Appendix: Definition of the Upper Cretaceous stages and substages

Introduction

The Upper Cretaceous Series is divided into six stages by international agreement. These stages are further divided into substages, zones and subzones. For parts of the succession, such as the Upper Turonian Substage and the Campanian Stage, there is no currently agreed subdivision. This appendix reviews the current definitions of the various stages and substages, their boundaries and their application to the UK succession.

Cenomanian Stage

The Cenomanian Stage is the lowest division of the Upper Cretaceous Series ((Figure 1.2), Chapter 1; (Figure 2.10), Chapter 2). D'Orbigny's Cenomanian Stage (1847) is divided by international agreement into Lower, Middle and Upper substages (see Tröger and Kennedy, 1996). The base of the Cenomanian Stage is taken at the first occurrence (FO) of the planktonic foraminifer *Rotalipora globotruncanoides* Sigal at Mont Risou in the Vocontian Basin in south-eastern France, the candidate Global boundary Stratotype Section and Point (GSSP) for the Cenomanian Stage (Trager and Kennedy, 1996). This datum is situated a short distance beneath the FO of the basal Cenomanian zonal index ammonite, *Mantelliceras mantelli* (J. Sowerby), together with those of the heteromorph ammonites *Neostlingoceras oberlini* (Dubourdieu) and *Sciponoceras roto* (Cieslinski). These latter species are elements of the lowest subzone (*Neostlingoceras carcitanense* Subzone) of the basal Cenomanian *Mantelliceras mantelli* Zone. The base of the Cenomanian Stage, thus defined, actually falls in the top part of the terminal *Arraphoceras briacensis* (ammonite) Subzone of the Upper Albian *Stoliczkaia dispar* (ammonite) Zone. In addition, the boundary falls between two well-marked peaks of the carbon stable isotope curve (Tröger and Kennedy, 1996, fig. 4).

In the Southern Province, as in many areas of northern Europe, there is a hiatus representing perhaps 1 to 2 million years of sedimentation, between the Albian and Cenomanian stages. At Abbot's Cliff, Folkestone (Folkestone to Kingsdown GCR site), this hiatus is marked by the burrowed contact between the Upper Albian Gault (mudstone) Formation and the Glauconitic Marl Member at the base of the Chalk Group. Here the Cenomanian age of the Glauconitic Marl, in the absence of ammonites, is given by the bivalve *Aucellina* and by benthic foraminifera (see Morter and Wood, 1983, and references therein). The top of the Glauconitic Marl is marked by a thin limestone that has yielded a single specimen of *Neostlingoceras carcitanense* (Matheron) (Gale, 1989). Near Lewes, Sussex, the *N. carcitanense* ammonite subzonal assemblage is also found in a limestone at the top of the Glauconitic Marl (Kennedy, 1969). In the south of the Isle of Wight, the assemblage, including the subzonal index fossil and *Sciponoceras roto,* occurs as phosphatized internal moulds in the Glauconitic Marl (Kennedy, 1969, 1970).

In the Northern Province, for example at Hunstanton Cliffs and correlative sites on the East Midlands Shelf, such as Melton Bottom Chalk Pit, the hiatus between the Albian and Cenomanian stages lies between the Hunstanton Red Chalk Formation and the Paradoxica Bed at the base of the revised Ferriby Chalk Formation (see Mitchell, 1995a, figs 11, 12). In the expanded section at Speeton Cliff (Flamborough Head GCR site), in the Cleveland Basin, there is an apparently continuous succession, albeit without ammonites, but with *Aucellina,* across the boundary. The base of the Cenomanian Stage can be extrapolated directly from the Mont Risou basal boundary stratotype using the carbon stable isotope curve (Mitchell, 1995a, fig. 11; see (Figure 5.21), Chapter 5). Speeton Cliff may therefore provide an additional European reference section for this stage boundary.

The base of the Middle Cenomanian Substage is taken at the FO of *Cunningtoniceras inerme* (Pervinquiere), the eponymous ammonite of the basal zone, with the first occurrences of *Inoceramus schoendorfi* Heinz and the planktonic foraminifer *Rotalipora reicheli* Mornod being used as subsidiary and/or proxy taxa. The candidate GSSP is in the Grey Chalk Subgroup succession at Southerham Grey Pit, Lewes (Tröger and Kennedy, 1996). In the Southern Province, the FO of *C. inerme* is approximately coincident with the base of the middle of the three *Orbirhynchia mantelliana* bands. In the expanded Northern Province section at Speeton Cliff (Flamborough Head GCR site), the position of the base of the Middle Cenomanian Substage can be inferred to fall at a major erosion surface (sequence boundary) below the complex

Totternhoe Stone. Elsewhere in the province where thin platform successions are developed (e.g. Hunstanton Cliffs, Melton Bottom Chalk Pit), the C. *inerme* Zone is missing, and the thin Totternhoe Stone (*Turrilites costatus* Subzone, *Acanthoceras rhotomagense* Zone) rests with erosive contact directly on the Lower Cenomanian *Mantelliceras dixoni* Zone.

There is no international agreement on the basal boundary marker for the Upper Cenomanian Substage: both the lower and upper limits of the zonal index fossil of the *Acanthoceras jukesbrownei* Zone are currently under consideration, with the latter being favoured (Tröger and Kennedy, 1996). The base of this ammonite zone is more or less coincident with the first occurrence of the inoceramid bivalve *Inoceramus atlanticus* (Heinz), which lies a short distance below Jukes-Browne Bed 7 in the Southern Province. The range of *I. atlanticus* ((Figure 2.14), Chapter 2) overlaps with the first occurrence of the typically Upper Cenomanian *Inoceramus pictus* J. de C. Sowerby ((Figure 2.14), Chapter 2) in the oyster-rich event at the base of Jukes-Browne Bed 7 and the correlative Nettleton Stone in the Southern and Transitional + Northern provinces respectively. This *Pycnodonte* event of European event stratigraphy (Ernst *et al.,* 1983; Ernst and Rehfeld, 1997; Kaplan *et al.,* 1998); the Nettleton Pycnodonte Marl of the Northern Province, lies just below the acme-occurrence of the index ammonite. The last occurrence (LO) of *A. jukesbrownei* (Spath) lies several marl–limestone couplets above the top of Jukes-Browne Bed 7.

All of these key datums are present at Southerham Grey Pit ((Figure 3.108), Chapter 3). Hancock (1959) suggested *Calycoceras* (*C.*) *naviculare* (Mantell) as the index species for the next (Upper Cenomanian) ammonite zone above the *jukesbrownei* Zone, but the entry of this species is well above the top of the range of *A. jukesbrownei,* and its type horizon and acme is actually in the lower part of the Plenus Marls Member, in the overlying *Metoicoceras geslinianum* Zone. The interval from the top of the *A. jukesbrownei* Zone to the base of the *M. geslinianum* Zone is currently assigned to the Upper Cenomanian *Calycoceras guerangeri* Zone (Tröger and Kennedy, 1996) although the zonal index species appears some way up in the interval between the top of the *jukesbrownei* Zone and the base of the Plenus Marl Member (base of the *M. geslinianum* Zone).

Turonian Stage

As in the case of the Cenomanian Stage, the Turonian Working Group has recommended a subdivision of d'Orbigny's (1850, 1852) Turonian Stage ((Figure 1.2), Chapter 1; (Figure 2.9), Chapter 2) into Lower, Middle and Upper substages.

The basal boundary marker is the first occurrence (FO) of the ammonite *Watinoceras devonense* Wright and Kennedy at the base of the W. *devonense* Zone in the Rock Canyon Anticline section, Pueblo, Colorado, USA, (Bengston, 1996; Kennedy *et al.,* 2000). As the name implies, this species occurs in, and was first described from, the condensed sections in south-east Devon (Wright and Kennedy, 1981), where it occurs immediately on top of the Haven Cliff Hardground and/or the terminal Cenomanian Neocardioceras Pebble Bed. It also occurs in the expanded basal Turonian sections at Holywell and Beachy Head, Eastbourne, where the base of the Turonian Stage is recognized by the extinction of the terminal Cenomanian *Neocardioceras juddii* Zone ammonites in the interval between Meads Marls 4 and 5 in the Holywell Nodular Chalk Formation

The base of the Turonian Stage is marked worldwide by a major change in the inoceramid bivalve assemblage: the relatively thin-shelled genus *Mytiloides* enters at or immediately below the boundary, replacing the *Inoceramus pictus*-dominated assemblages of the terminal Cenomanian Stage. *Mytiloides* undergoes rapid speciation in the Lower Turonian Substage, following which the Middle Turonian inoceramid assemblages are dominated by the genus *Inoceramus* itself; with *Mytiloides* (or a closely related genus) again dominating the assemblages towards the top of the stage.

The base of the Middle Turonian Substage is defined by the FO of the ammonite *Collignoniceras woollgari* (Mantell) ((Figure 2.10), Chapter 2) in the Rock Canyon Anticline section, Pueblo, Colorado, USA (Bengtson, 1996; Kennedy *et al.,* 2000). This species was originally described by Mantell (1822) from the Lewes pits, Sussex, where its lowest record is in the basal New Pit Chalk Formation at Glyndebourne Pit (Mortimore and Pomerol, 1991a, 1996). In the Southern, Transitional and Northern provinces and in the Paris Basin there is a significant faunal and sedimentary change just below this level, from the *Mytiloides* shell-detrital chalks of the Holywell Nodular Chalk Formation, to the characteristically smooth chalks of the New Pit Chalk Formation, with poorly preserved large *Mytiloides subhercynicus* (Seitz) and related forms. This level is additionally marked by the conspicuous appearance of medium- to large-sized terebratulid brachiopods (*Concinnithyris* sp.), a datum that has also been recognized in northern Germany (cf Ernst *et al.,* 1998). The echinoid *Conulus subrotundus* (Mantell) also occurs commonly in the basal beds of the Middle Turonian Substage.

There is no agreement on a basal marker taxon for the Upper Turonian Substage, and no section was suggested at Brussels as a candidate GSSP. However, a section at Lengerich, Westphalia, northern Germany is currently under investigation (Wiese and Kaplan, 2001). The Turonian Working Group has considered using the FO of either of two ammonite species, *Romaniceras deverianum* (d'Orbigny) and *Subprionocyclus neptuni* (Geinitz) (Bengtson, 1996), both of which occur in the UK. There are considerable problems in using either or both of these taxa because of uncertainty regarding potential discrepant ranges and first occurrences in various parts of Europe (cf. Wiese, 1997). Inoceramid bivalves have been considered as a possible better alternative to ammonites, and the FO of *Mytiloides costellatus (sensu lato non* Woods) (including forms close to or conspecific with *Inoceramus perplexus* Whitfield — see discussion in Walaszczyk and Wood, 1999b) has been proposed and is under review (Bengtson, 1996). In the limestone facies of northern Germany, the FO of *I. costellatus sensu lato* approximates to that of *S. neptuni,* in the so-called (*Inoceramus) costellatus/ (Sternotaxis) Plana* event (Ernst *et al.,* 1983; Kaplan and Kennedy, 1996), which is taken there to mark the base of the Upper Turonian Substage.

The first occurrences of *Subprionocyclus* in the Southern and Transitional provinces are situated in the lower part of the Lewes Nodular Chalk Formation, just above the lower of the two Southerham Marls at Dover (*S. hitchinensis* (Billinghurst)) and just below the Fognam Marl (the inferred equivalent of the same marl) at Fognam Quarry (*Subrinocyclus* intermediate between *S. neptuni* and *S. brannereri* (Anderson)) respectively (see discussion in Gale, 1996). On stable isotope correlation data (Voigt and Hilbrecht, 1997; Wiese and Wilmsen, 1999; Voigt and Wiese, 2000) these levels are significantly below the inferred position of the German *costellatus/plana* event. This latter event is believed to lie just below the Caburn Marl, at a level which has yielded sporadic *Romaniceras deverianum* in Sussex (Mortimore, 1986a; Mortimore and Pomerol, 1987, 1996) and in the Chiltern Hills (Gale, 1996). The inferred equivalent of this event in the Northern Province lies just below the Deepdale Lower Marl and has yielded a single specimen of *S. neptuni* (Wood, 1992).

Using the FO of *R. deverianum* in Sussex as the basal marker, the base of the Upper Turonian Substage would lie between the Glynde Marls and the Southerham Marls, i.e. within the interval that includes the FO of *Subprionocyclus neptuni* in the Transitional Province. *R. deverianum* actually ranges throughout this interval and up to the Caburn Marl (Mortimore, in prep.). *S. neptuni* has generally been found higher up-section, in the Kingston Beds, and is relatively common in the ammonite assemblages of the pebble bed of the terminal (Hitch Wood) hardground of the Chalk Rock.

Parallel to the ammonite zonal scheme, there is a provisional inoceramid bivalve zonation (Figure 2.9), (Figure 2.21), (Figure 2.22) and (Figure 2.27), Chapter 2 used in northern Europe (Ernst *et al.,* 1983; Trager, 1989), which is currently under review. The penultimate Upper Turonian zone in Europe, the *Mytiloides scupini* Zone, is dominated by a poorly understood assemblage of *Mytiloides,* including forms such as the zonal index and *M. herbichi* (Atabekian), characterized by a distinctive, widely splayed posterior wing (Walaszczyk and Wood, 1999b; (Figure 2.18), Chapter 2). Some elements of this assemblage are represented in the basal beds of the upper Lewes Nodular Chalk in the Southern Province, particularly in the expanded sections at Southerham Pit, Lewes. The highest part of the Turonian Stage is marked by the entry in flood abundance, of *Cremnoceramus waltersdorfensis* (Andert) (Figure 2.19), Chapter 2.

Coniacian Stage

Coquand's (1857) Coniacian Stage is the shortest Cretaceous stage, lasting about 2.4 million years ((Figure 1.2), Chapter 1; (Figure 2.21), Chapter 2). The original concept was based on the largely unfossiliferous, glauconitic, sandy sediments exposed at the Richemont Seminary, near Cognac, Charente, in the Aquitaine Basin, south-west France.

The base of the Coniacian Stage is taken at the FO of the basal marker taxon, the inoceramid bivalve *Cremnoceramus rotundatus sensu* Tröger *non* Fiege ((Figure 2.19), Chapter 2) (correctly C. *deformis erectus* (Meek) — see Walaszczyk and Wood, 1999b; Walaszczyk and Cobban, 2000) in the candidate GSSP, the Salzgitter-Salder limestone quarry, Lower

Saxony, Germany (Kauffman *et al.,* 1996). This datum is a short distance above a flood occurrence of *C. waltersdorfensis,* an event bed with *C. waltersdorfensis* and the thin-shelled bivalve *Didymotis costatus* (Fritsch) and another event bed with *C. waltersdorfensis* (Walaszczyk and Wood, 1999b). The ammonite criterion used to define the base of the stage, the FO of *Forresteria petrocoriensis* (Coquand) has not been identified there, but is known from Westphalia, at a horizon significantly higher than the level of the base recognized using inoceramid bivalves (Kauffman *et al.,* 1996).

In England, the Coniacian Stage is developed entirely in chalk facies with common *Cremnoceramus,* but with only rare and poorly preserved ammonites. The basal marker taxon, associated with *C. waltersdorfensis,* has been collected 0.2 m above the Navigation Hardground at Shoreham Cement Works, Sussex (Mortimore, 1986a), and at a slightly higher horizon at Dover. A juvenile ammonite, either a *Forresteria,* or possibly a *Barroisiceras,* was collected from inside a broken *Micraster* incorporated in the top Navigation Hardground at Langdon Stairs, Dover (Folkestone to Kingsdown GCR site) (Gale and Woodroof, 1981), and a single poorly preserved *Didymotis* was found in soft chalk in the group of Navigation Hardgrounds at Ness Point, St Margarets Bay. Neither of these records helps with the placing of the base of the Coniacian Stage in the extremely condensed successions in the Southern Province, but this datum is usually placed, on no particularly good evidence, at the base of the Navigation Hardgrounds (e.g. Bailey *et al., 1983,* 1984). In the Northern Province, basal Coniacian *Cremnoceramus,* associated with poorly preserved *Didymotis,* occur just below the second of the three Kiplingcotes Marls, the inferred correlative of the Navigation Marls.

Inoceramid bivalves are common in the Coniacian chalks of the UK and, fortunately, they are currently used internationally in preference to ammonites to define the Lower, Middle and Upper substages. The base of the Middle Coniacian Substage is taken at the FO of *Volviceramus koeneni* (Müller) (Kauffman *et al.,* 1996). This species is not common in the UK, but has been identified in the Southern Province at the base of the Belle Tout Beds (base of the Seaford Chalk Formation), above Shoreham Marl 2, in Upper Beeding Quarry, Shoreham, Sussex and at the equivalent horizon at Dover. It has also been found at Titchwell Chalk Pit on the Norfolk coast in the indefinite boundary zone between the Transitional and Northern provinces. In the Northern Province proper, V. *koeneni* is found just above above the Little Weighton marls, the equivalent of the Shoreham Marls (Wood, 1992). The *koeneni* Zone here has yielded *Inoceramus gibbosus* Schlüter and a unique specimen of the belemnite *Actinocamax bohemicus* Stolley, which is generally rare throughout Europe (Christensen, 1982).

The base of the Middle Coniacian Substage in the Southern Province approximates to the FO of the benthic foraminiferal species *Stensioeina granulata granulata* (Olbertz) ((Figure 2.41), Chapter 2), which is closely followed by that of *S. exsculpta exsculpta* (Reuss) ((Figure 2.42), Chapter 2) (Bailey *et al.,* 1983).

The base of the Upper Coniacian Substage is taken internationally (Kauffman *et al.,* 1996) at the FO of *Magadiceramus subquadratus* (Schlüter), an inoceramid bivalve that is generally absent from chalk facies, but is relatively common in marlstones. In the Cuckmere Beds of the Seaford Chalk Member of the Southern Province there is an interval informally referred to as the 'Barren Beds' because of the scarcity of macrofossils (e.g. Mortimore *et al.,* 1990). A band of *Volviceramus* has been recorded towards the top of these beds and a possible *Magadiceramus* occurring as very thin sheets has also been recorded (Mortimore; Reports for Channel Tunnel Rail Link). This interval is inferred to correspond, in part, to the lower part of the *subquadratus* Zone in Europe, which is characterized by the co-occurrence of the last *Volviceramus* and the first *Magadiceramus.*

Santonian Stage

Coquand's (1857) Santonian Stage ((Figure 1.2), Chapter 1; (Figure 2.22), Chapter 2) is named after Saintes, in the northern Aquitaine Basin of south-west France, where a glauconitic nodular limestone with Coniacian exogyrine oysters is overlain by soft micaceous chalk of the Santonian Stage (Lamolda and Hancock, 1996).

The Working Group on the Santonian Stage identified the FO of the inoceramid bivalve *Cladoceramus undulatoplicatus* (Roemer) ((Figure 2.23), Chapter 2) as the basal boundary marker. One of the sections chosen as a candidate GSSP for the Santonian Stage is Seaford Head (Cuckmere to Seaford GCR site), Sussex (Lamolda and Hancock, 1996), and a formal proposal to validate this is in preparation. The FO of C. *undulatoplicatus* here is on the top surface of the Michel

Dean Flint, but this marker taxon is most abundant in and above the Bedwell's Columnar Flint (Mortimore, 1986a, 1997). In the Northern Province, one or more *Cladoceramus* events are found near the top of the (Burnham Chalk Formation) at Selwicks Bay (Flamborough Head GCR site), Yorkshire.

Division of the Santonian into Lower, Middle and Upper substages has been generally accepted, but there has been no agreement on index taxa or basal substage boundary stratotype sections. The last occurrence (LO) of *Cladoceramus undulatoplicatus* or the FO of *Cordiceramus cordiformis* (J. de C. Sowerby) have both been suggested for defining the base of the Middle Santonian Substage. At Seaford Head (see Cuckmere to Seaford GCR site report, this volume), the LO of C. *undulatoplicatus* is some 4 m above the Bedwell's Columnar Flint Band/Flat Hill Flint, in a shell bed of mixed *Cladoceramus* and *Platyceramus* shells. The same event can also be identified in the Thanet Coast succession and in cored boreholes in the London Basin for the Channel Tunnel Rail Link. In the Northern Province, an interval with relatively common *Cordiceramus cordiformis,* 3 m (see (Figure 5.29) and (Figure 5.31), Chapter 5 beneath the top of the Burnham Chalk Formation near Selwicks Bay (Flamborough Head GCR site), can provisionally be taken to mark the base of the Middle Santonian Substage.

The base of the Upper Santonian Substage is generally taken at the entry of the crinoid *Uintacrinus socialis* Grinnell (Lamolda and Hancock, 1996). In the Southern Province, this datum coincides with Buckle Marl 1 at the base of the Newhaven Chalk Formation at Seaford Head (Cuckmere to Seaford GCR site). It also approximates to the entry of the benthic foraminifer *Stensioeina granulata perfecta.* In the Northern Province, the FO of *Uintacrinus* in the Flamborough Head GCR site (Mitchell, 1994) lies 30 m (see (Figure 5.31), Chapter 5) above the base of the Flamborough Chalk.

The Upper Santonian Substage of this account comprises the successive zones of the crinoids *Uintacrinus socialis* and *Marsupites testudinarius* (Schlotheim). In the Thanet Coast succession there is a small gap betweeen the LO of *Uintacrinus* and the FO *of Marsupites.* The biostratigraphically important benthic foraminifer *Bolivinoides strigillatus* (Chapman) enters here at or not far below the top of the range of *Uintacrinus.* As elsewhere, two stratigraphically successive morphotypes can be distinguished in the calyx plates of *Marsupites,* which may eventually need to be assigned to different species.

Campanian Stage

Coquand's (1857) Campanian Stage ((Figure 1.2), Chapter 1; (Figure 2.27), Chapter 2) in the northern Aquitaine Basin at Grande Champagne near Aubeterre-sur-Dronne in south-west France, comprises shallow-water chalks which contain virtually no planktonic foraminifera, ammonites or bivalves.

Ever since de Grossouvre (1901) suggested that the LO of the crinoid *Marsupites testudinarius* (Schlotheim) should be used to define the Santonian–Campanian boundary, this datum has been widely accepted. Both the Copenhagen (Birkelund *et al.,* 1984) and Brussels (Hancock and Gale, 1996) Cretaceous Stage Boundary symposiums supported this view. The LO of *Marsupites* is approximately coincident with the first evolutionary appearance of the belemnite *Gonioteuthis granulataquadrata* (Stolley). A candidate GSSP for the Campanian Stage is the succession at Splash Point, Seaford Head (Cuckmere to Seaford GCR site), where the LO of *M. testudinarius is* at Friars Bay Marl 1 in the Newhaven Chalk Formation. In the Northern Province, this datum is situated 70 m above the base of the Flamborough Chalk Formation.

A basal Campanian zone defined by the total range of the crinoid *Uintacrinus anglicus* Rasmussen has been recommended by some workers (e.g. Bailey *et al.,* 1983, 1984) for the Southern Province and is formally recognized in the Northern Province by Mitchell (1995b).

Contrary to recent practice in the Southern Province, whereby the total range of *U. anglicus* is included in the *Offaster pilula* Zone, we recognize a basal Campanian *U. anglicus* Zone in this account. The FO of the eponymous echinoid, *Offaster pilula* (Lamarck), is at the Black Rock Marl, which is well above the base of the Campanian Stage as defined by the extinction of *Marsupites* and also significantly above the top of the range of *U. anglicus.* The FO of *U. anglicus* is invariably separated from the LO of *Marsupites* by a small gap. In the Southern Province, *U. anglicus* occurs between the Friars Bay Mans at Seaford Head (Cuckmere to Seaford GCR site), and at Friars Bay and Black Rock in the Newhaven to Brighton GCR site. *U. anglicus* has also been recognized in the Thanet Coast GCR site at Margate and at Flamborough Head, Yorkshire. An interval characterized by *U. anglicus,* above the LO of *Marsupites,* has now been identified almost worldwide, notably in Australia, Kazakhstan and Texas (Hancock and Gale, 1996).

The Campanian Stage is the longest of the Upper Cretaceous Stages (12.2 million years) and the least well understood. No agreement on its subdivision has been reached, although the idea that the existing bipartite subdivision into Lower and Upper substages should be replaced by a subdivision into Lower, Middle and Upper substages was accepted at Brussels (Hancock and Gale, 1996). The traditional twofold division is used in this book, with the boundary being taken between the belemnite zones of *Gonioteuthis quadrata* and *Belemnitella mucronata sensu anglico.* This boundary presents problems because the two index belemnites co-occur in the highest beds of the *quadrata* Zone, in the so-called 'overlap Zone' (Schmid, 1953, 1959) of belemnite stratigraphers. The base of the Upper Campanian Substage is marked in northern European chalk facies by the LO of *Gonioteuthis,* a datum that is difficult to recognize, in view of the rarity of *Gonioteuthis* near the upper limit of its range.

The base of the Upper Campanian Substage and base of the *B. mucronata* Zone *sensu anglico* is taken in the UK at the lower of the paired Farlington Marls at Farlington Quarry, Portsdown and at Whitecliff and Scratchell's Bay, Isle of Wight. This datum does not necessarily coincide with the LO of the terminal Lower Campanian zonal index belemnite *Gonioteuthis quadrata* (Blairsville) at the top of the 'overlap Zone',which is difficult to identify satisfactorily. It is also probable that some of the belemnites from the 'overlap Zone' in the British Geological Survey collections include *Belemnitella praecursor* Stoney, as in the case of the succession near Hannover in northern Germany (cf. Christensen, 2000). It approximates to the FO of the small echinoid *Echinocorys subconicula* Brydone and of the benthic foraminifer *Gavelinella monterelensis* (Marie). In East Anglia (Transitional Province) this may equate with the thick marls associated with *Echinocorys* ex gr. *conica* (Agassiz) a short distance above the phosphatized hardground marking the Peine tectonic event (Mortimore *et al.,* 1998) in the British Geological Survey Trunch cored borehole (Wood *et al.*, 1994).

Maastrichtian Stage

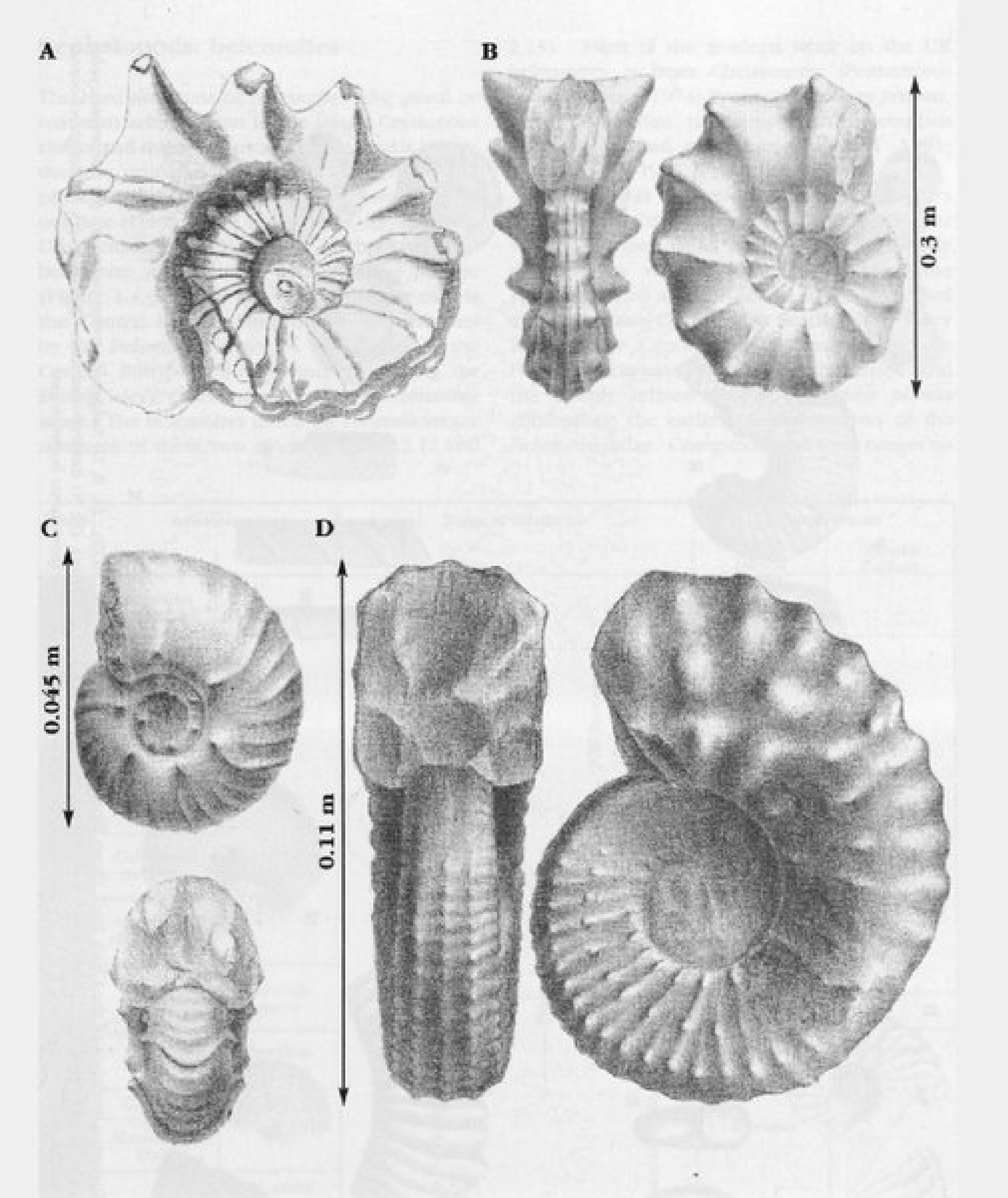
The Maastrichtian Stage of Dumont (1849) is present as chalk facies in the UK only in Norfolk (e.g. Overstrand to Trimingham Cliffs GCR site) and Northern Ireland (Wood, 1967, 1972; Fletcher, 1977; Fletcher and Wood, 1978). The original type locality for the Maastrichtian was near Maastricht, Limburg, Netherlands, but the sections here are not continuous across the Campanian–Maastrichtian boundary, and the stratotype section at the ENCI Quarry actually corresponds to the Upper Maastrichtian Substage of the modern classification. Several sections have been considered as the basal boundary stratotype. In the Boreal Realm, the chalk section at Kronsmoor (Saturn Quarry), north of Hamburg, Schleswig-Holstein, Germany (Schonfeld and Schulz, 1996) is used as the standard. In this section, the FO of the belemnite *Belemnella lanceolata* (Schlotheim) is taken as the basal boundary datum, but this taxon is restricted to the Boreal Realm ((Figure 2.13), Chapter 2). The Maastrichtian Working Group take the Tethyan Realm section at Tercis, Landes, south-west France, as the candidate GSSP, with the FO of the ammonite *Pachydiscus neubergicus* (von Hauer) as the basal boundary marker (Odin, 1996). It was believed that this datum was approximately coincident with the FO of *Belemnella lanceolata* in the Boreal Realm chalks of northern Europe. It is now thought that the entry of *P. neubergicus* is significantly higher and *Belemnella* can no longer be considered an exclusively Maastrichtian genus.

The Maastrichtian Working Group recommended a subdivision into Lower and Upper substages. However, the highest preserved Maastrichtian Zone in the UK (*Belemnella sumensis* (belemnite) Zone) does not even reach the top of the Lower Maastrichtian Substage. Both in Norfolk and in Northern Ireland it is possible to apply the Boreal northern Europe belemnite zonal scheme introduced by Schulz, (1982; see also Christensen, 1996). The base of the Maastrichtian Stage in the UK is provisionally taken on a microfaunal (foraminiferal) basis in the succession exposed in the glaciotectonic 'Overstrand Hotel Lower Mass' at Overstrand (Overstrand to Trimingham Cliffs GCR site), Norfolk (Bailey *et al.,* 1983, 1984). This datum (the 'Overstrand Upper Marl' of this account) is marked by the LO of the foraminifer *Globorotalites hiltermanni* Kaever and a flood occurrrence of the foraminifera *Reussella szajnochae szajnochae* (Grzybowski), closely followed by the FO of the benthic foraminifer *Neoflabellina reticulata* (Reuss). This bundle of foraminiferal bio-events is recognizable in offshore successions in the Southern North Sea Basin. The first *Belemnella,* including *B. lanceolata,* associated at Overstrand with *Belemnitella,* appear higher up-section, several metres above the Sidestrand Marl. A new definition of the base of the stage, using foraminifera in combination with nannofossils, is currently under review.

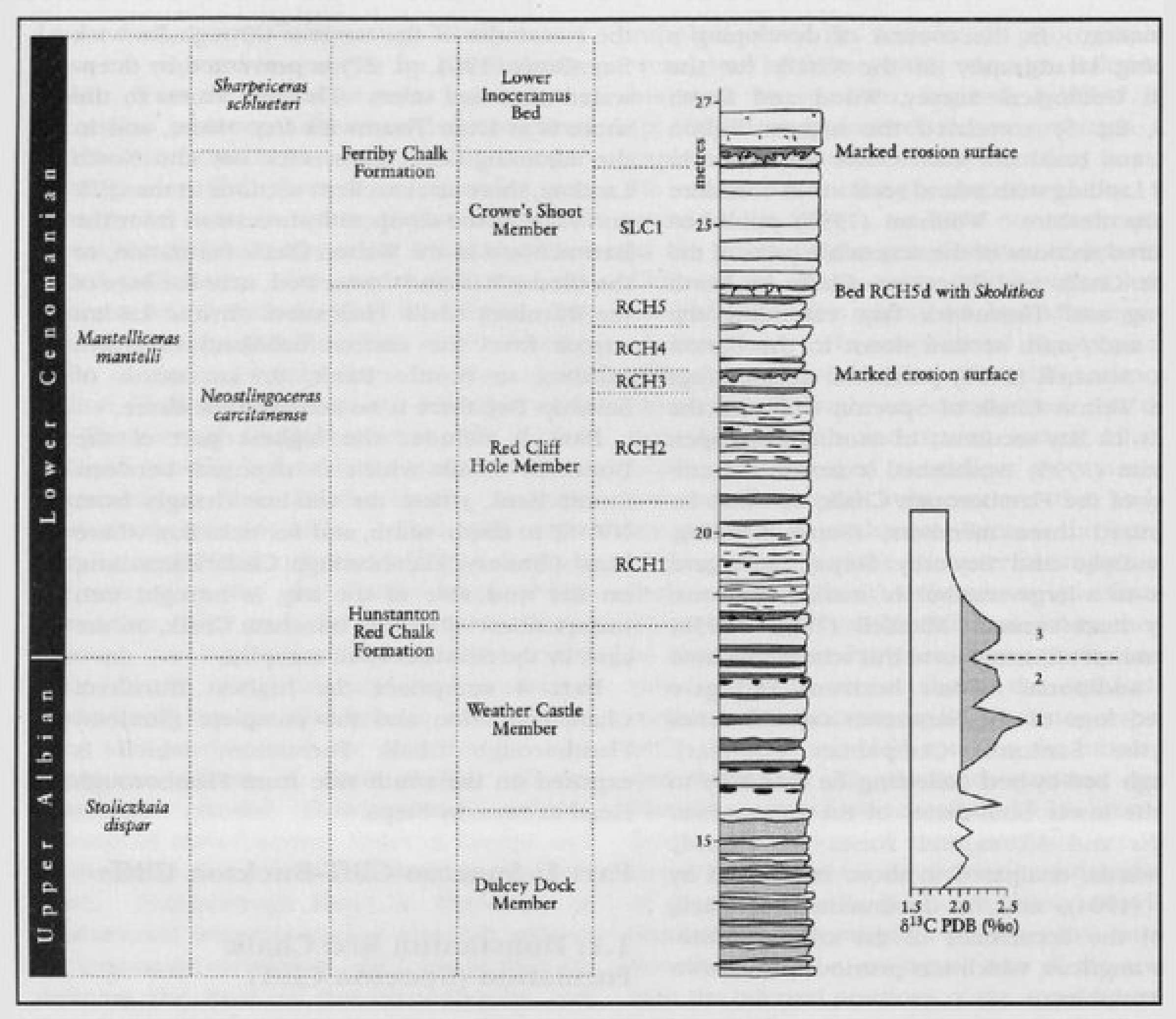
References

Series	Age (Ma)	Stages	Time span
Upper Cretaceous	65.4	Maastrichtian (Dumont, 1849)	5.9
	71.3	Campanian (Coquand, 1857)	12.2
	83.5	Santonian (Coquand, 1857)	2.8
	86.3	Coniacian (Coquand, 1857)	2.4
	88.7	Turonian (d'Orbigny, 1840–47)	4.6
	93.3	Cenomanian (d'Orbigny, 1840–47)	5.2
Lower Cretaceous	98.5	Albian (d'Orbigny, 1840–47)	13.5
	112	Aptian (d'Orbigny, 1840–47)	9.0
	121	Barremian (Coquand, 1861)	6.0
	127	Hauterivian (Renevier, 1874)	3.0
	130	Valanginian (Desor, 1854)	5.0
	135	Berriasian	7.0
	142		

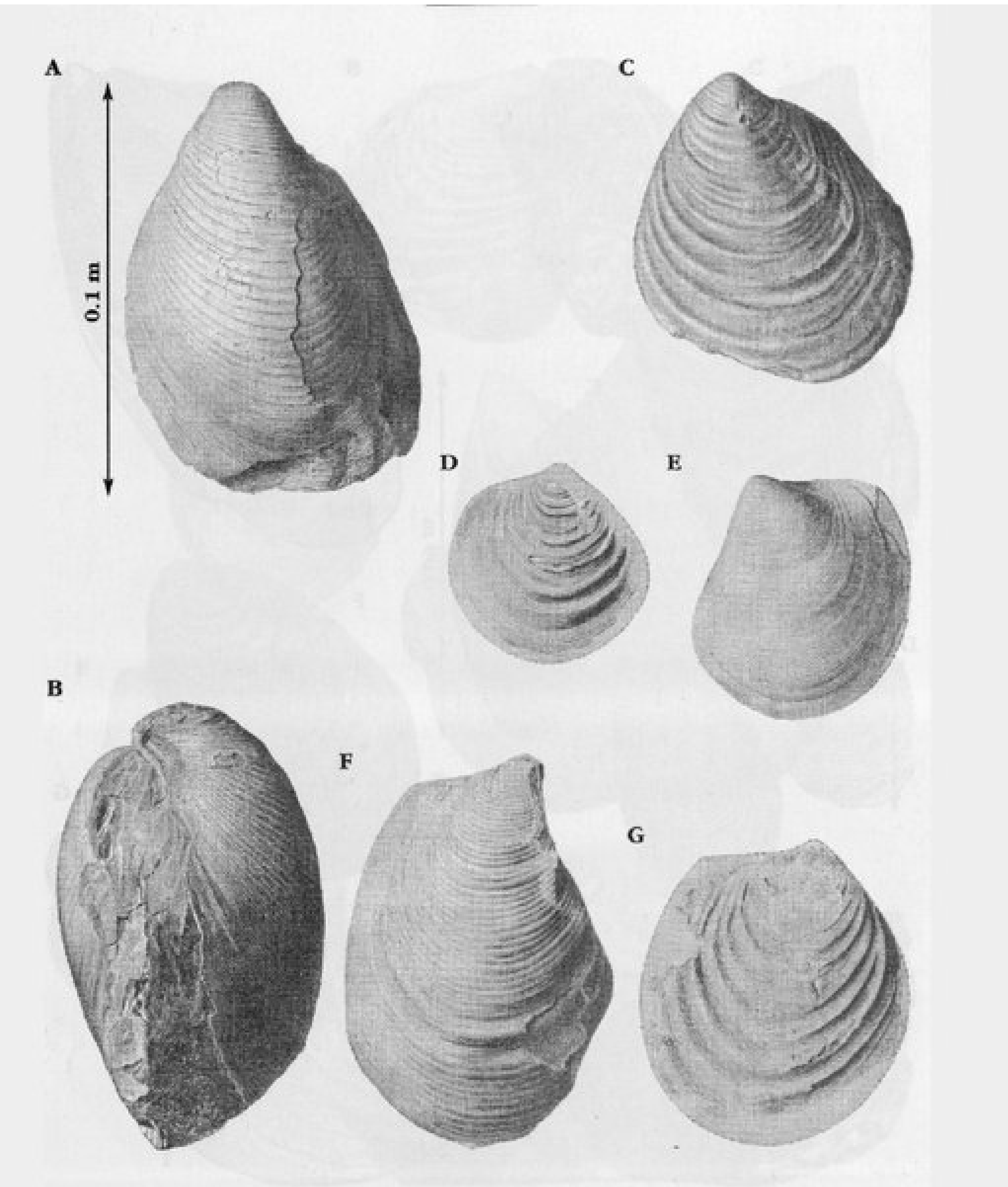
(Figure 1.2) Cretaceous (D'Halloy, 1822) series and stages (Birkelund et al., 1984). Age picks (Ma = million years) based on Obradovitch (1993) and Gradstein et al. (1999). (Dates obtained using $^{40}Ar/^{39}Ar$ laser fusion on 50–500 µg samples of sanidine from bentonites (volcanic ash/marls) interbedded with precisely dated fossiliferous marine sediments.)



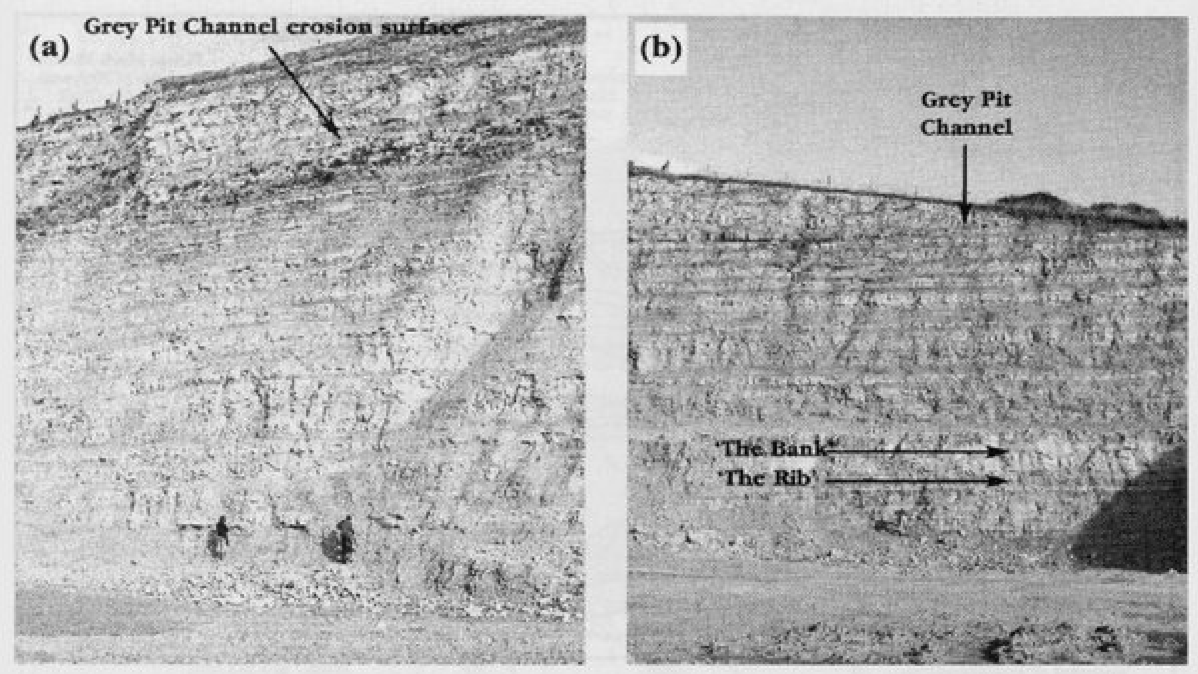
(Figure 2.10) Middle and Upper Turonian. ammonites. (A) Collignoniceras woollgari (from Mantell, 1822, Tab. 21, fig. 16). (B) Collignoniceras woollgari (from Sharpe 1853–1857, p1. 11), typical of the New Pit Chalk Formation. (C) Lewesiceras mantelli (from Sharpe, 1853–1857, p1. 10) from the topmost Chalk Rock and above the Lewes Marl. (D) Romaniceras deverianum (from Sharpe 1853–1857, pl. 19), typical between the Glynde Marl and Caburn Marl, basal Lewes Nodular Chalk Formation.



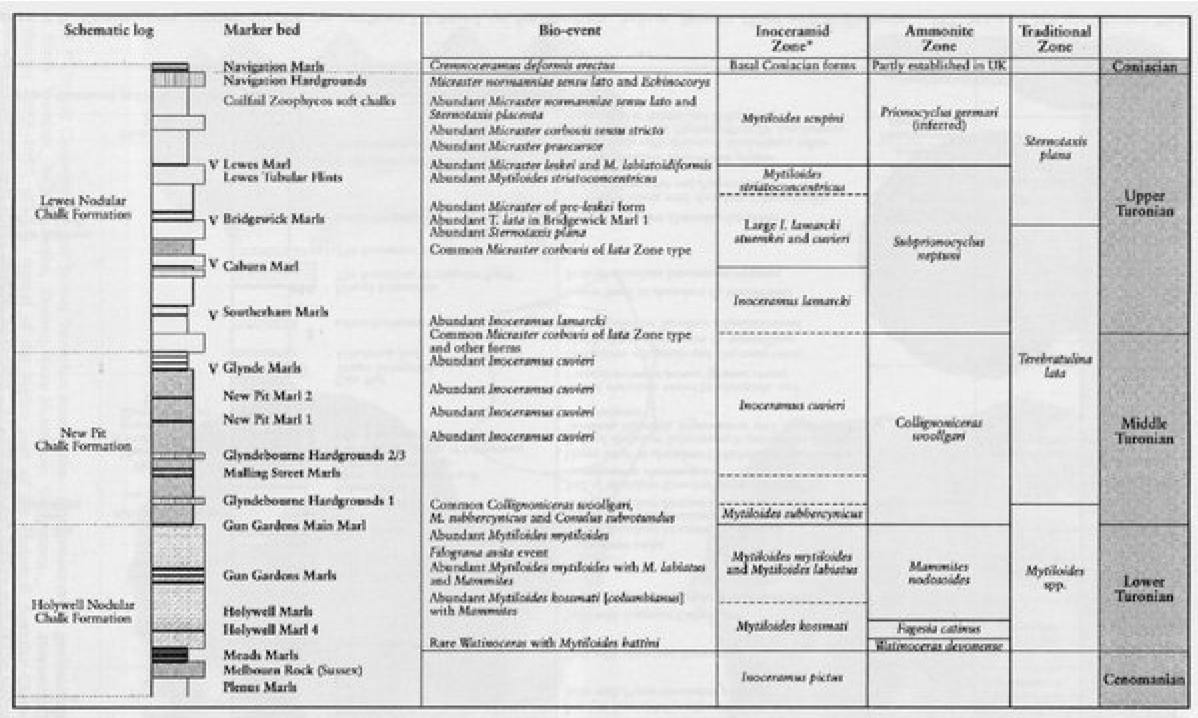
(Figure 5.21) The Hunstanton Red Chalk and Ferriby Chalk formations at Speeton Cliff, Yorkshire, showing the stable isotope $S^{13}C$ curve used to identify the Albian–Cenomanian boundary, between peaks 2 and 3. (Modified from Mitchell, 1995a, fig. 11.)



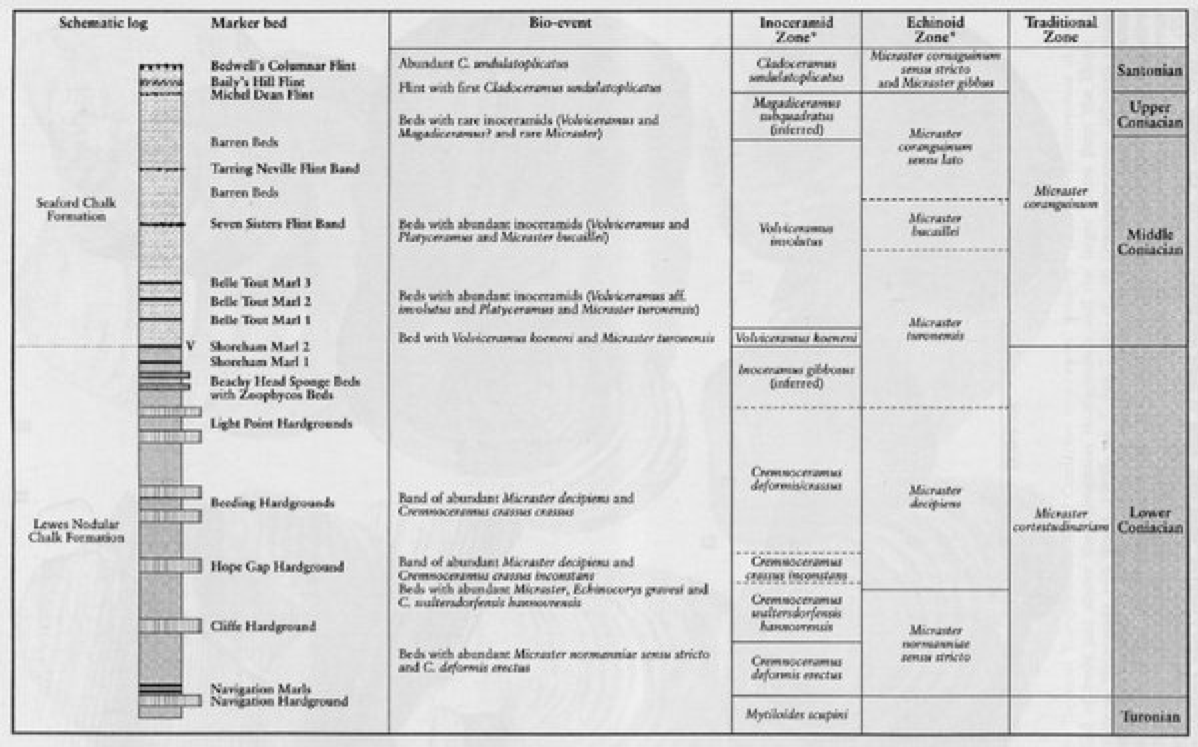
(Figure 2.14) Cenomanian inoceramid bivalves. (A, B) Holotype of Actinoceramus tenuis (from Woods, 1911, text-fig. 31). (C) Inoceramus crippsi (from Woods, 1911, text-fig. 34). (D) Inoceramus atlanticus (from Woods, 1911, pl. 48, fig. 5). (E) Inoceramus virgatus scalprum (from Woods, 1911, pl. 49, fig. 3a) typical of the Lower Cenomanian 'Bank' of limestones. (F) Inoceramus pictus (from Woods, 1911, pl. 49, fig. 5) typical of the Plenus Marls Member and the basal few metres of the Melbourn Rock, Upper Cenomanian. (G) Inoceramus atlanticus (from Woods, 1911, pl. 49, fig. 1), typical of the Middle Cenomanian 'atlanticus' flood. Scale bar applies to all specimens.



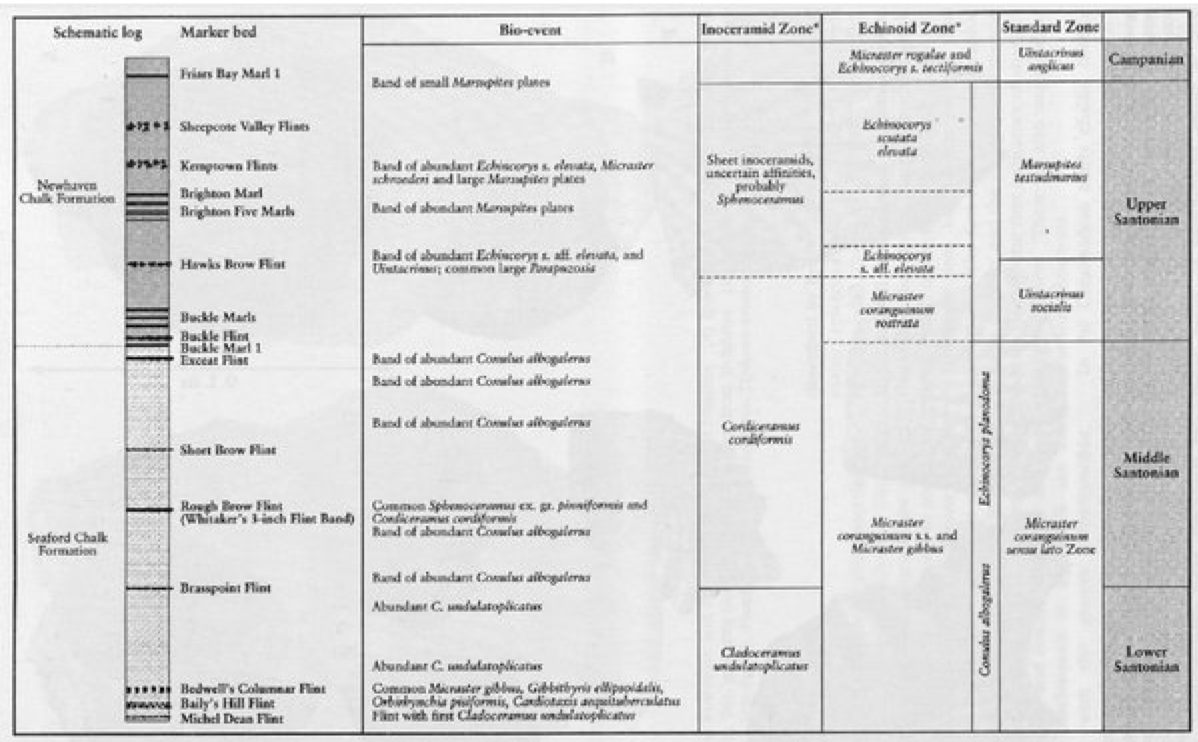
(Figure 3.108) (a, b) Southerham Grey Pit, Lewes, Sussex, in 1976 prior to closure in 1978. Marker beds and the rhythmic sedimentation used to establish the cyclostratigraphy in the lower part of the Grey Chalk Subgroup are indicated (see also (Figure 3.5)). (Photos: R.N. Mortimore.)



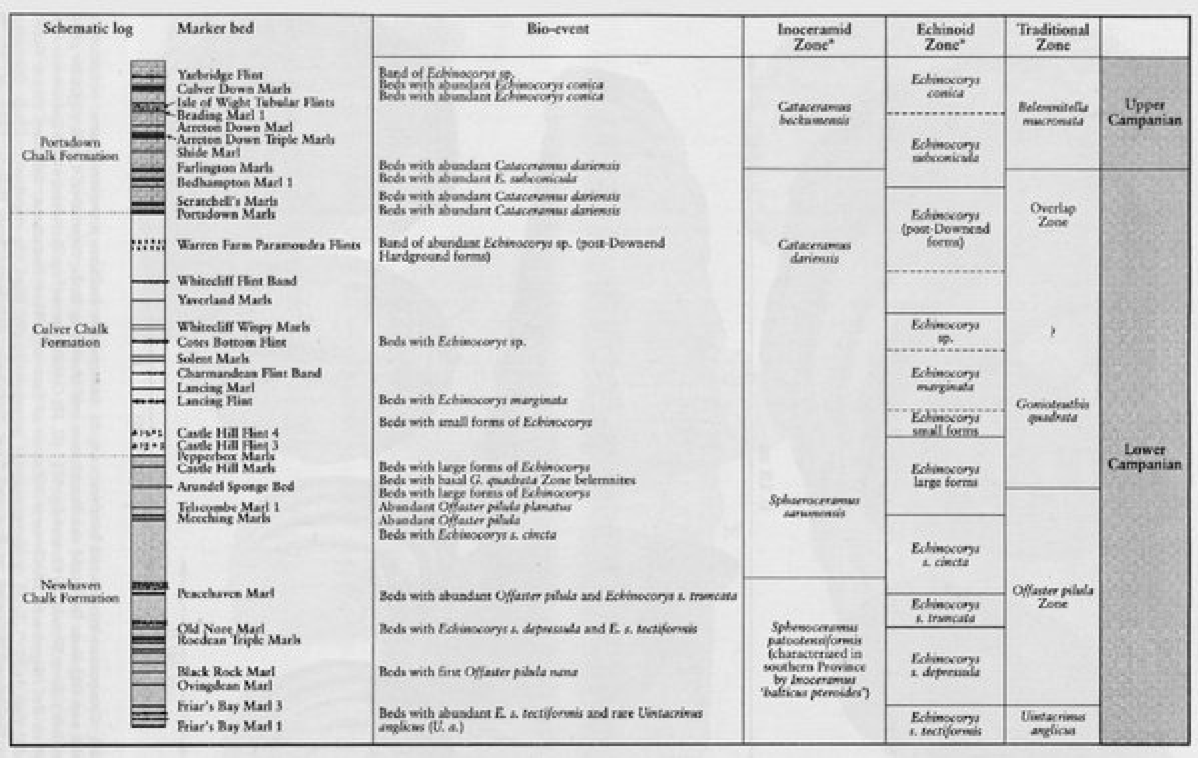
(Figure 2.9) Turonian stratigraphy for the onshore UK based on Lewes Pits and Beachy Head, Southern Province. V = marl derived from volcanic ash. (= The inoceramid zones used are transferred from the current scheme used in Northern Europe and are under review.)*



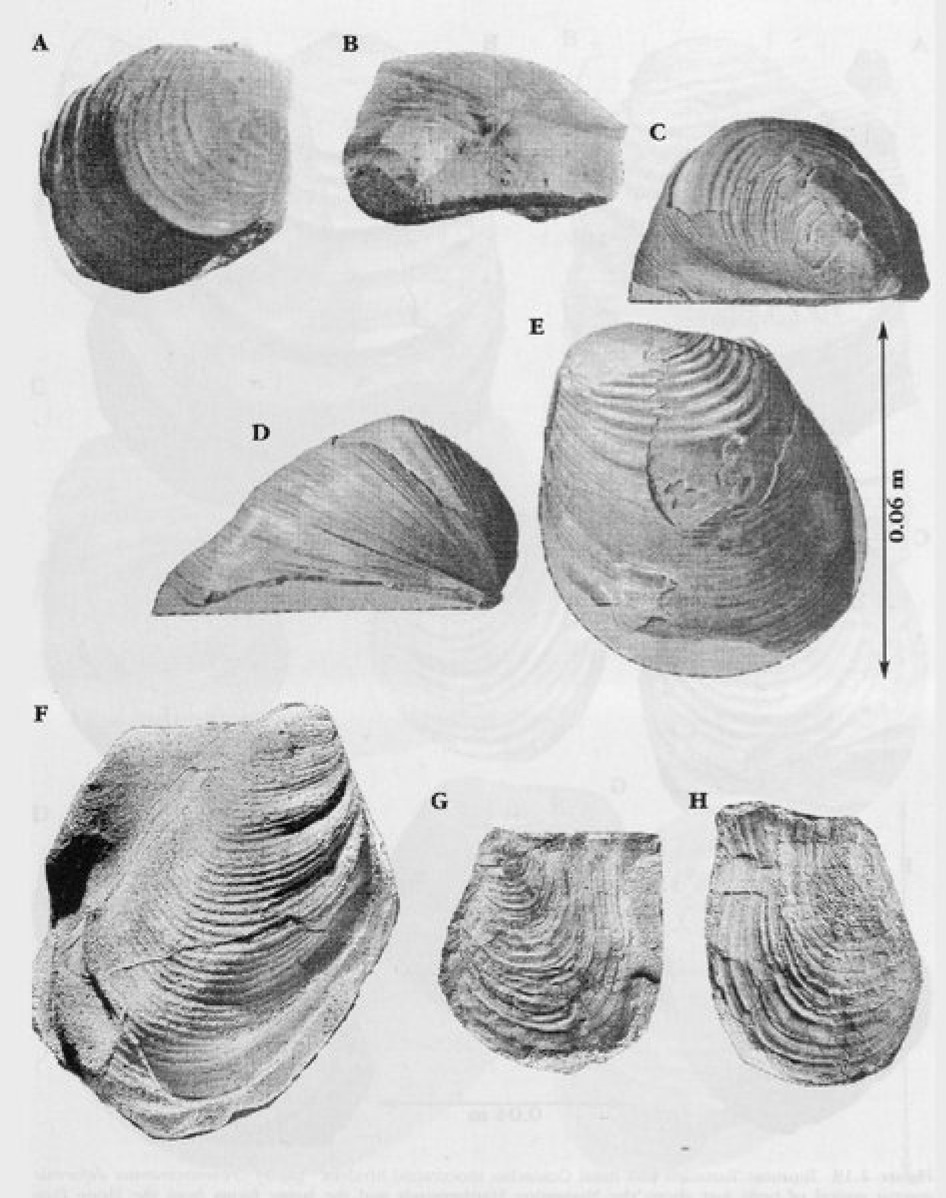
(Figure 2.21) Coniacian stratigraphy for the onshore UK based on the Southern Province sections at Lewes, Beachy Head, Seaford Head and Dover. (* = informal zones applied in this book; V = vulcanogenic marl.)



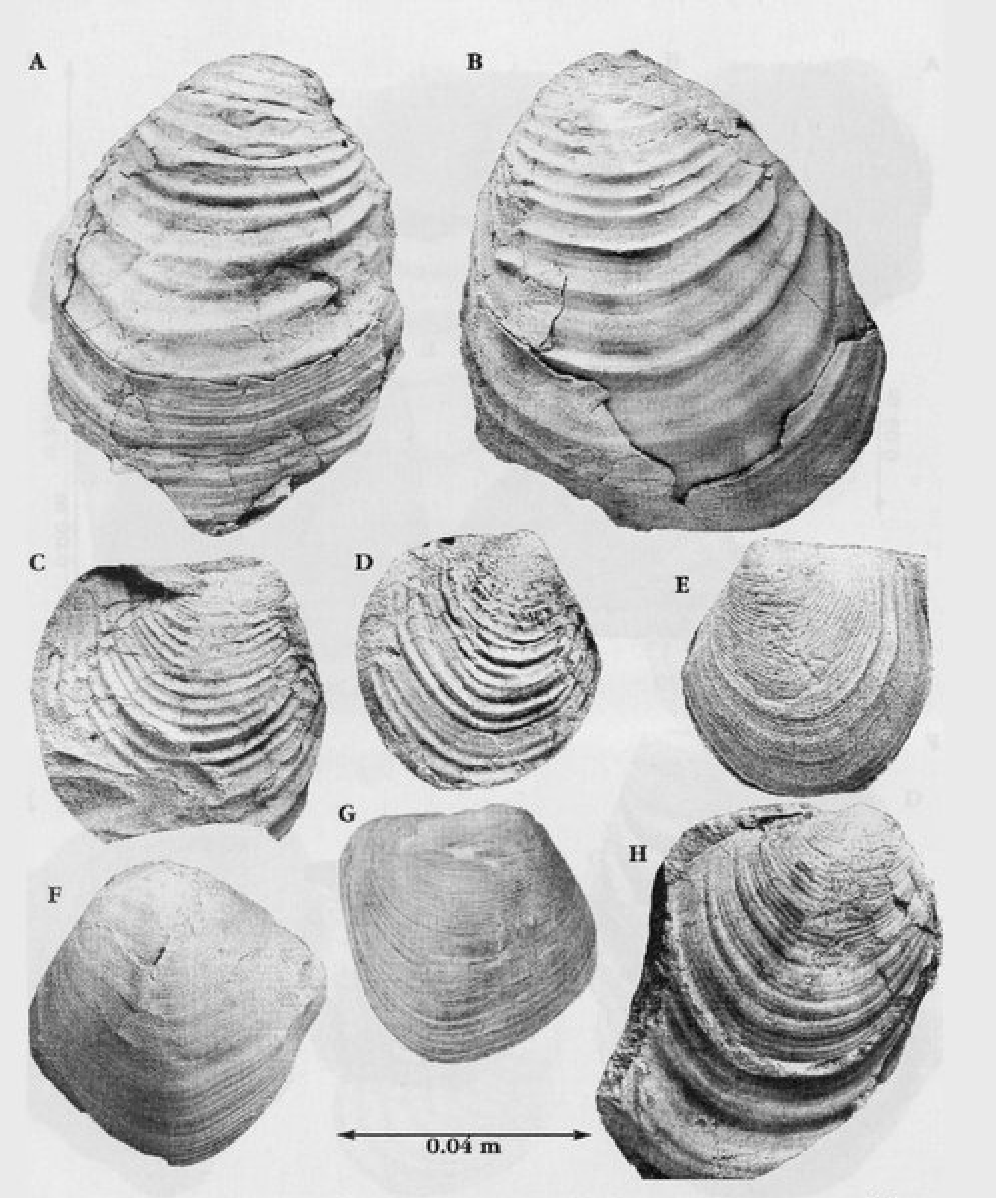
(Figure 2.22) Santonian stratigraphy for the onshore UK based on the Southern Province sections at Lewes, Beachy Head, Seaford Head and Dover. (* = informal zones applied in this book.)



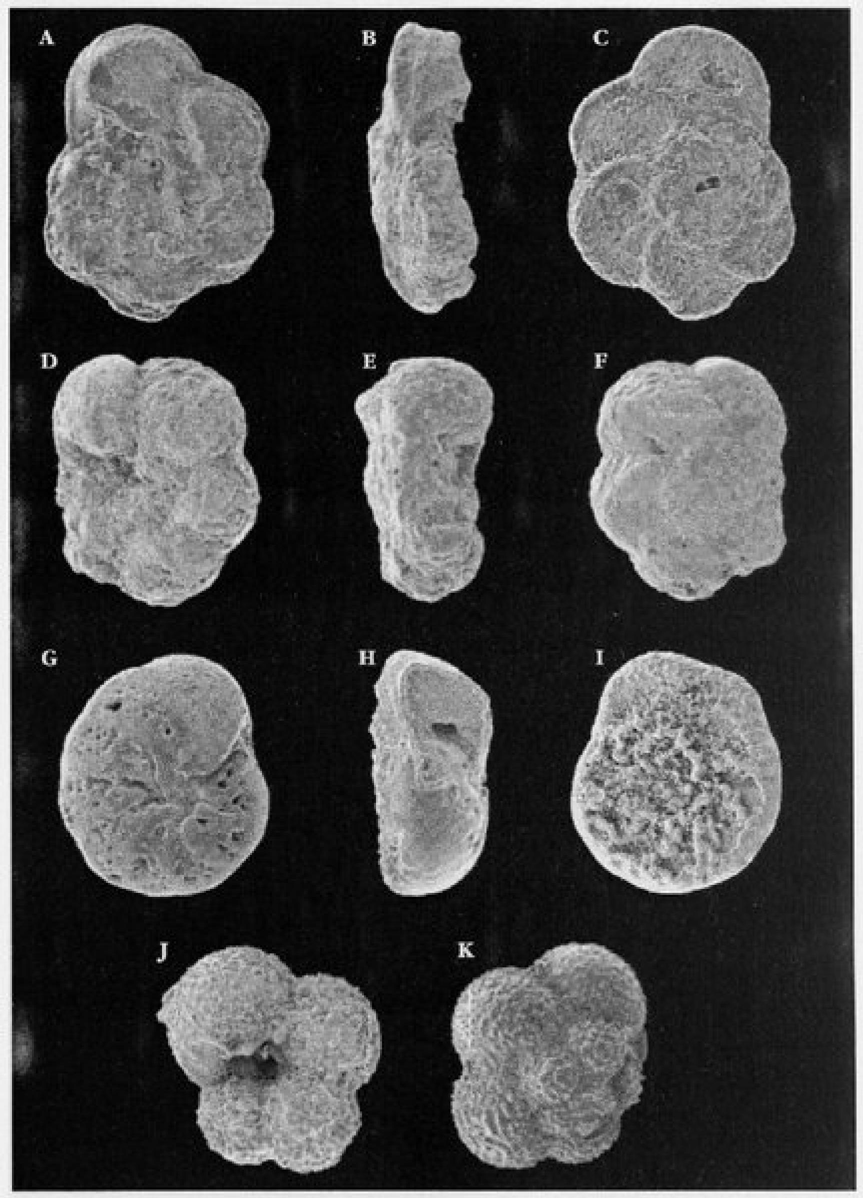
(Figure 2.27) Campanian stratigraphy for the onshore UK based on the Southern Province sections at Seaford Head, Portsdown and the Isle of Wight. (= informal zones applied in this book.)*



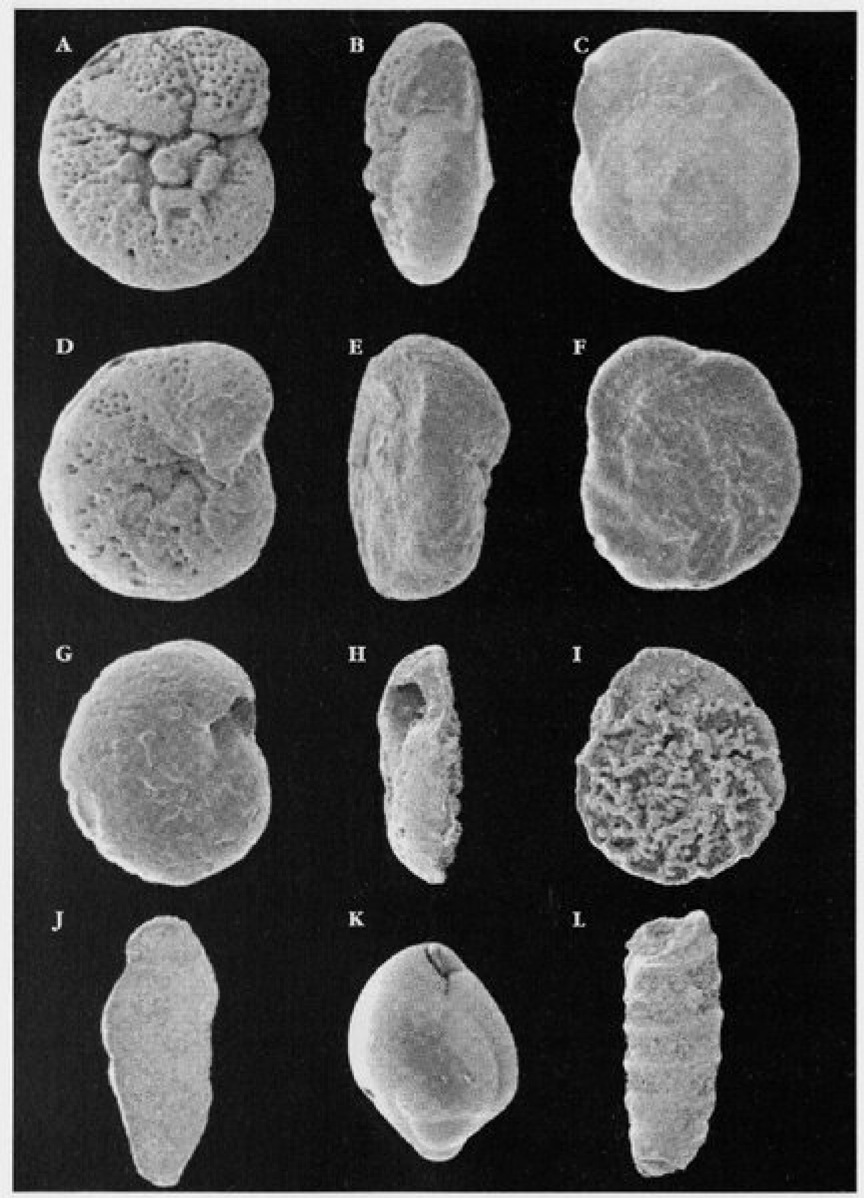
(Figure 2.18) Upper Turonian and Lower Coniacian inoceramid bivalves. (A–E) Cremnoceramus crassus inconstans; (A, B) the lectotype, the original of Inoceramus sp., Mantell, 1822 (from Woods, 1912, text-fig. 42); (C–E) from Woods, 1912, text-fig. 43. (F) Inoceramus lusatiae, holotype: typical of the Navigation Hardgrounds (from Walaszczyk and Wood, 1999b, pl. 2, fig. 4). (G, H) Mytiloides herbichi, probably typical of the beds around the Cuilfail Zoophycos (from Walaszczyk and Wood, 1999b, p1. 1, fig. 5). Scale bar applies to all specimens.



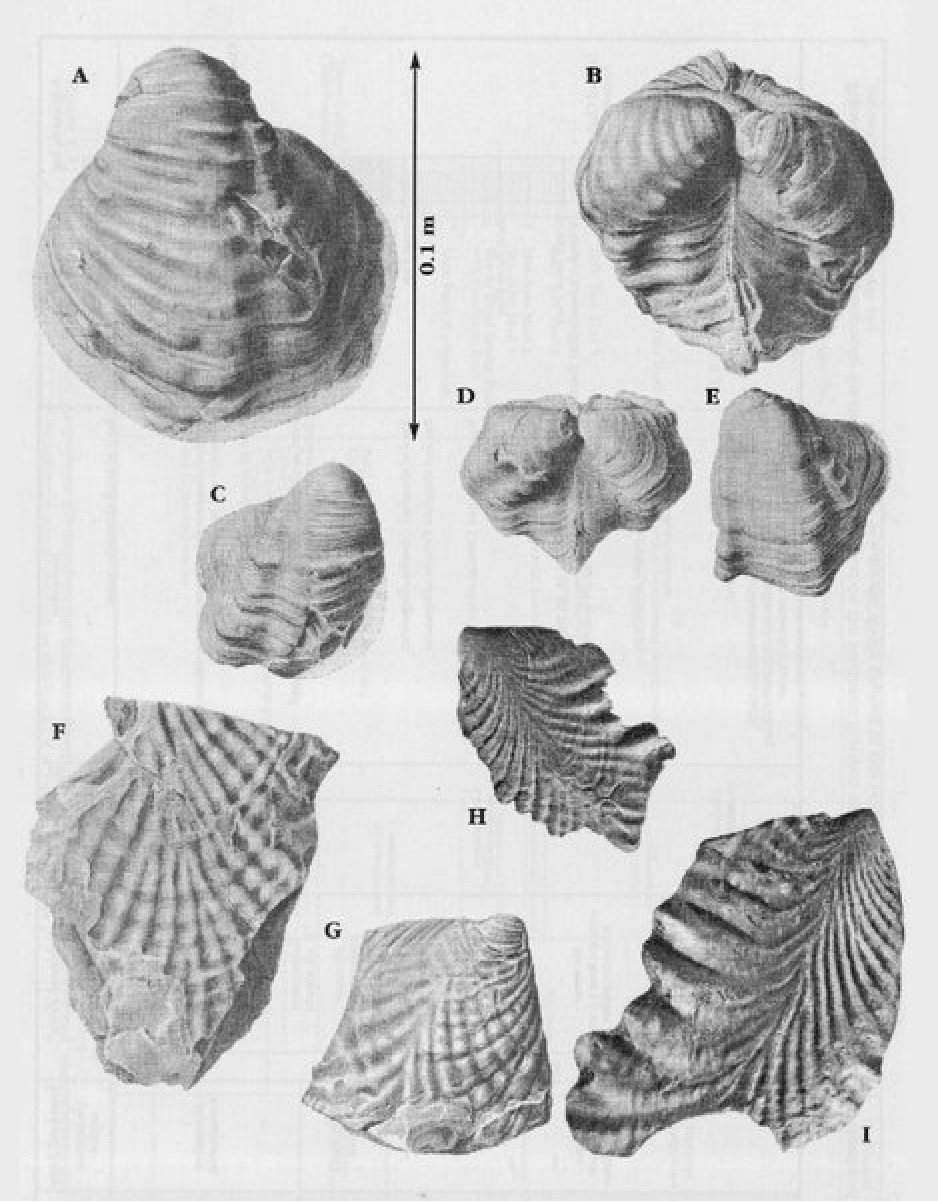
(Figure 2.19) Topmost Turonian and basal Coniacian inoceramid bivalves. (A, B) Cremnoceramus deformis erectus typical of beds just above the Navigation Hardgrounds and the larger forms from the Hope Gap Hardground (from Walaszczyk and Wood, 1999b, pl. 7, figs 7, 8). (C, D) Cremnoceramus deformis erectus, typical of Navigation Marls, (from Walaszczyk and Wood, 1999b, p1. 7, figs 1, 2). (E-G) Cremnoceramus waltersdorfensis waltersdorfensi; (E) typical of the Southern Province (from Walaszczyk and Wood, 1999b, pl. 15, fig. 2); (F) typical of beds below the Navigation hardgrounds (from Walaszczyk and Wood, 1999b, pl. 17, fig. 3); (G) typical of beds between Navigation and Cliffe hardgrounds in the Southern Province (from Woods, 1912, pl. 52, fig. 1). (H) Cremnoceramus waltersdorfensis hannovrerzsis typical of beds between Cliffe and Hope Gap hardgrounds (from Walaszczyk and Wood, 1999b, pl. 11, fig. 2). Scale bar applies to all specimens.



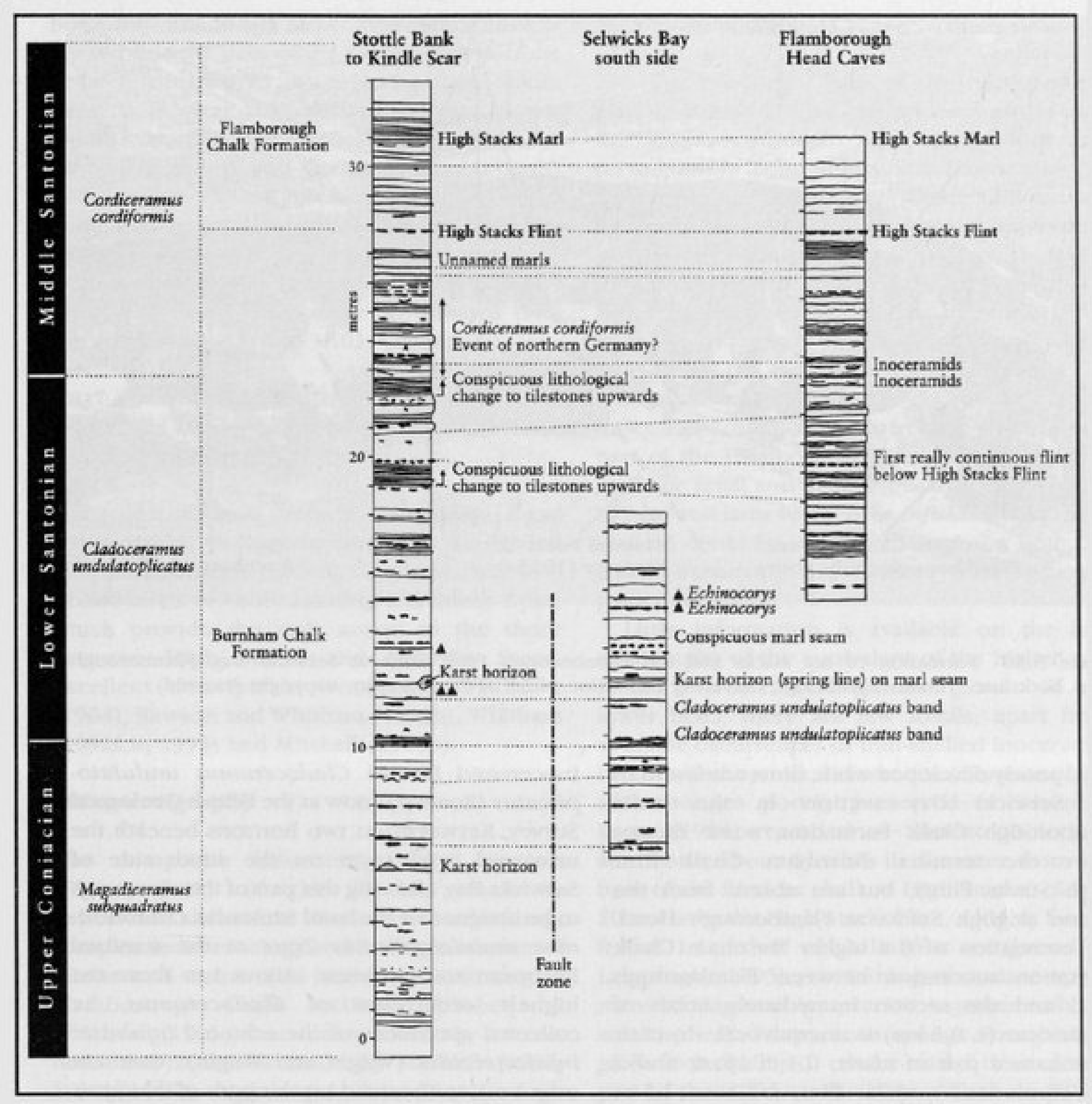
(Figure 2.41) Turonian and Coniacian foraminifera. SEM images of Turonian and Coniacian foraminifera. (A–C) Marginotruncana pseudolinneiana (Pessagno) (× 150) (planktonic), from New Pit, Lewes, East Sussex, (New Pit Chalk Formation), Middle Turonian Collignoniceras woollgari Zone. Range: Turonian to Santonian. Remarks: key zonal form in Europe, entry marks a planktonic foraminiferal zone in the Turonian. (D–F) Helvetoglobotruncana helvetica (Bolli) (× 150) (typical Tethyan planktonic), from New Pit, Lewes, East Sussex, (New Pit Chalk Formation), Middle Turonian Collignoniceras woollgari Zone. Range: Lower to Middle Turonian. Remarks: key entry zonal index fossil. (G–I) Stensioeina granulata granulata (Olbertz) (× 150) (benthic), from Seaford Head (Cuckmere to Seaford GCR site) East Sussex (Seaford Chalk Formation), Middle Coniacian Micraster coranguinum Zone. Range: base of Middle Coniacian to Middle Santonian. Remarks: key marker at base of Seaford Chalk Formation (Bailey et al., 1983, 1984). O, K) Whiteinella baltica (Douglas and Rankin) (× 150) (planktonic), from Euston, Suffolk, M coranguinum Zone. Range: Base of Coniacian to Upper Santonian.



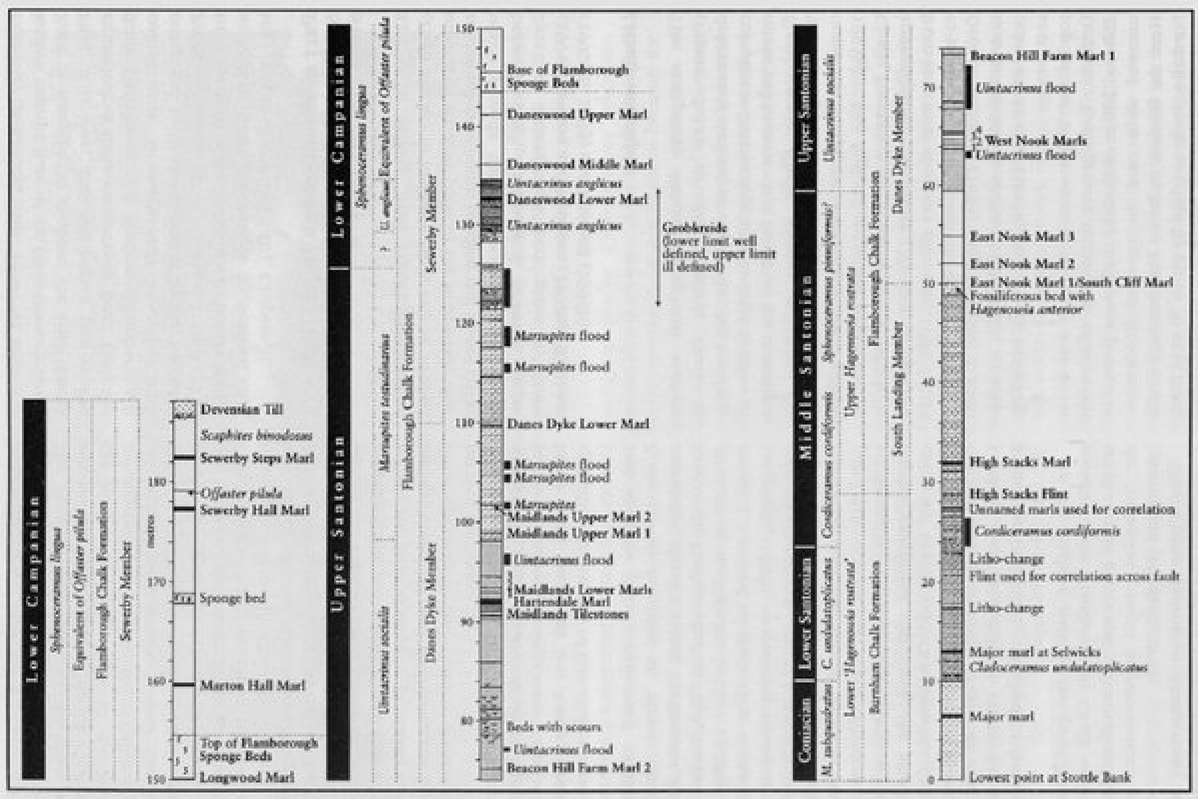
(Figure 2.42) Santonian foraminifera. SEM images of Santonian foraminifera. (A–C) Gavelinella cristata (Goel) (× 100) (benthic), from Ipswich, Suffolk, Lower Campanian. Range: Upper Santonian to Lower Campanian. Remarks: entry is approximately coincident with base of Uintacrinus socialis Zone (Bailey et al., 1983). (D–F) Stensioeina granulata polonica (Witwicka) (× 150) (benthic), from Euston, Suffolk (Seaford Chalk Formation), Upper Coniacian M coranguinum Zone. Range: entry in Upper Coniacian. Remarks: zonal index in UKB scheme (Bailey et al., 1983). (G-I) Stensioeina exsculpta exsculpta (Reuss) (× 150) (benthic), from Euston, Suffolk (Seaford Chalk Formation), Upper Coniacian M. coranguinum Zone. Range: Benthic Foraminiferal Zone in the Middle and Upper Coniacian. Remarks: ranges from just above the Shoreham Marls to the Flat Hill Flint, Seaford Chalk Formation. (1) Loxostomum eleyi (Cushman) (× 150) (benthic), from Ipswich, Suffolk, Lower Campanian. Range: Santonian to Upper Campanian. (K) Praebulimina reussi (Morrow) (× 150) (benthic), from Ipswich, Suffolk, Lower Campanian. Range: Santonian to Upper Campanian. (L) Vaginulinopsis scalariformis (Porthault) (× 50) (benthic), from Euston, Suffolk, Seaford Chalk Formation M coranguinum Zone. Range: Middle Coniacian and Lower Santonian.



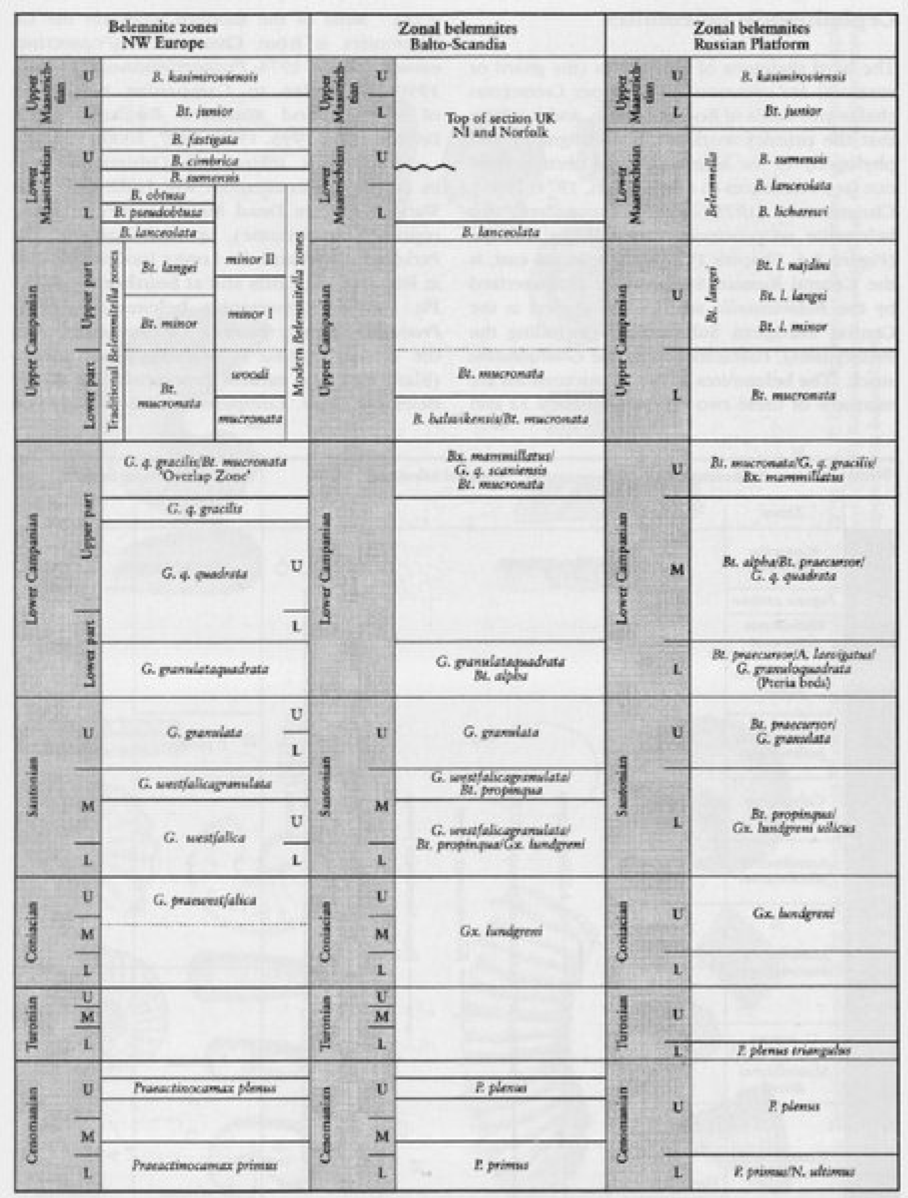
(Figure 2.23) Lower Santonian inoceramid bivalves. (A–E) Cordiceramus cordiformis; (A, B) Seaford Chalk Formation, Gravesend, Kent (holotype from Woods, 1912, pl. 53, figs 8a,b); (C–E) from the Seaford Chalk Formation, Micheldever, Hants (from Woods, 1912, pl. 54, figs 3a,b, 4). (F–1) Cladoceramus undulatoplicatus; (F, G) typical of the basal Santonian including Bedwell's Columnar Flint Band (from Woods, 1912, text-figs 60, 61), from Haldon, Devon; (H, 1) typical of the basal Santonian (from Seitz, 1961). Scale bar applies to all specimens.



(Figure 5.29) Correlation from Stottle Bank across the Selwicks Bay Fault to Flamborough Head (High Stacks) with inferred biostratigraphy.



(Figure 5.31) A simplified true scale section of the highest Burnham Chalk Formation and Flamborough Chalk Formation from Stottle Bank to the Sewerby Steps Quaternary cliff section. For details of the highest Burnham Chalk and basal Flamborough Chalk formations, see (Figure 5.29).



(Figure 2.13) Comparison of Upper Cretaceous belemnite zones across Europe, which are only partly represented in the UK and mainly on the Anglo-Brabant Massif. (After Christensen, 1991.) (A. = Actinocamax; B. = Belemnella; Bt. = Belemnitella; Bx. = Belemnellocamax; G. = Gonioteuthis; Gx. = Goniocamax; N. = Neohibolites; P. = Praeactinocamax.)