Overstrand to Trimingham Cliffs, Norfolk

[TG 228 420]–[TG 306 375]

Introduction

The Overstrand to Trimingham Cliffs GCR site (Figure 4.27) and (Figure 4.28) comprises three components:

1. foreshore exposures of in-situ Chalk west of Overstrand;
2. cliff and foreshore exposures of glacio-tectonic masses of Chalk between Overstrand and Sidestrand (Figure 4.29),(Figure 4.30), (Figure 4.31), (Figure 4.32), (Figure 4.33);
3. cliff and foreshore exposures of glacio-tectonic masses of Chalk between Trimingham and Mundesley (Figure 4.34), (Figure 4.36).

To facilitate description, each of these components is treated as a separate locality, followed by an overall interpretative discussion of the entire composite succession. The exposures are continually changing over time as a result of marine erosion of the cliffs and foreshore. Historically, a continuous chalk platform was visible in the foreshore between Sidestrand and Trimingham (Taylor, 1824) but there is no evidence of this at present.

The Cretaceous Chalk masses within the Overstrand to Trimingham Cliffs are spectacularly rafted exotic blocks enclosed in Quaternary glacial tills and outwash deposits. Tertiary Crag and Quaternary lacustrine sands, silts and peats and outwash gravels are also present. The various glacio-tectonic masses of Chalk, commonly with a capping of Crag, provide a composite section through the highest Upper Campanian succession, and the lower part of the richly fossiliferous Lower Maastrichtian Chalk. High Upper Campanian Chalk is exposed *in situ* in intermittent foreshore exposures, from the western margin of the site as far east as Overstrand, beyond which point the easterly regional dip takes the Chalk below beach level. Most of the glacio-tectonic masses expose Lower Maastrichtian Chalk, although terminal Campanian Chalk is additionally found at the base of some of the Overstrand masses. In general, successively higher beds are incorporated in the masses from west to east. The highest preserved Chalk preserved onshore in the UK, the so-called 'Trim(m)ingham Chalk' of the early workers, is seen in cliff sections and intermittently exposed foreshore sections through masses near Trimingham and Mundesley.

Description

(1) Foreshore exposures of in-situ Chalk west of Overstrand

The so-called 'Thorpe Mass' [TG 230 420] consists of a reef composed of flints and blocks of highly fossiliferous Chalk, which is exposed at low tide seaward of the Cromer Lighthouse. It is presumed that in-situ Chalk is present immediately beneath the beach at this point. Loose echinoids (*Micraster* aff. *grimmensis* Nietsch, *M. ciplyensis* Schlüter and thick-tested *Echinocorys*) filled with hard chalk are common. The reef takes its name from the occurrence of a distinctive assemblage of echinoids associated with hard chalk that was formerly found in the Thorpe Asylum Pit east of Norwich (Peake and Hancock, 1970, pp. 339F–G; Wood, 1988). The association of hardgrounds and rich echinoid faunas at the latter locality characterizes the higher part of the Paramoudra Chalk (Paramoudra Chalk$_2$ of Wood, 1988).

To the east of the 'Thorpe Mass' there are no more foreshore exposures of Chalk until a point *c.* 150 m west of Overstrand [TG 242 414].

There, at low tide, an intermittent foreshore accumulation can be seen of blocks of indurated chalk containing belemnites and large, closely packed echinoids (*Echinocorys pyramidata* Portlock). This hard chalk is informally known as the 'Pyramidata Hardground' and is generally presumed to represent the highest in-situ Chalk exposed on the Norfolk coast (Peake and Hancock, 1970, p. 339G).

(2) Cliff and foreshore exposures of glacio-tectonic masses of Chalk between Overstrand and Sidestrand

2a: Overstrand

Brydone (1906) stated that ten Chalk masses were formerly visible at the foot of the cliffs over a length of nearly half a mile at Overstrand. All but one of these rested on a bed of till. These sections were first discussed by Brydone (1908, 1938), who drew attention to the common occurrence in them, and in blocks of chalk on the beach at Overstrand, of the crinoid *Austinocrinus bicoronatus* (Hagenow), which linked his 'Overstrand Chalk' stratigraphically with the '*Torosphaera* Beds' at the base of the Trimingham succession.

The easternmost of these masses, the so-called 'Overstrand Hotel Lower Mass' (Wood, 1967; Mass 1 of this account), can still be seen in the cliffs [TG 253 408] below the site of the former Overstrand Hotel (Figure 4.29) and (Figure 4.30) from which it took its name. It exposes flinty chalk with several well-developed marl seams: in ascending order, the Overstrand Lower Marl, the Overstrand Upper Marl and the Sidestrand Marl, all of which are new names herein. An additional marl seam could formerly be seen at a lower horizon, but this is now buried. The Sidestrand Marl is named after the marl seam at the base of the Sidestrand Western Mass (see below; and (Figure 4.31), (Figure 4.32), (Figure 4.33)). The succession above the Sidestrand Marl includes a conspicuous paramoudra flint, above which there is a distinctive semi-tabular flint.

Above and slightly to the west of Mass 1, a highly fossiliferous 3 m section, termed by Wood (1967) the 'Overstrand Hotel Upper Mass', was formerly exposed at the extreme eastern end of an elongate Chalk mass (Mass 2). This key section has now slipped away and has broken up. However, the exposure of Mass 2, of which it formed a part, is better exposed than hitherto. The higher unit of the 'Lower Mass' (Mass 1), with its paramoudra flint horizon and basal Sidestrand Marl, is demonstrably an integral part of Mass 2, from which it has become detached. Some 2 m of beds are visible below the Sidestrand Marl in Mass 2, but the downward continuation is obscured by talus.

Farther to the east, adjacent to the construction road leading down to the sea defences, Mass 3 has the Sidestrand Marl at its base and exposes beds above the marl (Figure 4.29). Mass 4, on the seaward side of the construction road, exposes a Chalk succession partly truncated on the eastern side by a channel filled by flint cobbles with shell debris at the base. The succession in this mass includes a marl seam (inferred to be the Sidestrand Marl) which shows evidence of intra-Chalk folding.

(Figure 4.32) and (Figure 4.33) show logs of the Overstrand Mass 1 and the Sidestrand Western Mass.

Lithostratigraphy

Wood (1967) split off the Overstrand Campanian–Maastrichtian succession as the *pre-Porosphaera* Beds, on the (faunal) basis of the co-occurrence in the Overstrand Hotel Upper Mass (Mass 2) of the belemnite genera *Belemnella* and *Belemnitella,* which had not been recorded from the *Porosphaera* Beds of the Sidestrand masses. Johansen and Surlyk (1990), placed the entire succession in the glacio-tectonic slices that lay stratigraphically beneath their Trimingham Sponge Beds Member (i.e. Wood's Pre *Porosphaera* Beds + *Porosphaera* Beds), irrespective of whether or not it included Upper Campanian strata, into a formally defined Sidestrand Chalk Member, with its base taken at the Pyramidata Hardground. Accordingly, the Overstrand composite succession is included in this member.

Biostratigraphy

The composite succession includes the basal boundary of the Maastrichtian Stage and, on belemnite evidence alone, falls partly in the *Belemnitella minor* II Zone (which crosses the Campanian–Maastrichtian boundary (see Christensen, 1997), and partly in the basal Maastrichtian restricted *Belemnella lanceolata* Zone of the standard European belemnite scheme ((Figure 2.13), Chapter 2). However, the identification of this boundary is unclear at present.

The Overstrand masses are very fossiliferous, yielding predominantly rhynchonellid and terebratulid brachiopods, large thick-tested echinoids (*Echinocorys* cf. *belgica* Lambert), the crinoid *Austinocrinus bicoronatus* and belemnites. There is a significant change in the belemnite assemblage in the highest part of the composite Overstrand succession above the Sidestrand Marl. Small *Belemnitella* sp. alone are found up to the semi-tabular flint above the paramoudra flint horizon near the top (Figure 4.32), at which level appears a mixed fauna of the long-ranging genus *Belemnitella* and the diagnostic Maastrichtian genus *Belemnella,* including *B. lanceolata* (Schlotheim). The *Belemnella* from the Overstrand masses were later assigned to the basal Lower Maastrichtian restricted *Belemnella lanceolata* Zone of the standard scheme (Schulz, 1982; Christensen, 1997). On this basis, at least the highest beds of the Overstrand succession belong in the Lower Maastrichtian Substage.

The boundary between the low, but not basal, Lower Maastrichtian *Rugia acutirostris–R. spinosa* Zone and the overlying *R. spinosa–Trigonosemus pulchellus* microbrachiopod Zone was reported to fall in the middle of the Overstrand Hotel Upper Mass (Johansen and Surlyk, 1990). From the stratigraphical interpretations presented here, this boundary must lie in the highest part of the composite Overstrand succession, i.e. in the unit above the Sidestrand Marl, and approximately at the level of the mixed belemnite assemblage.

The reported entry (Swiecicki, 1980) of the benthic foraminifer *Bolivinoides peterssoni* Brotzen just below the Overstrand Lower Marl marks the base of the UKB20 benthic foraminiferal Zone (Hart *et al.,* 1989) (see (Figure 1.5), Chapter 1). Swiecicki (1980) noted a fundamental change in the microfauna at the Overstrand Upper Marl. The foraminiferal assemblage below the marl was characterized by the occurrence (and upper limit) of the benthic taxa *Gavelinella monterelensis* (Marie), *Globorotalites hiltermanni* Kaever and *Reussella szajnochae szajnochae* (Grzybowski) ((Figure 2.44), Chapter 2), the last occurring in increasing abundance up to a flood occurrence below the marl. For practical purposes, the *Reussella s. szajnochae* bio-event that is associated with the extinction of *Globorotalites hiltermanni* is taken as a marker in the offshore successions for the Campanian–Maastrichtian boundary (Bailey *et al.,* 1983; Hart *et al.,* 1989). Immediately above the Overstrand Upper Marl, *Bolivina incrassata* Reuss is present in flood abundance; *Neoflabellina reticulata* (Reuss) enters higher, above the Sidestrand Marl, overlapping with the top of the range of the long-ranging *N. praereticulata* Hiltermann.

Interpretation

The 'Overstrand Hotel Lower Mass' (Mass 1) has been considered by some workers (e.g. Peake and Hancock, 1961) to be composite, comprising several stacked thrust-slices, each repeating the same succession and separated by marl-filled thrust-planes containing Quaternary fossils. The highest of these supposed thrust-slices has been inferred to comprise the repeated succession overlain by higher beds. However, better exposure of the higher part of the mass has revealed that three of the supposed thrust-planes have the internal structure of primary marl seams and that the 'thrust-slices' are part of a normal Chalk succession, albeit one containing several well-developed marl seams.

It is noteworthy that the Campanian–Maastrichtian boundary interval of the Overstrand masses is characterized by flinty chalk with well-developed marl seams, since no marl seams are known from the remainder of the (exposed) Upper Campanian succession of Norfolk. Thin marl seams are present in the Trimingham Sponge Beds Member, higher in the Lower Maastrichtian Substage, but these are associated with a condensed succession comprising closely spaced hardgrounds. It is also interesting that the large paramoudra flints that characterize the (Upper Campanian) Paramoudra Beds Member continue into Maastrichtian beds in the lower part of the Sidestrand Chalk Member.

Since the Campanian–Maastrichtian boundary falls somewhere within the Overstrand composite succession, it follows that the so-called 'Pyramidata Hardground', at the base of the Sidestrand Chalk Member, lies in the higher part of the Upper Campanian Substage rather than at the base of the Maastrichtian Stage. It is possible that this hardground marks the top of the in-situ Chalk and that it may have served as a plane of decollement for the successions in the glacio-tectonic masses to the east. However, there was no evidence of a hardground at this level in the British Geological Survey Trunch Borehole.

The belemnites in the composite Overstrand succession do not enable definite identification of the Campanian–Maastrichtian boundary. The diagnostic Maastrichtian genus *Belemnella* is already relatively common where it appears in the mixed *Belemnitella/Belemnella* assemblage. In view of the extreme rarity of *Belemnella* in the basal beds of the boreal standard basal boundary succession at Kronsmoor in northern Germany (Schulz, 1982), the mixed

Overstrand assemblage is likely to be some distance above the base of the stage. This interpretation is supported by the microbrachiopod data, which place the horizon with the mixed belemnite assemblage within the Lower Maastrichtian Substage and not at the base. Unfortunately, due to the relative inaccessibility of this part of the succession, only limited belemnite collections have been made from the (Maastrichtian) interval between the Sidestrand Marl and the level with the mixed assemblage and it is impossible to know whether or not *Belemnella* is present. The evidence from foraminifera was, until recently, thought to support a lower level for the base of the Maastrichtian Stage. New evidence on the entry of the basal Maastrichtian index ammonite, *Pachydiscus newbergicus,* suggests that this boundary may be significantly higher, well above the entry of *Belemnella.*

2b: Sidestrand

Three complex glacio-tectonic masses, collectively known as the 'Sidestrand masses', and termed, from west to east, the 'Sidestrand Western Mass', 'Central Mass' and 'Eastern Mass', respectively (Peake and Hancock, 1961), were progressively revealed by erosion of the cliffs at Sidestrand (Figure 4.31). The succession in these masses terminates in the lower part of the Trimingham Sponge Beds Member and extends lower in the Porosphaera Beds (Sidestrand Chalk Member) than the lowest beds in the foreshore masses at Trimingham. Of these masses, only the composite Western Mass (Figure 4.33) is still well exposed (Figure 4.31); the Central Mass has now completely disappeared and the Eastern Mass has now been eroded right down to beach level, where it is represented only by intermittent foreshore exposures at low water. Contrary to the statement in Peake and Hancock (1961), the Chalk masses at Sidestrand rest directly on, and are enclosed by, Quaternary deposits.

The Sidestrand masses can be correlated directly with the Overstrand masses by means of the Sidestrand Marl, which is situated just above the base of the western of the two component masses of the Western Mass (Figure 4.33). As in the Overstrand masses, the chalk above the Sidestrand Marl contains large paramoudra flints ((Figure 1.14)a, Chapter 1). The immediately overlying succession overlaps with the top of the composite Overstrand succession but it is difficult to correlate on a bed-by-bed basis. However, the broad correlation, which involves the recognition of a more or less flintless interval, is indisputable.

Biostratigraphy

The *Porosphaera* Beds have been assigned to the *Belemnella pseudobtusa* Zone and the overlying *B. obtusa* Zone, with the latter extending up to the top of the Trimingham Sponge Beds (Schulz, 1982). In view of the correlation between the top of the Overstrand composite succession and the base of the Sidestrand succession, the level in the restricted *B. lanceolata* Zone with the mixed *Belemnitella/Belemnella* fauna must be present at Sidestrand, even though it has not yet been identified.

The entry of the benthic foraminifer *Bolivinoides paleocenicus* (Brotzen) at the top of the Sidestrand Chalk Member (i.e. *Porosphaera* Beds), immediately beneath the Trimingham Sponge Beds Member, marks the base of the *B. paleocenicus* benthic foraminiferal Zone (UKB21, (Figure 1.5), Chapter 1). Another benthic species *Angulogavelinella bettenstaedti* Holker enters at the same level, and ranges up into the middle of the Sponge Beds, where it occurs in flood abundance before its upper limit. The *A. bettenstaedti* flood is an important bio-event in the Rowe Formation of the offshore succession, located a short distance above the *Reussella szajnochae szajnochae* acme (Lott and Knox, 1994).

The *Porosphaera* Beds are very fossiliferous and, in addition to common belemnites, they are particularly characterized by large simple corals (*Desmophyllum* sp.), the large rhynchonellid brachiopod *Cretirhynchia magna* Pettitt (a *Cyclotbyris?*) and the smaller *Cretirhynchia retracta* (Roemer), together with very large, thick-tested *Echinocorys* ex gr. *belgica* Lambert and small *Galerites* sp.. Brydone's idea that this unit contains particularly abundant specimens of the small spherical calcisponge *Porosphaera,* is difficult to understand.

The overlying Trimingham Sponge Beds Member is poorly exposed today, but in previous years extensive bed-by-bed collections made by the British Geological Survey from the basal beds forming the relict Sidestrand Eastern Mass included large *Belemnella obtusa* and large *Galerites* sp.. The member takes its name from the numerous hexactinellid sponges with the skeletal meshwork picked out in pyrite that are found preserved in the harder beds. As in the case of the Catton Sponge Bed at Catton Grove Chalk Pit, the most indurated beds (the chalkstones beneath the hardgrounds) contain moulds of originally aragonite-shelled bivalves and gastropods, comparable with the so-called '*reussianum* fauna' of the Upper Turonian Chalk Rock (e.g. Fognam. Quarry and Kensworth Chalk Pit GCR sites). Unfortunately no determinable ammonites have been collected from this level.

(3) Cliff and foreshore exposures of glacio-tectonic masses of Chalk between Trimingham and Mundesley

In the 19th century (cf. Lyell, 1833, 1852), and in the early years of the 20th century, there were extensive exposures through three, structurally complex, glacio-tectonic masses in the cliffs and foreshore at Trim(m)ingham (Figure 4.27). Some of these masses at the time stood high above beach level, but they became progressively eroded by the action of the sea. There are numerous sketches and photographs in the literature recording the erosion and eventual disappearance of these masses (Figure 4.35). The question of whether or not the masses represented in-situ, albeit glacially contorted, Chalk, glacially transported Chalk, or simply sea-stacks of in-situ Chalk, was the subject of considerable, often acrimonious, controversy, which filled the pages of the scientific journals at that time (see Peake and Hancock (1961) for a comprehensive review). From approximately west to east, the masses were known as the 'Western Mass', 'Central Mass' and 'Eastern Mass', these being subsequently termed by Brydone (1906), 'Mass C', 'Mass A' and 'Mass B', respectively. A rib of Chalk intermittently exposed on the foreshore, some distance to the east, was given the designation D. Today, only the cliff section at Marl Point, representing the termination of Mass A, can be seen, although foreshore exposures of Mass C can sometimes be observed at extreme low water under favourable tidal conditions when the wind is blowing offshore.

Although he produced no detailed logs, Brydone (1908) mapped the Trimingham exposures in great detail, tracing the succession from the cliff into the truncated foreshore exposures.

The accuracy of his work was confirmed by photographs (Figure 4.35) of fortuitous exposures following storms (Sainty, 1949, pl. 7). Although Brydone failed fully to appreciate the structural complexity of the individual masses, and the structural inter-relationships between them, he neverthelesss had far better exposures available to him than the poor remnants that exist today. Moreover, he had a clear understanding of the overall succession, and of the biostratigraphy. In his classic 1908 paper he subdivided the Trimingham succession into five partly lithostratigraphical, partly biostratigraphical units that, albeit renamed, remain in use today.

Lithostratigraphy

In ascending order, Brydone's units were the *Porosphaera* Beds; the Sponge Beds; the White Chalk without *Ostrea lunata;* the White Chalk with *Ostrea lunata;* and the Grey Beds. Brydone also used the term 'General beds' to group the entire post-Sponge Beds succession. The *Porosphaera* Beds took their name from the remarkable abundance in them of the small spherical calcisponge *Porosphaera globularis* (Phillips). The overlying Sponge Beds, constituting a succession of hardgrounds, were named after the conspicuous large sponges that they contained. The term 'White Chalk with *Ostrea lunata* [now *Agerostrea*]' referred to chalks containing the eponymous thin-shelled oyster ((Figure 2.28)a, Chapter 2), at some levels in rock-forming quantities. The Grey Beds were so designated after the overall smoky grey colour of the flints. At that time, only the highest *Porosphaera* Beds were exposed in the cores of the truncated anticlinal structures, but lower parts of the succession subsequently became exposed in the glacio-tectonic masses farther to the west at Sidestrand. Brydone's informal units were given formal lithostratigraphical member status by Johansen and Surlyk (1990). They named the *Porosphaera* Beds, together with the underlying succession in the Sidestrand masses, the 'Sidestrand Chalk Member'; the Sponge Beds, the Trimingham Sponge Beds Member'; the White Chalk with and without *Ostrea lunata,* the 'Little Marl Point Chalk Member'; and the Grey Beds, the 'Beacon Hill Grey Chalk Member', respectively (Figure 4.28).

The cliff section at Little Marl Point extends from the top of the Trimingham Sponge Beds to a level inferred to be near the top of the oyster-rich beds of the Little Marl Point Member (Figure 4.36). The section given by Peake and Hancock (1961, fig. 7) is essentially correct up to their flint C, but the higher part of the section contains additional flint bands not shown by them. A fortuitous foreshore exposure of the Beacon Hill Member in Mass C was logged and collected in considerable detail by Mr A.A. Morter (then of the British Geological Survey) in 1976. He also later prepared a skeletal log, without measurements, of the immediately underlying beds, but it is difficult to correlate the highest flints recorded by him with the highest flints seen in the bluff. It is, likewise, difficult to accept the Peake and Hancock interpretation of the correlation between the bluff and foreshore exposures. (Figure 4.36) is a composite section, in which the present authors, with the agreement of Mr Morter, attempt to link his unpublished logs with our log of the bluff. The top of Morter's Mass C section, which terminates against Quaternary till, can probably be inferred to represent the highest Chalk ever observed at Trimingham. These unpublished logs were used by Gale to produce a composite log for the entire Maastrichtian succession (Jenkyns *et al*., 1994, fig. 9).

The sediments of the Beacon Hill Grey Chalk Member are overall relatively coarse grained, and include one or more beds that are true bioclastic calcarenites. These represent the closest approach in the English succession (albeit in the Lower Maastrichtian Substage) to the tuffeau lithology that characterizes the (Upper) Maastrichtian strata in the type area.

Biostratigraphy

The palaeontological richness and diversity of the fossils in the Chalk at Trimingham caught the attention of amateur and professional geologists. Taylor (1824) was the first to appreciate the distinctness of the Trimingham Chalk, and its superposition on the Norwich Chalk. In the Cromer Memoir (Reid, 1882), it was stated that the Trimingham belemnites included, in addition to *Belemnitella mucronata,* forms referable to *Belemnitella lanceolata* Schlotheim, although the biostratigraphical significance of this perspicacious observation was not understood for almost another seventy years. In fact, it was clearly stated then (Reed, 1882, p. 5) that all the fossils listed were 'Upper Chalk forms; none characteristic of higher zones, such as the Maestricht Chalk, having at present been found'. Jukes-Browne and Hill (1904) also appreciated the distinct nature of the faunas of the Trimingham Chalk, and the superposition of that unit on the Chalk of Norwich. Brydone, in a series of key papers on the Trimingham Chalk (1900, 1906, 1908, 1938), drew attention to the fact that both the bryozoans and the serpulids pointed to a much higher stratigraphical level than the 'Norwich Chalk', and suggested a correlation with the Chalk of the island of Rügen in the Baltic region. This interpretation was also supported by the evidence from the asteroids.

Belemnites are very common in the Trimingham masses, and extensive, albeit only broadly horizoned, collections were made by Brydone. These collections, now housed in the British Geological Survey collection at Keyworth, were studied by Jeletzky, who realized (Jeletzky, 1951) that the Trimingham belemnites belonged, not to the Upper Campanian zonal index fossil *Belemnitella mucronata* (Schlotheim), as previously thought, but to the diagnostic Maastrichtian genus *Belemnella,* including forms related to the then standard European zonal index fossil *B. lanceolata.* He thereby broadly confirmed Brydone's own ideas (1900, 1906, 1908), regarding the similarity between the (Lower Maastrichtian) Rügen and Trimingham faunas. He later plotted (Jeletzky, 1958, fig. 8) the inferred range of the Trimingham succession in terms of a much more refined European belemnite biostratigraphy, demonstrating that it belonged in the Lower Maastrichtian Substage, and pointing out that the basal beds of the Maastrichtian Stage were missing. He additionally noted that the genus *Belemnitella* was extremely rare, constituting about 2% of the total examined, with half the records coming from the lowermost *Porosphaera* Beds. He also observed that the *Belemnella* assemblages from the *Porosphaera* and Sponge Beds differed from those of the overlying beds, matching the general biostratigraphical succession elsewhere in Europe. Subsequently Schulz (1982) and, more recently, Christensen (1995) have revised Jeletzky's nomenclature while accepting his general conclusions, and have tentatively correlated the Maastrichtian succession with the standard belemnite zonal scheme.

The faunas of the Little Marl Point Member, dominated in the higher part (Brydone's 'White Chalk with *Ostrea lunata'*) by rock-forming concentrations of the oyster *Agerostrea lunata* (Woods *non* Nilsson), are of relatively low diversity, contrasting markedly with the abundant and high-diversity faunas of the overlying Beacon Hill Grey Chalk Member. The latter is particularly rich in very well preserved echinoids, including *Cardiaster granulosus* (Goldfuss), the large irregular species *Gauthieria princeps* (Hagenow) and the distinctive small *Echinocorys limburgica* Lambert. Other important elements are the small pectinacean bivalve *Lyropecten (Aequipecten) pulchellus* (Nilsson) and oysters, notably *Gryphaeostrea canaliculata* (J. Sowerby) and, in the calcarenitic beds, very large *Pycnodonte vesiculare* (Lamarck). The brachiopod assemblage contains many terebratulids (large *Neoliothyrina obesa* Sahni in addition to smaller

Chatwinothyris sp.), together with the rhynchonellid *Cretirhynchia limbata* (Schlotheim). Other brachiopods characteristic of this bed include *Magas chitoniformis* (Schlotheim), *Terebratulina gracilis* (Schlotheim) and *Trigonosemus pulchellus* (Nilsson). Extensive macrofossil collections made by Brydone and others are housed in the Sedgwick Museum in Cambridge and at the British Geological Survey, Keyworth.

The composite Trimingham succession (Figure 4.28) and (Figure 4.36) visible today, comprising the Little Marl Point bluff section and intermittent foreshore exposures of Mass C, spans the higher part of the *Belemnella obtusa* Zone and the *Belemnella sumensis* Zone of the standard European belemnite zonal scheme (Schulz, 1982; Christensen, 1995). The change from the large, obtuse ended, lanceolate *B. obtusa* Schulz in the Trimingham Sponge Beds, to the more cylindrical *B. sumensis* Jeletzky in the overlying beds, is conspicuous.

The Trimingham succession falls within the *Bolivinoides paleocenicus* benthic foraminiferal Zone (UKB21) (Swiecicki, 1980; Hart *et al.,* 1989). The entry of *Tappanina selmensis* (Cushman) at the base of the White Chalk with *Ostrea lunata* (higher part of the Little Marl

Point Chalk Member) was taken by Swiecicki (1980) to mark the base of his B6ii benthic foraminiferal Subzone ((Figure 1.5), Chapter 1).

The entry of *Trigonosemus pulchellus* (Nilsson) in the Grey Beds (Beacon Hill Grey Chalk Member) marks the base of the *T. pulchellus* microbrachiopod zone of the northern European scheme (Johansen and Surlyk, 1990).

Interpretation

The various masses in the Overstrand to Trimingham Cliffs site provide a composite succession through the highest onshore Upper Cretaceous strata in England ((Figure 4.28); (Figure 4.5)), in highly fossiliferous soft chalks ideal for the collecting of macrofossils and the extraction of microfossils and nannofossils. The origin of these masses is controversial (e.g. Eyles *et al.,* 1989). Within the succession, there is evidence (Overstrand Mass 4) for internal, intra-Cretaceous slumping akin to some of the events recognized in the Central Graben structure in the North Sea Basin. It is noteworthy that the composite Lower Maastrichtian succession of the site spans virtually the same stratigraphical range as the in-situ Maastrichtian component (Port Calliagh and Ballycastle Chalk members) of the Ulster White Limestone Formation that is preserved in a synclinal structure beneath the Tertiary basalts on the North Antrim coast (see Wood, 1967; Fletcher, 1977; Fletcher and Wood, 1978). It follows that the highest onshore Chalk in Britain extends no higher than the lower part of the Lower Maastrichtian Substage (*Belemnella sumensis* belemnite Zone); higher Maastrichtian strata in the Southern North Sea Basin are first found to the east of the continuation of the Dowsing Fault ((Figure 1.8), Chapter 1). The large *Belemnella lanceolata* from the Port Calliagh Member match those from the original Overstrand Hotel Upper Mass assemblage.

The three successions between Overstrand and Trimingham, particularly the Overstrand Hotel masses (Sidestrand Chalk Member), and the Trimingham Sponge Beds Member, are critical to the interpretation of the foraminiferal biostratigraphy of the offshore successions of the Southern North Sea Basin. Of particular importance is the identification *in situ* in the Overstrand Hotel Lower Mass (Overstrand Mass 1) of the *Reussella szajnochae szajnochae* flood event, indicative of the Campanian–Maastrichtian boundary (Schonfeld and Burnett, 1991), and, in the lower part of the Sponge Beds, of the *Angulogavelinella bettenstaedti* flood event. These events allow the onshore Maastrichtian strata to be placed in the Rowe Formation ((Figure 5.3), Chapter 5) of the North Sea Chalk Group (Lott and Knox, 1994). The composite Overstrand–Trimingham succession has been placed within the standard European belemnite zonal scheme. The (now disappeared) Overstrand Hotel Upper Mass is older than most of the succession exposed in the Sidestrand masses, belonging to the restricted *Belemnella lanceolata* Zone, rather than to the *Belemnella pseudobtusa* and *obtusa* zones. This is supported by the micromorphic brachiopod evidence (Johansen and Surlyk, 1990), which places the Upper Mass in the low, but not basal Maastrichtian, *Rugia spinosa–Trigonosemus pulchellus* Zone. Although they reported that the basal Maastrichtian *Gisilina jasmundi–Rugia acutirostris* Zone was missing from the Overstrand masses, their sampling did not extend as low as the Campanian–Maastrichtian boundary determined on foraminiferal evidence. The anomalous succession of Lower Maastrichtian belemnite assemblages, which apparently involves two successive immigrations of *Belemnella* into the Norfolk area (Christensen, 1996), requires further investigation but may be partly explicable by the previous incomplete understanding of the stratigraphical relationships between the Overstrand and Sidestrand masses.

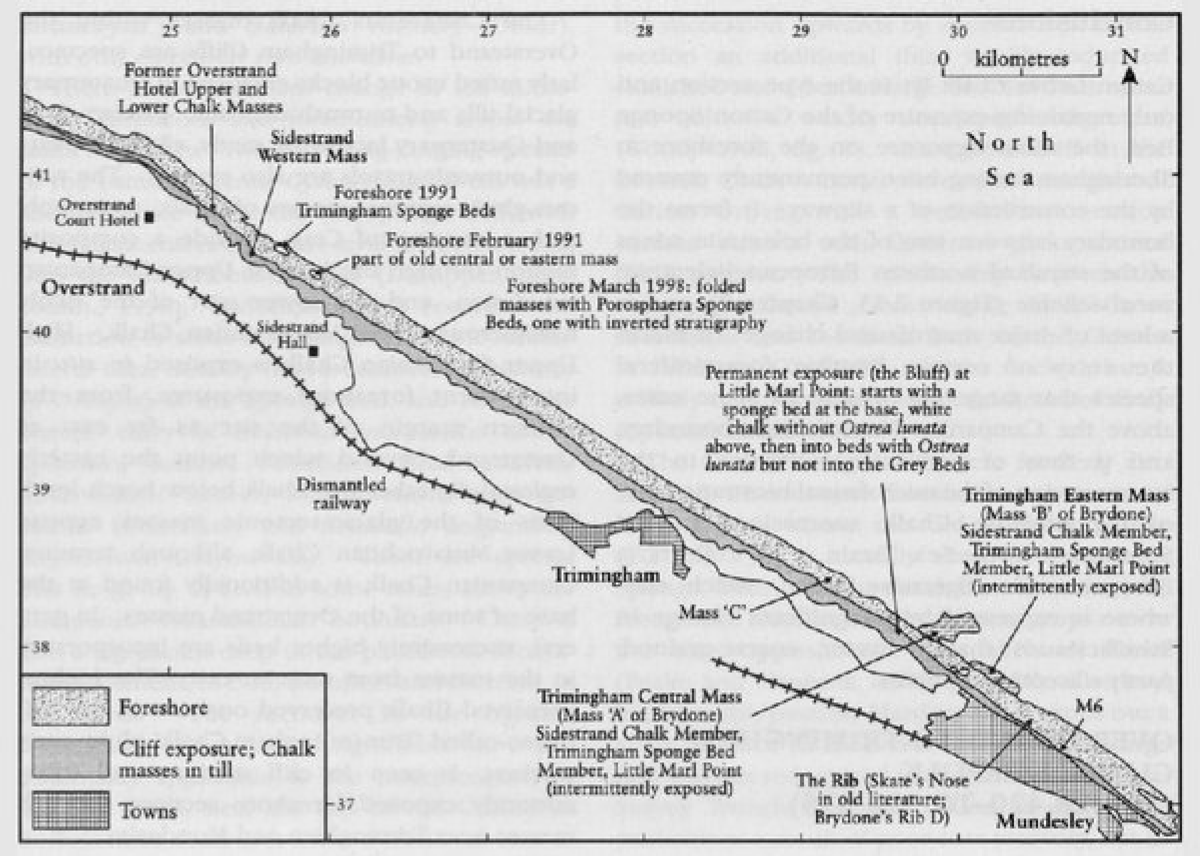
The Trunch Borehole [TG 2933 3455], which cored the entire Chalk succession, entered in-situ Chalk, beneath *c.* 45 m of Quaternary deposits, in the lower part of the Trimingham Sponge Beds Member, and proved the *Angulogavelinella bettenstaedti* flood event (Wood *et al.,* 1994). At this site, 3 km from Trimingham, which was deliberately chosen to intersect the top of the Chalk at a topographically high level, the higher part of the Trimingham sucession was actually missing, presumably as a result of erosion. The higher part of the core beneath the Sponge Beds consisted of remarkably soft chalk and recovery was very poor. There was no evidence for a hard-bed corresponding to the Pyramidata Hardground of the coast. The identification, at 61 m, of the *Reussella szajnochae szajnochae* flood-occurrence, *c.* 16 m beneath the Sponge Beds, almost exactly matches the composite stratigraphy in the Sidestrand and Overstrand masses (see (Figure 4.28)), where the corresponding interval from the Sponge Beds to the Sidestrand Marl is 15 m.

The Mundesley Borehole [TG 317 364] entered Chalk beneath 13.4 m of Pleistocene deposits and proved 1.7 m of highly fossiliferous calcarenitic chalk with grey flints before terminating. The lithology and fauna (Wood *et al.,* 1994) indicated that the highest (presumed in-situ) Chalk at this locality belonged to the Beacon Hill Grey Chalk Member. The succession here extends no higher than that in Mass C, implying that the Beacon Hill Grey Chalk Member marks the top of the onshore Maastrichtian succession. A tentative correlation of the Maastrichtian succession of the Norfolk coast and that proved in inland boreholes around Wroxham was shown by Pitchford (1991).

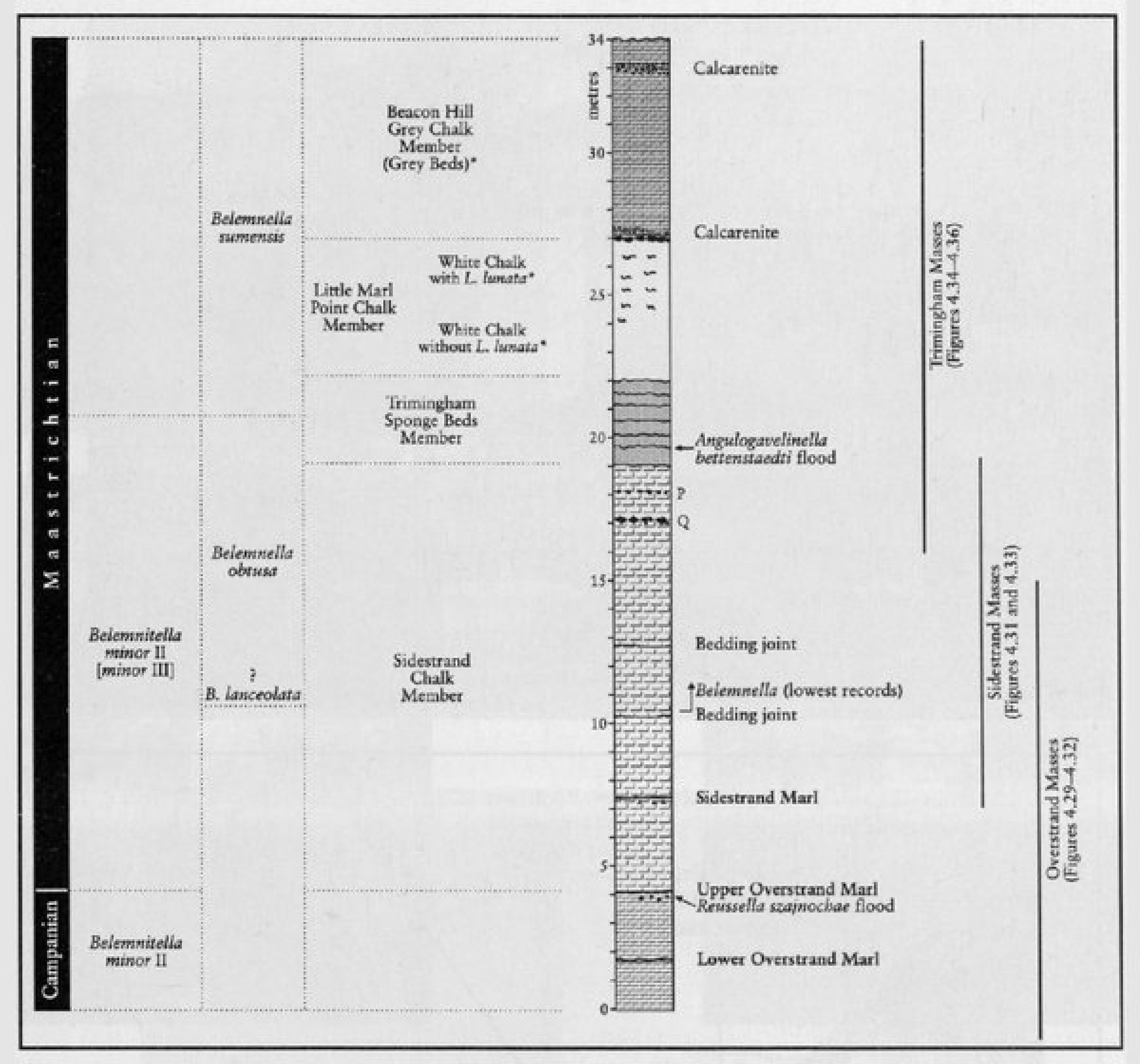
Conclusions

The three Chalk successions in the Overstrand to Trimingham Cliffs site at Overstrand, Sidestrand and Trimingham, are of great historical interest in the development of ideas on the stratigraphy of the highest part of the Upper Cretaceous succession in Britain. The origin of the masses, which are believed to have been detached by ice action from the floor of the North Sea, is controversial and is still being investigated. These masses provide a small-scale British analogue of the huge masses of Chalk incorporated in glacial deposits on the Island of Mon, Denmark and the German Island of Rügen in the Baltic. The Overstrand masses, in particular, are of key significance in the interpretation of the foraminiferal biostratigraphy of the offshore successions in the Southern North Sea Basin. They are thus of great importance in the search for oil and natural gas. The highly fossiliferous, soft chalks are ideal for collecting macrofossils as well as for the extraction of microfossils and nannofossils. Within the succession there is also evidence for internal, intra-Cretaceous slumping akin to some of the events recognized in the Central Graben, North Sea.

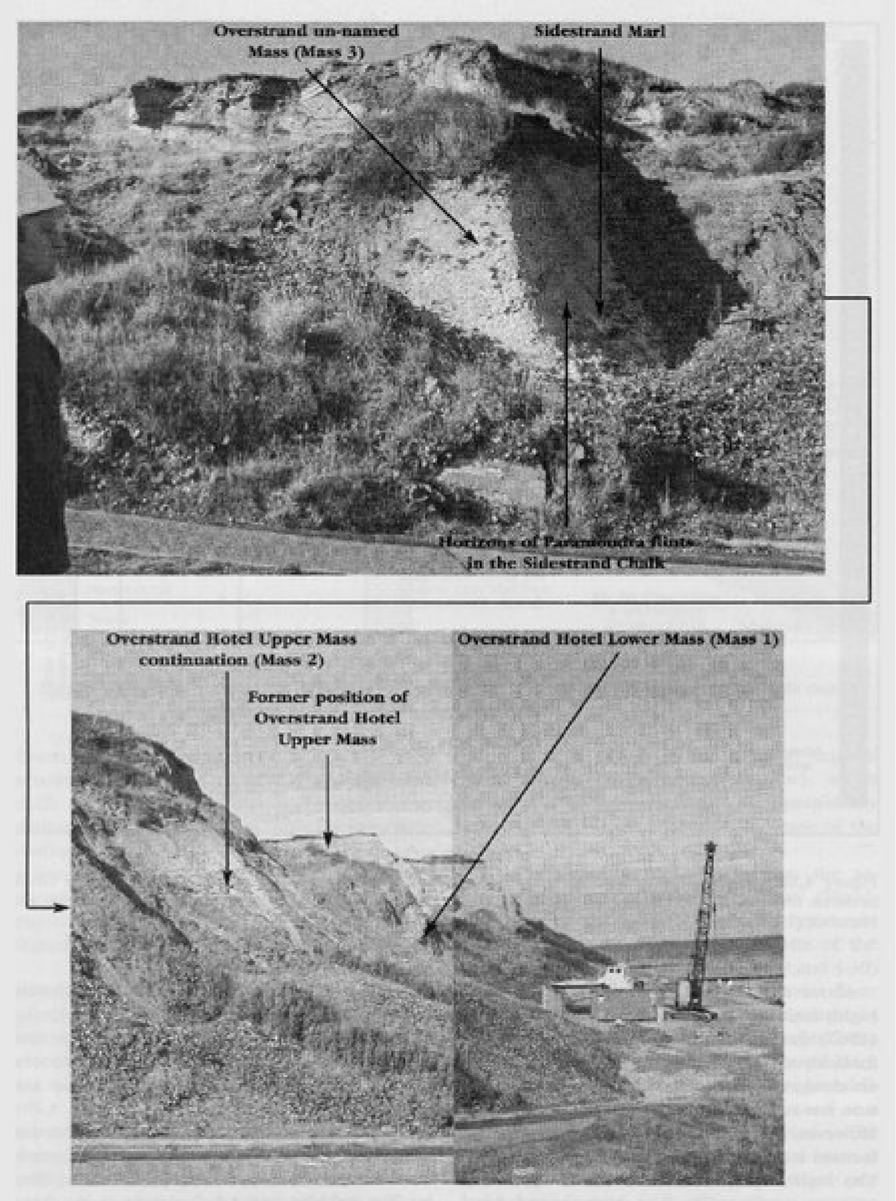
References



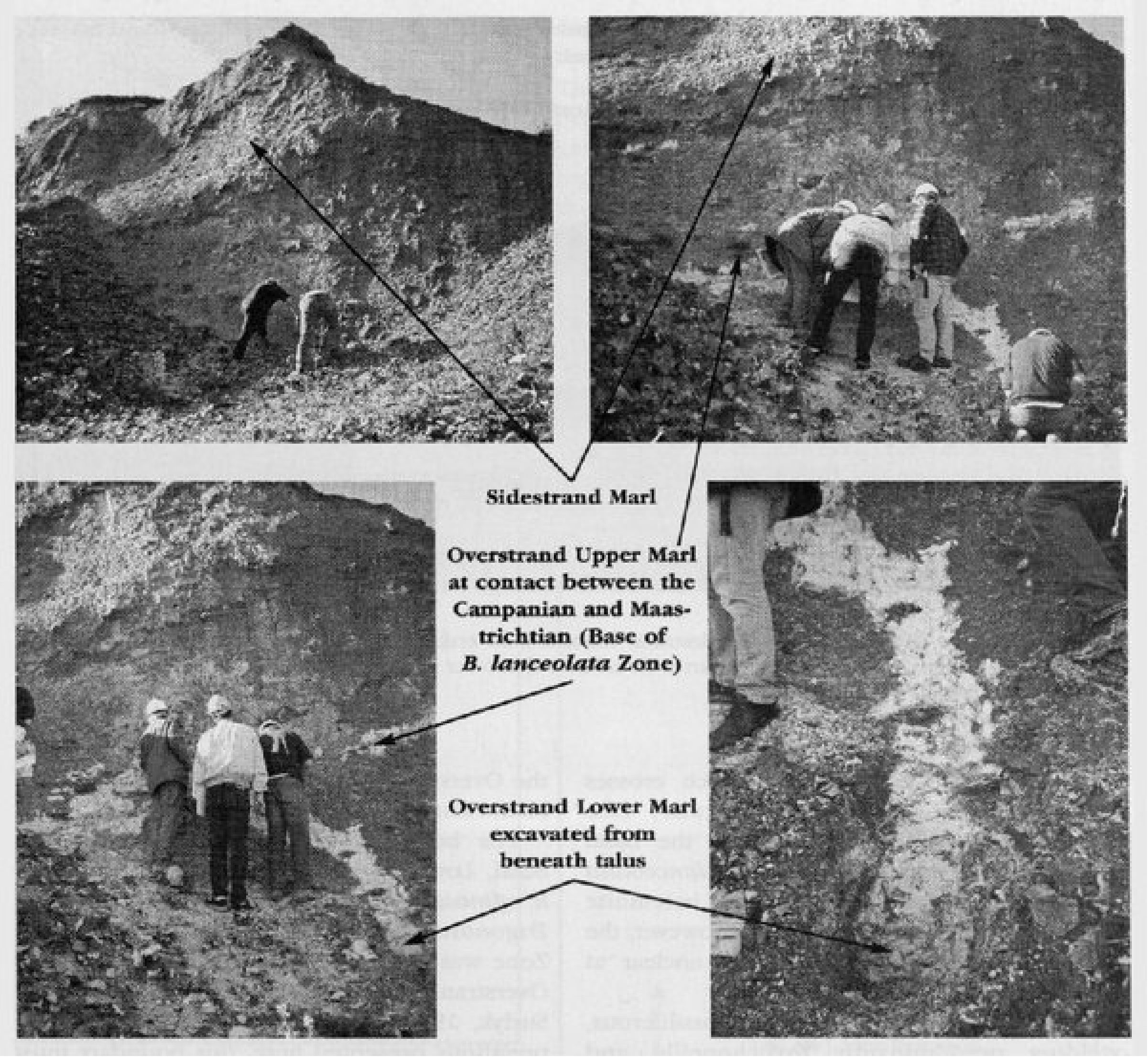
(Figure 4.27) The Overstrand to Trimingham Chalk exposures in ice-rafted masses, north Norfolk coast.



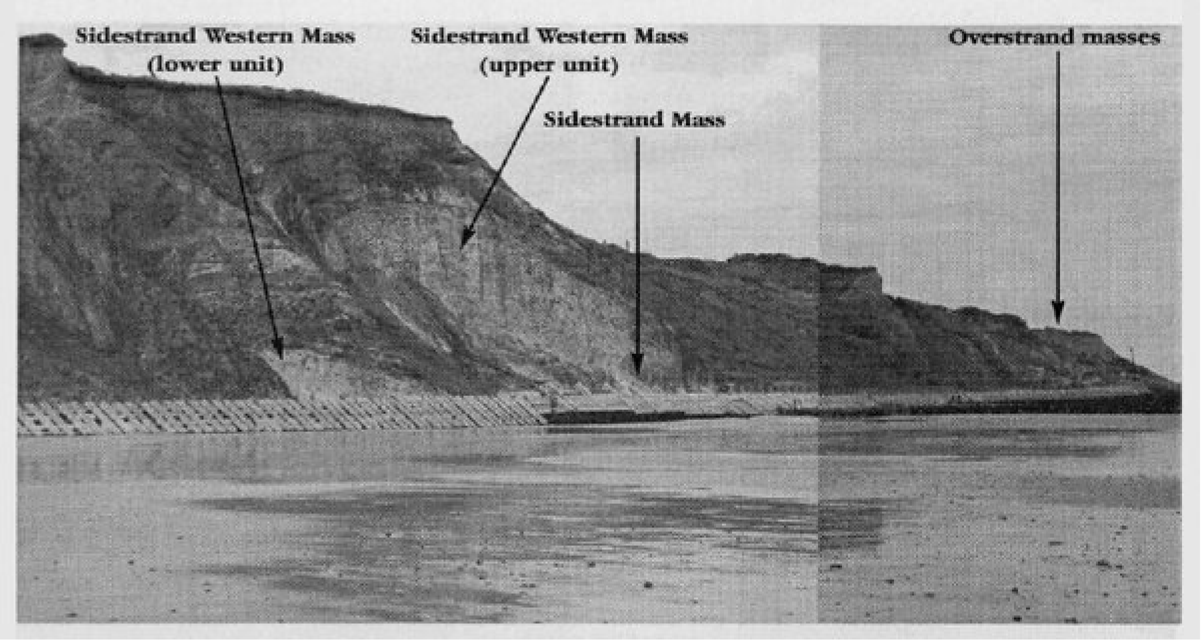
*(Figure 4.28) Composite, simplified section for the latest Campanian and Lower Maastrichtian of the Chalk between Overstrand and Trimingham, north Norfolk coast. (P and Q are marker flint bands of Peake and Hancock (1961, 1970); * = Brydone's terms.)*



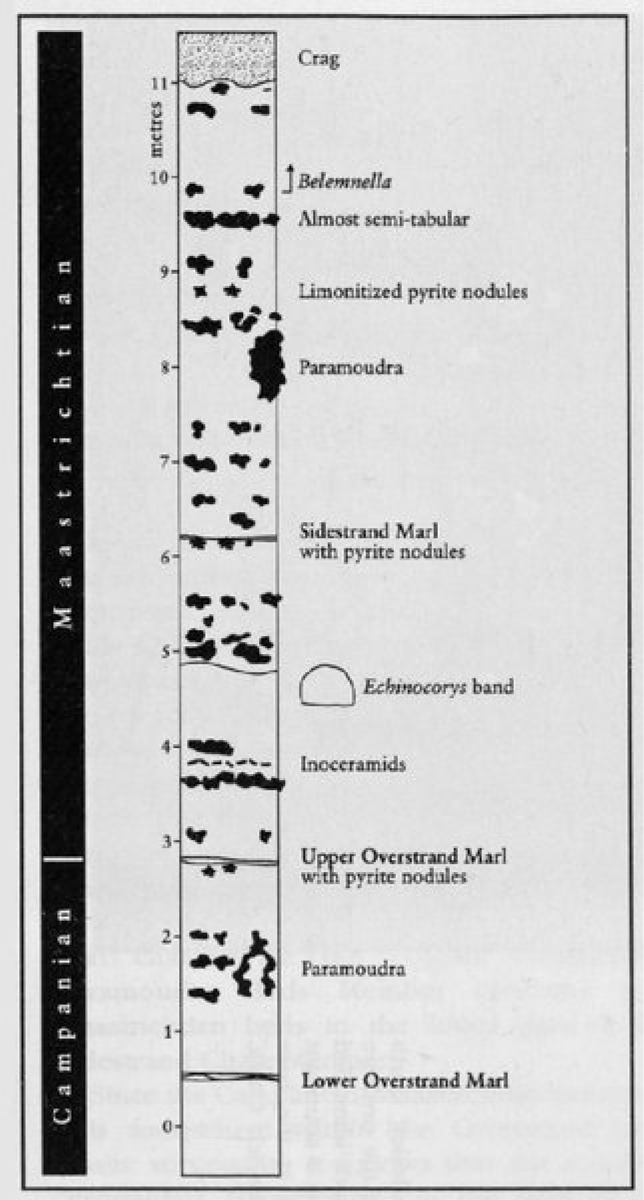
(Figure 4.29) The Overstrand Hotel Chalk Masses, incorporated in Quaternary sediments and partly landslipped Overstrand Cliffs, north Norfolk coast. All the masses are in the Sidestrand Chalk Member. (Photomosaic: R.N. Mortimore.)



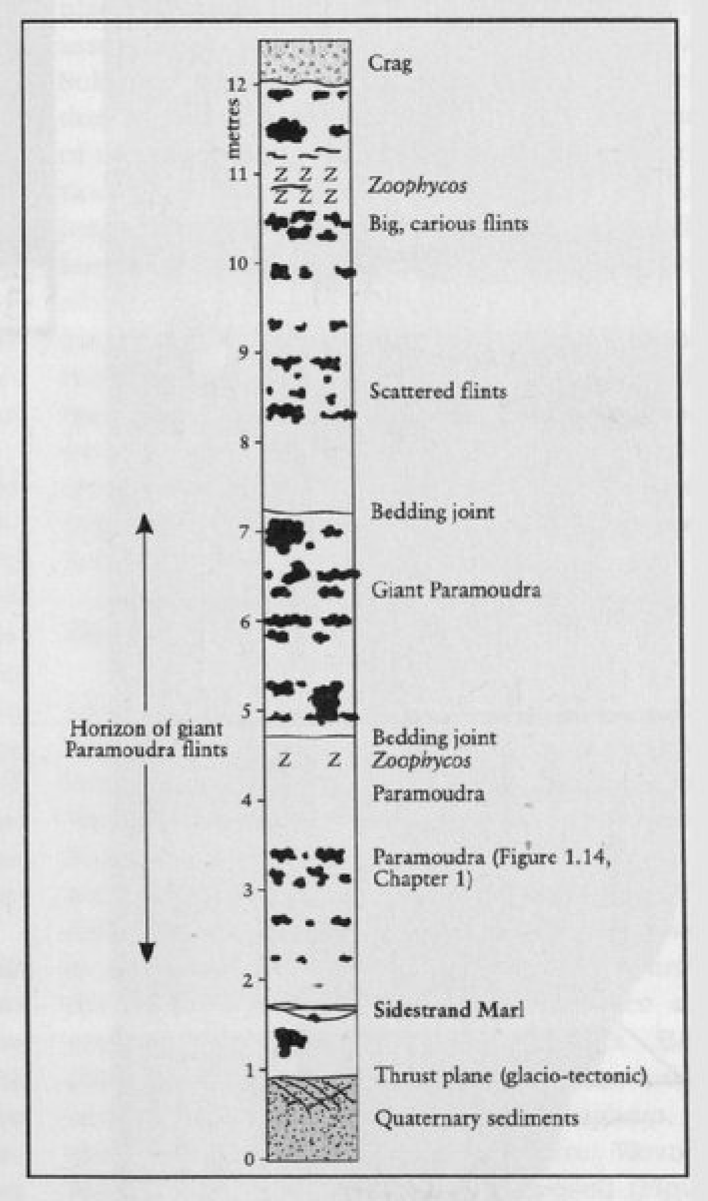
(Figure 4.30) Mass 1 (Overstrand Hotel Lower Mass) containing the Overstrand and Sidestrand marl seams and the Campanian–Maastrichtian boundary (Photos: R.N. Mortimore.)



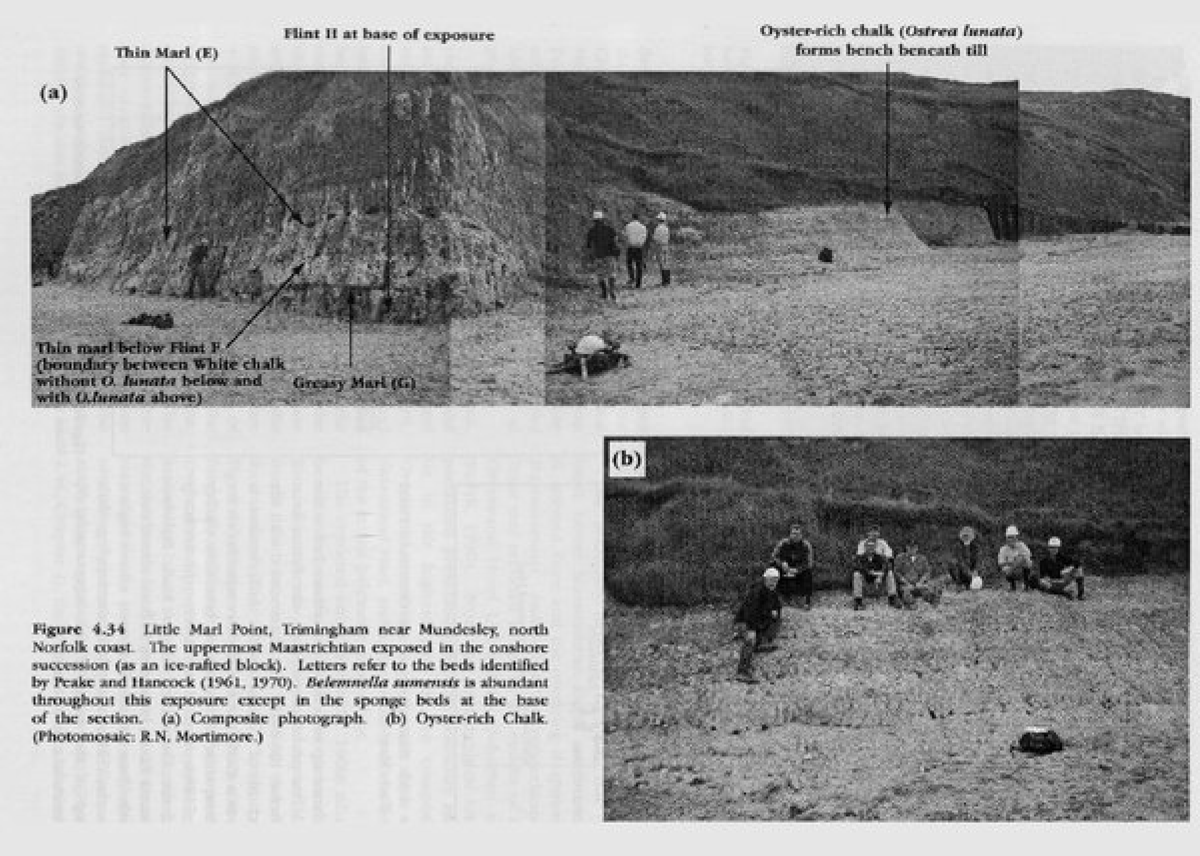
(Figure 4.31) Two components of the Sidestrand Western Mass enfolded in Quaternary sediments, Sidestrand beach, north Norfolk coast. The upper part is thrust over the lower part and contains the Sidestrand Marl at its base. (Photomosaic: R.N. Mortimore.)



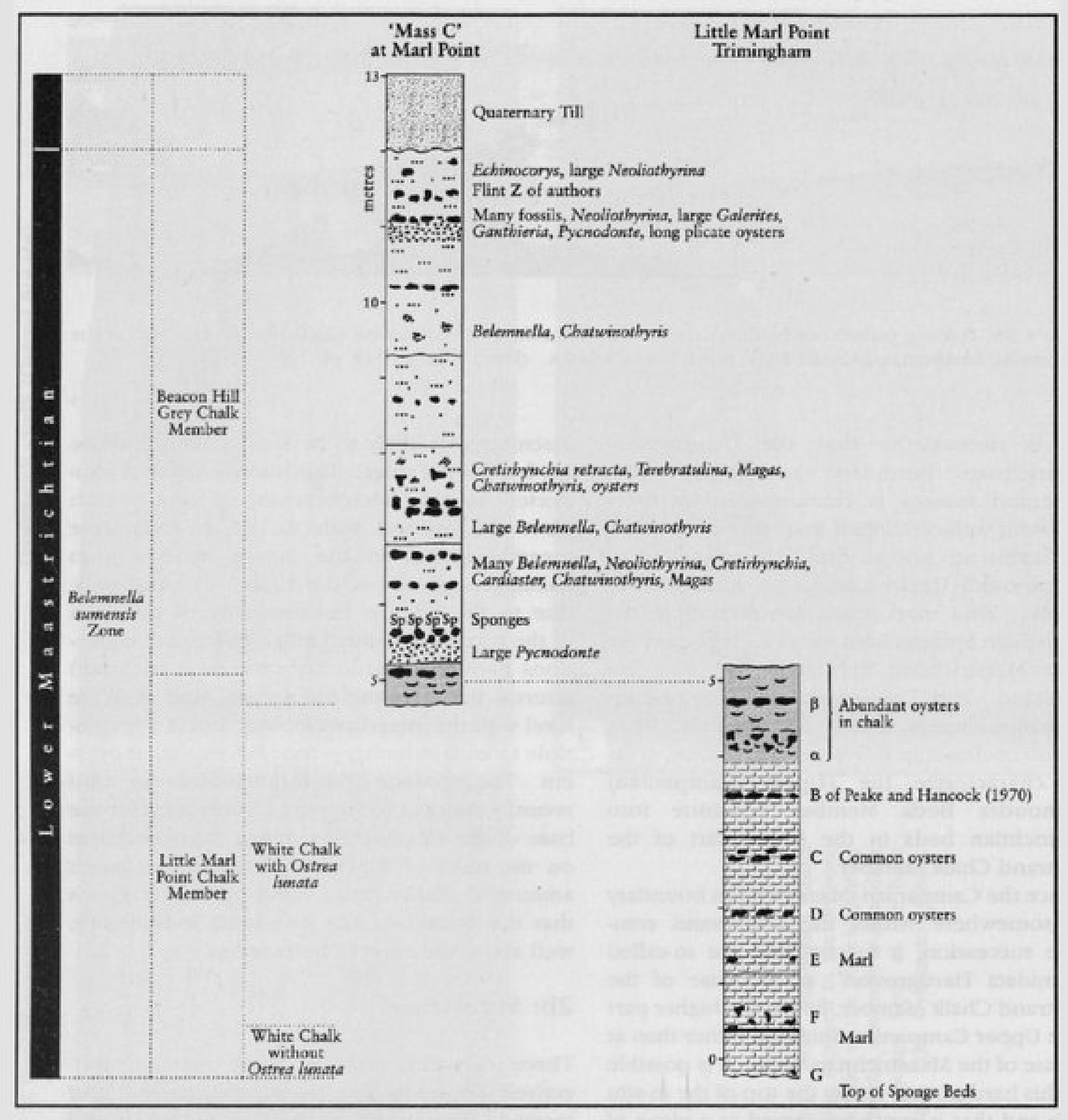
(Figure 4.32) Stratigraphy of the Overstrand Hotel Lower Mass (Mass 1).



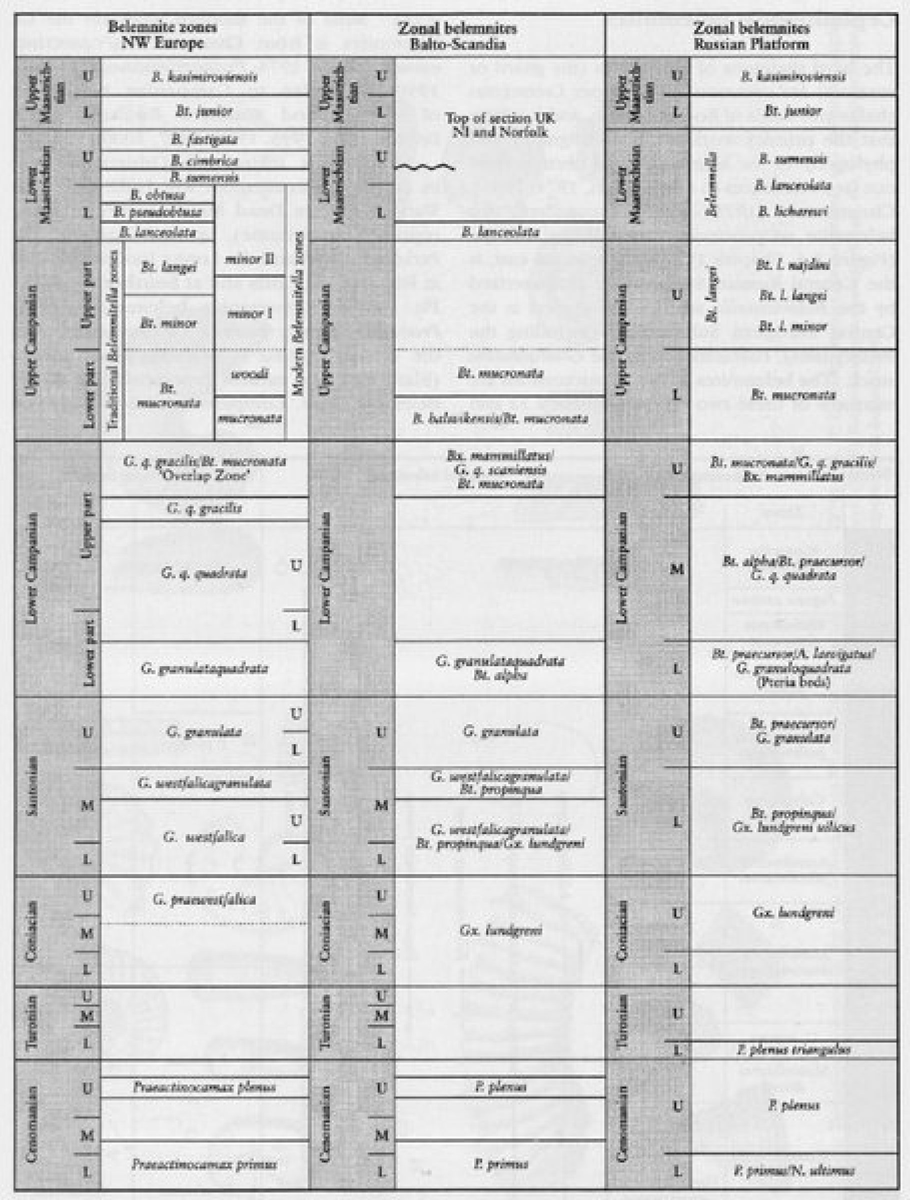
(Figure 4.33) Stratigraphy of the Sidestrand Western Mass.



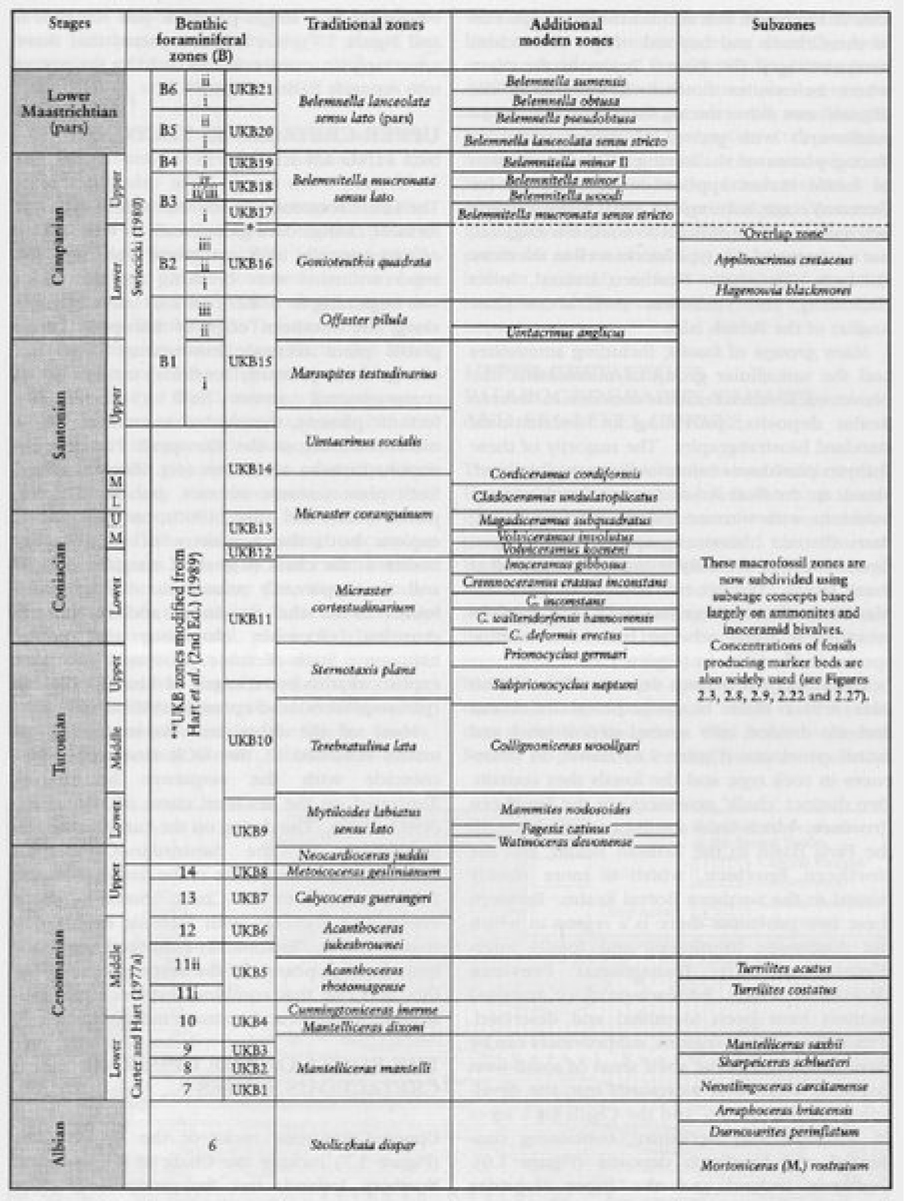
(Figure 4.34) Little Marl Point, Trimingham near Mundesley, north Norfolk coast. The uppermost Maastrichtian exposed in the onshore succession (as an ice-rafted block). Letters refer to the beds identified by Peake and Hancock (1961, 1970). Belemnella sumensis is abundant throughout this exposure except in the sponge beds at the base of the section. (a) Composite photograph. (b) Oyster-rich Chalk. (Photomosaic: R.N. Mortimore.)



(Figure 4.36) Sections in the highest onshore chalk in England at Trimingham.

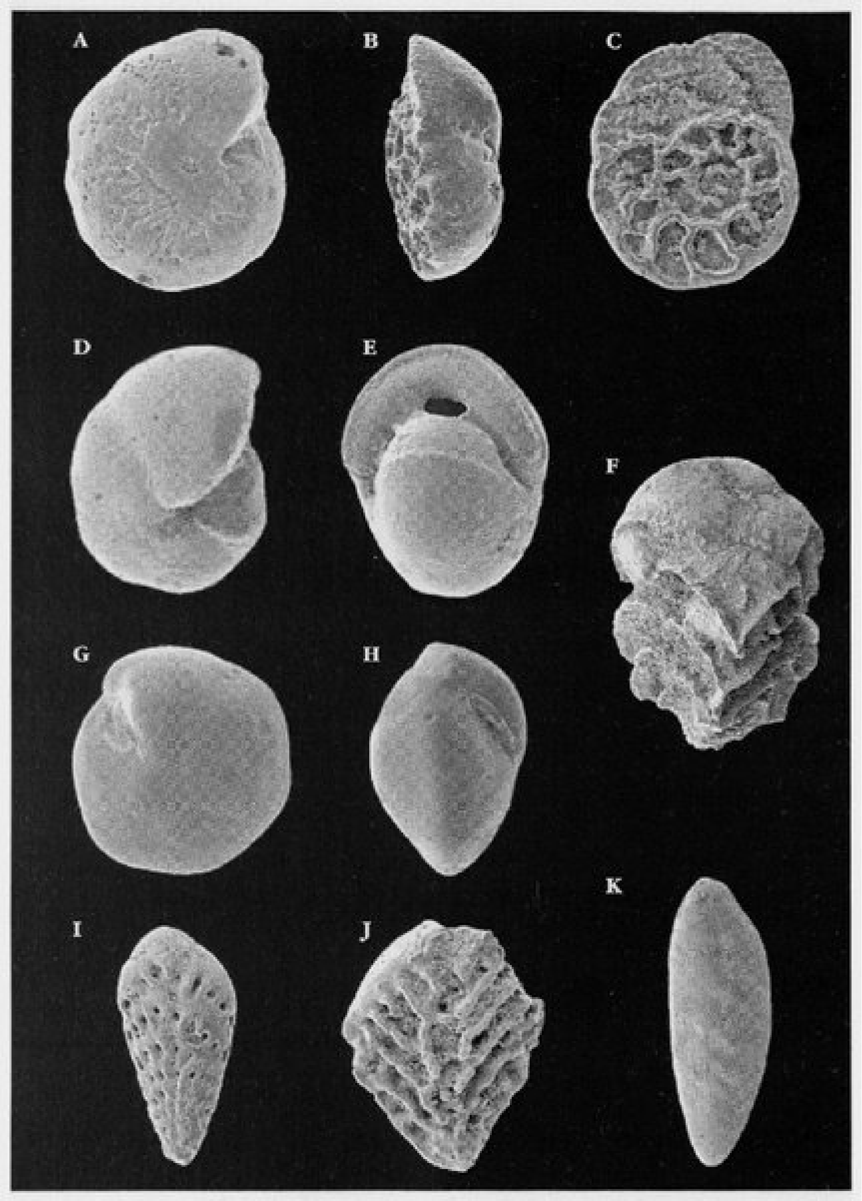


(Figure 2.13) Comparison of Upper Cretaceous belemnite zones across Europe, which are only partly represented in the UK and mainly on the Anglo-Brabant Massif. (After Christensen, 1991.) (A. = Actinocamax; B. = Belemnella; Bt. = Belemnitella; Bx. = Belemnellocamax; G. = Gonioteuthis; Gx. = Goniocamax;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

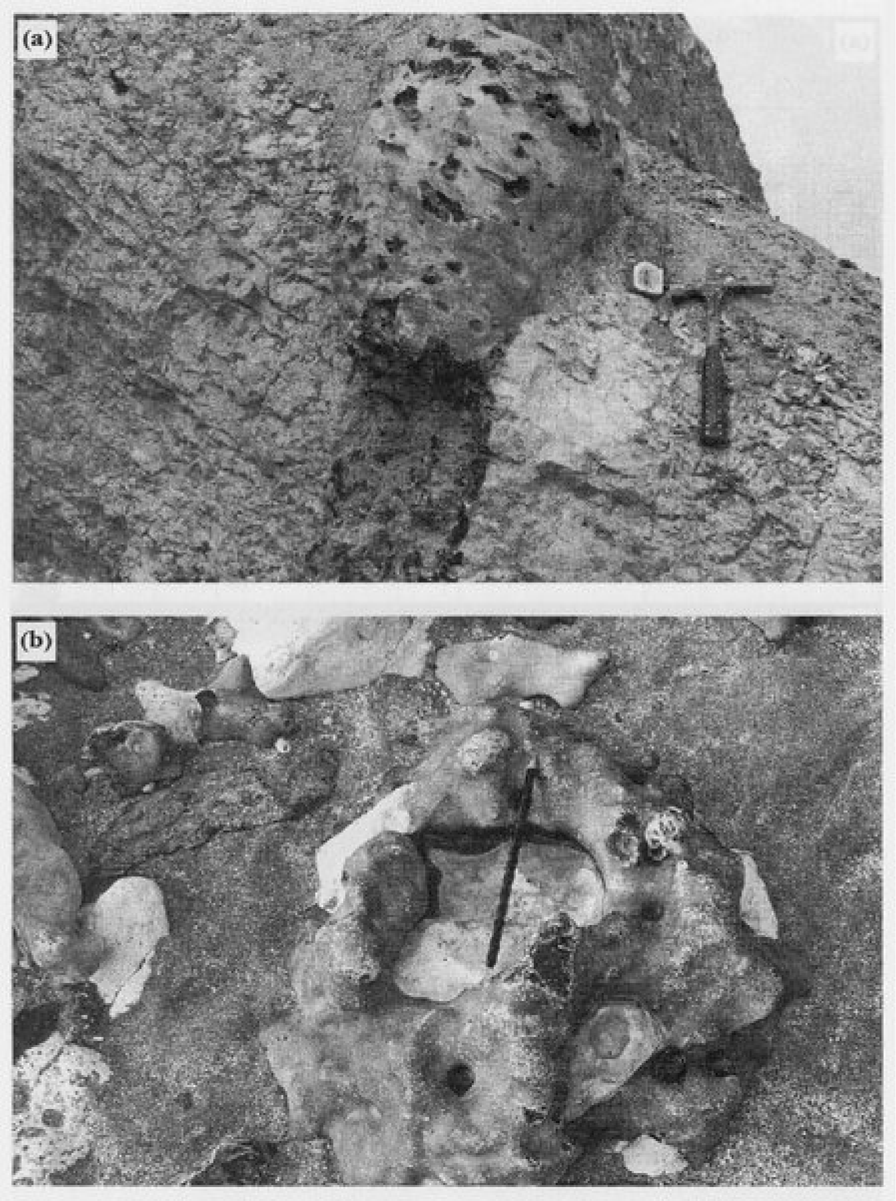


Stages		Benthic foraminiferal zones (B)				Traditional zones	Additional modern zones	Subzones
Lower Maastrichtian (pars)		Swiecicki (1980)	B6	ii	UKB21	*Belemnella lanceolata sensu lato* (pars)	*Belemnella sumensis*	
				i			*Belemnella obtusa*	
			B5	ii	UKB20		*Belemnella pseudobtusa*	
				i			*Belemnella lanceolata sensu stricto*	
Campanian	Upper		B4	i	UKB19	*Belemnitella mucronata sensu lato*	*Belemnitella minor* II	
			B3	iv	UKB18		*Belemnitella minor* I	
				ii/iii			*Belemnitella woodi*	
				i	UKB17		*Belemnitella mucronata sensu stricto*	
					*			
	Lower		B2	iii	UKB16	*Gonioteuthis quadrata*		'Overlap zone'
				ii				*Applinocrinus cretaceus*
				i				*Hagenowia blackmorei*
			B1	iii	UKB15	*Offaster pilula*		These macrofossil zones are now subdivided using substage concepts based largely on ammonites and inoceramid bivalves. Concentrations of fossils producing marker beds are also widely used (see Figures 2.3, 2.8, 2.9, 2.22 and 2.27).
				ii			*Uintacrinus anglicus*	
Santonian	Upper			i		*Marsupites testudinarius*		
		**UKB zones modified from Hart *et al.* (2nd Ed.) (1989)			UKB14	*Uintacrinus socialis*		
	M					*Micraster coranguinum*	*Cordiceramus cordiformis*	
	L						*Cladoceramus undulatoplicatus*	
Coniacian	U				UKB13		*Magadiceramus subquadratus*	
	M						*Volviceramus involutus*	
					UKB12		*Volviceramus koeneni*	
	Lower				UKB11	*Micraster cortestudinarium*	*Inoceramus gibbosus*	
							Cremnoceramus crassus inconstans	
							C. inconstans	
							C. waltersdorfensis hannovrensis	
							C. deformis erectus	
Turonian	Upper					*Sternotaxis plana*	*Prionocyclus germari*	
							Subprionocyclus neptuni	
	Middle				UKB10	*Terebratulina lata*	*Collignoniceras woollgari*	
	Lower				UKB9	*Mytiloides labiatus sensu lato*	*Mammites nodosoides*	
							Fagesia catinus	
							Watinoceras devonense	
Cenomanian	Upper					*Neocardioceras juddii*		
		Carter and Hart (1977a)	14		UKB8	*Metoicoceras geslinianum*		
			13		UKB7	*Calycoceras guerangeri*		
	Middle		12		UKB6	*Acanthoceras jukesbrownei*		
			11ii		UKB5	*Acanthoceras rhotomagense*		*Turrilites acutus*
			11i					*Turrilites costatus*
	Lower		10		UKB4	*Cunningtoniceras inerme*		
						Mantelliceras dixoni		
			9		UKB3	*Mantelliceras mantelli*		*Mantelliceras saxbii*
			8		UKB2			*Sharpeiceras schlueteri*
			7		UKB1			*Neostlingoceras carcitanense*
Albian			6			*Stoliczkaia dispar*		*Arrhaphoceras briacensis*
								Durnovarites perinflatum
								Mortoniceras (M.) rostratum

(Figure 1.5) Zones of the Upper Cretaceous Chalk. (= Gap in UKB scheme; ** = UKB zonal scheme modified for this book.)*

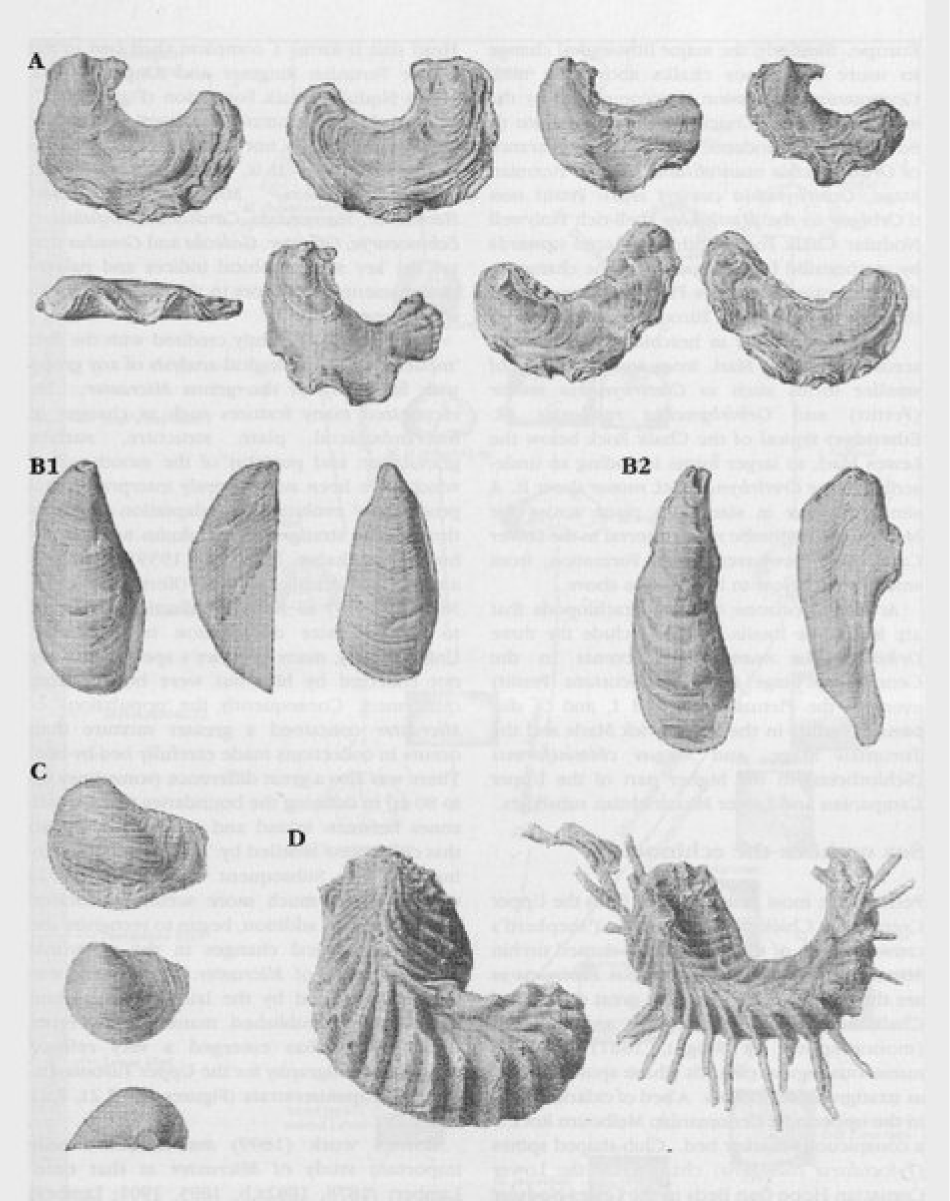


(Figure 2.44) Campanian and Maastrichtian foraminifera. SEM images of Campanian and Maastrichtian foraminifera. (A-C) Stensioeina pommerana (Brotzen) (× 150) (benthic), from Ipswich, Suffolk, Lower Campanian. Range: Lower Campanian to Maastrichtian. Remarks: enters in Offaster pilula Zone (Bailey et al., 1983), upper limit Lower Maastrichtian. (D, E) Pullenia quaternaria (Reuss) (× 150) (benthic), from Ipswich, Suffolk, Lower Campanian. Range: Middle Campanian to Maastrichtian. Remarks: entry a critical marker low in the Gonioteuthis quadrata Zone (Apflinocrinus cretaceus Subzone. (F) Reussella szajnochae szajnochae (Grzybowski) (× 80) (benthic), from Overstrand, Norfolk. Range: Upper Campanian to Upper Maastrichtian. Remarks: two key flood events, one at base of Maastrichtian at Overstrand Upper Marl, another one in Southern North Sea Basin near base of the Upper Maastrichtian (Bailey et al., 1983, 1984). (G, H) Eponides beisseli (Schijfsma) (× 80) (benthic), from Overstrand, Norfolk, Lower Maastrichtian. Range: Upper Upper Campanian to Lower Maastrichtian. Remarks: enters on top of Catton Sponge Bed. (I) Bolivinoides sidestrandensis (Barr) (× 100) (benthic), from Overstrand, Norfolk, Lower Maastrichtian. Range: Upper Campanian to Lower Maastrichtian. Remarks: enters with B. draco miliaris at the bio-event just below the base of the Paramoudra Chalk. (J) Bolivinoides draco miliaris (Hiltermann and Koch) (× 100) (benthic) from Trimingham, Norfolk, Lower Maastrichtian Belemnella sumensis Zone. Range: Upper Campanian to Lower Maastrichtian. Remarks: entry is a bio-event within the UKB zonal scheme. (K) Bolivina incrassata (Reuss) (× 80) (benthic), from Trimingham, Norfolk, Lower Maastrichtian. Range: upper Upper Campanian to Maastrichtian. Remarks: critical species enters in the Canon Sponge Bed.

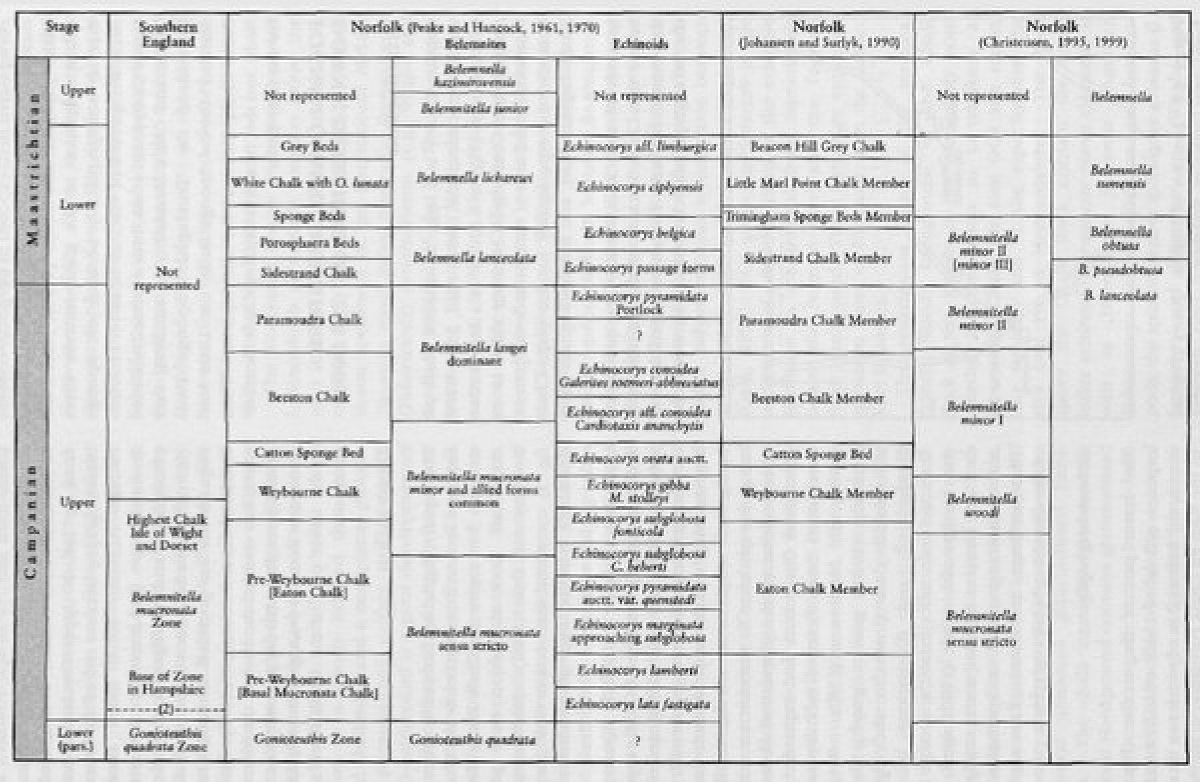


(Figure 1.14) Paramoudra flints. (a) Giant flint in the Sidestrand Western Mass, north Norfolk coast. The hammer is 320 mm long. (b) Paramoudra with internal, hardened chalk core, foreshore at Dumpton Gap, Thanet Coast, Kent. The pencil is 160 mm long. (Photos: R.N. Mortimore.)

(Figure 4.35) Folding picked out by flint bands within the rafted Ostrea lunata Chalk masses exposed in the foreshore at Trimingham, August 1949, north Norfolk Coast. (From Sainty, 1949, pl. 7.)

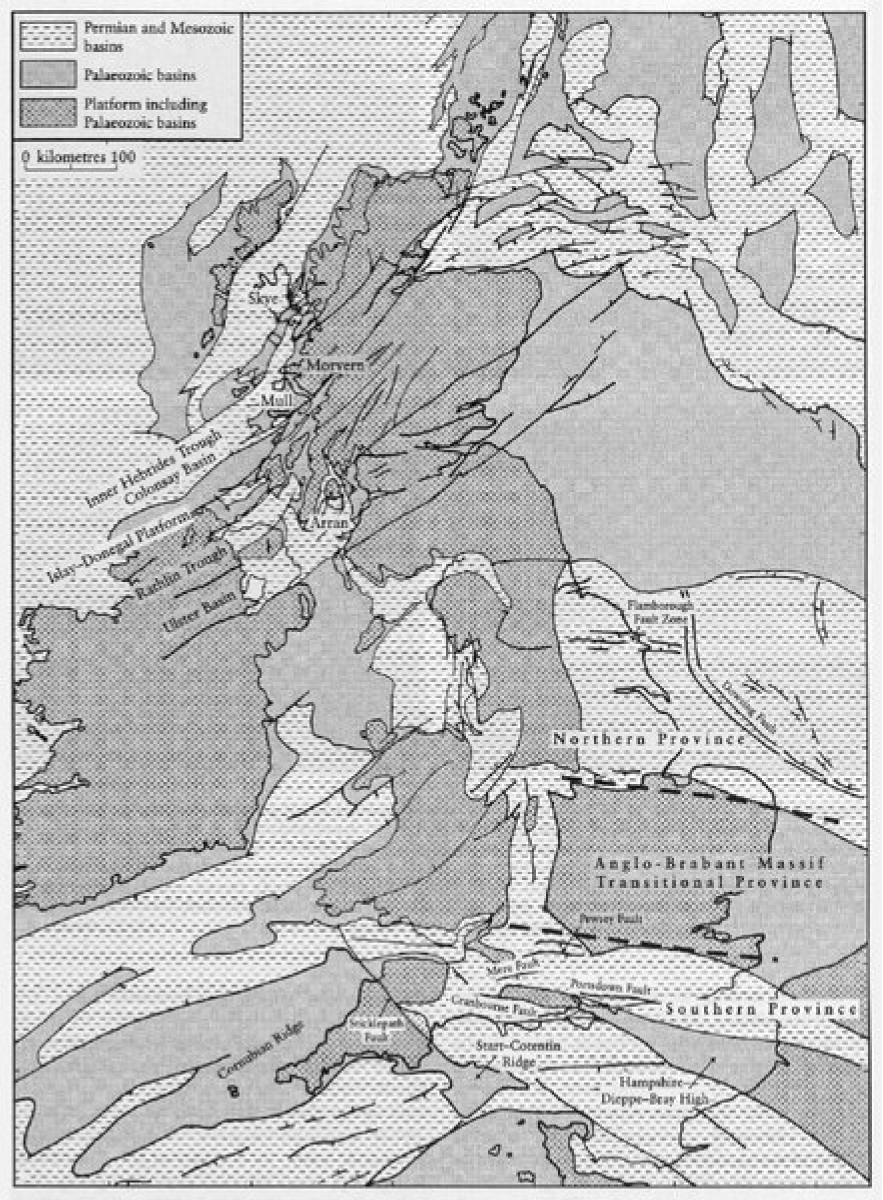


(Figure 2.28) Key Upper Cretaceous Chalk oysters. (A) *Agerostrea lunata*, Lower Maastrichtian, Norfolk (from Woods, 1912, p1. 61, figs 1–5). (B1, B2) *Pseudoperna boucheroni* from the Santonian–Campanian boundary 'Grobkreide' facies (from Woods, 1912, p1. 60, figs 1–3). (C) *Pycnodonte* from the Cenomanian *Pycnodonte* event (Woods, 1912, p1. 55, figs 8, 9). (D) *Rastellum colubrinum*, Lower Cenomanian *Sharpeiceras schlueteri* Subzone (from Woods, 1912, text-fig. 122). All specimens natural size.

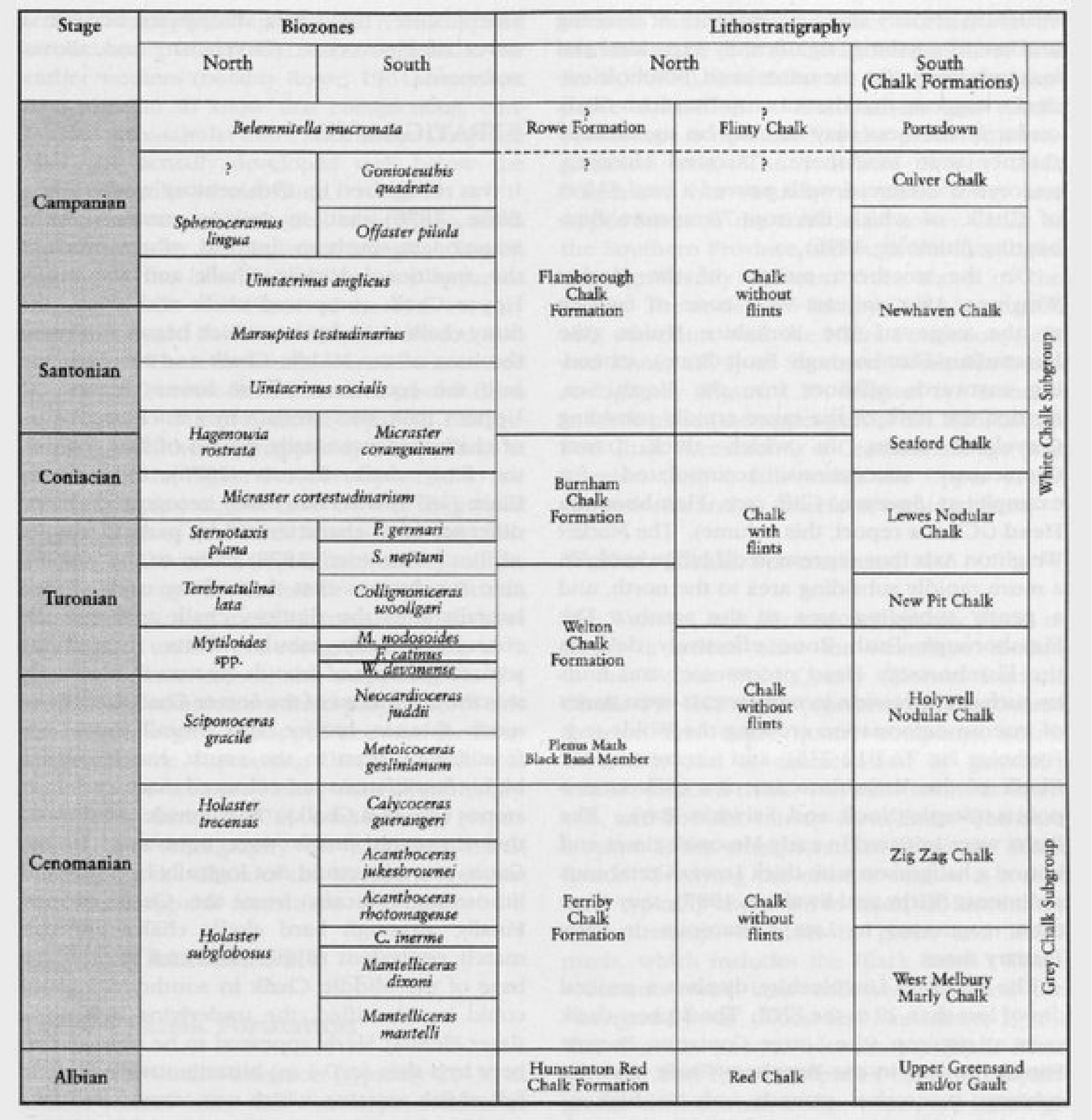


Stage		Southern England	Norfolk (Peake and Hancock, 1961, 1970)			Norfolk (Johansen and Surlyk, 1990)	Norfolk (Christensen, 1995, 1999)	
				Belemnites	Echinoids			
Maastrichtian	Upper	Not represented	Not represented	*Belemnella kazimiroviensis*	Not represented		Not represented	*Belemnella*
				Belemnitella junior				
	Lower			*Belemnella lichareui*				
			Grey Beds		*Echinocorys* aff. *limburgica*	Beacon Hill Grey Chalk		*Belemnella sumensis*
			White Chalk with O. *lunata*		*Echinocorys ciplyensis*	Little Marl Point Chalk Member		
			Sponge Beds			Trimingham Sponge Beds Member		
					Echinocorys belgica		*Belemnitella minor* II [*minor* III]	*Belemnella obtusa*
			Porosphaera Beds	*Belemnella lanceolata*		Sidestrand Chalk Member		
					Echinocorys passage forms			
			Sidestrand Chalk					*B. pseudobtusa* *B. lanceolata*
Campanian	Upper		Paramoudra Chalk	*Belemnitella langei* dominant	*Echinocorys pyramidata* Portlock	Paramoudra Chalk Member	*Belemnitella minor* II	
					?			
			Beeston Chalk		*Echinocorys conoidea* *Galerites roemeri-abbreviatus*	Beeston Chalk Member	*Belemnitella minor* I	
					Echinocorys aff. *conoidea* *Cardiotaxis ananchytis*			
				Belemnitella mucronata minor and allied forms common				
			Catton Sponge Bed		*Echinocorys ovata* auct.	Catton Sponge Bed		
			Weybourne Chalk			Weybourne Chalk Member		
					Echinocorys gibba *M. stolleyi*		*Belemnitella woodi*	
		Highest Chalk Isle of Wight and Dorset *Belemnitella mucronata* Zone Base of Zone in Hampshire (2)						
					Echinocorys subglobosa fonticola			
			Pre-Weybourne Chalk [Eaton Chalk]			Eaton Chalk Member		
							Belemnitella mucronata sensu stricto	
					Echinocorys subglobosa *C. heberti*			
				Belemnitella mucronata sensu stricto				
					Echinocorys pyramidata auct. var. *quenstedti*			
					Echinocorys marginata approaching *subglobosa*			
			Pre-Weybourne Chalk [Basal Mucronata Chalk]		*Echinocorys lamberti*			
					Echinocorys lata fastigata			
	Lower (pars.)	*Gonioteuthis quadrata* Zone	*Gonioteuthis* Zone	*Gonioteuthis quadrata*	?			

(Figure 4.5) The 'high' Chalk of Norwich and north Norfolk based on Peake and Hancock (1961, 1970); Wood (1988); Johansen and Surlyk (1990); and Christensen (1995, 1999).



(Figure 1.8) Broad structural features affecting sedimentation of the Upper Cretaceous deposits in the British Isles. (Based on British Geological Survey 1:1 000 000 maps of the Geology of the UK, Ireland and Continental Shelf; North and South Sheets.)



Stage	Biozones		Lithostratigraphy			
	North	South	North		South (Chalk Formations)	
Campanian	*Belemnitella mucronata*		? Rowe Formation	? Flinty Chalk	Portsdown	White Chalk Subgroup
	?	*Gonioteuthis quadrata*	? Flamborough Chalk Formation	? Chalk without flints	Culver Chalk	
	Sphenoceramus lingua	*Offaster pilula*			Newhaven Chalk	
	Uintacrinus anglicus					
Santonian	*Marsupites testudinarius*					
	Uintacrinus socialis					
Coniacian	*Hagenowia rostrata*	*Micraster coranguinum*			Seaford Chalk	
	Micraster cortestudinarium		Burnham Chalk Formation	Chalk with flints	Lewes Nodular Chalk	
Turonian	*Sternotaxis plana*	*P. germari*				
		S. neptuni				
	Terebratulina lata	*Collignoniceras woollgari*	Welton Chalk Formation		New Pit Chalk	
	Mytiloides spp.	*M. nodosoides*		Chalk without flints	Holywell Nodular Chalk	
		F. catinus				
		W. devonense				
Cenomanian	*Sciponoceras gracile*	*Neocardioceras juddii*				
		Metoicoceras geslinianum	Plenus Marls Black Band Member			
	Holaster trecensis	*Calycoceras guerangeri*	Ferriby Chalk Formation	Chalk without flints	Zig Zag Chalk	Grey Chalk Subgroup
	Holaster subglobosus	*Acanthoceras jukesbrownei*				
		Acanthoceras rhotomagense				
		C. inerme			West Melbury Marly Chalk	
		Mantelliceras dixoni				
		Mantelliceras mantelli				
Albian			Hunstanton Red Chalk Formation	Red Chalk	Upper Greensand and/or Gault	

(Figure 5.3) The stratigraphy of the Northern Province Chalk (compare with (Figure 1.5), Chapter 1 and Figures 2.8, 2.9, 2.21, 2.22 and 2.27, Chapter 2).