British Upper Cretaceous Stratigraphy

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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 (Tröger 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* (Pervinquière), the eponymous ammonite of the basal zone, with the first occurrences of *Inoceramus schoendorfi* Heinz and the planktonic foraminifer *Rotalipora ręicheli* 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 currrently 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. branneri* (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 (Figures 2.9, 2.21, 2.22 and 2.27, Chapter 2) used in northern Europe (Ernst *et al.*, 1983; Tröger, 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* Troger *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 Figures 5.29 and 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 Marls 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* (Blainville) 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* Stolley, 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 (Schönfeld 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.

Maastrichtian Stage

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

In this reference list the arrangement is alphabetical by author surname for works by sole authors and dual authors. Where there are references that include the first-named author with others, the sole-author works are listed chronologically first, followed by the dual author references (alphabetically) followed by the references with three or more authors listed *chronologically*. Chronological order is used within each group of identical authors.

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Glossary

This glossary provides brief explanations of the technical terms used in the introductions to the chapters and in the 'conclusions' sections of the site reports. These explanations are not rigorous scientific definitions but are intended to help the general reader. Detailed stratigraphical terms are omitted as they are given context within the tables and figures. Words in **bold** type indicate an internal reference to another glossary entry.

In addition to the terms defined below, there is a more comprehensive list of Upper Cretaceous stratigraphical terminology used in England contained in the International Stratigraphical Lexicon on the Cretaceous edited by J.M. Hancock, 1972 (*Lexique Stratigraphique International*, Volume I: Europe – Angleterre, Pays de Galles, Écosse. Fascicule 3a XI. CRÉTACÉ). The list below includes terms either not in the Lexicon, or re-defined or introduced since the Lexicon was published.

Abundance zone (formerly 'acme zone'): a **biostratigraphical unit** characterized by the time range in which one or more **taxa** were the most abundant.

Age: a time unit, usually taken to be the smallest standard division of geological time, of shorter duration than an **epoch**.

Ammonite: an advanced group of **cephalopods** characterized by typically coiled, chambered shells that have complex sutures between the chamber walls and the outer wall of the shell.

Anglo-Brabant Massif: submerged, ancient land-mass comprising the London Platform, its northern extension beneath East Anglia and its continuation beneath the area of the present southern North Sea to join the emergent Brabant massif in Belgium. This complex structural unit exerted considerable control over **Cretaceous** sedimentation.

Anoxia (adj. anoxic): state of oxygen-depletion in sedimentary environments, including anoxia in pore waters within sediments, and in the bottom waters of a sea or ocean bed.

Aragonite: a magnesium-rich mineral form of calcium carbonate that is more soluble in cold water than in warm. Shells made of aragonite ('mother-of-pearl'), such as those of **ammonites** and **nautiloids**, scaphopods, many **bivalves** and most **gastropods** were not normally preserved in the relatively deep and, consequently, cooler water of the **Upper Cretaceous** Chalk seas, but were preserved in shallower and perhaps warmer depositional environments. For this reason, well-preserved ammonites in the **Chalk** are mostly found in **hardgrounds** and thin **condensed limestone successions**.

Assemblage zone: type of fossil **zone** (*biozone*) that is based on an assemblage of fossil species and not on the occurrence or range of a single species. The **index fossil** of an assemblage zone (AZ) is not necessarily restricted to that zone. Most of the traditional **macrofossil** biozones of the Chalk are assemblage zones. Contrast with *total range Zone* (TRZ), which is based on the total range of the zonal index fossil, and *partial range* *zone* (PRZ), which involves overlapping ranges of zonal index fossils. The last term is particularly used in **microfossil** and macrofossil **biostratigraphy**.

Band/Belt/Horizon: three synonyms frequently used to describe the occurrence of a fossil or a particular geological feature that is used in correlation of rock strata over a wide area. For example, the upper belt of abundant *Offaster pilula* (an irregular **echinoid** fossil occurring in Lower Campanian strata) spans more than one bed of chalk in England. This belt or horizon is traceable across northern Europe. Similarly, the horizon of the irregular echinoid *Hagenowia blackmorei* spans several beds of chalk. In the same way the three bands of the fossil **brachiopod** *Orbirhynchia mantelliana* in the Cenomanian Stage all span several beds or couplets of marl–limestone in the **Chalk**. The purely descriptive terms do not specify or imply a particular thickness of rock.

Basin/basinal sequence, basinal succession: basins are relative depressions or 'lows' in the Earth's crust in contrast to surrounding 'highs'. The **Anglo-Brabant Massif** was a 'high' during the **Late Cretaceous Epoch**. In contrast, areas to the south (e.g. Sussex and Hampshire) and to the north (North Sea) were relative 'lows' where thicker successions of sediment accumulated. Even within basins there may be further local 'highs'. The amount of sediment input to the basins and on the 'highs' was partly dependent on supply from land areas, the productivity of **coccoliths** in the oceans and seas and on sea-level fluctuations. Where there is considerable input of sediment from land areas at times of low sea level (sea-level *lowstands*), there is generally a transition from coarse-grained sediments (sands, calcarenites) near the margin of such a depositional area to fine-grained sediments (chalks, muds) in the basin centre as the heavier, coarser detritus is progressively deposited. At times of high sea level (sea-level *highstands*) with minimal supply of land-derived sediment to the basin, there may be a basinward transition from thin, **condensed limestone successions**, including **hardgrounds**, to chalks. The fauna of such a transect changes from margin to basin, leading to various **biofacies**. The concept of basinal successions is particularly important in the Turonian Stage and the Lower Campanian Substage, where **marl** seams and volcanic clays that are preserved in the deeper environments (e.g. the Southern Province successions) are progressively lost as they are traced into the condensed **Chalk Rock** successions of local 'highs'.

Bathichnus paramoudrae: a unique **trace fossil** around which **paramoudra flints** commonly form, having a vertical shaft 20–60 mm in diameter and 5–9 m long with sub-horizontal side branches <100 mm in length (originally described by Bromley *et al.*, 1975).

Beer Stone: a local freestone from Beer quarries in south-east Devon described by De La Bèche (1826) and Jukes-Browne and Hill (1903, 1904). Unlike **coccolithic** chalk, the Beer Stone is a **calcarenite** almost entirely composed of comminuted **echinoderm** skeletal material (mainly micro**crinoid**) forming a soft, gritty limestone within the Holywell Nodular Chalk Formation (near the base of the former 'Middle Chalk').

Belemnite zone: macrofossil **biozone** with a belemnite **index species**, e.g. the *Gonioteuthis quadrata* Zone. See **cephalopod**.

Belt: see **band**.

Benthic (noun: **benthos**): Living on or near the sea bottom. Contrast with **planktonic**.

Bioclastic/bioclastic chalk: Chalk composed of detritus of organic origin, e.g. comminuted and/or fragmented **inoceramid bivalve** shell. Such chalks are typically more or less coarse-grained and gritty to the touch, e.g. the Lower and Upper Inoceramus Beds of the Ferriby Chalk Formation, the Totternhoe Stone.

Bio-event bed: a bed characterized by a fossil occurrence. The 'event' may be, for example, a fossiliferous bed within a generally unfossiliferous succession, an acme-occurrence or short-term occurrence of some particular fossil, a short-term immigration of a warm or cold-water fauna, or something distinctive such as the occurrence of **inoceramid bivalve** shells encrusted by serpulid worm-tubes (the *Filograna avita* event) in the Holywell Nodular Chalk Formation.

Biofacies: the sum total of a rocks' gross fossil faunal/floral characteristics that together reflect the particular environment in which the rock formed.

Biostratigraphy: type of **stratigraphy** involving the use of fossils (**macrofossils**, **microfossils**, **nannofossils**) for the establishment of **zones** and for the correlation of rock strata.

Biostratigraphical unit: a stratigraphical unit, or body of rock, defined or characterized by its fossil contents without regard to lithological or other physical features or relations. The basic unit is a biozone (see **zone**) of which there are several kinds.

Bivalve: a type of aquatic shellfish that have their bodies enclosed by two, often mirror-image, shells (valves). Modern examples include cockles and mussels (cf. **brachiopod**).

Boreal Realm: reconstruction of palaeoenvironments for the **Late Cretaceous** Earth split the sphere into two palaeohemispheres, a Boreal northern and an Austral southern hemisphere, separated by an equatorial Tethyan Realm. In the Boreal northern palaeohemisphere, sea-water temperatures are *generally* held to have been cooler than those of areas immediately to the south, but this is not universally true.

Brachiopod: a major group of shellfish superficially similar to the **bivalves** but distinguished by a different anatomy. The two shells (valves) are typically dissimilar.

Calcarenite: coarse, gritty limestone formed of mainly sand-sized calcareous fragments.

Calcareous nannofossils: all calcareous fossils smaller than 30 microns (μm), defined by Lohmann (1909) as including the **plankton** that pass through the finest plankton nets (i.e. <63 μm). This includes many organisms such as ascidian spicules, **calcispheres** and juvenile **foraminifera**, but by far the most predominant group are the haptophyte algae (golden-brown algae). Fossil calcareous haptophyte algae are the primary chalk-forming organisms (see **coccoliths** and **nannofossils**).

Calcispheres: round or oval-shaped calcareous grains about 500 μm in size, common at many levels in the Chalk, particularly Cenomanian and Turonian **nodular chalks** and **hardgrounds** (sphere-rocks), in which they are present in rock-building quantities. Thought to be the fossil cysts of calcareous dinoflagellates.

Calcite: the main mineral form consisting predominantly of calcium carbonate ($CaCO_3$). The calcite in the skeletons of the chalk-forming calcareous algae is composed of low-magnesium calcite, a very stable carbonate.

Carbonate: in geology, a synonym for limestone.

Cephalopod: a group of marine molluscs including the modern squid, cuttlefish and octopus and their extinct fossil relatives including belemnites (a form possessing a bullet-shaped internal calcium carbonate shell) and the **ammonites**.

Chalk: a very fine-grained limestone formed primarily by **coccoliths**. 'The Chalk' used as a proper noun with a capital letter, is taken to be equivalent to the **Upper Cretaceous** Series, reflecting the dominance of the chalk rock type in strata of **Late Cretaceous** age (cf. **Chalk Rock**).

Chalk facies: chalk is a special type of limestone formed from a rain of the calcareous skeletal material produced by marine **plankton** onto the seabed. These plankton are primarily **coccoliths**. Other types of **nannofossil** may be abundant at certain horizons in the Chalk and these produce different-shaped calcite crystals, affecting the properties of a chalk. Such nannofossils include cylindrical nannoconids and rhabdoliths, and prismatic Micula (see Figure 1.9, this volume). Other chalks may contain abundant **calcispheres** or **foraminifera**, which are around 500 μm in size in comparison to the 5–10 μm size of the nannofossils. Chalk is the characteristic rock of the **Upper Cretaceous** succession in north-west Europe and gives its name to the **Cretaceous System** (Creta = Latin for chalk). Chalk facies is replaced laterally towards the margins of depositional basins by coarser-grained sediments, including **calcarenites** and **calcite**-cemented sandstones (e.g. the Wilmington Sands).

Chalk Marl: the former lowest division of the Chalk Group in southern England. 'Chalk Marl' was the name applied to the Chalk wherever it had a soft **marly** character. The term has been superseded in part by the name 'West Melbury Marly Chalk Formation' (Bristow *et al.*, 1997: Rawson *et al.*, 2001). The former Chalk Marl is not co-extensive with this formation, but also includes the lower part of the succeeding Zig Zag Chalk Formation.

Chalk Rock: the Chalk Rock was defined by Whitaker (1861) and used by the [British] Geological Survey as the mapping boundary between the Middle Chalk and Upper Chalk (former divisions of the **Chalk**) in parts of the Chiltern Hills (Penning and Jukes-Browne, 1881; Jukes-Browne and Hill, 1903, 1904). Bromley and Gale (1982) re-defined the Chalk Rock as a formation comprising a number of **hardgrounds** that varied in intensity and number from west Wiltshire to Cambridgeshire. The Chalk Rock now forms a Member at or towards the base of the Lewes Nodular Chalk Formation in those areas where it can be defined, primarily in Wiltshire and Berkshire. The names for the various hardgrounds introduced by Bromley and Gale (1982) for the Chalk Rock are retained where they can be recognized.

Chalkstone: a term introduced by Bromley and Gale (1982) to describe the creamy, hard, well-cemented 'stony' parts of the **Chalk Rock hardgrounds**. The term can also be applied to other re-cemented chalks such as those in Northern Ireland and Yorkshire or to chalks re-cemented by Quaternary processes. The intact dry density of chalkstones is usually greater than 20 000 kg/m^3

Chert: cryptocrystalline silica (SiO_2) which may be of organic or inorganic origin, occurring as layers or nodules in sedimentary rocks (mainly limestones). **Flint** is a form of chert.

Chert Beds: beds of sandstone or calcareous sandstone with seams of chert characterizing the Upper **Greensand** of Wessex (Dorset and south-east Devon).

Chronostratigraphy: 'time layer writing', the **correlation** and subdivision of rock units on the basis of relative age – a hierarchy of sequential units to which the layers of sedimentary rocks are allocated, through the study and interpretation of their **stratigraphy**. The hierarchy of principal chronostratigraphical units is **system**, **series** and **stage**, which are related, respectively, to the geological time units of **period**, **epoch** and **age**. Rocks of the **Jurassic System** (a chronostratigraphical unit) were laid down in the Jurassic **Period** (a geological time unit).

Clay Minerals (Hydrous Aluminium Silicates): clay minerals are formed by the chemical weathering of other silicates (e.g. some feldspar minerals convert to the clay mineral kaolinite), whilst most micas are produced by the subsequent pressure recrystallization of clay minerals (see **metamorphic rocks**). Clay minerals are the component of an engineering soil that gives it plasticity. Clays have the properties of becoming plastic and easily moulded when wet and of becoming hard and rock-like on heating above a certain temperature. Bentonite and Fullers Earth, belong to the smectite or montmorillonite subgroup of active clays. Kaolinite is widely used for ceramics, white-wares, and refractory bricks, aggregates etc, structures. Clay minerals are significant in the Grey Chalk Subgroup and in units of chalk with significant **marl** seams such as the Newhaven Chalk and Flamborough Chalk formations.

Coccoliths: calcareous, **planktonic**, haptophyte algae.

Condensation/condensed succession: beds that are thinner in some parts of the depositional area than beds of equivalent age elsewhere, e.g. towards the margins/palaeoshoreline or over structural 'highs', are said to be 'condensed'. Simple condensation implies a smaller amount of deposition per unit time. More complex condensed successions may contain erosional hiatuses or 'non-sequences' (omission surfaces) resulting from interruptions in deposition. Longer breaks in sedimentation are commonly marked by mineralized **hardgrounds**. Good examples of condensed successions are provided by the Cenomanian Beer Head Limestone Formation of Devon and the Turonian Chalk Rock. In both cases, there is a lateral change in the type of sediment, with basinal chalks passing laterally into hard limestones.

Conjugate joint sets: two sets of **joints** believed to represent complementary shear sets in which the maximum principal stress is horizontal. Such joint sets are particularly characteristic of the Holywell Nodular Chalk, New Pit Chalk, Newhaven Chalk and Flamborough Chalk formations.

Contemporaneous: a geological event that occurs at the same time as a deposit is forming. Compare with **penecontemporaneous**.

Cored borehole: a borehole that is drilled in such a way as to recover a cylindrical core of the rocks through which the drill penetrates. This is an extremely expensive method, but one which provides the maximum amount of information, particularly **biostratigraphical** (fossil) data. Other boreholes are rock-rollered or chipped so as to produce a hole in the rocks that can be used for the production of **geophysical logs**. From a study of the rock chippings and the form of the geophysical logs the nature of the succession drilled can be inferred.

Cretaceous: a **period** of geological time from 142–65 million years ago (see Figure 1.2).

Cretaceous Quiet Zone: term used in **magnetostratigraphy** to describe the long time interval in the **Late Cretaceous Epoch** without numerous magnetic reversals.

Crinoid: a group of **echinoderms** with a flowering-plant-like structure, hence the common name 'sea lily'.

Cyclostratigraphy/cyclostratigraphical couplet: type of **stratigraphy** based on the identification of couplets of **marls** and chalks/limestones that are inferred to result from orbital control of sedimentation owing to changes in the amount of sun (insolation) reaching the Earth's surface. Individual couplets and groups of couplets can be traced over enormous distances (cf. Gale, 1995, 1996, 1998) enabling extremely high resolution in the correlation of rock strata. In the **Chalk**, the couplets are inferred to be precession-driven, i.e. they have a periodicity of 19–23 million years. This inferred periodicity can be checked against absolute dating based on radioactive decay of elements (e.g. Potassium/Argon (K/Ar)) in sanidine grains included in volcanic beds (bentonites).

Decollement zone/zone of decollement: term normally applied in Alpine structural geology to describe the surface along which an upper series of **tectonically**-folded rocks has slid over an underlying packet of less-deformed or undeformed rocks. Used in this book to describe any surface in the **Chalk** along which detachment of one mass from another has occurred. This includes the **glacio-tectonic** chalk-masses of the Norfolk coast, which are inferred to have become detached, and also includes slide planes and detached masses such as those at Downend, Portsdown and Hope Gap, Seaford Head.

Diachronous: a continuous rock body that is a different age in different places. The Glauconitic Marl is older in Sussex and Kent than it is on the Isle of Wight and younger still on the Dorset coast (see Compton Bay and White Nothe site descriptions). Hence this sedimentary deposit 'crosses time'.

Diagenesis: the changes that take place in a sediment due to physico-chemical and biochemical processes at low temperature (<200°C) that convert a sediment to a sedimentary rock. These changes include early cementation on, or beneath, the seabed (formation of **nodular chalks**, **hardgrounds** and **flints**). They also include early consolidation (often effected by burrowing organisms) and mechanical compaction.

Diastem: small amounts of geological time not represented by sedimentation. A **hardground** or **nodular chalk** bed may represent a diastem.

Dip: rock layers are generally tilted at angles between horizontal and vertical (the angle of dip). The angle of dip is measured using an inclinometer from the horizontal downwards. Dip also has a compass direction identified as the direction of the maximum dip angle of the strata.

Disconformity: an erosional surface separating two sequences of parallel strata from one another. The erosional surface on which the Southerham Grey Pit channel has formed is a typical disconformity.

Dissolution: the dissolving of rock, particularly limestone, usually by percolating acidic groundwater. Dissolution in chalk leads to a variety of **karst** features including dolines, pipes, opening of **joints** to form fissures, and underground cavities with a range of sizes.

Echinoderm: a group of marine invertebrates, characterized by five-fold symmetry and calcareous skeleton. The group includes starfish, sea urchins, sea lilies and their fossil relatives.

Echinoid: sea urchin.

Epigenetic: structures formed after the lithification of a sediment into a rock.

Epoch: a unit of geological time, of shorter duration than a **period** and itself divisible into **ages** (e.g. the **Late Cretaceous** Epoch).

Era: one of the five major divisions of geological time, namely the Archean, Proterozoic, **Palaeozoic**, **Mesozoic** and Cainozoic, each of which comprises several **periods**.

Erosional hiatus: a gap in the stratal succession resulting from erosion of the underlying beds prior to the deposition of the overlying sediments, e.g. the erosional contact below the Totternhoe Stone. An erosional hiatus involves some degree of angular discordance between strata and is therefore more or less conspicuous, whereas a 'non-sequence' results merely from a break in sedimentation without angular discordance and may be difficult to detect.

Event horizon/stratigraphy: a **band** ('horizon') characterized by a wide-ranging, short-term event, which may be an occurrence of a fossil, a concentration of a particular mineral (e.g. iridium), a clay seam (either detrital or vulcanogenic), a 'spike' on a stable isotope curve, a distinctive sediment (e.g. a black shale). Many events are, by definition, either near- or absolutely isochronous and can be used to help construct a composite correlation framework for rock strata (event stratigraphy). Such frameworks are increasingly used in the case of the **Chalk** and coeval sediments.

Facies: the lithological and biological characteristics of a sedimentary rock that results from deposition in a particular environment.

Facies model: a general summary of a specific sedimentary environment and the biological and lithological features that result from processes of sedimentation within that environment.

Fault: a fracture in rock that has a measurable off-set of the layers of rock on either side of the fault plane (surface of fracture).

Flint: (the old English word for hardstone) a siliceous rock whose composition is about 98% pure silica (i.e. SiO_2 in a variety of crystalline forms, including chalcedony, opal and quartz). The dark black flints appear to be made of a compact mass of microscopic, needle-like crystallites of quartz. By contrast, in the case of the grey flints of Northern Ireland and the Northern Province (Lincolnshire–Yorkshire), the crystals are less fibrous, stouter and much shorter (Shepherd, 1972). Others have found that flint has replaced the original chalk to such an extent that when flint is etched with acid and viewed with a scanning electron microscope the original structure of the chalk can be seen (Clayton, 1986). Details of the original pore structure of chalk are preserved. Flint is, therefore, formed during **diagenesis**, at an early stage of burial of the chalk.

Flood event/occurrence: a super-abundant occurrence of one or a few fossils (either macro- or microfossils) over a large geographical area and typically at one **horizon**, e.g. the occurrence of the **inoceramid bivalve** *Cladoceramus undulatoplicatus* at the base of the Santonian Stage in the Seaford Chalk Formation. Flood events are of great value for long-range inter-regional correlation of rock strata as they may cross from one **facies** to another, e.g. the *Cladoceramus* event(s) are found in chalks, sandstones, siltstones and mudstones and can be traced from North America to central and southern Europe.

Foraminifera: single-celled, calcareous, aquatic micro-organisms usually less than one millimetre in diameter (a few are larger). Foraminifera from the **Chalk** are usually divided into **benthic** forms and **planktonic** forms (that lived in the top 50–60 m of the water column). Benthic/planktonic ratios and abundances of different species are used for both correlation and environmental interpretation. Detailed stratigraphies of foraminifera have been used to establish the geology along the route of the Channel Tunnel (e.g. Harris *et al.*, 1996a) and other tunnels in the UK.

Gastropod: a class of univalved molluscs, mostly characterized by helical shells made of **aragonite**.

GCR: Geological Conservation Review, in which nationally important geological and geomorphological sites were assessed and selected with a view to their long-term conservation as **SSSIs**.

Geophysical borehole log: method whereby a continuous trace of the physical characteristics of the rocks penetrated by a drill, e.g. radioactivity (gamma radiation), electrical resistivity, etc. can be obtained from an instrument lowered slowly down the borehole. Such traces (commonly called 'down-hole wireline logs') are of enormous value in inferring the nature of the rocks penetrated and, particularly, in long-range correlation. The identification of **marl** seams from low restivity 'spikes' enables the marl seam and volcanic clay framework of field sections to be confidently recognized in the subsurface succession of rock strata (cf. Mortimore and Wood, 1986; Mortimore and Pomerol, 1987).

Glacio-tectonic: refers to the detachment and deformation of rocks by contact with a mass of moving ice, e.g. the complex folded masses of Campanian and Maastrichtian Chalk on the

Norfolk coast, which are inferred to have been detached from the bed of the North Sea and carried bodily southwards.

Glauconite: akin to an iron-rich clay mineral, illite, with a similar structure to that of mica. Its colour ranges from olive-green, yellowish, greyish to blackish-green. The presence of glauconite in a sediment imparts a green colour (e.g. greensands and **Glauconitic Marl**), and usually indicates a shallow-water, marine origin for the deposit.

Glauconitic Marl (known as 'Chloritic Marl' in the earlier literature): a **glauconite**-rich sandy **marl** also rich in chocolate-brown phosphate nodules, constituting a member at the base of the Chalk Group in southern England.

Global boundary Stratotype Section and Point (GSSP): an internationally agreed point in a rock succession at a particular locality that is taken to mark a **stage** or substage boundary (strictly speaking, the *base* of a stage or substage).

Greensand: term loosely applied in the **Cretaceous** rock succession to units of arenaceous rocks, which are green at their type localities but which elsewhere are commonly weathered brown (e.g. Aptian–Albian Lower Greensand). Where green, the coloration is generally due to the presence of the dark green mineral **glauconite**. The basal member of the Chalk Group in the Southern and Transitional provinces is typically developed as a glauconitic sediment, e.g. the Glauconitic Marl Member, Cambridge Greensand.

Hardground: the end member in a **diagenetic** series from soft nodules, through hard **nodular chalks** to a fully mineralized hardground. **Calcitic** cement pervades the rock and the convoluted erosion surface marking the top of the hardground, as well as burrow-walls penetrating into the hardground, are coated with purple-brown calcium phosphate and green glauconite. Iron-mineralization (goethite) is common. Strictly speaking, the term refers only to the surface, although it is in general use to describe both the surface and the underlying chalkstone (see Bromley, 1975b).

Hiatus: literally a 'gap', usually referring to a gap in a sedimentary succession, caused either by erosion and/or no deposition. The time 'missing' or not represented at an **unconformity** or other break in the stratigraphical record.

Horizon: see **band**.

Illite: a **clay mineral** intermediate in structure between the mica muscovite and the clay mineral montmorillonite.

Index fossil: see **zone**.

Inoceramid bivalve: extinct family of **Jurassic** and **Cretaceous** marine **bivalves** characterized by a hinge plate with ligament pits but without teeth, and a shell composed of an external layer of prismatic crystals of **calcite** arranged at right angles to the shell surface and an internal layer of laminar **aragonite** ('mother-of-pearl'). Both layers are commonly preserved in mudstones but only the outer layer is normally preserved in chalks.

***Inoceramus atlanticus* event**: the wide-ranging common occurrence (**event**) of the distinctive eponymous **inoceramid bivalve** over a narrow interval in the higher part of the Middle Cenomanian Substage, immediately preceding the *Pycnodonte* event.

Interfluves: the ridges between fluvial valleys. In the **Chalk** downland, interfluves form the high ground between dry valleys.

Intraclasts: fragments of rock (clasts) contained in the same type of rock that they are derived from. Hence a fragment of chalk contained in chalk is an intraclast.

Iridium anomaly: refers to a concentration of the element iridium at a particular **horizon** in a sedimentary succession. Such concentrations are inferred to result from the impact of an extra-terrestrial body with the Earth, e.g. the widely-believed end-**Cretaceous** impact event.

Joints: fractures in rock with no measurable offsets on the layers of rock on either side of the fracture. Joints often form in sets or groups that have a statistically consistent orientation.

Jurassic: a **period** of geological time from 213–144 million years ago.

Karst: the following definition is from Fairbridge, 1968, *Geomorphology*: 'The term **karst** is derived from the German form of the Slavonic word, *krs* or *kras*, meaning rock. The word was a regional name for the area of massive limestone country north and south of the port of Rjeka in Yugoslavia, a district of many rocks, sinkholes and underground streams. The word is now more widely used to denote a type of terrain with a distinctive and unique assemblage of landforms...the result of one dominant erosion process, **dissolution**. The main characteristic of a karst area is the predominance of vertical and underground drainage and the complete absence of surface streams. The Adriatic coastal areas of Yugoslavia from Istria to Kotor were the first karstlands to be described in a scientific manner by European writers (Cvijic, 1893)'. In the **Chalk** of England karst features include ephemeral streams (winterbo(u)rnes) and streams that flow into cave systems (Mimms valley, Hertfordshire) as well as the features described above under dissolution. Past sea levels have largely controlled the pattern of past karstic horizons.

Late Cretaceous Epoch: the youngest epoch of the **Cretaceous Period**, which is followed by the Palaeogene Period. It comprises the Cenomanian, Turonian, Coniacian, Santonian Campanian and Maastrichtian ages

Litho-event bed: a body of sedimentary, extrusive igneous or **metamorphic** strata that is distinguished and delimited on the basis of lithological characteristics and stratigraphical position. Both the vulcanogenic and detrital **marl** seams in the Chalk are litho-event beds. Similarly, many of the sponge-beds, **hardgrounds** and marl–limestone couplets are litho-event beds.

Lithofacies: a unit of rock defined and recognized on the basis of lithological characteristics such as rock type, colour and composition.

Lithostratigraphy: a classification of sedimentary successions based on the rocks of which they are composed, and not on their included fossils. Such classifications involve a hierarchy of terms such as Supergroup, Group, Subgroup, Formation, Member, and Bed, in descending order of scale. A formation is the lowest category that can actually be mapped, although in practice it is sometimes possible to map members.

London-Anglian Platform (see **Anglo-Brabant Massif**)

Lower Chalk: formerly the lowest division of the **Chalk** in England. Now divided into two mapping units in southern England, the West Melbury Marly Chalk and Zig Zag Chalk formations. In the Northern Province, where the succession is thinner, only one unit, the Ferriby Chalk Formation is recognized.

Listric: listric (also 'lystric') surfaces are the planes of thrust fractures in rocks that curve into more vertical **faults**.

Macrofossil: macrofossils in the **Chalk** range in size from shells around 2 mm to large **ammonites** that can be 3 m in diameter (e.g. the very large *Parapuzosia* found in the Zig Zag Chalk Formation, the Plenus Marls Member of the Holywell Nodular Chalk Formation and, commonly, in the Newhaven Chalk Formation and the Margate Chalk Member). The most important groups of macrofossils for identification of the stratigraphical level of the Chalk in field sections and in borehole cores are the **inoceramid bivalves** that are common throughout the Chalk; the ammonites, common in the Grey Chalk Subgroup; **echinoids** such as *Holaster*, *Sternotaxis*, *Micraster*, *Echinocorys*, *Conulus* and *Offaster*, common in the White Chalk Subgroup; and the belemnites, common in the higher part of the Chalk Group.

Magnetochron: a period of time defined by the remnant magnetic polarity and distinguished from adjacent magnetochrons that have different magnetic polarities.

Magnetostratigraphy: **stratigraphy** based on the **palaeomagnetic reversals** recorded in the 'fossil' remnant magnetism in rocks.

Major tectonic line: a line in the Earth's crust distinguished by the presence of a structural feature, such as a **fault**, fold or fold belt. Such faults or fold belts are not local features and usually extend hundreds of kilometres, as opposed to local features, which may be on a metre or kilometre scale.

Marker horizon: a conspicuous bed of rock such as a **flint** band or **marl** seam, or a level with an abundance of a particular species of fossil. Other marker horizons include **palaeomagnetic reversals**, volcanic ash-falls or geochemical 'spikes'.

Marl: calcareous mudstone.

Melbourn Rock: a unit of rock comprising a number of layers of hard chalkstone marking the base of the old 'Middle Chalk' in south Cambridgeshire (Melbourn), north Hertfordshire and the Chiltern Hills (Penning and Jukes-Browne, 1881). In some areas, such as Dover, the term 'Melbourn Rock' has been mistakenly applied to all the chalk with abundant shell-debris of the fossil **bivalve** ***Mytiloides***. The Melbourn Rock of the type area underlies the main shell-rich chalks of the Holywell Nodular Chalk Formation.

Metamorphic rocks: rocks that have undergone changes in the solid state by heat and/or pressure but without melting.

Microfossils: the remains of microscopic animals and plants whose study requires the use of a microscope. The main groups of microfossils in chalk include the **foraminifera**, ostracods, dinoflagellates, sponge spicules, bryozoa and some radiolaria. Foraminifera in particular are used to zone the **Chalk** and interpret environments. Even smaller microfossils include the **nannofossils**.

Microfossil biostratigraphy: **stratigraphy** based on **microfossils**.

Milankovitch Cycles: named after the Serbian mathematician Milutin Milankovitch, who studied at Vienna in the 1920s under Alfred Wegner. Milankovitch Cycles refer to climatic changes brought about by shifts in the Earth's orbit around the Sun and the resultant changes in solar radiation reaching the Earth (Milankovitch, 1941). Within the Milankovitch waveband there are three primary cycles; (1) shifts in the Earth's orbit around the Sun from more circular to more elliptical over a period of 100 000–400 000 years (the *eccentricity* cycle); (2) variation in the tilt of the Earth's axis on a 41 000-year cycle (the *obliquity* cycle) and (3) the wobble or precession of the Earth's axis on a 19 000–23 000-year cycle (the *precession* cycle). Despite being called 'Milankovitch Cycles' these potential controls on the Earth's climate were first recognized by the Scottish Geologist James Croll (Croll, 1875), and applied to cyclically bedded **Cretaceous** sediments in the Western Interior of the USA by G.K. Gilbert (Gilbert, 1895).

Millet-seed sands: sand composed of quartz grains of millet-seed size and roundness. A term used by Bailey (1924) to describe some of the sand grains in the Scottish **Upper Cretaceous** deposits of the Inner Hebrides.

Montmorillonite: see **clay minerals**.

Mundford Grades: an engineering classification developed for the weathered and fractured state of chalk at Mundford, near Thetford, Norfolk, in the site investigation for the foundations of a large proton accelerator (Ward *et al*., 1968). Mundford Grades have subsequently been used for the engineering classification of chalk throughout the UK. During the 1990s a new classification system has been developed, the CIRIA Grades (Lord *et al*., 2001) and these are now used in place of Mundford Grades.

Mytiloides (Inoceramus) labiatus sensu lato: *Inoceramus labiatus*, an **inoceramid bivalve**, was formerly used in a very broadly defined sense as the **index fossil** for the **assemblage zone** corresponding to the Holywell Nodular Chalk Formation (i.e. topmost Upper Cenomanian and Lower Turonian substages). However, the species *M. labiatus sensu stricto* occurs in only a very small interval in the Lower Turonian part of this formation (see **Turonian Stage**).

Nannofossils: see **calcareous nannofossils**.

Nautiloid: an almost-extinct group of **cephalopods** with straight or coiled chambered conical shells.

Nodular chalk: hard lumpy layers of chalk about 200–300 mm thick, frequently red-orange iron-stained. Individual nodules of high-density chalk are often separated by soft, low-density, grey chalks that are late-stage burrow-fills, their high porosity preserved by the skeletal framework of interconnecting nodules. Such nodular beds and **hardgrounds** are defined and illustrated by Bromley (1975b), who has demonstrated the change in seabed ecology from soft sediment burrowing to hard sediment boring as the cementation progresses. Kennedy and Garrison (1975) illustrated the sequence from weak nodular beds to the development of **hardgrounds**.

Nodular flint: a form of **flint** comprising nodules with spines or horns and an irregular shape. Nodules range widely in size from a few millimetres thick to more than 300 mm thick and metres wide, and frequently form in bands of dispersed nodules. These flints have been variously referred to as 'burrow-fill' or 'nodular horn-flints'.

Ocean floors: strictly those marine environments underlain by *oceanic crust* in a geotectonic (**Plate Tectonic**) sense. Sea floors are underlain by continental crust.

Oceanic anoxic events: periods of time when the oxygen minimum zone of the ocean floors is thought to have risen on to shelf regions leading to the formation of black shales on shelves as well as ocean basins. Three such events are recognised in the **Late Cretaceous Epoch** (see Jenkyns, 1980).

Oxic: oxygen-rich environments (for the purposes of this book this means oxygen-rich sea-floor environments).

Palaeogeography: reconstruction of the past geographies of the Earth in both physical and biological terms. The past distribution of oceans, seas, land, climate and ecosystems.

Palaeomagnetic reversals: a reversal of the Earth's magnetic field results in the north magnetic pole becoming the south magnetic pole. The present magnetic arrangement is termed normal (N) in contrast to the reversed situation (R). Magnetic reversals have occurred regularly throughout the Earth's history and are thought to take place over very short time intervals (days/weeks/years) and are, therefore, geologically instantaneous events providing unique marker horizons.

Paramoudra Flint: a special type of **flint** that forms cylindrically around the trace fossil ***Bathichnus paramoudrae*** (Bromley *et al.*, 1975a). Paramoudra flints are generally very large (can be more than 2 m in diameter and several metres high). The flint is usually very compact and hard. The highest uniaxial compressive strengths have been obtained from such flints (around 800–1000 MPa). Paramoudra flints occur at specific stratigraphical horizons and are a feature of Bedwell's Columnar Flint in southern England, the Warren Farm Paramoudra Flints in the Spetisbury Chalk Member of the Culver Chalk Formation and, particularly, in the 'Paramoudra Chalk' of Norfolk and Northern Ireland.

Penecontemporaneous: a geological event such as **faulting**, folding, uplift, channel erosion or **diagenesis** that occurs broadly within the rock-forming period. For example, the uplift and resultant sliding and slump folding of the Chalk at Downend Chalk Pit, Portsdown, in the Culver Chalk Formation, occurred before the highest beds of the Culver Chalk formed but after the earlier chalks had partially consolidated.

Periglacial: literally *in front of* a glacier or ice-sheet. The region of tundra conditions where the tree-line stops but where no permanent ice sheet or glacier is present. Frozen ground is common. Periglacial weathering features including patterned ground, ice-wedges, intense fracturing are a feature of the chalk in England and relate to the past cold-periods of the Quaternary Period.

Period: a major division of geological time, of shorter duration than an **era** and itself divisible into **epochs.**

Plankton: generally small organisms that drift in water bodies and have limited powers of locomotion.

Plate Tectonics: the theory that the Earth's lithosphere (Earth's crust and upper mantle) is divided up into a series of rigid 'plates' that move relative to each other (a few centimetres per year). Over geological time the continents carried by the 'plates' can 'drift apart' or 'collide' and oceans can 'grow' and 'close' as a result. Relative movement between the plates leads to earthquake and **tectonic** activity, which is most concentrated at boundary zones between plates.

Plenus Marls: a division of the **Chalk**; the basal member of the Holywell Nodular Chalk Formation and the base of the White Chalk Subgroup. Named after the occurrence of the belemnite *Praeactinocamax plenus* in the higher four of the eight beds into which the member is divided.

Rudist bivalve: type of extinct aberrant reef-building **bivalve**, particularly characteristic of the shallow, warm water environments of the Tethyan Realm (cf. **Boreal Realm**). Rudists are rare in the **Upper Cretaceous** rocks of the UK since these were deposited in a much higher palaeolatitude, where relatively cooler and much deeper water conditions prevailed.

Seabed: floor of a sea on which sedimentary processes are acting. Strictly a sea not underlain by oceanic crust (see **ocean floors**).

Sequence boundaries/stratigraphy: **unconformity** or **disconformity** bounded sequences of strata.

Sea-level curves: curves of relative sea-level change through geological time. These may be global curves or more local curves for particular basins and regions.

Sheet-flints: distinguished from **tabular flints** by being located on both sub-horizontal and sub-vertical fracture planes. Hence these are not strictly in place stratigraphically but may be confined broadly to a stratigraphical unit. Sheet-flints are thin (4–200 mm thick) sheets of flint, often forming two planes separated by a chalky interior. Clayton (1986) illustrated the early formation of sheet-flints and the processes that form them.

Silcrete: a silicified palaeosol ('fossil soil').

SSSI: Site of Special Scientific Interest; the designation of an area of land for statutory protection under the provisions of the *Wildlife and Countryside Act 1981*.

Stable isotope curves: curves derived from determination of the differing proportions of two of the stable isotopes of carbon, (^{12}C and ^{13}C) and two of the stable isotopes of oxygen (^{18}O and ^{16}O) in **carbonate** sediments (see Jenkyns *et al*., 1994, Mitchell *et al*., 1996, 1997). These determinations (referred to as $\delta^{13}C$ and $\delta^{18}O$ values respectively) may be based on analysis of the rock (so-called 'bulk-rock analysis') or of specific bioclastic components of the rock such as **macrofossils** and/or **microfossils** and **nannofossils**. In the most refined determinations, separate analyses are made of macrofossils, and separations of **benthic foraminifera**, **planktonic** foraminifera and **coccoliths** (e.g. Jeans *et al*, 1991). Seawater palaeotemperatures can be calculated from $\delta^{18}O$ values. $\delta^{13}C$ curves are of great value in long-range correlation, particularly where no fossils are present. In addition they can be used to infer sudden changes in oceanographic parameters relating to transgressions. Stable isotope curves are a key element in the establishment and testing of integrated stratigraphical frameworks.

Stages: internationally agreed divisions of the geological series (see **chronostratigraphy**) into smaller units of time based largely on fossil assemblages. The **Upper Cretaceous** series is divided into six stages. During the 1980s, international working groups were organised to review the palaeontology, definition and subdivision of each **Cretaceous** stage (Birkelund *et al*., 1984; Rawson *et al*., 1996). These two publications are the primary source of information relating to stages, stage boundary definitions and stage subdivisions of the Cretaceous **System**. Updated details relating to the application of stage boundaries in the Upper Cretaceous rocks of the UK are given in the Appendix of this book. Two sites in England, Southerham Grey Pit, Lewes, Sussex and Seaford Head, Sussex, have been nominated as candidate global basal boundary **stratotypes** and points (GSSPs) for the base of the Middle Cenomanian Substage; and for the bases of the Santonian and Campanian Stages respectively.

Sternotaxis [Holaster] plana: a fossil **echinoid** that characterizes the interval of chalk from just above the Glynde Marls to the Lewes Marl in the lower Lewes Nodular Chalk Formation. *Sternotaxis plana* was the **index fossil** of one of the traditional **assemblage zones** of the **Chalk** in England and France (see Owen and Smith, 1987; and British Museum (Natural History), 1962; also **Turonian Stage**, Appendix).

Stratigraphy: the study of the order of succession or relative position of strata (layers of rock) and the global correlation of rocks and geological events. Stratigraphy is divided broadly into lithostratigraphy, biostratigraphy, chronostratigraphy and more recently magnetostratigraphy, sequence stratigraphy, cyclostratigraphy and chemostratigraphy. Each of these topics is covered excellently by Doyle and Bennett (1998).

Stratotype: an exposure where a specific part of the stratigraphical succession is defined and acknowledged in a publication and/or by national or international agreement.

Strike: the compass direction perpendicular to the **dip** direction.

Subhercynian tectonic phases: highly misleading term introduced by Stille (1924) referring to a succession of Late **Cretaceous** phases of deformation (uplift and rotation) of the Cretaceous rocks in the area to the north of the then uplifting Harz Mountains massif in Germany – hence the name. Must be clearly distinguished from Hercynian (i.e. later Palaeozoic) structural deformation, which takes its name from the same massif. The subhercynian tectonic phases were compressive orogenic (mountain building) pulses that were initiated during the later Late Cretaceous as a result of the progressive collision of elements of the North African plate with the European platform in the initial phases of the Alpine mountain building period. The subhercynian phases of uplift and deformation are the Ilsede, Wernigerode and Peine phases, to which may be added the latest **Late Cretaceous** Laramide phase, which was first described from North America. For further details see Mortimore *et al*.

(1998); Mortimore and Pomerol (1998).

Sub-Plenus erosion surface: erosion surface beneath the Plenus Marls Member of the Holywell Nodular Chalk Formation at the base of the White Chalk Subgroup.

Subzone: a subdivision of a **biozone** used in **biostratigraphy**.

Synsedimentary: a geological event that occurs at the time of sedimentation.

System: a **chronostratigraphical** unit comprising all the rocks formed during a geological **period**, e.g. the Jurassic System comprises all the rocks of the Jurassic **Period**.

Tabular flints: stratigraphically consistent, continuous tabular masses of flint from 5–30 mm thick. The most significant tabular flints in the English Chalk occur in the Northern Province (Lincolnshire and Yorkshire Wolds) at the boundary between the Welton Chalk and Burnham Chalk Formations (Wood and Smith, 1978).

Taxon (pl. taxa): a classification unit of organisms based on physical similarities or surmised evolutionary relationships.

Tectonism (adj. tectonic): the processes of crustal deformation (e.g. folding and **faulting**) often associated with **Plate Tectonics** and mountain building.

Terebratulina lata: a diminutive fossil **brachiopod** (lamp-shell) that characterizes part of the Turonian (see **Turonian Stage** in Appendix, this volume). *T. lata* is the **index fossil** of one of the traditional **assemblage zones** of the **Chalk**.

Thalassinoid flint/horn flint: **flint** reflecting the silicified sedimentary fill of a burrow of *Thalassinoides* type. Such flints are described as burrow-fill or burrow-form flints. Where there is incomplete silicification of the burrow fill, the flint takes on an irregular shape reminiscent of a horn or part of an antler.

Totternhoe Stone: a coarse, calcarenitic chalk resting on an erosion surface in the '**Lower Chalk**' of the Chiltern Hills at the boundary between the West Melbury Marly Chalk and the Zig Zag Chalk formations. The Stone was originally quarried as a building freestone. The Totternhoe Stone was first described by Whitaker (1865b).

Trace fossils: many animals, some of unknown origin, lived on and in the chalk sediment forming the Late **Cretaceous** sea floor. These animals left behind the crawling, burrowing, boring or feeding traces of their existence, now fossilized in rock (hence *trace fossils*). The shapes and sizes of the traces, such as branching, vertical pipes, spiral or U-shaped are classified and given names including *Thalassinoides*, *Chondrites*, *Skolithos*, *Bathichnus*, *Zoophycos*. These names do not indicate the animal that created the trace. For example large (20–30 mm diameter) branching traces (*Thalassinoides*), are thought to have been produced by callianassid shrimps such as the present-day *Callianassa say* or *Callianassa major* (Bromley, 1967). In contrast, the small branching traces of *Chondrites* are of unknown origin. The trace fossils of the Chalk are illustrated by Bromley (1975a); Bromley and Ekdale (1984a,b); Ekdale and Bromley, (1984) and Bromley (1990, 1996). Burrowing activity was a prime control on **diagenesis** (e.g. dewatering, redox shifts) leading to the development of nodular chalks and **hardgrounds** and to the formation of flint. The suite of trace fossils in a chalk sample greatly influences its porosity and permeability. Variation in physical properties, such as density and porosity in a laboratory sample, are in part a reflection of the original trace fossil fabric of the chalk.

Transgression: the landward migration of shorelines. This may result from a rise in sea level, an increase in crustal subsidence or reduction in sediment input to a shelf area.

Tubular flints: characteristically slender (20–30 mm diameter) cylindrical, branching **flints** that can extend continuously through more than 3 m of chalk. The tube is formed by an outer annulus of flint separated from an inner flint core by a chalky layer. Frequently the inner-core is missing, forming a tube. There are several horizons of tubular flints that are stratigraphically continuous over vast distances. These include the Lewes Tubular Flints, Shoreham Tubular Flints, Old Nore Tubular Flints and Isle of Wight Tubular Flints (see Mortimore, 1986a; Mortimore and Pomerol, 1991b).

Type locality: a place or area containing the **stratotype** section. This can apply to both **lithostratigraphy** and **biostratigraphy**. For example, Holywell, Eastbourne, is the stratotype section for the Holywell Nodular Chalk Formation. (See also **stratotype** and **GSSP**).

Also refers to the locality from which a particular fossil species was first named and described.

Unconformity: a break in the relationship between successive strata resulting from a lack of deposition during an intervening phase of **tectonism** and erosion; the unrepresented time interval may be substantial and there is often an angular discordance in the layers either side of the unconformity surface.

Upper Cretaceous: the upper series of the **Cretaceous** Period from the base of the Cenomanian Stage to the base of the Palaeocene (base of Danian Stage) spanning the time interval from 98.5–65.4 million years ago (see Table 1.2, this volume). In ascending order, the upper Cretaceous is divided into the Cenomanian, Turonian, Coniacian, Santonian, Campanian and Maastrichtian stages (see Appendix, this volume).

Variscan structures: term referring to structural elements initiated during the Variscan Orogeny (mountain building period); commonly described as 'Hercynian' because they relate to the orientation of the Harz Mountains massif of Palaeozoic rocks in Germany. Hercynian structures must be clearly differentiated from **subhercynian** structures.

Zone: a subdivision of a **Stage** based on the occurrence of a defining fossil (*index fossil*) or an assemblage of fossils, for example, the occurrence of the free-swimming fossil **crinoid** (sea lily) *Marsupites testudinarius* in a given interval of the Chalk on the Sussex coast defines that zone in those cliffs. The same fossil may occur in another type of rock elsewhere in the world. A zone is, therefore, independent of rock type and is a **biostratigraphical** concept. Other zones are defined by the entry of a particular fossil **taxon**, which may range beyond the interval of the zone.

Zoophycos Flints: flints formed around the spiralling trace fossil *Zoophycos* (see Bromley and Ekdale, 1984a). There are several conspicuous horizons of *Zoophycos* flints in the **Chalk** including the Cuilfail Zoophycos, Beachy Head Zoophycos and the Tavern Flints (Mortimore, 1986a; Mortimore and Pomerol, 1991b).

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Note: Page numbers in **bold** and *italic* type refer to **tables** and *figures* respectively

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