Project: Fe 240/2 „Quantitative mikropaläontologische Untersuchungen zu „Sedimentäre, biotische und geochemische Zyklen in der borealen Kreide"", Project Leader: J. Fenner (Hannover)

Palaeontological Results from the Boreal Albian (Cores Kirchrode I and II), Biostratigraphy, Paleoenvironment and Cycle Analysis

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Area of Study: Lower Saxony Basin, Northwest Germany
Stratigraphy: Albian
Depositional Setting: Epicontinental basin
Facies: Basin deposits
Organisms: Benthic and planktonic foraminifera, ammonites, calcareous nannofossils, radiolaria, palynomorphs
Controlling Factors: Nutrients, ocean currents, paleoclimate
Research Topic: paleooceanographic changes and sedimentary cycles in the boreal Albian

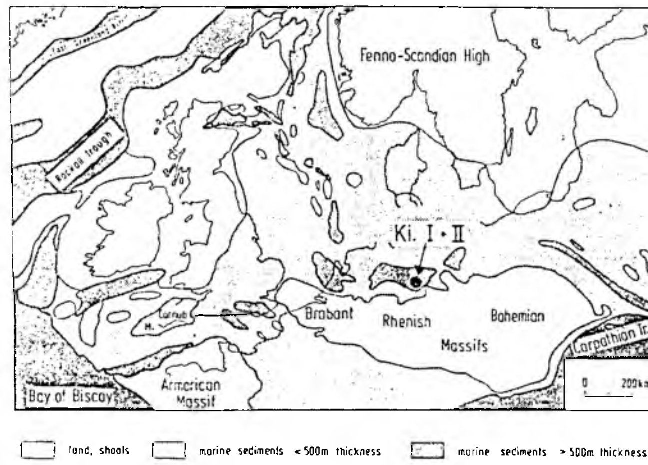


Fig. 1: Land-sea distribution in the early Cretaceous (simplified map after ZIEGLER 1991) with the location of the research wells Kirchrode I and II).

Abstract

A 370 m thick section of Albian sediments from cores Kirchrode I and II in the Lower Saxony Basin of NW-Germany was quantitatively analyzed for micro- and macrofossils with the aim to study paleooceanographic changes, sealevel fluctuations and Milankovitch cycles in a "greenhouse-world" situation. Beside the microfossil groups of benthic and planktonic foraminifera and calcareous nannofossils also the macrofossil group ammonites is present and relatively abundant throughout the recovered Early to Late Albian deposits. The ammonites provide the biostratigraphic frame, with planktonic foraminifera making the correlation with the tethyan realm possible.

The benthic foraminifera, ammonites, and the t/m index of palynomorphs indicate an offshore shelf-environment. Periods of intensified circulation are reflected in the planktonic as well as the benthic organism record. E.g., within the Middle Albian and lower part of the Late Albian periods of intensified circulation are indicated by abundance maxima of the characteristic Tethyan species of the planktonic foraminifera genus *Ticinella* coinciding with abundance maxima of suspension feeding benthic organisms e.g. species of the benthic foraminifera genus *Spiroplectinata*.

During the more calm paleoenvironmental conditions in the middle Late Albian sedimentary cycles in the abundance of biogenic components can be recognized in the three main calcareous microfossil groups studied: benthic foraminifera, planktonic foraminifera and calcareous nannofossils. The clearest signal is interpreted to represent a ca. 100,000 yr cyclicity. A ca. 40,000 signal is also recognizable. Benthic foraminifera indicate that the main control on these cyclic changes are changes in productivity. The time interval during which recognizable biogenic sedimentary cycles are deposited is preceded and succeeded by periods of more chaotic sedimentation with the abundance of microfossil groups and of species changing with no recognizable cyclicity.

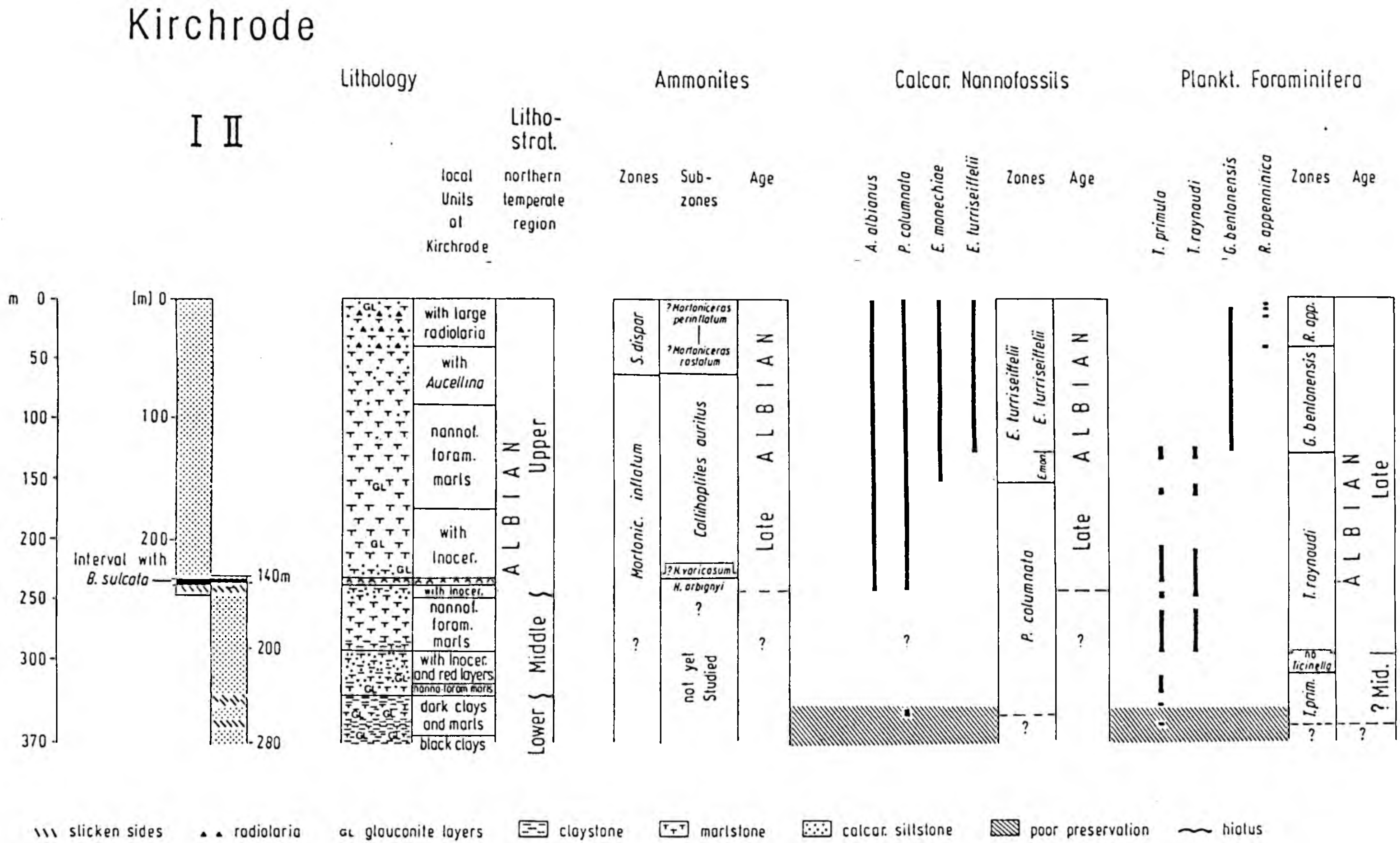
1 Introduction and Methods

The thick hemipelagic Albian sediment sequence in the Lower Saxony Basin between the saltdomes Lehrte and Benthe was cored by two cores Kirchrode I and Kirchrode II which are positioned just about two kilometers apart from each other. Because of the high sedimentation rates at this location, the cored sequence was ideally suited for detailed

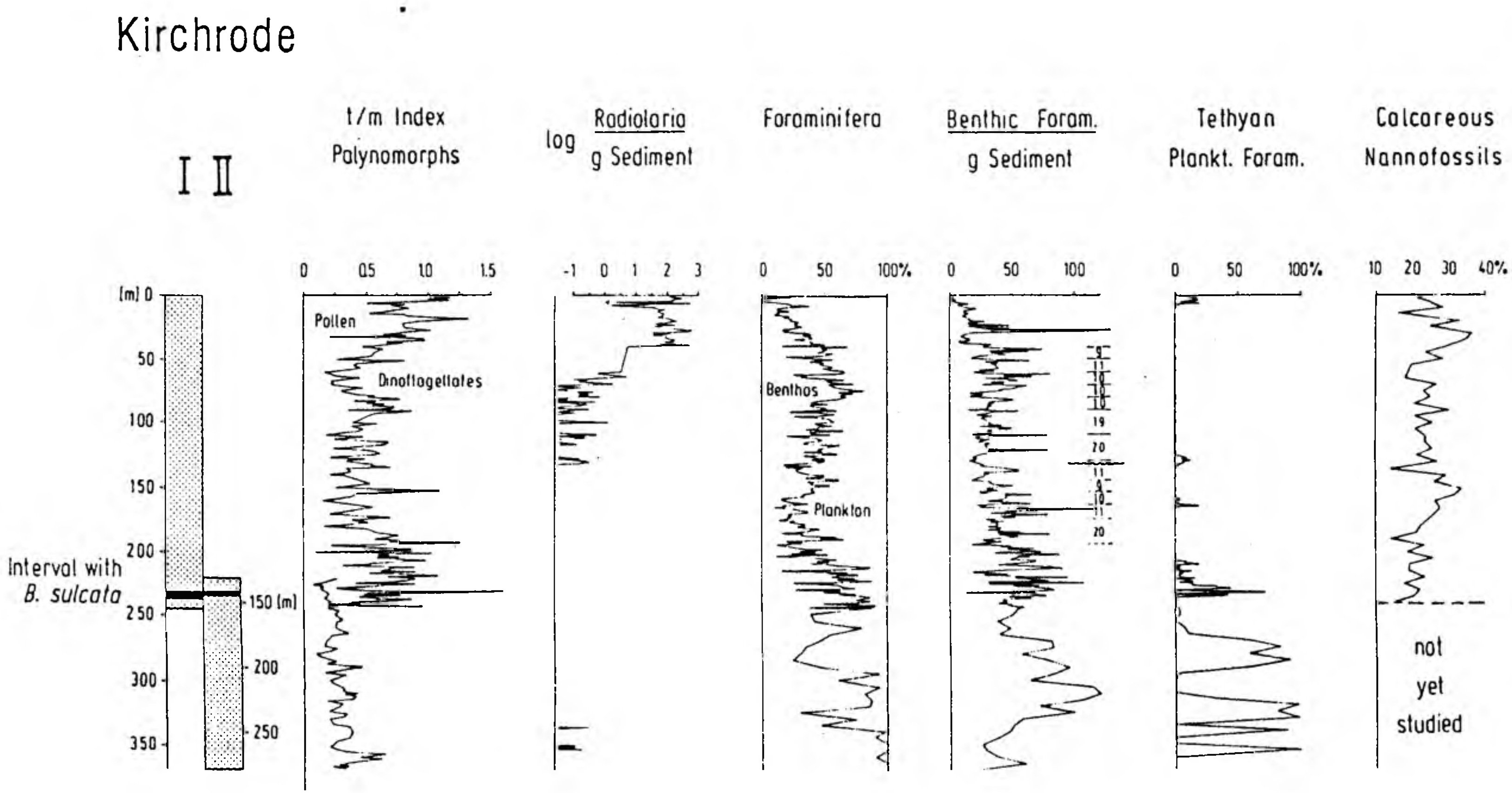
Fig. 2 (next page): Lithological units and the presence of slickensides (FENNER in prep.) in the investigated core intervals of cores Kirchrode I and II with the ranges of the biostratigraphical marker species of the calcareous nannofossils (CEPEK in prep.), planktonic foraminifera (WEIß in prep.), and the Ammonite Zones (WIEDMANN & OWEN pers. comm.) and the age interpretation of these authors. The age interpretation of the lithology follows the conventional age assignments in the boreal realm of the Lower Saxony Basin. The age interpretation from planktonic foraminifera is based on the correlation to sections in the tethyan region (e.g. Umbria, Italy) and Madagascar.

Fig. 3 (page after next): Abundance fluctuations of the main microfossil groups in the investigated core intervals of cores Kirchrode I and II: palynomorphs, radiolaria >125 µm, plankton/benthos ratio in foraminifera >125 µm and benthic foraminifera >125 µm/g sediment, *Ticinella* spp., *Rotalipora* spp. (Tethyan planktonic foraminifera) >125 µm, calcareous nannofossils.

REITNER, J., NEUWEILER, F. & GUNKEL, F. (eds., 1996): Global and Regional Controls on Biogenic Sedimentation. II. Cretaceous Sedimentation. Research Reports. – Göttinger Arb. Geol. Paläont., **Sb3**, 5-12, Göttingen



Kirchrode
Lithology
Ammonites
Calcar. Nannofossils
Plankt. Foraminifera
I II
Litho-strat.
local Units at Kirchrode
northern temperate region
Zones
Sub-zones
Age
A. albianus
P. columnata
E. monechiae
E. turriseiffelii
Zones
Age
T. primula
T. raynaudi
G. benlonensis
R. appenninica
Zones
Age
m 0
50
100
150
200
250
300
370
(m) 0
100
200
Interval with B. sulcata
140m
200
280
with large radiolaria
with Aucellina
nannof. foram. marls
with Inocer.
with Inocer.
nannof. foram. marls
with Inocer. and red layers
nanno-foram marls
dark clays and marls
black clays
ALBIAN
Upper
Middle
Lower
S. dispar
Mortonic. inflatum
?Mortoniceras perinflatum
?Mortoniceras rostatum
Callihoplites auritus
?K. varicosum
H. orbignyi
not yet studied
Late
?
E. turriseiffelii
E. turriseiffelii
E. mon.
P. columnata
ALBIAN
Late
R. app.
G. benlonensis
T. raynaudi
no ticinella
T. prim.
ALBIAN
Late
? Mid.
slicken sides
radiolaria
GL glauconite layers
claystone
marlstone
calcar. siltstone
poor preservation
hiatus


Kirchrode
I II
t/m Index
Polynomorphs
log
Radiolaria
g Sediment
Foraminifera
Benthic Foram.
g Sediment
Tethyan
Plankt. Foram.
Calcareous
Nannofossils
[m] 0
50
100
150
200
250
300
350
150 [m]
200
250
Interval with
B. sulcata
Pollen
Dinoflagellates
Benthos
Plankton
not
yet
studied

studies of biostratigraphy, of paleooceanographic changes and of sedimentary cycles and their duration.

The Albian northern temperate epicontinental seas (Fig. 1) in NW Europe were open to influences from the Tethyan realm as well as to influences from the more eastern, western, and northern regions and therefore are placed in a key position for tracing faunal and floral immigrations and paleocirculation changes.

The Albian was chosen for this study as an example for the "greenhouse-world" with the aim to better understand how sedimentary cycles are formed in a world free of large ice caps. What causes sedimentary and biogenic cycles under such conditions? How is paleocirculation changing? Can sealevel changes be traced in such offshore epicontinental basins?

All fossil groups were studied quantitatively and regular sample spacing was chosen as a precondition for performing cycle and spectral analysis with the data obtained. The microfauna was analyzed in the >125 µm fraction.

The project is part of the special research program of the German Science Foundation (DFG) "Global and regional processes controlling biogenic sedimentation. Part: Sedimentation in the Cretaceous". It is a contribution to the international program "Cretaceous Resources, Events, and Rhythms (CRER)" and its project "ALBICORE" under the umbrella program "Global Sedimentary Geology Program". Close cooperation was practiced with the organic and inorganic geochemists, isotope geologists, the clay mineralogists, sedimentologists, the paleomagnetists and geophysicists responsible for the borehole measurements, who all worked at the same time at this project. First results covering all these aspects were published two years ago (BCCP-group 1994). At the present stage of the project the analyses of Kirchrode I, which were planned for this program, are finished and will be presented in a special volume of "Sedimentary Geology" 1996 or early 1997. For Kirchrode II fossil analyses will not be finished before the end of 1996.

In this paper we present an overview of the paleontological results obtained so far from both cores, Kirchrode I and II. The results and interpretation of the ammonites are by Wiedmann and Owen, of the benthic foraminifera and plankton/benthos ratio of the foraminifera by Thies and Tyszka, of the planktonic foraminifera by Weiß, of the palynomorphs by Prauss, of the lithology, coarse fraction analysis, and of the occurrence of *Birostrina sulcata* (PARKINSON) and of radiolaria by Fenner, of the calcareous nannofossils in core Kirchrode I by Cepek. The *Eiffellithus* lineage was studied by Bruns and Cepek. On a few samples of core Kirchrode II a preliminary survey for biostratigraphic marker species of calcareous nannofossils was done by A. Köthe.

2 Biostratigraphy

Correlation of the two cores Kirchrode I and II (Fig. 2) was accomplished by using the interval with the bivalve *Birostrina sulcata* (PARKINSON) in the lower part of the late Albian.

The high frequency of ammonite finds in the cored sediments permitted the recognition of the ammonite zones and subzones of OWEN (1979) for the northern temperate region (European faunal province). It provided the most detailed biostratigraphic zonation for the drilled sequence (Fig. 2). Unexpected was the long core interval, from 69 m to 228 m core depth, falling into the *Callihoplites auritus* Subzone, a subzone that before had not been recorded from NW-Germany. The youngest subzone identified is the *Mortoniceras rostratum* Subzone and with some doubt the *M. perinflatum* Subzone of the late Late Albian. The *Hysteroceras varicosum* and *H. orbignyi* Subzones of the Ammonite Zonation are represented by just very short core intervals at the base of Kirchrode I. Also the core interval with *Birostrina sulcata* (PARKINSON) is relatively short. This and the presence of slickensides below this core interval (at 242.3 m) suggest that the sedimentary sequence of the lower part of the late Albian is not complete.

Most of the biostratigraphic marker species among calcareous nannofossils used in the Tethyan region could also be used in the Lower Saxony Basin, e.g. *Eiffellithus turriseiffelii* (DEFLANDRE), *Axopodorhabdus albianus* (BLACK) and *Prediscosphaera columnata* (STOVER). The evolutionary lineage of *Eiffellithus monechiae* CRUX to *E. turriseiffelii* (DEFLANDRE) could be traced in cores Kirchrode I and II. The first accounts of these two species are used to define two new subzones within the *E. turriseiffelii*-Zone.

Among the planktonic foraminifera, boreal species did not prove useful for a biostratigraphic zonation neither did the standard biostratigraphic marker species used in the Tethyan region. But species of the genus *Ticinella*, e.g. *T. primula* LUTERBACHER and *T. raynaudi* SIGAL allowed correlation with the Tethys. A correlation with ranges of *Ticinella* species described from the southern temperate region (e.g. Madagascar, SIGAL 1966, RANDRIANASOLO & ANGLADA 1989) and the Tethyan region (e.g. TORNAGHI et al. 1989, Umbria, Italy) places the Middle-/Late Albian boundary at the base of the *Ticinella raynaudi* Zone (compare Fig. 2) at 205 m in core Kirchrode II, that is ca. 55 m deeper than the first occurrence of *Birostrina sulcata* (PARKINSON). The first occurrence of *Ticinella primula* LUTERBACHER is according to SIGAL (1977) of Middle Albian age and according to SLITER et al. (1992) of Early Albian age. In Kirchrode II *Ticinella primula* occurs first at 265 m core depth, which is dated as within the Middle Albian because planktonic foraminifera are not known in the Lower Saxony basin during Early to early Middle Albian times (BARTENSTEIN & BETTENSTAEDT 1962).

Whereas there is agreement about placing the 245 m recovered in core Kirchrode I into the Late Albian, the age assignments by planktonic foraminifera for the sediments recovered in Kirchrode II differ from those obtained using lithostratigraphy. For the characterization of the local lithological units, which were determined shortly after recovering the cores, grain size, calcium carbonate content and sediment color, and also the main and easily detectable biogenic component groups were used. The age assignment for these lithological units was made by comparison with other well dated profiles from the Lower Saxony Basin (compare e.g. KEMPER & ZIMMERLE 1982, KEMPER 1982, 1989a, b, FRIEG & KEMPER 1989, KELLER et al. 1989) and by considering the first occurrence of *Birostrina sulcata* (PARKINSON), which OWEN (1979, 1984) describes as a common species in the *H. cristatum* and the *H. orbignyi* ammonite Subzones, as occurring just above the base of the Late Albian. This age assignment thus follows the age assignments at use within the northern temperate region.

The first author does not see this differing age assignment as a conflict, but rather sees it as an expression of the different concepts in age assignment practiced in the Tethyan and northern temperate regions. The correlation between the independently developed stratigraphies of these two regions is difficult because they have relatively few good stratigraphic marker species in common. The use of the paleogeographically wide-spread species of the genus *Ticinella* may be a way of bringing both age concepts together.

3 Paleooceanographic Setting and Changes through Time

Concerning the paleooceanographic setting the sediment composition of the marls, which have no clastic mineral detritus >125 µm and also the generally low ratio of pollen versus dinoflagellates (t/m index of the palynomorphs), indicate that the site of deposition was probably pretty far from land. Pollen occur in the middle Late Albian with an abundance one order of magnitude lower than that of the dinoflagellates, whereas in the early and late Late Albian the abundance of pollen is higher and the t/m index approaches 1.

The t/m-index may not simply reflect the distance from the coast alone. This is demonstrated by the fact that the t/m ratios differ within the studied 25 m of overlap between the two cores (Fig. 3). In Kirchrode II the relative abundance of pollen is clearly less than in Kirchrode I, although both boreholes are located just 2 km away from each other. In this case this difference in the t/m ratio could have been caused by component sorting controlled by topography or by surface water currents.

The benthic foraminifera and macrofossils indicate an offshore environment of about 100-200 m water depth or deeper. Fossil remains indicating shallow water or nearshore environment are missing.

In the benthic foraminifera assemblages the epistominids, which are characteristic of shallower shelf environments, are very rare. Instead, gavelinellids and astrorhizids are common. The diversity is high. Around 250-300 species are identified and counted, with about 40-60 % of the specimens being arenaceous foraminifera. All these characters in Recent environments are typical for the outer shelf and upper continental slope. During periods of extended epicontinental seas as they existed during the Albian these characters were indicative also for the deeper, offshore epicontinental basins.

The abundance fluctuations of benthic as well as planktonic foraminifera and the plankton/benthos ratio of the foraminifera document four intervals of increased plankton abundance through the recovered Middle and Late Albian which correlate with decreases in the pollen/dinoflagellate ratio (with the exception of the upper 40 m in Kirchrode I) and which are interpreted as reflecting more oceanic conditions and higher sealevel. These results (Fig. 3) document two distinct steps towards increased oceanity to occur during the Middle Albian.

In the planktonic foraminifera assemblages, the real deep-water species are missing and obviously did not intrude into this epicontinental sea. The assemblages generally are dominated by shallow and surface water species (habitats <100 m) like *Globigerinelloides bentonensis* (MORROW), *Biticinella breggiensis* (GANDOLFI), *Ticinella primula* (LUTERBACHER), *T. raynaudi* (SIGAL) and *T. digitalis* (SIGAL) and by species, which are thought to have lived in similar habitats or in the lower part of the mixed surface layer or in the transitional to deeper waters, like *Hedbergella planispira* (TAPPAN), *H. delrioensis* (CARSEY), *H.* aff. *trochoidea* (GANDOLFI), *Favusella hiltermanni* (LOEBLICH & TAPPAN), and *F. washitensis* (CARSEY). Species considered to represent intermediate water depth are missing through most of the Albian. Only in the late Late Albian two such species, *Praeglobotruncana delrioensis* (PLUMMER) and *Rotalipora appenninica* (RENZ), came in and even then were rare. According to HART & BAILEY (1979) these species required greater water depths to support their full life cycle. Species of planktonic foraminifera which are known as characteristic Tethyan elements are represented by small specimens in these northern boreal regions possibly in response to colder water temperatures.

Benthic foraminifera provide also information on nutrient availability and oxygenation of the bottom waters. Bottom waters with limited oxygen are documented only in the dark clays of presumably Early Albian age at the base of core Kirchrode II. The benthic foraminifera assemblage here is dominated by epibenthic and shallow endobenthic arenaceous foraminifera such as ammodiscids, accompanied by ammosphaeroidinids, and astrorhizids. The diversity of calcareous foraminifera in this interval is low and consists mainly of epibenthic *Gavelinella*. Higher up in the section oxygen was not a limiting factor. Instead food-controlled benthic foraminifera assemblages are present with variable proportions of gavelinellids, and nodosariids, of ammosphaeroidinids, astrorhizids, ataxophragmiids, hormosinids, verneuilinids, as well as *Spiroplectinata* spp. and other taxa occupying a diverse variety of epibenthic to deep endobenthic habitats. These assemblages suggest for the Middle and Late Albian mesotrophic to weakly oligotrophic conditions.

Through the Late Albian long-term changes in the abundance of macro- and microfossil groups reflect three successive sedimentation phases:

1) The **lower part of the Late Albian** in core Kirchrode I, besides a higher relative pollen abundance, is characterized also by more reworked plant remains from the Carboniferous, both demonstrating a higher terrigenous input. Ammonites and belemnites are relatively common. The larger numbers of floating organisms and among the benthic organisms of suspension filterers, e.g. *Spiroplectinata annectens* (JONES & PARKER) among the benthic foraminifera, and e.g. inoceramids among the bivalves suggest stronger deep water and surface current activity during this period. At the same time also the abundance of Tethyan planktonic foraminifera, species of the genus *Ticinella* (e.g. *T. primula* LUTERBACHER, *T. raynaudi* SIGAL), reach maxima, marking periods of immigrations from the Tethys. These two *Ticinella* species are considered to have lived in near-surface waters. Three such immigration events can be recognized. The cooccurrence of abundance maxima of

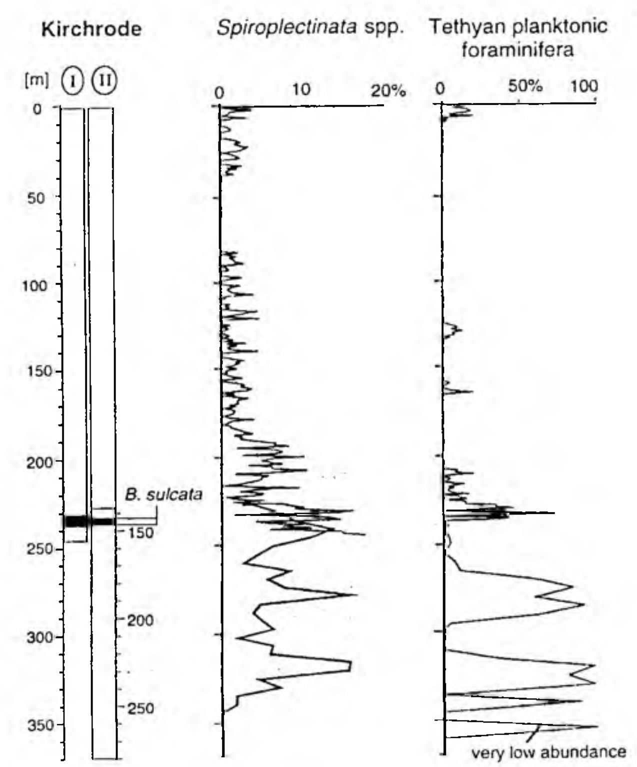


Fig. 4: Correlation of abundance peaks of the suspension feeding benthic foraminifera of the genus *Spiroplectinata* with abundance peaks in the Tethyan planktonic foraminifera of the genera *Ticinella* and *Rotalipora*.

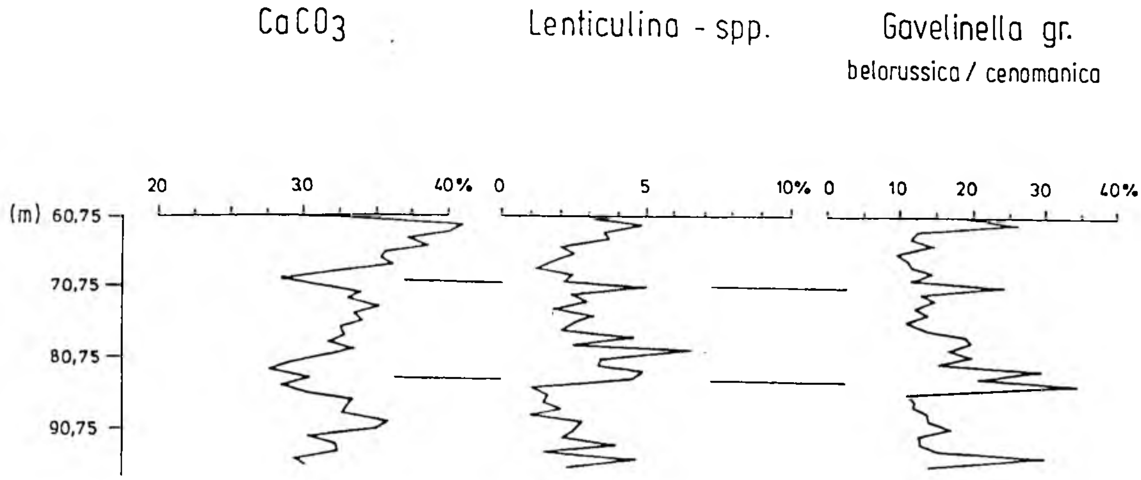


Fig. 5: Selected interval of core Kirchrode I showing the way the abundance of benthic foraminifera and among these *Gavelinella* gr. *belorussica/cenomanica* and *Lenticulina* spp. are correlated with the $CaCO_3$ cycles.

Ticinella spp. with abundance maxima of suspension filtering benthic foraminifera, e.g. of the genus *Spiroplectinata* (Fig. 4), is interpreted as representing phases of intensified circulation.

2) In the middle part of the late Albian, documented in core Kirchrode I by the **interval from 40 to 180 m**, calm conditions prevailed. Among the planktonic foraminifera the species *Globigerinelloides bentonensis* (MORROW) becomes abundant reaching more than 50 % in some samples besides *Hedbergella planispira* (TAPPAN) and *H. delrioensis* (CARSEY). In addition, *Biticinella breggiensis* (GANDOLFI) is present. While the two *Hedbergella* species are common in both the northern temperate ("Boreal") and the Tethyan regions, the two latter species indicate an influence of tropical to warm-temperate oceanic water masses (LOEBLICH & TAPPAN 1961, MASTERS 1977, GORBACHIK & KUZNETSOVA 1983) in the Lower Saxony Basin. For the increase in abundance of these two species either a more permanent Tethyan influence or a general climatic improvement may be considered. Among the benthic foraminifera during this period the endobenthos feeding on organic detritus in the sediment increases in abundance while suspension filterers decrease. Among the mollusks, the inoceramids, which were dominant below, are replaced by species of the genus *Aucellina*. Ammonites and belemnites become more rare. The t/m index of palynomorphs, if used as a proxy for the distance to the coast, indicates the most marine conditions within the Late Albian with dinoflagellates being about one order of magnitude more common than pollen and spores. Occasionally, rare radiolaria occur during this interval.

3) Radiolaria become the dominant component in the sand fraction of the sediment in **the upper part of the Late Albian.** Only in a few samples in the uppermost 7 m of core Kirchrode I the radiolaria are occasionally preserved with their original shell material, opal A. Generally, calcium carbonate or pyrite replicas or molds of the original radiolarian skeletons were recovered. The high abundance of radiolaria in the sand fraction coincides with an increase in silt-sized quartz (KÜHN 1995) and a relative increase in pollen. Both suggest increased wind intensity which could have caused upwelling along submarine ridges. In addition, in this interval the Ba- and P-content of the sediment is slightly higher suggesting slightly higher productivity (RACHOLD 1994). Moreover benthic foraminifera show a relative increase in endobenthic *Arenobulimina* spp. and *Falsogaudryinella alta* (MAGNIEZ-JANNIN), which also supports enhanced productivity in the late Late Albian.

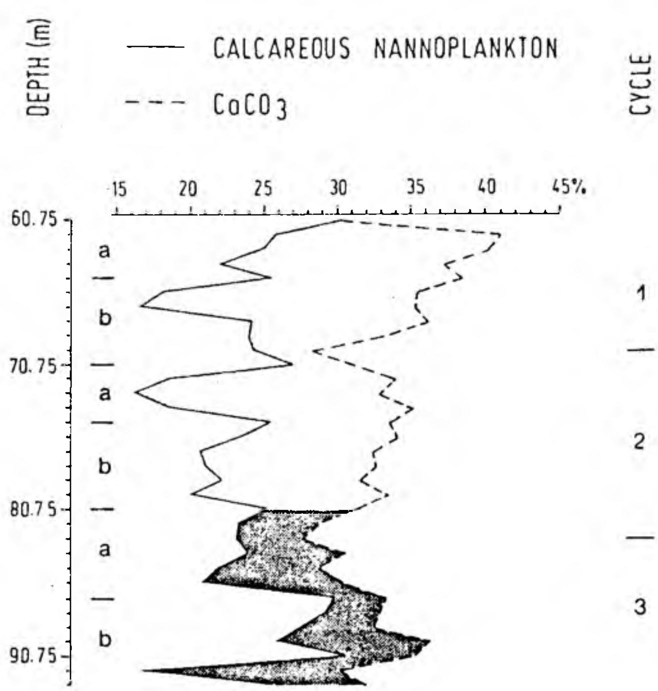


Fig. 6: Correlation of cycles in calcareous nannofossil abundance with cycles in the $CaCO_3$ content of the sediment between 60 and 90 m in core Kirchrode I. Light gray marks the intervals with inverse correlation of these two parameters. Dark gray marks the interval with a positive correlation between these two parameters.

During this period other groups of Tethyan planktonic foraminifera were brought into the Lower Saxony Basin such as globigerinelloids and rotaliporids. The deeper dwelling rotaliporids are very rare. In addition, the abundances reached by the globigerinelloids are minor compared to the abundances reached by the shallow dwelling ticinellids and e.g. *Globigerinelloides bentonensis* (MORROW) in the early and middle Late Albian (Fig. 3). An increase in the abundance of suspension feeders among the benthic foraminifera, such as *Spiroplectinata* spp. and *Ramulina globulifera* BRADY, indicates increased deep water circulation in this epicontinental sea during the late Late Albian.

4 Sedimentary and Biogenic Cycles

Through the recovered Middle and Upper Albian profile a general decrease in the average benthos/plankton ratio of the foraminifera is evident (Fig. 3) documenting the overall rising sealevel during this time interval. Within the sedimentation period documented from the Middle and Late Albian in boreholes Kirchrode I and II four 3rd order cycles can be recognized in the grainsize distribution and the t/m index of the palynomorphs. Of these cycles, each starting with slightly coarser sediments and higher t/m ratios, two are documented in the Middle Albian of core Kirchrode II, the lower beginning at 273 m core depth, the next starting at 225 m. This second cycle is cut by a hiatus. Two Late Albian cycles can be recognized in Kirchrode I, above the hiatuses near the base of this core. One starts at about 225 m with the interval containing *Birostrina sulcata* and the next is starting at about 93 m core depth.

Overlying these longer term cycles are shorter term fluctuations, which can be recognized in several microfossil groups and also in changes in the $CaCO_3$ content of the sediment, and which show regular cycles of 9-13 m length in the interval from 40 m to ca. 200 m in core Kirchrode I. For these $CaCO_3$-cycles spectral analysis (of the core interval from 40-100 m) has shown that they produce the characteristic peak pattern of Milankovitch cycles (PROKOPH 1994, RACHOLD 1995). The most distinct cyclicity has a length between 9-13 m reflecting a cycle length of ca. 100,000 years.

In the abundance curve of the benthic foraminifera per gram sediment 15 cycles with thicknesses between 9 and 11 m can be recognized in the middle part of the Late Albian, between 40 to 195 m core depth in Kirchrode I. Within this cyclic interval a hiatus is present (at 132 m depth in core Kirchrode I) where ammonites, inoceramids and glauconite are concentrated. Adopting the interpretation that these cycles each represent approximately 100,000 years, this would mean, that

1) the average sedimentation rates during this period were 9-11 cm/1,000 yrs, and

2) through at least 1.5 Myrs relatively calm sedimentation characterized the middle part of the Late Albian in the Lower Saxony Basin, and average sedimentation rates did not change much.

But these abundance fluctuations of calcareous microfossils correlate only over part of the cyclic interval with the $CaCO_3$ fluctuations. For the benthic foraminifera the interval of correlation with the $CaCO_3$ fluctuation is restricted to the core interval from 50-95 m in core Kirchrode I (e.g. Fig. 5). Within this interval also the overall abundance of calcareous nannofossils shows a correlation with the $CaCO_3$-cycles (Fig. 6). Besides a cyclicity representing ca. 100,000 yrs also a clear cyclicity of ca. 40,000 yrs is evident.

Concerning the factors which control the calcium carbonate cycles, dissolution of calcium carbonate does not seem to have been important, because during analysis of the main calcareous microfossil groups (planktonic and benthic foraminifera, and calcareous nannofossils) no effects of dissolution were observed within the cyclic interval in the Late Albian. According to THIERSTEIN (1980), an additional argument against dissolution is the relatively high abundance of the dissolution susceptible calcareous nannofossil species *Biscutum constans* (GORKA) in core intervals with relatively low $CaCO_3$ content.

Also dilution with fine clastic terrigenous material is not an evident cause controlling the $CaCO_3$ cycles. Because, if dilution would be the controlling mechanism, the abundance changes in all main calcareous microfossil groups in the sediment should show the same trend and should be correlated. But this is not the case.

The benthic foraminifera give an indication that changes in productivity had an influence. The $CaCO_3$ cycles between 60 and 90 m depth in core Kirchrode I show a correlation with changes in the abundance of benthic foraminifera/g sediment and within this group with changes in the relative abundance of *Lenticulina* spp. and *Gavelinella* gr. *belorussica/cenomanica* (Fig. 5). From recent paleoecological studies it is known that *Lenticulina* spp. avoids high productivity areas (SCHIEBEL 1989). One could thus interpret the $CaCO_3$ cycles as productivity cycles. The higher $CaCO_3$ content of the sediment accordingly reflects higher productivity, and less $CaCO_3$ content reflects reduced productivity. But this works only for the cycles between 60 and 90 m core depth in core Kirchrode I. What causes the cyclic pattern above 60 m and below 90 m core depth is still being studied.

Acknowledgements

The authors thank H.-J. Dürbaum and K. Hinz for their help to obtain money for drilling and coring boreholes Kirchrode I and II. The work of three scientists (Prauss, Thies, Tyszka) involved in this project was financed by the "German Science Foundation (DFG)" through grants Pr 288/2, Ri 154/17, Ce 35/1 and Fe 240/2. We are especially grateful to E. Kemper who accompanied this project with his advice.

References

BARTENSTEIN, H. & BETTENSTAEDT, F. (1962): Marine Unterkreide (Boreal und Tethys). – In: BARTENSTEIN, H., BETTENSTAEDT, F. et al. (eds.): Leitfossilien der Mikropaläontologie (Arbeitskreis deutscher Mikropaläontologen), 225-297, Berlin

BCCP-Group (1994): The Upper Albian of northern Germany: results from the Kirchrode 1/91 borehole. Boreal Cretaceous Cycles Project (BCCP). – Zbl. Geol. Paläont., Teil I, **7/8**, 809-822

CEPEK, P. (in prep.): Calcareous nannoplankton, their biostratigraphy, paleoecology, cyclicity, and quantitative species analysis in the Boreal late Albian of NW-Germany (borehole Kirchrode I). – Sed. Geol., Spec. Vol.

FENNER, J. (in prep.): Geological setting and basic data of the research wells Kirchrode I and II, – including water contents and grain size analyses. – Sed. Geol., Spec. Vol.

FRIEG, C. & KEMPER, E. (1989): Mikropaläontologische Gliederung und Abgrenzung von Ober-Alb und Unter-Cenoman in Nordwestdeutschland. – Geol. Jb., A, **113**, 73-193, Hannover

GORBACHIK, T.N. & KUZNETSOVA, K.I. (1983): Jurassic and Early Cretaceous planktonic foraminifera (Favusellidae). Stratigraphy and paleobiology. – Zitteliana, **10**, 459-466, München

HART, M.B. & BAILEY, H.W. (1979): The distribution of planktonic foraminiferida in the mid-Cretaceous of NW-Europe. – In: WIEDMANN, J. (ed.): Aspekte der Kreide Europas. – IUGS Series A, **6**, 527-542, Stuttgart

HILL, M.E. (1976): Lower Cretaceous calcareous nannofossils from Texas and Oklahoma. – Palaeontographica, B, **156**, 103-179, Stuttgart

KELLER, S., KEMPER, E., KOCH, R., MUTTERLOSE, J., NÖLTNER, T., OWEN, H.G., SPAETH, C., STOFERS, P., WALTER, P. & ZIMMERLE, W. (1989): Das Unter- und Mittel-Alb von Alfeld (Leine). – Geol. Jb., A, **113**, 223-316, Hannover

KEMPER, E. (1982): Schichtenfolge und Sedimentationsraten des hohen Apt und tiefen Alb südlich und östlich Hannover. – Geol. Jb., A, **65**, 633-640, Hannover

KEMPER, E. (1989a): Das Mittel-Alb im östlichen und mittleren Niedersächsischen Becken. – Geol. Jb., A, **113**, 195-221, Hannover

KEMPER, E. (1989b): Vorschlag einer mikropaläontologischen Gliederung von Apt und Alb in Mitteleuropa. – Geol. Jb., A, **113**, 451-469, Hannover

KEMPER, E. & ZIMMERLE, W. (1982): Das Ablagerungsmilieu zur

Zeit des späten Apt und frühen Alb im Niedersächsischen Becken. – Geol. Jb., **A 65**, 655-680, Hannover

KÜHN, V. (1995): Mineralogische Untersuchungen an Sedimenten der norddeutschen Unterkreide unter besonderer Berücksichtigung der Tonmineralogie sowie diagenetischer Bildungen. – unpublished Ph.D.-Thesis, Universität Göttingen, 59 pp.

LOEBLICH, A.R., JR. & TAPPAN, H. (1961): Cretaceous planktonic foraminifera: Part I: Cenomanian. – Micropaleontology, **7** (3), 257-304, New York

MASTERS, B.A. (1977): Mesozoic planktonic foraminifera. A world-wide review and analysis. – In: RAMSAY, A.T.S. (ed.): Oceanic Micropaleontology, **1**, 301-731, London (Academic Press)

OWEN, H.G. (1979): Ammonite zonal stratigraphy in the Albian of North Germany and its setting in the Hoplitinid faunal province. – In: WIEDMANN, J. (ed.): Aspekte der Kreide Europas. – IUGS Series A, **6**, 563-588, Stuttgart

OWEN, H.G. (1984): Albian Stage and Substage boundaries. – Bull. geol. Soc. Denmark, **33**, 183-189, Cøbenhaven

PROKOPH, A. (1994): Zyklische Sedimentation im Oberalb des Norddeutschen Beckens. Sedimentologie, Zeitreihenanalyse, Zyklostratigraphie, Biostratigraphie. – Tübinger Geowissenschaftliche Arbeiten, A, **19**, 163 pp., Tübingen

RACHOLD, V.E. (1994): Geochemie der Unterkreide Nordwestdeutschlands: Zyklen und "Events". – unpublished Ph.D.-Thesis, Universität Göttingen, 108 pp.

RANDRIANASOLO, A. & ANGLADA, R. (1989): La lignee *Hedbergella wondersi* nov. sp.-*Planomalina buxtorfi* (Gandolfi) (Foraminiferes planctoniques) dans l'Albo-Cenomanian du Bassin d'Antsiranana (Nord du Madagascar). – Geobios, **22** (6), 803-823, Lyon

SCHIEBEL, R. (1989): Zur Taxonomie und Verbreitung von *Lenticulina* und *Neolenticulina* im Nordost-Atlantik. – unpublished Ph.D.-Thesis, Univ. Kiel, 24 pp.

SIGAL, J. (1966): Contribution à une monographie des Rosalines. 1. Le genre *Ticinella* Reichel, souche des Rotalipores. – Eclogae geol. Helvet., **59** (1), 185-217, Basel

SILTER, W., ELLIS, G., ERBA, E., FENNER, J., GAMPER-LONGORIA, M., KOUTZOUKOS, E., LECKIE, M., LONGORIA, J.F., LUPERTO-SINNI, E., MUTTERLOSE, J., PREMOLI-SILVA, I., PRINGLE, M., ROTH, P. & THIES, A. (1992): Science advisory committee on paleontology and biochronology. – In: APTICORE-ALBICORE, a workshop on global events and rhythms of the mid-Cretaceous, 8-12, Perugia

THIERSTEIN, H.R. (1980): Selective dissolution of the Late Cretaceous and earliest Tertiary calcareous nannofossils: experimental evidence. – Cretaceous Research, **1**, 165-176, Belfast

TORNAGHI, M.E., PREMOLI-SILVA, I. & RIPEPE, M. (1989): Lithostratigraphy and planktonic foraminiferal biostratigraphgy of the Aptian-Albian "Scisti a Fucoidi" in the Piobicco core, Marche, Italy: background for cyclostratigraphy. – Riv. It. Paleont. Strat., **93** (3), 223-264, Florenz

WEIß, W. (in prep.): Late Albian immigrations of planktonic foraminifera into the Boreal sea: results from borehole Kirchrode I (Hannover, NW-Germany). – Sedimentary Geology Spec. Vol.

ZIEGLER, P.A. (1990): Geological Atlas of western and central Europe. 2nd Edition. – Shell Internat. Petroleum Maatschappij B.V., 238 pp., Den Haag