

A TETHYAN-BOREAL CORRELATION OF PRE-APTIAN CRETACEOUS STRATA: CORRELATING THE UNCORRELATABLES



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Abstract: Because of the high provinciality of the marine biota during the pre-Aptian Cretaceous times, there is no hope of a precise correlation of Tethyan with Boreal successions by means of biostratigraphy alone. Correlations with a detail as shown in the correlation schemes presented here, can be achieved only with the combination of all available correlation tools such as biostratigraphy, magnetostratigraphy and sequence stratigraphy.

Key words: Tethyan-Boreal correlation, pre-Aptian Cretaceous, biostratigraphy, magnetostratigraphy, sequence stratigraphy, Spain, France, Germany, England.

Introduction

The most recent biostratigraphical correlations of Tethyan with Boreal pre-Aptian Cretaceous successions are:

For the Berriasian: Hoedemaeker 1987, 1991;

For the Valanginian: Kemper et al. 1981; Hoedemaeker 1987;

For the Hauterivian: Kemper et al. 1981;

For the Barremian: Kakabadze 1983;

For the entire pre-Aptian: Rawson 1995.

The latter is the most recent correlation of Tethyan and Boreal pre-Aptian strata, which clearly shows how rough and imprecise the biostratigraphic correlation still is. The precise correlations proposed here deviate in many respects from this correlation.

The above correlations show that, because of the high provinciality of the marine biota during pre-Aptian Cretaceous times, there are very few reliable biostratigraphic tie-points between the Tethyan and Boreal realms. Fossils common to both realms are very scarce. The Boreal marine pre-Aptian Cretaceous strata have always been considered hardly correlatable by biostratigraphic means with the Tethyan standard succession, the Purbeck and Wealden successions are even virtually uncorrelatable. A better correlation cannot be expected by biostratigraphic means only. If more precise and more detailed correlations are required, magnetostratigraphy and sequence stratigraphy should be used as additional correlation tools. Such a correlation is attempted in this paper and is the principle aim of the multidisciplinary biostratigraphic and sequence-stratigraphic investigation of the Lower Cretaceous succession along the Río Argos near Caravaca, SE Spain — the so-called Río Argos Project, an ongoing research project of the National Museum of Natural History of the Netherlands, lately incorporated in IGCP Project 362: Tethyan and Boreal Cretaceous Correlation. In order to perform such a correlation, a sequence-stratigraphic analysis of the Boreal pre-Aptian succession has to be made, which has not been done before. The correlation of the Boreal and

Tethyan depositional sequences should be supported by as many biostratigraphical and magnetostratigraphical correlating ties as possible.

Correlation of depositional sequences

It appears (see folded chart in enclosure) that all depositional sequences determined in the Tethyan Río Argos succession (Caravaca, SE Spain) (Hoedemaeker & Leereveld 1995; Hoedemaeker 1995, 1996, in press) can be retrieved and identified not only in SE France (sections of Berrias, La Charce and Angles) (Hoedemaeker, in press), but also in the Boreal pre-Aptian Cretaceous in north Germany and in England.

The interpretation of the pre-Aptian sequences in the Río Argos succession and their correlation with those in SE France (Hoedemaeker 1999) are not repeated again here. The lithological columns published by Giraud (1995) and the author's observations were used in the sequence-stratigraphic interpretation of the French sections. Only one more sequence, BA4', was determined in the upper Barremian of the Río Argos succession, the highstand systems tract of which is a rather isolated condensed set of limestone/marlstone beds amidst a siliciclastic sandy turbidite succession. Hoedemaeker (1999) slightly changed the sequence-stratigraphic interpretation of the Berriasian stratotype of Jan du Chêne et al. (1993). These changes are maintained here; they better match with the magnetostratigraphic/sequence-stratigraphic correlation of the English Purbeck Formation and the Berriasian stratotype.

The magnetostratigraphic interpretation of the stratotype of the Berriasian Stage in SE France (Galbrun & Rasplus 1984; Galbrun 1985; Galbrun et al. 1986) and of the Purbeck Beds of the Durlston Succession in S England (Ogg et al. 1991; Ogg et al. 1994, 1995) permit a far better correlation of these successions than was previously possible. This correlation could be made more precise by means of sequence stratigraphy. In the correlation

schemes presented here, the depositional sequences and magnetostratigraphic zones of the Purbeck Formation and Berriasian stratotype fit very well.

Since a sequence-stratigraphic interpretation of most Boreal sections is still lacking or inadequate, a Tethyan-Boreal correlation is only possible after an interpretation was made of the precise stratigraphic positions of the various depositional systems tracts in the Boreal sections of England and northern Germany. Such an interpretation can only be done in sections which have been accurately measured and lithologically described in great detail, and from which the bed-by-bed fossil content is known. Such descriptions furnish all data necessary to form a well-founded interpretation of the sequence-stratigraphic boundaries. Such well-described Boreal sections are known. These are:

1. The Speeton Clay near Speeton (Valanginian-Barremian), England (Neale 1960, 1962a,b, 1968; Rawson 1970; Rawson & Mutterlose 1983; Mutterlose 1983) (Figs. 2–5).
2. The the German Wealden in the Isterberg 1001 borehole (Strauss et al. 1993) (Fig. 6).
3. The Valanginian in Sachsenhagen (Kemper 1961; Mutterlose 1984) and Suddendorf (Kemper 1961; Below 1981), Germany (Fig. 7).
4. The Hauterivian in the Moorberg clay pit near Sarstedt, Germany (Mutterlose 1984) (Fig. 8).
5. The Barremian in the Gott clay pit near Sarstedt, Germany (Mutterlose 1983, 1984) (Fig. 9).
6. The Purbeck and Valanginian successions in the Neuchâtel region (Switzerland) and southern Jura Mountains (France) (Strasser 1988, 1994; Darsac 1983; Arnaud, personal communication) (Fig. 10).
7. The section along the Mittellandkanal near Pollhagen, Germany (Quensel 1988) (Fig. 11).
8. The Purbeck in Dorset, England (Anderson & Bazley 1971; Anderson 1985; Wimbledon & Hunt 1983; Hunt 1985, 1987; Strasser, personal communication).
9. The Wealden of the Warlingham borehole, England (Worssam & Ivimey-Cook 1971; Anderson 1985; Feist et al. 1995).

The major part of this article concerns a sequence-stratigraphic interpretation (including short argumentations) of these lithologically and biostratigraphically well-described boreal sections. For most of the Boreal successions this interpretation is new and allows a correlation with the Mediterranean successions at a level of detail which has never been possible before. Several additional sections were studied of which the data are not as detailed as the above mentioned, but from which additional correlation data could still be gathered. The correlations do not contradict the biostratigraphic correlations on the basis of ammonites (Kemper et al. 1981; Hoedemaeker 1987, 1991; Kakabadze 1983; Rawson 1995) and dinoflagellate cysts (Leereveld 1995); the correlations are supported by 25 first and last occurrences of dinoflagellate cysts.

The Boreal Realm contains a few stratigraphic intervals for which there are no detailed logs, for instance the Katzberg Member and the upper B Beds of the Speeton section. The depositional sequences shown for these units in the correlation schemes are inferred.

How to read the correlation scheme (see folded chart in enclosure)

The first column on the left and the seventh column on the right of the correlation chart represent the Tethyan successions along the Río Argos in SE Spain and of the 'Vocontian trough' in SE France respectively. The sequences of these two columns are drawn in accordance with the interpretation of Hoedemaeker (1999). The columns between these two Tethyan ones represent Boreal successions except the sixth column, which represents the shallow Berriasian and Valanginian successions of the southern Jura Mountains in France and Switzerland and the Hauterivian ammonite zones of Argentina, as described by Aguirre-Urreta & Rawson (1997). The second column exhibits the sequences of German successions: the peritidal Katzberg Member, the Serpulit Member, the Bückeberg Formation, and the marine successions (Hils Formation and its lateral equivalents) beginning with the Valanginian *Platylenticeras* Beds up to the basal Aptian. Column 3 shows the sequences of the peritidal Purbeck and Wealden Formations in southern England. Column 4 shows the sequences of the Speeton Clay Formation in eastern England. The fifth column shows the English ammonite zones.

The vertical axis of the correlation schemes does not represent a time-scale in which equal lapses of time have the same lengths, but represents the rate of sedimentation in the Río Argos succession, which is rather variable.

The most striking feature of the correlation schemes is the large hiatuses, represented by shaded blocks. These hiatuses correspond to the lowstand systems tracts, which are preserved in the Río Argos succession but not in some of the Boreal successions, where they represent times of non-deposition (sediment bypassing or emergence). The rate of deposition of the lowstand systems tracts in the Río Argos succession is estimated to be approximately twice to thrice as large as of the transgressive and highstand systems tracts. This would imply that the time of deposition of the lowstand systems tracts is about the same as the time of deposition of the transgressive and highstand systems tracts together.

The white blocks between the shaded blocks represent the preserved parts of the depositional sequences; they represent times in which actual deposition occurred. The deposits of each white block generally correspond to the transgressive and highstand systems tracts together. However the presence of a transgressive systems tract cannot be ascertained everywhere; in many cases only an unknown part of the transgressive systems tract may be preserved or even only the highstand systems tract, for instance in the peritidal Purbeck and Wealden successions. Only in those cases in which it has definitely been shown that only the highstand systems tract is preserved, it is presented as such. In all other cases the entire transgressive and highstand systems tracts are drawn, which makes many of the white blocks larger than they should be.

About 50 % of the successions considered here are not preserved and in the peritidal deposits of the Purbeck and

Wealden successions still more is missing. The hiatuses may span unknown biostratigraphic zones and boundaries of biostratigraphic units. For instance the lower boundary of magnetozone M17r is still unknown, but probably situated in the middle of the Subalpina Subzone. In correlation schemes these hiatuses must not be neglected.

Another striking feature is the light-shaded stripes at the sequence boundaries BE3, BE7, VA4, HA3, HA7, BA2, AP2. These boundaries were interpreted as representing rapid and extra deep sea-level falls, which are of much larger amplitude than those around most other sequence boundaries (Hoedemaeker 1995). These falls are attended by considerable extinctions of ammonite species followed by the appearance of many new species. They can be regarded as type 1 sequence boundaries and are without exception directly preceded by extra high sea-level stands, in which fossils abound. These sharp deep falls of the sea level can readily be discerned in any succession that embraces a sufficient lapse of time, even when the sequence-stratigraphic signal is weak, as for instance in condensed deep-pelagic successions. They form a strong and reliable correlation tool. The so-called 'Late Kimmerian Unconformity' (Be7) (Rawson & Riley 1982) and the DHo-Discontinuity (Ha3) (Kemper 1992) are well-known Boreal examples.

The standard ammonite zones used in the schemes (folded chart in enclosure) were established at the meetings of the International Lower Cretaceous Cephalopod I.G.C.P.-Team in Digne (Hoedemaeker & Bulot 1990), Mula (Hoedemaeker & Company 1993) and Piobbico (Hoedemaeker & Cecca 1995). The only deviations are the Valanginian *Campylotoxus* Zone in France (column 7) being subdivided in accordance with the recent ideas of Atrops & Reboulet (1995) and Reboulet (1995), and the Barremian *Caillaudianus* Zone in accordance with the ideas of Company et al. (1995).

It should be noted that the lower boundaries of the lower Hauterivian *Jeannoti* ammonite subzone and *Nodosoplicatum* Zone in La Charce (France) occur at levels which differ from those along the Río Argos (Spain); this is interpreted as due to collection failure in France. Also, according to the correlations proposed here it turns out that the base of the *Gottschei* Zone in England is situated at a lower level than in Germany, and that the English *Inversum* Zone does not exactly cover the German *Aegocrioceras* Beds.

As for the ammonite zones, it should be noted that the beds assigned by Hoedemaeker (in: Hoedemaeker & Leereveld 1995; Hoedemaeker 1999) to the Aptian *Deshayesites* Zone (designated by the letter D) in the Río Argos succession, in reality belong to the *Weissi* Zone. It has been corrected in the correlation scheme.

The short horizontal lines with bed numbers in columns 2 and 7 represent the boundaries of the various systems tracts in Germany and SE France respectively.

I recently (Hoedemaeker 1999) changed my interpretation of the stratigraphic positions of the sequence boundaries Ba2 and Ba3 in the Barremian stratotype section near Angles (column 7). On the basis of peaks in the sporomorph/dinoflagellate cyst ratio (Wilpshaar, personal communi-

cation) sequence boundary Ba2 should be drawn at the top of limestone bed 129 instead of 136, and Ba3 on top of limestone bed 135 instead of 143. There are no hiatuses in the sequences Ba2 and Ba3 in the Angles section; these sequences are only condensed. These changes were corrected on the correlation scheme (see folded chart in enclosure).

The 'Sables turbiditiques roux' is a thick reddish sandstone intercalation separating the basal part of the Fuhri Subzone from the lower part of the *Pronecostatum* Horizon with a slight angular unconformity in the La Charce section in SE France (column 7). The few limestone beds intercalated within this slumped sandstone body yielded the ammonites *Busnardoites campylotoxus* and *Karakaschiceras biassalensis* characteristic for the *Campylotoxus* Zone, but did not yield ammonites that characterize the *Verrucosum* Horizon. Though generally thought to be time equivalent to the 'Calcaire roux' or to the Formation de Bourget, the 'Sables turbiditiques roux' are here thought to represent either the lowstand systems tract deposited above sequence boundary Va3', on account of the ammonites they contain, or the lowstand systems tract directly above type 1 sequence boundary Va4, because they are directly overlain by the lower part of the *Pronecostatum* Horizon. In the latter case the ammonites should be reworked and the whole unit would have been deposited during the *Pronecostatum* time. The latter interpretation would also explain why the 'Sables turbiditiques roux' produced such a big erosion channel, but cannot explain the absence of reworked *Verrucosum* Zone ammonites. It rather represents the erosion products of the 'Calcaire roux' instead of being equivalent to it. The so-called 'Petit Lumachelle' in the Carejuan section in SE France is directly overlain by the *Verrucosum* Horizon and represents the lowstand systems tract of sequence Va3'.

It should finally be noted that the Boreal ammonites (black triangles in column 7) invaded the Tethyan Realm generally during sea-level lowstands, whereas Tethyan ammonites invaded the Boreal Realm generally during highstands. This suggests a one-way traffic in the Polish Strait: during lowstands from the north, during highstands from the south. It must also be emphasized that almost all Boreal ammonites present in the Mediterranean region invaded the Tethyan Realm during the Valanginian, which may indicate a cooler climate during that time.

For the Boreal marine successions the belemnite zones are also given, and for the English Wealden succession the ostracod zones of Anderson (1985). The *Chara* assemblage zones are given for the lower Purbeck Beds. The mutual correlation of the English, German and Swiss *Chara* assemblages by Feist et al. (1991), Feist et al. (1995); Detraz & Mojon (1989) and Schudack (1996) is quite different from the correlation with the help of sequence stratigraphy and ostracods as presented here. More study is necessary.

The signs E1 to E6 in the second column refer to the six most prominent shaly intercalations between the pre-Aptian Cretaceous sandstones in the subsurface of northern Germany (Kemper 1992). Some of these intercalations are referred to as 'Zwischenmittel' (= substance in between).

The bases and tops of the preserved parts of the depositional sequences (white blocks) in column 3 are correlated with the named faunicycles of Anderson (1985), but this should be considered a mere approximation of the stratigraphic levels of the sequence boundaries. As these faunicycles provide the finest subdivision of the Purbeck and Wealden successions, they represent the finest biostratigraphic resolution; we cannot be more precise. If a faunicycle comprises only one saline phase (S phase) overlain by one freshwater phase with *Cypridea* (C phase) it may correspond to one parasequence. However, most faunicycles comprise more than one S/C doublets, the number of which has not been published. It must be realized that in many cases the sequence boundaries are situated within a faunicycle as is apparent from the detailed logs of the Warlingham borehole.

Each column has a white strip on the right side in which all relevant biostratigraphic information is given. The first (↑) and last (↓) occurrences of fossils are marked, as well as some single occurrences (←). The first and last occurrences of the ostracods from the English Purbeck and Wealden (column 3) are given according to Anderson (1985) and those of the 'Wealden' in Germany (column 2) mainly from Wolburg (1959) and, to a lesser extent, Elstner & Mutterlose (1996). The latter use a slightly different taxonomy and in the schemes the taxonomy and synonymy of Anderson is used. In the white strip along column 5 the various proposals for stage boundaries are marked. From the scheme it becomes obvious that the boundaries closest to the type 1 sequence boundaries are the most natural stage boundaries, because the changes among the fossil species are the most rapid and the biostratigraphic definitions of the boundary stratotypes are therefore easy to give and easy to recognize in other sections. In shallow depocenters they are preserved as hiatuses, which are also natural and easily traceable boundaries.

In the white strips along columns 3 and 7 the magnetostratigraphies of Ogg et al. (1994a,b) and Galbrun et al. (1985), respectively, are depicted. It should be noted that the magnetostratigraphy of the Berriasian stratotype as presented by Jan du Chêne et al. (1993) deviates in several details from those presented by Galbrun in 1984, 1985 and 1986. The magnetostratigraphy of the basal Valanginian Otopeta Zone is the one of Ogg et al. (1988). The magnetostratigraphy of the remainder of the Valanginian is the one published by Besse et al. (1986) and discussed in the thesis of Boisseau (1987).

In the white strip along column 6 the stratigraphic positions of the type 1 sequence boundaries are shown, but also the numbered depositional discontinuities (Di1 to Di3) discerned in the shallow carbonate Berriasian to Valanginian sediments by the French in the southern Jura Mountains (Darsac 1983; Boisseau 1987). These discontinuities are now recognized as representing maximum flooding surfaces (Arnaud, personal communication). In the white strip along column 7 the discontinuities discerned by Autran (1989) are marked (DVm, DVs, DZl).

In the following the sequence-stratigraphic interpretation of the Boreal pre-Aptian successions presented in the

correlation chart is elucidated. Each Boreal sequence boundary is given the code of the Mediterranean sequence boundary with which it can be correlated. First the interpretation of the English sequences will be given, which is necessary to interpret the sequences of the German Wealden succession.

Sequence-stratigraphic analysis of the English sections (Columns 3, 4, 5)

1. Purbeck Beds in South England: Berriasian (column 3) (Fig. 1)

Magnetostratigraphic investigations of the Purbeck Limestone Formation of the Durlston section in southern England (Ogg et al. 1991; Ogg et al. 1994, 1995) and of the stratotype section of the Berriasian Stage (Galbrun & Rasplus 1984; Galbrun 1985; Galbrun et al. 1986) permit correlation of the Purbeck Limestone with the uppermost Tithonian, Berriasian and lowermost Valanginian. In addition Hunt (1987) documented characteristics of dinoflagellate cyst and acritarch associations in the Purbeck formations of the Durlston section. The peaks in the dinoflagellate cyst diversity given by Hunt are here inferred to reflect highstand systems tracts; the bases of the intervals with low dinoflagellate cyst diversity on top of these diversity peaks are interpreted as representing sequence boundaries. The positions of the sequence boundaries in relation to the various polarity chrons in the Purbeck Succession precisely match those in the Berriasian stratotype. This strengthens the reliability of the Boreal-Tethyan correlation of the Berriasian succession.

1. Ogg et al. (1994) and Ogg et al. (1995) showed that magnetozone M19r is situated within the Broken Beds, which means that it correlates with the Mediterranean Durangites Zone (Ogg et al. 1984). The gypsum-bearing Broken Beds are therefore interpreted as the transgressive systems tract and the fully marine lower part of the Cypris Freestones on top of the latter as the highstand systems tract of the latest Jurassic sequence below sequence boundary Be1 at the base of the Jacobi Zone. The sequence boundary of Be1 should be situated on top of the fully marine lower part of the Cypris Freestones.

2. Sequence Be1 comprises the brackish, more marly upper part of the Cypris Freestones interpreted as the transgressive systems tract, and the Hard Cockle Limestone Bed interpreted as the highstand systems tract. The basalmost part of the succeeding marly Soft Cockle Beds shows a high microplankton diversity peak and is interpreted as the topmost part of the highstand systems tract. The Hard Cockle Bed is situated within polarity chron M19n.

3. The next sequence (Be1') is rather thin and merely represents the lower part of the Soft Cockle Beds below the gypsum beds. The bed just below the gypsum shows a microplankton diversity peak and is interpreted as the topmost part of the highstand systems tract.

4. The base of the gypsum beds is considered to represent a sequence boundary Be2; the gypsum beds themselves are interpreted as the transgressive systems tract of this sequence. Sequence Be2 is topped by the Mammal Bed. The lower part of the Marly Fresh Water Beds just below the Mammal Bed is considered to represent a highstand systems tract, because it shows a peak in the diversity of

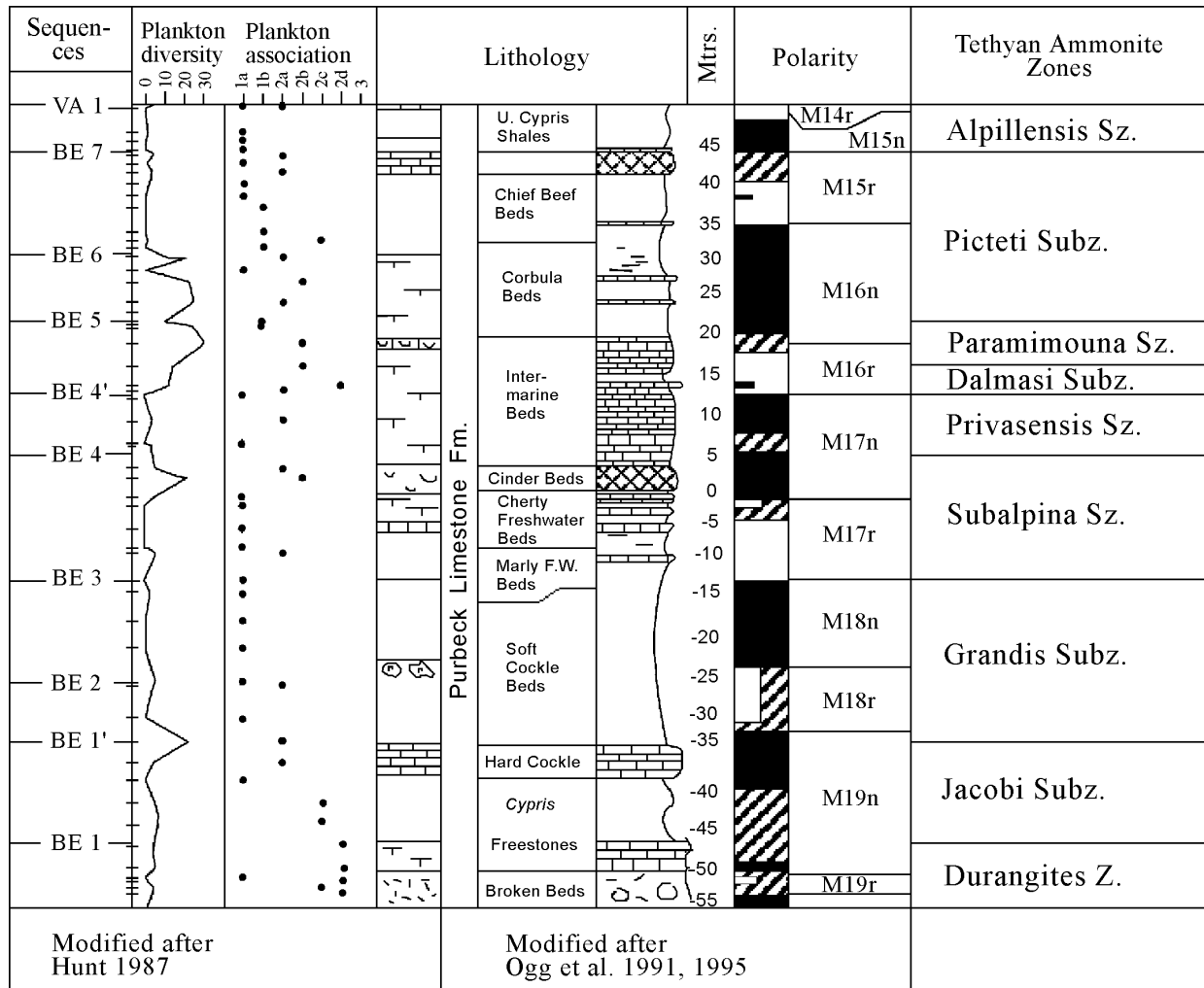


Fig. 1. The magnetostratigraphic analysis of the Purbeck Formation (Ogg et al. 1991) makes it possible to correlate this formation with the stratotype of the Berriasian Stage in France. The microplankton associations and diversities studied by Hunt (1987) make it possible to do a sequence stratigraphic analysis, which exactly matches the sequences of the Berriasian Stage in the stratotype section and in the succession along the Río Argos (Hoedemaeker & Leereveld 1995; Hoedemaeker 1999). Mikroplankton associations: 1a — freshwater to brackish; 1b — brackish lagoon; 2a,b,c,d — restricted, brackish to shallow marine; 3 — shallow marine.

microplankton. The gypsum beds and the part of the Soft Cockle Beds directly above it embrace polarity chron M18r. The upper part of sequence Be2 embraces polarity chron M18n, which is truncated by the hiatus of the Mammal Bed.

5. The Mammal Bed represents a very important emergence episode, during which a thick soil layer was formed in which a famous collection of vertebrate remnants has been found. It correlates with the channelled erosion surface overlying the Lower Purbeck in the Weald area. This bed is therefore interpreted as representing the sequence boundary of Be3, a type 1 sequence boundary. The Mammal Bed is situated within the Ashdown faunicycle (Morter 1984). Sequence Be3 comprises the upper part of the Marly Fresh Water Beds, the Cherty Fresh Water Beds and the Cinder Bed, which clearly represents the highstand systems tract of sequence Be3. The next sequence boundary, Be 4, is just above the diversity peak of the microplankton in the top part of the Cinder Bed. The Fresh Water Beds above the Mammal Bed are situated in the polarity chron M17r, which is truncated by the Mammal Bed hiatus. Therefore the Fresh Water Beds correlate with the lower part of the Subalpina Subzone. The upper part of the Subalpina Subzone and the lower part of the overlying Privasensis Subzone in the stratotype

of the Berriasian Stage have not been analysed magnetostratigraphically by Galbrun (1984). As the Cinder Bed correlates with the highstand systems tract in the upper part of the Subalpina Subzone, it implies that the upper part of the Subalpina Subzone should be situated within polarity chron M17n, as is the Cinder Bed.

6. The next microplankton diversity peak is situated in the middle of the Inter-marine Beds and represents the top highstand systems tract of sequence Be4. It probably represents the so-called 'Royal event' of Morter (1984), which is followed immediately by sequence boundary Be4'. The lower Inter-marine Beds are situated within polarity chron M17n.

7. The Scallop Bed is interpreted as representing the highstand systems tract of sequence Be4' and is characterized by a microplankton diversity peak. The sequence boundary of Be5 is situated just above the Scallop Bed. The upper Inter-marine Beds are situated within polarity chron M16r. The base of M16r coincides with the base of the Dalmasi Subzone in the stratotype of the Berriasian Stage. The Scallop Bed is probably situated at the base of M16n.

8. Sequence Be5 embraces the Corbula Beds, which are topped by a microplankton diversity peak representing the highstand systems tract. The Corbula Beds are situated within polarity chron M16n.

9. The next sequence embraces the Chief Beef Beds and the Broken Shell Limestone. The latter contains a peak in the microplankton diversity and represents the top part of the highstand systems tract of sequence Be6. It is topped by the sequence boundary of Be7. The upper part of the Chief Beef Beds, and possibly also the Broken Shell Limestone, are situated within polarity chron M15r.

10. The lower part of the Upper Cypris Clays and Shales falls within polarity chron M15n and correlates with the Valanginian Otopeta Zone. The upper part of the Upper Cypris Clays and Shales, the Battle faunicycle, is however situated within M14r. This implies that the sequence boundary of Va1 should be situated within the upper part of the Upper Cypris Clays and Shales, presumably between the Tyneham and Battle faunicycles. It coincides with the last occurrences of *Cypridea alta alta*, *C. setina setina*, and *C. obliqua* and with the first appearance of *C. recta recta*.

The Battle faunicycle is the top part of the Purbeck Formation in its stratotype area. The base of the type Wealden, however, correlates with the base of the Broken Shell Limestone, which is appreciably lower. The types of the Purbeck and Wealden formations overlap (Morter 1984). For convenience the description of the Wealden in the next paragraph begins with the Hastings faunicycle overlying the Battle faunicycle.

It appears that the distribution of magnetozones in the Lower and Middle Purbeck sequences are exactly the same as in the stratotype of the Berriasian Stage, thus supporting the inter-realmal correlation, but also the number and stratigraphic position of the sequence boundaries.

2. The Wealden succession in the Warlingham borehole: Valanginian, Hauterivian and Barremian (Column 3)

The correlation of this succession is rather tentative because of a scarcity of means of biostratigraphic correlation.

The base of the Weald Clay has traditionally been correlated with the base of the Hauterivian. I followed this assumption and considered it as a calibration point. Consequently the Hastings Beds are regarded as Valanginian in age.

The ostracod faunal change at the base of the *Cypridea aculeata* ostracod zone was typified by Anderson (in appendix B of Worssam & Ivimey-Cook 1971) as 'one of the most evident in the whole Purbeck-Wealden succession'. This faunal change 'coincides with a significant change in sedimentation. Below, the lithology is more akin to that of the Purbeck Beds, i.e. predominantly shale with limestones whilst above it the sandstones, silts and clays of the Wealden are most common'. The Lindfield Cycle is the horizon at which the change becomes evident. This faunal change is here interpreted as the expression of a type 1 sequence boundary in the upper Valanginian, i.e. Va4, in the basal part of the Pronocostatum Horizon. The changing frequency of ostracods and the schematic lithological columns depicted by Anderson (1985) were used to interpret the sequence-stratigraphic signal.

The boundary between the 'Horsham Phase' and the 'Henfield Phase' is also characterized by a marked ostracod faunal change (Anderson 1985) and therefore tentatively correlated with the type 1 sequence boundary of Ha3 in the upper part of the *Nodosoplicatum* Zone just below the boundary between the lower and upper Hauterivian. The sequences of the 'Horsham Phase' itself are the result of scientific guessing since no lithological log was available.

Topley's bed 5 (the numbering of Worssam & Ivimey-Cook 1971 is used here, not the numbering of Feist et al. 1995), a prominent sandstone bed at the top of the Henfield Phase, is tentatively correlated with the top part of the last and highest highstand systems tract below the type 1 sequence boundary in the uppermost Hauterivian Ha7. It is interpreted as a latest highstand subaerial complex, which is characterized by fluvial sediments deposited during a relative sea-level stillstand and built-up above sea level, enabling the fluvial systems to maintain their optimum equilibrium gradient as the highstand systems tract progresses seaward. The sand and the pellets (at depth 1325/8) in the upper part of the Bonnington faunicycle are also interpreted as such. Topley's bed 6, a limestone bed (at depth 1252) with large '*Paludina*' (= *Viviparus fluviorum*), is interpreted as a maximum flooding surface.

Topley's bed 7, another prominent sandstone interval, is interpreted in the same way as Topley's bed 5 and is correlated with the highest highstand systems tract directly below type 1 sequence boundary Ba2 (sharp top lined with a pebble bed at depth 1219/8). So, the type 1 sequence boundaries could readily be indicated.

In addition, the four thin pebble beds in the Henfield Phase that contain pebbles or coarse quartz grains, are interpreted in the same way. They are correlated with the topmost parts of the highstand systems tracts: at depths of 1450 ft./6 in. in the lower part of the Plumpton faunicycle, 1442 ft. at the top of the Ockley faunicycle, 1430 ft./6 in. at the top of the Newdigate faunicycle, 1416 ft., i.e. 8 inches above the top of Topley's bed 5 within the Capel faunicycle. The ironstone beds (at depths of 1513 ft./11 in., 1105 ft./4 in., 1076 ft./4 in., 1066 ft./10 in.) are interpreted as marking the transgressive surfaces of depositional sequences. Beds with marine fauna or with *Filosina* and *Cyrene* are interpreted as maximum flooding surfaces.

In this way many sequences of the Wealden Clay were reconstructed. It appears that the numbers of sequences thus found between the type 1 sequence boundaries Ha3, Ha7, Ba2 and from there up to the base of the Aptian, are the same as in the Río Argos succession in SE Spain. This suggests that the correlation proposed is realistic.

There is one biostratigraphic correlation possible: *Cribroperidinium boreas* enters just above Cement Bed number 4, in bed 138 of the Gott section in Germany (beds with *Hemicrioceras rude*) and in the Warlingham borehole at 1078 ft./1 in. depth, two feet below the ironstone bed (Harding 1990). These beds were already correlated with each other through sequence-stratigraphic considerations before the detection of this biostratigraphic tie, which thus supports the correlation achieved.

3. Speeton section parts E and D: Valanginian (Columns 4 and 5) (Figs. 2 and 3)

The uppermost highstand systems tracts of the various sequences in this part of the Speeton Clay Formation can be picked out quite easily with the help of the distribution of foraminifers (Fletcher 1973) and ostracods (Neale 1962b), and by the variations in the amount of pyrite (Neale 1968) at exactly the same levels. These three different lines of evidence lead to one and the same sequence-stratigraphic interpretation.

1. Foraminiferal fauna 5 in beds D8–D7E. The base of the Speeton Clay Formation is considered to be represented by the so-called ‘Late Kimmerian Unconformity’, which separates Kimmeridgian clays from late Ryazanian clays. The transgression on top of the unconformity begins with the coprolite bed E. Foraminiferal fauna 5 with only species of *Haplophragmoides*, a restricted fauna of arenaceous foraminifers, begins in bed D8 immediately above the coprolite bed. Bed D7G yielded the first dinoflagellate cyst *Oligosphaeridium diluculum* and the last *Kleithriasphaeridium porosispinum* (Heilmann-Clausen 1987), the association of which is characteristic of the *Stenomphalus* Zone. In the Río Argos succession *O. diluculum* appears at the base of the lowstand marls just above bed Y234. The top of bed Y234 is the type 1 sequence boundary of Be7, which is considered equivalent to the so-called ‘Late Kimmerian Unconformity’ in the North Sea. Beds E-top D5E3 comprise one depositional sequence, Be7, and embraces also foraminifer fauna 4.

Foraminiferal fauna 4 in beds D7D to top D6 (a similar division can be made with ostracods). It is interpreted here that during the deposition of bed D7E the water gradually became more aerated, for bed D7E yields the first ammonite and the first dinocyst *Pseudoceratium pelliferum*, bed D7D has the first foraminifer of foraminiferal fauna 4. Bed D7E may be equivalent to the base of the Valhall Formation in the subsurface of the northern North Sea. The whole bed D6 contains many ostracods, many foraminifers and much pyrite, and can be interpreted as a highstand systems tract. Bed D6I may be the maximum flooding surface, because it contains the peak in the abundance of ammonites. The lowest part of bed D5, i.e. levels D5E4+3, is barren of foraminifers, has the relatively poorest pyrite content and is considered to represent the shallow deposits in the top part of the highstand systems tract. Sequence boundary Va1 and the transgressive surface are interpreted to be on top of level D5E3, which represents a paleontological break (Neale 1968); above this level the pyrite content increases again.

With respect to the position of the *Stenomphalus* Zone in relation to the so-called ‘Late Kimmerian Unconformity’, stratigraphers seem to be confronted with the problem of two different rockunits that have been given the same age, but which have different stratigraphic positions: one above and the other below the ‘Late Kimmerian Unconformity’. So something must be wrong.

In its type area the *Stenomphalus* Zone is characterized by the concurrence of the last *K. porosispinum* and *Gonyaulacysta* sp. A, and of the first *O. diluculum* and overlies an important unconformity, which separates Kimmeridgian strata from upper Ryazanian strata. The same situation exist in the Speeton section and in the southern North Sea (Lott et al. 1989), where strata with *K. porosispinum* and *O. diluculum* (according to Heilmann-Clausen 1987; Davey 1982 these species occur in bed D7G) overlie a hiatus which separates them from Kimmeridgian strata. In the northern part of the North Sea, however, a stratigraphic unit characterized by (Davey 1979) the concurrent range of the last *Gonyaulacysta* sp. A (which starts its range in the Kochi Zone) and the first *O. dilucu-*

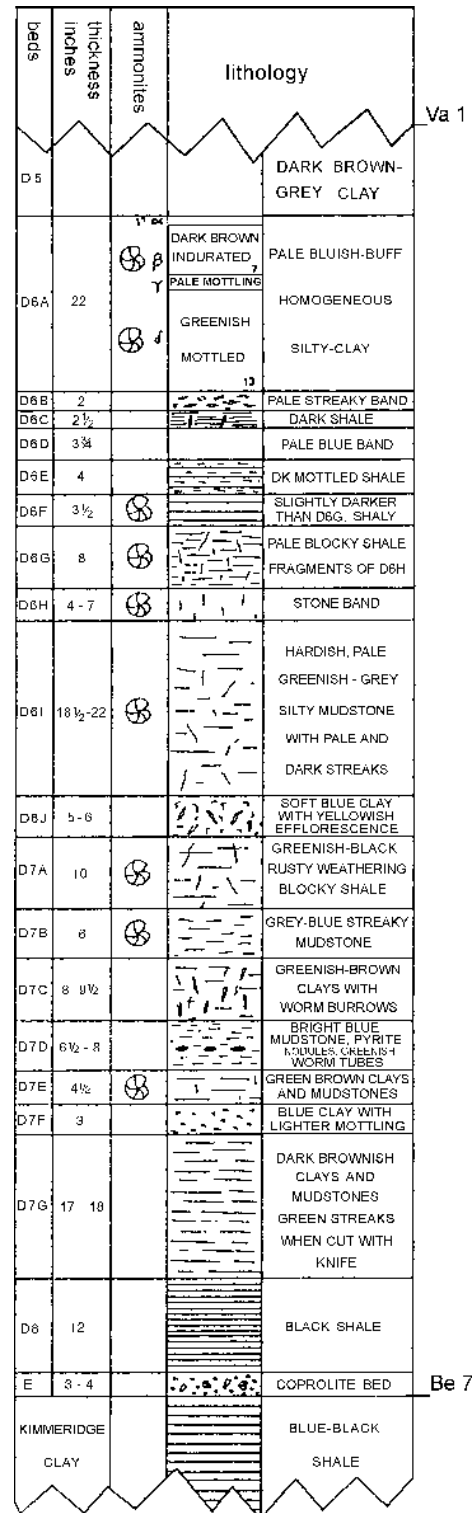


Fig. 2. Section through the lower D beds of the Speeton Clay near Speeton (E–D5); modified after Neale 1962.

lum is situated directly below the ‘Late Kimmerian Unconformity’. It is called the ‘*Stenomphalus* Maximum Flooding Surface’ (Partington et al. 1993).

In the northern part of the North Sea the ‘Late Kimmerian Unconformity’ is considered to be at the base of the Valhall Forma-

tion. The tectonic event producing this unconformity caused the relatively restricted and stagnating bottom waters of the North Sea to be flushed by well-oxygenated waters from outside the area. According to Rawson & Riley (1982) this event is situated below the *Stenomphalus* Zone, as is the case in the onshore situation. However, according to Partington et al. (1993) the characteristic *Stenomphalus* dinoflagellate cyst association is situated below this event in the northern North Sea.

In fact there are only two solutions to the problem. Either the true 'Late Kimmerian Unconformity' in the northern North Sea subsurface is situated still undetected within a more or less 'hot' clay succession directly below the *Stenomphalus* dinoflagellate cyst association (if this is true, the base of the Valhall Formation would be merely an oxygenating event), or there is a stratigraphic unit situated directly below the 'Late Kimmerian Unconformity' and confusingly called 'Stenomphalus MFS' which is not time-equivalent to the *Stenomphalus* ammonite zone (= transgressive systems tract of sequence Be7), but instead time-equivalent to the Tethyan upper Picteti Subzone (= highstand systems tract of sequence Be6). The latter solution is preferred here. The upper Picteti highstand systems tract is one of the highest sea-level stands of the Berriasian Stage and it would be strange if the corresponding depositional systems tract is not preserved in the North Sea; it is definitely not preserved onshore. If this stratigraphic unit is preserved in the northern North Sea, it may be characterized by a similar, but not the same, dinoflagellate cyst association to that of the Boreal *Stenomphalus* association. If the 'Stenomphalus MFS' below the Late Kimmerian Unconformity really correlates with the upper Picteti Subzone, *O. diluculum* would start its range in this stratigraphic unit instead of in the true *Stenomphalus* Zone directly above the Late Kimmerian Unconformity. The presence of *O. diluculum* in the Río Argos succession at a level very close to the Late Kimmerian Unconformity at the base of the lowstand systems tract (Leereveld 1997), which is not preserved in the Boreal Realm but is correlatable with levels appreciably below the Icenii Zone, may point in this direction. The Icenii Zone is a Remanié Horizon at the base of the *Stenomphalus* Zone and contains only fossils that are reworked from older stratigraphic units.

The English Kochi Zone was correlated by Hoedemaeker (1987, 1991) with the Tethyan *Privasensis/Dalmasi* subzones. It contains the ammonite *Borealites* cf. *fedorovi*. However, since it represents the lowest preserved transgressive deposits of the Ryazanian (the Runtoni Zone is merely based on phosphatic ammonites reworked in the basal part of the Kochi Zone), it correlates better with the worldwide large upper Berriasian transgression at the beginning of the Paramimouna Subchron. The so-called '*fedorovi*'-beds within the Kochi Zone sensu lato (Hoedemaeker 1987, 1991) may therefore better correlate with the transgressive systems tract of sequence Be4' near the base of the Paramimouna Subzone. The Siberian *Constans* Subzone and the *Buchia okensis* Zone in British Columbia may correlate with the maximum flooding interval of the same sequence (= Be 4').

2. Foraminiferal fauna 3 in beds D5E2 to top D4D. Level D5E2 yielded the first foraminifers of foraminiferal fauna 3. The base of bed D4D contains much pyrite and should therefore still be interpreted as forming part of the highstand systems tract. The upper part of bed D4D is devoid of foraminifers and should, by analogy with the levels D5E4+3, be considered to represent the shallowest deposits in the top part of the highstand systems tract, it is devoid of pyrite. The sequence boundary of Va1' and the transgressive surface of the overlying sequence should be situated on top of D4D. Foraminifers reappear in level D4C6.

3. The sequence comprising levels D4C6–D4C2. These levels still form part of foraminifer fauna 3. Level D4C2 is devoid of foraminifers and is interpreted as representing the shallow deposits in the topmost part of the highstand systems tract, but also represent-

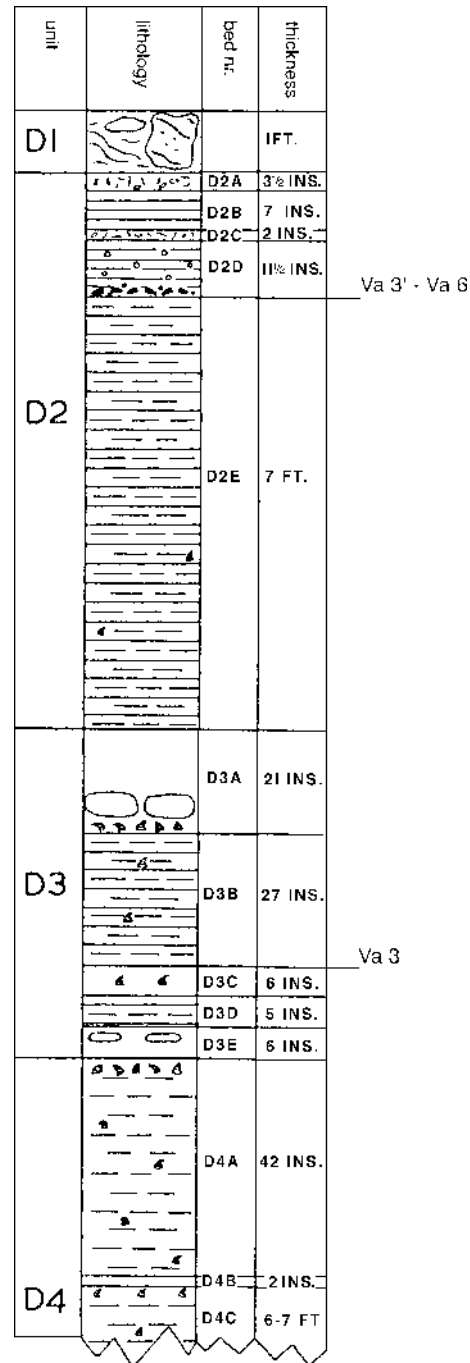


Fig. 3. Section through the upper D beds of the Speeton Clay near Speeton (D4–D1); modified after Neale 1960. The whole section consists of clay. Beds D1, D3A, and D3E contain limestone nodules and are prominent marker beds. Beds D2a and D2c are strongly mottled. The other prominent marker bed is D2D, which is highly glauconitic; black phosphatic nodules occur at its base; this base is packed with belemnites and other macrofossils. The small fossil symbols denote *Exogyra sinuata*. Sequence boundary Va2' is situated just below the column shown here.

ing the basal sediments of the overlying sequence, since it contains the first specimens of a new ostracod fauna (Neale 1962b). The sequence boundary of Va2 and the transgressive surface of the overlying sequence is situated within level D4C2. The overlying level D4C1 yielded the first foraminifers of foraminifer fauna 2.

4. Beds D4C2–D3C represent the next sequence of which the foraminifers-barren bed D3C is interpreted as representing the upper highstand systems tract. This bed contains the highest percentage of light fraction, siderite crystals, much pyrite and many remains of *Serpula*. The sequence boundary of Va3 and the transgressive surface of the next sequence are situated on top of bed D3C.

5. Beds D3B–D2E embrace the next sequence. It constitutes the upper part of foraminiferal fauna 2. Sequence boundary Va3' is on top of bed D2E, which represents a large hiatus with an important paleontological break. Bed D3A may be the maximum flooding surface; it contains brown nodules and much pyrite. Bed D2D and higher are of Hauterivian age.

4. Speeton section D2D to LB5E: Hauterivian (Fig. 4)

In principle, the pale clay beds are interpreted as shallower water deposits than the dark clay beds, so that sudden changes from dark bed sets (sets of beds in which dark clay dominates) to pale bed sets (sets of beds in which pale clays dominate) are candidates for sequence boundaries. Relatively abundant occurrences of ammonites are interpreted as representing more condensed deposits than the sediments in which the ammonites are relatively scarce. Abrupt changes in ammonite composition are also interpreted as candidates for sequence boundaries. The sea-level highstand systems tracts are clearly recognizable and often contain ammonites which immigrated from the Tethys. By determining these highstand systems tracts the sequences could be reconstructed.

1. The first highstand systems tract comprises bed D1 because of the abundance of ammonites and the presence of Tethyan taxa (*Olcostephanus* sp.). The abrupt end of this abundance marks the sequence boundary of Ha1 on top of bed D1. This horizon is bioturbated.

2. The second highstand systems tract comprises bed C9D because of the dark colour of the clay. The abrupt appearance of many new ammonite species in the overlying pale bed C9C marks sequence boundary Ha2 on top of C9D; this top is bioturbated.

3. The third highstand systems tract is bed C8B because of the abundance of ammonites and of the dark colour of the clay. The ammonite fauna contains several Tethyan taxa. An abrupt change in the ammonite fauna on top of C8A marks the sequence boundary of Ha2'. This change marks the base of the Inversum Zone.

4. The fourth highstand systems tract comprises bed C7H. The fauna in this bed is quite different from that in the underlying beds and is abruptly separated by the sequence boundary of Ha3 from the overlying bed and fauna. This sequence boundary marks the transition from a fauna with warm-water organisms to a pure cold-water fauna, which begins with a pale clay. Bed C7H comprises the whole sequence; the glauconite in this bed is reworked.

These four sequences are relatively thin, which implies a relatively slow deposition. This is also indicated by the relative richness in ammonites. The two next sequences, the fifth and sixth, are relatively thick and rather poor in ammonites. This implies rapid deposition during that time.

5. The fifth highstand systems tract comprises beds C6–C5K because of the abundance of fossils, among which are Tethyan species, and the dark colour of the clay. Sequence boundary Ha4 is chosen at the bioturbated top of the first pale bed C5J.

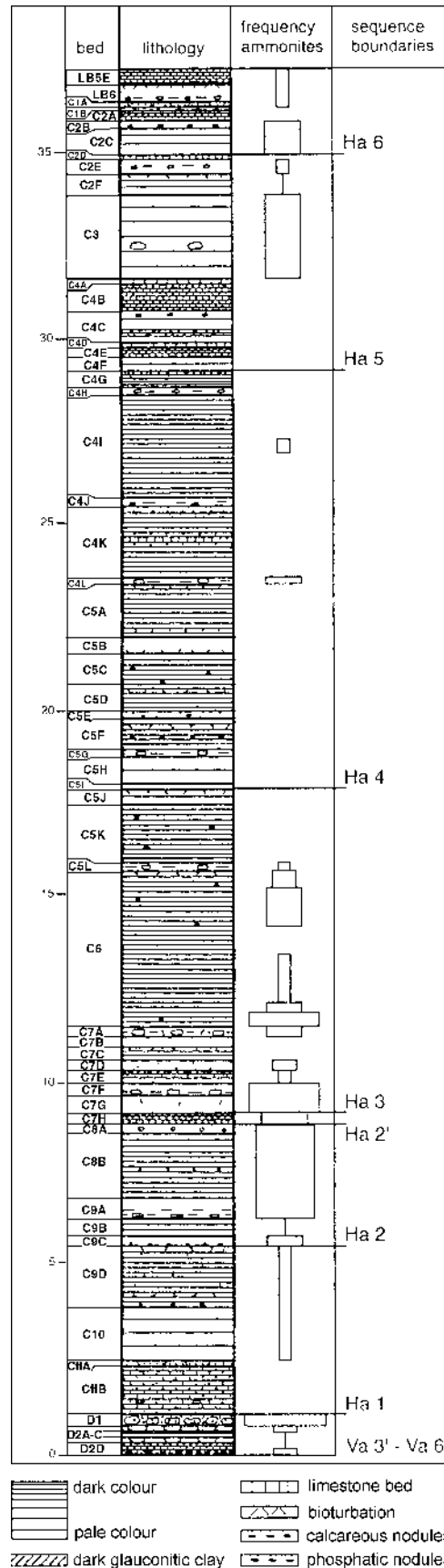


Fig. 4. Section through the Hauterivian of the Speeton clay succession near Speeton (D2D–LB5E); modified after Rawson 1970.

6. The sixth highstand systems tract comprises beds C4L–G because of the dark colour of the clay and because of the presence of ammonites. C4L is considered the maximum flooding surface as it contains several ammonites; they mark the beginning of the Gottschei fauna. The sequence boundary of Ha5 is placed below the first pale bed C4F on top of a bioturbated bed.

The next two highstands are relatively thin again and contain many ammonites.

7. The seventh highstand systems tract is bed C3 because of the abundance of ammonites of the Margaritatus Zone, and the presence of many *Echinospatangus*. Although it is a highstand systems tract, bed C3 is very pale instead of dark, which means that there had been a change in environment. Apparently most of the dysaerobic deeper waters had disappeared. It seems that the extreme average high sea level caused an influx of well-oxygenated water. The sequence boundary of HA6 was placed at the base of the abrupt faunal change at the top of C2D. This faunal change marks the base of the Variabilis Zone.

8. The eighth highstand contains the dark clay beds LB5E+D. The glauconite bed LB5E yields the last Hauterivian *Simbirskites*. LB5D yielded already flattened ammonites resembling *Crioceratites* (*Paracrioceras*) *rarocinctum*, from which it can be inferred that the Hauterivian/Barremian boundary sensu Hoedemaeker (1996) (i.e. in the middle of the *Pseudothurmannia* beds at the base of the Catulloi Zone), is probably situated between LB5E and LB5D. The sequence boundary of HA7 is considered to be on top of bed LB5C, which consists of pale clay and is barren of foraminifers (Fletcher 1973), and is therefore considered to represent the shallow facies characteristic of the top part of highstand systems tracts. The Variabilis Zone has been put into the basal Barremian (Kemper et al. 1981) merely on account of the presence of *Paracrioceras spathi* in bed C2C. Because of the similarity of the ornamentation this species has been considered close to *Emericiceras thiollierei* (Kemper et al. 1981), which is restricted to the Barremian. However, *P. spathi* is not an *Emericiceras*, because the latter genus is characterized by a very open initial spire, has a very slow increase in whorl height and has a compressed whorl section; *P. spathi* does not show these characteristics and therefore is no basis for including the Variabilis Zone in the Barremian.

5. Speeton section LB5B to lowest 2 Cement Beds: Barremian (Fig. 5)

1. The first highstand above HA7 comprises beds LB4D to LB3E and yielded a few ammonites *Crioceratites* (*Paracrioceras*) cf. *rarocinctum* and *C. (P.)* cf. *occultum*. Beds LB4B, LB4A, and LB3E consist of pale clay and contain a level without foraminifers, bed LB4A (Fletcher 1973). They are therefore interpreted in a similar way as bed LB5C, as the top highstand systems tract. The sequence boundary of Ba1 is considered to be on top of LB3E.

2. The second highstand comprises at least bed LB3A, which also yielded a few ammonites, viz. *Hoplocrioceras* cf. *phillipsi* and *C. (P.) fissicostatum*. The sequence boundary of Ba1' is considered to be on top of bed LB3A.

3. The third highstand consists of dark clays with pyrite. It contains the ammonites *C. (P.) fissicostatum* and, at two levels, *C. (P.)* cf. *varicosum*. The sequence boundary of Ba2 is considered to be situated at the base of the first group of pale coloured beds on top of bed LB1F.

4. The fourth highstand also consists of dark clays with pyrite and ammonites, *Barremites* sp. and *C. (P.) elegans* at two levels. The sequence boundary of Ba3 should be drawn on top of bed LB1A

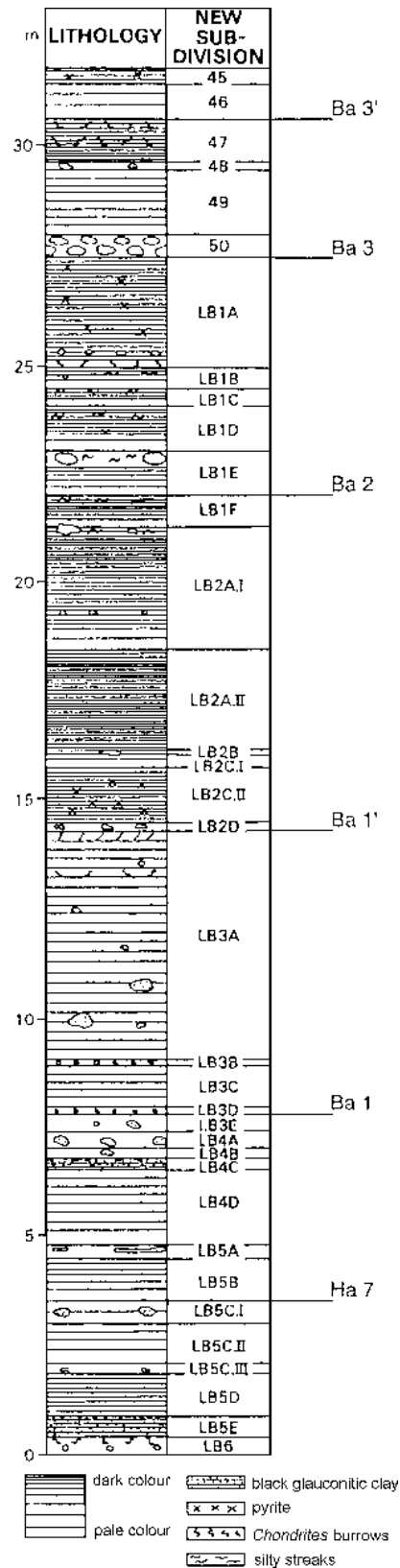


Fig. 5. Section through the Lower B Beds and Lower Cement Beds (Barremian) of the Speeton clay succession near Speeton (LB6–bed CB6); modified after Rawson & Mutterlose 1983.

at the base of the next shallow, pale coloured bed, which is at the base of the first, double, cement bed (bed 50 = cement bed 7).

5. The fifth highstand consists of dark clays with pyrite and ammonites and comprises bed 47 (= directly above cement bed 6). The sequence boundary of Ba3' is on top of this bed and is followed by a pale coloured clay bed, bed 46.

A sequence stratigraphic interpretation of the higher Cement Beds and the Upper B Beds is not possible because of the lack of detailed lithological and paleontological descriptions. The subdivision into sequences is merely inference.

Sequence-stratigraphic analysis of the German sections (column 2)

1. Katzberg Member, Serpulit Member and Bückeberg Formation (Figs. 6 and 7).

The Isterberg 1001 borehole described by Strauss et al. (1993), is the best log of the Bückeberg Formation described in the literature. The sequences can be interpreted with the aid of the palynology and palynofacies records from this borehole. The depositional sequences as interpreted by Strauss et al. (1993) are largely followed. It is thought that the lowstand systems tracts are not preserved because of the extremely shallow depositional setting and that the Bückeberg Formation is a stacking of mainly highstand systems tracts. The intervals with abundant degraded terrestrial matter are interpreted here as terrestrial freshwater deposits prograding basinward in the highest parts of highstand systems tracts. The tops of the intervals with abundant degraded organic matter are interpreted as sequence boundaries/transgressive surfaces. The thin or absent transgressive systems tracts and the maximum flooding episodes exhibit 'clean' palynofacies assemblages and the 'blocky claystone beds' are the most frequent type of lithology in these assemblages.

The correlation of the sequences can only be done after correlation with the Purbeck-Wealden succession in England by means of ostracods. The correlation with the English Purbeck and the Tethyan Río Argos succession are discussed in Leereveld & Hoedemaeker (in prep.).

The sequences drawn in the correlation chart (see folded chart in enclosure) in the Katzberg Member are attributable to pure inference. The appearance of *Cypridea inversa* was chosen as the base of the correlation chart. This species appears at the base of the *Cypris* Freestones but also low in the Katzberg Member. These levels were correlated with each other. On account of magnetostratigraphy, the basal part of the English Purbeck Beds up to a level within the *Cypris* Freestones correlates with the Tethyan Durangites Zone (Ogg et al. 1994a,b). A similar age can therefore be inferred for the basal part of the Katzberg Member and for the entry of *C. inversa*.

On account of the presence of the ostracods *Cypridea dunkeri dunkeri* (= *C. sowerbyi*) and *C. posticalis*, the Serpulit Member correlates with the lower part of the Middle Purbeck (Anderson &

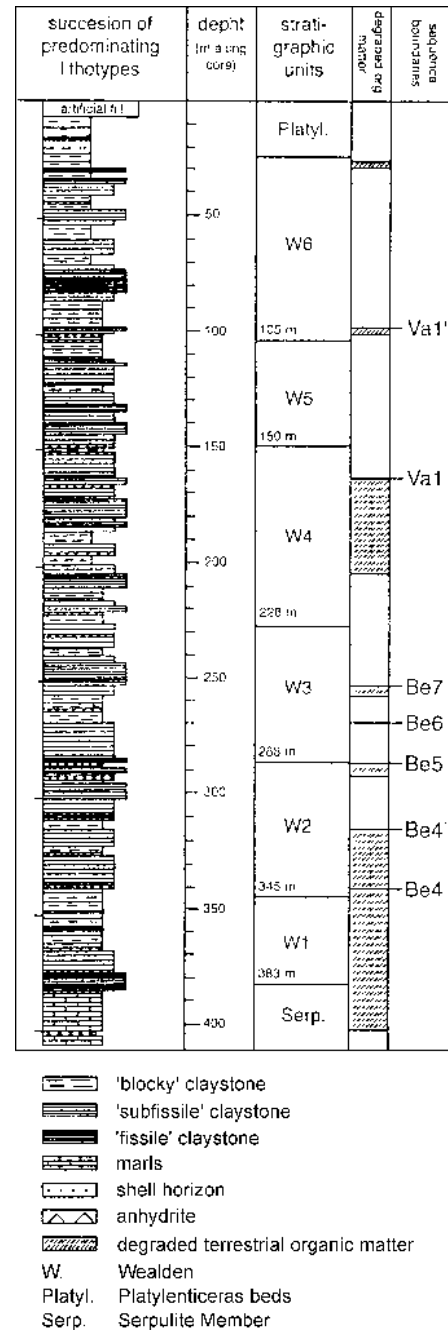


Fig. 6. 'Wealden' succession in Isterberg Borehole 1001; modified after Strauss et al. 1993.

Hughes 1964), or, more precisely, with the upper Ashdown, Swanage, Netherfield and Durlston faunicycles. The Mammal Bed, within the Ashdown faunicycle (Morter 1984), represents the most prominent emergence episode during Purbeck times and most likely corresponds to type 1 sequence boundary Be3. This level correlates with the base of the Serpulite Member. The top part of the Serpulite Member can be correlated with the Durlston faunicycle (Anderson & Hughes 1964; Anderson & Bazley 1971; Anderson 1985); this cycle and the highest part of the Serpulite Member contain the overlap of the ranges of *Cypridea posticalis* and *C. granulosa fasciculata* (Klingler et al. 1962; Anderson 1985).

The correlation of the Cinder Bed with the lower part of the German 'Wealden' 1 has been made by Anderson & Hughes

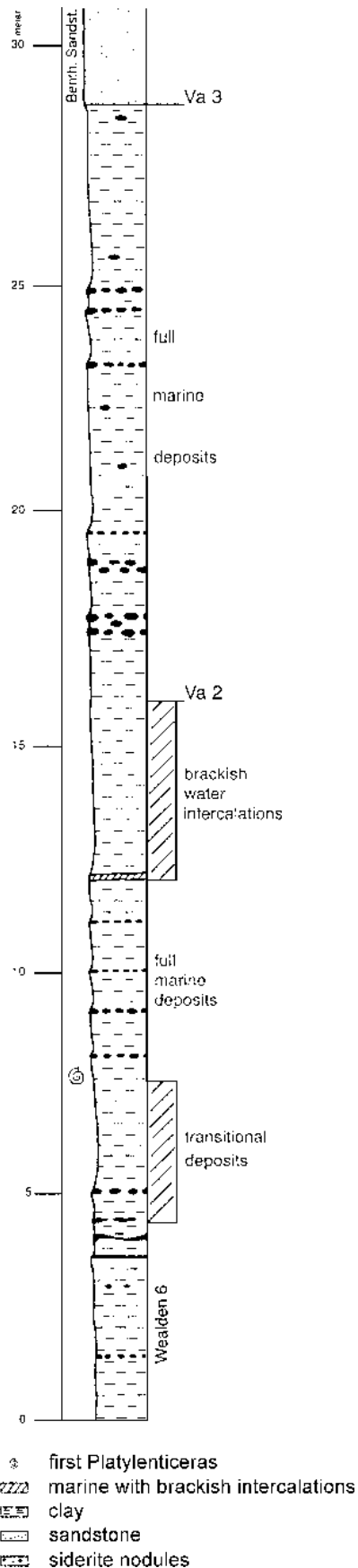


Fig. 7. *Platyentoceras* Beds at Suddendorf; modified after Kemper 1961.

(1964), by Anderson & Bazley (1971) and by Anderson (1973) on the basis of ostracods. In this paper the Cinder Bed is correlated with the blocky claystones and shell beds in the upper part of Wealden 1. The sequence boundary of Be4 is considered to be situated a few metres above the base of 'Wealden' 2, at 340 m depth along the core.

The Middle Purbeck Scallop Beds, a quasi marine interval amidst brackish to freshwater deposits in England, is marked by the entry of *Cypridea dolabrata* s.l., *C. brevirostrata*, *C. rectidorata*, *C. bimammata* (Anderson 1962; Anderson & Bazley 1971; Anderson 1985). On the basis of these ostracods this level correlates with the highest part of the German 'Wealden' 2. This means that the sequence boundary, interpreted as being at the top of the interval with degraded organic matter in the middle of 'Wealden' 2, should represent the sequence boundary of Be4' (316 m depth). This implies that the sequence boundary considered to top the thin interval of degraded organic matter at the base of 'Wealden' 3 should represent the sequence boundary of Be5 (depth 288 m).

The sequence boundary of Be6 is not readily apparent, but is interpreted as occurring at 270 m depth along the core. The dinoflagellate cyst peak at 276.1 m depth represents the maximum flooding surface that in France has been called 'Discontinuité 1' (Di1). The maximum flooding surface drawn by Strauss et al. (1993) at 233 m depth is not interpreted as a maximum flooding surface here.

The base of the Lulworth faunicycle, which comprises the Upper Broken Shell Limestone at the base of the Upper Purbeck in England, is marked by the entry of *Cypridea setina setina* (= *C. setina ovata*). According to Wolburg (1959) this species also appears in the middle of 'Wealden' 3 in Germany. As the Broken Shell Limestone Bed represents the highest prograding part of the highstand systems tract of sequence Be6, this would imply that the Upper Broken Shell Limestone apparently correlates with the interval of degraded organic matter in the middle of 'Wealden' 3. This would also mean that the sequence boundary on top of this interval with degraded organic matter (at 252 m depth) should be the type 1 sequence boundary of Be7, the so-called 'Late Kimmerian Unconformity'. This 'unconformity' seems to coincide with the well-known K-horizon of the Schlumberger resistivity curve of the Bückeberg Formation (Wick & Wolburg 1962; also apparent from fig. 5 in Strauss et al. 1993), which near the basin margins seems to be onlapping. According to Wolburg (1959) *C. alta alta* and *C. setina* s.l. appear just below the K-horizon, which is in accordance with the appearances of these taxa in England, i.e. just below the sequence boundary of Be7. The ranges for *C. alta alta* and the subspecies of *C. setina* given by Elstner & Mutterlose (1996) are quite different from those of Anderson (1985) and Wolburg (1959). As to *C. alta alta*: Anderson & Bazley (1971) state that forms similar to this species occur in the Scallop faunicycle, which would explain the early start of the range of *C. alta alta* according to Elstner & Mutterlose (1996) in the highest part of 'Wealden' 2.

The dinocyst acme at 220.6 m depth along the core would represent the maximum flooding surface that in France is called 'Discontinuité 2'. This dinoflagellate cyst acme contains the concurrence of *Amphorula delicata* and *Kleithriasphaeridium fasciatum*, which occur together only in the upper part of the Be7 sequence in the Tethyan Realm. Between 220.7 and 221.5 m depth the co-occurrence of the ostracods *Cytheropteria triebeli* and *Schuleridea juddi* permits a correlation with Speeton Bed D6 (Neale 1962b) in the upper part of sequence Be7.

The next sequence boundary, that of Va1, should be drawn on top of the thick interval of degraded matter at 153 m depth along the core. The boundary between 'Wealden' 4 and 5 is characterized by the disappearance of *Cypridea alta alta*, *C. setina setina*,

and *C. obliqua* and by the appearance of *C. recta recta* (Wolburg 1959). This level can therefore be correlated with the top of the stratotype of the Purbeck Formation in England, which is the boundary between the Battle and Hastings faunicycles.

The sequence boundary of Va1' is interpreted as occurring on top of the thin interval with degraded organic matter at 114 m depth along core. The maximum flooding interval of sequence Va1' is considered to be represented by the first fully marine ammonite bearing beds of the Robustum Zone, the lower Platylenticeras Beds. The Robustum highstand systems tract is shallowing upward into brackish fossil-rich deposits, which are interpreted as the basinward prograding shallow near-coastal facies in the top part of the highstand systems tract. The top of this brackish interval is interpreted as sequence boundary Va2 and abruptly overlain again by fully marine sediments with many ammonites.

The sequence of Va2 has been referred to by Kemper (1961) as 'the second more extensive Valanginian transgression'. The sequence boundary of Va2 is situated in the lower part of the Heteropleurum Zone and sequence Va2 embraces the middle and upper part of the Heteropleurum Zone and the Involutum Zone. This depositional sequence yielded the first *Dissiliodinium globulum* and *Occusicysta tentorium* (Below 1981) which also have their first appearances in the same sequence in the Río Argos succession. The presence of species of the genus *Paratollia* (Kemper 1961, 1976, 1992) in the upper part of the Platylenticeras Beds confirms the correlation of the Platylenticeras Beds with the upper part of the English Paratollia Beds. Several species of the genera *Propolyptychites*, *Polyptychites* and *Euryptychites* were also found above the sequence boundary of Va2 in the upper Platylenticeras Beds (Kemper 1961). None of these genera have been found yet in the upper Paratollia Beds of the Speeton section where only one badly preserved specimen of *Platylenticeras* cf. *involutum* (Doyle, personal communication). The specimens of *Platylenticeras* found in the Mediterranean area are all from sequence Va2 (Thieuloy 1973, 1977) and are restricted to the lowstand systems tract.

The base of the Bentheimer Sandstone is interpreted as the sequence boundary of Va3, the main sandstone body as the lowstand systems tract of sequence Va3.

2. The middle Valanginian of Northern Germany

For this stratigraphic interval no detailed log is available. The appearance of *Saynoceras verrucosum* slightly above the base of the Hollwedensis Zone (Kemper et al. 1981) provides a good correlation with the base of the Mediterranean Verrucosum Zone. The top of the 'Bentheimer Sandstein', i.e. the base of the 'Erectum Zwischenmittel', is a well-known transgressive event, which corresponds to the top lowstand surface just below the base of the Verrucosum Zone. The 'Erectum Zwischenmittel' itself represents the transgressive and highstand systems tracts of sequence Va3'. Bartenstein & Bettenstaedt (1962) and Kemper (1978, 1987) repeatedly emphasized the important faunal break at the top of the 'Erectum Zwischenmittel', which is directly followed by the second mass influx of Tethyan taxa. This level is interpreted to represent type 1 sequence boundary Va4.

The 'Romberg Zwischenmittel', a shaly intercalation within the 'Bentheimer Sandstein' (Kemper 1992), should consequently correlate with the high sea-level stand (transgressive and highstand systems tracts of sequence

Va3) in the upper part of the Campylotoxus Zone, equivalent to the Eristavites platycostatus Subzone.

The genus *Polyptychites* is present from the top lowstand surface of sequence Va2 to the top of sequence Va3' in the Boreal as well as in the Tethyan Realm (Thieuloy 1973, 1977). *Prothocythere hannoverana* has the same range in Germany and England (Bartenstein & Bettenstaedt 1962; Neale 1962b). The first occurrences of *Prodichotomites* and of the ostracod *Prothocythere praetriplicata* are situated in sequence Va3' in both realms (Donze 1976; Cotillon 1971; Bartenstein & Bettenstaedt 1962; Thieuloy 1973, 1977).

3. The uppermost Valanginian and lowermost Hauterivian along the Mittellandkanal near Pollhagen (Fig. 11)

The maximum flooding surfaces in this stratigraphic interval are recognized only by the ammonite frequency peaks shown by Quensel (1988: fig. 11) and the lowstand systems tracts by the frequency minima between the peaks.

The most prominent peak-frequency of the ammonites is situated at the base of the Noricum Zone, which is therefore considered to coincide with a maximum flooding surface.

There are two other peak-frequencies, viz. in the middle of the Bidichotomoides Zone and near the base of the Paucinodum Zone. The upper part of the Bidichotomoides Zone and the upper part of the Paucinodum Zone are therefore interpreted as highstand systems tracts.

Deep lows in the megafossil frequency are situated in the Ivanovi Zone and in the lower Amblygonium Zone. The Ivanovi Zone and the lower Amblygonium Zone are therefore interpreted as lowstand systems tracts. The lowstand systems tract in the Ivanovi Zone contains a peak in detrital quartz grains.

Also the 'Grenzsandstein' is interpreted as an expression of a lowstand systems tract, and this is an argument for the assumption of the 'Grenzsandstein' being time-equivalent with the lower Amblygonium Zone. Another argument is that the first *Endemoceras* has been found by the oil geologists in Emsland at a level just below the upper dentation of the so-called BH-dentations (Kemper 1992), which mark the Schlumberger resistivity curve of the 'Grenzsandstein'.

The higher part of the German Amblygonium Zone contains the level in which the first *Acanthodiscus radiatus* has been found (which by definition is the base of the Hauterivian) and the 'Grenzsandstein' therefore probably represents the lowstand systems tract at the top of the Valanginian; thus the lower part of the Amblygonium Zone is of Valanginian age. The two peak-frequencies of ammonites below the Amblygonium Zone, viz. of the Paucinodum and Bidichotomoides zones, should therefore correspond to the highstands in the top and at the base of the Furcillata Horizon respectively. This is in accordance with the range of *Olcostephanus densecostatus*, which starts in the Furcillata Horizon and is abundantly present in the Paucinodum Zone (Bulot 1992).

The Crassus and Triptychoides zones are considered to correlate with two transgressive/highstand systems tracts between the Bidichotomoides and Polytomus highstands and should as a matter of course correspond to the highstands determined in the lower Peregrinus and lower Nicklesi horizons.

As a consequence of these correlations the ranges of *Varlheidites perigrinus* in Germany and in France coincide exactly with each other, as do the first appearances of *Dichotomites* and of *Protocythere frankei* (ostracod) and the last occurrence of *Protocythere praetriplicata* (ostracod) (Bartenstein & Bettenstaedt 1962; Donze 1976). The entry of *P. triplicata* in the Paucinodum Zone (Niedziolka 1988) also correlates with its appearance in the Tethyan Furcillata Horizon (Donze 1976). Thus, there is good biostratigraphic support for the correlation of the sequences in this stratigraphic interval.

4. Sequences in the Moorberg clay pit near Sarstedt (Germany) (Fig. 8)

The principle sequence-stratigraphic line of thought followed with respect to the analysis of this clay succession is that the dark-grey clay intervals represent sediments deposited during relative sea-level highstands, when the rising anoxic/dysoxic, cool deeper waters reached the local depositional level, whereas the light-grey clay intervals represent sediments deposited during relative sea-level lowstands in better oxygenated, shallower, warmer waters. Moreover, in such clayey successions the sea-level highstand systems tracts generally have a relatively high lime content because of the concentration of calciflora due to condensation. The bases of the intervals in which dark-coloured clay beds dominate, are interpreted as maximum flooding surfaces; the bases of the intervals in which light-coloured clay beds dominate, are interpreted as sequence boundaries. When dark-grey beds cyclically alternate with light-grey beds, the former are interpreted as deposited on top of marine flooding surfaces and the dark-light couples as parasequences.

This means that the following (groups of) beds in the Moorberg clay pit are interpreted as highstand systems tracts:

- 1) The lower part of the Noricum Zone (bed 99). The sequence boundary of Ha1 on top of bed 99.
- 2) The middle part of the Regale Zone (beds 80–87). The sequence boundary of Ha2 on top of bed 87.
- 3) The lower part of the upper Regale Zone (beds 83 + 82). Maximum flooding surface in bed 83. The sequence boundary of Ha2' on top of bed 82, which has a high lime content (i.e. more condensed) and a bioturbated top. Sequence Ha2' begins with beds with a relatively low lime content (i.e. less condensed).
- 4) The upper part of the Regale Zone (beds 80–74). The type 1 sequence boundary of Ha3 on top of bed 74. This is the level of the so-called 'DHo discontinuity' of Kemper (1992) interpreted by him as an important global regressive/transgressive event attended by an important faunal turnover.

5) The lower part of the Staffi Zone (bed 72). The sequence boundary of Ha4 on top of bed 72.

6) The upper part of the Staffi Zone (beds 64–59). The sequence boundary of Ha5 on top of bed 59.

7) The upper part of the Gottschei Zone and the basal part of the Discofalcatus Zone (beds 39 to –13). The glauconite-bearing bed –1 is maximum flooding surface (correlates with bed 50 of the Gott section). The sequence boundary of Ha6 on top of bed –13 marks the end of a bioturbated interval.

8) The uppermost part of the Discofalcatus Zone (bed –24). The type 1 sequence boundary of Ha7 on top of bed –24.

9) The Rarocinctum Zone (beds –29 to –34). The sequence boundary of Ba1 on top of bed –34.

10) The lower Fissicostatum Zone (beds –36 to –48) (Chondrites Beds). Sequence boundary on top of bed –48.

11) The upper Fissicostatum Zone (bed –50) (Hauptblättertön). The type 1 sequence boundary of Ba2 on top of bed –50.

5. Sequences in the Gott clay pit near Sarstedt (Germany) (Fig. 9)

The same sequence-stratigraphic line of thought as in the Moorberg clay pit is used to determine the sequences in the Gott clay pit. The following (groups of) beds are interpreted as highstand systems tracts:

1) The upper part of the Gottschei Zone and lower part of the Discofalcatus Zone (beds 50–57). The sequence boundary of Ha6 on top of bed 57.

2) The upper part of the Discofalcatus Zone (beds 69–71). The type 1 sequence boundary of Ha7 on top of bed 71. This level corresponds to a faunal caesura (Mutterlose 1984).

3) The Rarocinctum Zone (beds 79–82). The sequence boundary of Ba1 on top of bed 82.

4) The lower Fissicostatum Zone (beds 84–98). The sequence boundary of Ba1' on top of bed 98.

5) The upper Fissicostatum Zone (bed 100) (Hauptblättertön). The type 1 sequence boundary of Ba2 on top of bed 100.

6) Bed 109–115, interpreted to be the Elegans Zone. The sequence boundary Ba3 on top of bed 115.

7) Bed 117, interpreted to represent the Denckmanni Zone. The sequence boundary of Ba3' on top of bed 117.

8) Bed 135–137 (= beds with *Hemicrioceras rude* according to Kemper, personal communication in Heilmann-Clausen & Thomsen 1995). The sequence boundary of Ba4 on top of bed 137. (Beds 126–132 = beds with "*Crioceratites*" *sparsicostata* according to Kemper, personal communication in Heilmann-Clausen & Thomsen 1995).

9) Bed 185, possibly equivalent to the Stolley Zone. The sequence boundary of Ba4' on top of bed 185.

10) Bed 191–198, presumably Bidentatum Zone. The sequence boundary of Ba5 on top of bed 198.

Berriasian and Valanginian of the Swiss and French Jura Mountains (column 6)

It is difficult to detect sequences in very shallow marine limestones. In such facies lowstand systems tracts are not preserved. For the middle and upper Berriasian Stage and the Valanginian Stage the sequence stratigraphic interpretation by Arnaud (personal communication) in the Chambotte section (southern Jura) was used. For the lower Ber-

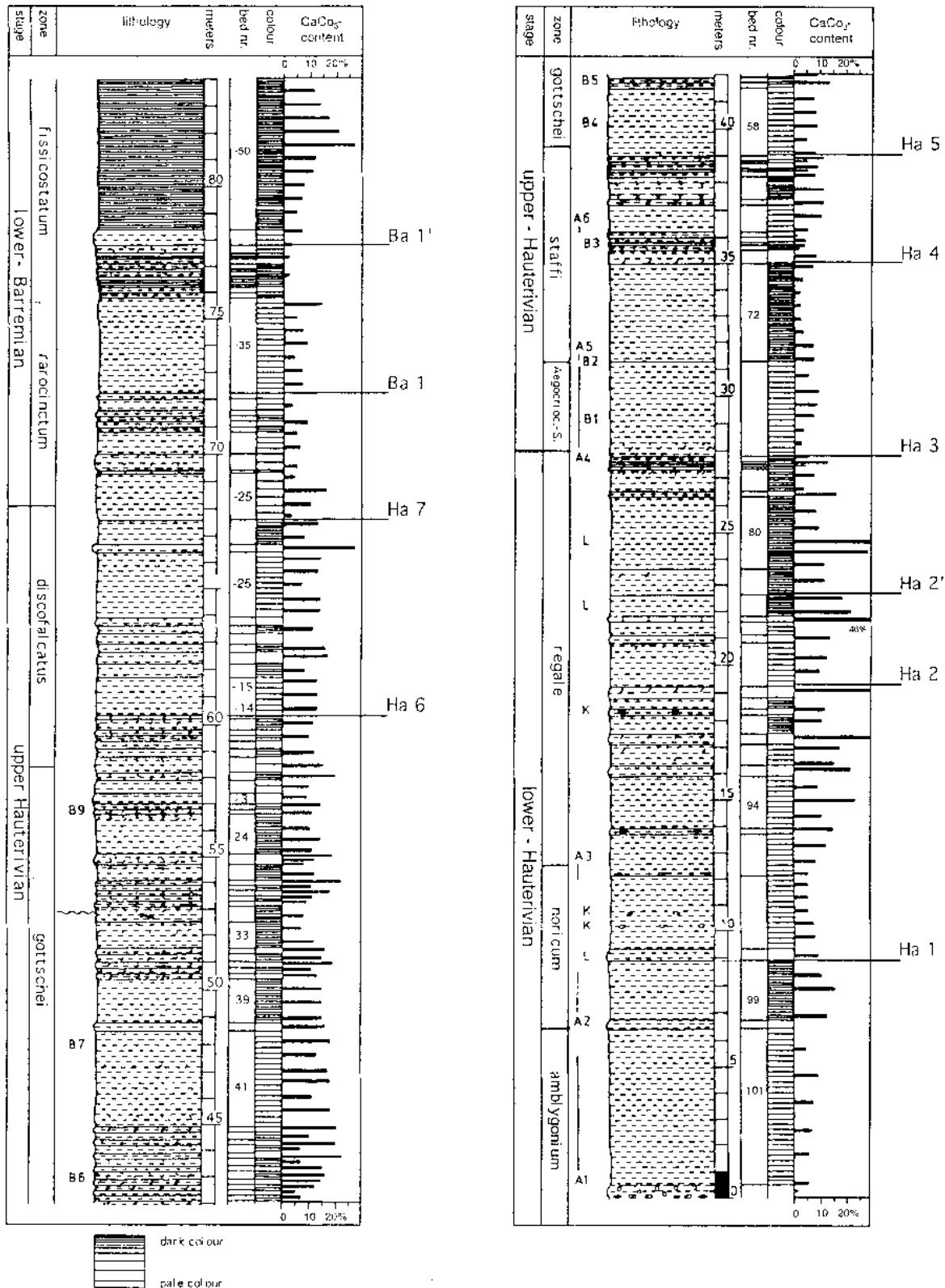


Fig. 8. Section through the Hauterivian of the Moorberg clay pit near Sarstedt; modified after Mutterlose 1984.

riasian the section of the Goldberg Formation was used (Strasser 1988, 1994). Strasser interpreted the beds of the Goldberg Formation as an expression of the Milankovitch cyclicity and numbered the 100,000 year cycles (Fig. 10).

1. Ostracods of the Goldberg Formation indicate a correlation with Anderson's (1985) ostracod assemblages 2 and 3 (Detraz & Mojon 1989) of the Lower Purbeck of England. This means that the lowest sequence boundary, at the base of cycle 17, should be considered to be equivalent to Be1. The base of cycle 17 has been

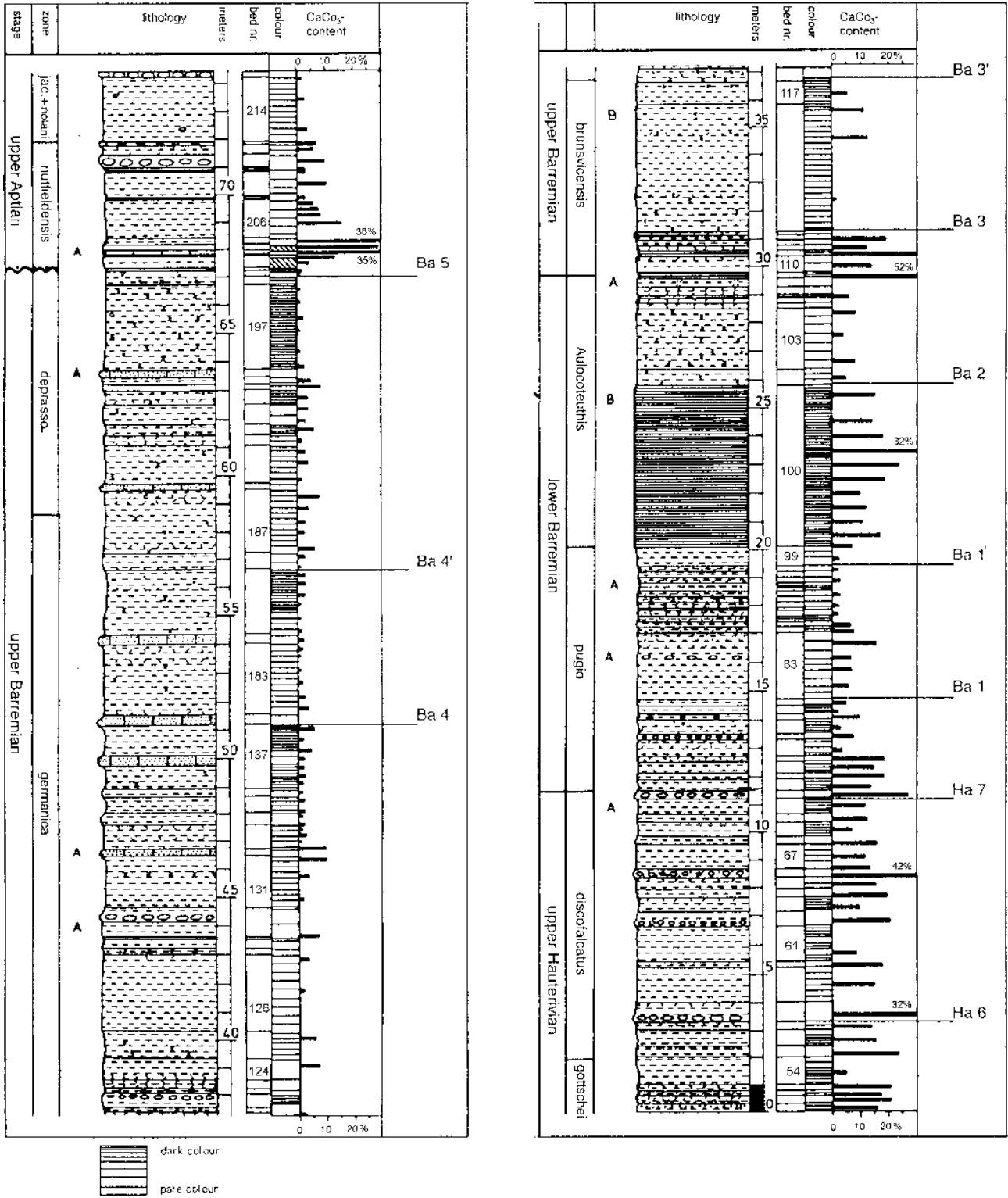


Fig. 9. Section through the Barremian of the Gott clay pit near Sarstedt; modified after Mutterlose 1984.

chosen as a sequence boundary because it shows brecciation and calcrete has formed on top of it. This bed is the first subtidal oolite grainstone bed on top of an intratidal bed with algal mats and dessiccation polygons.

2. The next sequence boundary, that of Be1', is placed on top of cycle 22 which is slightly evaporitic. Calcrete has also formed here

on top of the bed signifying emersion. Cycle 22 is overlain by the first subtidal rudstone bed and underlain by a set of intratidal beds.

3. The next sequence boundary, that of Be2, is placed at the top of cycle 24, which is brecciated, topped by calcrete and was subaerially exposed. It is slightly evaporitic and is probably a sabkha deposit. It forms the top of a set of supratidal beds with much *Chara-*

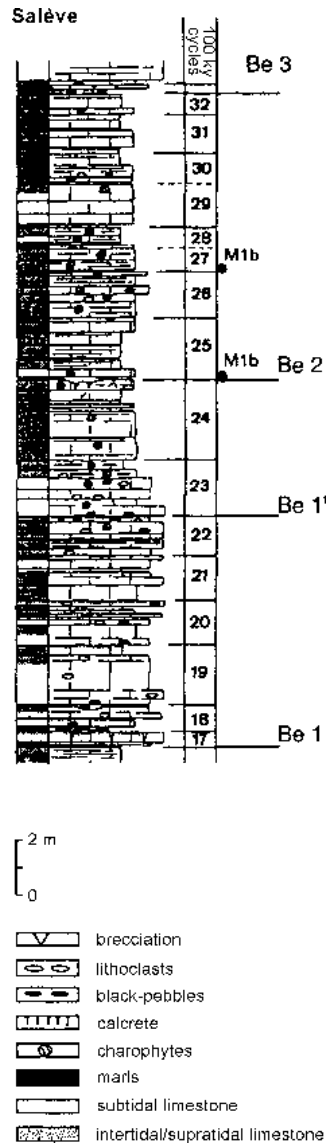


Fig. 10. Section through the Goldberg Formation (Berriasian) near Salève (France); modified after Strasser 1994.

remains and is overlain by a subtidal bed. It seems to be the base of Chara Zone M1b (Detraz & Mojon 1989) and of ostracod assemblage 3.

4. The sequence boundary which tops the Goldberg Formation is the type 1 sequence boundary of Be3 and is inferred to be on top of cycle 32, which shows dessiccation polygons. This sequence boundary is followed by the Pierre Châtel Formation the base of which is generally thought to be equivalent to the 'Oolitische Mergel und Kalk Zone' (= Unité inférieure oolithique). The lacustrine interval intercalated within this fully marine unit is interpreted as representing the prograding top part of the highstand systems tract of sequence Be3, which is equivalent to the Cinder Bed in England. Ostracods support this correlation (Detraz & Mojon 1989).

The sequence-stratigraphic interpretation of the Pierre Châtel, Vions, Chambotte and Bourget formations is largely in accordance with the interpretation of Arnaud (personal

communication, 1992), which is based on the detailed facies analyses of Darsac (thesis 1983). The few modifications introduced here result from the recognition of three more sequences, Be4', Va1', and Va 3', in this stratigraphic interval.

The stratigraphic position of the famous 'Astieria Mergel' (= Marnes à Astieria) in the Neuchâtel area (Switzerland) was solved by Bulot 1992, who showed that the dominant species in the 'Astieria Mergel' is *Olcostephanus guebhardi* and that the biostratigraphically significant ostracod is *Protocythere praetriplacata*. This implies that the 'Astieria Mergel' correlates with the top part of the Campylotoxus Zone and/or with the Verrucosum Horizon and that it was deposited during the high sea-level stand of sequence Va3'.

The Hauterivian succession in the Neuquén Basin in Argentina (column 6)

In this scheme we used the Austral-Tethyan correlation of the Hauterivian as proposed by Aguirre-Urreta & Rawson (1997), who correlated the Argentinian *Holcoptychites neuquensis* Zone with the Mediterranean *Acanthodiscus radiatus* Zone. Their correlations were largely followed here with the exception of the Avilé Sandstone. For, from a sequence-stratigraphic point of view it is preferred here to relate the Avilé Sandstone to the type 1 sequence boundary of Ha3. This deviates from the correlation by Aguirre-Urreta & Rawson. It is interpreted here that the fluvial Avilé Sandstone represents the prograding top part of the highstand systems tract during the rapid and extra deep fall of the sea level at the close of sequence Ha2'. As a consequence the *Spitidiscus ricardii* Zone should correlate with the Cruasense Horizon in France and with the *Spitidiscus rotula* level in England instead of with the Mediterranean *Nodosoplicatum* Zone. It is a matter of course that the *Paraspiticeras groeberi* Zone has a lowest Barremian age. The correlation of the other Argentinian zones is merely interpolated.

The lowest Aptian sequences

The works of Casey (1961) and Kemper (1967) were consulted for the lowest Boreal Aptian. Casey illustrated the stratigraphic succession of the Lower Greensand of Atherfield, Isle of Wight. The abundance of fossils may indicate that the highest part of the Perna Beds represent a maximum flooding interval. The overlying Atherfield Clay and Lower Lobster Bed may represent the highstand systems tract of the same sequence, which should be Ba5. The sandstone of the Crackers is intercalated within a predominantly clayey succession (= the so-called Atherfield Clay Series of Casey 1961) and can be interpreted as representing the highest shallowing-upward part of the highstand systems tract. The overlying clays of the Upper Lobster Bed represent the highstand systems tract of the next sequence (Ap1) (Hesselbo et al. 1990). These clays are overlain by the Ferruginous Sands, the lowest part of which be-

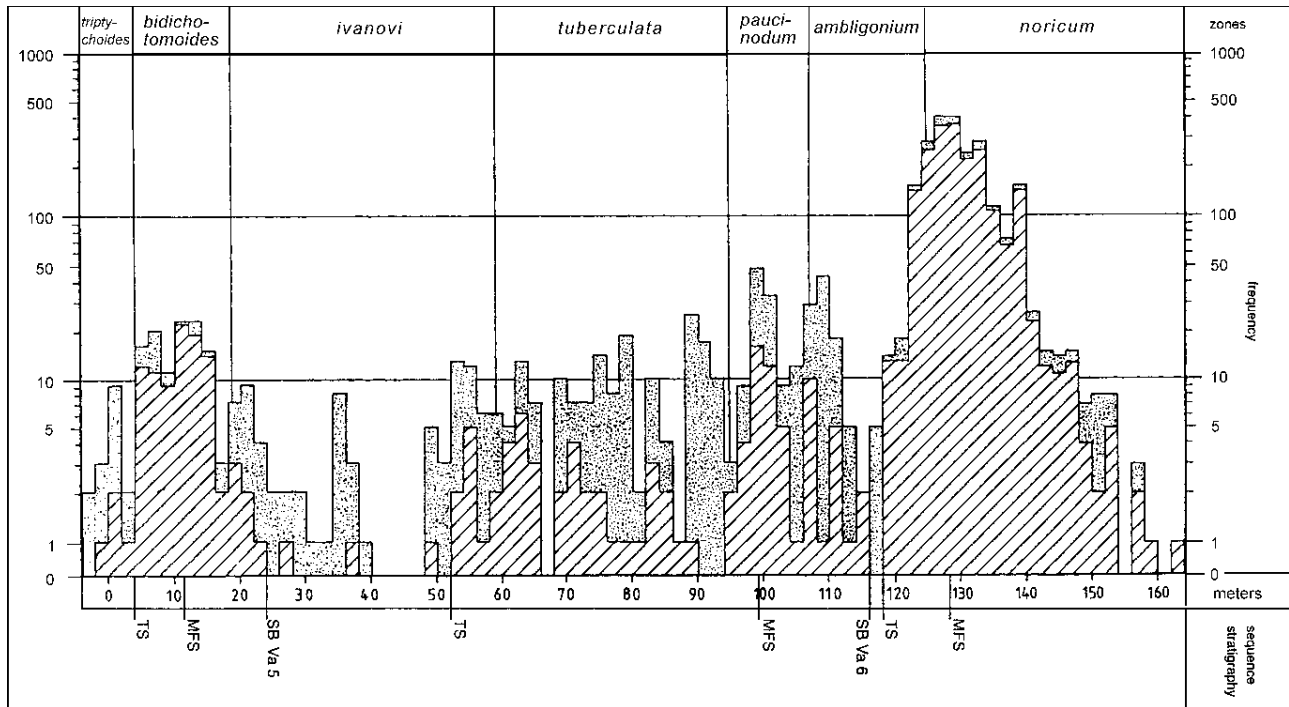


Fig. 11. Section along the Mittellandkanal near Pollhagen: frequency distribution of macrofossils; modified after Quensel 1988. Hatching: ammonite frequency; dotted: frequency of other macrofossils. The vertical scale is logarithmic.

longs to the *Deshayesites deshayesi* Zone. The strong lithological change from the Atherfield Clay Series to the Ferruginous Sands is interpreted as a direct consequence of the type 1 sequence boundary Ap2.

If this sequence-stratigraphic interpretation is true, the correlation with Germany may be as follows: The German beds with *Prodeshayesites bodei* in the lower part of the *Prodeshayesites "tenuicostatus"* Zone (*P. "tenuicostatus"* (Koenen) is a younger synonym of *P. fissicostatus* (Phillips)) are not preserved in England, whereas the middle and upper parts of the *Prodeshayesites "tenuicostatus"* Zone without *P. bodei* correlates (1) with the English Perna Beds, which are included in the English *Prodeshayesites fissicostatus* Zone, and also (2) with the overlying *Deshayesites forbesi* Zone. As the German Fischschiefer should represent the highest sea-level highstand directly before the type 1 sequence boundary of Ap2 (Hoedemaeker 1995; Kemper 1995), it should be incorporated in the upper part of the "Tenuicostatus" Zone and should correlate with the Upper Lobster Beds in the upper part of the English *Forbesi* Zone. This highstand systems tract is directly followed by the first appearance of *Leupoldia cabri* in the Río Argos succession as well as in northern Germany (Kemper 1995). The Fischschiefer correlates with the Selli Level (Hoedemaeker 1995; Kemper 1995), which is also directly followed by the first appearance of *L. cabri*. The sea-level fall corresponding to the type 1 sequence boundary of Ap2 caused the drowning of the Urganian platform in SE France.

It should be noted that the Aptian beds of the Río Argos succession marked by the letter D were assigned to the *Deshayesi* ammonite Zone because of the presence of

the first *Chelonicerias* (Hoedemaeker & Leereveld 1995); this is erroneous because *Chelonicerias* is already present in the Weissi Zone (Delanoy 1995). The Weissi Zone should therefore be extended up to the sequence boundary of Ap2.

The various biostratigraphic events and fossil names

Dinoflagellate cysts

The first and last occurrence data of the dinoflagellate cysts that occur in the Boreal as well as in the Tethyan Realm and that are relevant to a Boreal-Tethyan correlation, were added in the white strips alongside the columns only after the correlation of the depositional units by sequence stratigraphy was finished. They can therefore be considered a confirmation of the correctness of this correlation. The dinoflagellate cysts are the best biostratigraphic correlation tools available at this moment, and therefore of the utmost importance.

Amphorula delicata

Río Argos, LO bed Y240 (Leereveld 1997a)
Isterberg, LO depth 220.6 m (Strauss et al. 1993)

Aprobolocysta eilema

La Buissière, SE France, FO lowest part of Sayni Zone (Londeix 1990)
Speeton, FO bed C7E (Leereveld 1995)
Boring Konrad 101, FO middle part of Aegocrioceras beds (= middle of transgressive systems tract) (Prössl 1990)

Río Argos, LO bed A131 (Leereveld 1997b)
 Speeton, LO bed C2D (Leereveld 1995)
 Northern Germany, LO in the lower part of the Gottschei Zone (Lutat 1995)

Batioladinium pomum

England, FO in Lamplugh Zone
 Purbeck Formation, FO "in a buff calcareous shale with ostracods immediately above the Broken Beds at the base of the Marls with Gypsum and Insect Beds in the Durlston section" (Norris 1985, referring to his Ph. D. thesis written in 1963).

This is a rather cryptic level, for in old literature the Marls with Gypsum containing Insect Beds were supposed to begin with the Cypris Freestones immediately overlying the Broken Beds. But the Cypris Freestones are marine limestones and not 'calcareous shales'. Arkell (1956), however, who was regarded as an authority on the Purbeck Beds when Norris wrote his Ph. D. thesis, considered the 'Marls with Gypsum and Insect Beds' to begin above the limestones of the Hard Cockle Beds (see the correlation of Arkell's subdivision with Bristow's subdivision by Norris 1969, table 2). Nowadays the name 'Marls with Gypsum and Insect Beds' is not used anymore. Norris apparently used Arkell's subdivision when he wrote his Ph. D. thesis, which would mean that the first *B. pomum* was found at the base of what is now generally referred to as Soft Cockle Beds. However, this level is not 'immediately above the Broken Beds'; it may however actually be the first sample he took above the latter.

Bourkidinium spp.

Río Argos, LO bed A154 (Leereveld 1997b)
 SE France, LO in middle of undivided Angulicostata Zone (= near top of Ohmi Zone) (Londeix 1990)
 Speeton, LO in bed C2D (Leereveld 1995)
 Gott, LO in upper part Dicofalcatius Zone (Lutat 1995)

Cauca parva

Gott, FO bed 117 (Heilmann-Clausen & Thomsen 1995)
 Speeton, FO directly below bed CB6 (Heilmann-Clausen & Thomsen 1995; Duxbury 1980)

Coronifera oceanica

Río Argos, FO bed A92 (lower part Ligatus Zone) (Leereveld 1997b)
 Vergons, FO bed 108 (lower part Ligatus Zone) (Londeix 1990).
 FO in the middle of Staffi Zone (Lutat 1995)
 Speeton, FO base of C4 (Davey 1979)

Criproperidinium boreas

Speeton, FO just below bed CB3 (Harding 1990)
 Warlingham borehole, Wealden, FO depth 1078/1 (Harding 1990)
 Gott, FO in bed 138 (Harding 1990)

Dissiliodinium globulus

Río Argos, FO bed M249 (Leereveld 1997a)
 P. heteropleurum Zone, Suddendorf 27 m (Below 1981)

Exiguiphaera phragma

Río Argos, LO bed A170 (Leereveld 1997b)
 Speeton, LO bed LB4D (Harding 1990)
 Gott, LO bed 78 (Harding 1990)

Florentinia interrupta

Río Argos, FO bed A48 (Leereveld 1997b)
 Speeton, FO upper part of bed C6 (Leereveld 1995)

Gonyaulacysta fastigiata

Río Argos, LO bed V₂ 45 (Leereveld 1997b)
 Speeton, LO just below bed CB3 (Duxbury 1980)

Kleithriasphaeridium fasciatum

Río Argos, FO bed Y267 (Leereveld 1997a)
 Speeton, FO bed D7A (Duxbury 1977)
 Berrias, FO bed 198 (Monteil 1993)
 Angles, FO bed 170 (Monteil 1993)
 Isterberg 1001, FO depth 220.6 m (Strauss et al. 1993)
 Río Argos, LO bed Q93 (Leereveld 1997b)
 Speeton, LO bed LB1A (Leereveld 1995; Duxbury 1980)

Muderongia staurota

Río Argos, FO bed P11 (Leereveld 1997b)
 Top part Amblygonium Zone (Lutat 1995)

Nexosispinum vetusculum

Río Argos, FO bed P13 (Leereveld 1997b)
 Speeton, FO bed C11 (Davey 1979)
 Río Argos, LO bed Q100 (Leereveld 1997b)
 Speeton, LO bed LB1A (Leereveld 1995; Duxbury 1980)

Occicucysta tentorium

Río Argos, FO bed M248 (Leereveld 1997a)
 Suddendorf, FO in P. heteropleurum Zone, at 21 m (Below 1981)

Odontochitina operculata

Río Argos, FO bed Q93 (Leereveld 1997b)
 Speeton, FO bed LB1A (Leereveld 1995)
 Angles, FO bed 142 (Wilpshaar 1995a,b)

Oligosphaeridium complex

Río Argos, FO bed Y271 (Leereveld 1997a)
 Isterberg 1001, depth 120 m (Strauss et al. 1993)

Oligosphaeridium diluculum (see comments in chapter: Speeton E+D)

Speeton, FO bed D7G (Heilmann-Clausen; Davey 1982)
 Río Argos, FO bed Y234 (Leereveld 1997a)
 Subsurface North Sea, FO in "Stenomphalus maximum flooding surface K. 10" (Partington et al. 1993)

Prolixosphaeridium parvispinum

Río Argos, FO bed V₂45 (Leereveld 1997b)
 Barremian Angles, FO bed 144 (De Reneville & Raynaud 1981)
 Gott, FO top part bed 116 (Heilmann-Clausen & Thomsen 1995)
 Speeton, FO directly below bed CB6 (Heilmann-Clausen & Thomsen 1995)

Pseudoceratium pelliferum

Speeton, FO bed D7E (Lott et al. 1989)
 Río Argos, FO bed Y206 (Leereveld 1997a)
 Berrias, FO bed 198 (Monteil 1993)

Spiniferites spp.

Río Argos, FO bed Y271 (Leereveld 1997a)
 Isterberg, FO depth 61.6 m (Strauss et al. 1993)

Subtilisphaera terrula

Río Argos, FO bed A78 (Leereveld 1997b)
 Speeton, FO base of C4 (Davey 1979)
 Río Argos, LO bed Q100 (Leereveld 1997b)
 Speeton, LO bed LB1A (Harding 1990)
 Gott, LO bed 109 (Harding 1990)

Ammonite names mentioned in the white strips:

Acanthodiscus bivirgatus (begins its range in the Amblygonium Zone before the so-called 'Bivirgaten-Schichten', Mutterlose 1984).

Aconeceras sp. and *Heteroceras* sp. Speeton: Upper B Beds, base of Bidentatum Zone (Rawson 1995).

Breistrofferella sp. and n.sp. (depicted as 'Ammonit indet.' by Kemper 1992): The presence of *Breistrofferella* is a new still unpublished fact and confirms the correlation of the Boreal upper Amblygonium and lower Noricum zones with the Tethyan Radiatus Zone. The specimens were identified by J. Klein (National Museum of Natural History of The Netherlands) as *Breistrofferella* (personal communication).

Barremites sp. In Speeton bed LB1A (Doyle, personal communication).

Crioceratites duvali: First occurrence in the Boreal Realm is at the same level as in the Tethyan Realm (Kemper et al. 1981).

Dichotomites: The ranges are similar for the Boreal and Tethyan Realm (Thieuloy 1973, 1977; Cotillon 1971).

Endemoceras: First occurrence in the 'Grenzsandstein' (Kemper 1992).

Jeannoticeras jeannoti. Speeton: lower part of bed C7H (Doyle 1989).

Karakaschiceras biassalense, *K. cf. inostranzewi*, and *Neohoplloceras submartini*. Speeton: base of bed D2D (Kemper et al. 1981).

Lytoceras in the Speeton section (Donovan 1957; Whitehouse & Brighton 1924).

Olcostephanus: Last Boreal occurrence at the DHo discontinuity (Kemper 1985; Rawson 1971). In the Río Argos in the lowstand systems tract between the beds A34 and A35 just above the DHo discontinuity.

Platylenticeras: The range of this genus in the Tethyan Realm is shorter than in the Boreal Realm (Thieuloy 1973, 1977). This genus occurs only in the lowstand systems tract of sequence Va2'.

Platylenticeras cf. involutum. Speeton: bed D4C (Doyle, personal communication).

Polyptychites: The Boreal and Tethyan ranges are nearly the same.

Prodichotomites: This genus starts its range in the Boreal and Tethyan realms at the same level (Thieuloy 1977).

Sarasinella cf. trezanensis + *Menjaites*: Base of Clax by Irostone (Kemper et al. 1981).

"*Shastrioceras*" *anglicum*. Speeton: bed D1 (Doyle 1963).

Other fossils named in the white strips. They are listed here in order to know to which group they belong.

Belemnites: *Praeoxyteuthis pugio*, *Hibolites jaculoides*, *Acrotythis acmonoides*.

Ostracods (they all belong to the genus *Cypridea*): *C. alta alta*, *C. altissima*, *C. amisia*, *C. bimammata*, *C. brevirostrata*, *C. dolabrata*, *C. dunkeri carinata*, *C. dunkeri dunkeri*, *C. fasciculata*, *C. inversa*, *C. obliqua*, *C. posticalis*, *C. recta recta*, *C. rectidorsata*, *C. setina setina*, *C. tuberculata adjuncta*, *C. tumescens tumescens*.

Nannoplankton: *Calcicalathina oblongata*, *Cruciellopsis cuvillieri* (Boreal last occurrence datum according to Jakubowski 1987), *Chiastozygus litteratus* (according to Kemper 1995, and Thierstein 1971, 1976, this species appears just below the Barremian-Aptian boundary).

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