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

Philip J. Hoedemaeker

National Museum of Natural History, POB 9517, 2300 RA Leiden, The Netherlands

Abstract: Because of the high provinciality of the marine biota during the pre-Aptian Cretaceous times, there is no hope for a precise correlation of Tethyan with Boreal successions by means of biostratigraphy only. Correlations with a detail as shown in the correlation scheme presented here, can be achieved only with the combination of all available correlation tools such as biostratigraphy, magnetostratigraphy and sequence stratigraphy. This paper and correlation scheme are a revised and updated edition of those published in 1999 in *Geologica Carpathica*, 50, 2, 101-124.

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

11.1 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 last 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.

From the above correlations can be learned that, because of the high provinciality of the marine biota during pre-Aptian Cretaceous times, there are only 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 difficult to correlate by biostratigraphic means with the Tethyan standard succession, while 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-Boreal Cretaceous. In order to perform such a correlation, a sequence-stratigraphic analysis of the Boreal pre-Aptian succession has to be made, and the correlation should be supported by as many biostratigraphical and magnetostratigraphical correlating ties as possible. Such a detailed correlation was first attempted by Hoedemaeker (1999), and this paper is a revised and corrected version of that attempt.

11.2 Correlation of depositional sequences

It appears that all depositional sequences determined in the Tethyan Río Argos succession (Caravaca, SE Spain) (Hoedemaeker & Leereveld 1995; Hoedemaeker 1995, 1996, 1999) can be retrieved and identified not only in SE France (sections of Berrias, La Charce and Angles) (Hoedemaeker 1998), 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 1998) are not repeated again here. The lithological columns published by Giraud (1995) and my own field observations were used in the sequence-stratigraphic interpretation of the French sections. For the various sequence boundaries, the French codes (Arnaud-Vanneau & Arnaud 1990, 1991; Jacquin et al. 1991; Hunt & Tucker 1993) are used instead of the absolute age codes used in the cycle chart of Haq et al. (1988) and the sequence-chronostratigraphic charts of Hardenbol et al. (1998). 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 concealed amidst a siliciclastic sandy turbidite succession. Hoedemaeker (1998) slightly changed the sequence-stratigraphic interpretation of the Berriasian stratotype of Jan du Chêne et al. (1993). These changes are followed here; they better match with the magnetostratigraphic/sequence-stratigraphic correlation of the English Purbeck Formation and the Berriasian stratotype.

In this revised edition I introduced again three new sequence boundaries: Be8, Va3^0, and Va4^0. The existence of these boundaries became apparent in the Boreal sections of the Speeton D beds and Isterberg after the publication of the correlation chart in 1999, of which this paper is a revised edition. The first sequence boundary, Be8, became apparent after a thorough study of the logs of the D Beds described by Neale (1968) of the Speeton Clay succession. All sequence boundaries in the D Beds coincide with minima in the amount of pyrite and with levels barren of foraminifers separating quite different foraminifer assemblages. Such a coincidence occurs at the boundary of beds D7E and D7D. The maximum flooding surface of the same sequence has been recognized by Strauss et al. (1993) at depth 235 m along core and the lowstand systems tract of that sequence can be recognized in the Río Argos succession as a marly interval between bundles of limestone beds. The sequence can be recognized in three widely separated sections and can be accepted as a sequence boundary. The new sequence Va3^0 became apparent in the French section at the Preynes farm (Robert 1994 unpublished Mémoire de Maîtrice de Géologie, Grenoble; Bulot 1995, unpublished Thèse de Doctorat du Museum National d'Histoire Naturelle), where three sequence boundaries can be indicated between sequence boudary Va2 and Va4. Between sequence boundaries Va3 and Va3' there was an additional sequence boundary which I gave the code Va3^0. This sequence boundary could also be determined in a correlatable stratigraphic interval in other French platform and basin sections (base of bed 60 of the Carejuan section and base of bed 14 of the Point Sublime section); it can also be recognized in the Spanish Río Argos succession and in the Speeton D beds at the base of bed D2E, where it characteristically coincides with a pyrite minimum and a level separating two quite different foraminiferal assemblages. In the Angles and La Charce sections the new sequence boundary, Va4^0, is situated at the level that I formerly correlated with the level of sequence boundary Va4 in the Río Argos section (Hoedemaeker 1998, 1999). The latter sequence boundary, which is conspicuously expressed in the Río Argos succession, was erroneously correlated with a level which is now situated halfway up the Pronecostatum Subzone. Recent correlations and field observations show that sequence boundary Va4 should be correlated with the top of bed 306b in the Angles section and with the base of bed 204 in the La Charce section. This shift necessitates the introduction of sequence boundary Va4^0 at the level formerly correlated with Va4 halfway up the Pronecostatum Subzone.

In this revised edition also the stratigraphic levels of sequence boundaries Ha6 and Ha7 in the Moorberg and Gott sections are shifted a little upward. Ha6 in the Gott section now correlates better with Ha6 in the Moorberg section.

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 then 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 was done in the 1999 correlation chart 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. 11.1, 11.2, 11.3, 11.4).
2. The German Wealden in the Isterberg 1001 borehole (Strauss et al. 1993) (Fig. 11.5).
3. The Valanginian in Sachsenhagen (Kemper 1961; Mutterlose 1984) and Suddendorf (Kemper 1961; Below 1981), Germany (Fig. 11.6).
4. The Hauterivian in the Moorberg clay pit near Sarstedt, Germany (Mutterlose 1984) (Fig. 11.7).
5. The Barremian in the Gott clay pit near Sarstedt, Germany (Mutterlose 1983, 1984) (Fig. 11.8).

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. 11.9).
7. The section along the Mittellandkanal near Pollhagen, Germany (Quensel 1988) (Fig. 11.10).
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 of a correlation with the Mediterranean successions to such a detail as 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 nevertheless additional correlation data could 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.

In the Boreal Realm are 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.

11.3 How to read the correlation scheme (= folded chart)

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 basin and platform' in SE France respectively. The sequences in these two columns are drawn in accordance with the interpretation of Hoedemaeker (1999); four additional sequences are added (see introduction). The columns between these two Tethyan columns represent Boreal succesions 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). In this revised version the platform deposits of the Barremian Glandasse and Urgonian Limestone Formations are added because of the excellent way in which the sequences are interpreted in these formations by Arnaud et al. (1998). 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 scheme 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 most 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 that 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 is 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 boundaries of magnetozones M18n, M17r, and M15n are still unknown, but probably situated in the middle of the Grandis Subzone, Subalpina Subzone and Alpillensis Subzone respectively. In correlation schemes these hiatuses must not be neglected.

Another striking feature is the light-shaded stripes at the sequence boundaries Be3, Be7, Va1, Va4, Ha3, Ha7, Ba2, Ba4 (added in this revised edition), Ap2. These boundaries were interpreted to represent 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 'Basal Cretaceous Unconformity', 'Late Cimmerian 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 were established in the meetings of the International Lower Cretaceous Cephalopod I.G.C.P.-Team in Digne (Hoedemaeker & Bulot 1990), Mula (Hoedemaeker & Company 1993 + 16 co-authors), Piobbico (Hoedemaeker & Cecca 1995 + 16 co-authors), London (Rawson & Hoedemaeker 1999 + 11 co-authors), and

Vienna (Hoedemaeker & Rawson 2000). The only deviation is the Valanginian Campylotoxus Zone in France (column 7) being subdivided in accordance with the recent ideas of Atrops & Reboulet (1995) and Reboulet (1995). It should be noted that on the correlation chart the names of the ammonite subzones are put to the left of those of the zones.

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 to be due to collection failure in France. In the Río Argos succession the first appearance of *J. jeannoti* is in bed P25 in the transgressive systems tract of sequence Ha1, whereas in the La Charce section *J. jeannoti* does not appear below bed 287 in the maximum flooding surface of sequence Ha2. In the Río Argos succession the ammonite genus *Lyticoceras* appears in bed A0 in the lowstand systems tract of sequence Ha2', whereas in the French La Charce section it does not appear below bed 294 in the transgressive surface of sequence Ha2'. 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. Finally the base of the belemnite Oxyteuthis brunswicensis Zone in Germany is at the base of the ammonite Paracrioceras elegans Zone, whereas in England it begins in the top part of the Elegans Zone.

As for the ammonite zones, it should be noted that the beds assigned by Hoedemaeker (in: Hoedemaeker & Leereveld 1995) 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.

In contrast to the columns published by Hoedemaeker & Leereveld (1995), I changed my interpretation of the stratigraphic positions of the sequence boundaries Ba2, Ba3 and Ba3' in the Barremian stratotype section near Angles (column 7). In contrast to the correlation scheme published in 1999 (Hoedemaeker 1999) I interpreted the presence of hiatuses above the upper Barremian sequence boundaries Ba2, Ba3, Ba4, and Ba4', because the lowstand systems tracts belonging to them merely consist of one (and a half) limestone/marlstone couplet, which do not show any signs of condensation.

The so-called 'Petit Lumachelle' in the Carejuan section in SE France is directly overlain by the Verrucosum Horizon and is interpreted to represent the transgressive systems tract of sequence Va3'.

For the Boreal marine successions also the belemnite zones are 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) does not concord with the correlation with the help of sequence stratigraphy and ostracods as presented here. More study is necessary.

In this revised version of my previous correlation chart I interpreted the sandstone intervals in the German Hilston Formation (Bentheim Sandstone, Dichotomites Sandstone, 'Grenzsandstein', Noricum Sandstone and the Gildehaus Sandstone) in the same way as they are interpreted in the "Stratigraphic Nomenclature of the Netherlands" (Van Adrichem Boogaert & Kouwe 1993, part G), *viz.* as sandstone tongues consisting of prograding offshore-shoals and coastal-barrier systems, which are overlain by intensely reworked basal transgressive sands. These systems are interpreted as forming part of the top highstand systems tract and of the transgressive systems tract respectively, which are separated by a sequence boundary and by a hiatus along which the lowstand systems tract is absent. The sandstones are not interpreted as lowstand systems tracts anymore as done by me in the 1999 correlation chart (Hoedemaeker 1999), because in these shallow deposits the lowstand systems tracts are thought to be very thin or not developed. Though they represent a substantial part of the German deposits, they are rapidly deposited and represent only a rather small fraction of geologic time.

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', which means 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 couplets, 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 and from the sequence boundary Be3, bounded by the famous Mammal Bed (a paleosoil), which is situated halfway the Ashdown Faunicycle.

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 successions (column 3) are 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 correlation scheme 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. The biochronostratigaphic definition of the boundary stratotype are therefore comparatively easy to give and easy to recognize in other sections. In shallow depocenters they are commonly 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 part 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, which is given thereafter.

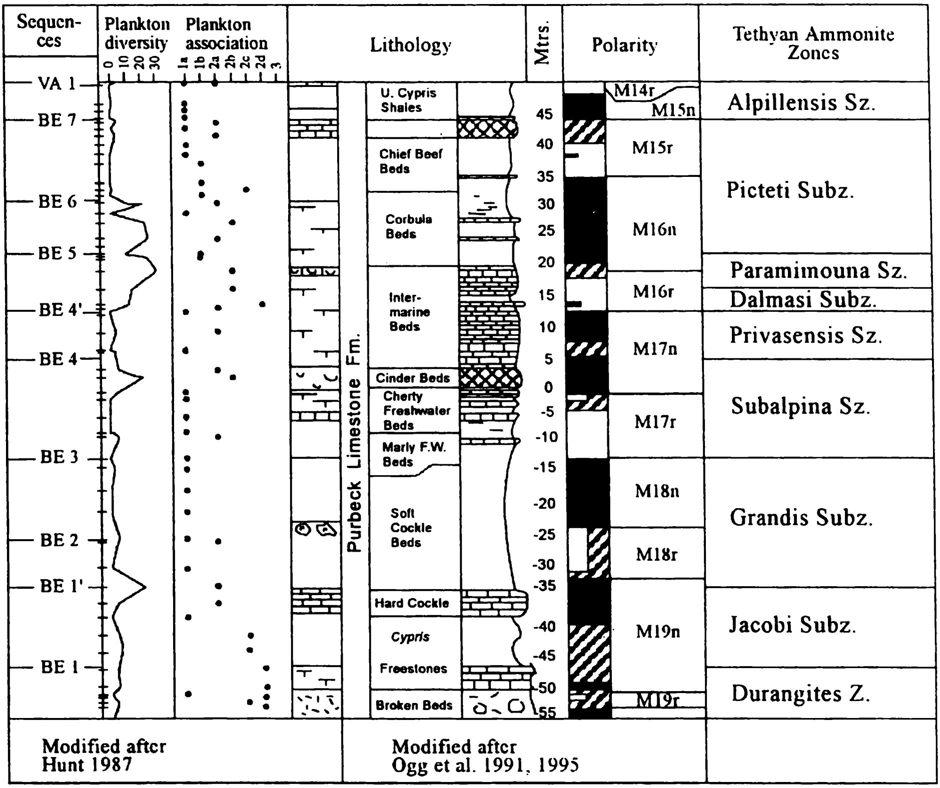
11.4 Sequence-stratigraphic analysis of English sections (Columns 3, 4, 5)

11.4.1 Purbeck Beds in South England: Berriasian (column 3) (Fig. 11.1).

Magnetostratigraphic investigations of the Purbeck Limestone Group of the Durlston Bay section in south 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 succession of the Durlston Bay section (the stratotype of the Purbeck Limestone Group in England). The peaks in the dinoflagellate cyst diversity given by Hunt are here inferred to reflect maximum flooding intervals and highstand systems tracts; the bases of the intervals with low dinoflagellate cyst diversity closely above these diversity peaks are interpreted to represent sequence boundaries. The positions of the so determined sequence boundaries in relation to the various magnetistratigraphic polarity chrons in the Purbeck succession precisely match with the position of the sequence boundaries in relation to the polarity chrons in the Berriasian stratotype. This strengthens the reliability of the Boreal Tethyan correlation of the Berriasian succession as presented in the correlation chart. The bed numbers refer to the numbers used by Clements (1993) for the beds in the Durlston Bay section.

1. Ogg et al. (1994, 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 were 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. Sequence boundary Be1 should be situated on top of the fully marine limestone beds (bed 14) that are overlain by restricted brackish marly clays of the remainder 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. Sequence boundary Be1' is drawn on top of bed 38. The Hard Cockle Bed is situated within polarity chron M19n.



Modified after Hunt 1987

Modified after Ogg et al. 1991, 1995

Fig. 11.1. The magnetostratigraphic analysis of the Purbeck Group (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 ananlysis, 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 1998). Microplankton associations: 1a — freshwater to brackish; 1b — brackish lagoon; 2a,b,c,d — restricted, brackish to shallow marine; 3 — shallow marine.

3. The next sequence (Be1') begins with marly shales, is rather thin and merely represents the lower part of the Soft Cockle Beds below the gypsum beds. The bed just below the gypsum beds 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 microplankton. The gypsum beds and the part of the Soft Cockle Beds directly above it embrace 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 to represent sequence boundary 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, Be4, is just on top of the Cinder Bed just above the microplankton diversity peak 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. The Fresh Water Beds correlate therefore 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 (Jan du Chêne et al. 1993), 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 Intermarine 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' on top of biosparitic limestone bed 133 (Red Rag). The lower Intermarine 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. Sequence boundary Be5 is situated just above the Scallop Bed on top of bed 153. The upper Intermarine 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 is topped by a microplankton diversity peak representing the highstand systems tract. Sequence boundary Be6 is situated on top of bed 189, which is the top bed of a bundle of biosparitic limstones beds and which is overlain by shales with beef. 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 sequence boundary Be7 on top of bed 221, which contains plant and turtle remains. 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 Alpillensis Zone. The so-called Green Marble, however, is already situated in polarity chron M14r, and should represent the highstand systems tract that correlates with the Otopeta Zone. Consequently sequence boundary Be8 can readily be placed at the top of the bundle of limestone beds above the Broken Shell Limestone bed, i.e. on top of bed 232.

11. Sequence Be8 starts with shales and ends with the highstand systems tract represented by the massive *Viviparus* biosparite of the Green Marble. The latter bed correlates with the highstand systems tract of the Otopeta Zone and is already situated in polarity chron M14r. Sequence boundary Va1 should be situated on top of this bed (= bed 237) which is just above the base of polarity chron M14r.

12. The upper part of the Upper Cypris Clays and Shales, also called the Paludina Clays, belong to the Battle Faunicycle. The Green Marble represents the saline phase of the Battle Faunicycle. The entire Battle Faunicycle is situated within polarity chron M14r. Sequence boundary Va1 on top of the Green Marble, 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 highest faunicycle of the Purbeck Limestone Group 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 are overlapping (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 are the same.

11.4.2 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, halfway the Verrucosum Subzone. 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 Ha3 in the upper part of the Nodosoplicatum Zone just below the boundary between the lower and upper Hauterivian; this boundary is also characterized by an ammonite faunal change (Hoedemaeker 1995). The sequences of the 'Horsham Phase' itself are the result of scientific guessing since no lithological log was available.

For the Henfield Phase and higher the depths in feet and inches of the various sequence boundaries refer to the Warlingham Borehole.

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 progrades seaward. Also the sand and the pellets (at depth 1325/8) in the upper part of the Bonnington Faunicycle is 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 Newgate 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 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.

11.4.3 Speeton section parts E and D: Valanginian (Columns 4 and 5) (Figs. 11.2, 11.3).

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 marked changes in the distribution of foraminifers (Fletcher 1973) and ostracods (Neale 1962b), and by the variations in the amount of pyrite (Neale 1968), which show minima at exactly the same levels as the foraminiferal faunal changes. The foraminiferal faunal changes are often bounded by levels barren of foraminifers, which are interpreted as representing the shallow facies at the top of the highstand systems tracts. These three different lines of evidence lead to the same sequence-stratigraphic interpretation.

1. Foraminiferal fauna 5 in beds D8-D7E. The base of the Speeton Clay Formation is considered to represent 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 characteristic for anoxic conditions, begins in bed D8 immediately above the coprolite bed. It ends at the top of Bed D7E where a quite different foraminiferal fauna begins, foraminiferal fauna 4, which is characteristic of well oxygenated waters. This level coincides with a minimum in the amount of pyrite; such a coincidence characterizes all sequence boundaries in the Lower D beds. Therefore I interpreted this level as a sequence boundary which I gave the code Be8. Beds E-top D7E containing foraminiferal fauna 5 therefore comprise one depositional sequence, Be7.

The ammonite-bearing Stenomphalus Zone in its type area (as described by Casey 1973) is characterized by the concurrence of the last *Dichadogonyaulax culmula*, and *Gonyaulacysta* sp. A (recently rebabtized into *Daveya boresphaera* A) and the first *Oligosphaeridium diluculum* (Davey 1979, 1982); it is overlying an important unconformity, which separates Portlandian strata from upper Ryazanian strata. *O. diluculum* seems to be restricted to the Stenomphalus Zone. Also in the Speeton section and in the southern North Sea (Lott et al. 1989) ammonite-barren strata with *O. diluculum*,

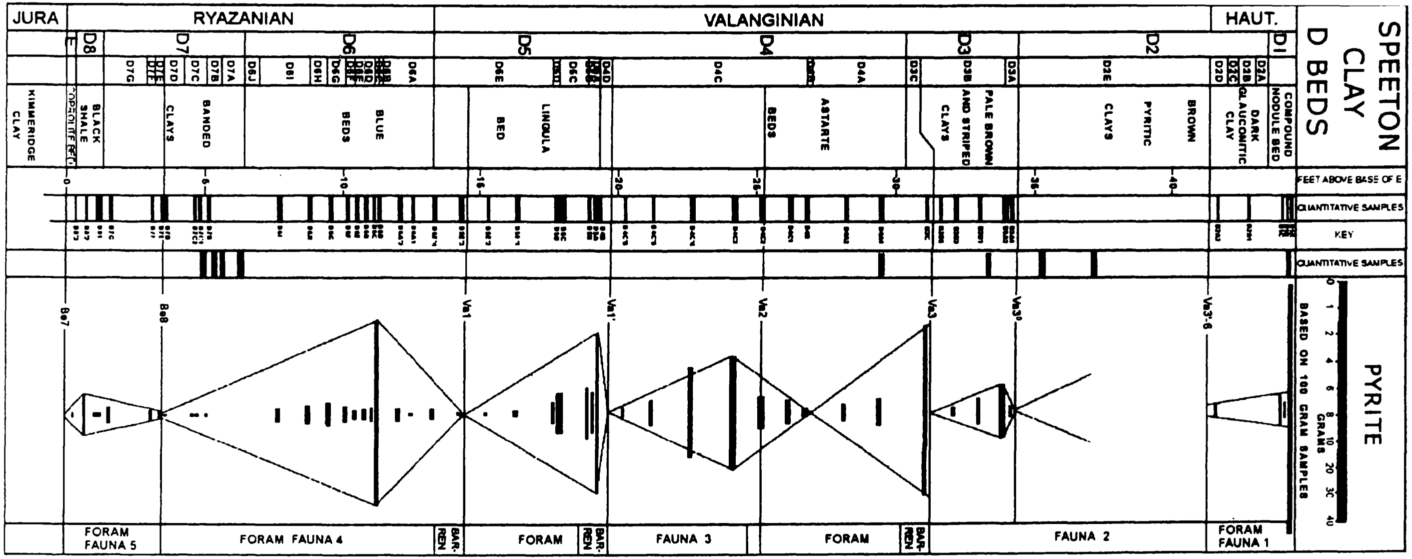


Fig. 11.2. Section through the D beds of the Speeton Clay near Speeton; modified after Neale (1968). The whole section consists of clay. The variation in the pyrite content is shown and the 5 foraminiferal faunas distinguished by Fletcher (1973). The the foraminifer-barren levels are shown. It turns out that the foraminifer-barren levels coincide with the levels in which the ammount of pyrite is minimal. These levels are interpreted as sequence boundaries. There is only one exception at sequence boundary Va2. All sequence boundaries coincide with marked changes in the composition of the fauna, but Fletcher (1973) did not deem them all workable on a supraregional scale.

D. culmula (according to Heilmann-Clausen 1987, and Davey 1982, these species occur in bed D7G) and *Daveya boresphaera* A (in beds E and D8 according to Hoedemaeker & Herngreen in prep.) are overlying an unconformity, which separates them from Kimmeridgian sediments. This unconformity is known as the 'Late Kimmerian Unconformity'. Rawson & Riley (1982), therefore, rightly state that the Late Kimmerian Unconformity is situated below the Stenomphalus Zone.

In the northern part of the North Sea, however, the 'Stenomphalus Maximum Flooding Surface K10' (Partington et al. 1993), which is also characterized by the concurrent range of the last *Gonyaulacysta* sp. A and the first *O. diluculum*, is interpreted to be situated directly below the 'Late Kimmerian Unconformity', which is generally assumed to be situated at the base of the Valhall Formation (Rawson & Riley 1982; Partington et al. 1993). The well-oxygenated sediments of the Valhall Formation are overlying the anoxic sediments of the Kimmeridge Clay/Farsund Formations. According to Heilmann-Clausen (1987), finally, the basal part of the Valhall Formation in the wells Adda-1 and E-1 has a dinocyst association characteristic for the Albidum Zone. Some of these assumptions have to be wrong. I think that the following argumentation leads to the only possible solution.

Firstly, I assume with Rawson & Riley (1982) that the unconformity at the base of Bed E, the Coprolite Bed at the basal bed of the Speeton Clay Formation, is the Late Kimmerian Unconformity, because it is the only unconformity with a major hiatus (Portlandian and lower Ryazanian are missing) closest to the Stenomphalus Zone. Secondly, according to Herngreen (Hoedemaeker & Herngreen in prep.), who studied some samples taken from the lowest part of the Speeton Clay Formation, there is not any impediment to consider the dinocyst association in beds E up to and including D7E to be equivalent to the association in the type Stenomphalus Zone. Thirdly, the high TOC values of Speeton Beds E up to and including D7E (Steffen 1993) indicate that these beds were still deposited in restricted and stagnating bottom waters before the North Sea became flushed by well-oxygenated waters from outside the area. The deposition of well-oxygenated sediments begins at the base of Bed D7D. Fourthly, the well-oxygenated deposits of the Albidum Zone in the Speeton Clay Formation (at least from D7A+D6) presumably correlate with the well-oxygenated deposits of the Valhall Formation. This means that the Late Kimmerian Unconformity is not situated at the base of the Valhall Formation, but at some distance below it within a more or less anoxic clay succession below the Stenomphalus dinoflagellate cyst association; it is presumably situated on top of the *Hectoroceras kochi*-bearing beds, which occur 56 feet below the base of the Valhall Formation in well E-1 in the Danish part of the Central North Sea Graben (Birkelund et al. 1982). Fifth, according to Rawson (personal communication) the Icenii Zone in East England is merely preserved as a remanié deposits at the base of the Stenomphalus transgression and contains phosphoritic nodules and many reworked fossils. The transgression following the Late Kimmerian Unconformity should therefore be considered to begin with the Icenii Zone.

The boundary between Beds D7E and D7D is the boundary between anoxic and oxygenated sediments, but also the boundary between sequences Be7 and Be8. It must be concluded that the 'Stenomphalus Maximum Flooding Surface K10' (Partington et al. 1993) is not situated below the Late Kimmerian Unconformity, but above it. It is equivalent to the maximum flooding surface of sequence Be7, whereas the base of the Vallhall Formation marks the transgression of sequence Be8 and conformably overlies the anoxic shales below it.

It should be mentioned here that 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 Runctoni 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 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 bed D7D shows the abrupt beginning of foraminiferal fauna 4. Bed D7D may be equivalent to the base of the Valhall Formation in the subsurface of the northern North Sea. The whole bed set 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 set 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.

3. 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, however, 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. Sequence boundary Va1' and the transgressive surface of the overlying sequence should be situated on top of D4D. Foraminifers reappear in level D4C6.

4. The sequence comprising levels D4C-D4C2. These levels still form part of foraminiferal fauna 3. Level D4C2 is devoid of foraminifers and is interpreted to represent the shallow deposits in the topmost part of the highstand systems tract, but also to represent the basal sediments of the overlying sequence, since it contains the first specimens of a new ostracod fauna (Neale 1962b). Sequence boundary Va2 and the trangressive surface of the overlying sequence is situated within the level of sample D4C2. The overlying level D4C1 yielded the first foraminifers of foraminiferal fauna 2. This is the only level in which the foraminifer-barren level does not coincide with the level of the minimum ammount of pyrite in bed D4B.

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

6. Beds D3B-D3A embrace the next sequence. It constitutes the middle part of foraminiferal fauna 2. Sequence boundary Va3^0 is on top of bed D3A, where the minimum of pyrite content coincides with a notable change of the foraminiferal fauna.

7. Bed D2E represents sequence Va3^0. The top of D2E represents a large hiatus with an important paleontological break. Bed D2E contains brown nodules and much pyrite. Bed D2D is already of Hauterivian age.

11.4.4 Speeton section D2D to LB5E: Hauterivian (Fig. 11.4).

In principle, the pale clay beds are interpreted to be 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. Part of the pale beds may represent the highest parts of the highstand systems tracts just below the sequence boundaries. Relative abundant occurrences of ammonites are interpreted to represent deposits that are more condensed than the sediments in which the ammonites are relatively scarce. Abrupt changes in ammonite composition also are interpreted as candidates for sequence boundaries. The sea-level highstand systems tracts are clearly recognizable and often contain ammonites immigrated from the Tethys. By deter-

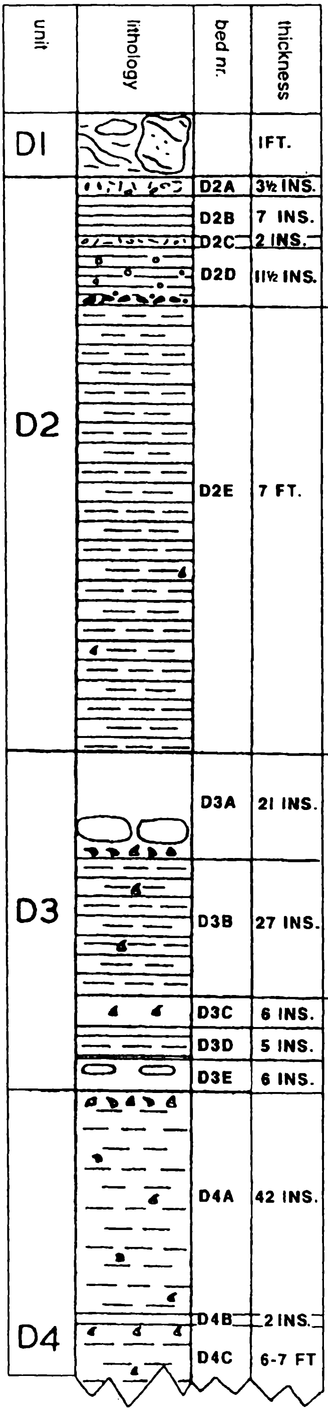


Fig. 11.3.

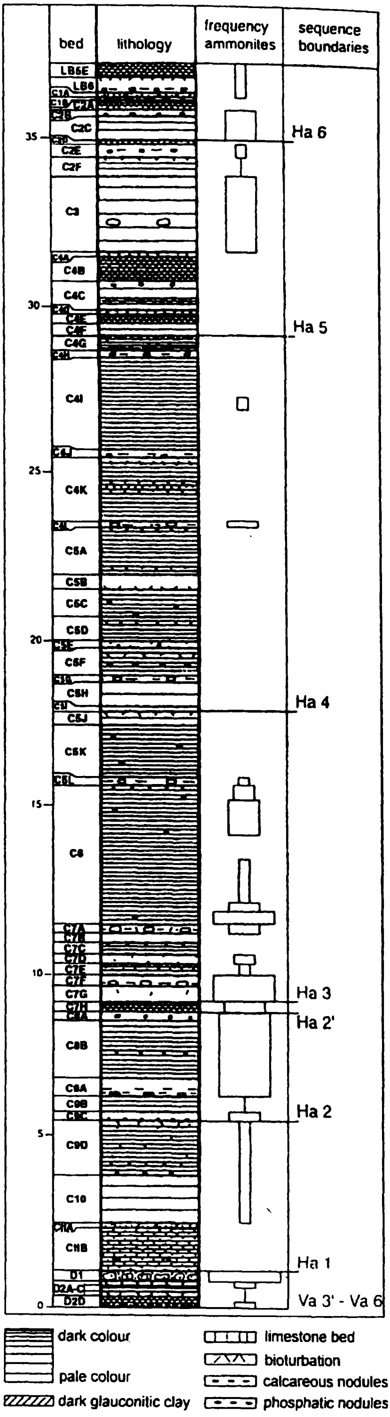


Fig. 11.4.

mining these highstand systems tracts the sequences could be reconstructed. My interpretation is as follows:

1. The first highstand systems tract comprises bed D1 because of the abundance of ammonites and the presence of Tethyan taxa (*Olcostephanus* sp.). Their presence is here interpreted as an indication of high sea-level stand. The abrupt end of this abundance marks the sequence boundary 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 sequence boundary 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 sequence boundary 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.
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. Sequence boundary Ha5 is chosen 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

---

◀◀

Fig. 11.3. 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.

◀

Fig. 11.4. Section through the Hauterivian of the Speeton Clay succession near Speeton (D2D-LB5E); modified after Rawson (1970).

tract, bed C3 is very pale instead of dark, which means that there has been a change in environment. Apparently most of the dysaerobic deeper waters have disappeared. It seems that the extreme average high sea level caused an influx of well-oxygenated water. Sequence boundary HA6 was chosen at the base of the abrupt faunal change on 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. Sequence boundary HA7 is interpreted 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 for 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.

11.4.5 Speeton section LB5B to lowest 2 Cement Beds: Barremian (Fig. 11.5).

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. Sequence boundary Ba1 is interpreted 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*. Sequence boundary Ba1' is interpreted 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*. Sequence boundary Ba2 is interpreted 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. Sequence boundary Ba3 should be drawn on top of bed LB1A 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 (= cement bed 6). The sequence boundary 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.

▶
Fig. 11.5. 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).

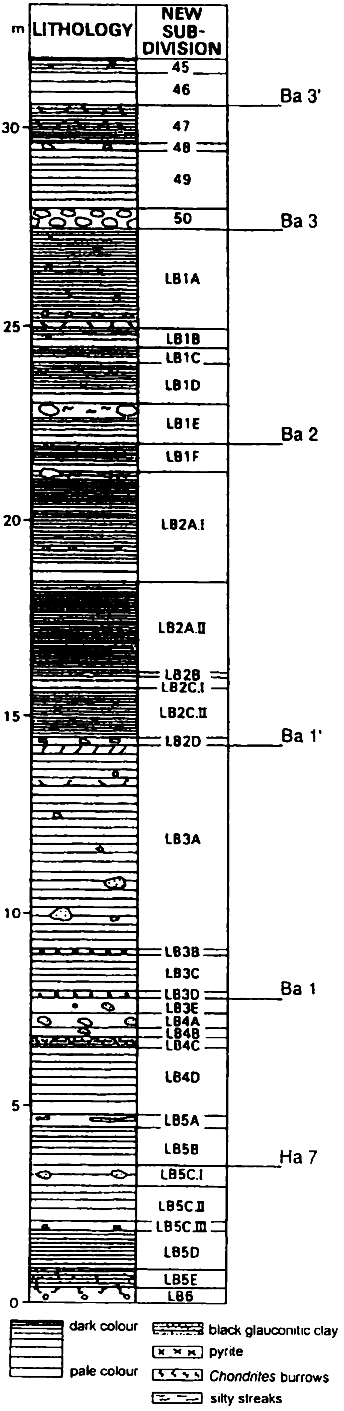

m
LITHOLOGY
NEW SUB-DIVISION
45
46
Ba 3'
30
47
48
49
50
Ba 3
LB1A
25
LB1B
LB1C
LB1D
LB1E
Ba 2
LB1F
20
LB2A.I
LB2A.II
LB2B
LB2C.I
15
LB2C.II
LB2D
Ba 1'
LB3A
10
LB3B
LB3C
LB3D
Ba 1
LB3E
LB4A
LB4B
LB4C
LB4D
5
LB5A
LB5B
Ha 7
LB5C.I
LB5C.II
LB5C.III
LB5D
LB5E
LB6
0
dark colour
pale colour
black glauconitic clay
pyrite
Chondrites burrows
silty streaks

Fig. 11.5.

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

11.5.1 The lower Valanginian of northern Germany (Figs. 11.6 and 11.7).

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 sequences as interpreted by Strauss et al. (1993) are largely followed. It is interpreted 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 sequences drawn in the correlation chart 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*.

1. 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 & 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 Serpulit Member. The top part of the Serpulit Member can be correlated with the Durlston Faunicycle (Anderson & Hughes 1964; Anderson & Bazley 1971; Anderson 1985); this cycle as well as the highest part of the Serpulit Member contain the overlap of the ranges of *Cypridea posticalis* and *C. granulosa fasciculata* (Klingler et al. 1962; Anderson 1985).
2. The correlation of the Cinder Bed with the lower part of the German 'Wealden' 1 has been made by Anderson & Hughes (1964), by Anderson & Bazley (1971) and by Anderson (1973) on the basis of ostracods. In this paper the Cinder Bed is correlated with the fissile and subfissile claystones in the lower part of Wealden 1. The sequence boundary Be4 is therefore interpreted to be situated at 368 m depth along core.
3. The Middle Purbeck Scallop Beds, a quasi marine interval amidst brack to freshwater deposits in England, is marked by the entry of *Cypridea dolabrata* s.l., *C. brevirostrata, C. rectidorsata, C.*

▶

Fig. 11.6. 'Wealden' succession in Borehole Isterberg 1001; modified after Strauss et al. (1993).

▶▶

Fig. 11.7. Platylenticeras Beds at Suddendorf; modified after Kemper (1961).

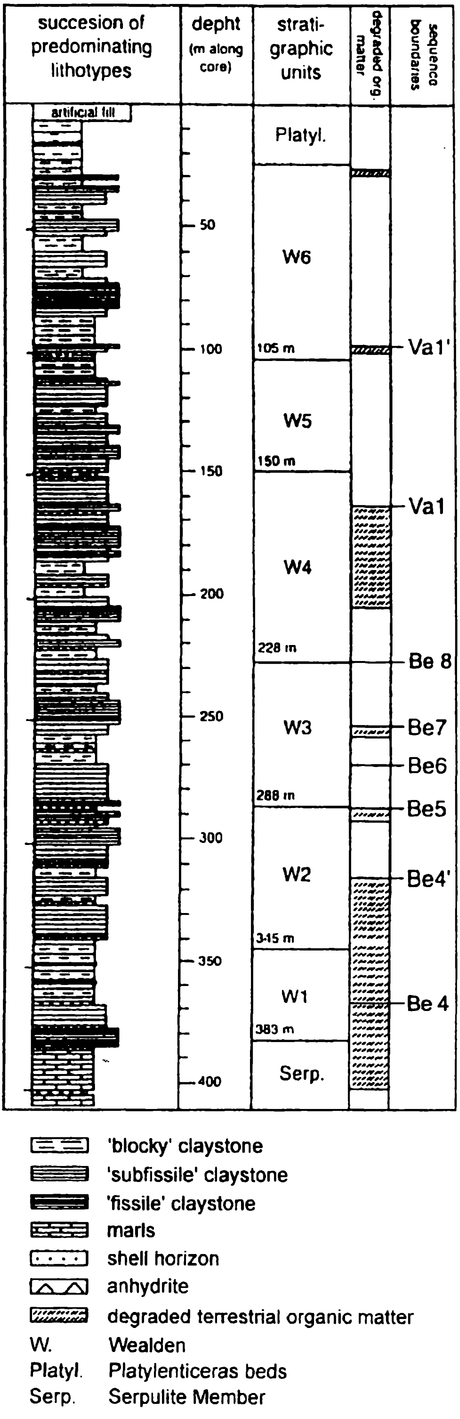


Fig. 11.6.

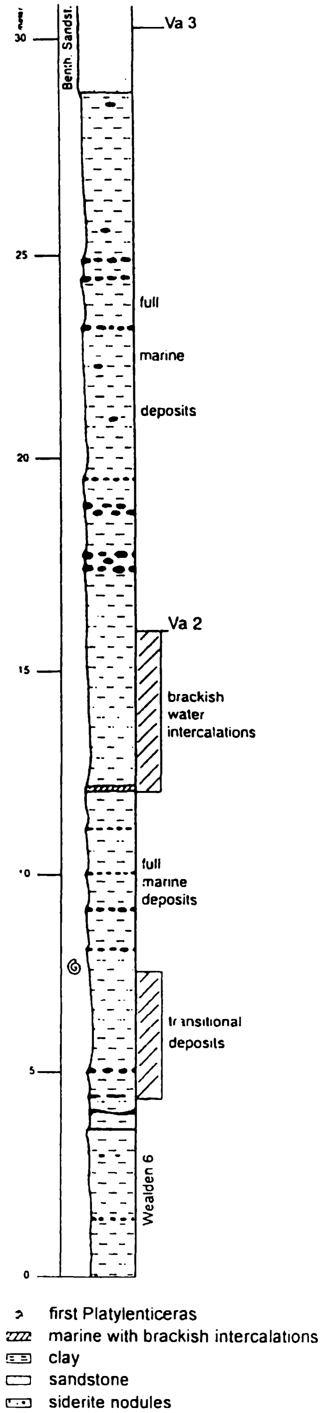


Fig. 11.7.

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 at the top of the interval with degraded organic matter in the middle of 'Wealden' 2, should represent sequence boundary Be4' (316 m depth).

4. This implies that the sequence boundary interpreted to top the thin interval of degraded organic matter at the base of 'Wealden' 3 should represent sequence boundary Be5 (depth 288 m).

5. Sequence boundary Be6 is not readily apparent, but is interpreted to occur at 270 m depth along core. The dinoflagellate cyst peak at 276.1 m depth represents the maximum flooding surface that in France has been called 'Discontinuité 1' (Di1).

6. 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*) (Anderson 1985). 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 also would mean that the sequence boundary on top of this interval with degraded organic matter (at 251 m depth) should be the type 1 sequence boundary 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 sequence boundary 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* in the range chart of Elstner & Mutterlose (1996), *viz.* in the highest part of 'Wealden' 2. The maximum flooding surface recognized by Strauss et al. (1993) at 233 m depth is the maximum flooding surface of sequence Be7.

7. The dinocyst acme at 220.6 m depth along core would represent the maximum flooding surface that in France is called 'Discontinuité 2' and is the maximum flooding surface belonging to sequence Be8. In the correlation scheme of 1999 (Hoedemaeker 1999) I did not recognized sequence Be8 and I could not explain the presence of this maximum flooding surface. This dinoflagellate cyst acme contains the concurrence of *Amphorula delicata* and *Kleithriasphaeridium fasciatum*, which occur together only in the Be8 sequence in the Tethyan Realm. Between 220.7 and 221.5 m depth the co-occurrence of the ostracods *Cytheropterina triebeli* and *Schuleridea juddi* permits a correlation with Speeton Bed D6 (Neale 1962b), which is also a part of sequence Be8. Sequence boundary Be8 should be situated at 231 m depth along core.

8. The next sequence boundary, Va1, should be drawn on top of the thick interval of degraded matter at 153 m depth along 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.

9. Sequence boundary 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 interpreted 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.

10. Sequence Va2 has been referred to by Kemper (1961) as 'the second more extensive Valanginian transgression'. Sequence boundary 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. Also several species of the genera *Propolyptychites*, *Polyptychites* and *Euryptychites* were found above sequence boundary 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 is 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.

11. The base of the Bentheim Sandstone cannot be interpreted as a sequence boundary (as was done in the correlation chart of Hoedemaeker 1999), because there is no sighn of a hiatus whatsoever; instead the base shows the sedimentary sole marks that develop when sand is deposited on a muddy sea bottom (Kemper 1976, 1992). The basal bioturbated beds are interpreted as the highest part of the highstand systems tract of the Involutum Zone. Sequence boundary Va3 should be sought for on top of these basal beds.

The Bentheim Sandstone falls apart into three tongues (Mutterlose & Bornemann 2000). In my 1999 correlation chart I interpreted the sandstone tongues as deposited in lowstand systems tracts (Hoedemaeker 1999). It is my interpretation now that each tongue consists of a lower prograding part and an upper retrograding part separated by a sequence boundary. The tongues are separated by shaly intercalations, which represent the maximum flooding intervals. The highest shaly intercalation is called 'Romberg Zwischenmittel' (Kemper 1992) or Romberg Shale, which separates the Bentheim Sandstone into a lower and upper part. The lower shaly intercalation is thin and not penetrating as far west as the Romberg Shale. Lowstand systems tracts are not developed. The three sandstone tongues are formed around three sequence boundaries: Va3, Va3^0, and Va3'.

11.5.2 The lower part of the upper Valanginian of Northern Germany.

For this stratigraphic interval between the top of the Bentheim Sandstone and the Bidichotomoides Zone there is no detailed log 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' and includes the Polytomus Zone. 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 genus *Polyptychites* is present from the top lowstand surface of sequence Va2 up to 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 & Bettensteadt 1962; Neale 1962b). The first occurrences of *Prodichotomites* and of the ostracod *Protocythere praetriplicata* are situated in sequence Va3' in both realms (Donze 1976; Cotillon 1971; Bartenstein & Bettensteadt 1962; Thieuloy 1973, 1977).

The Crassus and Triptychoides Zones are interpreted to correlate with the transgressive/highstand systems tracts, which occur between the Bidichotomoides and Polytomus highstands, and should as a matter of course correspond to the highstand systems tracts determined in the basal Pronecostatum Subzone, the lower Peregrinus Subzone, and the lower Nicklesi Subzone.

As a consequence of these correlations the ranges of *Varlheideites 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). Also the entry of *P. triplicata* in the Densicostatus Zone (Niedziolka 1988) correlates with its appearance in the Tethyan Furcillata Horizon (Donze 1976). So there is good biostratigraphic support for the correlation of the sequences in this stratigraphic interval.

According to the outcrops near Bentheim more to the west in Emsland the Dichotomites Sandstone consists of three sandstone tongues separated by two shaly intercalations (Kemper 1976, textfig. 18; Mutterlose & Bornemann 2000: fig. 8). In this revised and corrected edition of the correlation chart each tongue is interpreted to correspond to a prograding lower part representing the deposits in the top highstand systems tract, and a retrograding upper part representing the basal transgressive systems tract. The sequence boundaries separating these prograding and retrograding parts should therefore correspond to the three sequence boundaries Va4^0, Va4', and Va4". Each sequence boundary is accompanied by a hiatus. The Dichotomites sandstone units were plotted in the correlation chart with the purpose of precise age correlation and sequence stratigraphic correspondence.

11.5.3 The uppermost Valanginian and lowermost Hauterivian along the Mittellandkanal near Pollhagen (Fig. 11.11); age of the "Grenzsandstein".

The maximum flooding surfaces in this stratigraphic interval are recognized only by the ammonite frequency peaks shown by Quensel (1988; Fig. 11.11) 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 interpreted 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 Densicostatus Zone (= old 'Astieria zone' = Paucinodum Zone sensu Quensel 1988, = rebaptized by Rawson 1995 as the Olcostephanus densicostatus Zone, because this zone should better remain characterized by *Olcostephanus* instead of by a poorly understood species and because some specimens have been identified as *O. densicostatum* by Bulot (1992) and Mutterlose (1992)). The upper part of the Bidichotomoides Zone and the upper part of the Densicostatum 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.

In this revised and corrected edition the 'Grenzsandstein' is interpreted, like all sandstone tongues in the Hilston Formation, as prograding sands in the top highstand systems tract directly overlain by retrograding sands at the base of the following transgressive systems tract. The prograding and retrograding sands are separated by a sequence boundary, Va6, and by a hiatus which corresponds to the lowstand systems tract of sequence Va6. As according to the frequency curve of Quensel (1988: Fig. 11.11) sequence boundary Va6 appears to be located in the middle of the Amblygonium Zone, it may be assumed that the 'Grenzsandstein' is time-equivalent to the lower part of the Amblygonium Zone. Another argument as to the age of the 'Grenzsandstein' 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). The BH-dentations mark the Schlumberger resistivity curve of the 'Grenzsandstein'. Since sequence boundary Va6 is situated just below the Callidiscus Subzone in the upper Valanginian and since also the base of the transgressive systems tract of sequence Va6 is still situated below the first appearance of *Acanthodiscus radiatus* in SE France, it may be assumed that the entire 'Grenzsandstein' is situated in the Valanginian and has a top Furcillata/ Callidiscus age; the lower part of the Amblygonium Zone is still of Valanginian age. The higher part of the German Amblygonium Zone contains the level in which the first *Acanthodiscus radiatus* has been found. This level is virtually coincident with the appearance datum in the Tethyan Realm. The two peak-frequencies of ammonites below the Amblygonium Zone in Quensel's (1988) diagram, *viz.* in the Densicostatum and Bidichotomoides Zones, should therefore correspond to the highstands in the upper part and at the base of the Furcillata Horizon respectively. This is in accordance with the range of *Olcostephanus densicostatus* in SE France, which starts in the Furcillata Horizon and is abundantly present in the Densicostatus Zone (Bulot 1992).

11.5.4 Sequences in the Moorberg clay pit near Sarstedt (Germany) (Fig. 11.8); Noricum and Gildehaus Sandstones.

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 relative high calcium carbonate 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, but may correspond to top highstand deposits as well. When dark-grey beds cyclically alternate with light-grey beds, the former may be 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). Sequence boundary Ha1 on top of bed 99.
2. The middle part of the Regale Zone (beds 90-87). Sequence boundary Ha2 on top of bed 87, which is bioturbated.

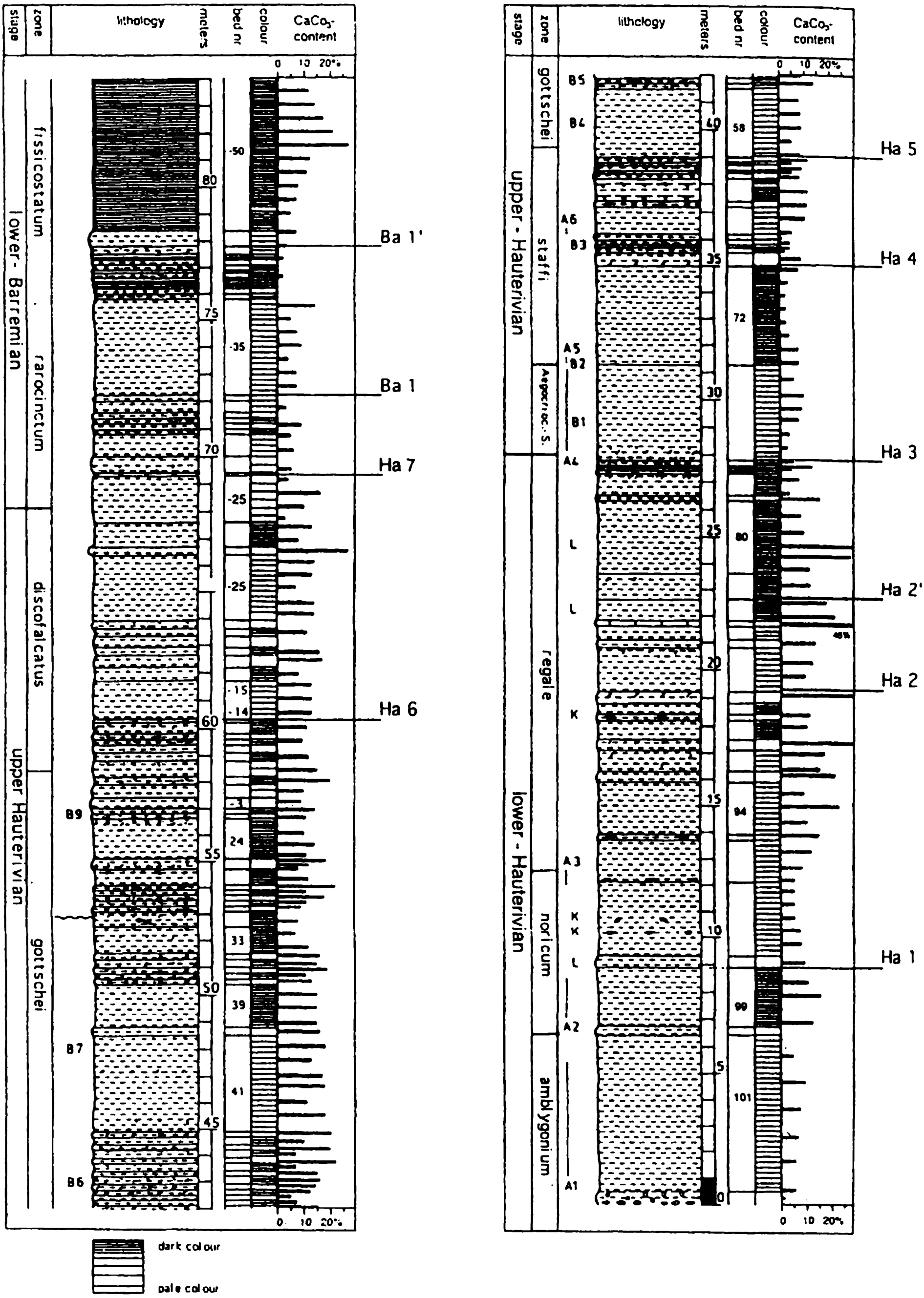


Fig. 11.8. Section through the Hauterivian of the Moorberg clay pit near Sarstedt; modified after Mutterlose (1984).

3. The lower part of the upper Regale Zone (beds 83 + 82). Maximum flooding surface in limestone bed 83. Sequence boundary 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 $CaCO_3$ content (i.e. less condensed).

4. The upper part of the Regale Zone (beds 80–74). Type 1 sequence boundary 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). Sequence boundary Ha4 on top of bed 72.

6. The upper part of the Staffi Zone (beds 64–59). Sequence boundary 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 Gott section). Sequence boundary Ha6 on top of bed -13 marks the end of a bioturbated interval; in this revised and corrected edition of the correlation chart I correlated it with the top of bed 58 of the Gott section.

8. The uppermost part of the Discofalcatus Zone (bed -24). Type 1 sequence boundary Ha7 on top of bed -26, which correlates with bed 76 of the Gott section. In this revised and corrected version of the correlation chart I shifted sequence boundary Ha7 two beds upward.

9. The Raricinctum Zone (beds -29 to -34). Sequence boundary Ba1 on top of bed -34 (= Gott 84).

10. The lower Fissicostatum Zone (beds -36 to -48) (Chondrites Beds). Sequence boundary on top of bed -48 (= Gott 98).

11. The upper Fissicostatum Zone (bed -50) (Hauptblätterton). Type 1 sequence boundary Ba2 on top of bed -50 (= Gott 100).

The Noricum Sandstone and Gildehaus Sandstone, which is not developed in the Moorberg section, but more to the west in Emsland, where we can find the coastal sediments of the Lower Saxony Basin, are plotted on the chart to reveal their precise age and correlation.

The Noricum Sandstone does not occur in the Noricum Zone, but in the Regale Zone. This is the reason why Kemper (1992) proposed to call these sandstones 'Leberich Kalksandstein', but geologists still prefer to call them Noricum Sandstone, so this name was maintained in the correlation chart. The Noricum Sandstone falls apart into two tongues, each consisting of a prograding lower part and a retrograding upper part representing the top highstand systems tract and the basal transgressive systems tract respectively separated by a sequence boundary and a hiatus. The two sequence boundaries in the middle of the two sandstone tongues are Ha2 and Ha2'. I preferred this interpretation above the old interpretation of the Noricum Sandstone representing lowstand systems tracts (Hoedemaeker 1999).

The Gildehaus Sandstone consists of three sandstone tongues separated by two more shaly intercalations (Van Adrichem-Boogaert & Kouwe (compilers), part G, Annex G22, 1993). The middle tongue is the thinnest. The Gildehaus Sandstone is not developed in the Moorberg area but only more west in Emsland and in the eastern Netherlands. In the latter area the threefold division is apparent (Van Adrichem-Boogaert & Kouwe, part G, 1993). In this revised and corrected edition of the correlation chart each Gildehaus Sandstone tongue is interpreted, like all other sandstone tongues in the Hilston Formation, as consisting of two parts, *viz.*. a lower part representing the prograding top part of the highstand systems tract and an upper part which represents the retrograding basal transgressive systems tract. These two parts are separated by a sequence boundary and a hiatus. So the Gildehaus Sandstone comprises three sequence boundaries, Ha3, Ha4, and Ha5.

11.5.5 Sequences in the Gott clay pit near Sarstedt (Germany) (Fig. 11.9).

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). Sequence boundary Ha6 on top of bed 58, which is one bed higher than I drew it in the correlation chart of 1999 (Hoedemaeker 1999).
2. The top of the Discofalcatus Zone (beds 69-76). Type 1 sequence boundary Ha7 on top of bed 76. This level corresponds to a faunal caesura (Mutterlose 1984) and correlates with bed -26 of the Moorberg section. In this revised and corrected edition of the correlation chart I shifted sequence boundary Ha7 upward 1½ m.
3. The Rarocinctum Zone (beds 79-82). Sequence boundary Ba1 on top of bed 82. This bed correlates with bed -34 of the Moorberg section.
4. The lower Fissicostatum Zone (beds 84-98). Sequence boundary Ba1' on top of bed 98 (= Moorberg -48).
5. The upper Fissicostatum Zone (bed 100) (Hauptblätterton). Type 1 sequence boundary Ba2 on top of bed 100 (= Moorberg -50).
6. Bed 109-115, interpreted to be the Elegans Zone. Sequence boundary Ba3 on top of bed 115.
7. Bed 117, interpreted to represent the Denkmanni Zone. Sequence boundary Ba3' on top of bed 117.
8. Bed 135-137 (= beds with *Hemicrioceras rude* according to Kemper, personal communication in Heilmann-Clausen & Thomsen 1995). Sequence boundary Ba4 on top of 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. Sequence boundary Ba4' on top of bed 185.
10. Bed 191-198, presumably Bidentatum Zone. Sequence boundary Ba5 on top of bed 198.

11.6 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 preseved. For the middle and upper Berriasian Stage and the Valanginian Stage the sequence interpretation by Arnaud (personal communication) in the Chambotte section (southern Jura) was used. For the lower Berriasian 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 years cycles (Fig. 11.9).

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 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.

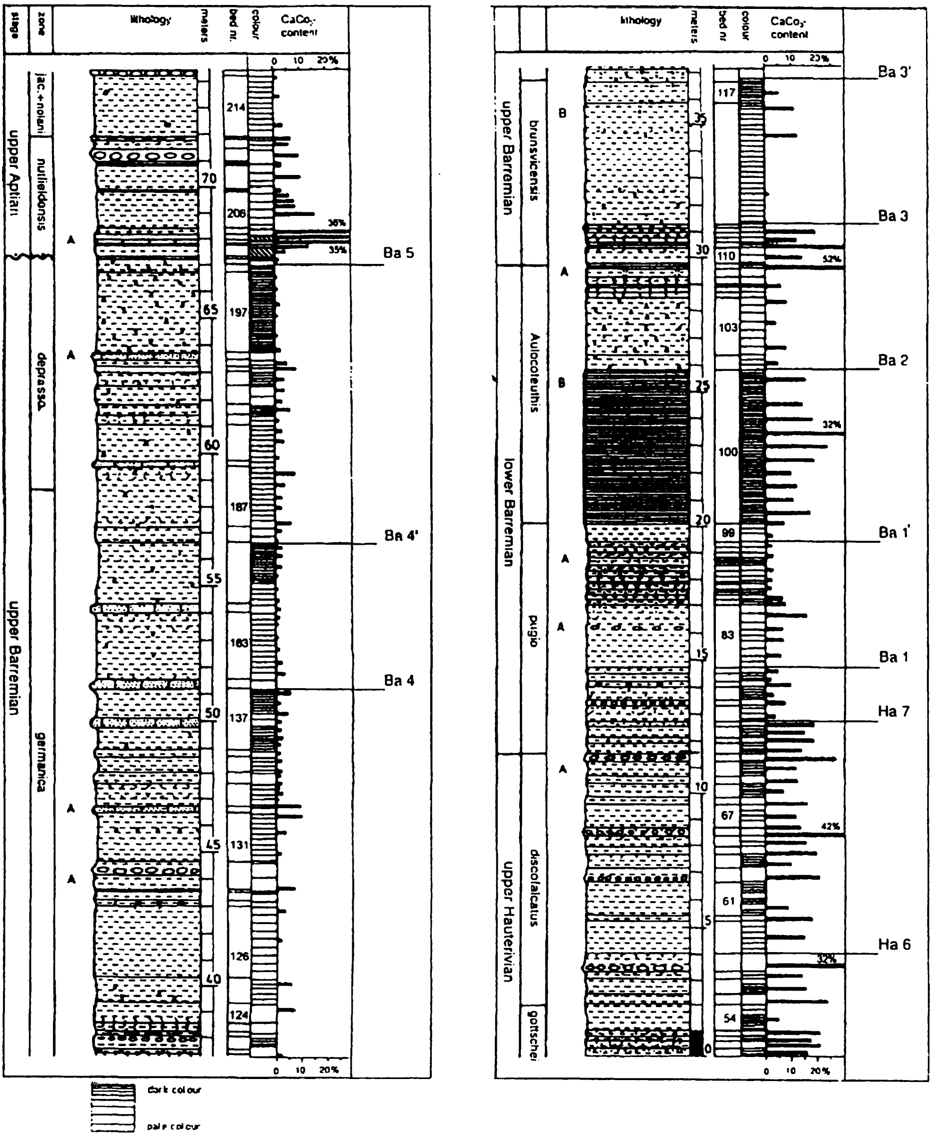


Fig. 11.9. Section through the Barremian of the Gott clay pit near Sarstedt; modified after Mutterlose (1984).

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

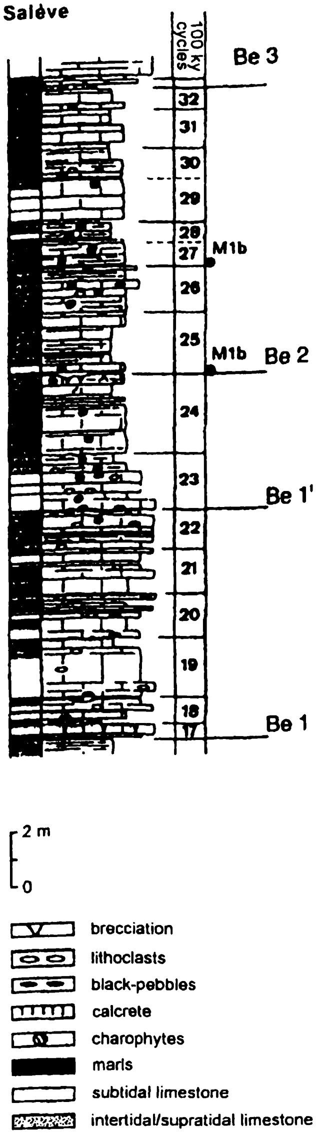


Fig. 11.10. Section through the Goldberg Formation (Berriasian) near Salève (France); modified after Strasser (1994).

the top of a set of supratidal beds with much *Chara*-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 type 1 sequence boundary Be3 and is inferred to be on top of cycle 32, which shows desiccation 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 inférieur oolithique). The lacustrine interval intercalated within this fully marine unit is interpreted as representing the prograding top part of the highstand

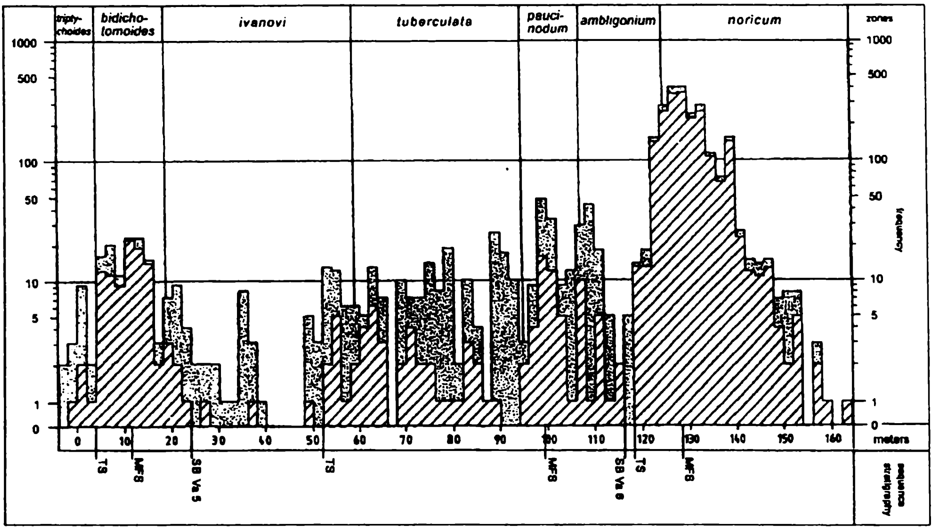


Fig. 11.11. Section along Mittellandkanal near Pollhagen: frequency distribution of macrofossils; modified after Quensel (1988). *Hatching* — ammonite frequency; *dotted* — frequency of other macrofossils. The vertical scale is logarithmic.

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', Va3^0, 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 praetriplicata*. 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'.

11.7 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 Mulichinco Sandstone with the type 1 sequence boundary Va4 and the Avilé Sandstone with type 1 sequence boundary Ha3. This deviates from the correlation by Aguirre-Ureta & 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'. It also contains the thin retrograding sand of the following trangression. As a consequence the Spitidiscus ricardii Zone should correlate with the Cruasense Horizon in France, the Spitidiscus inflatus level in Germany and with the Spitidiscus rotula level in England instead of with the Mediterranean Nodosoplicatum Zone. This is only a small upward shift and in fact of secondary importance. It is a matter of course that the Paraspiticeras groeberi Zone has a lowest Barremian age. The Mulichinco Sandstone has mainly been deposited in the lowstand systems tract of sequence Va4 and should therefore have an upper Verrucosum Subzone age (= former Neocomiensis Horizon of Atrops & Reboulet 1993). The correlation of the other Argentinian ammonite zones is merely interpolated.

11.8 The lowest Aptian sequences

The works of Casey (1961) and Kemper (1967) were consulted for the lowest boreal Aptian. Casey figured 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 to represent 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 belongs 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 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 sucession 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 type 1 sequence boundary Ap2 caused the drowning of the Urgonian 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 *Cheloniceras* (Hoedemaeker & Leereveld 1995); this is erroneous because *Cheloniceras* is already present in the Weissi Zone (Delanoy 1995). The Weissi Zone should therefore be extended up to sequence boundary Ap2.

11.9 Barremian carbonate successions in SE France (Column 6)

In this revised and updated edition of the correlation chart I included the sequence stratigraphy of the Glandasse Limestone Formation and the Urgonian Limestone Formation, because it is since the works of Arnaud (1981; written communication 1990) and Arnaud et al. (1998) one of the best documented successions for the Barremian. We use here the codes for the sequences used by Arnaud (written communication 1990; Jacquin et al. 1991; Hunt & Tucker 1993). Later Arnaud et al. (1998) changed some of the codes of the sequence boundaries, which is very confusing.

However, I distiguished two more sequences in the Barremian, which I gave the codes Ba1' and Ba3'. Changing already established codes causes confusion. They could also traced in SE France (Hoedemaeker 1998).

Crucial for the ages of the various sequences are their correlation with the type section of the Barremian Stage near Angles. This poses serious problems because the sedimentary expression of the various sequences in the Barremian stratotype is not always clear. Therefore the correlation of the Barremian in the correlation chart is still not satisfactory.

The way in which the various depositional systems tracts in pelagic basins — in which the micritic limestones are formed by accumulating tests of calcareous plankton such as coccoliths or nannoconus — should be interpreted, is totally different from the way in which the depositional systems tracts are interpreted on the platform.

The first reasoning as to the interpretation of the position of maximum flooding intervals in pelagic basins is that they are characterized by condensed sedimentation and starvation of clastic sediments, clay for instance. These intervals consist of thick, closely packed, pelagic limestone beds with very thin marlstone interbeds, wich may be absent; the maximum flooding surfaces represent positive peaks in the amount of pelagic limestone and negative peaks in the amount of marlstone. The measure of condensation is expressed by the greater number of fossils per volume of rock. The limestone/marlstone couples deposited during one precession cycle are relatively thin. The depocentre of the siliciclast-bearing marlstones is shifted towards the platform.

The second reasoning is that lowstand systems tracts are characterized by rather thick marlstone interbeds representing positive peaks in the amount of marlstone and negative peaks in the amount of pelagic limestone. This is because the depocentre of the siliciclast-bearing marlstones has shifted into the basin. The number of fossils per volume of rock is less than in maximum flooding intervals. The limestone/marlstone couples deposited during one precession cycle are relatively thick.

This reasoning means that sequence boundaries in a pelagic basin are situated at the base of the thickest marlstone intervals and not, as many French sedimentologists do, at the base of bundles of closely packed limestone beds. Maximum flooding surfaces are situated at the peaks in the amount of limestone and not at the peaks of the amount of marlstone, as many French sedimentologists prefer. For example, the Limentinus Marls and La Bequère Marls on the platform correlate with thick limestone bundles almost without marly interbeds in the basin. The consequence of this difference in interpretation is that French ages of sequence boundaries or maximum flooding surfaces are generally out of phase and often younger than my ages. The position of the sequence boundaries drawn on the correlation chart in the stratotype of the Barremian near Angles is in accordance with the here elucidated views and only differ slightly from those of Arnaud (1998), who followed the French view.

Last but not least the third reasoning: the lowstand systems tracts as well as the top highstand systems tracts are generally characterized by high continental/marine ratio (C/M ratio), which means a relatively large amount of continent-derived elements, for instance pollens in relation to the amount of marine dinoflagellate cysts (Wilpshaar, written communication, 1992). The dinocysts also show an unmistakable shift from deeper to shallower facies through some Hauterivian and Barremian sequences near Angles (Terberg, written communication, 1987); a sequence boundary should be interpreted on top of each of these regressive tendencies.

1. Sequence boundary Ha6 is chosen at the base of the thick marlstone interbed on top of limestone bed 27 of the Angles section. This marlstone interbed shows a peak in the C/M ratio (Terberg, written communication).

2. If one follows the gradual shift among the dinocysts from relatively deep water species to relatively shallow water species in the uppermost Hauterivian highstand systems tract (Terberg, written communication, 1987), sequence boundary Ha7 should be situated between the two successive samples analysed from beds 42 and 72, and was interpreted to be situated at the base the thin marly interval on top of limestone bed 64. Jacquin (1993) drew the sequence bounday at the top of the same marly interval, i.e. in marly interbed 65.

I prefer (Hoedemaeker 1994, 1998) the first appearance of *Barremites* and of *Pseudothurmannia* of the *simionescui* group at the base of bed 63 to be the lower boundary of the Barremian. These ammonites begin their ranges at the base of the Catulloi Subzone.

3. A similar shift from relatively deep water to relatively shallow water dinocyst species ends in bed 101; the top of limestone bed 101 was interpreted as sequence boundary Ba1.

4. In this revised edition of the correlation chart I chose the base of the marl-rich interval on top of bed 111c at the base of the Compressissima Zone of the Angles stratotype section as the level of sequence boundary Ba1', but according to Everts (1994) and Arnaud et al. (1998) this sequence boundary is situated at the top of member Bi5 of Arnaud (1981) above the Upper Fontaine Graillère Marls and below the Fontaine Colombette Marls, and correlates with the approximate base of the Moutoni/Darsi Zone; it should therefore be situated at the base of the marl-rich interval on top of bed Angles 124. However, the marly interval that begins on top of bed 111c is far more pronounced than the one on top of bed 124 and therefore I chose the top of bed 111c as the level of Ba1'. If one searches to determine

the level of the maximum flooding surface of sequence Ba1', then there are two levels that may come into consideration as maximum flooding surfaces, *viz.* beds 114 and 132, which correspond, in accordance with the ages given by Arnaud et al. (1998), to the Upper Fontaine Graillère Marls and the Fontaine Colombette Marls. Towards the basin these two marlstone intervals fuse together into the Combau Marls. So sequence boundary Ba1' could be situated below or above the Upper Fontaine Graillère Marls. I chose here the first solution, but the latter solution may be equally possible.

5. In this revised edition of the correlation chart I interpreted, virtually similar to my interpretation in 1998 (Hoedemaeker 1998) and to that of Arnaud et al. (1998), but contrary to my interpretation in 1999 (Hoedemaeker 1999), the major sequence boundary Ba2 (= Ba3 of Arnaud et al. 1998) as situated at the base of the marlstone interval on top of limestone bed 135 instead of bed 129 of the Angles stratotype section. The reasons for this upward shift are that, firstly, the base of the consistent presence of *Odontochitina operculata* in bed Angles 142 falls in line with the base of its consistent presence in the Spanish Río Argos succession, in England and in the Netherlands, secondly, that the first appearance of *Ancyloceras vandenheckii* in bed 142 virtually falls in line with its appearance in the Río Argos succession. However, *Macroscaphites tirolensis* from bed 134 below the sequence boundary designates an upper Barremian age as do the dinocysts sampled in the Fontaine Colombette Marls (Wilpshaar 1995a); the marls may be correlatable with bed 132 of the Angles stratotype. So on account of the ages sequence boundary Ba2 may equally well be situated on top of limestone bed 129 (as was done by Hoedemaeker 1999); the marlstone interbed on top of it has a marked peak in the C/M ratio. Sequence boundary Ba2 is probably accompanied by a large hiatus, because the lowstand systems tract consists only of two beds, 135 and 136, which have not been palynologically analysed. The base of bed 137 has been interpreted as a major sequence boundary by Arnaud-Vanneaux & Arnaud (1991), Jacquin (1993), Hoedemaeker (1998) and Arnaud et al. (1998).

6. Sequence boundary Ba3 was interpreted as being situated at the top of the lower limestone part of bed Angles 144. The thinness of the lowstand systems tract suggests an appreciable hiatus on top of this limestone part. The marlstone interbed shows a peak in the C/M ratio and also marks the end of a regressive trend among the dinocysts (Terberg, Wilpshaar, written communication). It has been interpreted as a maximum flooding surface by Jacquin (1993).

7. Sequence boundary Ba3' is situated just below the base of the Sartousiana Zone and may be placed at the top of bed 155 of the Angles stratotype section. The thinness of the lowstand systems tract suggests an appreciable hiatus on top of this sequence boundary. The marlstone of beds 165 and 166 shows a peak in the C/M ratio and its top has been interpreted as a sequence boundary by Arnaud et al. (1998).

8. In this correlation chart the base of the marly interval on top of limestone bed 168 was interpreted to be the level of sequence boundary Ba4, which is accompanied by a large hiatus. This level has been interpreted as a maximum flooding surface by Jacquin (1993) and the slightly thicker marly interbed of bed 172 in the same way by Arnaud (written communication, 1990) and Arnaud et al. (1998). The beds have not been palynologically analysed.

9. The base of the marlstone interbed on top of limestone bed 178 was interpreted to be the level of sequence boundary Ba4'. The top of this marlstone interbed has also been interpreted as a sequence boundary by Arnaud et al. (1998; his new level for Ba5). This marlstone interbed has not been palynologically analysed.

10. Bed 195, however, shows again a marked peak in the C/M ratio. The top of limestone bed 194 was interpreted to be the level of sequence boundary Ba5. Arnaud et al. (1998; his new level for Ap1) places the sequence boundary at the top of the marly interbed of bed 196.

11. Bed 210, a peak in clay content, shows again a prominent peak in the C/M ratio (Terberg, Wilpshaar, personal communication) and the base of the thick marlstone bed was chosen as the level of sequence boundary Ap1; Jaquin (1993) interpreted this level as a maximum flooding surface. Arnaud et al. (1998) do not adopt a sequence boundary between Ba5 and Ap2 anymore.

12. The type 1 sequence boundary Ap2 was drawn at the top of limestone bed 219 and is thought to be responsible for the channels in the top of the Urgonian Limestone Formation and for the drowning of the Urgonian platform in SE France.

It is remarkable that most of the marly intervals that should characterize lowstand systems tracts in the upper Barremian near Angles, i.e. from sequence boundary Ba2 upward, are not thicker than only one or two beds. This justifies the assumption that these lowstand systems tracts are not completely preserved; the lower main parts are apparently missing. This is in accordance with the results of the investigations of Lucas Wissler et al. (2001, in press) (written communication, 1999), who found that more than 50 % of the upper Barremian of the stratotype is missing. Also the lowstand marls of the lower Barremian sequences are thin and may not represent the totality of the lowstands.

11.10 Various biostratigraphic events and fossil names

11.10.1 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 as 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 for Tethyan-Boreal correlation, 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 Lamplughi 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 (Clements 1993). 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 Dicofalcatus 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)

Cribroperidinium 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)

Exiguisphaera 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 V_2 45 (Leereveld 1997b)
Speeton, LO just below bed CB3 (Duxbury 1980)

Hystrichosphaerina schindewolfii
Angles, FO bed 201 (Leereveld, written communication)

'Wealden' 6, FO depth along core 85.3 m (Strauss et al. 1993)

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)
Angles, LO bed 147 (De Reneville & Raynaud 1981)

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
Speeton, FO bed D7G (Heilmann-Clausen 1987; Davey 1982)
Río Argos, FO bed Y234 (Leereveld 1997a)
Subsurface North Sea, FO in "Stenomphalus maximum flooding surface K. 10" (Partington et al. 1993)

Prolixospaeridium parvispinum
Río Argos, FO bed $V_2$45 (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)

Tehamadinium tenuiceras
Angles section, FO bed 202 (Leereveld, personal communication)
Sample B14, depth 25.43 m, Hoheneggelsen borehole KB 50 = 1.26 m below FO of *Chiastozygus litteratus* (Below & Kirsch 1997)

Valensiella magna
Angles section, LO highest part of Sarasini Zone (Leereveld, personal communication)
Gott section, LO above Rude Zone (Heilmann-Clausen & Thomsen 1995)

11.10.2 Ammonite names mentioned in the white strips.

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

Aconeceras sp. and *Heteroceras* sp. (Rawson 1995).

Ancyloceras vandenheckii: first appearance in Angles section, bed 142 (Vermeulen 1998).

Argvethites: also found in France.

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).

Camereiceras limentinus: in maximum flooding interval of sequence Ba4 in upper part of Sartousiana Zone.

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

Crioceras (Paracrioceras) cf. *occultum.*

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

Deshayesites: First occurrence in Angles in bed 200; this specimen was found by Kakabadze and identified by Bogdanova as a *Deshayesites* during Cretaceous symposium in Vienna (2000).

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

Heinzia sayni: first appearance in Angles section in bed 147 (Vermeulen 1998).

Holcodiscus fallax: inferred range.

Holcodiscus uhligi: in bed 140 of Angles section (Vermeulen 1998).

Jeannoticeras jeannoti (Doyle 1989).

Karakaschiceras biassalense, K. cf. *inostranzewi*, and *Neohoploceras submartini* (Kemper et al. 1981).

Kotetishvilia compressissima (inferred range).

"Leptoceras" puzosianum: Angles section, bed 177 (Busnardo 1965).

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

Macroscaphites tirolensis: in bed 134 of Angles section.

Nicklesia pulchella: inferred range.

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.

Paracrioceras elegans: Speeton LB1A (Rawson & Mutterlose 1983).

Paracrioceras fissicostatum: Speeton LB2C2 (Rawson & Mutterlose 1983).

Paracrioceras cf. *occultum:* Speeton LB3E (Rawson & Mutterlose 1983).

Paracrioceras cf. *rarocinctum:* Speeton LB5D to LB4 (Rawson & Mutterlose 1983).

Paracrioceras tuba: CB48, CB47 (Rawson & Mutterlose 1983).

Paracrioceras cf. *varicosum:* LB2A1 (Rawson & Mutterlose 1983).

Phyllopachyceras: Speeton C7H.

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

Platylenticeras cf. *involutum* (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* (Kemper et al. 1981).

"Shasticrioceras" anglicum (Doyle 1963).

Simbirskites inversum: Its first occurrence mentioned by Kemper (1992), from the Nietberg Zwischenmittel (Regale Zone).

Spitidiscus pavlowi: Speeton C8A (Rawson 1970; Kemper et al. 1981).

Spitidiscus rotula (Speeton, bed, Rawson 1970).

Torcapella capillosa: Angles, bed 118.

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

Belemnites: *Praeoxyteuthis pugio, Hibolithes jaculoides, Acroteuthis 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, Protocythere triplicata, P. praetriplicata, P. frankei, P. hannoveriana, Estheria.*

Nannoplankton: *Calcicalathina oblongata, Cruciellipsis 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).

Gastropods: *Viviparus fluviorum, Filosina, Casiope, Cyrena.*

Acknowledgements: I am grateful for the stimulating discussions and enthusiastic support of Dr. Han Leereveld (Lower Cretaceous dinoflagellate cysts), who provided many biostratigraphic ties to the schemes. Also I am grateful to Messrs E. Aksoy, E. Bosch, S.B. Blankevoort and L.R. Jansen for drawing the complicated schemes on their computer and to mr R. Malherbe without his management this scheme would not have come into being. I also thank Dr. C. W. Winkler Prins for taking over the production of the schemes during my illness. Without the help M.Sc. N.M.N. Janssen (Belemnites and detailed correlation of the Valanginian in SE France), and M. Sc J. Klein (Valanginian and Hauterivian ammonites of SE France) this correlation scheme would not have acquired the high resolution which it has now.

References

Aguirre-Urreta M. & Rawson P.F. 1997: The ammonite sequence in the Agrio Formation (Lower Cretaceous), Neuquén basin, Argentina. *Geol. Mag.* 134, 449-458.

Allen P. & Wimbledon W.A. 1991: Correlation of NW European Purbeck-Wealden (nonmarine Lower Cretaceous) as seen from the English type areas. *Cretaceous Research* 12, 511-526.

Anderson F.W. 1962: Correlation of the upper Purbeck Beds of England with the German Wealden. *Liverpool and Manchester Geological Journal* 3, 21-32.

Anderson F.W. 1973: The Jurassic-Cretaceous transition: the non-marine ostracod faunas. In: Casey R. & Rawson P.F. (Eds.): The Boreal Lower Cretaceous. *Seel House Press,* Liverpool, 101-110.

Anderson F.W. 1985: Ostracod faunas in the Purbeck and Wealden of England. *J. Micropalaeont.* 4, 1-68.

Anderson F. W. & Bazley R.A.B. 1971: The Purbeck Beds of the Weald. *Bull. Geol. Surv. Gt Br.* 34, 1-138.

Anderson F.W. & Hughes N.F. 1964: The 'Wealden' of north-west Germany and its English equivalents. *Nature* 201, 907-908.

Arkell W.J. 1956: Jurassic geology of the world. *Oliver and Boyd Ltd.,* Edinburgh-London, 1-806.

Arnaud H. 1981: De la plate-forme urgonienne au basin vocontien: le Barrémo-Bédoulien des Alpes occidentales entre Isère et Buëch. *Géol. Alpine, Mém.* 12, 1-804.

Arnaud-Vanneau A. & Arnaud H. 1990: Hauterivien to lower Aptian carbonate shelf sedimentation and sequence stratigraphy in the Jura and northern Subalpine chains (southeastern France and Swiss Jura). *Spec. Publ. Inter. Assoc. Sedimentologists* 9, 203-233.

Arnaud-Vanneau A. & Arnaud H. 1991: Sédimentation et variations relatives du niveau de la mer sur les plates-formes carbonatées du Berriasien-Valanginien inférieur et du Barrémien dans les massifs subalpins septentrionaux et le Jura (sud-est de la France). *Bull. Soc. Géol. France*, 162, 3, 535-545.

Arnaud H., Arnaud-Vanneau A., Blanc-Alétru M.-C., Adatte T., Argot M., Delanoy G., Vermeulen J., Virgone A., Virlouvet B. & Wermeille S. 1998: Répartition stratigraphique des orbitolinidés de la plate-forme urgonienne subalpine et jurassienne (SE de la France). *Géol. Alpine* 74, 3-89.

Atrops F. & Reboulet S. 1993: Nouvelles données sur la zonation par ammonites du Valanginien supérieur de l'hypostratotype d'Angles (Alpes-de-Haute-Provence) et sur ses corrélations. *C. R. Acad. Sci.*

Paris 317, Série II, 499-506.

Atrops F. & Reboulet S. 1995: Le Valanginien-Hauterivien basal du bassin vocontien et de la bordure provençale: zonation et corrélations. *C. R. Acad. Sci. Paris* 320, série IIa, 985-992.

Autran G. 1989: L'évolution de la marge nord-est provençale (Arc de Castellane) du Valanginien R l'Hauterivien R travers l'analyses biostratigraphique des séries de la région de Peyroules: séries condensées, discontinuités et indices d'une tectogenèse distensive. *Thèse de l'Université de Nice*, 232 p.

Bartenstein H. & Bettenstaedt F. 1962: Marine Unterkreide (Boreal und Tethys). In: Arbeitskreis deutscher Mikropaläontologen: Leitfossilien der Mikropaläontologie. *Gebrüder Borntraeger*, Berlin-Nikolassee, 225-297.

Below R. 1981: Dinoflagellaten-Zysten aus den Platylenticeras-Schichten (unteres Mittel-Valendis) der Ziegeleitongrube Schnepper in Suddendorf/Nordwest-Deutschland. *Newslett. Stratigr.* 10, 115-125.

Below R. & Kirsch K. H. 1997: Die Kerogen-Facies der Tonstein-Blättertonstein-Rhythmite des Ober-Barrçme/Unter-Apt im niedersäcksischen Becken (Norddeutschland) am beispiel der Bohrung Hoheneggelsen KB 50. *Palaeontographica* B, 242, 1-3, 1-90.

Besse J., Boisseau T., Arnaud-Vanneau A., Arnaud H., Mascle G. & Thieuloy J.-P. 1986: Modifications sédimentaires, renouvellements des faunes et inversions magnétiques dans le Valanginien de l'hypostratotype d'Angles. *Bull. Cent. Rech. Ex.-Prod. Elf-Aquitaine* 10, 365-368.

Birkelund T., Clausen C.K., Hansen H.N. & Holm L. 1983: The Hectoroceras kochi Zone (Ryazanian) in the North Sea Central Graben and remarks in the Late Cimmerian Unconformity. *Dan. Geol. Unders.* (1982), 53-72.

Boisseau T. 1987: La plate-forme jurassienne et sa bordure subalpine au Berriasien-Valanginien (Chartreuse-Vercors). Analyse et corrélations avec les séries de bassin. *Thèse de doctorat de l'Université Scientifique Technologique et Médicales de Grenoble*, 31 octobre 1987, 1-413.

Bulot L.G. 1992: Les Olcostephaninae valanginiens et hauteriviens (Ammonitina, Cephalopoda) du Jura franco-suisse: Systematique et intérêt biostratigraphique. *Rev. Paléobiol.* 11, 149-166.

Bulot L.G., Thieuloy J.-P., Blanc E. & Klein J. 1992: Le cadre stratigraphique du Valanginien supérieur et de l'Hauterivien du Sud-Est de la France: Définition des biochronozones et caractérisation de nouveaux biohorizons. *Géol. Alpine* 68, 13-56.

Busnardo R. 1965: Le stratotype du Barrémien. In: Colloque sur le Crétacé inférieur, Lyon 1963. *Mém. Bur. Rech. Géol. Min. Paris* 34, 101-116.

Busnardo R. 1984: 1.2. Stratotypes et parastratotypes; 1.3. Echelles biostratigraphiques; 1.3.1. Ammonites. In: Cotillon P. (coordinator): Crétacé Inférieur. *Mém. Bur. Rech. Géol. Min. Paris* 126, 288-294.

Busnardo R. & Thieuloy J.-P. 1989: Les ammonites de l'Hauterivien jurassien: révision des faunes de la région du stratotype historique de l'étage Hauterivien. *Mém. Soc. Neuch. Sc. Nat.* 11, 101-147.

Busnardo R., Thieuloy J.-P. & Moullade M. (Eds.) 1979: Hypostratotype mesogéen de l'étage Valanginien (sud-est de la France). *Comité français de stratigraphie, Editions du C.N.R.S. Les stratotypes français*, 6, 143 p.

Busnardo R. & Vermeulen J. 1986: La limite Hauterivien-Barrémien dans la région stratotypique d'Angles. *C. R. Acad. Sci. Paris* 302, Série II, 7, 457-459.

Casey R. 1961: The stratigraphical palaeontology of the Lower Greensand. *Palaeontology* 3, 487-621.

Casey R. 1973: The ammonite succession at the Jurassic-Cretaceous boundary in eastern England. In: Casey R. & Rawson P.F. (Eds.): The Boreal Lower Cretaceous. *Geol. Journ., Spec. Issue* 5, 193-266.

Clements R.G. 1993: Type-section of the Purbeck Limestone Group, Durlstone Bay, Swanage, Dorset. *Proceedings of the Dorset Natural History and Archaeological Society*, 114, 181-206.

Colloque Lyon 1963: Conclusions générales du Colloque. In: Colloque sur le Crétacé inférieur, Lyon

1963. *Mém. Bur. Rech. Géol. Min. Paris* 34 (1975), 827-834.

Colloque Lyon 1973: VII. Discussions sur la position de la limite Jurassique-Crétacé. VIII. Discussion générale préliminaires au dépôt des motions. In: Colloque sur la limite Jurassique-Crétacé, Lyon, Neuchâtel, 1973. *Mém. Bur. Rech. Géol. Min. Paris* 86, 379-393.

Company M., Sandoval & Tavera M. 1995: Lower Barremian ammonite biostratigraphy in the Subbetic domain (Betic Cordillera, southern Spain). *Cretaceous Research* 16, 243-256.

Congress Copenhagen 1984. Birkelund T., Hancock J.M., Hart M.B., Rawson P.F., Remane J., Robaszynsky F., Schmid F. & Surlyk F. 1984: Cretaceous stage boundaries — proposals. *Bull. Geol. Soc. Denmark* 33, 3-20.

Congress Brussels 1996. Rawson P.F., Dhondt A.V., Hancock J.M. & Kennedy W.J. (Eds.) 1996: Proceedings "Second International Symposium on Cretaceous Stage Boundaries" Brussels 8-16 September 1995. *Bull. Inst. Royal Sci. Natur. Belgique, Sci. Terre* Suppl. 66, 117 p.

Cotillon P. 1971: Le Crétacé inférieur de l'arc subalpin de Castellane entre Asse et le Var. Stratigraphie et sédimentologie. *Mém. Bur. Rech. Géol. Min. Paris* 68, 1-313.

Darsac C. 1983: La plate-forme berriaso-valanginienne du Jura méridional aux massifs subalpins (Ain, Savoie). *Thèse de l'Université Scientifique et Médicale de Grenoble* (unpublished).

Davey R.J. 1979: The stratigraphic distribution of dinocysts in the Portlandian (latest Jurassic) to Barremian (Early Cretaceous) of northwest Europe. *American Association of Stratigraphic Palynologists Contribution Series 5B, 2, Mesozoic Palynology,* 49-81.

Davey R.J. 1982: Dinocyst stratigraphy of the latest Jurassic to Early Cretaceous of the Haldager No 1 borehole, Denmark. *Dan. Geol. Unders.* B, 6, 57 p.

Delanoy G.1994: Les zones à Feraudianus, Giraudi et Sarasini du Barrémien supérieur de la région stratotypique d'Angles-Barrême-Castellane (Sud-Est de la France). *Géol. Alpine, Mém. Hors Série* 20, 279-319.

Delanoy G. 1995: About some significant ammonites from the Lower Aptian (Bedoulian) of the Angles-Barrême area (South-East France). *Mem. Descr. Carta Geol. Ital.* 51, 65-101.

Detraz H. & Mojon P.-O. 1989: Evolution paléogéographique de la marge jurassienne de la Téthys du Tithonique-Portlandien au Valanginien: corrélations biostratigraphiques et séquentielles des faciès marins à continentaux. *Eclogae Geol. Helv.* 82, 37-112.

Donovan D.T. 1957: The Jurassic and Cretaceous Systems in East Greenland. *Meddr. Grønl.* 155, 1-214.

Donze P. 1976: Répartition stratigraphique des espèces du genre *Protocythere* Triebel 1938 (Ostracode), dans le Valanginien de la région de Chabrières (Alpes de Haute-Provence). *Rev. Micropaléont.* 19, 19-26.

Donze P. & Thieuloy J.-P. 1975: Sur l'extrême condensation du Valanginien supérieur dans le Jura neuchâtelois, en particulier dans le stratotype de Valangin, et sa signification dans l'ensemble des formations valanginiennes du Sud-Est de la France. *C. R. Acad. Sci. Paris*, 280, D, 1661-1664.

Doyle J.C. 1963: A new heteromorph ammonite from the Lower Cretaceous of Yorkshire. *Palaeontology* 6, 575-578.

Doyle J.C. 1989: The stratigraphy of a late lower Hauterivian horizon in the Speeton Clay formation (Lower Cretaceous) of East Yorkshire. *Proc. Geol. Ass.* 100, 175-182.

Duxbury S. 1977: A palynostratigraphy of the Berriasian to Barremian of the Speeton Clay of Speeton, England. *Palaeontographica* B 160, 17-67.

Duxbury S. 1980: Barremian phytoplankton from Speeton, East Yorkshire. *Palaeontographica* B 173, 107-146.

Elstner F. & Mutterlose J. 1996: The Lower Cretaceous (Berriasian and Valanginian) in NW Germany. *Cretaceous Research* 17, 119-133.

Feist M., Lake R.D. & Wood C.J. 1995: Charophyte biostratigraphy of the Purbeck and Wealden of southern England. *Palaeontology* 38, 2, 407-442.

Feist M. & Schudack M.E. 1991: Correlation of charophyte assemblages from the nonmarine Jurassic-

Cretaceous transition of NW Germany. *Cretaceous Research* 12, 495-510.

Fletcher B.N. 1973: The distribution of Lower Cretaceous (Berriasian-Barremian) foraminifera in the Speeton Clay of Yorkshire, England. In: Casey R. & Rawson P. F. (Eds.): The Boreal Lower Cretaceous. *Geol. Journ., Spec. Issue* 5, 161-168.

Galbrun B. 1985: Magnetostratigraphy of the Berriasian stratotype section (Berrias, France). *Earth Planet. Sci. Lett.* 74, 130-136.

Galbrun B. & Rasplus L. 1984: Magnétostratigraphie du stratotype du Berriasien. Premiers résultats. *C. R. Acad. Sci. Paris* 2, 6, 219-222.

Galbrun B., Rasplus L. & Le Hégarat G. 1986: Donnés nouvelles sur le stratotype du Berriasien: corrélations entre magnétostratigraphie et biostratigraphie. *Bull. Soc. Géol France* 8, 2, 575-584.

Giraud F. 1995: Recherche des périodicités astronomiques et des fluctuations du niveau marin à partir de l'étude du signal carbonaté des séries pélagiques alternantes. *Doc. Lab. Géol. Fac. Sci. Lyon* 134, 1-279.

Hallam A., Grose J.A., & Ruffell A.H. 1991: Palaeoclimatic significance of changes in clay mineralogy across the Jurassic-Cretaceous boundary in England and France. *Palaeogeogr., Palaeoclimatol., Palaeoecol.* 81, 173-187.

Harding I.C. 1990: A dinocyst calibration of the European boreal Barremian. *Palaeontographica* B 2, 18, 1-76.

Heilmann-Clausen C. 1987: Lower Cretaceous dinoflagellate biostratigraphy in the Danish Central Trough. *Dan. Geol. Unders.* A, 17, 54 p.

Heilmann-Clausen C. & Thomsen E. 1995: Barremian-Aptian dinoflagellates and calcareous nannofossils in the Ahlum 1 borehole and the Otto Gott clay pit, Sarstedt, Lower Saxony basin, Germany. *Geol. Jb. A* 141, 256-365.

Hesselbo S.P., Coe A.L. & Jenkyns H.C. 1990: Recognition and documentation of depositional sequences from outcrop: an example from the Aptian and Albian on the eastern margin of the Wessex Basin. *J. Geol. Soc. London* 147, 549-559.

Hoedemaeker Ph.J. 1981: The Jurassic-Cretaceous boundary near Miravetes (Caravaca, SE Spain); arguments for its position at the base of the Occitanica Zone. *Quadernos de Geología* 10 (1979), 235-247.

Hoedemaeker Ph.J. 1982: Ammonite biostratigraphy of the uppermost Tithonian, Berriasian, and lower Valanginian along the Río Argos (Caravaca, SE Spain). *Scripta Geol.* 65, 1-81.

Hoedemaeker Ph.J. 1983: Reconsideration of the stratigraphic position of the boundary between the Berriasian and the Nemausian (= Valanginian *sensu stricto*). *Zitteliana* 10, 447-457.

Hoedemaeker Ph.J. 1984: Proposals for the stratigraphic position of the Berriasian-Valanginian and the Valanginian-Hauterivian boundaries. *Bull. Geol. Soc. Denmark* 33, 139-146.

Hoedemaeker Ph.J. 1987: Correlation possibilities around the Jurassic-Cretaceous boundary. *Scripta Geol.* 84, 1-64.

Hoedemaeker Ph.J. 1991: Tethyan-Boreal correlations and the Jurassic-Cretaceous boundary. *Newslett. Stratigr.* 25, 37-60.

Hoedemaeker Ph.J. 1994: Ammonite distribution around the Hauterivian-Barremian boundary along the Río Argos (Caravaca, SE Spain). *Géol. Alpine, Mém. Hors Série* 20 (1994), 219-277.

Hoedemaeker Ph.J. 1995: Ammonite evidence for longterm sea-level fluctuations between the 2nd and the 3rd order in the lowest Cretaceous. *Cretaceous Research* 16, 231-241.

Hoedemaeker Ph.J. 1996: Proposal for a new stratigraphic position for the Hauterivian-Barremian boundary at one of the faunal turnovers that are caused by long-term cyclic high-amplitude sea-level falls. *Mitt. Geol.-Paläont. Inst. Univ. Hamburg* 77, 271-273.

Hoedemaeker Ph.J. 1998: The Berriasian-Barremian sequences in the Río Argos succession near Caravaca (SE Spain). *Soc. Econom. Paleontologists and Mineralogists, Spec. Publ.*

Hoedemaeker Ph.J. 1999: A Tethyan-Boreal correlation of pre-Aptian Cretaceous strata: correlating the uncorrelatables. *Geol. Carpathica* 50, 2, 101-124

Hoedemaeker Ph.J. & Bulot L. 1990: Preliminary ammonite zonation for the Lower Cretaceous of the Mediterranean region. *Géol. Alpine* 66, 123-127.

Hoedemaeker Ph.J. & Cecca F. (reporters) & 16 co-authors 1995: Report on the 3rd international workshop on the standard Lower Cretaceous ammonite zonation of the Mediterranean region. *Mem. Descr. Carta Geol. Ital.* 51, 213-215.

Hoedemaeker Ph.J. & Company M. (reporters) & 16 co-authors 1993: Ammonite zonation for the Lower Cretaceous of the Mediterranean region; basis for the stratigraphic correlations within IGCP-Project 262. *Rev. Esp. Paleont.* 8, 117-120.

Hoedemaeker Ph.J. & Leereveld H. 1995: Biostratigraphy and sequence stratigraphy of the Berriasian-lowest Aptian (Lower Cretaceous) of the Río Argos succession, Caravaca, SE Spain. *Cretaceous Research* 16, 195-230.

Hoedemaeker Ph.J. & Rawson P.F. 2000: Report on the 5th International Workshop of the Lower Cretaceous Cephalopod Team (Vienna, 5 September 2000). *Cretaceous Research* 21, 857-860.

Hunt C.O. 1985: Miospores from the Portland Stone Formation and the lower part of the Purbeck Formation (Upper Jurassic/Lower Cretaceous) from Dorset, England. *Pollen et Spores* 27, 419-451.

Hunt C.O. 1987: Dinoflagellate cyst and acritarch assemblages in shallow marine and marginal-marine carbonates; the Portland Sand, Portland Stone, and Purbeck Formations (Upper Jurassic-Lower Cretaceous) of southern England and northern France. In: Hart M.B. (Ed.): Micro-palaeontology of carbonate environments. *British Micropalaeontological Society Series, Ellis Horwood Ltd.*, Chichester, 208-225.

Hunt D. & Tucker M.E. 1993: Sequence stratigraphy of carbonate shelves with an example from the mid-Cretaceous (Urgonian) of southeast France. *Spec. Publ. Inter. Assoc. Sedimentologists* 18, 307-341.

Immel H. 1979: Die Ammonitengliederung des mediterranen und borealen Hauterive und Barrçme unter Berichtigung heteromorpher Ammoniten der Gattung *Crioceratites* Leveillé. *Newslett. Stratigr.* 7, 121-141.

Immel H. & Mutterlose J. 1980: Barrême-Cephalopoden aus dem kretazischen Untergrund des Stadtgebietes von Hannover (NW-Deutschland). *Paläont. Z.* 54, 241-266.

Jacquin T. 1993 (inedited): Sequence stratigraphic framework of the Urgonian platform. In: Fieldtrip 6: Vercors, France: sequence stratigraphy of an Early Cretaceous carbonate platform. *1993 AAPG International Conference & Exhibition, The Hague, October 1993, Part 4,* 59-75.

Jacquin T., Arnaud-Vanneau A., Arnaud H., Ravenne C. & Vail P.R. 1991: Systems tracts and depositional sequences in a carbonate setting: a study of continuous outcrops from platform to basin at the scale of seismic lines. *Marine and Petroleum Geology* 8, 122-139.

Jacquin T. & De Graciansky P.-C. 1998: Transgressive/regressive (second order) facies cycles: the effects of tectono-eustacy. *SEMP Spec. Publ.* 60, 31-42.

Jakubowski M. 1987: A proposed Lower Cretaceous calcareous nannofossil zonation scheme for the Moray Firth area of the North Sea. *Abh. Geol. B.-A. Wien* 39, 99-119.

Jan du Chêne R., Busnardo R., Charollais J., Clavel B., Deconinck J.-F., Emmanuel L., Gardin S., Gorin G., Manivit H., Monteil E., Raynaud J.-F., Renard M., Steffen D., Steinhauser N., Strasser A., Strohmenger C. & Vail P.R. 1993: Sequence-stratigraphic interpretation of upper Tithonian-Berriasian reference sections in south-east France: a multidisciplinary approach. *Bull. Cent. Rech. Ex.-Prod. Elf-Aquitaine* 17, 151-181.

Kakabadze M.V. 1983: On the Hauterivian-Barremian correlation between the south of the USSR and certain southern and northern regions of Europe. *Zitteliana* 10, 501-508.

Kemper E. 1961: Die Ammonitengattung *Platylenticeras* (= *Garnieria*). *Beih. Geol. Jahrb.* 47, 1-195.

Kemper E. 1967: Die älteste Ammoniten-Fauna im Aptium Nordwest-Deutschlands. *Paläont. Z.* 41, 119-131.

Kemper E. 1976: Geologischer Führer durch die Grafschaft Bentheim und die angrenzenden Gebiete mit einem Abrisz der emsländischen Unterkreide, 5. Auflage. *Das Bentheimer Land* 64, 1-206.

Kemper E. 1978: Die Beckenfacies der Unterkreide im nördlichen Vorland des Wiehengebirges. In: Kemper E., Ernst G. & Thiermann A. (Eds.): Excursion A1. Die Unterkreide im Wiehengebirgsvorland bei Lübbecke und in Osning zwischen Bielefeld und Bevergern. *Exkursionsführer Symposiums deutsche Kreide, Münster*, A1/14-A1/26.

Kemper E. 1987: Das Klima der Kreide-Zeit. *Geol. Jb. A* 96, 5-185.

Kemper E. 1992: Die tiefe Unterkreide im Vechte-Dinkel-Gebiet. Stichting Staringmonument, Losser, 95 p.

Kemper E. 1995a: Die Grenze Barrême/Apt und die Unterteilung dieser Stufen. *Geol. Jb. A* 141, 47-61.

Kemper E. 1995b: Changes in the Marine environment around the Barremian/Aptian boundary. *Geol. Jb. A* 141, 587-607.

Kemper E., Mutterlose J. & Wiedenroth K. 1987: Die Grenze Unter-/Ober-Hauterive in Nordwestdeutschland, Beispiel eines stratigraphisch zu nutzenden Klima-Umschwungs. *Geol. Jb. A* 96, 209-218.

Kemper E., Rawson P.F. & Thieuloy J.-P. 1981: Ammonites of Tethyan ancestry in the early Lower Cretaceous of north-west Europe. *Palaeontology* 24, 251-311.

Kilian W. 1896: Notice stratigraphique sur les environs de Sisteron et contributions à la connaissance des terrains secondaires du sud-est de la France. *Bull. Soc. Géol. France* 3, 23, 659-803.

Klingler W., Malz H. & Martin G.P.R. 1962: Malm NW-Deutschlands. In: Arbeitskreis deutscher Mikropaläontologen: Leitfossilien der Mikropaläontologie. *Gebrüder Borntraeger*, Berlin, 159-190.

Leereveld H. 1995: Dinoflagellate cysts from the Lower Cretaceous Río Argos succession (SE Spain). (Thesis Laboratory of Palaeobotany and Palynology, Utrecht). *LPP Contribution Series* 2, 175 p.

Leereveld H. 1997a: Upper Tithonian-Valanginian (Upper Jurassic-Lower Cretaceous) dinoflagellate cyst stratigraphy of the western Mediterranean. *Cretaceous Research* 18, 385-420.

Leereveld H. 1997b: Hauterivian-Barremian (Lower Cretaceous) dinoflagellate cyst stratigraphy of the western Mediterranean. *Cretaceous Research* 18, 421-456.

Le Hégarat G. 1971: Le Berriasien du sud-est de la France. *Doc. Lab. Géol. Fac. Sci. Lyon* 43, 576 p.

Londeix L. 1990: La distribution des kystes de dinoflagellés dans les sédiments hémipélagiques (Ardèche) et pélagiques (Arc de Castellane, S.E. de la France) en domaine vocontien, du Valanginien terminal au Barrémien inférieur. Biostratigraphie et relations avec la stratigraphie séquentielle. *Thèse Univ. Bordeaux I*, No 478, part I + II, 323+275 p.

Lott G.K., Fletcher B.N. & Wilkinson I.P. 1986: The stratigraphy of the Lower Cretaceous Speeton Clay Formation in a cored borehole off the coast of north-east England. *Proceedings of the Yorkshire Geological Society* 46, 39-56.

Lott G.K., Thomas J.E., Riding J.B., Davey R.J. & Butler N. 1989: Late Ryazanian black shales in the southern North Sea basin and their lithostratigraphic significance. *Proceedings of the Yorkshire Geological Society* 47, 321-324.

Lutat P. 1995: Die Fluktuationen der Palynomorphen-Vergesellschaften des Hauterive Nordwest-Deutschlands: Steuerung durch Meeresspiegel- und Klimaschwankungen. *Unpublished Ph. D. thesis, University of Hannover*, Germany, 1-141.

Mitchell S.F. 1992: The belemnite faunal changes across the Hauterivian-Barremian boundary in north-east England. *Proceedings Yorkshire Geological Society* 49, 129-134.

Monteil E. 1992: Kystes de dinoflagellés index (Tithonique-Valanginien) du sud-est de le France. Proposition d'une nouvelle zonation palynologique. *Rev. Paléobiol.* 11, 299-306.

Monteil E. 1993: Dinoflagellate cyst biozonation of the Tithonian and Berriasian of south-east France. Correlation with the sequence stratigraphy. *Bull. Cent. Rech. Ex.-Prod. Elf-Aquitaine* 17, 249-263.

Morter A.A. 1984: Purbeck-Wealden beds mollusca and their relationship to ostracod biostratigraphy, stratigraphical correlation and palaeoecology in the Weald and adjacent areas. *Proceedings of the*

Geologists' Association 95, 217-234.

Mutterlose J. 1983: Phylogenie und Biostratigraphie der Unterfamilie Oxyteuthinae (Belemnitida) aus dem Barrême (Unter-Kreide) NW-Europas. *Palaeontographica* A180, 1-90.

Mutterlose J. 1984: Die Unterkreide-Aufschlüsse (Valangin-Alb) im Raum Hannover-Braunschweig. *Mitt. Geol. Inst. Univ. Hannover* 24, 61 p.

Mutterlose J. 1991: Das Verteilungs- und Migrationsmuster des kalkigen Nannoplankton in der Unterkreide (Valangin-Apt) NW-Deutschlands. *Palaeontographica* B 221, 27-152.

Mutterlose J. 1992a: Migration and evolution patterns of floras and faunas in marine Early Cretaceous sediments of NW Europe. *Palaeogeogr., Palaeoclimatol., Palaeoecol.* 94, 261-282.

Mutterlose J. 1992b: Die Unterkreide-Aufschlüsse (Berrias-Hauterive) im nördlichen Wiehengebirgsvorland (N-Deutschland). *Geol. Paläont. Westf.* 21, 39-113.

Mutterlose J. & Bornemann A. 2000: Distribution and facies patters of Lower Cretaceoussediments in northern Germany: a review. *Cretaceous Research* 21, 733-759.

Mutterlose J. & Harding I. 1987: Phytoplankton from the anoxic sediments of the Barremian (Lower Cretaceous) of north-west Germany. *Abh. Geol. B.-A. Wien* 39, 177-215.

Neale J. W. 1960: The subdivision of the upper D Beds of the Speeton Clay of Speeton, East Yorkshire. *Geol. Mag.* 97, 353-362.

Neale J.W. 1962a: Ammonoidea from the lower D beds (Berriasian) of the Speeton Clay. *Palaeontology* 5, 272-296.

Neale J.W. 1962b: Ostracoda from the type Speeton Clay (Lower Cretaceous) of Yorkshire. *Micropalaeontology* 8, 425-484.

Neale J.W. 1968: Biofacies and lithofacies of the Speeton Clay D beds, E. Yorkshire. *Proceedings of the Yorkshire Geological Society* 36, 309-335.

Niedziolka K. 1988: Die Mikrofauna im Valangin-Hauterive-Grenzbereich des zentralen niedersächsischen Beckens (Pollhagen, Wiedensahl II). *Berliner Geowiss. Abh. A* 94, 89-173.

Norris G. 1963: Upper Jurassic and Lower Cretaceous miospores and microplankton from southern England. *Ph. D. thesis, Cambridge University*, 406 p.

Norris G. 1969: Miospores from the Purbeck Beds and marine upper Jurassic of southern England. *Palaeontology* 12, 4, 574-620.

Norris G. 1985: Correspondence: Palynology and British Purbeck facies. *Geol. Mag.* 122, 187-190.

Ogg J.G., Hasenyager R.W. & Wimbledon W.A. 1994: Jurassic-Cretaceous boundary: Portland-Purbeck magnetostratigraphy and possible correlation to the Tethyan faunal realm. *Geobios, M.S.* 17, 519-527.

Ogg J.G., Hasenyager R.W. & Wimbledon W.A. 1995: Jurassic-Cretaceous boundary: Portland-Purbeck magnetostratigraphy and possible correlation to the Tethyan faunal realm. *International symposium on Jurassic Stratigraphy, Poitiers.*

Ogg J.G., Hasenyager R.W., Wimbledon W.A., Channell J.E. & Bralower T.J. 1991: Magnetostratigraphy of the Jurassic-Cretaceous boundary interval — Tethyan and English faunal realms. *Cretaceous Research* 12, 455-482.

Ogg J.G., Steiner M.B., Company M. & Tavera J.M. 1988: Magnetostratigraphy across the Berriasian-Valanginian stage boundary (Early Cretaceous), at Cehegin (Murcia Province, southern Spain). *Earth Planet. Sci. Lett.* 87, 205-215.

Ogg J.G., Steiner, M.B., Olóriz F. & Tavera J.M. 1984: Jurassic magnetostratigraphy, 1. Kimmeridgian-Tithonian of Sierra Gorda and Carcabuey, southern Spain. *Earth Planet. Sci. Lett.* 71, 147-162.

Partington M.A., Copestake P., Mitchener B.C. & Underhill J.R. 1993: Biostratigraphic calibration of genetic stratigraphic sequences in the Jurassic-lowermost Cretaceous (Hettangian to Ryazanian) of the North Sea and adjacent areas. In: Parker J.R. (Editor): Petroleum Geology of Northwest Europe. *Proceedings of the 4th Conference*, 1, 371-386.

Prössl K.F. 1990: Dinoflagellaten der Kreide — Unter-Hauterive bis Ober-Turon — im niedersächsischen Becken. *Palaeontographica* B 218, 93-191.

Quensel P. 1988: Die ammonitenfauna im Valangin-Hauterive-Grenzbereich vom Mittellandkanal bei Pollhagen. *Berliner Geowiss. Abh. A* 94, 15-71.

Rawson P.F. 1970: The Hauterivian (Lower Cretaceous) biostratigraphy of the Speeton Clay of Yorkshire, England. *Newslett. Stratigr.* 1, 61-76.

Rawson P.F. 1993: The influence of sea-level changes on the migration and evolution of Early Cretaceous (pre-Aptian) ammonites. In: House M.R. (Editor): The Ammonoidea: Environment, Ecology, and Evolutionary Change. *Systematics Association Special Volume, 47, Clarandon Press,* Oxford, 227-242.

Rawson P.F. 1995: The "Boreal" Early Cretaceous (Pre-Aptian) ammonite sequences of NW Europe and their correlation with the western Mediterranean faunas. *Mem. Descr. Carta Geol. Ital.* 51, 121-130.

Rawson P.F., Curry D., Dilley F.C., Hancock J.M., Kennedy W.J., Neale J.W., Wood C.J. & Worssam B.C. 1978: A correlation of Cretaceous rocks in the British Isles. *Geol. Soc. London Spec. Rep.* 9, 1-70.

Rawson P.F & Hoedemaeker Ph.J. (reporters) and 11 co-authors 1999: Report on the 4th International Workshop of the Lower Cretaceous Cephalopod Team (IGCP-Project 362). *Scripta Geol., Spec. Issue* 3, 3-13.

Rawson P.F. & Mutterlose J. 1983: Stratigraphy of the Lower B and basal Cement Beds (Barremian) of the Speeton Clay, Yorkshire, England. *Proceedings of the Geologists' Association* 94, 133-146.

Rawson P.F. & Riley L.A. 1982: Latest Jurassic-Early Cretaceous events and the 'Late Cimmerian Unconformity' in the North Sea area. *Amer. Assoc. Petrol. Geol. Bull.* 66, 2628-2648.

Reboulet S. 1995: L'évolution des ammonites du Valanginienn-Hauterivien inférieur du bassin vocontien et de la plate-forme provençale (sud-est de la France): relations avec la stratigraphie séquentielle et implications biostratigraphiques. *Doc. Lab. Géol. Fac. Sci. Lyon* 137, 1-371.

De Reneville P. & Raynaud J.F. 1981: Palynologie du stratotype du Barrémien. *Bull. Cent. Rech. Ex.-Prod. Elf-Aquitaine* 5, 1-29.

Ruffel A.H. & Rawson P.F. 1994: Palaeoclimate control on sequence stratigraphic patterns in the late Jurassic to mid-Cretaceous, with a case study from eastern England. *Palaeogeogr., Palaeoclimatol., Palaeoecol.* 110, 43-54.

Schudack M.E. 1996: Die Charophyten des Niedersächsischen Beckens (Oberjura-Berriasium): Lokalzonierung, überregionale Korrelation und Palökologie. *N. Jb. Geol. Paläont. Abh.* 200, 27-52.

Spath L.F. 1924: On the ammonites of the Speeton Clay and the subdivisions of the Neocomian. *Geol. Mag.* 61, 73-89.

Strasser A. 1988: Shallowing-upward sequences in Purbeckian peritidal carbonates (lowermost Cretaceous, Swiss and French Jura Mountains). *Sedimentology* 35, 369-383.

Strasser A. 1994: Milankovitch cyclicity and high-resolution sequence stratigraphy in lagoonal-peritidal carbonates (Upper Tithonian-Lower Berriasian, French Jura Mountains). *Spec. Publ. Inter. Assoc. Sedimentologists* 19, 285-301.

Strauss C., Elstner F., Jan du Chêne R., Mutterlose J., Reiser H. & Brandt K.-H. 1993: New micropaleontological and palynological evidence on the stratigraphic position of the "German Wealden" in NW-Germany. *Zitteliana* 20, 389-401.

Thierstein H. 1971: Tentative Lower Cretaceous calcareous nannoplankton zonation. *Eclogae Geol. Helv.* 64, 459-488.

Thierstein H. 1973: Lower Cretaceous calcareous nannoplankton biostratigraphy. *Abh. Geol., B.-A.* 29, 1-52.

Thierstein H. 1976: Mesozoic calcareous nannoplankton biostratigraphy of marine sediments. *Marine Micropalaeont.* 1, 325-362.

Thieuloy J.-P. 1973: The occurrence and distribution of boreal ammonites from the Neocomian of southeast France (Tethyan Province). In: Casey R. & Rawson P. F. (Eds.): The Boreal Lower Cretaceous. *Geol. Journ., Spec. Issue* 5, 289-302.

Thieuloy J.-P. 1977: Les ammonites boréales des formations néocomiennes du Sud-Est français (Province subméditerranéenne). *Geobios* 10, 395-461.

Van Adrichem Boogaert H.A. & Kouwe W.F.P. (compilers) 1993: Stratigraphic nomenclature of the Netherlands, revision and update by RGD and NOGEPA. *Meded. Rijks Geol. Dienst* 50, part G.

Vermeulen J. 1998: Nouvelle biostratigraphie ammonitique du Barremien (pro part) du Sud-Est de la France. *C. R. Acad. Sci. Paris, Sciences de la terre et des planètes, 1998,* 327, 619-624.

Vašíček Z., Michalík J. & Reháková D. 1994: Early Cretaceous stratigraphy, palaeogeography and life in Western Carpathians. *Beringeria* 10, 3-169.

Whitehouse F.W. & Brighton A.G. 1924: Notes on some Neocomian Cephalopoda from Speeton. *Naturalist, London, 1 Dec. 1924,* 359-360.

Wick W. & Wolburg J. 1962: Wealden in NW-Deutschland. In: Arbeitskreis deutscher Mikropaläontologen: Leitfossilien der Mikropaläontologie. *Gebrüder Borntraeger,* Berlin-Nikolassee, 191-224.

Wilpshaar M. 1995a: Direct stratigraphic correlation of the Vercors carbonate platform in SE France with the Barremian stratotype by means of dinoflagellate cysts. *Cretaceous Research* 16, 273-281.

Wilpshaar M. 1995b: Applicability of dinoflagellate cyst stratigraphy to the analysis of passive and active tectonic settings. *(Thesis Laboratory of Palaeobotany and Palynology, Utrecht), Geologica Utraiectina* 134, 132 p.

Wimbledon W.A. & Hunt C.O. 1983: The Portland-Purbeck junction (Portlandian-Berriasian) in the Weald, and correlation of the latest Jurassic-Early Cretaceous rocks in southern England. *Geol. Mag.* 120, 267-280.

Wissler L. et al. 2001: Chemostratigraphic correlation of Barremian and earliest Aptian ammonite zones and magnetic reversals. *Int. J. Earth Sci. (formerly Geol. Rundschau)* (in press).

Wolburg J. 1959: Die Cyprideen des NW-deutschen Wealden. *Senckenberg. Lethaea* 40, 223-315.

Worssam B.C. & Ivimey-Cook H.C. 1971: The stratigraphy of the Geological Survey borehole at Warlingham, Surrey. *Bull. Geol. Surv. Gt Br.* 36, 1-146.

Text next to legend on the correlation chart (in enclosure).

The standard Tethyan Berriasian-Barremian successions of France and Spain are correlated with the most important Boreal successions of Germany and England (and for small stratigraphic intervals also with Argentina and Switzerland). Included in the correlation are also the continental to nearly continental successions of the Purbeck and Wealden in England and the Katzberg and 'Wealden' succession in Germany. In this revised edition the famous Barremian carbonate succession in SE France is included. All available biostratigraphic, magnetostratigraphic, and sequence stratigraphic correlation data sets were used to draw this correlation chart.

Lacunae in shallow marine sedimentary successions are correlated with sediments in deeper marine successions. Some sequence boundaries are tectonically enhanced and attended by extra deep falls of the sea level (Hoedemaeker 1995); they initiate important changes in the biota and sedimentary regimes of western Europe, *viz.* the boundaries of the transgressive regressive facies cycles of Jacquin & Graciansky (1998).

Some correlations results are worth mentioning: 1) The ammonite assemblage of the type Stenomphalus Zone in Lincolnshire (England) is stratigraphically situated above the so-called 'Late Kimmerian Unconformity'. 2) On account of dinocyst correlations it appears that the basal part of the Speeton Clay Formation (beds E, D8, D7E-G), which does not yield a distinguishable ammonite fauna, is time-equivalent to the beds containing the type Stenomphalus ammonite assemblage in Lincolnshire.