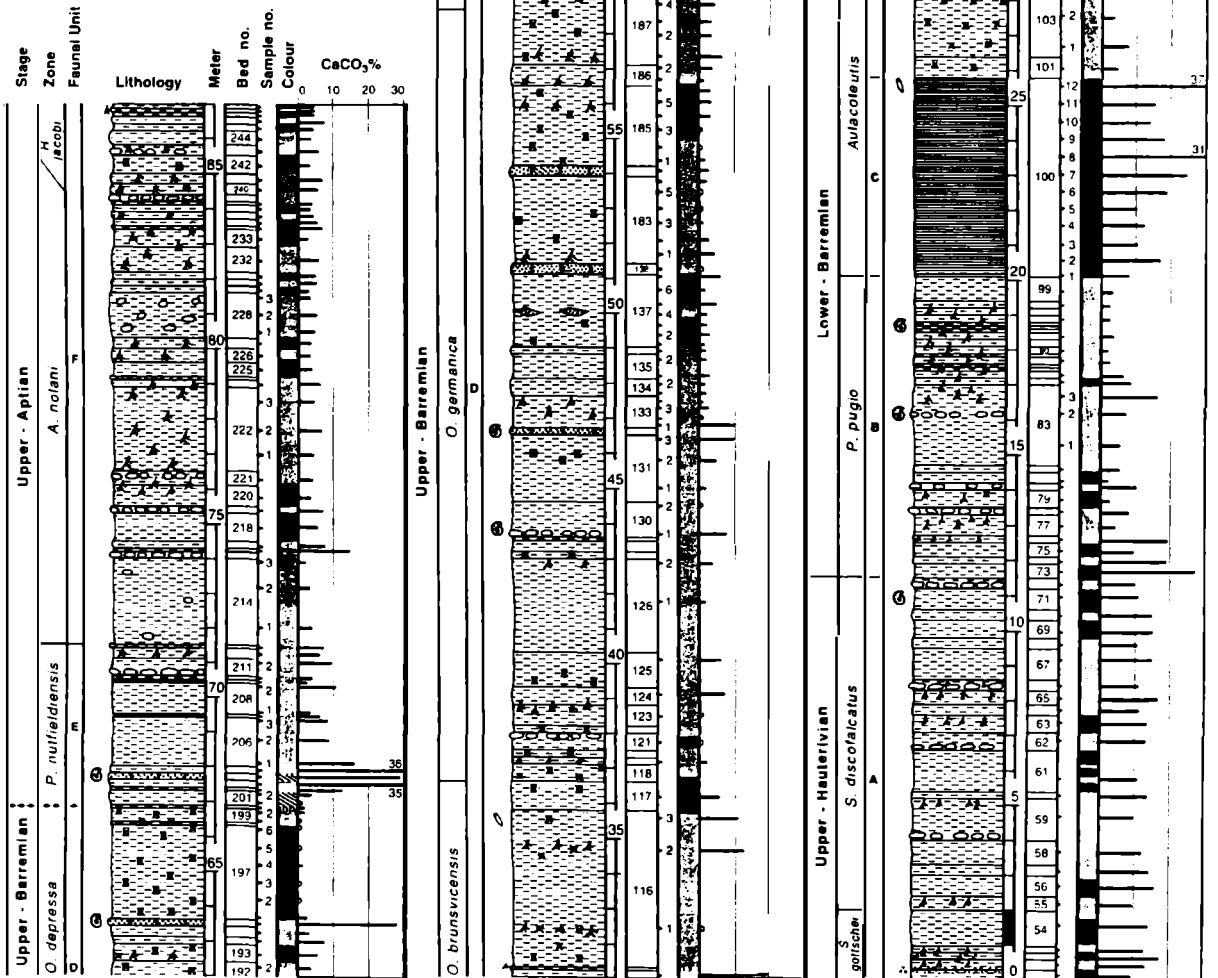


Fig. 39. Bio- and lithostratigraphy of the Gott section. Legend see Fig. 40.

rhythms of numerous pale and dark beds, intensively bioturbated at some horizons. These beds yield a rich micro- and macrofauna (interval A in Fig. 39).

The Barremian comprises about 56 m of medium and dark clays. The lithology of the lowermost 8.6 m (*Praeoxyteuthis pugio* belemnite Zone of the Early Barremian) is very similar to those of the Late Hauterivian (clay-marl rhythms, *Chondrites* horizons). These beds correspond to interval B in Fig. 39. About 5.7 m of finely laminated sediments, the Hauptblättertön of the Early Barremian, were deposited under anoxic conditions. These have been assigned to faunal interval C (Fig. 39). The remainder of the Barremian (interval D in Fig. 39) consist of 41.5 m of clays and marls. The lower 15 m are dominated by pale marly layers

and *Chondrites* beds. Beds rich in pyrite are common, and there are two thin Blättertön horizons. The carbonate content of this interval does not exceed 5%. In bed 107 *Crioceratites elegans* is common. The upper part of the Barremian is lithologically much more monotonous. The clay becomes darker towards the top and several sandy horizons are intercalated. Bed 197 yields *Paracyloceras bidentatum*. The belemnites *Oxyteuthis brunsvicensis*, *O. germanica* and *O. depressa* are common. The carbonate content decreases towards the top.

The Barremian-Aptian boundary is characterized by a hiatus, strata of Early Aptian and early Late Aptian age (*Prodeshayesites forbesi* to *Epicheloniceras tschernytschewi* ammonite Zones) are missing. The latest Aptian (*Parahoplites nutfieldensis* to

Legend:

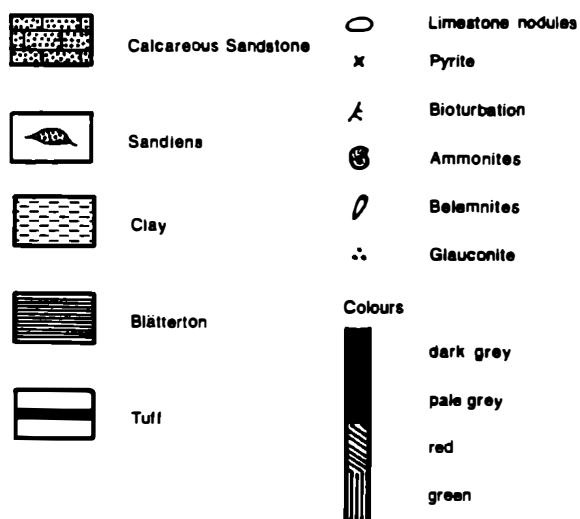


Fig. 40. Legend of Fig. 39.

Nolaniceras nolani ammonite Zones) is represented by 19 m of clays and marls. The basal 4 m (interval E) are represented by varicoloured pale and red marls (Hedbergellen Marl), which yield two tuff horizons (bed 207, 209). These are overlain by 14.7 m of pale-dark bedded clays (interval F), which gradually pass into black clays impoverished in carbonate.

Flora and fauna: The Gott pit is one of the best studied Lower Cretaceous sections in NW Germany. Micropalaeontologic groups studied in detail are palynomorphs (BELOW 1982; MUTTERLOSE & HARDING 1987a, b; HARDING 1990; LUTAT 1991), calcispheres (KEUPP 1980, 1981, 1993), calcareous nannofossils (MUTTERLOSE 1991) and foraminifera (LUTZE 1968; HEINRICH 1991). Macrofaunas include ammonites and belemnites (MUTTERLOSE 1983; Figs. 41-47). Based on the floral and faunal content six paleologic intervals (A-F) have been differentiated (Fig. 39).

Interval A: Clay-marl rhythms of the Hauterivian. Rich and diverse micro- and macrofauna, representing a well-oxygenated environment. The Boreal ammonite genus *Simbirskites* (*S. (C.) gottschei*, *S. (C.) discofalcatus*, *S. (C.) juddii*) and the Tethyan *Crioceratites strombecki* occur. The belemnites are of Tethyan (*H. jaculoides*) and Boreal provenance (*Acroteuthis rawsoni*, *A. stolleyi*). The distribution of the microfauna and -flora is comparable to that of the Frielingen sec-

tion (No. 14). The pale beds yield calcareous nannofossils of Tethyan provenance (*Nannoconus* spp.). A sudden influx of nanoconids in bed 58 (9% of the total abundance) allow a regional correlation with bed 117 of the Frielingen section. This *Nannoconus* event occurs just below a horizon characterized by the belemnite *Acroteuthis*. The foraminifera are dominated by *Epistomina caracolla* and *E. ornata*.

Interval B: Comparable to interval A; well-oxygenated nearshore environment. The Hauterivian/Barremian boundary is, however, marked by a change of faunas and floras. Within interval B, Boreal and endemic floras (*Nannoconus abundans*, *N. borealis*) and faunas (*Praeoxyteuthis*, *Hibolites minutus*) become common. These elements mark the closure of sea-ways towards the Tethys.

Interval C: Stagnant conditions caused by restricted palaeogeographic setting resulted in an anoxic environment, which in turn gave way to finely laminated sediments. *Chondrites* beds are absent, as is most of the benthos. Belemnites (*Aulacoteuthis* spp.) are common, rich fish faunas have been described from these beds (BRAHMS 1913). The C_{org} content reaches up to 4%, that of the normal clay facies is only 1.8%. Rich assemblages of calcareous nannofossils and dinoflagellates have been described from the Hauptblättertön (MUTTERLOSE & HARDING 1987b). The calcareous nannofossils are enriched in monospecific layers, causing the lamination. These beds have presumably been caused by a stable water stratification of warm surface waters and seasonal phytoplankton blooms.

Interval D: Re-establishment of normal marine conditions. The floras and faunas are, however, impoverished in comparison to those of interval B. This may have been caused by a decrease in oxygen. Boreal and endemic floras and faunas are common. The black clays of the *Oxyteuthis depressa* belemnite Zone are essentially barren of microflora and fauna.

Interval E: Well-oxygenated shallow-water sediments, rich in benthic and planktonic foraminifera (*Hedbergella*). The rich

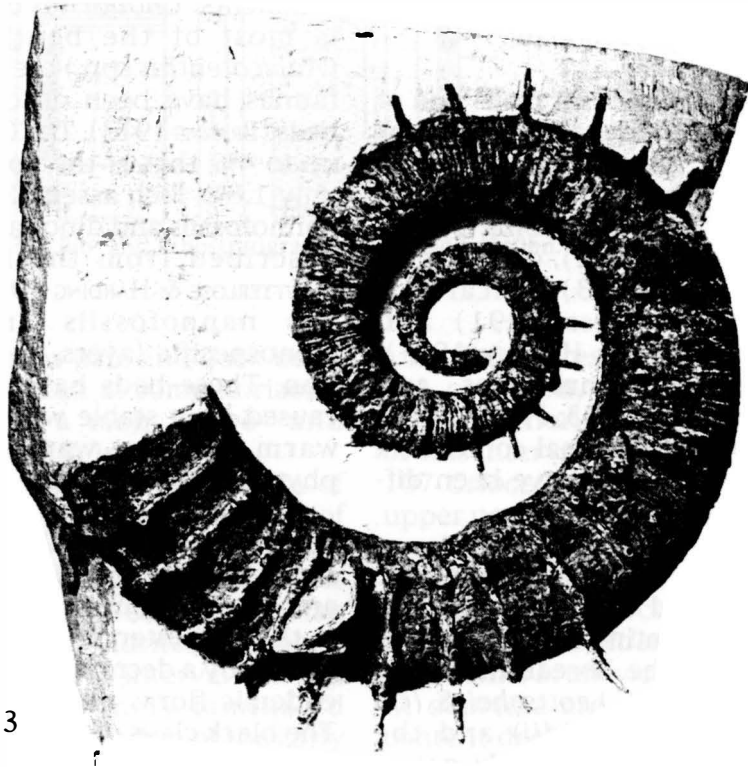
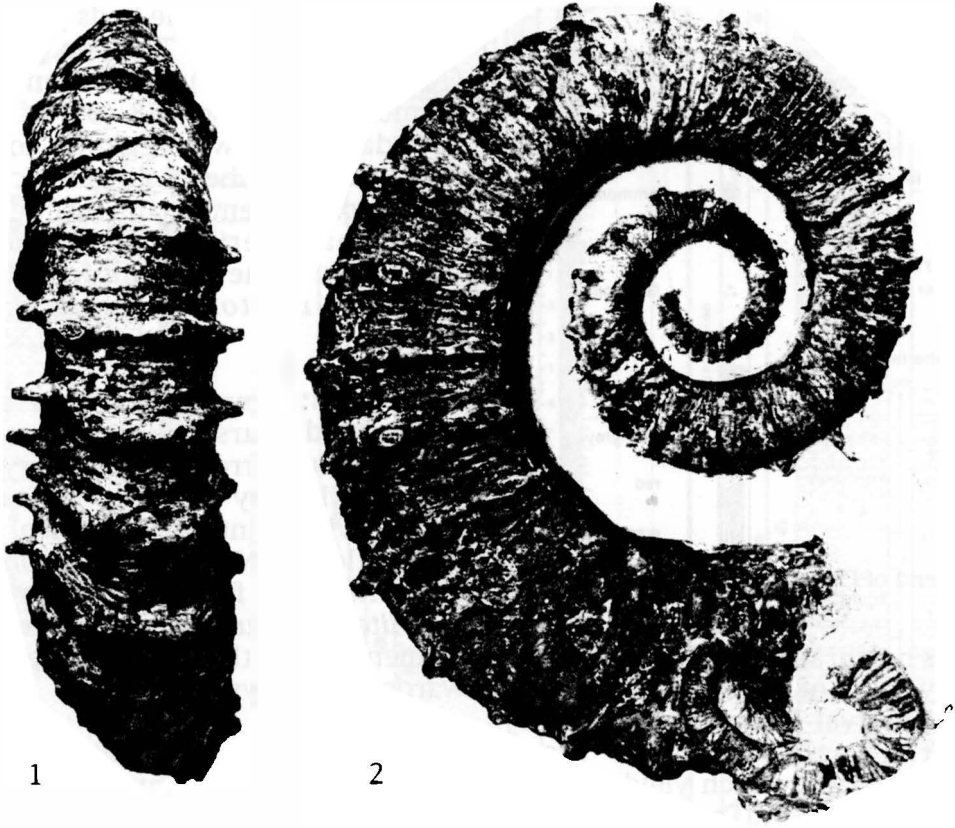


Fig. 41. Heteromorphs from the Late Hauterivian *discofalcatus* Zone, Gott clay-pit. 1, 2. *Crioceratites strombecki*, ventral and lateral view. 3. *Crioceratites strombecki*. Specimens from the collection of K. WIEDENROTH. All figures are x 0.4.

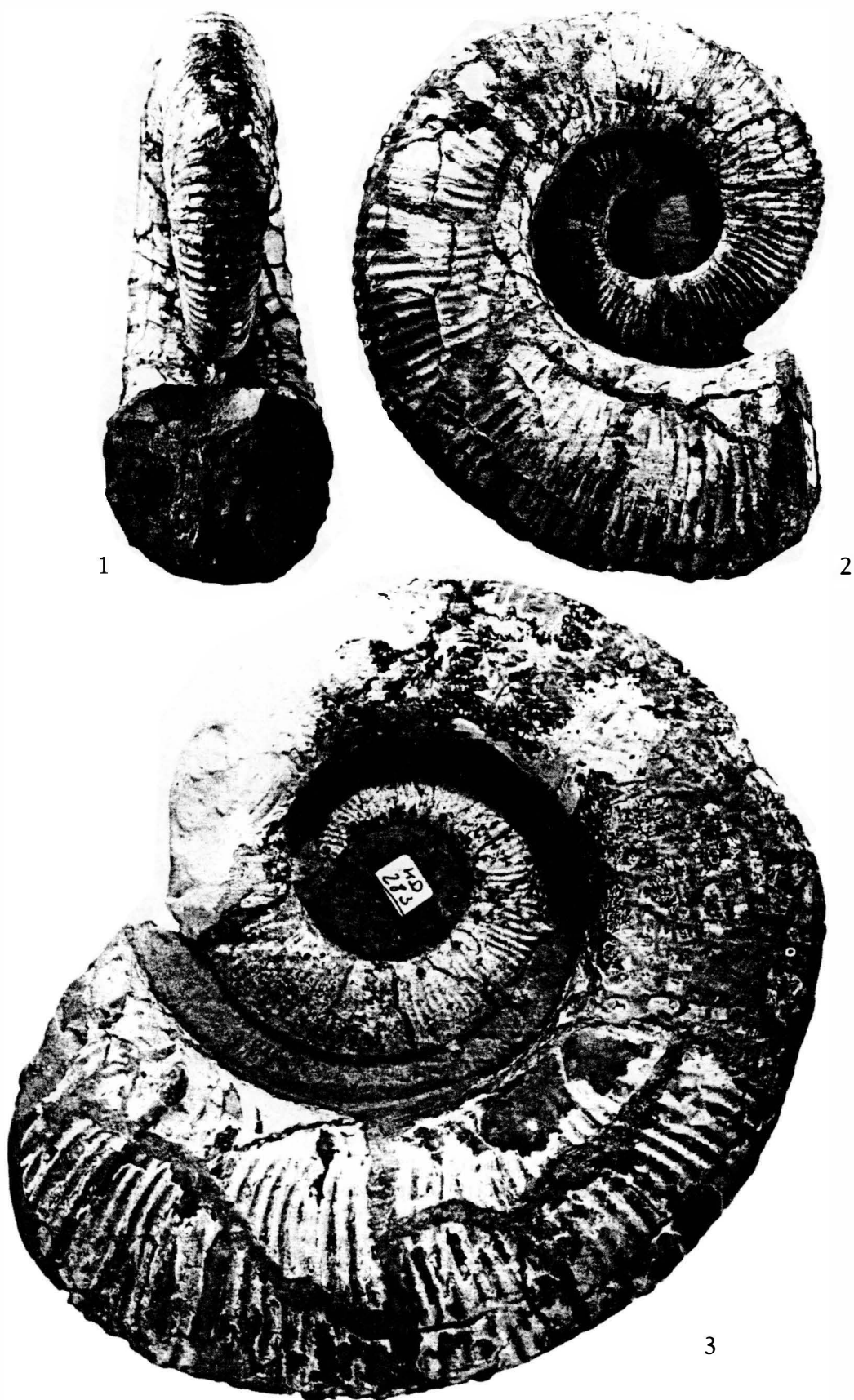


Fig. 42. Heteromorphs from the Early Barremian *rarocinctum* Zone, Gott clay-pit. 1, 2. *Hoplocrioceras rarocinctum*, ventral and lateral view. 3. *Hoplocrioceras* cf. *rarocinctum*. Specimens from the collection of K. WIEDENROTH. All figures are $\times 0.75$.

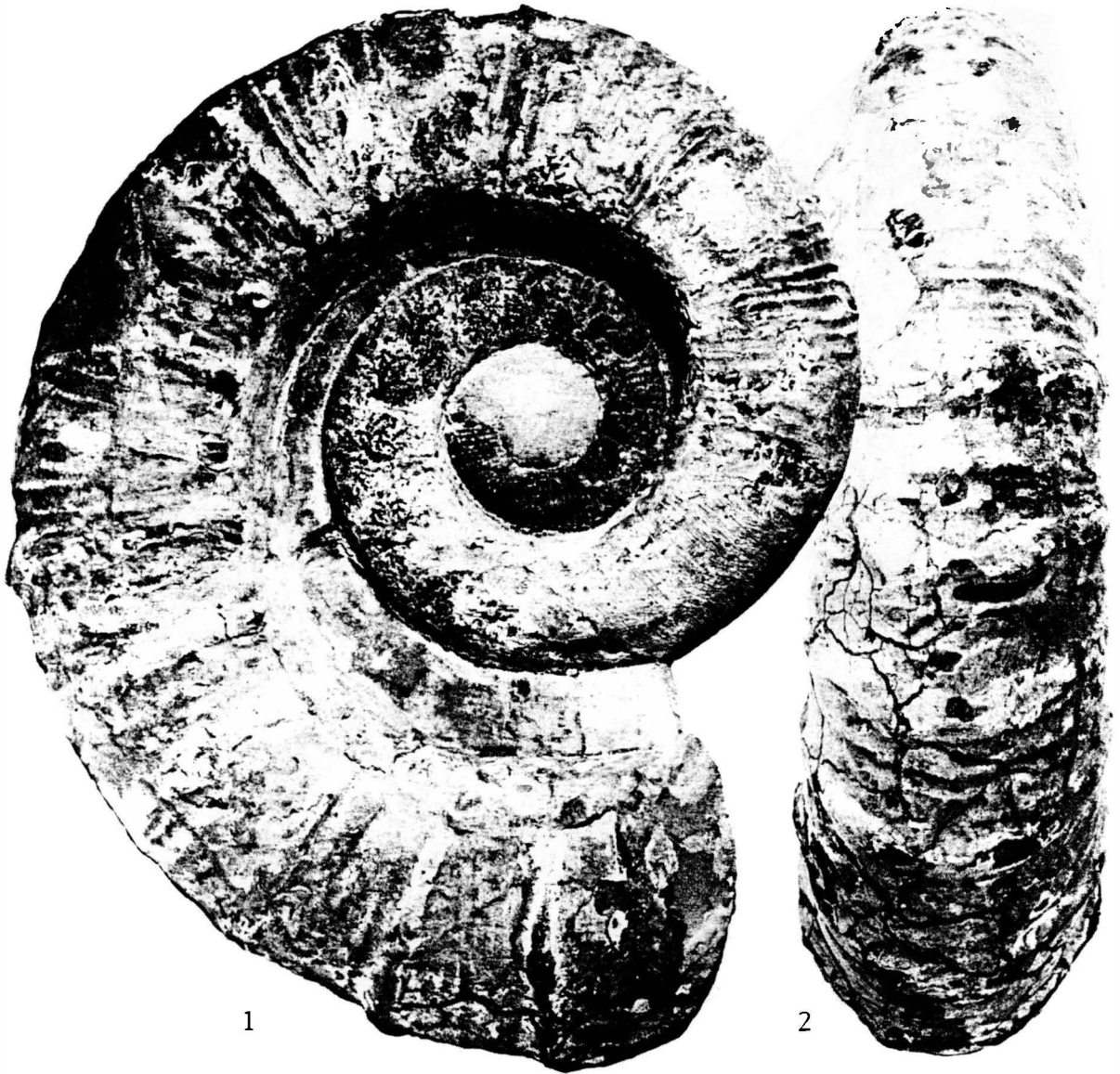


Fig. 43. 1, 2. *Hoplocrioceras rarocinctum*, Early Barremian *rarocinctum* Zone, Gott clay-pit, lateral and ventral view. Specimen from the collection of K. WIEDENROTH, x 0.4.

and diverse nannofossil assemblages consist of abundant *Rhagodiscus asper* and *Nannoconus truttii*. This assemblage reflects a major warm water pulse of the *nutfieldiensis* Zone, present throughout the North Sea. The nannofossils and microfauna are associated with *Neohibolites inflexus*. Elsewhere the same beds yield the Tethyan belemnite *Duvalia grasiana*.

Interval F: This interval is characterized by increased water depth and reduced oxygenation. The diversity of nannofloras and microfaunas decreases, macrofaunas are also impoverished. This black clay facies

of the *Nolaniceras nolani* and *Hypacanthoplites jacobi* ammonite Zones has a widespread distribution in NW-Germany (*jacobi-nolani* Clay). Recently two specimens of *N. nolani* have been found in this interval, confirming the age assignment.

Pale-dark bedding rhythms: Interval A (Late Hauterivian), which is about 12 m thick, is characterized by typical bedding rhythms. These consist of 11 clay-marl rhythms, each of these rhythms having an average thickness of about 0.9 m. Carbonate contents vary between 4% (sample 58/2) and 27% (sample 73/1) in the pale lay-

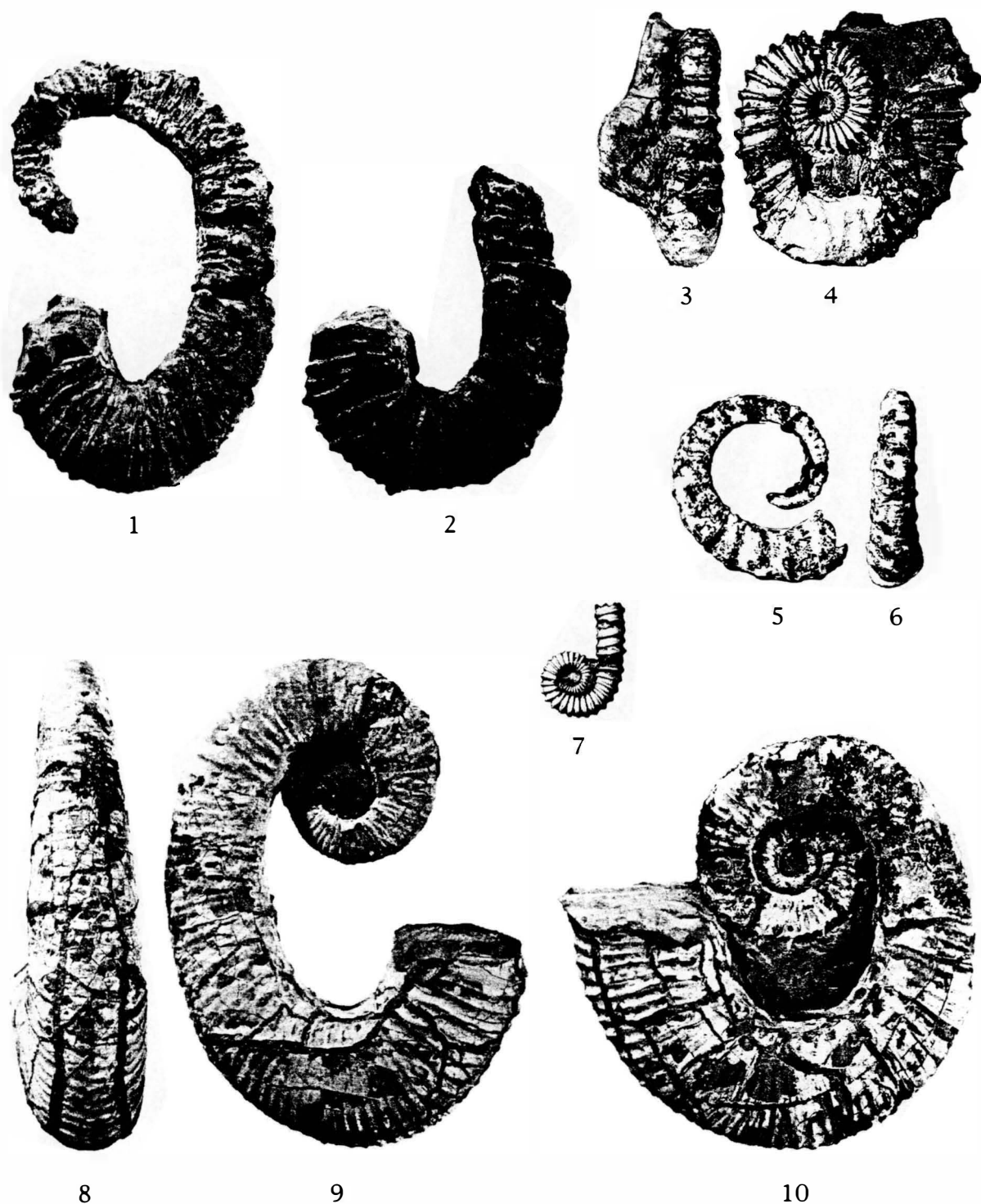


Fig. 44. Barremian heteromorphs, Gott clay-pit. 1. *Hoplocrioceras* sp., Hauterivian/Barremian boundary interval. 2. *Hoplocrioceras* sp., Hauterivian/Barremian boundary interval. 3,4. *Parancyloceras bidentatum*, ventral and lateral view, *bidentatum* Zone. 5,6. "*Crioceras*" *sparsicosta*, lateral and ventral view, *stolleyi* Zone. 7. *Parancyloceras scalare*, *bidentatum* Zone. 8,9. *Hoplocrioceras phillipsi*, ventral and lateral view, *rarocinctum* Zone. 10. *Hoplocrioceras phillipsi*, ventral and lateral view, *rarocinctum* Zone. Specimens from the collection of K. WIEDENROTH. All figures are x 1.

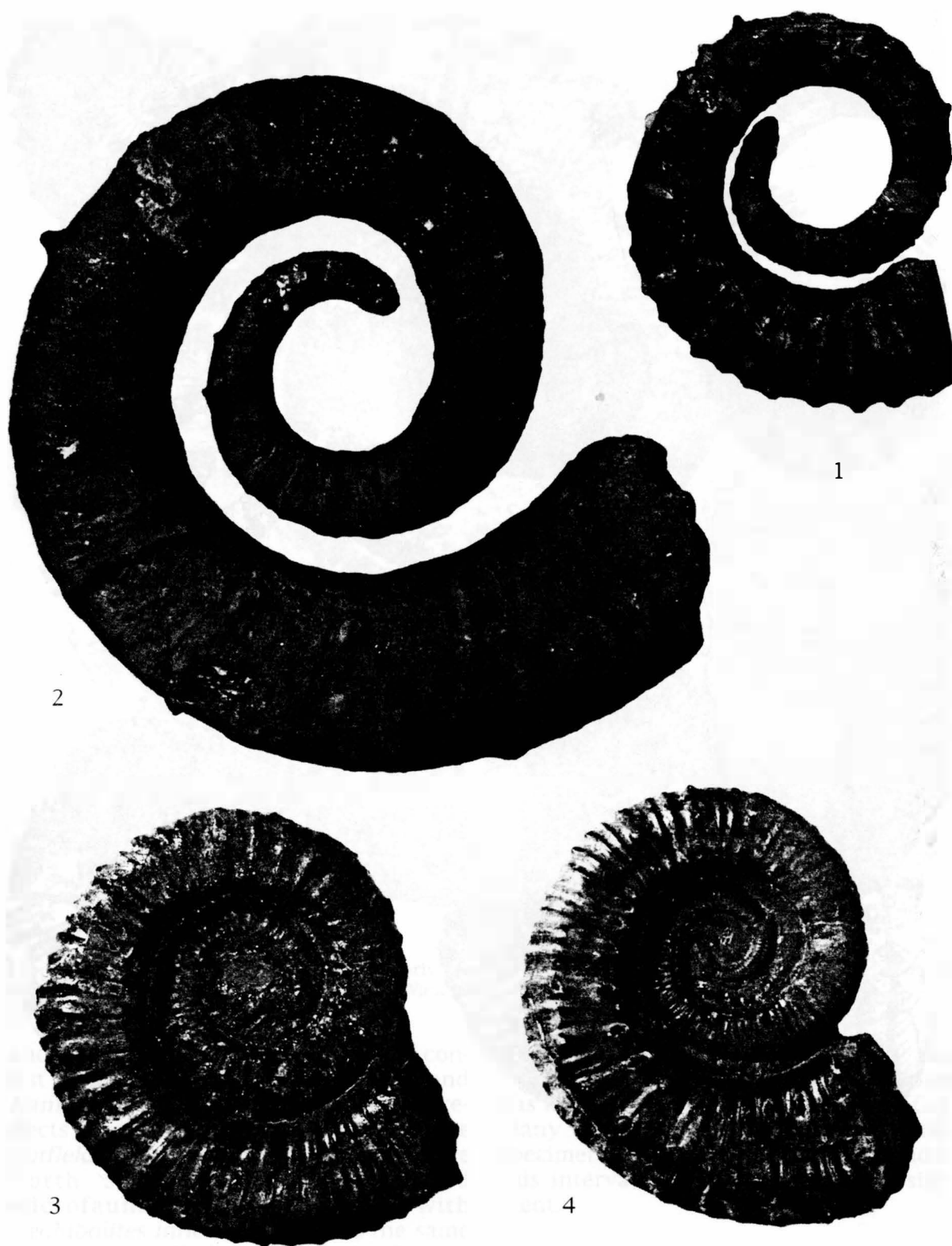
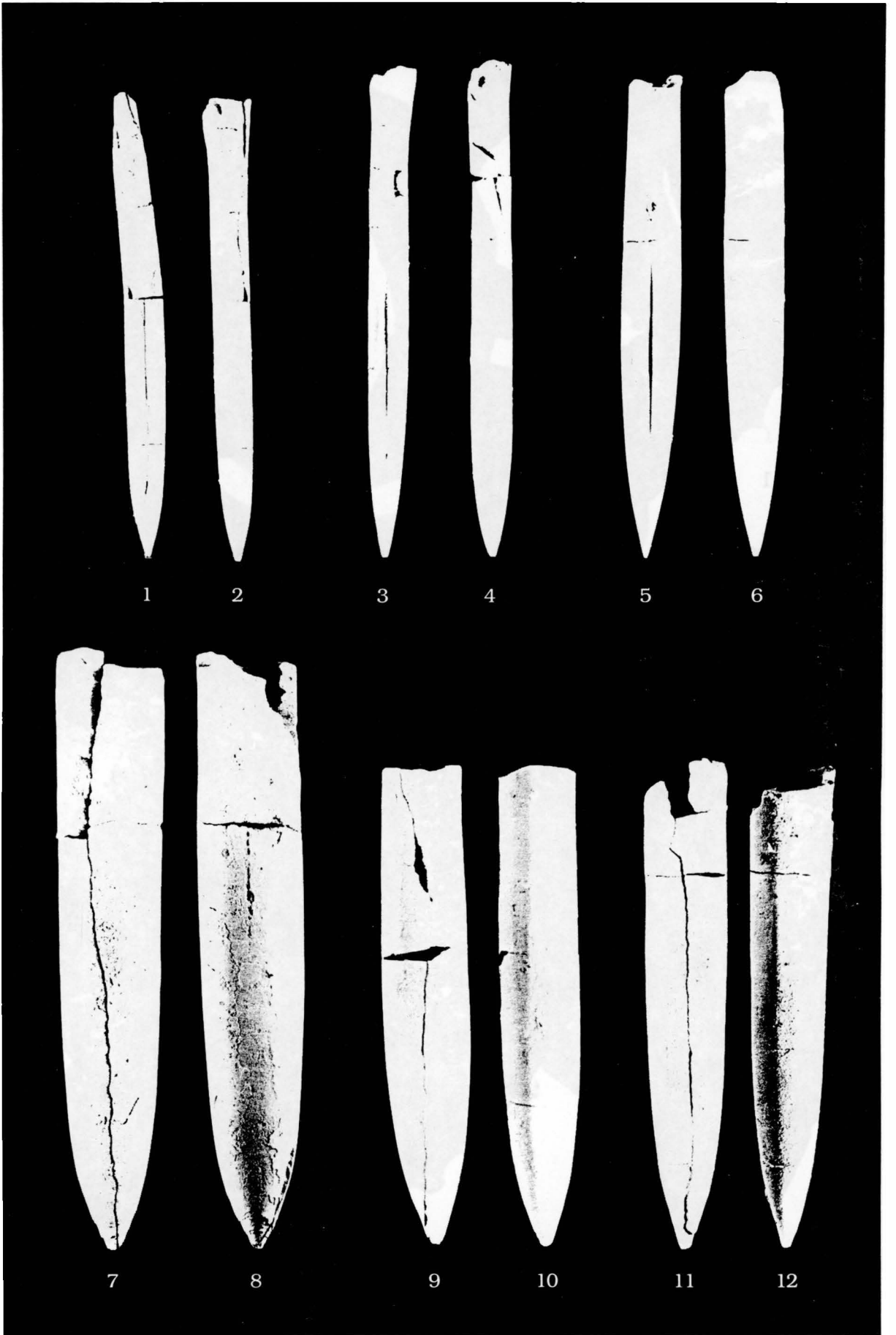


Fig. 45. Late Barremian heteromorphs from NW-Germany. 1. *Crioceratites* sp., *denckmanni* Zone, Mellendorf clay-pit. 2. *Crioceratites sparsicosta*, *stolleyi* Zone, Berenbostel clay-pit. 3. *Crioceratites tuba*, *denckmanni* Zone, Mellendorf clay-pit. 4. *Crioceratites tuba*, *denckmanni* Zone, Mellendorf clay-pit. Specimens from the collection of Niedersächsisches Landesmuseum, Hannover. All figures are x 0.75.



Fig. 46. Barremian heteromorphs from the Hannover-Aegi section. 1. *Crioceratites roeveri*, Late Barremian *elegans* Zone. 2. *Crioceratites aequicostatus*, Late Barremian *elegans* Zone. 3, 4. *Hoplocrioceras fissicostatum*, Early Barremian *fissicostatum* Zone. Specimens from the collection of K. WIEDENROTH. All figures are x 0.5.



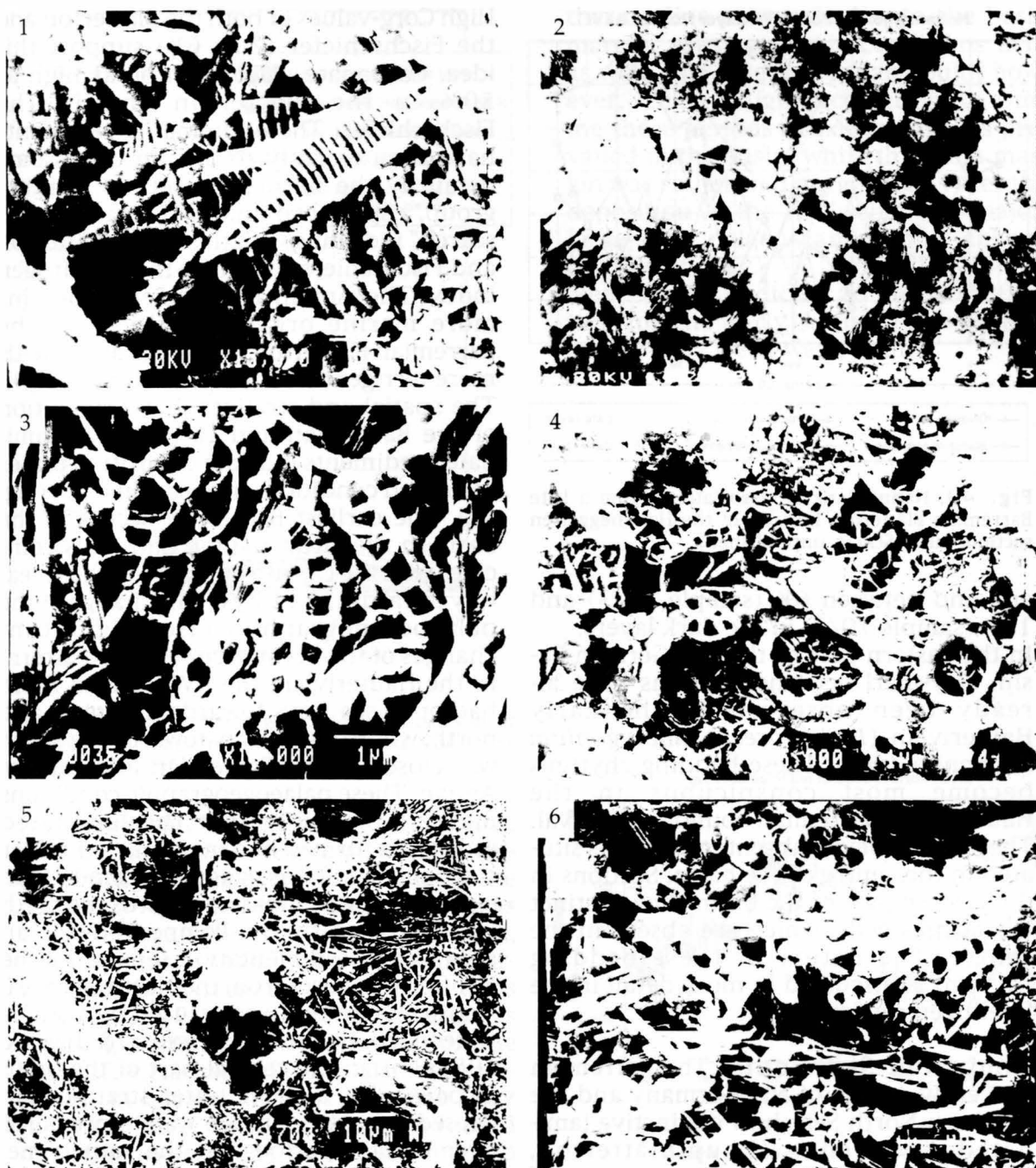


Fig. 48. SEM photographs of calcareous nannoplankton from the Blätterton, Barremian NW Germany. The bar in the lower right corner equals 1 micron. 1. Enrichments of *Scapholithus fossilis*, Late Barremian *germanica* Zone, Hoheneggelsen clay-pit, bed 118. 2. Enrichments of *Nannoconus abundans*, Early Barremian *Aulacoteuthis* Zone (Blätterton horizon), Gott clay-pit, bed 100. 3. Enrichments of *Truncatoscapus pauciramosus*, *Rhombolithion bifurcatum*, *Lithraphidites carniolensis*, Late Barremian *germanica* Zone, Hoheneggelsen clay-pit, bed 118. 4. *Manivitella pemmatoidea*, *Rhombolithion rhombicum*, *Vagalapilla matalosa*, Late Barremian *germanica* Zone, Hoheneggelsen clay-pit, bed 118. 5. Enrichments of *Lithraphidites carniolensis*, Late Barremian *germanica* Zone (Blätterton horizon), Hoheneggelsen clay-pit, bed 118. 6. *Lithraphidites carniolensis*, *Zeughrabdotos* spp., *Scapholithus fossilis*, Late Barremian *germanica* Zone (Blätterton horizon), Hoheneggelsen clay-pit, bed 118. Enlarged view of Fig. 5.

Fig. 47 (opposite page). Barremian belemnites of the subfamily Oxyteuthinae from NW-Germany. Each specimen is shown in ventral (left) and lateral view (right). 1, 2. *Aulacoteuthis compressa*, Early Barremian *Aulacoteuthis* belemnite Zone, Gott clay-pit, bed 100. 3, 4. *Aulacoteuthis compressa*, Early Barremian *Aulacoteuthis* belemnite Zone, Gott clay-pit, bed 100. 5, 6. *Aulacoteuthis absolutiformis*, Early Barremian *Aulacoteuthis* belemnite Zone. 7, 8. *Oxyteuthis brunsvicensis*, Early Barremian *brunsvicensis* belemnite Zone, Gott clay-pit, bed 116. 9, 10. *Oxyteuthis depressa*, Late Barremian *depressa* belemnite Zone, Westerberg clay-pit. 11, 12. *Oxyteuthis depressa*, Late Barremian *depressa* belemnite Zone, Westerberg clay-pit. All figures are $\times 1$.

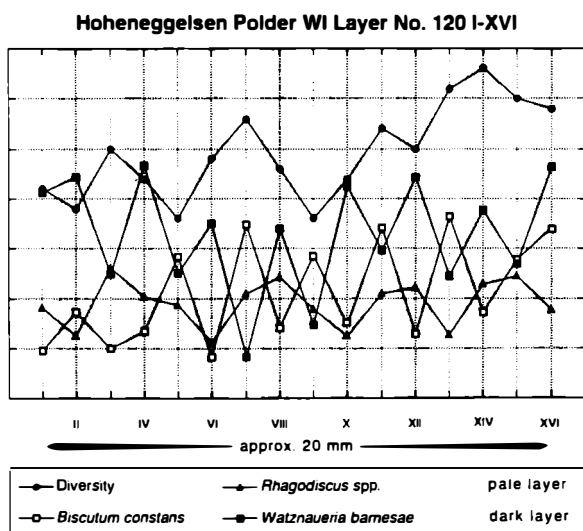


Fig. 49. Nannoplankton associations from a Late Barremian Blätterton horizon of the Hoheneggelsen section. (after SCHAAF, unpublished).

ers, and between 6% (sample 64/3) and 15% (sample 70/2) in the dark layers.

In the eastern part of the NW-German Basin, clay-marl bedding rhythms have already been observed in the Early Hauterivian (*Endemoceras amblygonium* ammonite Zone). These bedding rhythms become most conspicuous in the Hauterivian/Barremian boundary interval. They are, however, absent in outcrops situated in the centre of the basin. Sections in the eastern part of the basin show distinct *Chondrites* beds, which are absent in the centre. The nature of these bedding rhythms is discussed in more detail in the Frielingen section.

Laminated Sediments: The Barremian and early Aptian of NW Germany and the southern North Sea show distinctive laminated sediments (Hauptblätterton, Blätterton, Fischschiefer). These consist of alternating pale and dark laminae. The pale laminae are composed of monospecific enrichments of calcareous nannofossils (Fig. 48, 49), the dark laminae are enriched in dinoflagellates. The thickness of a pale-dark lamina varies between 50 and 150 μm . The pale laminae are about 60 μm thick, the dark ones about 35 μm . Diversity and abundance of benthic organisms is extremely impoverished. Good preservation of nectonic organisms indicates deposition under anoxic conditions. Well-preserved fish faunas have been described from the Blätterton and the Fischschiefer.

High Corg-values of both the Blätterton and the Fischschiefer (2 to 6%) support this idea. Carbonate values can be as high as 50% in the Blätterton and in the Fischschiefer. These laminated sediments have been recently studied in quite some detail by the German Apti-Core working group, a special volume of "Cretaceous Research" is dealing with this topic. Blätterton and Fischschiefer differ by their hydrogen index. The Aptian Fischschiefer contains more marine organic matter than the Barremian Blätterton, while the latter yields more terrigenous organic matter (Fig. 50). The spatial and stratigraphic distribution of the Barremian and early Aptian laminated sediments indicate deposition under restricted conditions in a marginal sea (Fig. 52). The earliest Blätterton occurs in the basin in the latest Hauterivian. This coincides with the closure of the Carpathian sea-way towards the Tethys. This change of the palaeoceanography caused significant changes of the oceanic circulation pattern. In the Hauterivian, the NW German Basin had open sea-ways towards the south and north, while the sea-way towards the south was closed in the Barremian and earliest Aptian. These palaeogeographic conditions make it plausible that the laminated sediments formed in a marginal sea under stagnant conditions (stagnation model). An exchange of water masses towards the north was restricted by the Pompeckj Swell, an area of non-sedimentation separating the NW German Basin from the North Sea area. Anoxic conditions were caused by a stable water stratification (MUTTERLOSE & HARDING 1987a, b). In the central part of the basin in particular, a stable water stratification caused by warm surface waters prevailed over certain periods. At the same time, waves and storms in the shallow marginal environments permitted the oxygenation of the bottom waters, resulting in the deposition of non-laminated sediments. Seasonal phytoplankton blooms of the warm surface water caused mono-specific enrichments, which are preserved as pale laminae. Organic-geochemic studies show that the laminated sediments have a higher portion of marine organic matter in comparison to the coeval black clays (Fig. 50).

The last laminated horizon, the Fischschiefer of the Early Aptian *Deshayesites deshayesi* ammonite Zone, was clearly deposited after the turnover of

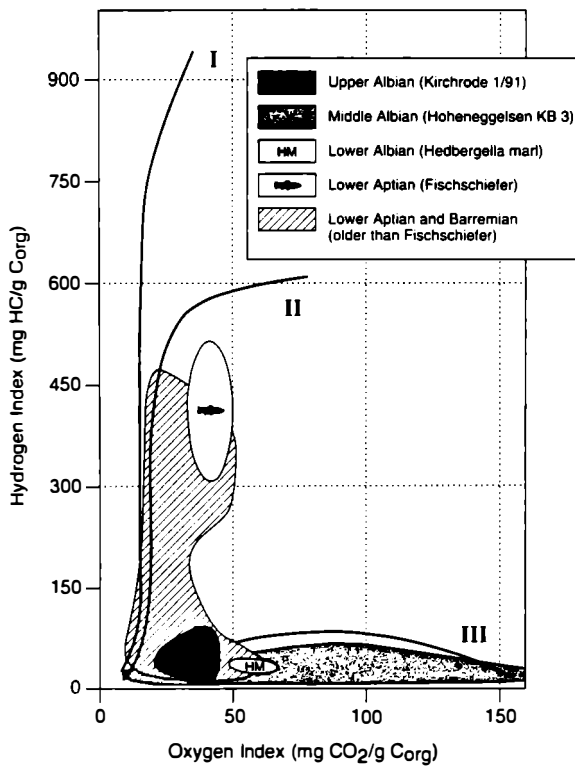


Fig. 50. Hydrogen/Oxygen-index: comparison of various sediments from the Early Cretaceous (after JENDRZEJEWSKI 1995).

the planktonic and nektonic organisms. This indicates that a thermally stable water stratification existed at least until the mid-Early Aptian. While floras and faunas of the surface waters had already changed, the deeper parts of the basin were still characterized by Barremian anoxic conditions (Fig. 52). The Early Aptian Fischschiefer has a wide geographic distribution within the basin. The Fischschiefer has also been observed in coastal settings near the Harz (Eisenkuhle). A water stratification caused by a fresh-water lens has been proposed for the Aptian Fischschiefer (MUTTERLOSE et al. in press). It seems most likely that the deposition of the laminated sediments was controlled by two factors:

- The palaeogeographic framework in Barremian and Early Aptian times resulted in a poorly oxygenated epicontinental sea, only open to the north.
- Warm-arid phases in the Barremian caused a thermally stable water stratification. The main warm periods were the late Early Barremian (Hauptblätterturon) and the mid-Early Aptian (Fischschiefer). During these warm-arid phases the

thermocline encroached onto the basin margin, causing anoxic conditions here as well. The Late Barremian could, however, reflect a slightly cooler phase. During these periods anoxic conditions prevailed in the basin, while the basin margin was rather well oxygenated. After the deposition of the Fischschiefer a major, large-scale palaeoceanographic change occurred.

- Recent finds indicate a water stratification for the Early Aptian Fischschiefer caused by a fresh-water influx.

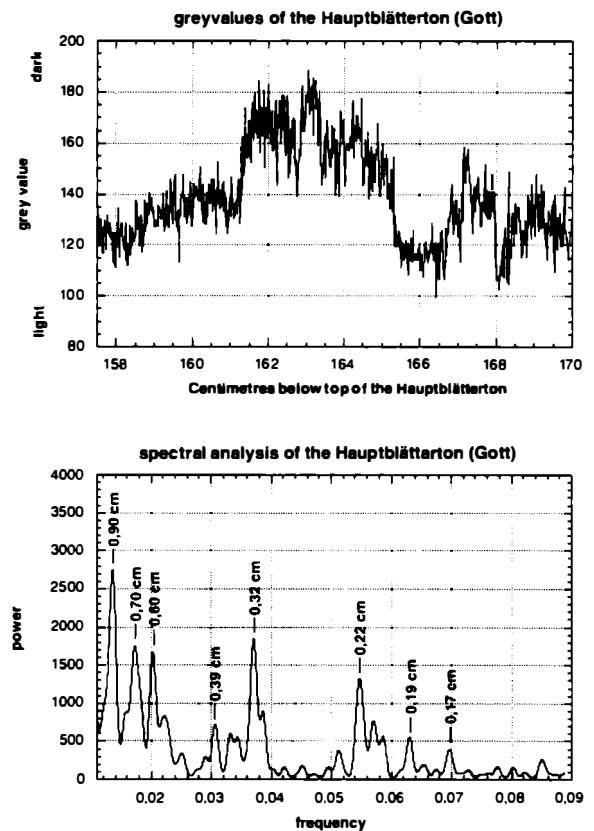
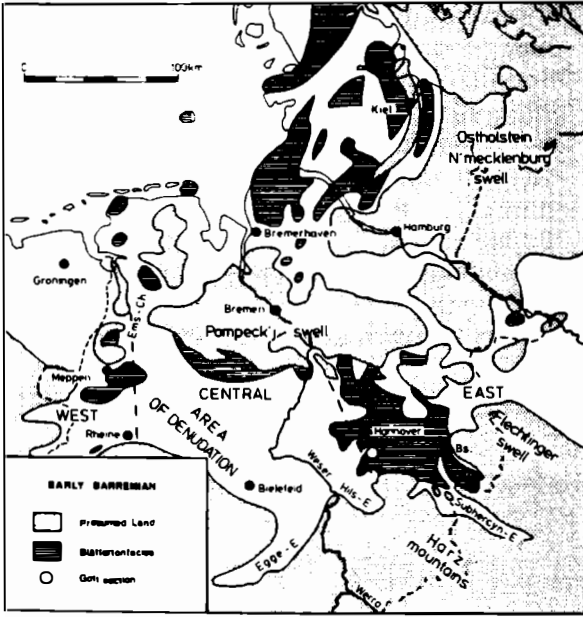


Fig. 51. Greyvalues (top) and spectral analysis (bottom) of a sample from the Hauptblätterturon (after NEBE 1994).



References: BELOW (1982); BRAHMS (1913); HARDING (1990); HEINRICH (1991); KEUPP (1980, 1981, 1993); LUTAT (1991); LUTZE (1968); MUTTERLOSE & HARDING (1987a, b); MUTTERLOSE (1983, 1984, 1991, 1995); MUTTERLOSE et al. (in press); NEBE (1994).

Fig. 52. Palaeogeographic map of the Early Barremian of NW Europe (after MUTTERLOSE 1995).

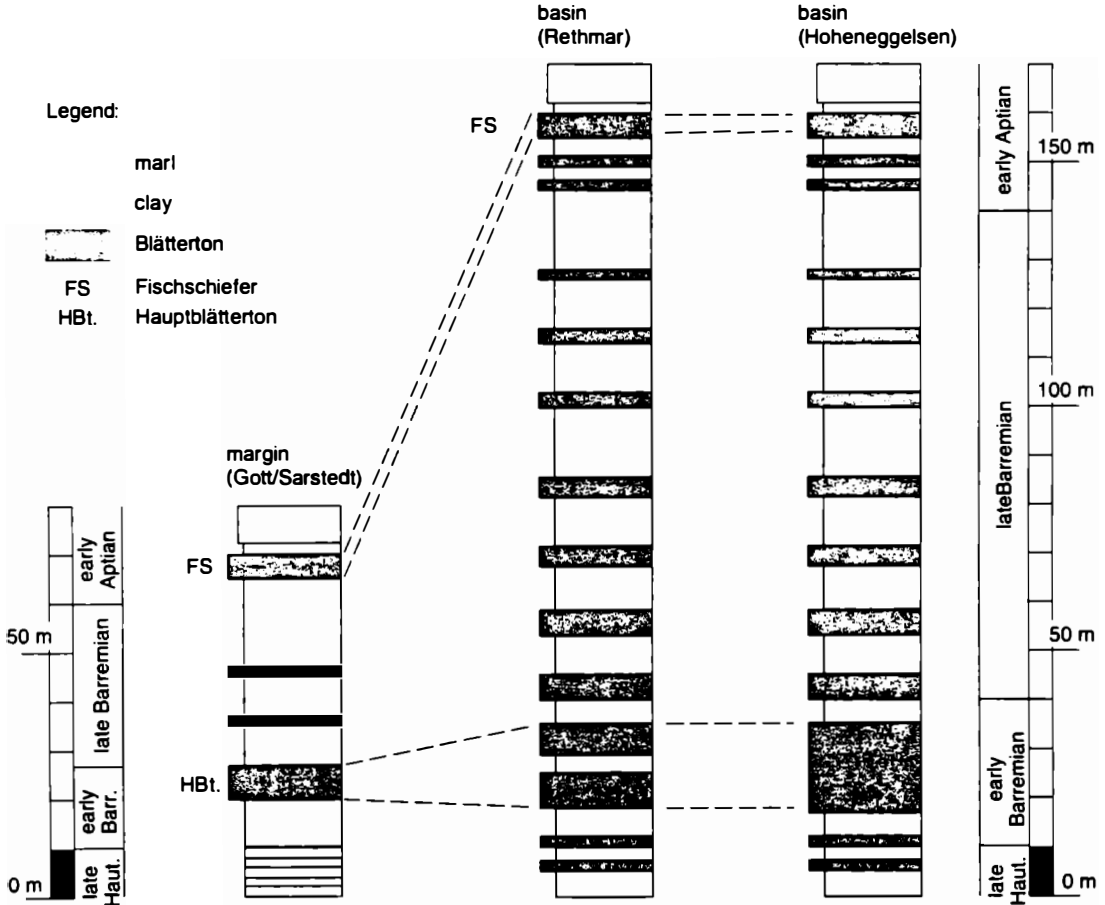


Fig. 53. Comparison of basinal and marginal successions of the Barremian and Early Aptian (after MUTTERLOSE & WIENROTH 1995).

2.10 HPCF II at Misburg (Figs. 54-56)

(by G. Ernst, B. Niebuhr & U. Rehfeld)

Location and grid reference: TK 25, 3625 Lehrte, R: 3559120, H: 5806320. The abandoned HPCF II (former Hannoversche Portland Cementfabrik AG) quarry lies at the eastern margin of Misburg, north of the canal to the cement factory.

Introduction: The exploitation of marly limestones by the cement industries near Höver and Misburg east of Hannover led to the development of numerous limestone quarries which now belong to the most important exposures of Upper Cretaceous strata in northwestern Germany. At the

moment, they comprise a 500 m thick composite succession, ranging stratigraphically from the higher Lower Cenomanian to the upper Upper Campanian. Three of these outcrops (HPCF II, Germania IV, Teutonia I) will be treated here.

The exposures are located in the Lehrte West and the Kronsberg synclines, which are, in their marginal parts, flanked by the NNE-SSW trending salt structures of Lehrte-Sarstedt and Benthe, the genesis of which is intimately linked with inversion tectonics and diapirism (Fig. 54) (BALDSCHUHN, FRISCH & KOCKEL 1985). These structures were affected by intermittent, halokinetic movements and periodic phases of uplift, which had an important influence on the sedimentologic and structural history of the

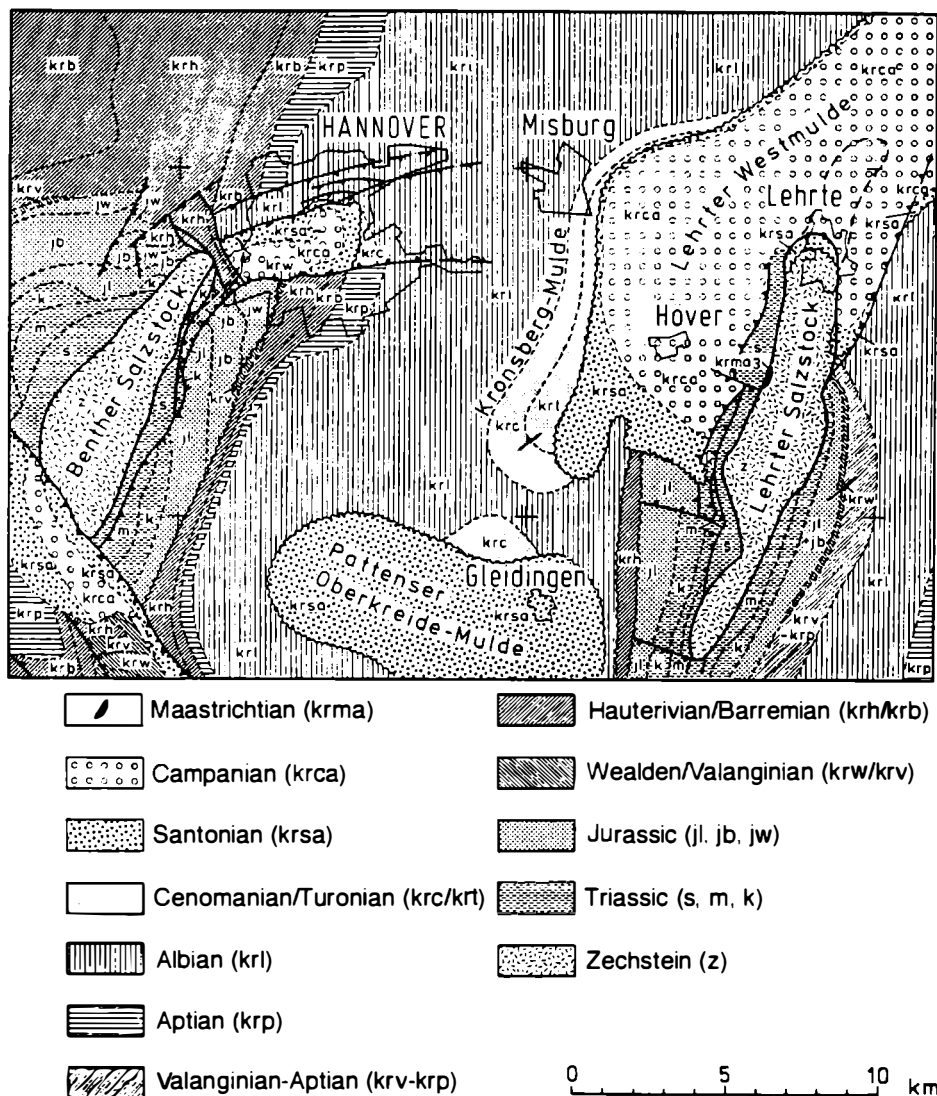


Fig. 54. Geologic map of the area between the salt structures of Benthe and Lehrte near Hannover (after ERNST 1975).

area during Late Cretaceous times. Based on data derived from numerous boreholes, BETTENSTAEDT & DIETZ (1957) carried out a detailed investigation of the Lehrte-Sarstedt salt structure. Already twenty years before the paper of VAIL et al. (1977) gave rise to the "era of sequence stratigraphy", these authors could recognize and date as many as 16 different transgressive surfaces, stratigraphically ranging from the Middle Jurassic to the Tertiary, on the flanks of the Lehrte-Sarstedt structure. Recently, the sedimentary cycles of the higher Upper Cretaceous in the eastern part of Lower Saxony and western Sachsen-Anhalt were treated comprehensively by NIEBUHR (1995; Fig. 55).

In the excursion-area, several Upper Cretaceous transgressions can be demonstrated in the quarries of Misburg and Höver. The most spectacular one is the late Santonian *Marsupites* transgression, which is expressed by an abrupt facies change and a basal lag containing reworked material of the earlier Mid-Santonian transgression. Due to the good exposures and the abundance of fossils, the quarries of Misburg and Höver have attained a certain fame amongst scientists and amateurs. It is therefore not surprising that, over the last decades, a lot of scientific papers were published on the Cretaceous of Misburg (see references below). As several international and numerous national excursions have visited this area in the past, the sections are now well known to experts not only in Lower Saxony. Furthermore, the multistratigraphic treatment of the Misburg strata is of fundamental importance in respect of biostratigraphic subdivision of the Campanian. Additionally, the sections can be shown to represent a link between the West- and East-European faunal provinces. In that sense, the sections are of great value for interbasinal correlation and calibration of Campanian zonal schemes.

Stratigraphy: The HPCF II quarry exposes the *dixonii* Zone of the Lower Cenomanian to the basal *conica/papillosa* Zone of the Lower Campanian. The upper Middle Turonian, Upper Turonian and the Coniacian is represented by a hiatus.

General Remarks: The quarry has been abandoned for several years and is used now as a repository for sand. Today, only

a few exposures remain of an Upper Cretaceous succession, that is highly differentiated. In respect of both facies and basin dynamics (Fig. 56), the continuity of this succession is interrupted by the above mentioned stratigraphically and tectonically induced hiatuses. At a major NE-SW fault extending from the northern wall to the middle of the western wall, black shales of the Cenomanian/Turonian boundary interval are downthrown (40 to 50 m) against light limestones of Cenomanian age. The former are overlain by pale, marly limestones of the Lower and basal Middle Turonian. On the eastern and northeastern walls, these Turonian limestones are overlain discordantly by transgressive Upper Santonian marls, which form a conspicuous dark water saturated intercalation between the pale coloured Turonian limestones below and the Lower Campanian limestones above. The Cretaceous strata are overlain by a thin, in places discontinuous, layer of fills of the Saale glaciation (Pleistocene), which, in turn, are covered by late to post-glacial lacustrine muds with an intercalation of Laach-type tuffs (DIETZ et al. 1958).

Because of the exposed Black Shale succession and the repeated transgressive events the quarry has been the subject of relatively detailed multidisciplinary investigations (for references before 1975 see ERNST 1975 and ERNST et al. 1983, 1984). The research on the Black Shale facies and its correlation and lateral interfingering with the proximal Rotpläner swell facies by HILBRECHT (1986, 1988), HILBRECHT & HOEFS (1986) and HILBRECHT & DAHMER (1994) is of particular importance in this context.

Cenomanian: Similar to the succession at Baddeckenstedt (No. 6), the Lower Cenomanian (higher *dixonii* Zone) is characterized by marl-limestone alternations of which roughly 15 m are exposed. However, thin, bioclastic marl layers with microphacoids show sharply defined basal bed contacts and intense post-event bioturbation and are therefore interpreted as allochthonites with possible derivation from the south. This feature is unknown from Baddeckenstedt. The limestone beds are bioturbated and are, therefore, clearly autochthonous. The fauna indicates a depositional area with only a small degree of subsidence and, at the most, only very

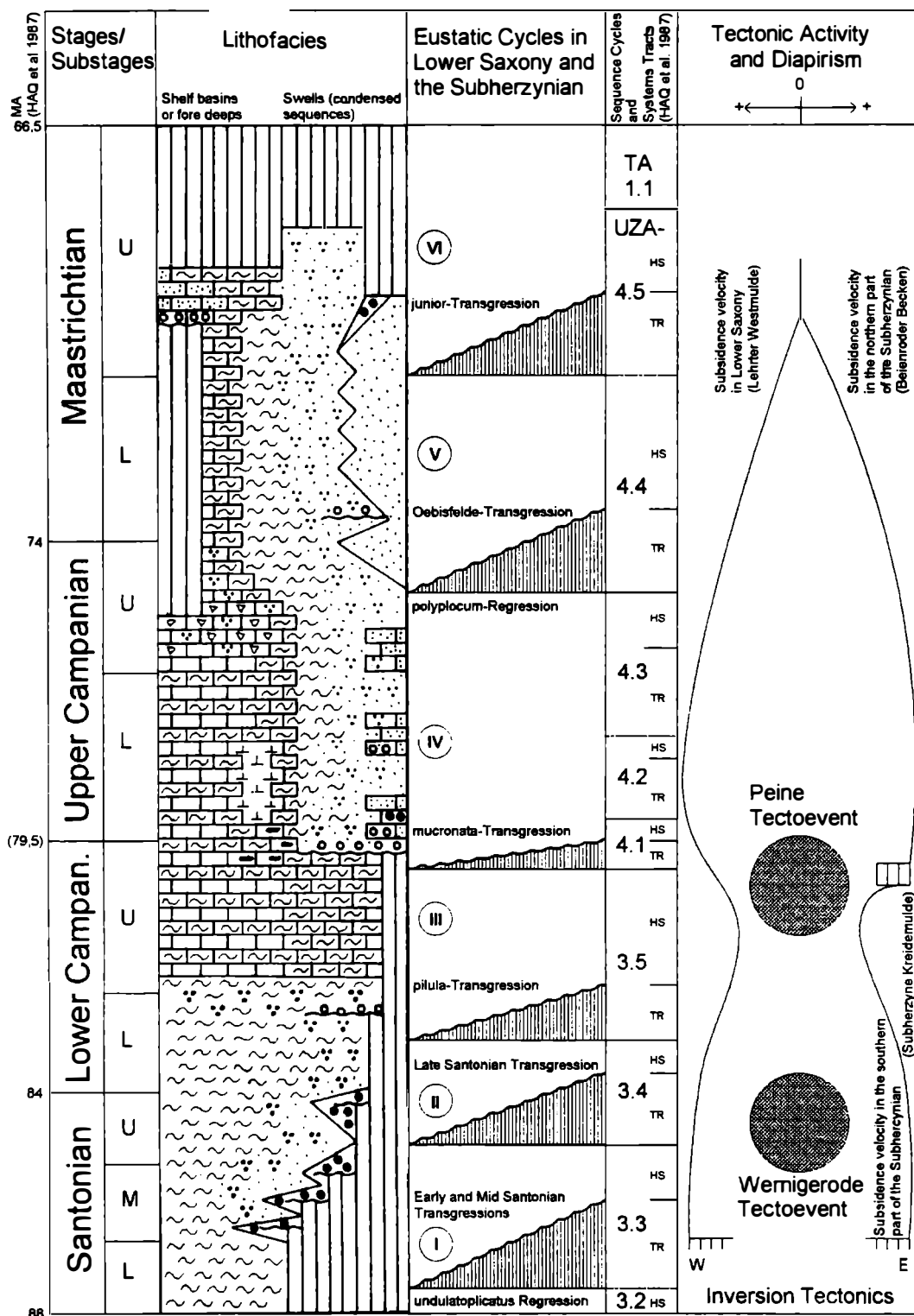


Fig. 55. Eustasy, sedimentary cycles and tectonic activity in the Late Cretaceous of Lower Saxony and Sachsen-Anhalt (after NIEBUHR 1995).

gentle palaeoslopes. Of importance for regional correlation with Baddeckenstedt is the proof of the *Schloenbachia/virgatus* Event. The lowermost 10 m of the ca. 40 m thick

Middle Cenomanian succession consist of bioclastic marls and marly limestones with two intercalated hardgrounds (HG I, HG II). Allochthonous sediments such as slumps and slides above HG II and, to a lesser ex-

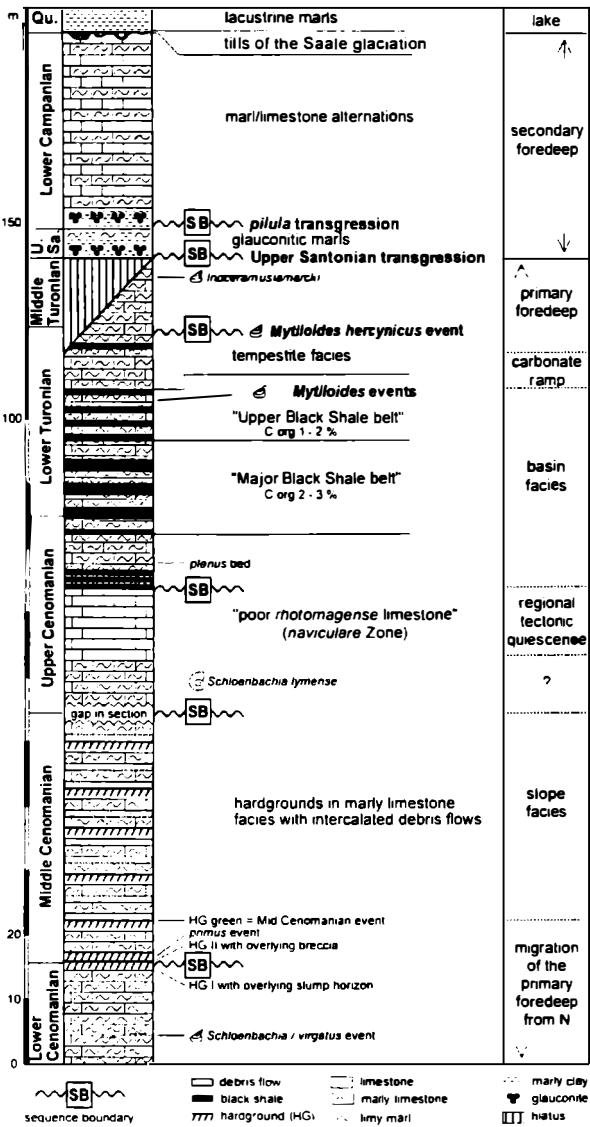


Fig. 56. Generalized section of the Upper Cretaceous of the HPCF II quarry (modified after HILBRECHT 1987).

tent, above HG I can be attributed to a lowstand regime that is overlain by the autochthonous and widespread (overlapping) *primus* Event. The presence of the event is proved by the typical *primus* fauna (*Magas geinitzi*, *Terebratulina nodulosa*, *Inoceramus schoendorfi*, *Hemiaster griepenkerli*) and one single find of the index-belemnite *Actinocamax primus*. The Mid-Cenomanian Event (MCE; HG green in Fig. 56) can be recognized by a metre-thick hardground-complex characterized by two omission surfaces containing green-stained *Thalassinoides* burrows. This hardground-complex represents the interbasinal Mid-Cenomanian non-sequence (probably a maximum flooding surface), which is followed by a sudden in-

crease in abundance and diversity of planktonic foraminifera (see DAHMER & ERNST 1986). About 1 m below the MCE, an association of *Schloenbachia* and the heteromorph ammonite *Anisoceras* is significant for an event that might be located in a transgressive systems tract.

Above the MCE, the succession is characterized by incipient hardgrounds, lithoclast-bearing debrites and grey marls. The latter were interpreted by HILBRECHT (1988) as pre-flow muds. The same author described a 30 m sequence of limestones and marly limestones with shear folds that is penetrated by shear planes. This structure was interpreted as gravitational slides and therefore syndimentary in origin, indicating a marginal position within a primary foredeep of a salt structure.

The lower Upper Cenomanian is characterized by a return to relatively quiescent sedimentation. The lower part consists of a bioturbated succession of 6 m marl-limestone alternations with *Schloenbachia lymense*, followed by 12 m of white, macrofossil depleted, coccolith limestones, known as the "Arme *rhotomagense*-Schichten" of *guerangeri* zonal age. The *Pycnodonte* Event, usually taken as the Middle/Upper Cenomanian boundary marker in Lower Saxony has not been recognized from the HPCF II section.

Cenomanian/Turonian boundary interval (ca. 30 m):

Renewed interregional tectonism caused an increase in relief of the depositional area and an intensification of halokinetic activities. In the foredeep of the salt structure of Lehrte, comparatively thick successions of "black shales" with intercalated white limestones accumulated (ERNST et al. 1983, 1984; HILBRECHT & DAHMER 1994). This so-called "Schwarz-Weiße Wechselfolge" (alternation of black and white beds) shows a tripartite subdivision into a "lower black shale belt" with four black beds, a middle "major black shale belt" with the thickest black beds and an "upper black shale belt", in which the black beds again become thinner (HILBRECHT & DAHMER 1994), indicating the end of the black shale period. The amount of C_{org} in the well laminated marls referred to as black shales, is very low (1 to 3%). In that sense, they do not represent black shales *sensu stricto*. However, the content of carbon particles is high. The usual positive

$\delta^{13}\text{C}$ excursion within the *plenus* Event has been proved by HILBRECHT & HOEFS (1986) also in the HPCF II section. The lower and upper unit, in particular, can be correlated as far as Lengerich in Westphalia (ERNST et al. 1984). The origin of the black shale beds is controversial. HILBRECHT (1986), HILBRECHT in BACHMANN & MUTTERLOSE (1987) and HILBRECHT & DAHMER (1994) interpreted them as allochthonites. According to ERNST et al. (1983) this interpretation cannot be accepted on account of the good correlation of even the thinner beds between eastern Lower Saxony and western Westphalia.

While the intercalated limestones are very poor in fossils, the black shales contain a remarkable fauna of mostly large inoceramids. One horizon, the so-called *juddii* Event, has yielded crushed pyritized ammonites, including *Neocardioceras juddii*, *Thomelites* sp., *Worthoceras* sp. and abundant *Sciponoceras*. Furthermore, remnants of fishes occur in several black shale layers (KRIWET & GLOY 1995) as well as a single find of a swimming crab.

Higher Lower and basal Middle Turonian: The last black shale couplet (Doppellage) coincides with the lowermost and original *Mytiloides* Event (sensu ERNST et al. 1983), which represents a mass-occurrence of mytiloid inoceramids in comparatively shallow water environment. It can be traced from the sandstone facies of Saxony and the Rotpläner platform facies into the basinal black shale facies of the excursion area. Good correlation and abundant fauna indicate an increasingly equilibrated relief and the recovery of water circulation. As the distribution of the event is not delimited by facies, it is a classical example of an overlapping and isochronous event, the lateral distribution of which ranges presumably from Khazakstan to Mexico.

Roughly 10 m above the first *Mytiloides* Event, the *Mytiloides hercynicus* Event is developed within a sequence of light, marly limestones. In terms of sequence stratigraphy, it probably corresponds to a flooding surface. As most of the Rotpläner-sections represent shallow water environment on a swell, the *hercynicus* Event is missing there. Only in the southeastern corner of the quarry, basal Middle Turonian strata with *I. apicalis*, *I. cuvierii* and *I. lamarcki* are exposed above the *hercynicus*

Event.

As the Turonian strata were slightly tilted by the Subhercynian inversion tectonism, the Upper Santonian transgression cut Turonian strata of different levels (Lower Turonian and lowermost Middle Turonian at HPCF II, Middle Turonian to lower Upper Turonian at the more southerly, but completely overgrown HPCF I quarry) with an angular unconformity.

Upper Santonian: The Upper Santonian transgression is marked by a weakly developed basal horizon of glauconitic marls with sparse pebbles. Most of the pebbles are edge-rounded, green intraclasts of limestones derived from the underlying Turonian Pläner limestones. Of very sporadic occurrence are dark phosphorite pebbles, originating from the rocks flanking the salt structure of Lehrte. The transgression is inferred to have proceeded in a in NW direction (AL-ABAWI 1968; ERNST 1975; NIEBUHR 1995). The completely homogeneous Santonian marls are only some few metres thick. Several bedding joints correlate with breaks in the evolution curve of *Goniot euthis* sp., indicating repeated hiatuses within that sequence (ERNST 1975). The marls yield an abundant and diverse fauna. So far, 13 species of bivalves, 11 species of echinoids, 5 species of brachiopods, 5 species of belemnites, 3 species of gastropods as well as several species of sponges were recorded by ERNST (1975). Biostratigraphic subdivision is based on the crinoid *Marsupites* and about 300 specimens of the *Goniot euthis*-lineage collected bed by bed.

Of palaeogeographic importance are the finds of corroded foraminifera and reworked *Goniot euthis* of Mid-Santonian age in the transgressive lag, because they clearly prove the Mid-Santonian transgression extending as far as the Misburg area. This Mid-Santonian transgression can be correlated over a distance of more than 50 km into the eastern parts of the basin near Peine and Meine (NIEBUHR 1995).

Lower Campanian: Separated by a hiatus comprising most of the *granulataquadrata* and at least parts of the *lingua/quadrata* Zones, the continuous sequence starts with a transgressive glauconite horizon, concordantly cutting into the underlying marls. This horizon is

characterized by the abundance of belemnites and can also be correlated over a distance of more than 50 km into the eastern parts of the basin (ERNST 1963, 1968; ABU-MAARUF 1975; NIEBUHR 1995). With the onset of transgression, a long period of uniform and continuous sedimentation resulted in the deposition of marl-limestone alternations, seen in the Germania IV and Teutonia I quarries described below.

References: ABU-MAARUF (1975); AL-ABAWI (1968); BALDSCHUHN et al (1985); BETTENSTAEDT & DIETZ (1957); DAHMER & ERNST (1986); DIETZ et al. (1958); ERNST (1975, 1963, 1968); ERNST et al. (1983, 1984); HILBRECHT & DAHMER (1994); HILBRECHT & HOEFS (1986); HILBRECHT (1986, 1988); KRIWET & GLOY (1995); BACHMANN & MUTTERLOSE (1987); NIEBUHR (1995); VAIL et al. (1977).

2.11 Germania IV quarry at Misburg (Figs. 57-60)

(by G. Ernst, B. Niebuhr & U. Rehfeld)

Location and grid reference: TK 25, 3625 Lehrte, R: 3559900, H: 5804250. The large Germania IV quarry (now called Teutonia II) lies east of Anderten, south of the railway track.

Stratigraphy: *conica/papillosa* to *stobaei/basiplana* Zones of the "Middle" Campanian (uppermost Lower to lowermost Upper Campanian).

General remarks: The quarries I to III of the former "Zementfabrik Germania" were abandoned about 40 years ago and are now backfilled. At Germania IV, a quarry only slightly affected by tectonism, exploitation has been recently resumed at the western quarry wall. The newly exposed section comprises the fossiliferous higher parts of the Lower Campanian (*conica/papillosa* Zone). The exposed section of Germania IV is 140 m thick and was documented by KHOSROVSHAHIAN (1972). He investigated the section by means of multistratigraphic methods and correlated it with the nearby exposed section of Teutonia I. ABU-MAARUF (1975) presented detailed micropalaeontologic results. By means of a highly diverse foraminiferal assemblage, he developed a high resolution ecostratigraphic framework. The stratigraphic ranges were proved in the section at the Nordcement (Alemannia) quarry at Höver, some 3 km from Germania IV.

Tectonic setting: The Germania IV quarry exhibits only faint tectonic stress with simple tension faults and displacements of less than 5 m. The faults show a steep easterly dip which may be explained by an easterly migration of the foredeep of the Lehrte-Sarstedt salt structure. This is substantiated by the development of syn-sedimentary phacoid-like shear bodies resulting in small-scale slump and slide structures in the "Middle" Campanian marly limestones and calcareous marls.

Lithostratigraphy and facies: The ca. 25 m thick *conica/papillosa/gracilis* Zone comprises a succession of calcareous marls and marly limestones, exposed at the west-

ern wall of the Germania IV quarry. The succession can be subdivided into at least eight lithologic units (Unit 1-8), mostly separated by distinct marl layers or marl couplets.

The section starts with nodular, marly limestones with unobvious intercalated, less calcareous marl layers of Unit 1. The top of the unit is marked by resedimentation phenomena, pebbly intraclasts of calcareous marls, accumulations of *Baculites* fragments, irregular echinoids (*Galeola papillosa*) and sponges. The unit is separated by a distinct dark marl layer, poor in carbonate.

The following sedimentary Unit 2 comprises a quite well and thick-bedded alternation between marlier and more calcareous limestones, relatively poor in biogenic components. This unit grades, without a distinct top layer, into the following unit.

The interval of Unit 3 comprises thinly bedded, nodular marl-limestone alternations, richer in biogenes than the subjacent unit. One horizon, ca. 1 m below a distinctly developed top marl layer, bears a rich faunal assemblage of *Galeola papillosa*.

Unit 4 is characterized by two less marly limestone horizons, each topped by incipient hardgrounds and a superjacent, distinct, dark marl layer. The lower limestone horizon has been chosen as a "marker horizon" in the quarry, since the relatively high carbonate content allows rapid recognition within the otherwise quite monotonous succession of more or less well developed marl-limestone alternations.

Unit 5 is a couplet of nodular, marly limestones, separated by a more calcareous horizon. The base of the second nodular, marly limestone bed is characterized by occurrences of the echinoid taxa *Micraster schroederi* and *Cardiotaxis lehmanni*. This unit is topped by a distinct limestone bed which can be easily correlated with the southern wall of the quarry, where the section, slightly displaced by tension faulting (see above), continues with the following unit.

Unit 6 comprises nodular, marly limestones with 2 to 3 weakly developed intercalations of marlier beds. It is topped by a more distinct calcareous bed which grades into unit 7.

Unit 7 is a nodular, marly limestone which lacks any recognizable differentiation. It is topped by a distinct, darker marl pair, with

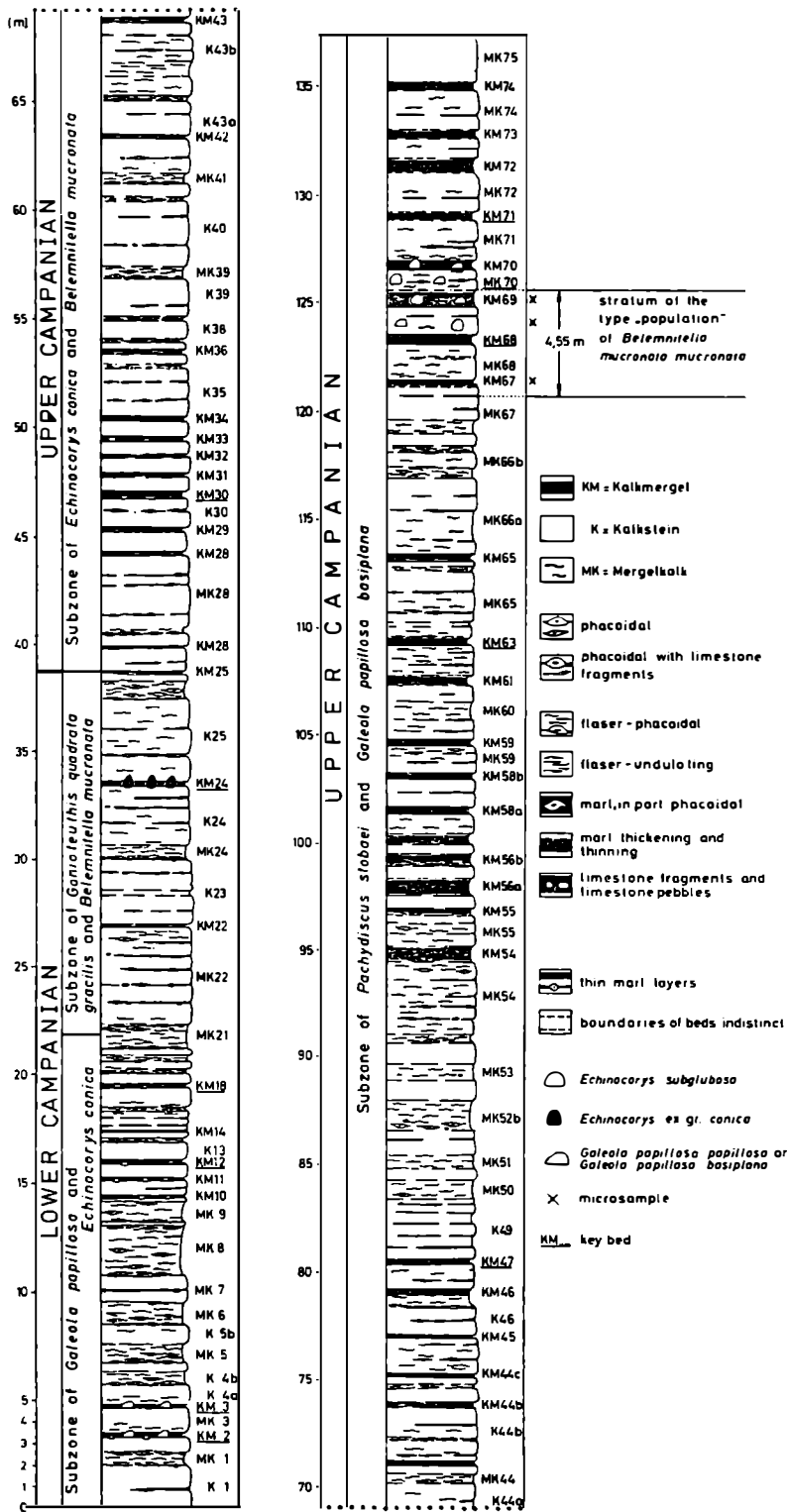


Fig. 57. Detailed stratigraphy of the Campanian of the Germania IV quarry (after KHOSROVSCHAHIAN 1972).

an intercalated marly limestone bed. The topmost Unit 8 of the *conica/papillosa/gracilis* Zone succession, like the underlying one, consists of undifferentiated nodular marly limestones with one intercalated

more distinct limestone bed. This unit is likewise topped by a distinct marl pair. Above this unit a completely undifferentiated sedimentary succession of nodular, marly limestones starts, which, near the

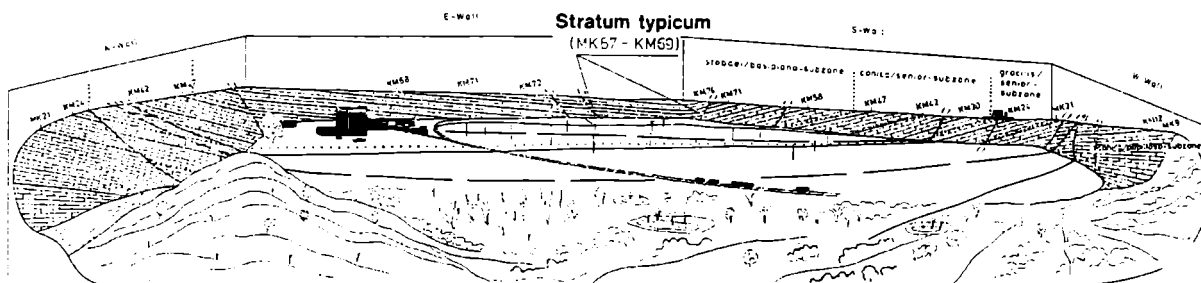


Fig. 58. Sketch of the Germania IV quarry (after KHOSROVSHAHIAN 1972).

base, contains the first *Belemnitella mucronata*, indicating the *gracilis/mucronata* Zone.

Biostratigraphy: The basic framework of the N-German subdivision of the Upper Campanian has been developed in the Schreibkreide facies of the so-called standard section of Lägerdorf (ERNST 1963; ERNST et al. 1996; SCHULZ et al. 1984). On account of their richness in fossils, the cement quarries in the Hannover area served as ideal exposures to test the validity of the zonal scheme and provided the impetus to extend and complete it (KHOSROVSHAHIAN 1972; ABU-MAARUF 1975).

The zonal scheme is based mainly on belemnites of the *Goniotentis* and *Belemnitella* lineages, irregular echinoids of the *Offaster/Galeola* lineages, as well as on the groups of *Echinocorys*, *Micraster* and *Galerites*. Inoceramids and ammonites serve as supplementary elements (SCHMID & ERNST 1975; NIEBUHR 1995, 1996a). In general, two index fossils have been used to name each zone. The *conica/papillosa* Zone (also termed *conica/gracilis* Zone), is characterized by the index echinoids *Echinocorys conica* and *Galeola papillosa* respectively, and the index belemnite *Goniotentis quadrata gracilis*. This zone is superseded by the uppermost zone of the Lower Campanian (according to German authors), which has been termed the *gracilis/mucronata* Zone on the basis of the co-occurrence of the index belemnites *Goniotentis quadrata gracilis* and *Belemnitella mucronata* in this transitional overlap zone. It represents a well traceable marker horizon in the N German Cretaceous.

Eco- and event stratigraphy: Apart from sponge-rich incipient hardgrounds (Fig. 58) echinoids are best for the estab-

lishment of a local ecostratigraphic framework. They allow a high resolution calibration at least within the exposures of the Lehrte West Syncline. For example, *Galeola papillosa* tends to be enriched at the base of the marly limestone beds (e.g. KM 2 and KM 3 in Fig. 57). *Echinocorys conica* likewise develops two significant eco-maxima, the first one in the lower *conica/papillosa* Zone (around MK7), and a second one in the higher *gracilis/mucronata* Zone (around KM 24). ABU-MAARUF (1975) documented species and individual frequency

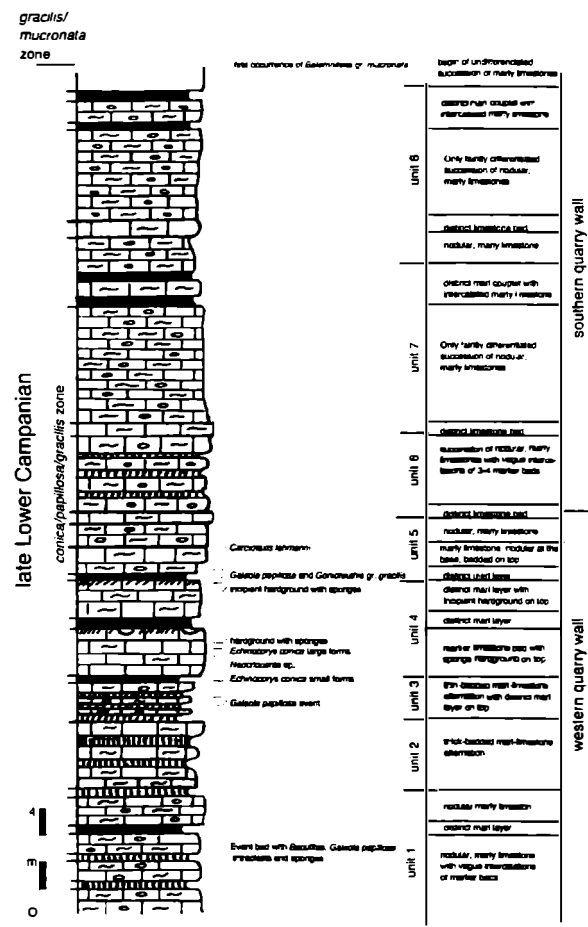


Fig. 59. Lithology and event beds of the *conica/papillosa/gracilis* Zone in the Germania IV quarry.

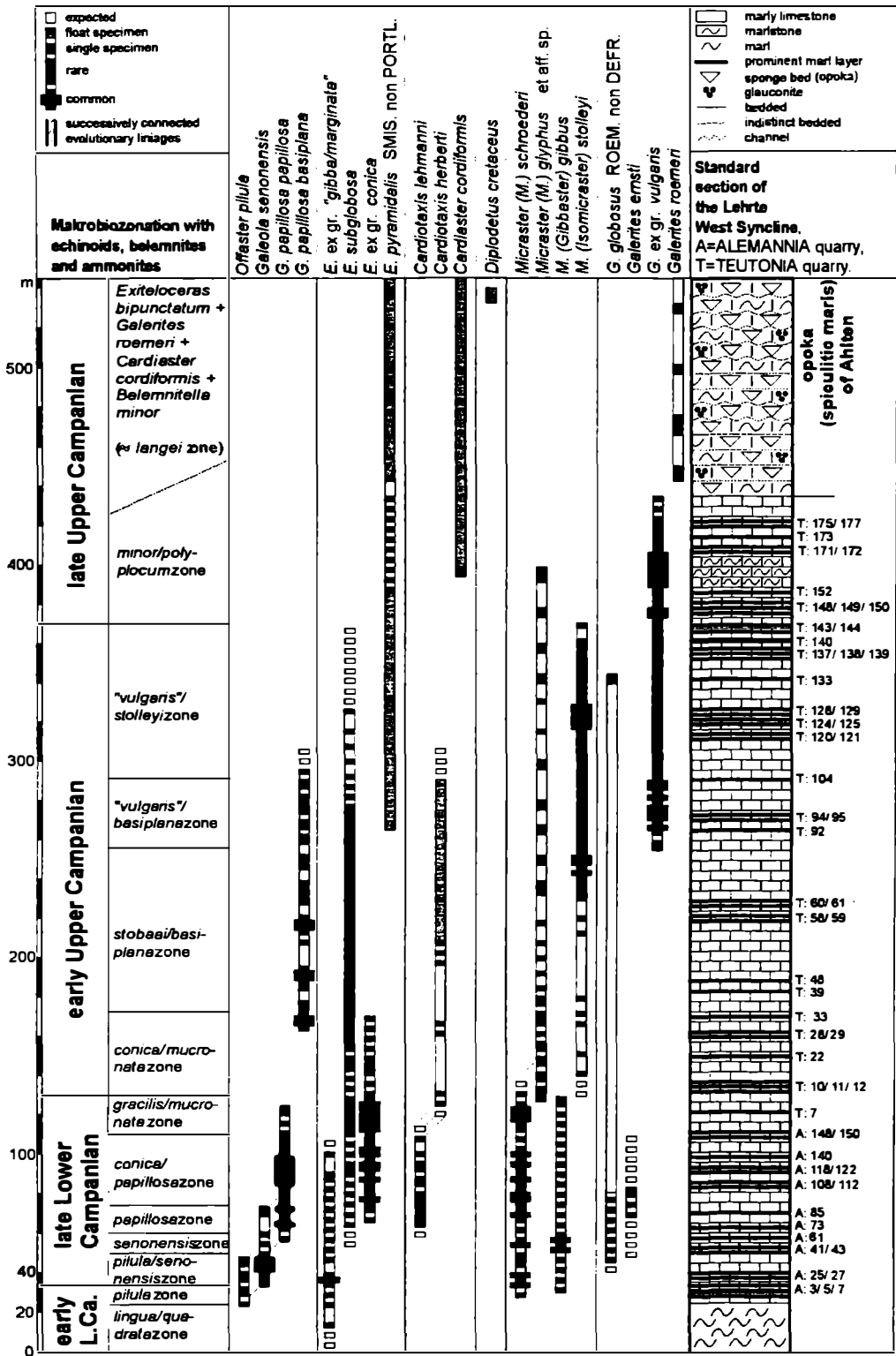


Fig. 60. Range and abundance of irregular echinoids from the Campanian of the Lehrte West Syncline (Höver-Misburg-Ahltten area; after ERNST 1975).

curves of foraminifera, their acme-occurrences and plankton/benthos ratios as well as frequencies of agglutinating and calcareous taxa for ecostratigraphic and facies analyses. The individual frequency curves proved to be the most suitable method for

inter-quarry correlations.

Facies pattern and biostratonomy: The typical benthonic faunal assemblage of the marly limestones of the Misburg area is characterized by siliceous sponges with

a rigid skeleton ("lithistid" demosponges and hexactinellids) and irregular echinoids. Both groups exhibit distinct differences in frequencies and morphotype variabilities, despite the relatively monotonous carbonate facies of the section. Siliceous sponges mostly settled on hard substrata of the incipient hardgrounds during times of very low sedimentation rates, where they formed cluster-like accumulations. In the case of the echinoids, *Echinocorys conica* occurs preferentially in the carbonate richer, *Galeola papillosa* in the marlier lithologies, so that in some of the typical marl-limestone pairs, the former succeeds the latter. Even the nectonic fauna like *Gonioteuthis* exhibits some degree of facies dependency. While *G. quadrata quadrata* still dominates in the marlier beds, the guards in limestones already exhibit the typical characters of the slender *G. quadrata gracilis*. Slight differences in the lithofacies influence the size and morphology of some echinoids. A good example is provided by the diverse morphological variations in the *Echinocorys conica* group, which are clearly not related to phylogenetic development (as considered by KHOSROVSCHAHIAN 1972) but seem rather to be facies-dependent.

According to the measurements of KHOSROVSCHAHIAN (1972), belemnite rostra at some horizons display preferred orientation, indicating temporary hardening of the seafloor, with currents towards the south-east.

Faunal migrations and palaeobiogeography: Apart from some minor eustatic sea level oscillations, the Germania IV section displays two distinct transgressive pulses which correlate with the appearance of new organisms. Both events are related to an only weakly differentiated "bedded calcareous marl facies" (sensu NIEBUHR 1995), which is underlain and superceded by marl-limestone alternations and probably reflect temporary shallowing (see Fig. 57).

In the course of the "Peine Phase" (RIEDEL 1942), inversion tectonics initiated at the

boundary between the *conica/papillosa* and *gracilis/mucronata* Zones. The Subhercynian was uplifted, the remote northern parts, e.g. the Beienroder Basin, the Allertal Graben, etc. were flooded (NIEBUHR & ERNST 1991; NIEBUHR 1995). With the so-called *mucronata* transgression, closely above the uppermost marl couplet of the *conica/papillosa* Zone (Fig. 59), *Belemnitella mucronata* migrated into the area from the Russian platform. Contemporaneously, or slightly later in the *gracilis/mucronata* Zone, short-termed invasions of *Belemnellocamax mammillatus*, *Bostrychoceras (Mobergoceras) indicum*, *Patagiosites stobaei* and certain exotic spatangoids, probably from the Scandinavian coast, took place.

Another immigration episode, connected with the so-called *spiniger* transgression, is documented at the boundary between the *conica/mucronata* and *stobaei/basiplana* Zones. *Patagiosites stobaei* reappears, now significantly more abundant and with larger forms than in the lower occurrence. *Trachyscapites spiniger* extended its area of distribution and rare occurrences of *Belemnellocamax balsvikensis* has been recorded (CHRISTENSEN & SCHULZ 1976). The exact stratigraphic position of the southern immigrants, such as the rare rudistid bivalve *Agriopleura suecica*, within the Lower and Upper Campanian, has not yet been determined. The dominating echinoids, belemnites, etc. display distinct affinities with the boreal Chalk on the one hand and with the southeasterly temperate province (Caucasus, etc.) on the other. Connections with the Westphalian marginal sea, were clearly less good, *Echinocorys conica* for example is rare and immigrated only during a short period.

References: ABU-MAARUF (1975); CHRISTENSEN & SCHULZ (1976); ERNST (1963); ERNST et al. (1996); KHOSROVSCHAHIAN (1972); NIEBUHR & ERNST (1991); NIEBUHR (1995, 1996); RIEDEL (1942); SCHMID & ERNST (1975); SCHULZ et al. (1984).

2.12. Teutonia I quarry at Misburg (Figs. 61-64)

(by G. Ernst, B. Niebuhr & U. Rehfeld)

Location and grid reference: TK 25, 3635 Lehrte, R 35 60300, H 58 05300. North of the railway track between the east side of Misburg and Autobahn A 7.

Stratigraphy: Upper *conica/papillosa* Zone of the Lower Campanian to the lower part of the *minor/polyplocum* Zone of the Upper Campanian. No significant hiatuses have been identified. The Lower Campanian section is poorly exposed in this quarry. Only the stratigraphically younger portions, exposed in the southeastern corner of the quarry, comprising the transitional successions between lower and upper Upper Campanian ("*vulgaris*"/*stolleyi* and *minor/polyplocum* Zones), will be referred to in this guide.

General remarks: The Teutonia I quarry is one of the largest cement quarries of the Lehrte West Syncline. A total thickness of 260 m of sediment is exposed. The quarry exhibits only minor normal faulting. For several years exploitation has been restricted to the eastern quarry wall, whereas particularly the western and northern walls are very degraded and barely accessible. The bedding planes in the lower parts of the section dip at 20° to the ESE towards the centre of the Lehrte salt structure foredeep. The dip decreases to 12° towards the quarry wall exposing the upper portion of the section.

The Lower Campanian and lower Upper Campanian has been studied in detail by KHOSROVSCHAHIAN (1972), who measured the section and investigated the faunal content. The deepest parts of the section correspond stratigraphically to the Germania IV quarry described above and therefore do not need further explanation. In the highest portions of the exposed section, the gradual transition from the so-called "Misburg facies" with marl-limestone alternations to the "Opoka" facies of Ahlten is seen, first studied by NIEBUHR (1995).

Lithology: The newly investigated highest part of the section is about 70 m thick. It is characterized by marl-limestone alternations which alternate on a decimetre scale. The carbonate content varies between

48 and 73%, sharp contacts between marl and limestone beds are not developed. The section can be subdivided into three lithologic units, comprising the upper "*vulgaris*"/*stolleyi* and the lower *minor/polyplocum* Zones.

Unit 1 (cycles 1-8 in Fig. 62) consists of eight marl-limestone cycles generally composed of limestones with 5 to 7 intercalated marl layers in three cases, respectively. Each cycle starts with weakly developed marl-limestone alternations and ends with a distinct marl couplet, which provides a conspicuous contrast with the sub- and superjacent limestone beds. The higher limestone beds within a cycle, especially in cycles 2 to 4, or the base just above the last cycle (cycle 7), contain calcareous nodular concretions; these represent the calcified tissues of siliceous demosponges with monaxone spicules ("soft sponges"). Sponge fragments and foraminifera may also be associated with the sponge bodies. Several of the spicules within these concretions are preserved as silica, but most of them became calcified. In exchange, the dissociated silica replaced most of the foraminiferal tests within the sponge concretions. Many of the nodules exhibit an internal septarian texture, implying a pore-filling origin (sensu ENGELHARDT 1973). These nodules may indicate reduced accumulation rates during their formation (see MÜLLER & FABRICIUS 1974). Bioturbation of the marl layers of unit 1 is largely limited to a *Chondrites* ichnofauna, whereas other trace fossils are common in the limestone beds.

The superjacent unit 2 (cycle 9 in Fig. 62) is characterized by a distinct facies turnover, which reflects the first regressive trends of the *polyplocum* regression with onset of lowering of the sea level. This unit is a "bedded calcareous marl facies" (NIEBUHR 1995) and only weakly differentiated by marl-limestone alternations, implying that the carbonate content of 60 to 70% remains rather constant. Only beds h and j are developed more distinctly. The former contains a basal Fe-rich sponge layer, the latter is a prominent limestone bed.

Unit 3 (cycles 10-11 in Fig. 62), which is characterized by marl-limestone alternations like unit 1, indicates that deeper water conditions prevailed once more before the ca. 140 m thick shallow water "Opoka" facies of Ahlten developed, which is no more exposed in the Teutonia I quarry.

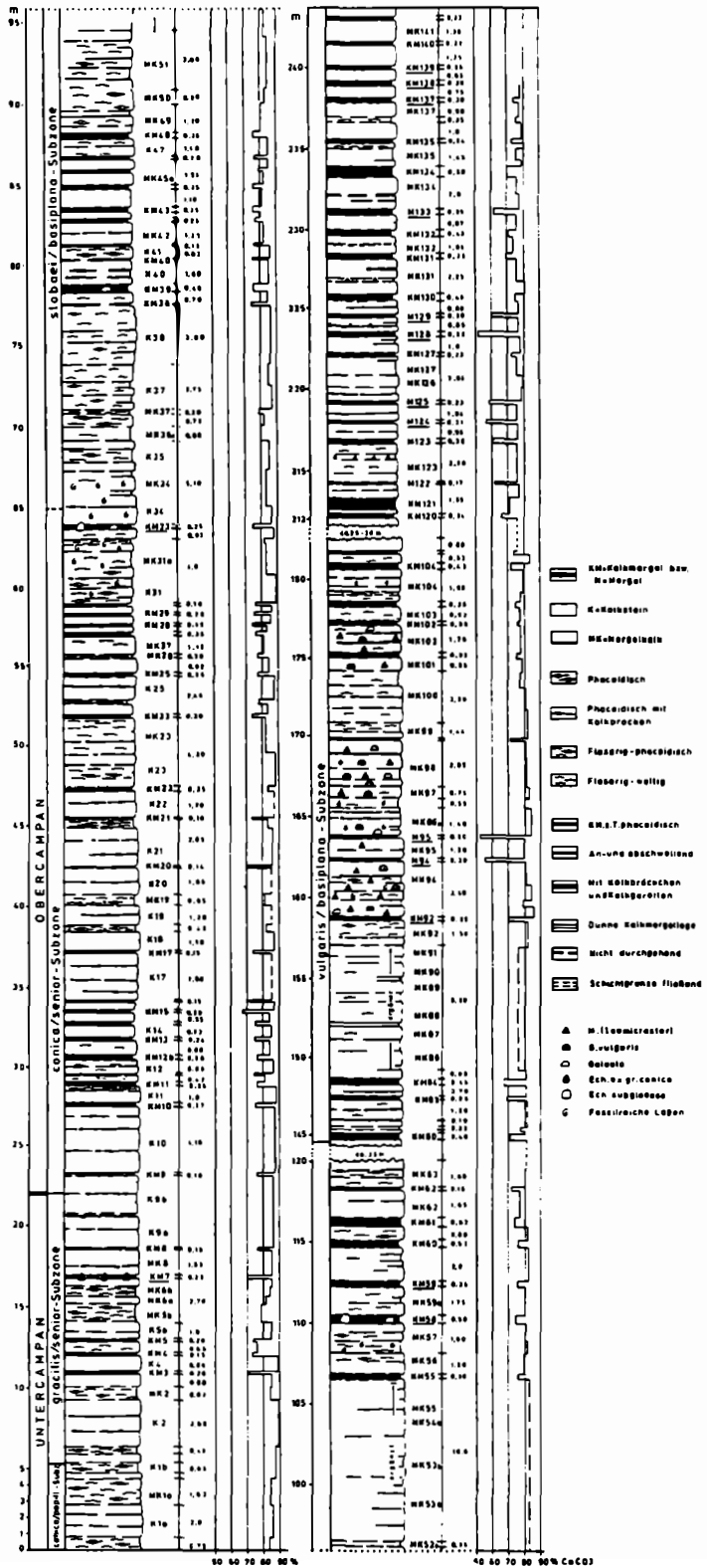


Fig. 61. Biostratigraphy, lithostratigraphy, and carbonate contents of the Teutonia I quarry section (after KHOSROVSCHAHIAN 1972).

As can be seen with the SEM, the sediments of the entire section exhibit pervasive calcite neomorphism, resulting in strong dissolution of the calcareous nannoplankton, which consequently becomes undetermina-

ble. This suggests migration of the carbonate solutions within the system, probably from the primarily carbonate-poorer into the carbonate-richer beds of the alternations (NIEBUHR 1995). The marl-limestone

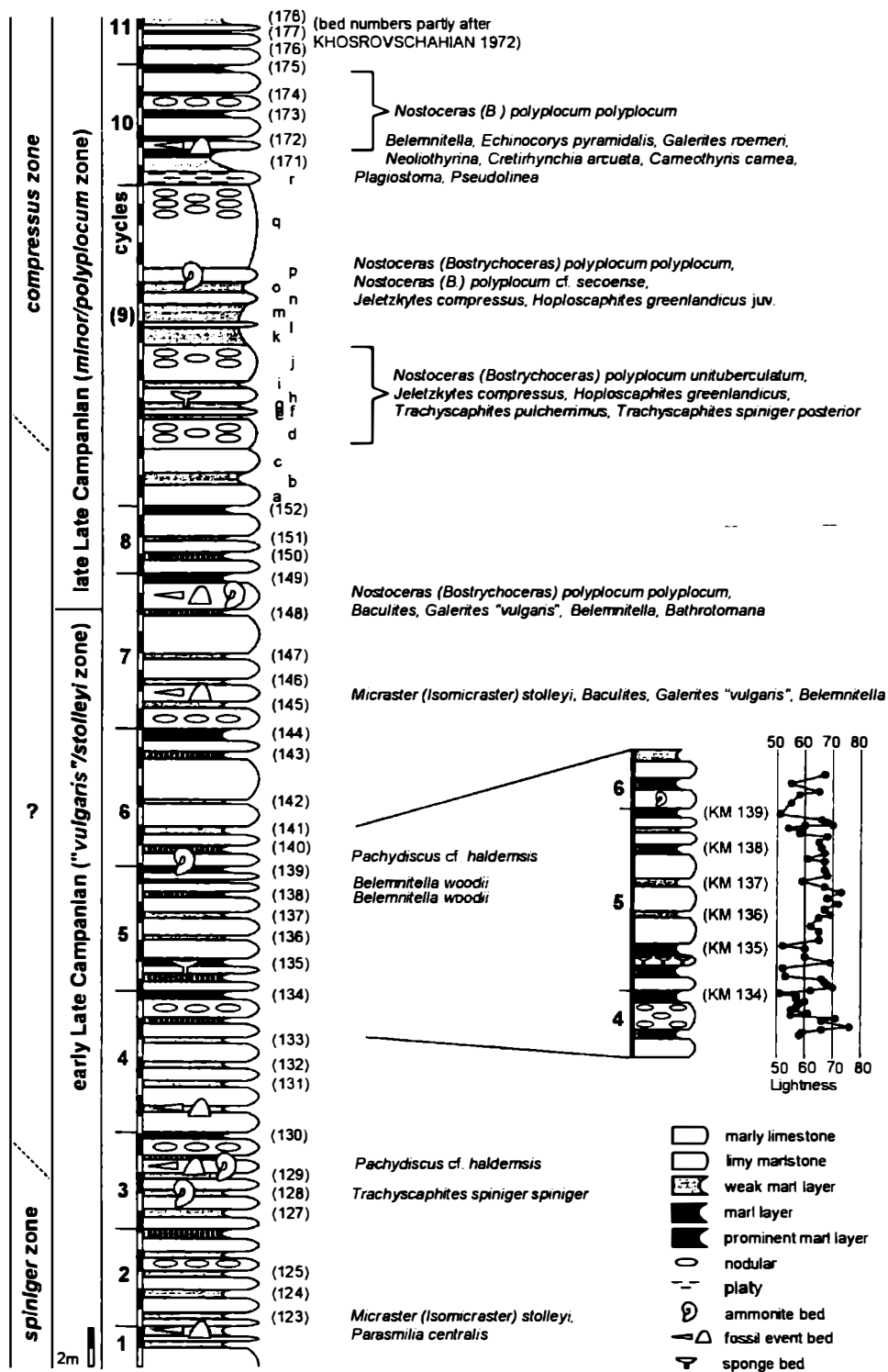


Fig. 62. Upper Campanian biostratigraphy, lithology and cyclic stratigraphy of the southern wall of the Teutonia I quarry.

alternations are foraminifera calcisphere wackestones. In the higher part of the section (unit 2), the matrix yields increasing concentrations of monaxone, siliceous spicules.

Fauna: The faunal assemblages of the section vary parallel to the lithological development.

Unit 1 (cycles 1-3) is rich in biogenic components like pycnodonteine oysters, some

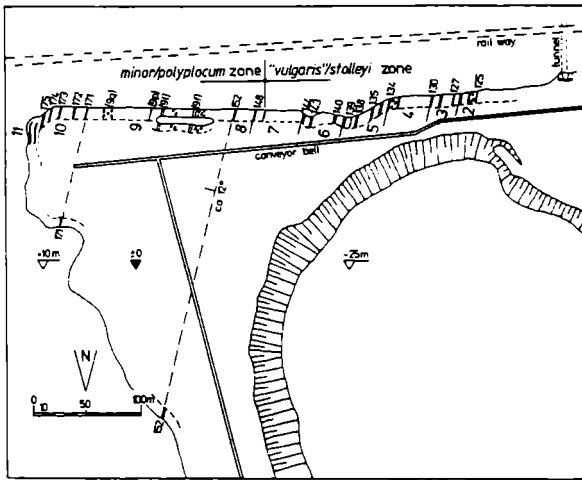


Fig. 63. Sketch map of the southeastern corner of the Teutonia I quarry.

corals (*Desmophyllum* sp.), echinoids such as *Galerites* "vulgaris" and *Micraster* (*Isomicraster*) *stolleyi*, rare ammonites (*Trachyscaphites spiniger*), belemnites (*Belemnitella* sp.) and sponges. According to ULBRICH (1974) the sponge fauna, containing corallistid demosponges such as *Pachinion scriptum*, indicates shallower water conditions. In the superjacent beds sponges remain diverse but contrary to the lower portions, taxa like the tetracadinid, thick-walled *Phymatella* sp., pachastrellid taxa like *Propachastrella* sp. and lychniscosan sponges (*Becksia* sp.) now suggest deeper water conditions. The uppermost limestone bed of cycle 7 yields a more diverse fauna, rich in baculitids, echinoids, belemnites, gastropods, *Dentalium* sp.. One fragment of *Nostoceras* (*Bostrychocers*) *polyplocum* from the collection of KHOSROVSCHAHIAN may well be assigned to this event bed, and indicates the boundary of the lower/upper Upper Campanian in Fig. 62.

The bedded calcareous marl facies of unit 2 exhibits a completely different faunal spectrum. In addition to faunal elements of the subjacent unit 1 like *Galerites* "vulgaris" and some rare *M.* (*Isomicraster*) sp., it comprises a fauna which is already reminiscent of the shallow marine "Opoka" facies of Ahlten (NIEBUHR 1995; NIEBUHR et al. in press). Scaphitid ammonites, like *Jeletzkytes compressus*, *Hoploscaphites greenlandicus* and *T. pulcherrimus* come in (NIEBUHR 1996a). The baculitid ammonites are significantly broader than in the subjacent rhythmically bedded unit 1. Further-

more, the fauna comprises cidarid echinoids, large brachiopods (*Cretirhynchia norvicensis*, *C. arcuata*, *Neoliothyryna obesa*, *Carneithyris carnea*, *Terebratulina chrysalis*, *Kingena pentangulata*, *Magnithyris magna*) and a highly diverse bivalve fauna. The pectinid bivalves (*Mimachlamys cretosa*, *M. mantelliana*, *Chlamys undulata*, *Syncyclonema membranaceum*, *Neithea quinquecostea*), pycnodontid oysters (*Pycnodonte vesicularis*, *Hyotyssa semiplana*), *Spondylus dutempleanus* and *Inoceramus haldemensis* are abundant and already relatively large. The sponge fauna is characterized by rhizomarine taxa like *Seliscothos* sp.. The entire faunal association is likewise characteristic of shallower water environments. For more details of macrofossil occurrence in unit 2 see NIEBUHR (1995, 1996a). Unit 3 is poor in fossils.

Sedimentation pattern and cyclicity:

The marl-limestone alternations are interpreted as climatically controlled cycles, reflecting orbital forcing of the Milankovitch frequency band (MILANKOVITCH 1941). Sedimentary anomalies like tempestites and turbidites are largely missing (NIEBUHR 1995). NIEBUHR (1995, 1996b) and NIEBUHR & PROKOPH (in press) have proved, that the 50 m cycles in boreholes of the deeper Upper Campanian (*conica/senior* to *vulgaris/basiplana* Zones after KHOSROVSCHAHIAN 1972; see Fig. 61) can be assigned to the long eccentricity of 400.000 years and that the 12.5 m cycles reflect the short eccentricity of 100.000 years. The boreholes in the deepest parts of the Lehrte West Syncline show sediment accumulation rates of 125 m/ma, consequently. The same long eccentricity cycles in the Teutonia I quarry, in the marginal parts of the foredeep, have a sediment thickness of 27 to 28 m and show accumulation rates of 68 to 69 m/ma.

The cycles of unit 1 of the "vulgaris"/*stolleyi* Zone with their bundles of 5 to 7 couplets have a sediment thickness of about 5 to 7.70 m (Fig. 62). The carbonate content of 48 to 73% shows a decrease of biogenic carbonate productivity. The subjacent marl-limestone alternations of the *conica/senior* to *vulgaris/basiplana* Zones, on the contrary, show a relatively high carbonate content of about 65 to 90%.

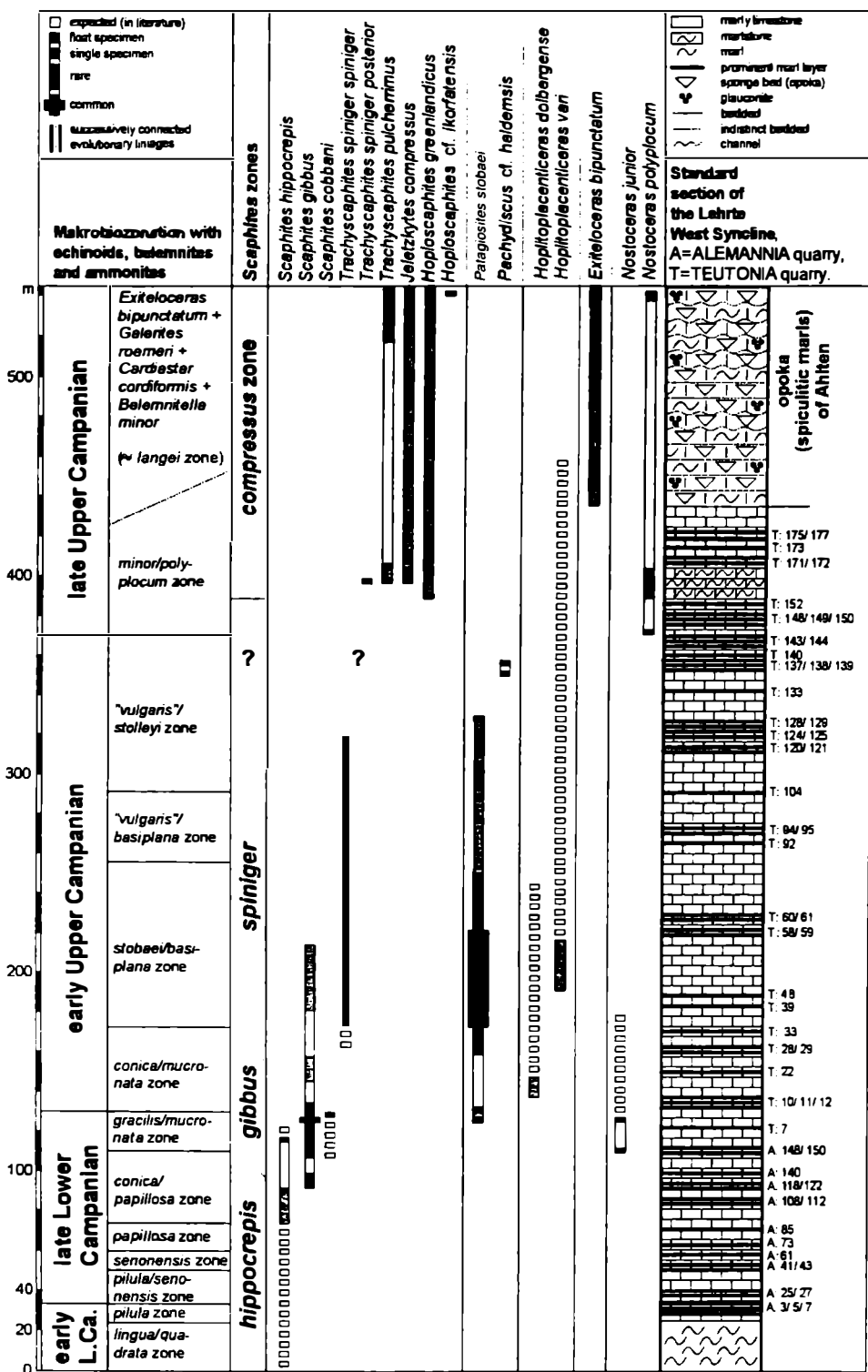


Fig. 64. Range of ammonites of biostratigraphic significance from the Campanian of the Lehrte West Syncline (Höver-Misburg-Ahlten area; after SCHMID & ERNST 1975; ERNST 1975; NIEBUHR 1995, 1996).

Geochemic data (REHFELD et al. in press) indicate that the cycles 5 to 7 exhibit regular shifts of the detrital phase at a 5 to 6 m interval, which may reflect the short eccentricity of 100.000 years. Variations are most

obvious in the K/Al and associated Si/Al and Ba/Al ratios. This is referred to shifts in the illite-smectite/kaolinite ratios which is interpreted to be due to climatic fluctuations. These have thus been obviously trig-

gered by shifts of the detrital composition and not by changes in carbonate bioproductivity (REHFELD et al., in press).

A striking correspondence can be observed between K/Al maximum ratios and ecoevent beds. If ecoevent beds should turn out to match climatic, Milankovitch-induced variations, they would provide an invaluable tool in tracing such cyclicities within sedimentary successions.

Cycle 8 contains only 3 marl beds and is distinctly thinner bedded than the subjacent cycles 2 to 7. It grades into the bedded calcareous marl facies of superjacent unit 2 (cycle 9), which is about 20 m thick and only faintly differentiated into marl and limestone beds, though orbital forcing cannot be proved.

Cycle 5 has been investigated by means of a "Croma-Meter" to determine the brightness in order to define the differences between calcareous and marly layers correctly. Calibrated by geochemical carbonate analyses (RFA), the carbonate content of a layer can be easily determined by this method. The "Croma-Meter" has a brightness index range between nearly 100 (pure white) to 0 (black). Within cycle 5 the index shows values in the marl layers which vary between 50 and 60, whereas the limestone beds are characterized by significantly higher values, ranging up to 87. It is noteworthy that the brightness index and thus the carbonate content within the thick middle bed increases towards the top.

Macrobiostratigraphy: Only few stratigraphic details will be given here, treating only the highest parts (Upper Campanian "*vulgaris*"/*stolleyi* and *minor*/*polyplacum* Zones) of the Teutonia I section.

The assignment of the "*vulgaris*"/*stolleyi* Zone to the echinoids *Galerites* "*vulgaris*" and *Micraster* (*Isomicraster*) *stolleyi* is provisional and urgently needs revision. This zone was termed the "*vulgaris*-Subzone" by KHOSROVSCHAHIAN (1972) and the "obere *vulgaris*-Subzone" by ERNST (1975). Initially, SCHULZ et al. (1984) likewise used the term "*vulgaris* Zone" for this interval in the standard section of Lägerdorf. Following a revision of the genus *Galerites*, SCHULZ (1985) replaced the *vulgaris* Zone by the *Galerites roemeri* Zone. In the opinion of the authors, this revision is not justified. Type locality and stratum typicum of

Galerites roemeri is the "Opoka" facies of Ahlten, which overlies the Teutonia I section (see above). There, probably in response to ecofacies factors, the *Galerites* lineages developed an unmistakable morphotype with features that significantly differ from those of the marl-limestone facies of Misburg. The variability of the Misburg populations of the "*vulgaris*" Zone is remarkable. Along with forms which resemble *G. sulcatoradiatus*, forms like *G. globosus* (sensu ROEMER non DEFRANCE) and morphotypes with a conical corona (ERNST 1975), co-exist. Thus, the terms *G. vulgaris* Zone and *G. roemeri* Zone here may be equally unsuited to characterize this interval.

Micraster (*Isomicraster*) *stolleyi*, the second index echinoid, is an easily identified distinct form, which ranges from the *stobaei*/*basiplana* to the *minor*/*polyplacum* Zone (Fig. 59). However, it is only at the base of the *vulgaris*/*basiplana* Zone, that this index echinoid becomes more abundant. At least as a secondary index fossil, this echinoid turns out to be of value for intra-European correlations, for example with Spain.

With respect to the ammonites, rare pachydiscid species (*P. cf. haldemisi*) may become important for the characterization of the "*vulgaris*"/*stolleyi* Zone (Fig. 64). The belemnitellids are in urgent need of restudy after CHRISTENSEN (1995) provided a quite confusing revision of this group. Along with large forms, which may possibly be assigned to *Belemnitella woodi*, small transitional forms with large fissure angle appear in the higher portion of the zone, the latter would have been formerly assigned to *Belemnitella minor*.

The base of the *minor*/*polyplacum* Zone does not correspond to the distinct change in facies. It is drawn at the above-mentioned event bed at the top of cycle 7 (bed K7e; Fig. 62), since a specimen of the heteromorph ammonite *Nostoceras* (*Bostrychoceras*) *polyplacum* has been inferred to come from this horizon (NIEBUHR 1996a). Accurately horizoned specimens are first recorded somewhat higher in the section in unit 9 (Fig. 62: beds d-j), which also yields abundant baculitid and scaphitid ammonites. Additional ammonites of this zone are *Jeletzkytes compressus*, *Hoploscaphites greenlandicus* and *Trachyscaphites pulcherrimus* (NIEBUHR

1995, 1996a). According to the former index ammonite, a *compressus* Zone has been coined in the scaphitid stratigraphy. The first occurrence of the index species corresponds to the unit 2 of the lower *minor/polyplocum* Zone (NIEBUHR 1996a; see Fig. 64). *Exiteloceras bipunctatum*, indicator of the higher *Didymoceras donezianum* Zone of Poland (BLASKIEWICZ 1980) is absent in the Teutonia I section since it characterizes the younger "Opoka" facies of Ahlten (NIEBUHR 1995, 1996a; NIEBUHR et al. in press).

The bostrychoceratids, so far collected, have been assigned to the subspecies *Nostoceras (B.) polyplocum polyplocum*, *N. (B.) polyplocum unituberculatum* and *N. (B.) polyplocum* cf. *secoense* sensu BLASKIEWICZ (1980) and KÜCHLER (in press). They are mostly preserved as fragments and rarely yield more than one or two whorls.

The belemnitellid fauna of this zone shows a significant turnover. Along with several large *Belemnitella woodi* or *B. minor* (sensu

type specimen), respectively, mostly small, slender forms appear with the internal structures of *B. minor* (sensu German authors).

Echinoids are represented throughout by *Micraster* sp. of the main lineage and *M. (Isomicraster) stolleyi*, which are missing in the "Opoka" facies of Ahlten. *Galerites "vulgaris"* continues to be enriched in certain beds and no forms transitional to *G. roemeri* of the Ahlten "Opoka" facies occur. However, a first occurrence of *Cardiaster cordiformis* announces the entry of new echinoid assemblages in unit 2.

References: BLASKIEWICZ (1980); CHRISTENSEN (1995); ENGELHARDT (1973); ERNST (1975); KHOSROVSCHAHIAN (1972); KÜCHLER (in press); MILANKOVITCH (1941); MÜLLER & FABRICIUS (1974); NIEBUHR & PROKOPH (in press); NIEBUHR (1995, 1996); NIEBUHR et al. (in press); REHFELD et al. (in press); SCHULZ (1985); SCHULZ et al. (1984); ULBRICH (1974).

2.13 Resse clay-pit (Figs. 65-72)

(by J. Mutterlose)

Location and grid reference: TK 25, 3523 Garbsen, R: 3534900, H: 5816500. The clay-pit is situated about 20 km north of Hannover directly west of the road from Engelbostel to Resse (Fig. 2). This pit, which has been operated since 1993, offers a good exposure of mid-Hauterivian claystones.

Tectonic setting: The section is situated in the centre of a narrow E-W striking graben structure of about 15 km length and 2 km width. The beds dip at 10° towards NW.

Palaeogeography: Central part of the NW German Basin about equidistant from the Hildesheim Peninsula to the south and the Pompeckj Block to the north. The distances towards each of the landmasses did not exceed 50 km. During the Hauterivian the paleogeography was fairly stable. A sea-way towards the Tethys via Poland (Carpathian sea-way) existed for most of the time, allowing floral and faunal exchanges. It is only in latest Hauterivian time that the configuration changed considerably (compare Frielingen, No. 14).

Lithology and stratigraphy: About 13 m of clays and marly clays of early Late Hauterivian age are exposed (Fig. 64). This pit offers currently the only section of the formerly well exposed *Aegocrioceras*/*Simbirskites* junction beds in NW Germany. The lithology consists of dark to medium grey claystones, the carbonate content is generally low. CaCO₃ values vary between 0.3% (sample 105/2) and 15.4% (sample 102/1). In contrast to outcrops farther west, no sideritic nodules have been observed in this section. Various horizons, however, yield small calcareous nodules which commonly contain ammonites. The thickness of these beds varies between 0.1 and 0.2 m, but they seem to be continuous. While coarser-grained clastics (silt) are generally absent in both the clays and the marls, some of these horizons are characterized by a distinct silt content (bed 100). Small pyritized burrows and pyrite nodules occur throughout the sequence. Pale-dark bedding rhythms (compare Frielingen, No. 14) are present, but less conspicuous than in other sections.

Ammonites of biostratigraphic importance (Figs. 67-71) occur throughout the section. The concretions, in particular, yield rich ammonite faunas which allow a detailed zonation. The beds are dated as early Late Hauterivian (upper part of the *Aegocrioceras* Beds and lower part of the *Simbirskites staffi* ammonite Zone).

The lower part of the section (beds 94, 96, 97, 98 and 100) is extremely rich in ammonites. The genus *Aegocrioceras* is restricted to the lowermost part of the section (beds 92-97) and has its last occurrence (LO) in the lower part of bed 97. *Aegocrioceras raricostatum* (common in bed 94) and *Aegocrioceras spathi* (common in bed 96) have been observed. The first *Simbirskites* were found in bed 96, *Simbirskites concinnus* and *Simbirskites decheni* have been recorded from bed 98. Bed 100 is characterized by the first occurrence (FO) of *Simbirskites staffi*, the index species of the *staffi* Zone. The heteromorph

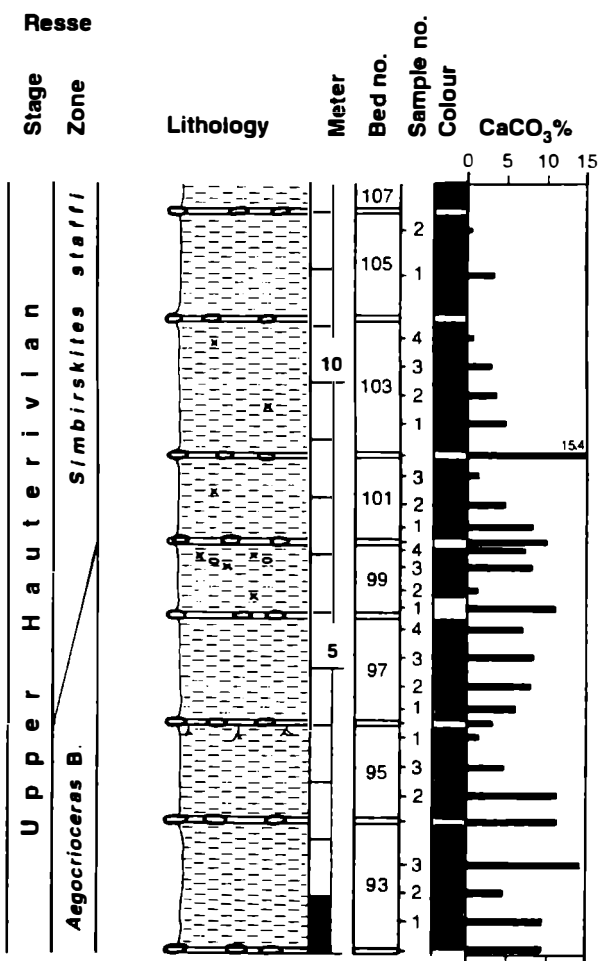


Fig. 65. Lithology and biostatigraphy of the Resse section.

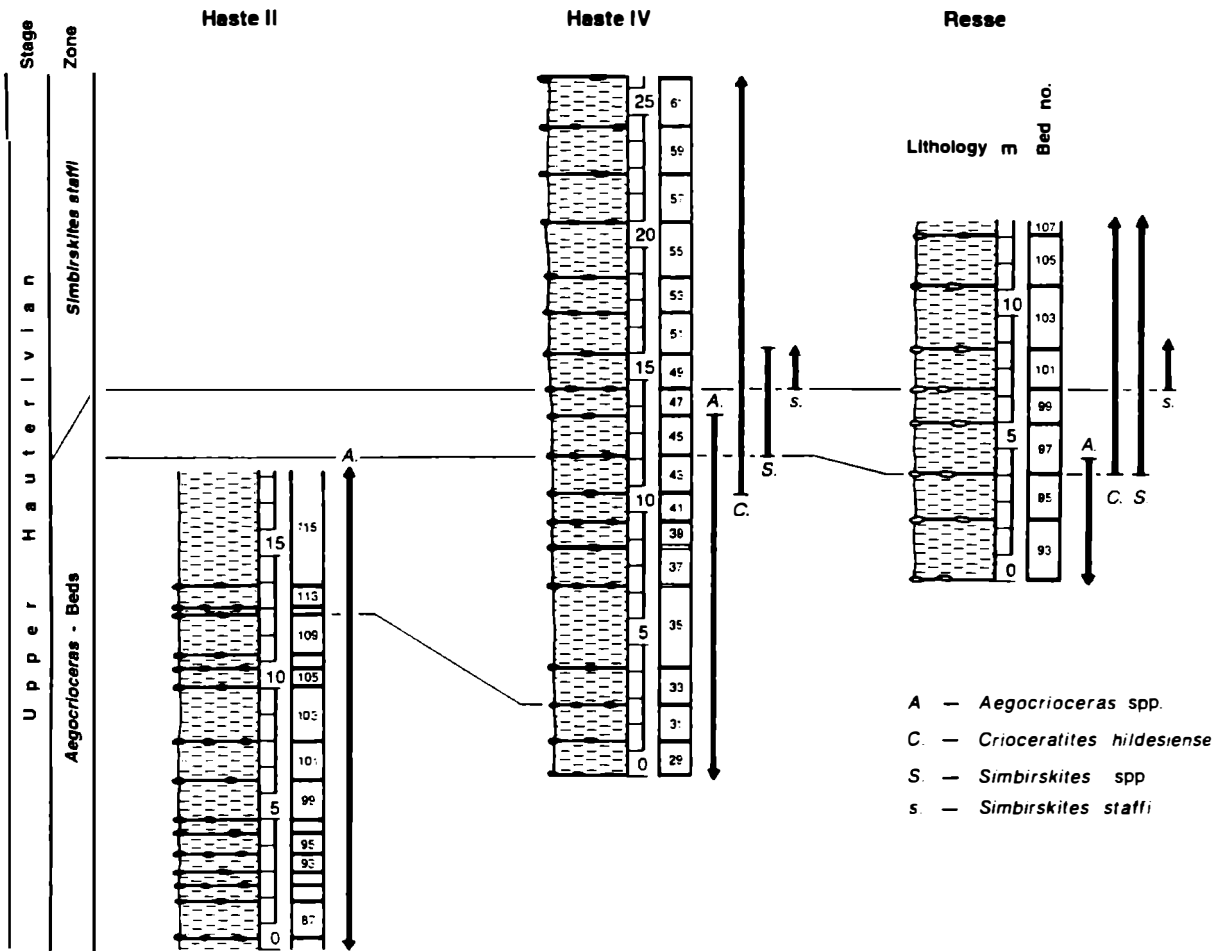


Fig. 66. Correlation of the *Aegocrioceras/Simbriskites* junction beds of the Resse, Haste II and Haste IV sections (from MUTTERLOSE & WIENROTH 1996).

ammonite *Crioceratites hildesiense* has its FO in bed 96 and occurs sporadically in the upper part of the section.

Apart from belemnites (*Hibolithes jaculoides*), bivalves (*Nucula* sp., *Thracia phillipsii*), gastropods (*Turbo* sp.) and crustaceans (*Mecochirus ornata*), remains of fishes and marine saurischians have been observed. The foraminifera are of low diversity and low abundance.

Biostratigraphy: The ammonites from the Resse section supplied new important information about the faunal succession of the *Aegocrioceras/Simbriskites* junction beds. In addition to the Resse section new ammonite finds have been made recently in the Haste sections, about 20 km west of Resse.

Traditionally, the lower Upper Hauterivian is subdivided into the *Aegocrioceras* Beds and the *Simbriskites staffi* Zone. The base of the *Aegocrioceras* Beds is defined by the FO of the genus *Aegocrioceras*, the base of

the *staffi* Zone by the FO of *S. staffi*. The *Aegocrioceras* Beds correspond to the *Simbriskites (Speetonicerus) inversum* Zone in England. Since only a few specimens of the index species *S. inversum* have been observed in Germany, the traditional name *Aegocrioceras* Beds is preferred over the *inversum* Zone. If the most recent proposal (MUTTERLOSE 1996) for defining the Lower/Upper Hauterivian boundary by the LO of the nannofossil species *Cruciellipsis cuvillieri* were be accepted, the base of the Upper Hauterivian would lie at the top of the *Aegocrioceras* Beds.

The old German zonation scheme, valid until 1971, subdivided the interval under discussion into a lower *Aegocrioceras capricornu* Zone and an upper *Crioceratites hildesiense* Zone (e.g. BARTENSTEIN & BETTENSTAEDT 1962). The *capricornu* Zone corresponds to the *Aegocrioceras* Beds of the current scheme, the base of the *hildesiense* Zone was defined by the FO of the heteromorph am-

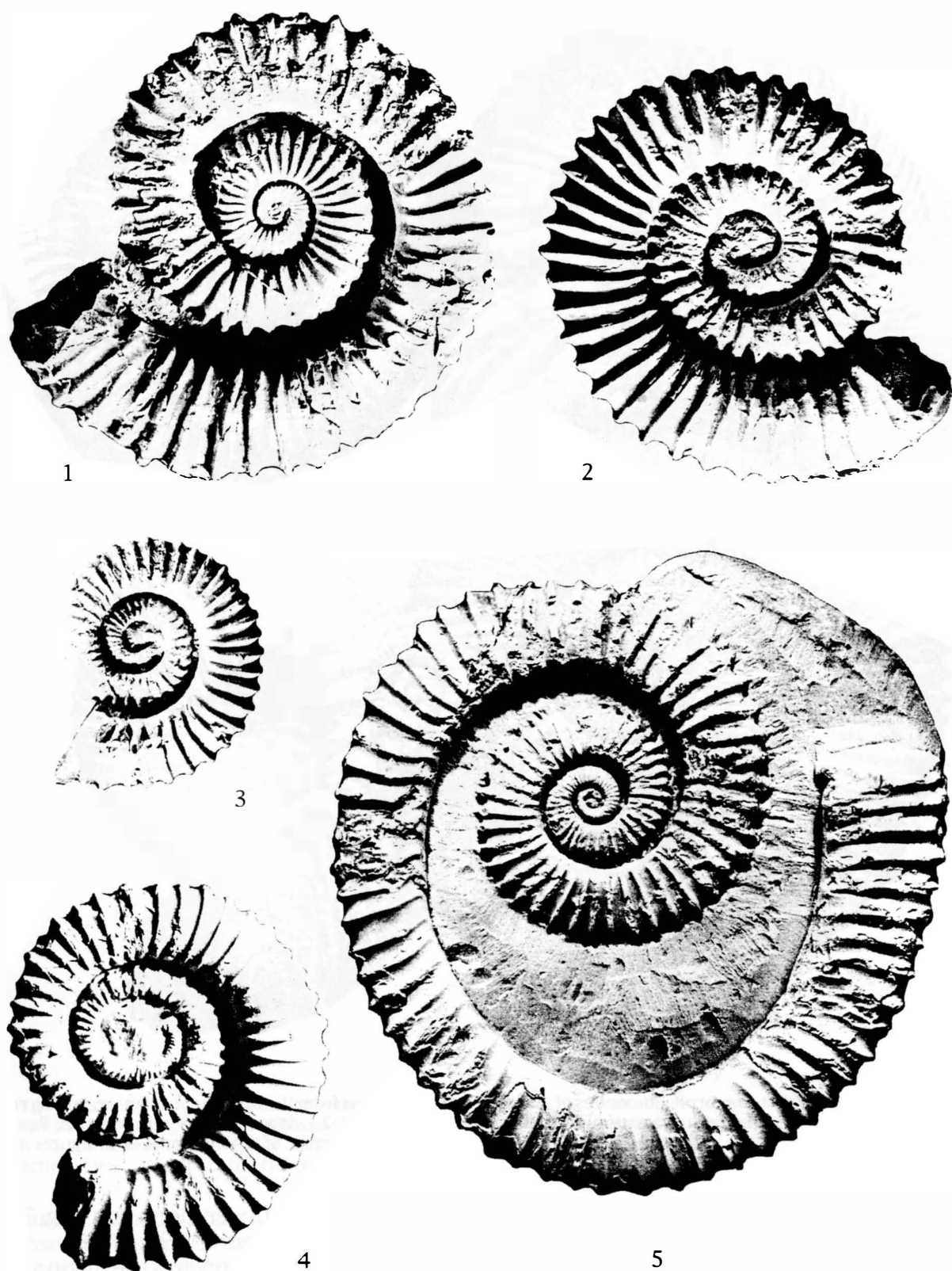


Fig. 67. Endemic ammonites from the Late Hauterivian *Aegocrioceras* Beds. 1. *Aegocrioceras capricornu*, Haste 2 section. 2. *Aegocrioceras quadratum*, Haste 2 section. 3. *Aegocrioceras spathi*, Resse clay-pit, bed 94. 4. *Aegocrioceras spathi*, Resse clay-pit, bed 96. 5. *Aegocrioceras raricostatum*, Haste 2 section. Specimens from the collection of K. WIEDENROTH. All figures are x 1.

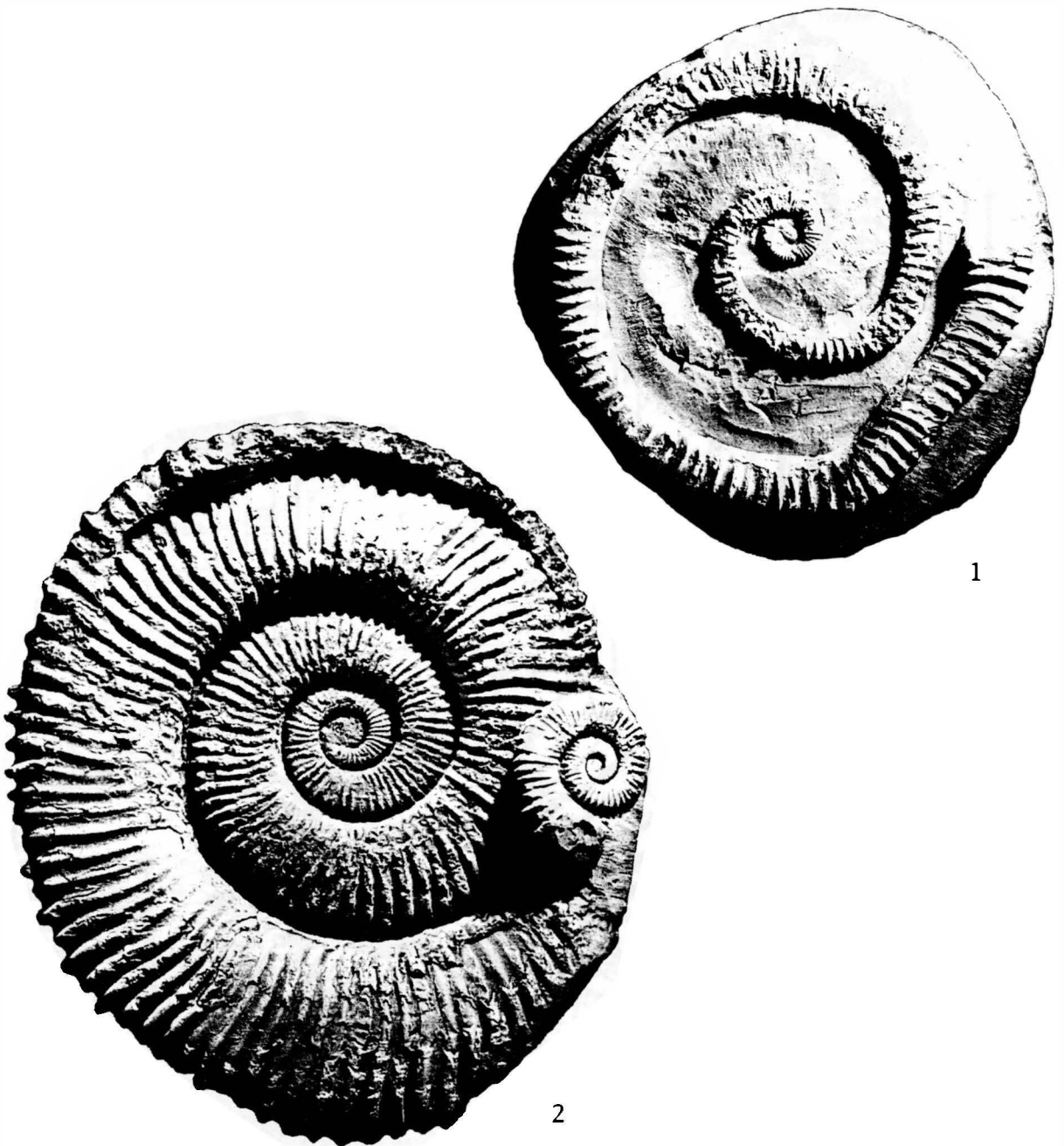


Fig. 68. Endemic heteromorph ammonites of the genus *Aegocrioceras* from the Late Hauterivian *Aegocrioceras* Beds, demonstrating the great variation of coiling within the genus. 2. *Aegocrioceras raricostatum*, Resse clay-pit. 1. *Aegocrioceras* sp., Haste 2 section. Specimens from the collection of K. WIEDENROTH. Both figures are x 0.5.

monite species *C. hildesiense*. The base of the *C. hildesiense* Zone and of the *S. staffi* Zone have approximately the same age. There are, however, only few reliable data available from condensed sections along the basin margin (Moorberg: BAHR 1964; Speeton: RAWSON 1971).

The most recent finds from Resse and Haste—both are expanded sections—now clearly demonstrate an overlap of the three

ammonite genera under discussion (Fig. 72; MUTTERLOSE & WIEDENROTH 1995, 1996).

Both the Haste 4 section and the Resse section exhibit partially overlapping occurrences of *Aegocrioceras*, *Crioceratites* and *Simbirskites*. In Haste 4, *Aegocrioceras* spp. and *Crioceratites hildesiense* co-occur in bed 42. Higher up in bed 44 these taxa co-occur with *S. (M.) concinnus* and *S. (S.) decheni*. It is noteworthy that *S. (S.) staffi*

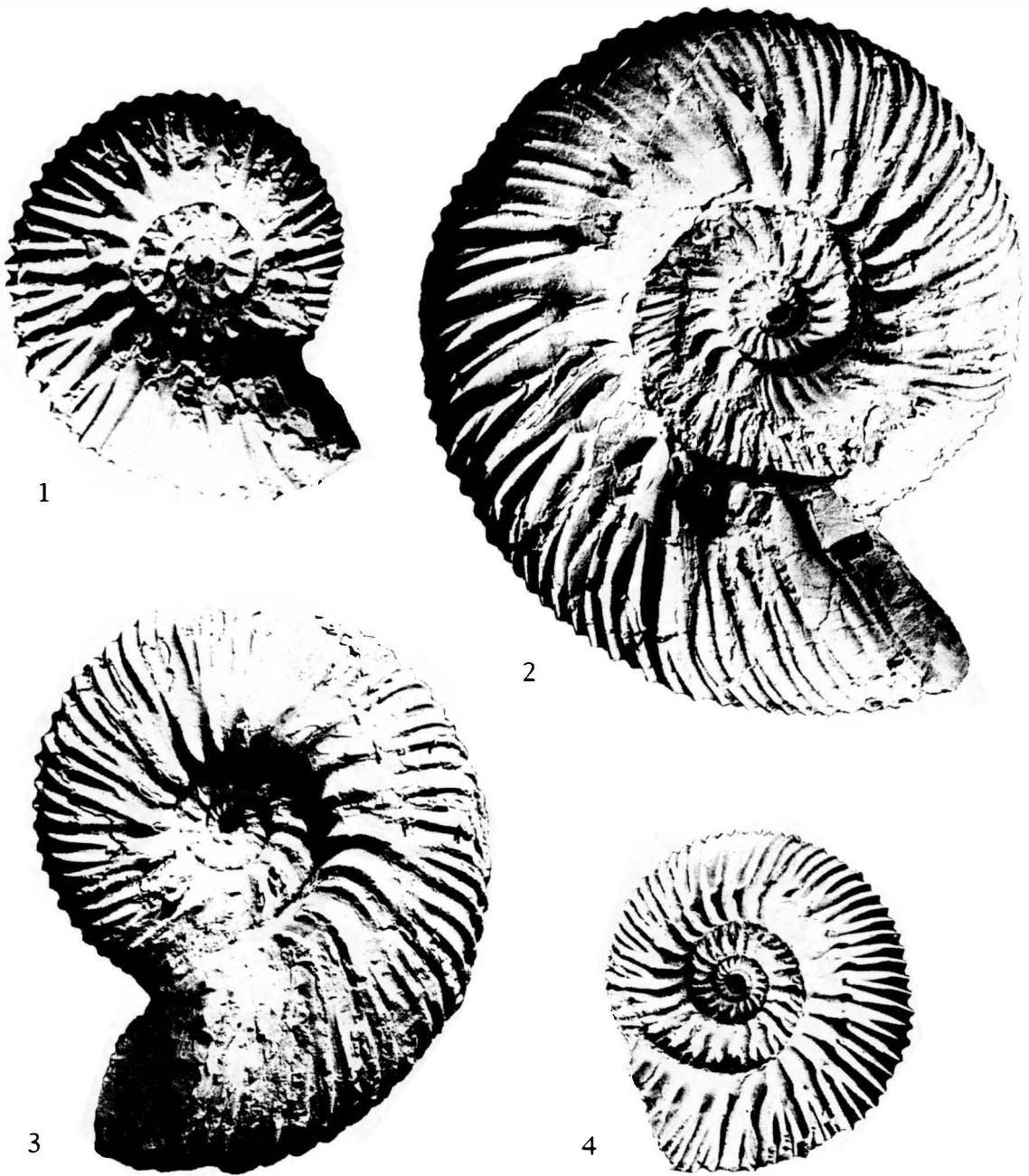


Fig. 69. Ammonites of Boreal provenance from the Late Hauterivian *Aegocrioceras* Beds. 1. *Simbirskites* (*Simbirskites*) ex gr. *decheni*, Resse clay-pit, bed 98. 2. *Simbirskites* (*Milanowskia*) *staffi*, Haste 3 section. 3. *Simbirskites* (*Milanowskia*) *concinnus*, Resse clay-pit, bed 98. 4. *Simbirskites* (*Milanowskia*) sp., Haste 3 section. Specimens from the collection of K. WIEDENROTH. All figures are x 1.

has its FO even higher, in bed 48. Similar observations have been made for the Resse section: *Aegocrioceras* spp. co-occurs with both *C. hildesiense* and *S. concinnus* and *S. decheni* in beds 96 and 97. The FO of *S. staffi* is definitely younger, it has been first observed in bed 100. Fig. 71 gives a comprehensive overview of the stratigraphic ranges of the sections and ammonites discussed.

Three different possibilities for subdividing the *Aegocrioceras*/*Simbirskites* junction beds result from these observations. The base of the first *Simbirskites* zone above the *Aegocrioceras* Beds may be defined as follows:

- LO of the genus *Aegocrioceras*. Following this definition, the *Aegocrioceras* Beds represent a full range zone, which yields in its upper part species of the genus

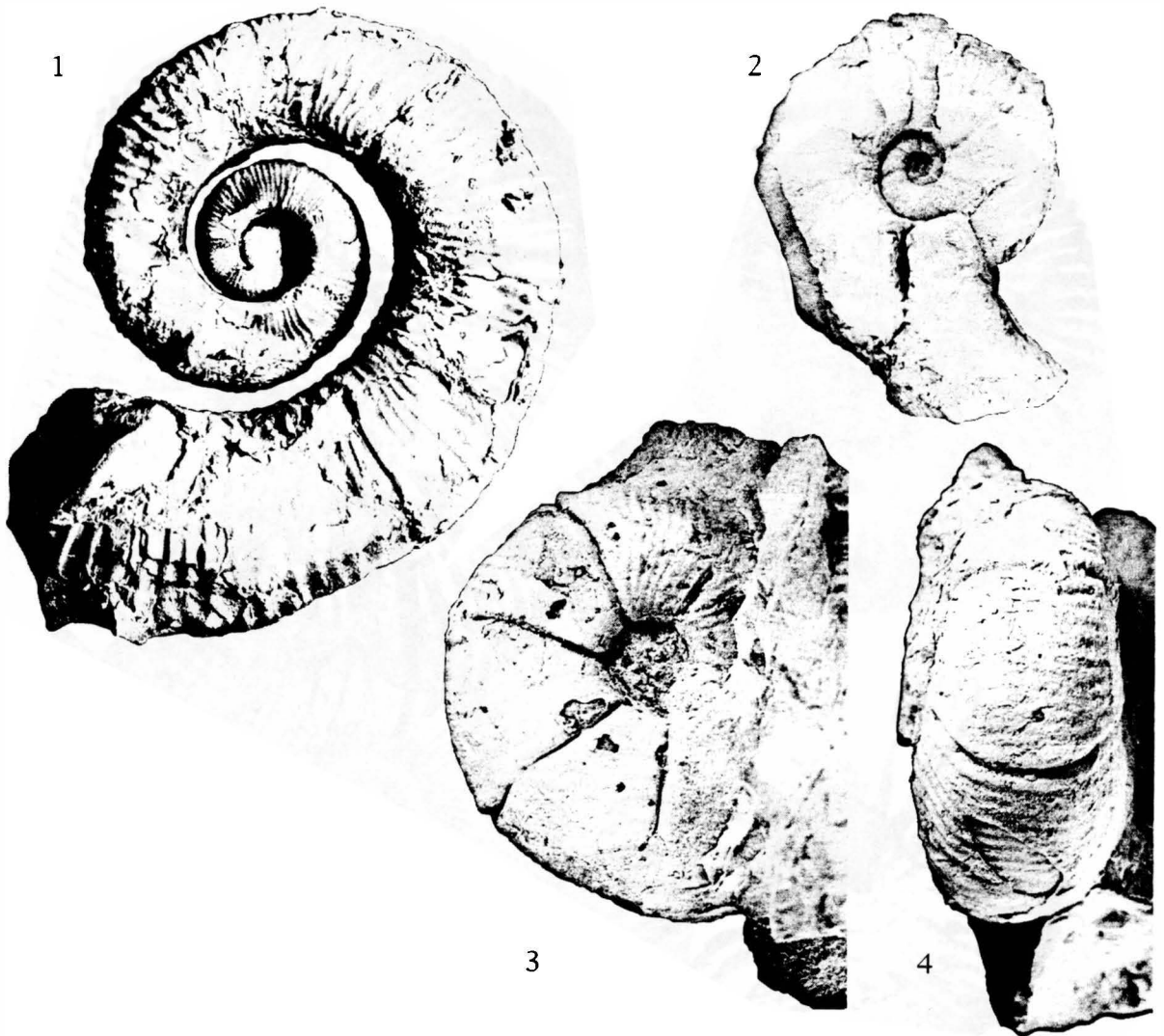


Fig. 70. Ammonites of Tethyan provenance from the Late Hauterivian *Aegocrioceras* Beds. 1. *Crioceratites* ex gr. *duvali*, Haste 3 section. 2. *Spitidiscus rotula*, Haste 2 section. 3, 4. *Spitidiscus rotula*, Resse clay-pit, lateral and ventral view. Specimens from the collection of K. WIEDENROTH. All figures are x 1.

Simbirskites (*S. concinnus*, *S. decheni*). This proposal does not define the interval between the LO of *Aegocrioceras* and the FO of *S. staffi*. In Fig. 72 (1st proposal) this undefined interval is stippled.

- FO of the subgenera *S. (Milanowskia)* and *S. (Simbirskites)*. In this case, the boundary would be defined by the FOs of *S. (M.) concinnus* and *S. (S.) decheni*, somewhere below the FO of *S. staffi*. The problem with this suggestion lies in the absence of the index species *S. staffi* in the lowermost part of the eponymous zone. The addition of a new *S. concinnus* or *S. decheni* Zone between the *Aegocrioceras* Beds and the *S. staffi* Zone does not make sense, since the interval covered by this zone is extremely small. A possible solution might be to rename the *S. staffi* Zone the *S.*

concinnus-staffi Zone. The interval under discussion is hatched in Fig. 72 (2nd proposal).

- FO of *Simbirskites staffi*. This definition does not define the interval from the LO of *Aegocrioceras* to the FO of *S. staffi*. In Fig. 72 this interval (3rd proposal) is hatched.

Migration of ammonites: The *Endemoceras/Aegocrioceras* junction beds are characterized by an immigration of Tethyan ammonites (*Crioceratites*, *Olcostephanus*, *Spitidiscus*) and Boreal genera (*Simbirskites*, *Speetonicer*). This co-occurrence of Tethyan and Boreal ammonite taxa within one bed has been demonstrated for the interval C8A, C7H at Speeton by DOYLE (1989). This interval may repre-

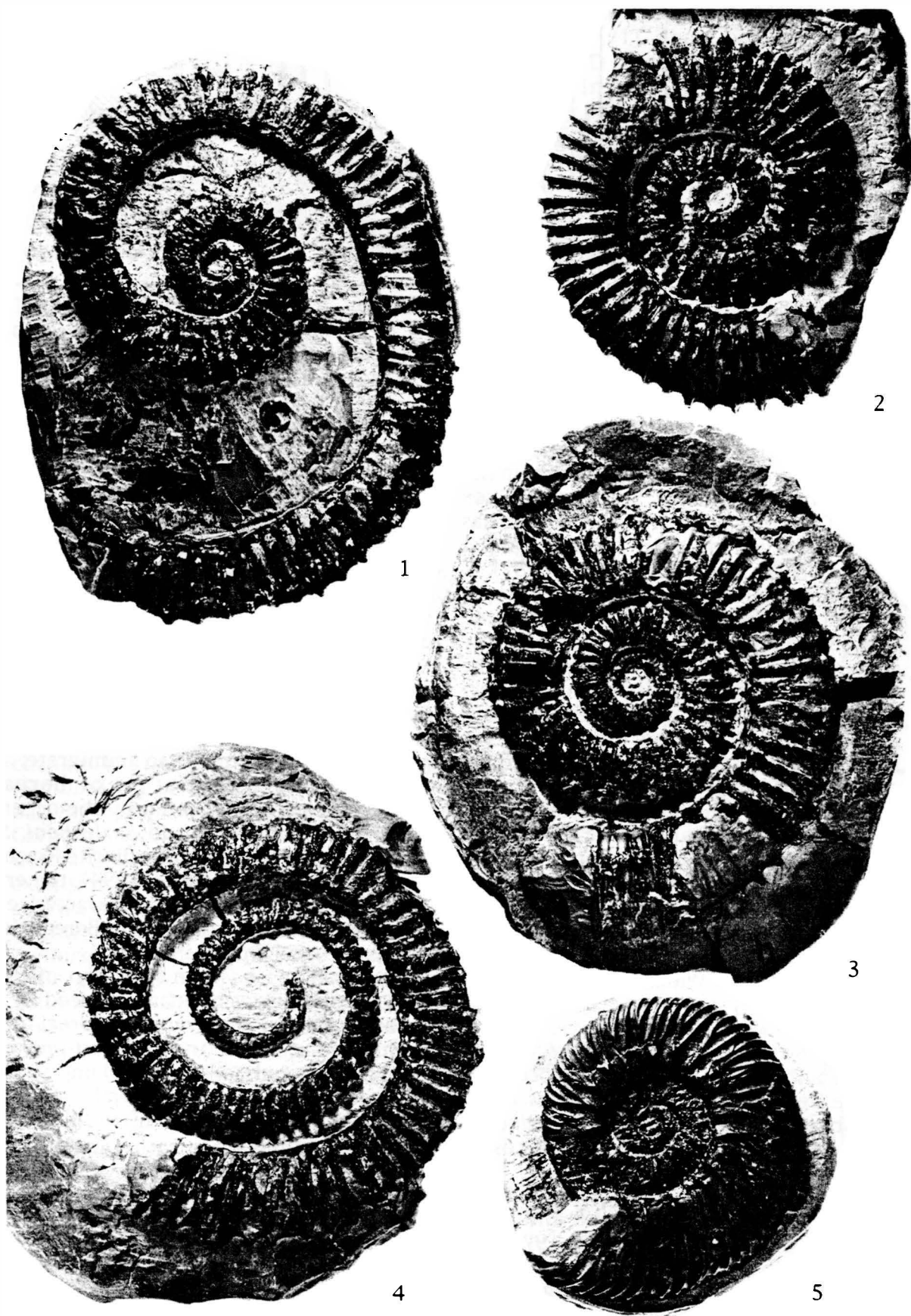


Fig. 71. Ammonites from the Late Hauterivian *Aegocrioceras* Beds, Niedernwöhren section. 1. *Aegocrioceras* sp. 2. *Aegocrioceras capricornu* 3. *Aegocrioceras capricornu* 4. *Aegocrioceras raricostatum* 5. *Simbirskites (Milanowskia) staffi*. Specimens from the collection of K. WIEDENROTH. All figures are $\times 0.75$.

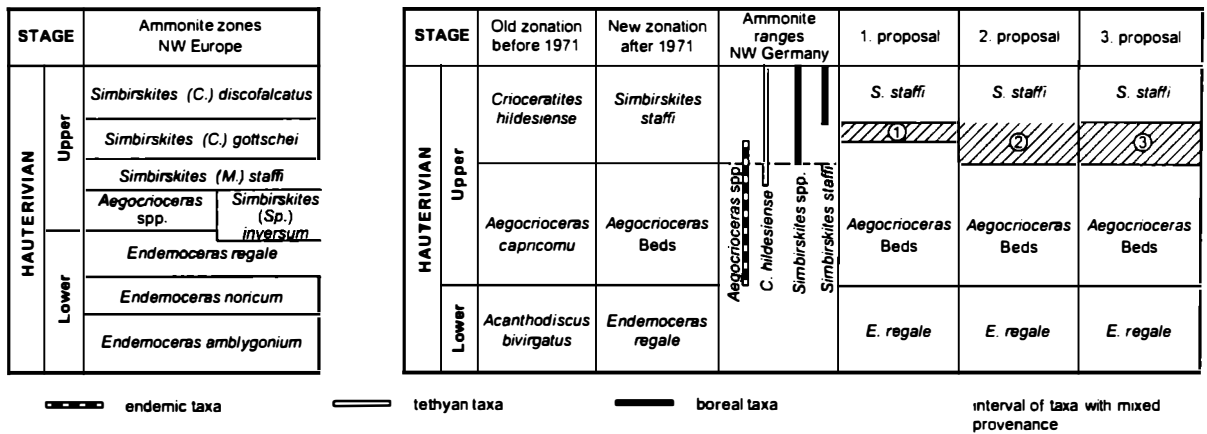


Fig. 72. Proposals for the ammonite zonation of the early Late Hauterivian of NW Europe (from MUTTERLOSE & WIEDENROTH 1996).

sent a maximum flooding surface. The Boreal-Arctic species *Simbirskites (Speetonceras) inversum* is common in the *Aegocrioceras* Beds of Speeton (RAWSON 1971; DOYLE 1989), in NW Germany it has been observed only in the lowermost *Aegocrioceras* Beds (KEMPER et al. 1987). *S. inversum* is more common in the western part of the NW German Basin (Bentheim, Teutoburger Wald, Niedernwöhren), only a few specimens have been recorded in the eastern part of the basin (Moorberg section). This indicates an immigration of *S. inversum* from the NW via the Netherlands. In NW Germany, the *Aegocrioceras* Beds are dominated by the heteromorph *Aegocrioceras*, which is extremely abundant in this interval. The origin of this group, which is also common at Speeton is still unclear (for discussion see RAWSON 1975, 1995; IMMEL 1979; KEMPER et al. 1987). Since *Aegocrioceras* is not known from the Tethys, it is a genus endemic to the North Sea area. KEMPER & WIEDENROTH (1987) interpret *Aegocrioceras* as a stenotherm cold water genus, RAWSON (1995) derives this endemic Boreal group from Tethyan *Crioceratites*. Up to now only two specimens of the Tethyan species *Spitidiscus rotula* have been recorded from the *Aegocrioceras* Beds of Haste and Resse (MUTTERLOSE & WIEDENROTH 1996).

Aegocrioceras is quite abundant both in the basin (Niedernwöhren, Haste and Resse sections; MUTTERLOSE & WIEDENROTH 1996) and in the basin margin (Moorberg section; KEMPER et al. 1987). The remaining fauna is extremely impoverished in the basin. Following the revision of RAWSON (1975) the

following species have been found in the Haste 2, Haste 4 and Resse sections: *Aegocrioceras spathi*, *Aegocrioceras bicarinatum*, *Aegocrioceras capricornu*, *Aegocrioceras compressum*, *Aegocrioceras quadratum*, *Aegocrioceras raricostatum*, *Aegocrioceras semicinctum*. Obviously this endemic group underwent a rapid evolution in the Boreal Realm. Ammonite genera of a Tethyan or Boreal provenance are extremely rare in these beds. This pattern changes in the uppermost *Aegocrioceras* Beds: *Crioceratites hildesiense* and *C. duvali*, two heteromorphs of Tethyan origin, are the first forms to immigrate. A slightly later immigration of Boreal *Simbirskites* is documented by the occurrence of *S. concinnus* and *S. decheni*. *S. staffi* occurs even later. According to RAWSON & RILEY (1982) and RAWSON (1994), the entire early Late Hauterivian is characterized by a sea-level rise. Tethyan and Boreal elements co-occur in this interval.

Thus, both the base and the top of the *Aegocrioceras* Beds are characterized by a co-occurrence of Tethyan and Boreal ammonite faunas, reflecting two short-termed transgressive pulses. This would imply that sea-level changes were the main factor controlling the biogeographic distribution pattern of ammonites.

References: BAHR (1964); BARTENSTEIN & BETTENSTAEDT (1962); DOYLE (1989); IMMEL (1979); KEMPER & WIEDENROTH (1987); KEMPER et al. (1987); MUTTERLOSE & WIEDENROTH (1995, 1996); MUTTERLOSE (1996); RAWSON & RILEY (1982); RAWSON (1971, 1975, 1994, 1995).

2. 14 Frielingen clay-pit (Figs. 73-90)

(by J. Mutterlose and A. Ruffell)

Location and grid reference: TK 25, 3523 Garbsen, R: 3534900, H: 5816500. The clay-pit is situated about 20 km north-west of Hannover, directly east of the Bundesstraße B6 (Fig. 2). Between 1993 and 1995 this pit expanded rapidly towards the west.

Tectonic setting: The pit is located at the westernmost margin of a narrow E-W graben. This structure, which has a length of 15 km and a width of 2 km, runs parallel to the southern flank of the Neustadt salt dome. The beds dip at 15° towards WSW, the strike is 150°.

Palaeogeography: Frielingen lies in the central part of the NW German Basin equidistant from the Hildesheim Peninsula to the south and the Pompeckj Block to the north. Despite changing sea-levels, the landmasses were never more than 50 km away. The palaeogeographic configuration during the Hauterivian was fairly stable. A sea-way towards the Tethys via Poland (Carpathian sea-way) existed for most of the time, allowing floral and faunal exchanges. It is only in latest Hauterivian time (*Simbirskites discofalcatus* Zone) that the palaeogeography changed. At this time, the Carpathian sea-way was closed and the NW German Basin became the southernmost extension of the Boreal Arctic Sea with no sea-way towards the south. However, slightly earlier in the Late Hauterivian *Simbirskites discofalcatus* Zone a transgression caused an influx of Tethyan derived nannofossils. This is supported by recent finds of Tethyan-derived bryozoa and foraminifera, which were observed in samples from the Frielingen pit (HEINRICH 1991; KLEIN & MUTTERLOSE in press).

Lithology and stratigraphy: About 20 m of clays and marly clays of latest Hauterivian age (*Simbirskites discofalcatus* Zone) are exposed (Fig. 73). Dark to medium grey claystones alternate with pale grey to whitish marls. CaCO₃ values in general vary between 5% (sample 114/1) and 53% (sample 121/1). The dark beds show a variation of CaCO₃ between 5% (sample 114/1) and 23% (sample 126/1), the pale

beds between 12% (sample 119/1) and 53% (sample 121/1). These pale-dark bedding rhythms (P-D rhythms) are extremely well exposed in this pit and offer a good possibility of detailed studies.

Small calcareous nodules, which rarely include ammonites, are common throughout the sequence. The thickness of these layers varies between 0.1 to 0.2 m and they appear to be continuous. Small pyritized burrows and pyrite nodules occur throughout the section.

Chondrites burrows occur at several levels and are quite distinctive. Further ichnotaxa observed include *Planolites* and *Thalassinoides*.

One horizon (bed No. 122) is rich in organic carbon and represents a forerunner of the Barremian Blätterton facies, depos-

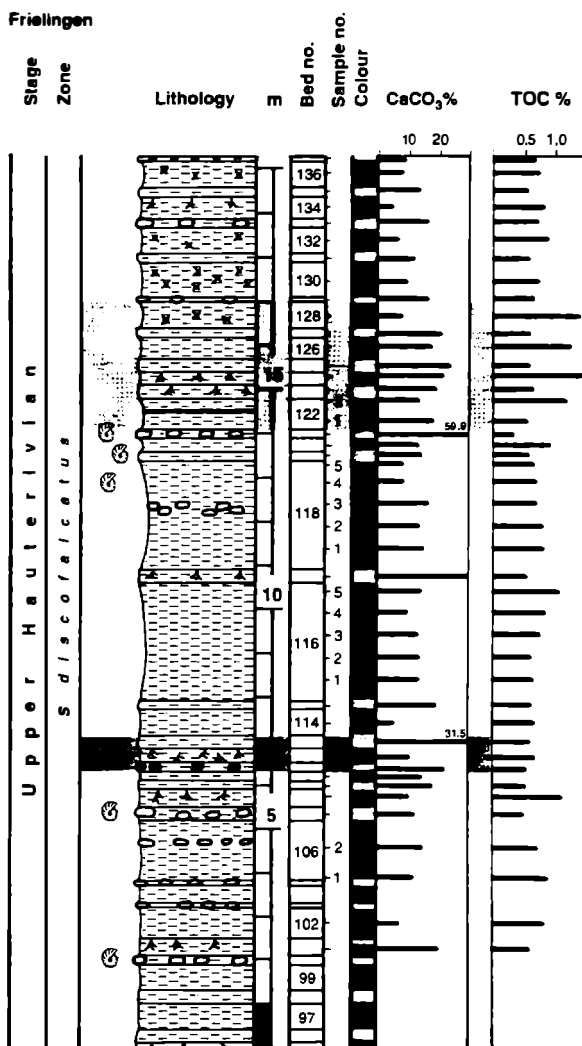


Fig. 73. Lithology and stratigraphy of the Frielingen section. The stippled intervals indicate the position of the detailed sections shown in Figs. 84, 85 and 88.

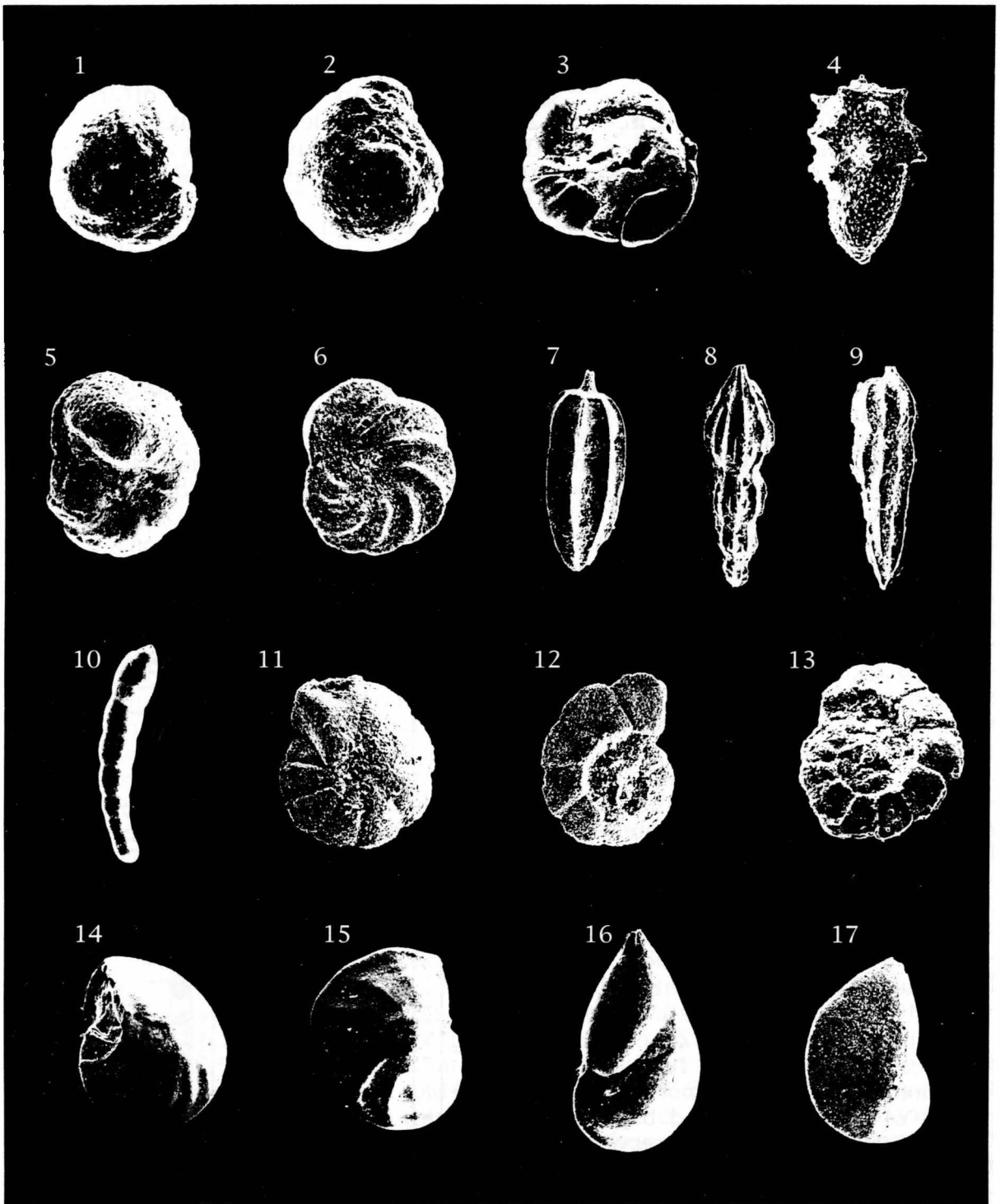


Fig. 74. SEM photographs of foraminifera from the Late Hauterivian *discofalcatus* Zone, Frielingen clay-pit. 1. *Meandrospira washitensis* x 200. 2. *Meandrospira washitensis* x 182. 3. *Hechtina antiqua* x 40. 4. *Globulina prisca*, fistulos, x 68. 5. *Lingulogavelinella sigmoicosta*, umbilical side, x 59. 6. *Lingulogavelinella sigmoicosta*, spiral side, x 58. 7. *Pyramidulina paucicosta* x 52. 8. *Pyramidulina sceptrum* x 52. 9. *Marginulina pyramidalis* x 50. 10. *Laevidentalina linearis* x 23. 11. *Epistomina caracolla*, umbilical side, x 37. 12. *Epistomina caracolla*, right coiled, x 41. 13. *Epistomina caracolla*, left coiled, x 37. 14. *Lenticulina muensteri* x 31. 15. *Lenticulina roemeri* x 30. 16. *Lenticulina* aff. *pulchella* x 67. 17. *Lenticulina dunkeri* x 43.

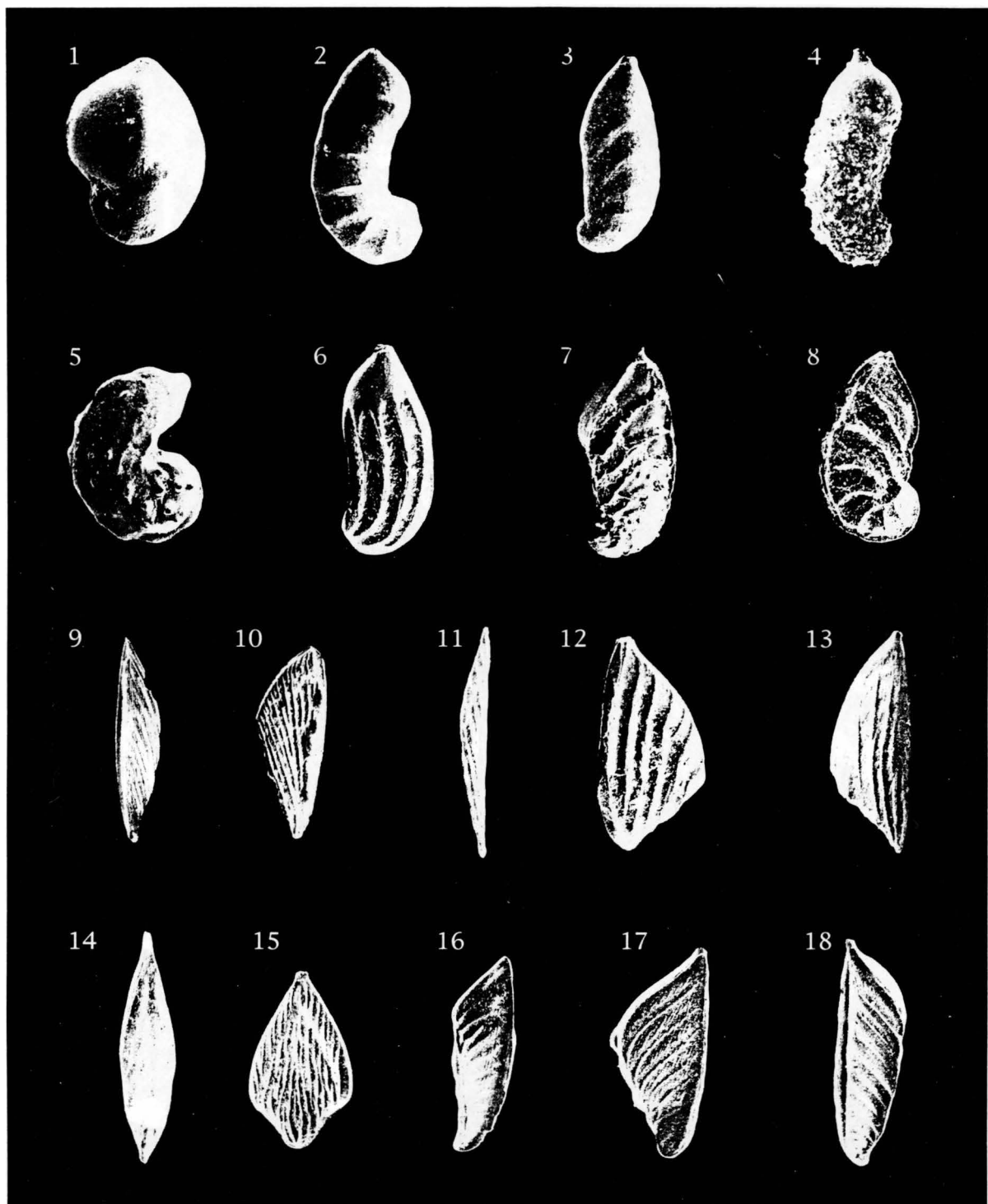


Fig. 75. SEM photographs of foraminifera from the Late Hauterivian *discofalcatus* Zone, Frielingen clay-pit. 1. *Saracenaria pyramidata* x 93. 2. *Astacolus* aff. *barremianus* x 23. 3. *Astacolus bronni* x 44. 4. *Marginulinopsis* ? *gracilissima* x 59. 5. *Lenticulina eichenbergi* x 27. 6. *Marginulinopsis jonesi* x 52. 7, 8. *Planularia tricarinella* x 42. 9. *Psilocitharella strigilata bettenstaedti* x 9. 10. *Bullopara laevis* on *Citharina striatula* x 8. 11. *Citharina acuminata* x 29. 12. *Citharina harpa* x 40. 13. *Citharina discors discors* x 15. 14. *Frondicularia hastata* x 26. 15. *Frondicularia concinna* x 29. 16. *Psilocitharella kochi prolaevis* x 12. 17. *Psilocitharella kochi kochi* x 22. 18. *Psilocitharella truncata* x 15.

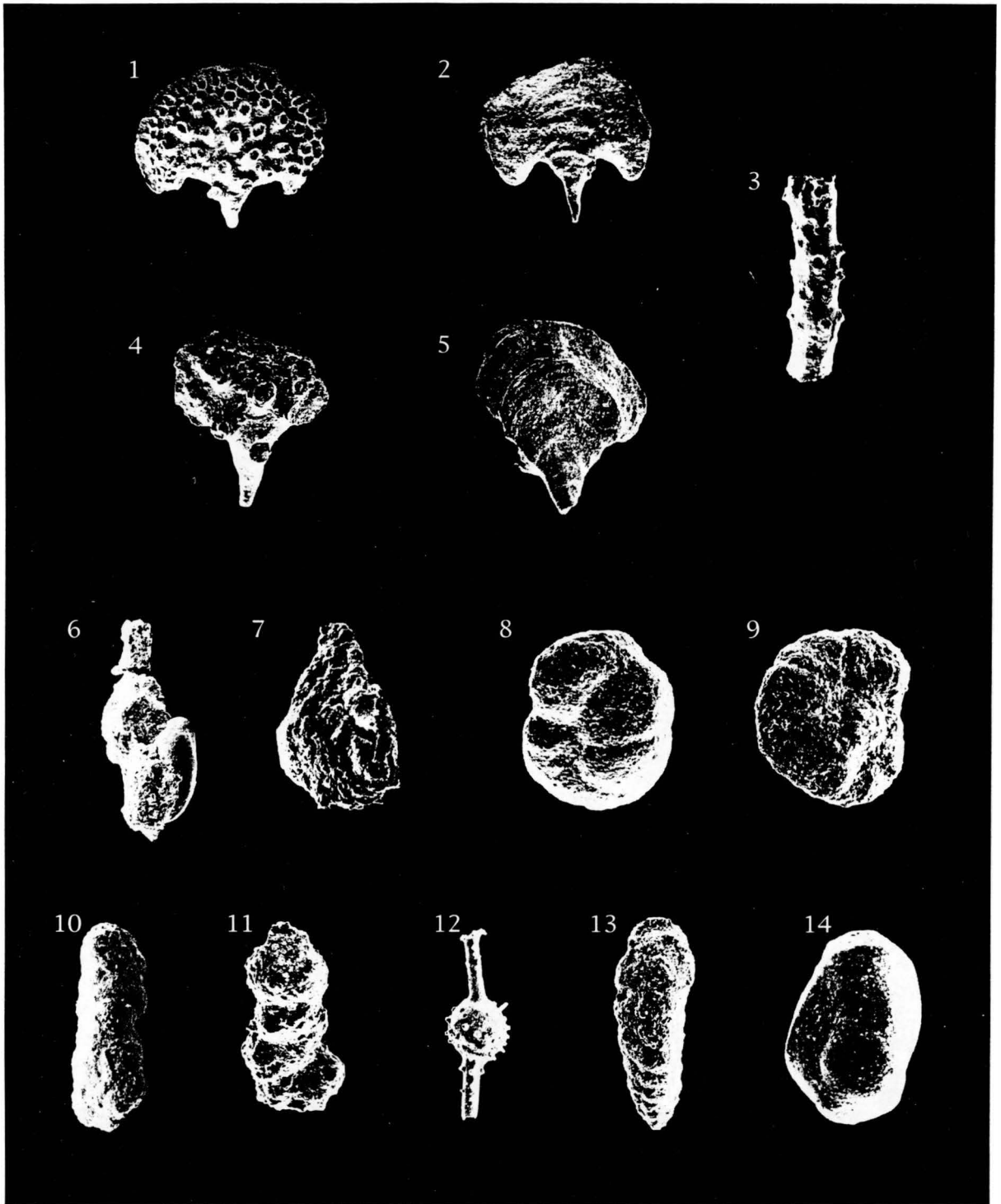


Fig. 76. SEM photographs of bryozoa (1-5) and foraminifera (6-14) from the Late Hauterivian *discofalcatus* Zone, Frielingen clay-pit. 1. *Berenicea tenuis* x 14. 2. *Berenicea tenuis* x 11. 3. *Clinopora* sp. x 13. 4. *Berenicea tenuis* x 26. 5. *Berenicea tenuis* small specimen x 26. 6. *Reophax scorpiurus* x 46. 7. *Proteonina ampullacea* x 122. 8. *Haplophragmoides cushmani* x 79. 9. *Haplophragmoides concavus* x 70. 10. *Haplophragmium aequale* x 15. 11. *Ammobaculites subcretaceus* x 60. 12. *Ramulina aptiensis* x 35. 13. *Verneuilinoides neocomiensis* x 52. 14. *Falsogaudryinella* sp. x 175.

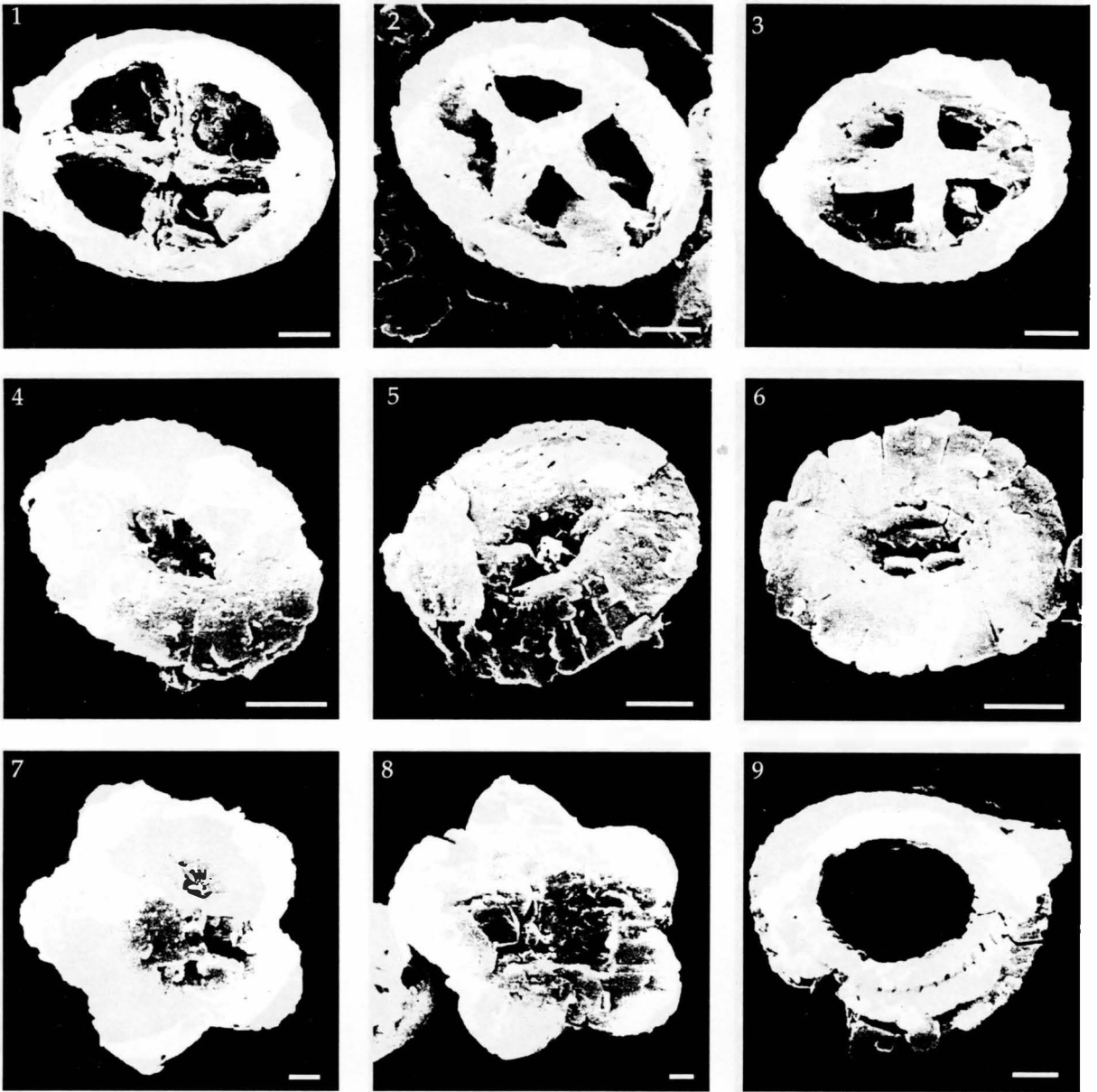


Fig. 77. SEM photographs of calcareous nannoplankton from NW Germany. The bar in the lower right corner equals 1 micron. 1. *Vekshinella stradneri* ssp., Late Hauterivian *discofalcatus* Zone, Gott clay-pit, bed 57. 2. *Vekshinella* sp., Late Hauterivian *discofalcatus* Zone, Frielingen clay-pit, bed 117. 3. *Vekshinella* sp., Late Hauterivian *discofalcatus* Zone, Frielingen clay-pit, bed 117. 4. *Biscutum constans*, Late Hauterivian *discofalcatus* Zone, Frielingen clay-pit, bed 117. 5. *Biscutum constans*, Late Hauterivian *discofalcatus* Zone, Frielingen clay-pit, bed 117. 6. *Crucibiscutum salebrosum*, Late Aptian *nutfieldiense* Zone, Gott clay-pit, bed 203. 7. *Micrantholithus obtusus*, Late Hauterivian *discofalcatus* Zone, Frielingen clay-pit, bed 117. 8. *Micrantholithus obtusus*, Late Hauterivian *discofalcatus* Zone, Frielingen clay-pit, bed 117. 9. *Manivitella pemmatoidea*, Late Hauterivian *discofalcatus* Zone, Gott clay-pit, bed 57.

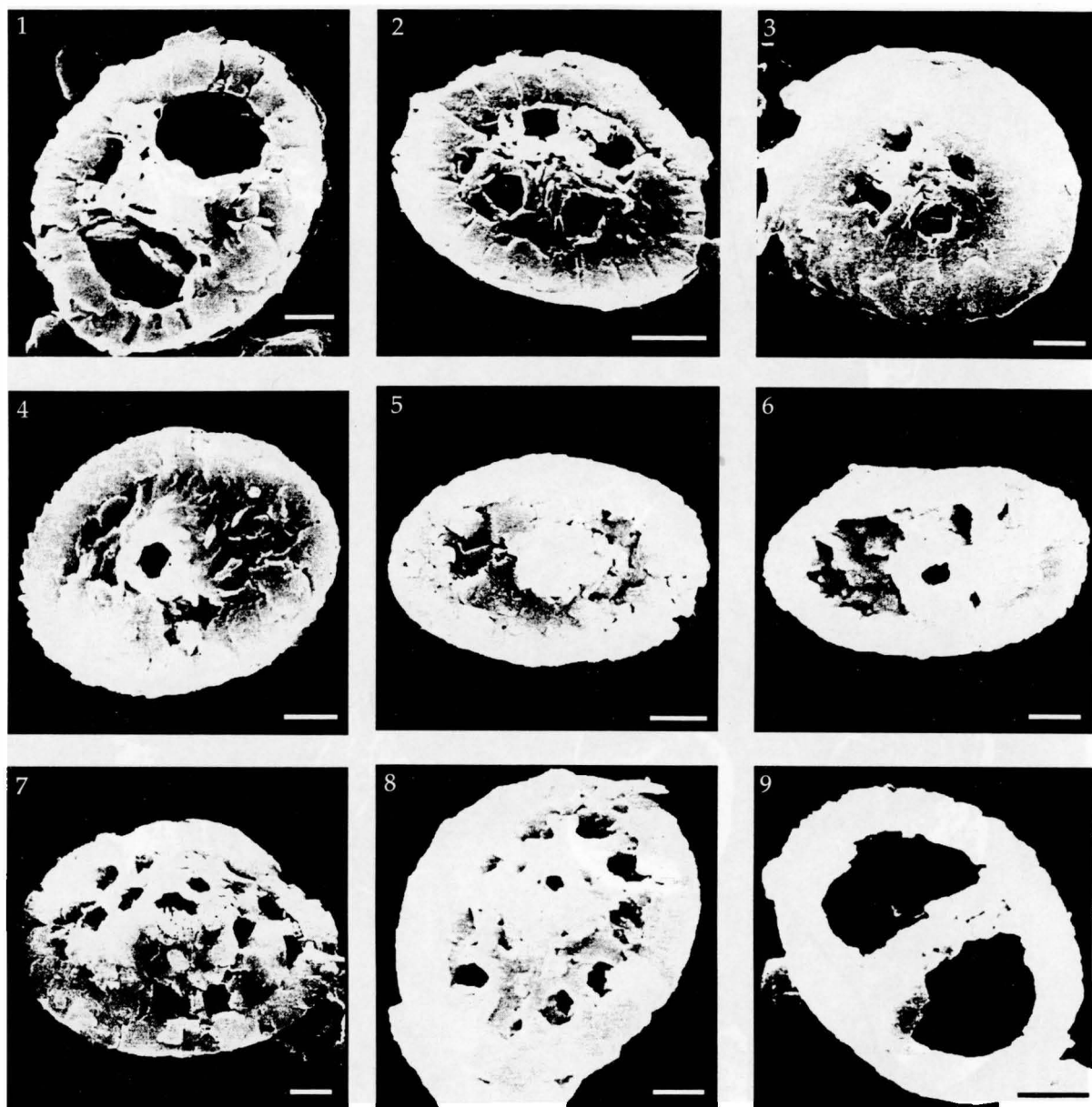


Fig. 78. SEM photographs of calcareous nannoplankton from NW Germany. The bar in the lower right corner equals 1 micron. 1. *Grantarhabdus meddii*, Late Hauterivian *discofalcatus* Zone, Gott clay-pit, bed 57. 2. *Cretarhabdus angustiforatus*, Late Hauterivian *discofalcatus* Zone, Gott clay-pit, bed 57. 3. *Microstaurus chiastius*, Late Hauterivian *discofalcatus* Zone, Gott clay-pit, bed 57. 4. *Rhagodiscus asper*, Late Hauterivian *discofalcatus* Zone, Frielingen clay-pit, bed 117. 5. *Rhagodiscus asper*, Late Aptian *nutfieldiensis* Zone, Gott clay-pit, bed 203. Heavily overgrown specimen. 6. *Rhagodiscus asper*, Late Aptian *nutfieldiensis* Zone, Gott clay-pit, bed 203. 7. *Perissocyclus plethotretus*, Late Hauterivian *discofalcatus* Zone, Gott clay-pit, bed 57. 8. *Perissocyclus plethotretus*, Late Hauterivian *discofalcatus* Zone, Frielingen clay-pit, bed 117. 9. *Zeugrhabdotus sisyphus*, Late Hauterivian *discofalcatus* Zone, Gott clay-pit, bed 57.

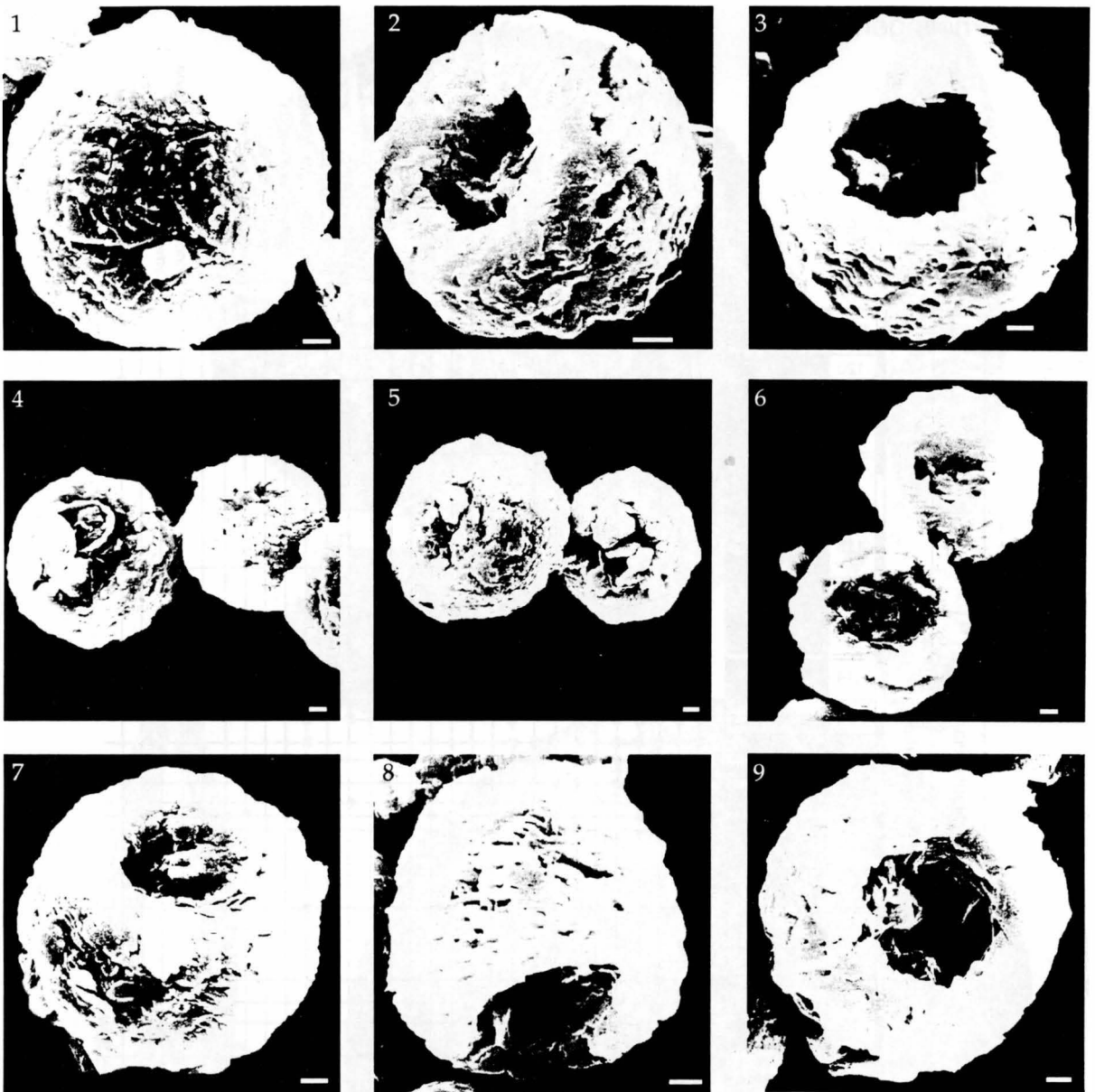


Fig. 79. SEM photographs of calcareous nannoplankton from NW Germany. The bar in the lower right corner equals 1 micron. 1. *Watznaueria barnesae*, Late Hauterivian *discofalcatus* Zone, Frielingen clay-pit, bed 117. 2. *Nannoconus circularis*, Late Hauterivian *discofalcatus* Zone, Frielingen clay-pit, bed 117. 3. *Nannoconus circularis*, Late Hauterivian *discofalcatus* Zone, Frielingen clay-pit, bed 117. 4. *Nannoconus minutus*, Late Hauterivian *discofalcatus* Zone, Frielingen clay-pit, bed 117. 5. *Nannoconus circularis*, Late Hauterivian *discofalcatus* Zone, Gott clay-pit Gott, bed 58. 6. *Nannoconus circularis*, Late Hauterivian *discofalcatus* Zone, Frielingen clay-pit, bed 117. 7. *Nannoconus circularis*, Late Hauterivian *discofalcatus* Zone, Gott clay-pit, bed 58. 8. *Nannoconus circularis*, Late Hauterivian *discofalcatus* Zone, Frielingen clay-pit, bed 117. 9. *Nannoconus circularis*, Late Hauterivian *discofalcatus* Zone, Frielingen clay-pit, bed 117.

Frielingen

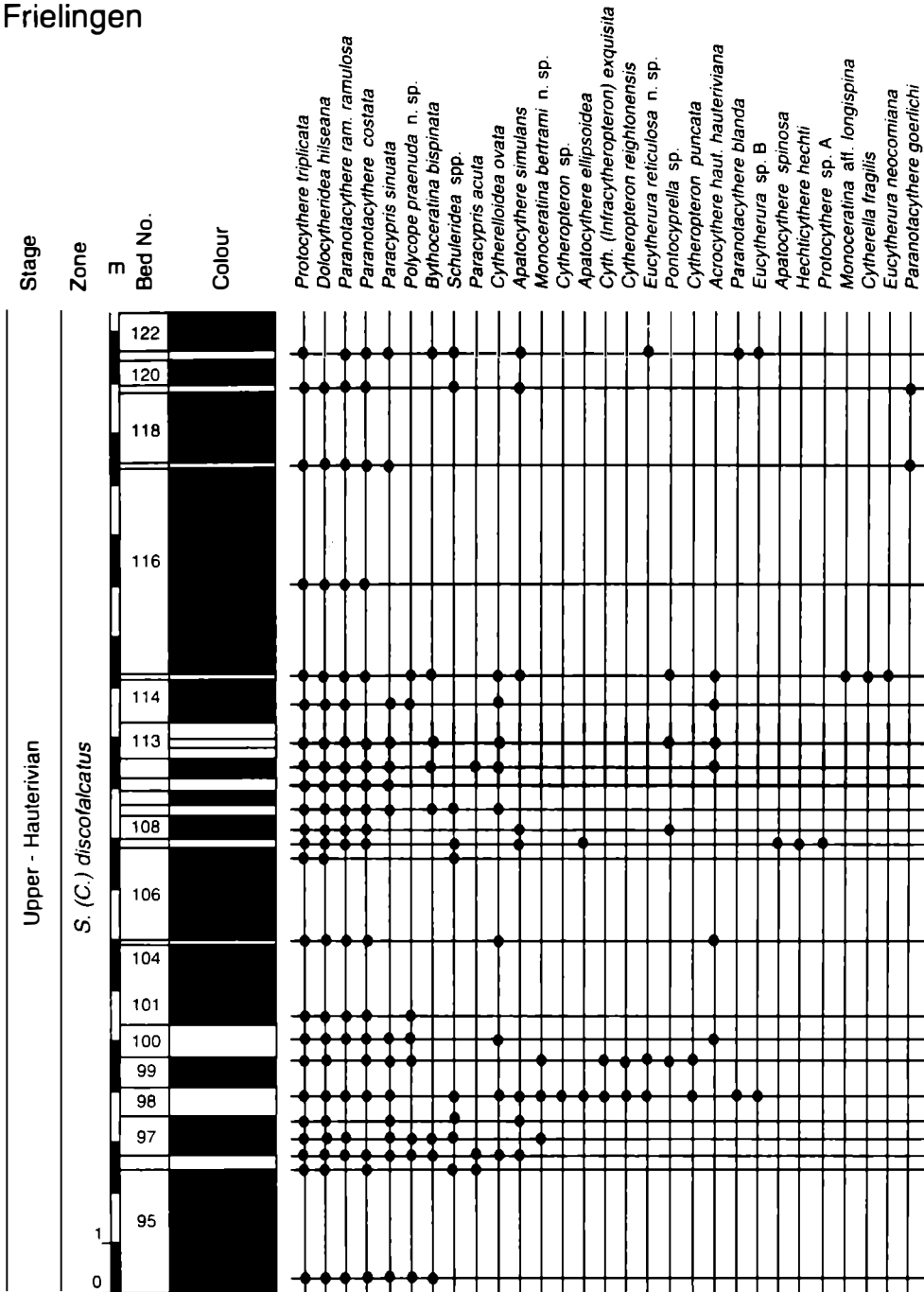


Fig. 80. Occurrence of ostracods in the Frielingen section. The shaded interval indicates the position of the detailed section shown in Figs. 84, 85 (from MUTTERLOSE, LUPPOLD & GREINDA 1995).

ited under anoxic conditions (MUTTERLOSE & HARDING 1987a).

Flora and fauna: Various groups of fossils, including palynomorphs (LUTAT 1990, 1995), calcispheres, calcareous nannofossils (MUTTERLOSE 1991a; MUTTERLOSE et al. 1994), foraminifera (HEINRICH 1991;

KLEIN & MUTTERLOSE in press) and belemnites (MUTTERLOSE, PINCKNEY & RAWSON 1987) from this pit have been studied in detail.

LUTAT (1990, 1995) studied palynomorphs (spores, pollen and dinoflagellates) from the Frielingen section. Of the dinoflagellates the *Spiniferites/Achomosphaera* group is most common, as it ranges between 9%

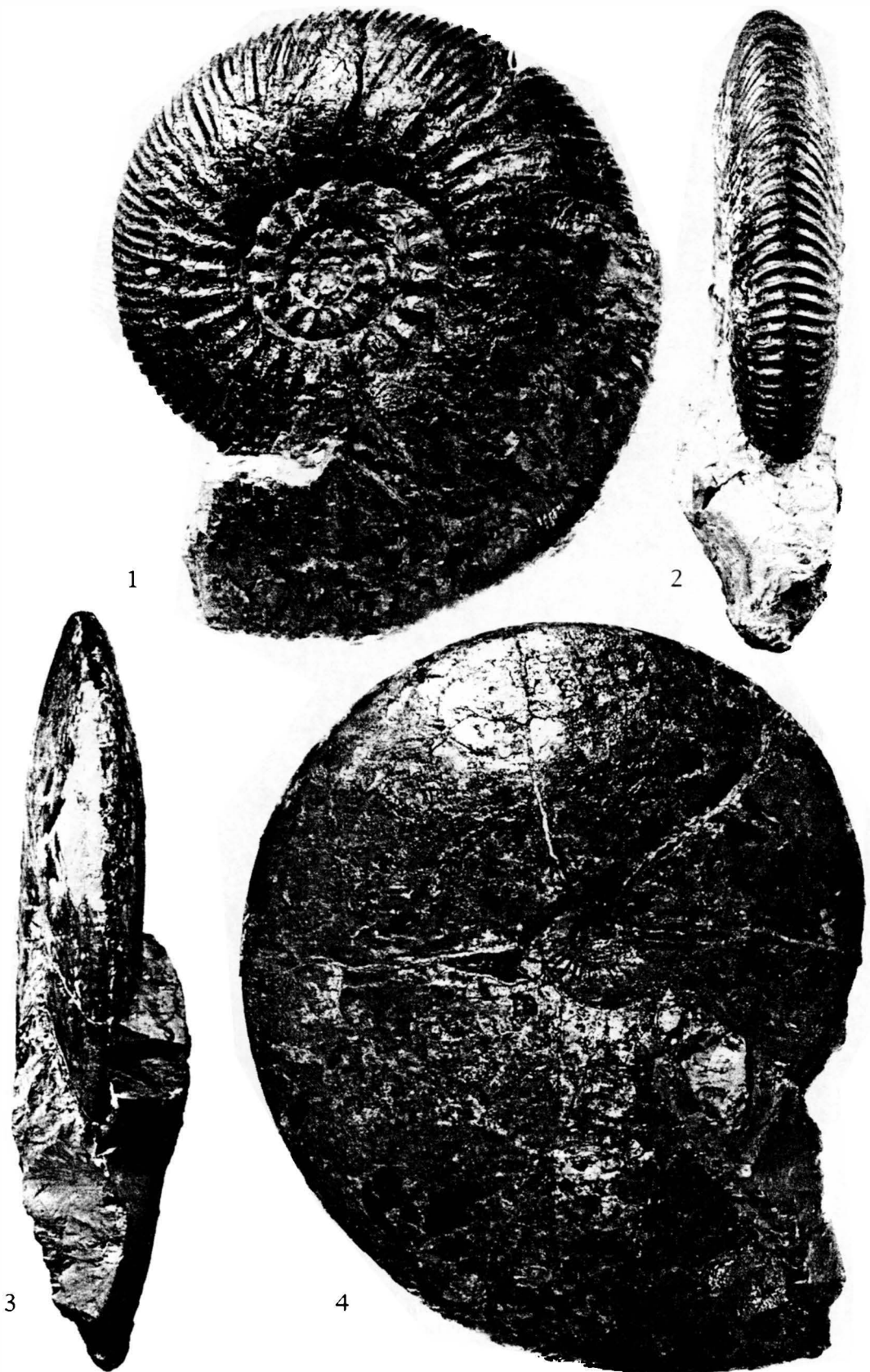


Fig. 81. Ammonites from the Late Hauterivian *discofalcatus* Zone, Frielingen clay-pit. 1, 2. *Simbirskites* (*Simbirskites*) *toensbergensis*, lateral and ventral view. 3, 4. *Simbirskites* (*Craspedodiscus*) *juddi*, ventral and lateral view. Specimens from the collection of K. WILDENROTH. All figures are x 0.5.

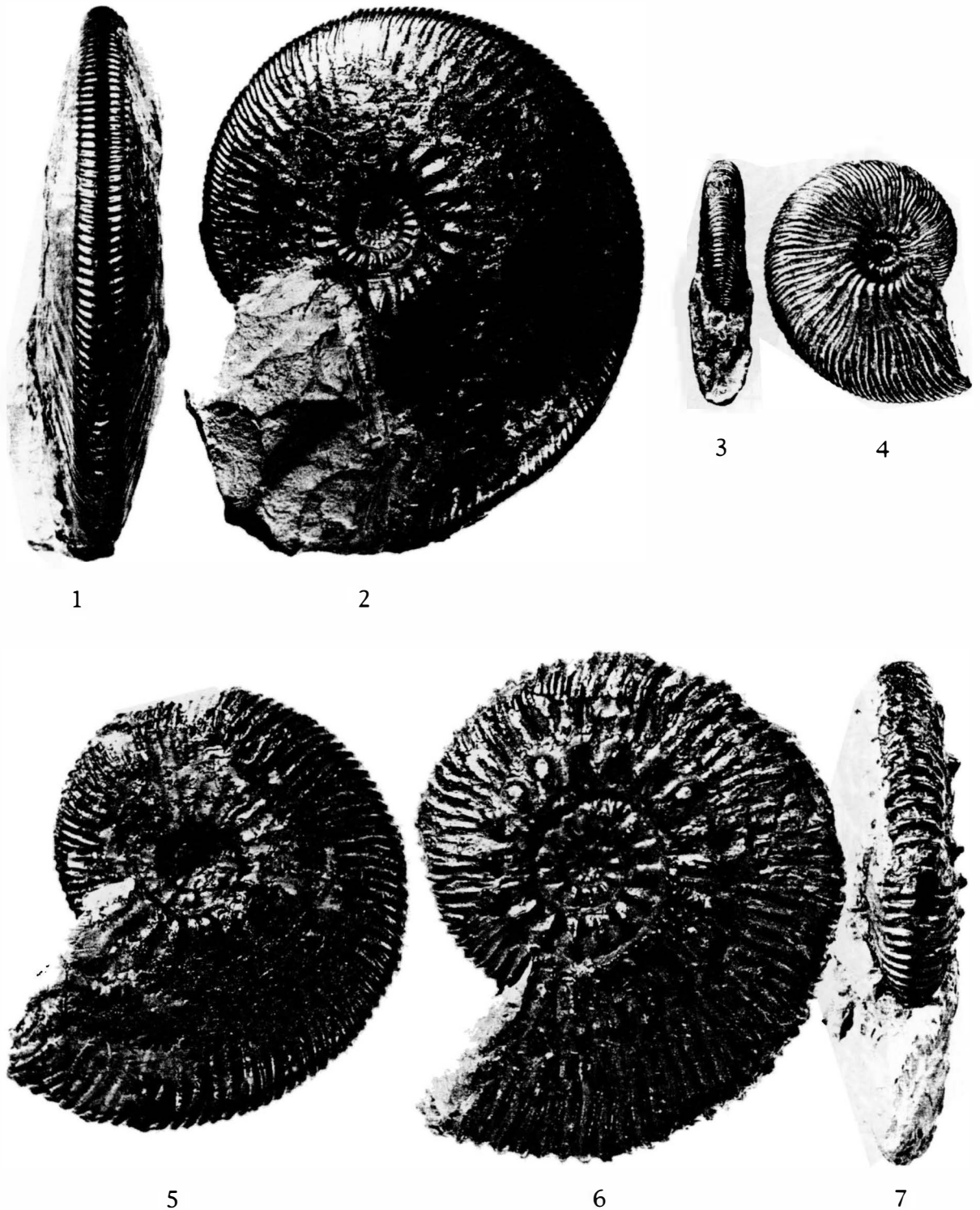
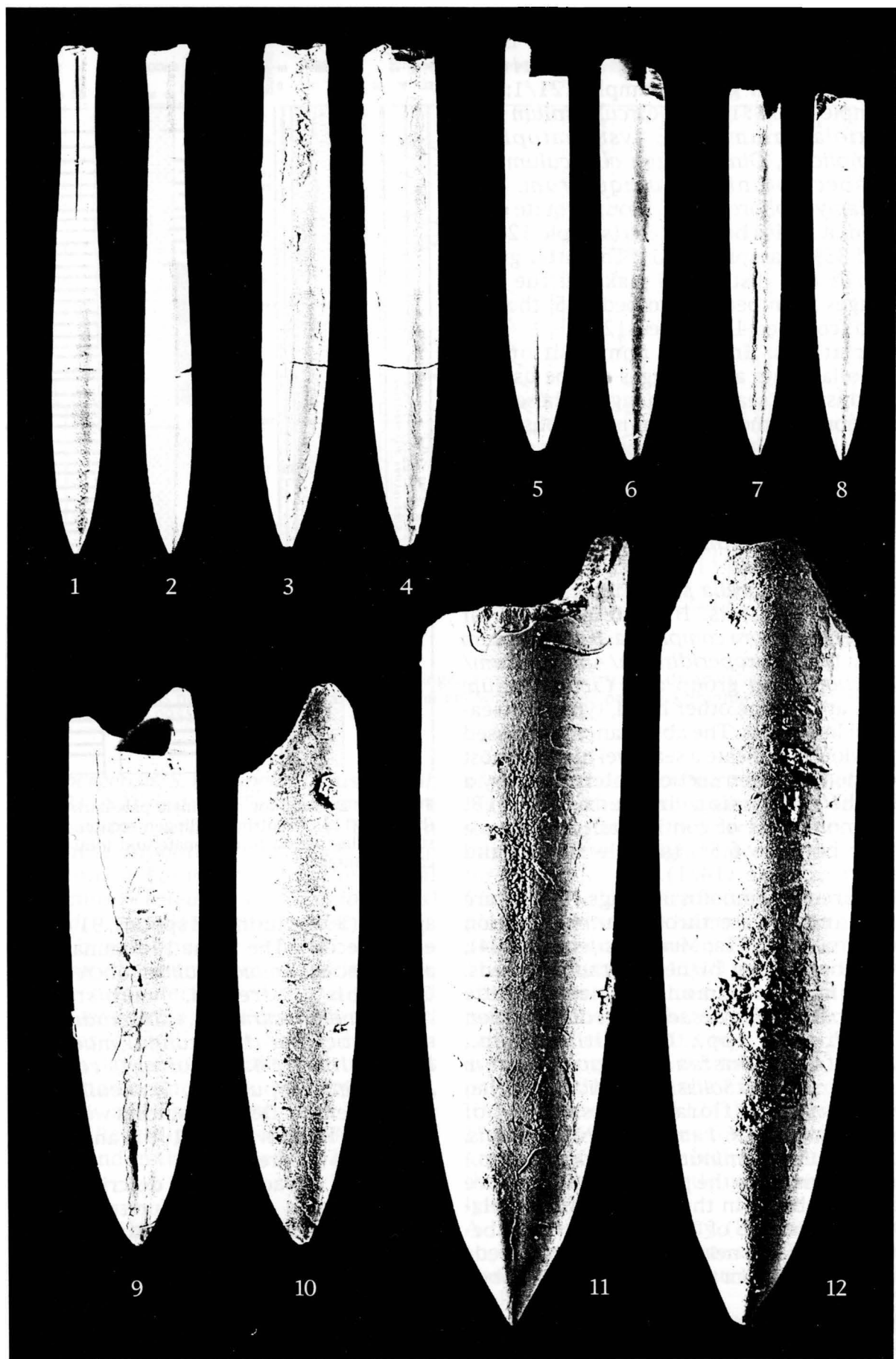


Fig. 82. Ammonites from the Late Hauterivian *discofalcatus* Zone. Frielingen clay-pit. 1,2. *Simbirskites (Craspedodiscus) discofalcatus*, ventral and lateral view. 3,4. *Simbirskites (Craspedodiscus) phillipsi*, ventral and lateral view. 5. *Simbirskites (Craspedodiscus) discofalcatus*. 6,7. *Simbirskites (Simbirskites) toensbergensis*, lateral and ventral view. Specimens from the collection of K. WIEDENROTH. All figures are x 0.6.

Fig. 83 (opposite page). Belemnites of Tethyan (*Hibolites*) and Boreal (*Acroteuthis*) provenance from the Late Hauterivian *discofalcatus* Zone. Each specimen is shown in ventral (left) and lateral view (right). 1,2. *Hibolites jaculoides*, Gott clay-pit. 3,4. *Acroteuthis (Boreioteuthis) rawsoni*, Frielingen clay-pit. 5,6. *Acroteuthis (Boreioteuthis) rawsoni*, Frielingen clay-pit. 7,8. *Acroteuthis (Boreioteuthis) rawsoni*, Frielingen clay-pit. 9,10. *Acroteuthis (Boreioteuthis) stolleyi*, Gott clay-pit. 11,12. *Acroteuthis (Boreioteuthis) stolleyi*, Gott clay-pit. All figures are x 1.



(sample 102/1) and 35% (sample 106/2) of the total content. Less common is the *Cribopteridinium/Apteodinium/Trichodinium* group (sample 121/1: 2%, sample 112/1: 15.5%), *Circulodinium* spp., *Batioladinium* spp., *Systematophora complicata*, *Dingodinium cerviculum* and *Trabeculodinium quinquetrum*. The *Chlamydophorella* spp. group is quite common, it varies between 5% (sample 124/1) and 33% (sample 113/1). The latter group shows two distinctive maxima: the first ranges from bed 108 to bed 115, the second from bed 118 to bed 122.

Variations in the composition of dinoflagellate assemblages can be used to reconstruct sea-level changes. These fluctuations are more obvious in sections of the basin margin (Gott, Moorberg), but are still present in basinal sections like Frielingen. Assemblages dominated by *Nematosphaeropsis* scala, (*Trabeculodinium quinquetrum* resp.), *Dingodinium cerviculum* and *Chlamydophorella* spp. characterize sea-level highstands. High abundances of *Systematophora complicata*, *Batioladinium* spp., the *Cribopteridinium/Apteodinium/Trichodinium* group and *Circulodinium* spp. are, on the other hand, typical of sea-level lowstands. The abundances discussed previously indicate a sea-level high for most of the Frielingen section, interrupted by a slight regression in beds 115-118. Palynomorphs of continental provenance vary between 6.5% (sample 118/5) and 50.9% (sample 114/1).

Calcareous nannofossils (Figs. 77-79) are rich and diverse throughout the section (MUTTERLOSE 1991a; MUTTERLOSE et al. 1994), with both being highest in the pale beds. The most common species include *Watznaueria barnesae*, *Rhagodiscus asper*, *Vekshinella* spp., *Corollithion* spp., *Biscutum constans*, *Crucibiscutum salebrosum* and *Sollasites horticus*. Tethyan warm-water floras consisting of nannoconids (*N. kamptneri*, *N. circularis*, *N. globulus*, *N. minutus*, *Nannoconus* spp.) are restricted to the pale beds and they are rare or absent in the dark beds. The relative abundance of *Nannoconus* varies between 0.3% to near 10% in the pale beds (with a maximum abundance of 9.9% in bed 117).

Benthic foraminifera (Figs. 74-76) are generally rich and diverse. They consist of 121

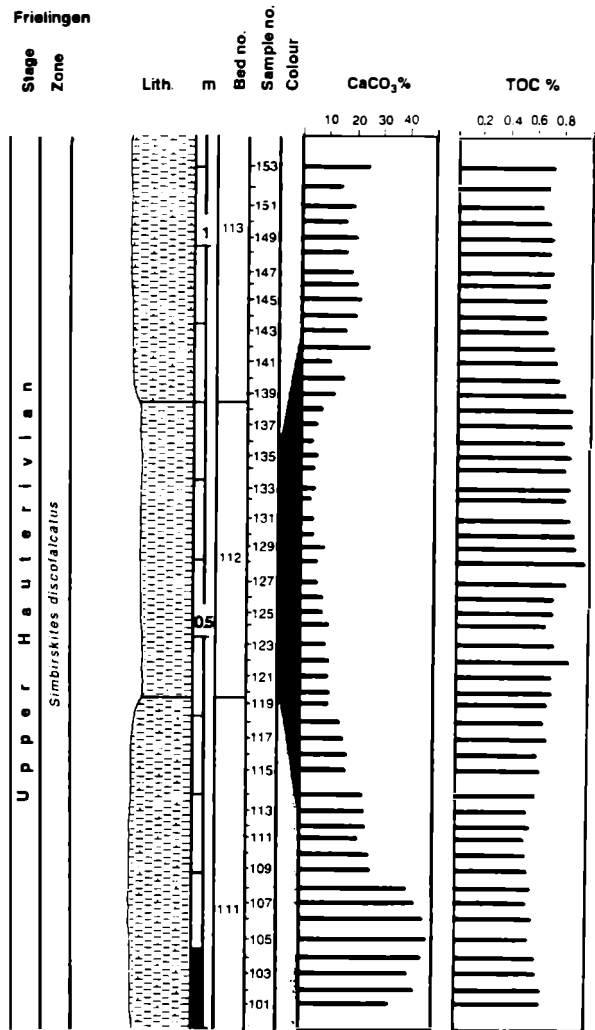


Fig. 84. Detailed log of a single pale-dark rhythm (bed 111-113) from the Frielingen section, demonstrating fluctuation in carbonate and total organic carbon content.

species (30 agglutinated species, 91 calcareous species). The fauna is dominated by eight species (*Ammobaculites subcretaceus*, *Discorbis dreheri*, *Epistomina* (*Hoeglundina*) *caracolla*, *Falsogaudryinella* sp., *Lenticulina* (*Lenticulina*) *muensteri*, *Lenticulina* (*Marginulina*) *robusta*, *Proteonina ampullacea*, *Verneuilinoides neocomiensis*). Detailed studies were completed by HEINRICH (1990, 1991) and KLEIN & MUTTERLOSE (in press).

29 taxa of ostracods were described from the Frielingen section (MUTTERLOSE et al. 1994), with the highest abundances in beds 96-100 and beds 107-113.

The macrofauna includes species of the Boreal ammonite genus *Simbirskites* (*S. (Craspedodiscus) discofalcatius*, *S. (Simbirskites) picteti*, *S. (Simbirskites)*

Frielingen

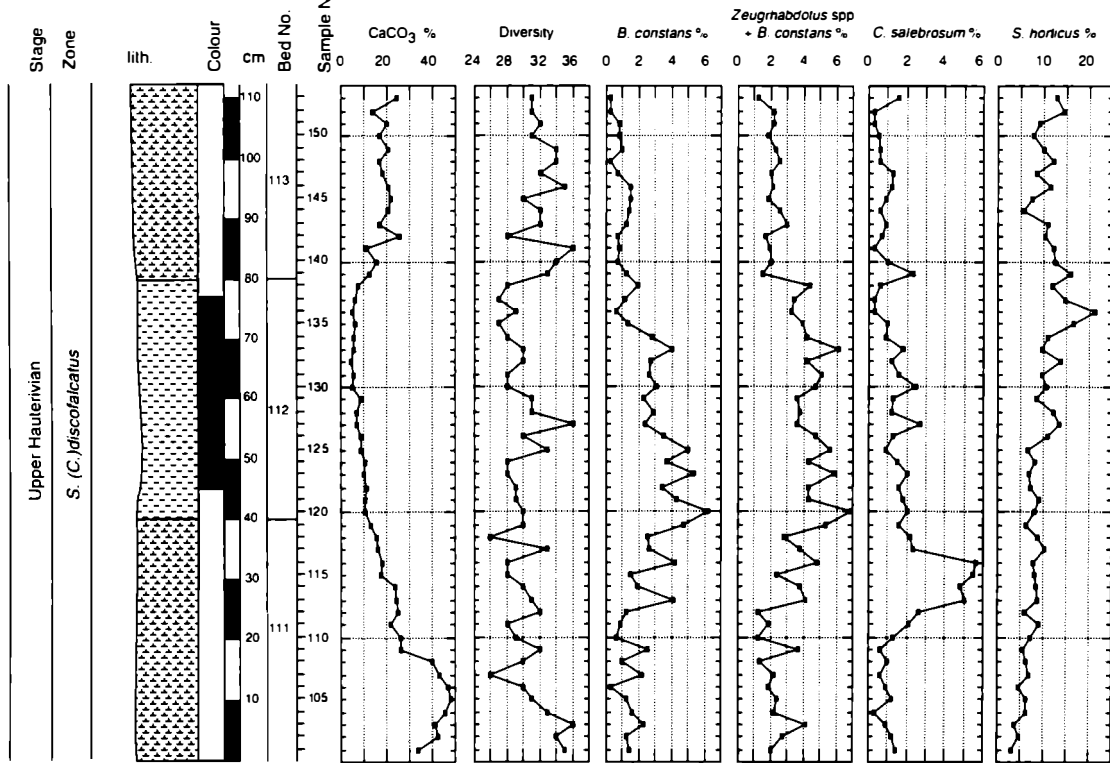


Fig. 85. Detailed log (bed 11-113) from the Frielingen section, demonstrating diversity and relative abundance of calcareous nannofossils and carbonate content within a single pale-dark rhythm (from MUTTERLOSE, LUPPOLD & GREINDA 1995).

toensbergensis, *S. (Craspedodiscus) juddii*; Figs. 81, 82) and the Tethyan ammonite *Crioceratites strombecki*. The Tethyan belemnite *Hibolithes jaculoides* is quite common, it co-occurs with the Boreal belemnite *Acroteuthis* (*A. (Boreioteuthis) stolleyi*, *A. (Boreioteuthis) rawsoni*; Fig. 83). The brachiopods, which include *Terebratulina martiniana*, *Rugitela rugosa*, *Rugitela roemeri*, *Cyrtothyris* sp. and *Lamellaerhynchia rostriformis* are of Boreal affinities, typical of the North-Sea-north German clay facies. In addition, crustaceans (*Callianassa uncifera*), solitary corals, serpulids and shark teeth have been observed. Recently bryozoans (*Berenicea*) were found in the pale beds 122, 124 and 126.

Pale-dark bedding rhythms: The lithic log, which is about 20 m thick, is characterized by typical bedding rhythms. These consist of 22 clay-marl rhythms, each of these rhythms having an average thickness of about 0.9 m. The visual differentiation

of pale and dark colours in the field is highly subjective, being dependent on the water saturation of the rocks and on the intensity of the sunlight (amongst other factors).

Carbonate values vary between 12% (sample 119/1) and 53% (sample 121/1) in the pale layers, and between 5% (sample 114/1) and 23% (sample 126/1) in the dark layers. The average values are higher in the pale beds than in the dark ones. Organic carbon varies from 0.3 to 1.7% C_{org} , most samples range from 0.5 to 0.9% C_{org} . The pale bed 121 shows the lowest C_{org} value (0.34%), the dark bed 124 the highest value (1.7%). The C_{org} values for the dark beds are in general slightly higher (0.2 to 0.3%) than those of the directly under- and overlying pale beds.

A high resolution study (Fig. 84) clearly shows that both carbonate and C_{org} fluctuations are gradual and can be linked to lithology.

In the eastern part of the NW German Basin clay-marl bedding rhythms have al-

Frielingen - basin

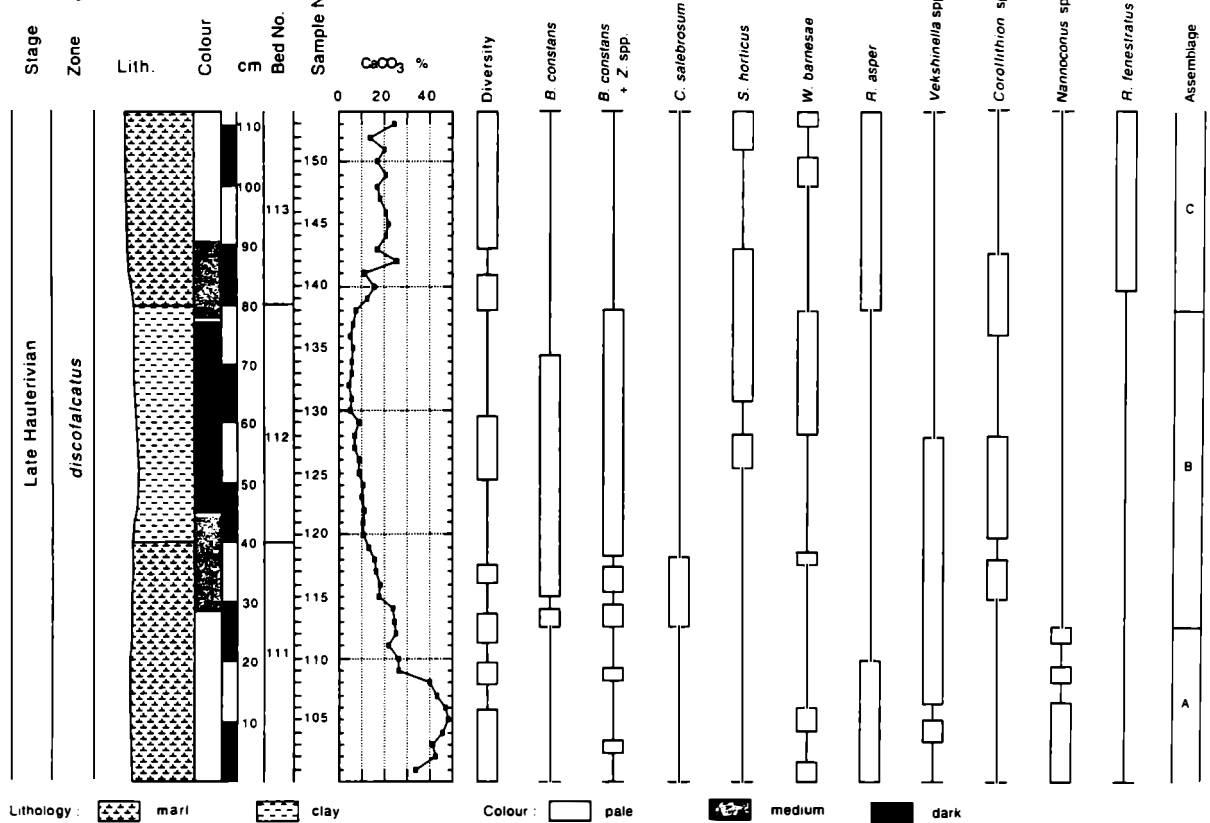


Fig. 86. Detailed log (bed 111-113) from the Frielingen section, showing the ranges of calcareous nannofossils within a single pale-dark rhythm (from MUTTERLOSE, LUPPOLD & GREINDA 1995).

ready been observed in the Early Hauterivian (*Endemoceras amblygonium* ammonite Zone). These bedding rhythms become most conspicuous in the Hauterivian/Barremian boundary interval. They are, however, absent in exposures situated in the centre of the basin. Sections in the western part of the basin show distinctive *Chondrites* layers, which are absent further west.

The distribution pattern of calcareous nannofossils clearly shows two different sedimentary cycles superimposed on one another. These are recognizable both along the basin margin (Gott section) and the basin centre (Frielingen section).

Each one of the horizons within a single pale-dark bedding rhythm shows a cyclic variation of all parameters studied (CaCO₃, C_{org}, distribution of calcareous nannofossils). Pale, marly layers are characterized by a relatively high CaCO₃ and a low C_{org} content, respectively. Tethyan and cosmopolitan floras (*Nannoconus* spp., *Conusphaera*, *Micrantholithus* spp.,

Rhagodiscus asper, *Cretarhabdus* spp.) are more common in the pale layers (Figs. 85-87). These taxa indicate warm surface waters, impoverished in nutrients. Dark layers, on the other hand, impoverished in CaCO₃ and enriched in C_{org}, show a relatively high percentage of *Watznaueria barnesae*, *Sollasites horticus*, *Corolithion* spp. and *Biscutum constans*. The latter species is common in cooler nutrient rich surface water and is taken as a proxy for a slightly higher productivity. The variation of calcareous nannofloras within each clay-marl rhythm may be best explained by climatic variation on the scale of Milankovitch cycles (precession and obliquity). These short term variations reflect changes of surface water temperature and fertility.

The foraminiferal diversity is generally higher in the pale beds than in the dark ones. *Meandrospira washitensis*, a species of presumed Tethyan warm water affinities, is common only in the pale layers (HEINRICH 1990, 1991; KLEIN & MUTTERLOSE in press). It is associated with the bryozoan

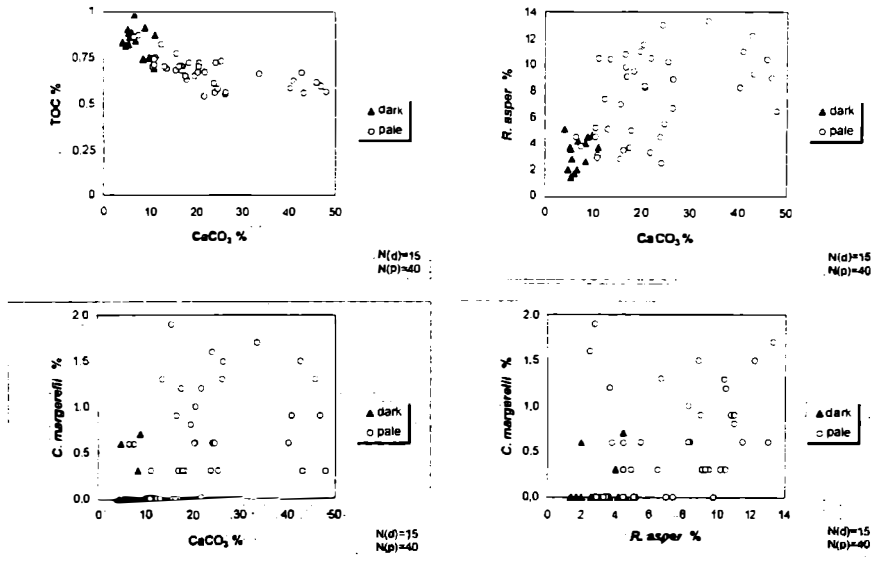


Fig. 87. Relations between total organic carbon, carbonate content and nannofossil abundance within pale and dark beds of the Frielingen section.

Berenicea, hitherto known only from the Early Hauterivian reef facies further northeast (Fig. 88). These observations support the inference that the pale beds were deposited under warm surface water conditions.

Ostracod diversity is considerably higher in the pale layers compared to that in the dark layers (Fig. 80). Species with eye tubercles and the thermophile genus *Cytherelloidea* are recorded among the ostracods within the pale layers. These occurrences suggest sedimentation in warm water within the photic zone.

Superimposed on these small-scale rhythms are lower order cycles caused by longer sea-level fluctuations. A sea-level highstand in the middle part of the *Simbirskites discofalcatus* ammonite Zone allowed an influx of Tethyan genera and species. The regression in the late *discofalcatus* Zone caused a dominance of the nannofossil species *Biscutum constans*.

Clay mineralogy: The results of a semi-quantitative analysis of the clay mineralogy of the pale-dark rhythms shows that pale (calcareous) beds contain abundant mixed-layer illite-smectites and always some chlorite (RUFFELL in prep.). The pale beds contain crystalline smectite, illite and kaolinite in lesser amounts than the dark beds. By contrast, the dark beds contain illite and kaolinite in abundance with lesser amounts of smectite and mixed-layer minerals. The variation in clay mineral abun-

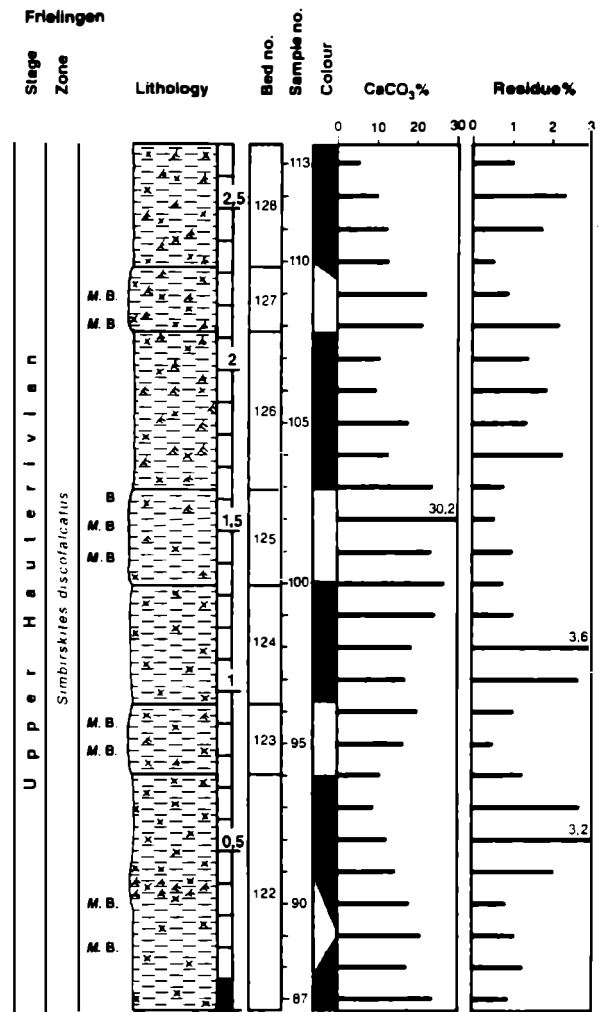


Fig. 88. Detailed section (beds 122-128) from the Frielingen section, demonstrating the exclusive occurrence of Tethyan derived foraminifera (*M*=*M. washitensis*) and bryozoa (*B*) in pale beds.

| | Factor 1 | Factor 2 | Factor 3 |
|-----------------------|----------|----------|----------|
| <i>E. caracolla</i> | 0.930 | -0.102 | -0.035 |
| CaCO ₃ | 0.787 | 0.072 | -0.019 |
| calcareous f. | 0.705 | 0.337 | -0.538 |
| agglutinated f. | -0.705 | -0.337 | 0.539 |
| TOC | -0.560 | -0.444 | 0.138 |
| <i>M. washitensis</i> | 0.168 | 0.820 | 0.113 |
| <i>F. tealbiensis</i> | 0.194 | 0.806 | 0.013 |
| diversity | -0.145 | 0.790 | -0.162 |
| <i>P. ampulacea</i> | -0.448 | -0.581 | 0.368 |
| <i>D. dreheri</i> | 0.037 | -0.150 | -0.845 |
| <i>T. agglutinans</i> | -0.156 | 0.018 | 0.772 |
| <i>Reophax</i> spp. | -0.084 | -0.268 | 0.732 |

| | Factor 1 | Factor 2 | Factor 3 |
|--------------------------|----------|----------|----------|
| <i>S. horticus</i> | -0.840 | -0.136 | -0.218 |
| <i>Nannoconus</i> spp. | 0.838 | -0.152 | 0.037 |
| <i>Cretarhabdus</i> spp. | 0.824 | 0.077 | 0.102 |
| CaCO ₃ | 0.763 | -0.451 | 0.260 |
| TOC | -0.640 | 0.262 | -0.541 |
| <i>C. margerelii</i> | 0.553 | -0.466 | -0.061 |
| <i>Corolithion</i> spp. | -0.528 | 0.476 | 0.397 |
| <i>B. constans</i> | 0.021 | 0.884 | 0.063 |
| <i>R. asper</i> | 0.291 | -0.806 | 0.195 |
| <i>Vekshinella</i> spp. | 0.168 | 0.710 | 0.498 |
| <i>W. barnesae</i> | 0.045 | -0.160 | -0.929 |
| <i>D. lehmanii</i> | 0.370 | -0.057 | 0.794 |

Fig. 89. Factor analysis of a Frielingen data-set containing foraminifera-, nannofossil-, carbonate-, and total organic carbon data.

dances between dark and pale beds is rarely more than 5% in any one mineral species, and is significantly lower than the changes in the abundance of different clays throughout the Upper Hauterivian.

It is important to place bed-by-bed changes in clay mineralogy in a regional context, in order to understand the likely mechanisms controlling their abundance.

The error margins involved in semi-quantitative analysis of clay mineral populations are potentially very high. In reconnaissance studies of the clays of the Lower Cretaceous, it was found that different methods of calculating mineral abundances could lead to a 5 to 10% variation in results. As bed-by-bed variations rarely exceed this figure, overall trends in the clay mineral population are taken as being more reliable than absolute values. In addition, due to the different origin of clay mineral species, relative proportions are also thought to reflect more accurately the changes in the amount of detrital clay minerals.

Although the margins of error are high in estimating absolute quantities of different clay mineral species in any given sample, the variations between pale and dark layers observed here are consistent throughout the Hauterivian sections studied. The majority of pale layers contain abundant mixed-layer illite-smectites, pure smectite in some samples, and lesser amounts of kaolinite and chlorite than in the dark layers. This may indicate more "off-shore" conditions, when sea-levels were high, tectonic uplands were low in relief and when the diagenetic alteration of illites and

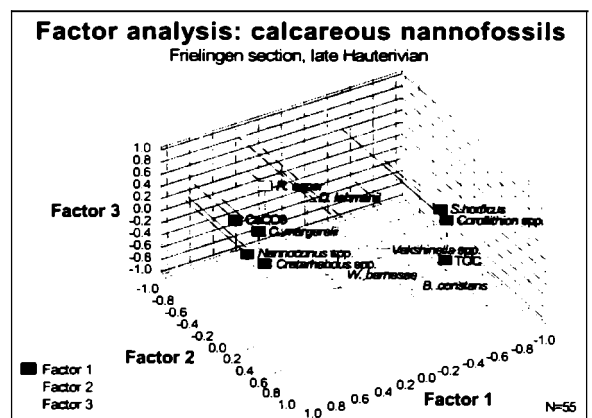
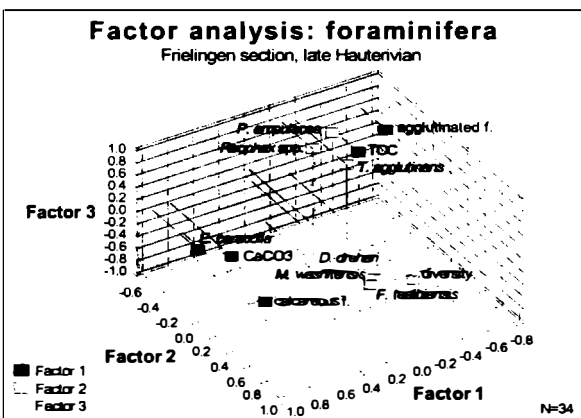


Fig. 90. Factor analysis of a Frielingen data-set containing foraminifera-, nannofossil-, carbonate- and total organic carbon data.

smectites could occur, i.e. in a seasonally arid climate. Dark layers generally show high quantities of kaolinite, smectite, with a few samples containing mixed-layer minerals and chlorite. This assemblage might indicate more “near-shore” conditions, although the presence of both smectite and kaolinite might be better explained by a

humid weathering regime, with hinterland areas being actively eroded.

References: HEINRICH (1990, 1991); KLEIN & MUTTERLOSE (in press); LUTAT (1990, 1995); MUTTERLOSE & HARDING (1987a); MUTTERLOSE (1991); MUTTERLOSE et al. (1994); MUTTERLOSE, PINCKNEY & RAWSON (1987); RUFFELL (in prep.).

2. 15 Münchehagen quarry (Figs. 91-96)

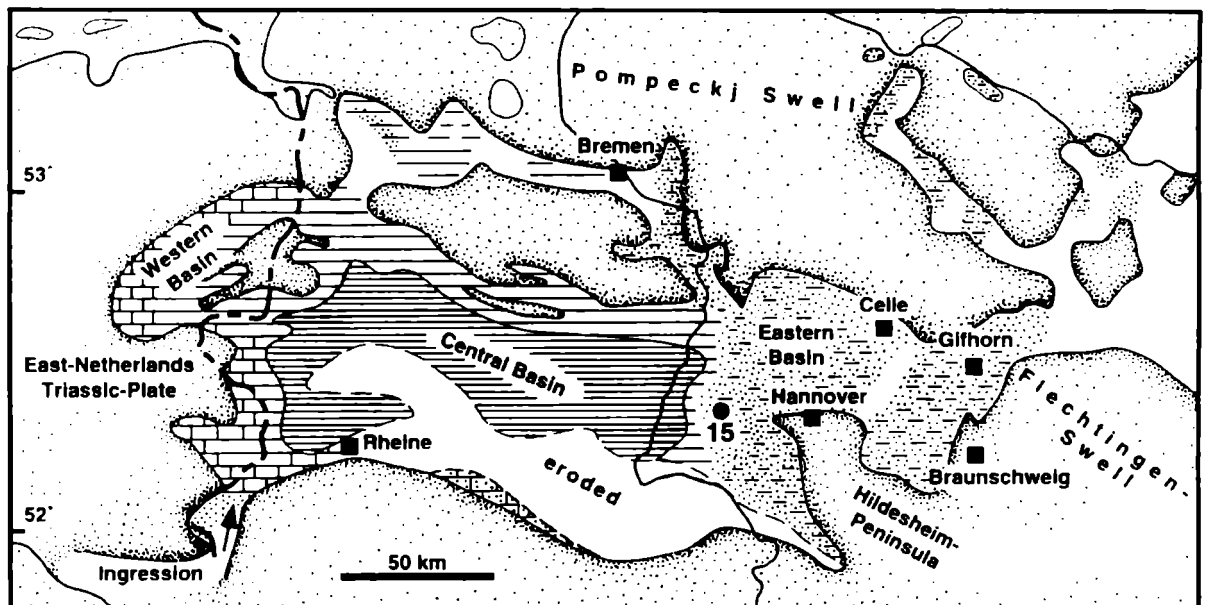
(by J. Mutterlose)

Location and grid reference: TK 25, 3521 Bad Rehburg, R: 351370, H: 581210. The disused quarry is now the central part of the "Dinosaurier-Freilichtmuseum Münchehagen". It is situated about 20 km northwest of Hannover, northeast of the village of Münchehagen (Fig. 2).

Tectonic setting: Southwestern shoulder of the NW-SE Rehburg Anticline. The central part of this salt-induced structure is formed by evaporites of latest Jurassic age (Münder Formation, Tithonian), the southwestern and northeastern shoulders by Berriasian sand- and siltstones (German Wealden). Due to the massive sandstones, Berriasian strata are resistant to weathering and thus form narrow elongated ridges (Rehburger Berge). Beds of Tithonian age, which form the central part of the anticline, crop out around the village of Wiedenbrügge, forming a topographic de-


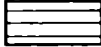

pression. The best overview can be obtained from a viewpoint near the windmill of Bergkirchen, about 3 km east of the park. The beds within the quarry dip at 10° towards WSW.

Palaeogeography: During the Berriasian the area now forming NW Germany consisted of an elongate basin extending about 280 km in west-east direction and about 80 km from north to south (Fig. 91). To the south the basin was bordered by the Rhenish Massif, where Carboniferous sandstones were exposed (BALDSCHUHN & KOCKEL 1994). Triassic sandstones and mudstones were exposed to the east on the Netherlands High and, to the north and northeast, the area was bounded by the Pompeckj Block. Throughout most of the Berriasian the NW German Basin was separated from the open ocean and brackish and freshwater conditions prevailed. Several short-lived periods of marine flooding are documented: in particular for the Bückeberg Formation or upper Wealden 2/lower Wealden 3 to upper Wealden 3/lower



Localities:

● 15 Münchehagen

 area of non-deposition/erosion
 clayey sediments (less than 400m thick)
 clayey sediments (more than 400m thick)



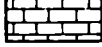
 predominantly sandstones
 clayey sediments with intercalated sandstones
 calcareous sediments

Fig. 91. Palaeogeography of the NW-German Basin in Berriasian times (from ELSTNER & MUTTERLOSE 1995). Compare also Fig. 6.

Wealden 4/lower Wealden 5 of the standard German lithostratigraphy (STRAUSS et al. 1993).

These marine flooding phases are marked by the presence of marine palynomorphs and foraminifera (STRAUSS et al. 1993). The marine incursions are presumed to have come from the west via the East Netherlands High since marine influences become less distinct towards the middle and eastern part of the basin. Similarly, both the abundance and diversity of marine microfaunas in these intervals diminishes towards the east.

Facies distributions and different sediment accumulation rates allow the NW German Basin to be subdivided into a western, central and eastern part (SCHOTT et al. 1967, 1969). The sediments of the western basin

margin (in the area west of the River Ems) are characterized by *Neomiodon* limestones and mudstones that also extend further east into the basin. This mudstone facies may exceed 400 m in thickness in the eastern-most part.

The central part of the basin is dominated by up to 700 m of mudstones. Sandstones and *Neomiodon* limestones occur only along the northern and southern rims, where coarse-grained clastics were shed from the northern Pompeckj Block and southern Rhenish Massif. Local areas of sediment accumulation were controlled by narrow E-W basins, created by synsedimentary salt diapirism. There is a general trend towards coarser clastic material towards the east (marked in the east by the present-day River Weser), where the

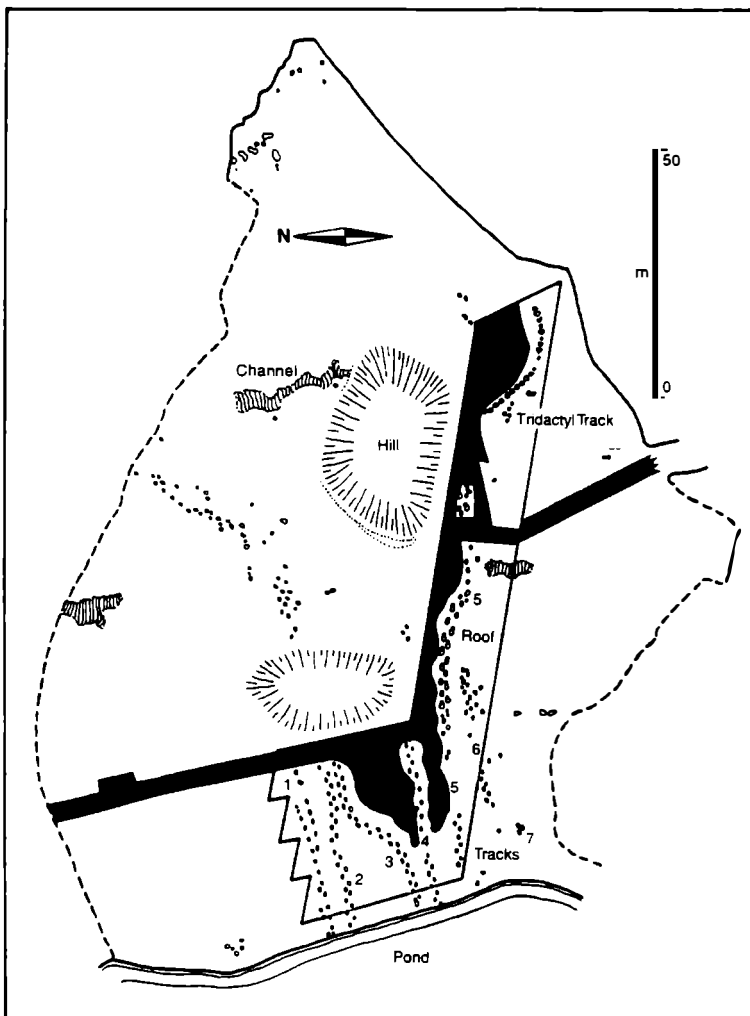


Fig. 92. Sketch map of the abandoned Münchehagen quarry, today forming part of the "Dinosaurier Freilichtmuseum Münchehagen" (modified after FISCHER & THIES 1993).

dominant fluvio-deltaic sands interdigitate with a variety of lithologies. This eastern area is dominated by sandstones, siltstones and silty claystones. *Neomiodon* limestones occur and coal seams are common. Two different sandstone fans, both shed from the south, can be differentiated. The smaller, western fan is present in the Osnabrück area, the eastern one is developed in the Bückeberg-Hannover area.

The sandstones exposed in the Münchehagen quarry are part of the eastern fan. The hinterland, situated about 40 km to the southeast in the Hils area, was characterized by the sedimentation of silty clays, siltstones and coal seams. These beds were deposited in a braided river system under a humid climate. North and west of the Hils area these fluvial deposits are replaced by thick, massive, non-marine sandstones with some coal seams. This so-called "Wealden Hauptsandstein" forms a large fan covering the Bückeberge-Harll-Deister-Rehburger Berge area. Sandstones of this age have been observed as far east as Sehnde, about 20 km east of Hannover. Traditionally, this sandstone fan has been interpreted as originating from a delta shedding material from the south into the basin (KAUENHOVEN 1927). Recently, the Wealden Hauptsandstein has been reinterpreted as a transgressive barrier sand deposited parallel to the coast-line (PELZER 1988).

Lithology and stratigraphy: About 8 m of grey to brown, fine-grained, thin- to medium-bedded sandstones are exposed. The sandstones represent the lowermost part of the Wealden Hauptsandstein, and are part of the Wealden 3. According to the

most recent zonation scheme they can be assigned to the *Cypridea alta formosa* ostracod Subzone (ELSTNER & MUTTERLOSE 1996). Several massive sandstone horizons varying in thickness between 0.5 and 1 m are separated by thin clay layers with a thickness of a few millimetres. The sandstone itself is a hard, medium brown, fine-grained quartz sandstone. The quartz grains are embedded in a fine-grained matrix. CHITSAZIAN (1985) studied the sandstone with respect to its petrography. Quartz makes up to 93 % (vol.), while rock fragments (quartzite, lydite, rare pebbles of igneous rock) make up about 2 % (vol.). Muscovite is not common and heavy minerals (tourmaline, rutile, zircon) are rare. They make up about 0.3 % (vol.). About 5 % (vol.) are formed by the matrix.

The Rehburg Sandstone is a silty, fine grained sandstone, having a maximum grain size of 50 to 60% between 112 and 200 μm . Medium-grained components make up 25 to 30%. According to these data, the Rehburg Sandstone can be classified as a well-sorted sandstone with medium rounding.

Ripple marks, both oscillatory wave ripples and current ripples, are common, the direction of the crests varies within one bed. Small-scale cross bedding can be observed. The basal bedding plane ("Sohlfläche"), which is exposed all over the quarry, has a thickness of 0.1-0.2 m and forms the lowermost sandstone bed of the Wealden Hauptsandstein. About 1 m of shale and a coal seam 0.2 m thick underlie the basal bedding plane (WILDE et al. 1995).

Macrofossils: Apart from ichnofossils, which are very common, particularly on the

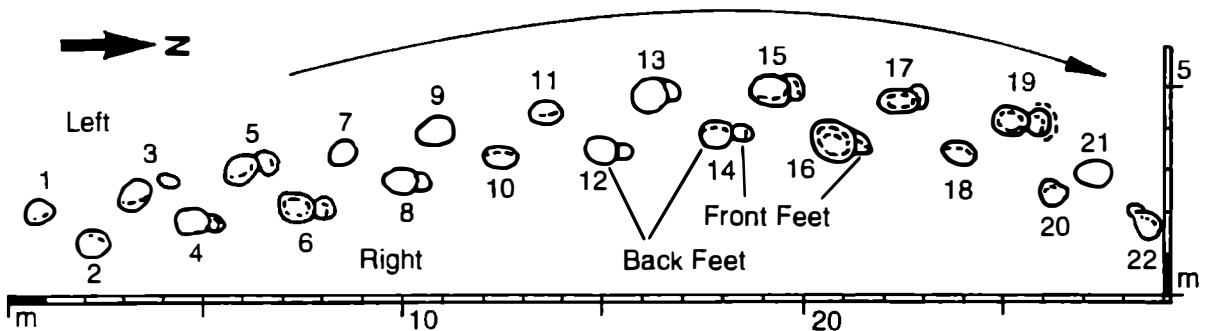


Fig. 93. Detail of a sauropod track (Track 5) from the Münchehagen quarry (modified after Look et al. 1988).

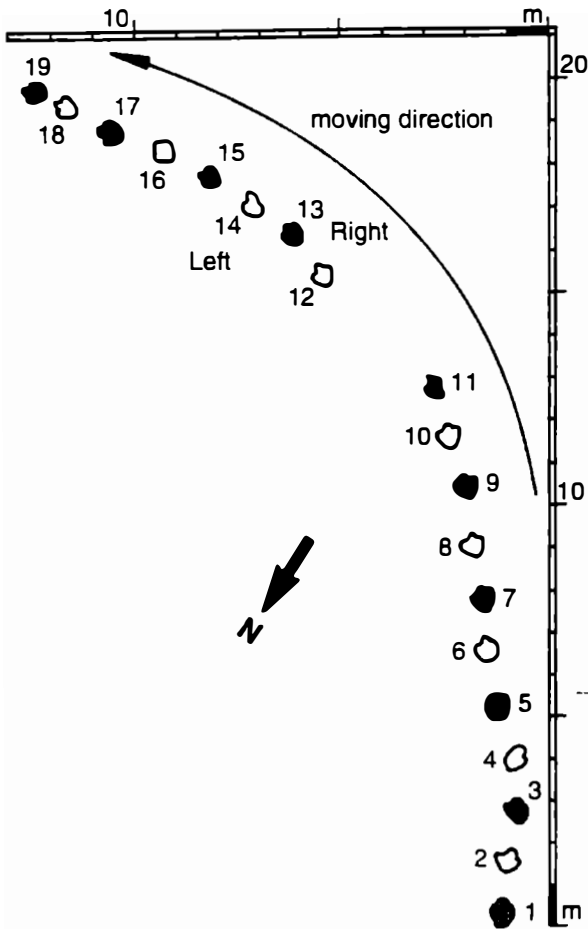


Fig. 94. Tridactyl track from the Münchehagen quarry (modified after Look et al. 1988).

surface of the basal bedding plane, body fossils are very rare. Internal moulds of the bivalve *Neomiodon* (= *Cyrena*) have been observed, indicating fresh water conditions. Plant debris also occurs.

Ichnofossils: The basal bedding plane is characterized by ichnofossils of high abundance and low diversity. Apart from the most spectacular dinosaur tracks, *Thalassinoides*, *Muensteria*, *Planolites*, *Pelecypodichnus*, *Cubichnia* and other taxa have been described by WILDE et al. (1995). These ichnofossil associations indicate a well-oxygenated environment with low sedimentation rates. The ripple marks must have formed under shallow-water conditions.

Dinosaur footprints: The most spectacular fossils are several tracks of dinosaur footprints, indicating a non-marine environment. A total of 275 footprints has been

observed in the former quarry. All footprints are preserved as imprints on the surface of the basal bedding plane and are partly covered with sediment. On the basis of shape and size, two main types are discernible: sauropod and three-toed imprints. The following data is taken from FISCHER & THIES (1993).

Seven tracks (Figs. 92, 93) in the western part of the quarry show round to suboval or triangular imprints. About 256 of these imprints have been mapped. Track 5 is the best preserved one, showing 22 footprints over a length of 80 m. The track consists of two parallel rows of imprints, 13 of which show the imprints of both front and hind legs. The imprints of the front legs are smaller and roundish, their diameter varies from 0.45 to 0.75 m. The imprints of the hind legs are bigger and oval, they are up to 1.3 m long and about 1 m wide. These are superimposed upon those of the front legs, indicating a movement from west to east. The stride (distance between two subsequent imprints of the left or, alternatively, right hind leg) averages 2.75 m, the distance between a left and right hind leg averages 1.15 m. From these data a size of 3.2 m for the front legs and of 3.9 m for the hind legs respectively has been calcu-

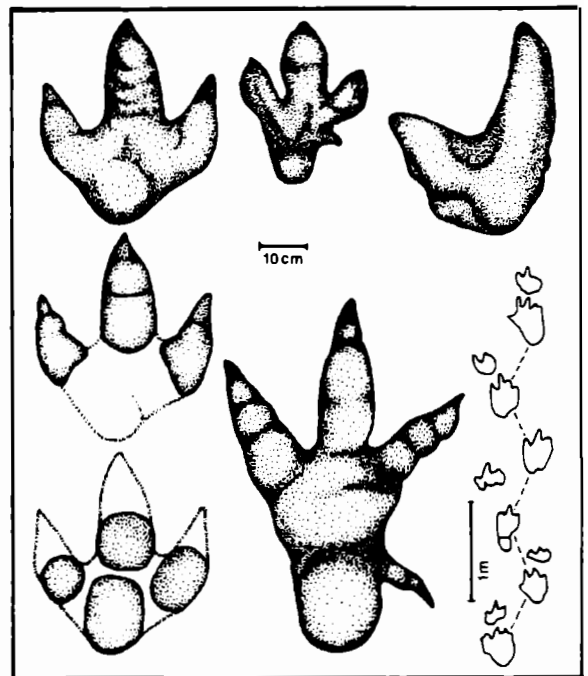


Fig. 95. Tridactyl footprints of bipedal dinosaurs (possibly *Iguanodon* or *Megalosaurus*) from the "Wealden Hauptsandstein" (modified after HAUBOLD 1984).

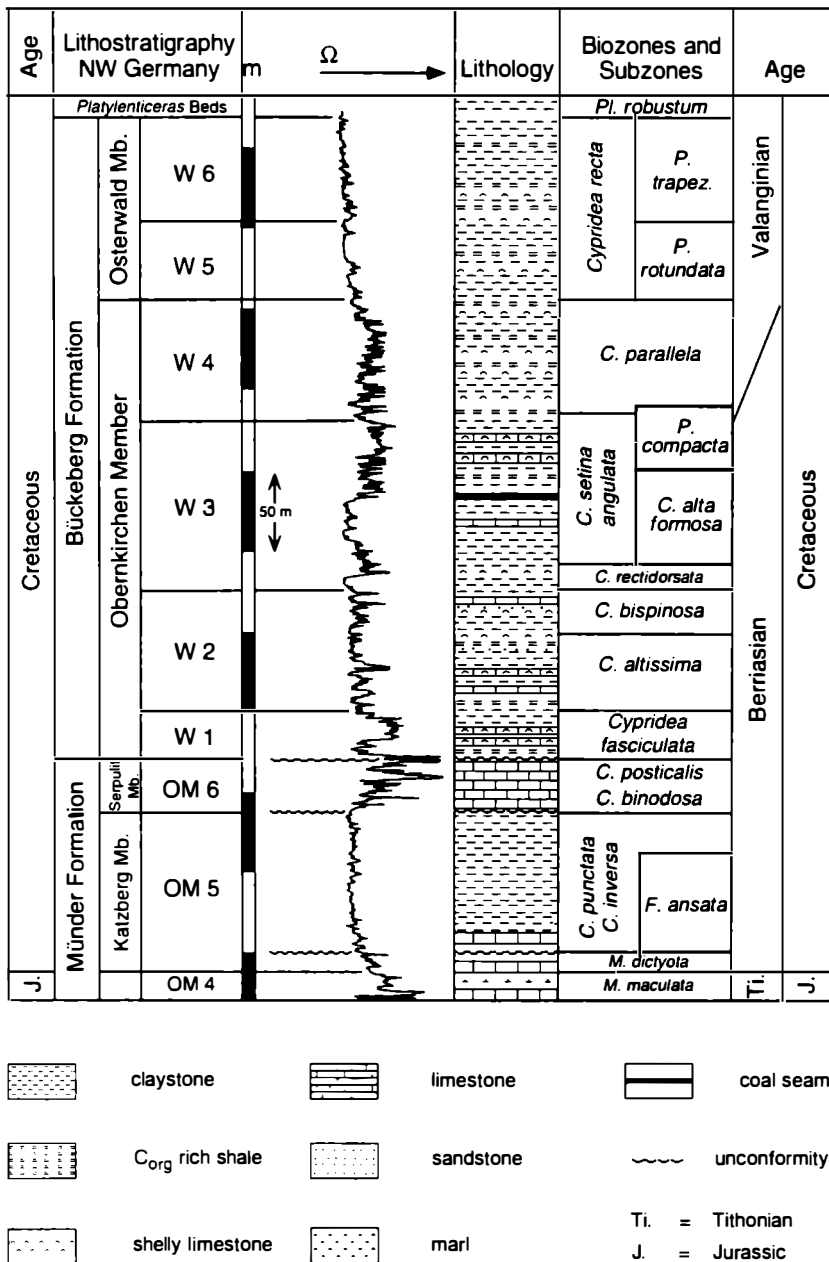


Fig. 96. Litho- and biostratigraphy of the non-marine Berriasian and basal Valanginian of NW Germany (from ELSTNER & MUTTERLOSE 1996).

lated, resulting in a body length of at least 5 m. As is indicated by the size of the imprints and the stride, track 5 was caused by the largest animal in comparison to the animals that made the other tracks. All these imprints were made by quadrupedal, "elephant-footed" sauropods. Movement of the animals from west to east is indicated for all the tracks. In vertical cross-section the large footprints of the hind legs show a regular asymmetry, characterized by one steep and one shallow side. The steeper crest is interpreted as reflecting the inner

side of the leg. From this interpretation, we may then reconstruct the direction in which the animal moved: in the present case, these quadrupedal animals all travelled from west to east.

A second type of footprint (Figs. 94, 95) is exposed over a length of 28 m in the south-eastern part of the quarry. 19 imprints, made by a bipedal three-toed dinosaur (possibly *Iguanodon* or *Megalosaurus*), form a track. The size of these imprints varies between 0.44 and 0.56 m (length) and 0.43 and 0.52 m (width). The average

stride is 2.51 m, the width is 1.22 m. Left and right-handed imprints can be distinguished by the orientation of the third toe. An overall body length of 7 to 8 m has been calculated, the animal's hip was about 2 m above the ground.

Biostratigraphy: The biostratigraphy of the non-marine Berriasian in NW Germany is based on ostracods. A recent review of the ostracod zonation has been given by ELSTNER & MUTTERLOSE (1996). According to this most recent zonation scheme, the Wealden Hauptsandstein can be assigned to the *Cypridea alta formosa* ostracod Subzone. It should be noted, however, that the ostracod zonation can be applied only to the basin facies further to the northwest.

It is less applicable in the sandy facies.

Palaeoecology: Sedimentologic features (cross bedding, ripple marks) and ichnofossil data clearly suggest deposition of the basal bed in a shallow aquatic regime. From the palaeontologic data a swampy fresh-water setting is most probable. The bivalves observed (*Neomiodon*, *Unio*) are clearly fresh-water taxa, and the dinosaur imprints indicate a shallow water depth of up to 1 or 2 m.

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