Flamborough Head, north and east Yorkshire

[TA 154 755]–[TA 200 685]

Introduction

The Flamborough Head GCR site comprises 17 km of sea cliff and rock platform sections on the north Yorkshire coast. These cliffs expose a continuous Northern Province Chalk succession from the base of the Upper Cretaceous Series, in the Hunstanton Red Chalk Formation at Speeton Cliff; up to the lower part of the Lower Campanian succession, at the top of the preserved Flamborough Chalk Formation at Sewerby Steps (Figure 5.19) and (Figure 5.20). Even higher (low Lower Campanian) Flamborough Chalk successions are exposed in quarries on the Yorkshire Wolds. From the Santonian strata upwards the succession is enormously expanded compared with its Southern Province equivalents.

At Speeton Cliff, there is an expanded, and possibly the most complete section in the UK across the Albian–Cenomanian boundary, here in red chalk facies. The coastal cliffs from the eastern end of Buckton Cliffs to Selwicks Bay provide the only available (albeit largely inaccessible) continuous section from the base of the Welton Chalk Formation to the boundary with the Flamborough Chalk Formation. The section in North Landing is famous for giant cylindrical (paramoudra) flints in the Upper Turonian *Sternotaxis plana* Zone. The cliffs from Flamborough Head to Sewerby Steps constitute the stratotype for the Flamborough Chalk Formation, and include the famous Flamborough (or Bridlington) Sponge Beds, with their diverse, abundant and well-preserved lithistid and hexactinellid sponge assemblages. They also provide what are probably the best exposures (albeit in hard chalks) of the Santonian crinoid (*Uintacrinus socialis, Marsupites testudinarius*) zones in Europe and of the basal Campanian *Uintacrinus anglicus* Zone. Flamborough Head is, therefore, of fundamental importance as a standard section for long-range correlation, and a key section for defining the base of the Cenomanian and Campanian stages.

Description

An amazingly perceptive review of the Yorkshire Chalk stratigraphy in general — but with particular reference to the Flamborough promontory — was undertaken on the basis of a brief visit by the Frenchman, Charles Barrois (1876). He was the first stratigrapher to attempt to understand the succession here in terms of the macrofossil zones that he and his collaborators had established in the Chalk of the Paris Basin. A few years later, an important sequence of papers, including measured sections of the highest Burnham Chalk and the overlying Flamborough Chalk, as well as photographs of the cliff sections and discussion of the fault zones, was published by Lamplugh (1880, 1894, 1895, 1896).

Detailed descriptions of the stratigraphy of the post-Cenomanian ('White Chalk') sections, supplemented by annotated photographs, were given by Rowe (1904) when he, following his work in southern England, fulfilled his (p. 194) 'long-cherished furtive ambition to explore this mysterious and legendary coast'. He came away deeply impressed by its grandeur (p. 196)… we have no counterpart in the South of the grand screes of Speeton Cliff nor are our southern cliffs, however lofty, comparable to the mighty tide-bound ramparts of Bempton'. He emphasized the physical difficulties of working on the cliff sections. However, although he commented on the poor preservation and sparse nature of the fossils, he managed to collect an amazing amount of material from sections that today are extremely unproductive. Because the faunas of the equivalent of the *Micraster coranguinum* Zone and the (then) *Actinocamax quadratus* Zone are significantly different from those in the Southern Province, Rowe introduced two local replacement zones, the *Infulaster rostratus* and *Inoceramus lingua* zones respectively. He also provided notes on the lithology and faunas of 32 pits and quarries near Flamborough and on top of the Wolds west of Bridlington. Most of these sections are no longer extant, and his observations are therefore of great value. His field companion, Charles Sherborn (see frontispiece photographs), additionally supplied a geological map of the area, with the inferred positions of the zonal boundaries, as well as interpretative longitudinal sections both of the cliffs themselves, and of the relationship between the cliffs and the inland pits. Rowe's essentially biostratigraphical investigation, although carried out at the beginning of the 20th century, is remarkably informative, and is still indispensable for anybody who wants to examine this site.

After this period, the only significant contribution to the study of the Yorkshire Chalk was a comprehensive review of the stratigraphy and faunas of the inland sections (Wright and Wright, 1942). In this key paper, the *Uintacrinus socialis* and *Marsupites testudinarius* zones were given formal zonal status in Britain for the first time, and the Subzone of *Discoscaphites binodosus* was introduced for the highest part of the flintless (Flamborough) chalk succession. Neale (1976) gave a tabular revision of the Upper Cretaceous stratigraphy, and provided a longitudinal section, but neither the table nor the section includes any new information. In the context of developing a mapping stratigraphy of the Chalk for the British Geological Survey, Wood and Smith (1978, fig. 5) correlated the highest Welton Chalk and basal Burnham Chalk succession in North Landing with inland sections in Yorkshire and Lincolnshire. Whitham (1991) published measured sections of the accessible parts of the Welton Chalk and Burnham Chalk in North Landing and Thornwick Bay, extending the Wood and Smith section down to the Barton Marls. Mitchell (2000) published detailed logs of the Welton Chalk of Speeton Cliff and the Thornwick Bay sections. In another key paper, Whitham (1993) established a new lithostratigraphy of the Flamborough Chalk, in which he recognized three members, (South Landing, Danes Dyke and Sewerby Steps), and gave names to a large number of marker horizons, mainly marl seams. Mitchell (1994, 1995b) made minor adjustments to this scheme, defined some additional marker horizons and gave detailed logs of the Santonian crinoid zones and the Santonian–Campanian boundary. Through bed-by-bed collecting he was able to shift the lower boundaries of the *Uintacrinus socialis* and *Marsupites* zones significantly downwards, compared to those recognized by Rowe (1904), and he documented (Mitchell, 1995b) the occurrence of the crinoid *Uintacrinus anglicus,* which was previously unknown from Yorkshire.

For descriptive purposes these 17 km of cliffs are divided into four parts and are treated separately:

Part 1 includes Speeton Cliff–Buckton Cliffs. This magnificent section through the Hunstanton Red Chalk Formation and Ferriby Chalk Formation (Figure 5.3), (Figure 5.20), (Figure 5.21), (Figure 5.22), (Figure 5.23), (Figure 5.24), (Figure 5.25), exposes a continuous succession from the Albian–Cenomanian boundary.

Part 2 comprises the vertical cliffs and scars (rock platforms) from Speeton Cliff and Buckton Cliffs eastwards to Stottle Bank in the Welton Chalk and Burnham Chalk formations. These cliffs include the Royal Society for the Protection of Birds (RSPB) bird reserve at Bempton Cliff, and the structurally complex area known as 'Staple Nook' or 'Scale Nab', which are inaccessible. However, it is possible, but with great difficulty, to walk at extreme low water along the boulder-strewn beach at the foot of the cliffs from Speeton Cliff as far as Staple Nook (adjacent to Scale Nab). Beyond Staple Nook the remainder of the traverse through Sanwick Bay (Rowe, 1904, pl. 27) is prevented by deep-water caves and inlets. The first access to the shore is at Little Thornwick Bay. Here, and in the adjoining Great Thornwick Bay and North Landing, there are excellent sections in the cliffs and scars of the composite succession from the Barton Marls in the Welton Chalk Formation, to the Ulceby Marl and Oyster Bed, near the base of the Burnham Chalk Formation. In the 1.8 km stretch from the eastern headland of North Landing to Stottle Bank, 0.5 km north of Selwicks Bay, there is no access to the shore.

Part 3 includes the highest part of the Burnham Chalk which is exposed between Stottle Bank, where the cliff-line changes from NW–SE to north–south, and Selwicks Bay, where basal (flintless) Flamborough Chalk Formation, on the west side of the bay, is brought into juxtaposition with flinty Burnham Chalk, on the east, by the Selwicks Fault complex.

Part 4 comprises the highest Burnham Chalk Formation and the complete (flintless) Flamborough Chalk Formation, which is exposed on the south side from Flamborough Head to Sewerby Steps.

Part 1: Speeton Cliff–Buckton Cliffs

1.1: Hunstanton Red Chalk Formation (Speeton Cliff)

Speeton Cliff; at the southern margin of the Cleveland Basin, provides a continuous, albeit intermittent, exposure in the sea cliff and shore platform of an expanded succession across the boundary between the Lower and Upper Cretaceous series. In contrast to the condensed successions on the East Midlands Shelf and Market Weighton Axis, the succession here is unbroken by a hiatus, and the boundary falls within the Hunstanton Red Chalk Formation, rather than at the base of the (redefined) Ferriby Chalk Formation. This section (Figure 5.21) is of critical importance in that, firstly, the position of the base of the Cenomanian Stage, as defined in the candidate Global boundary Stratotype Section and Point (GSSP) in the south of France, can be identified by means of stable isotope stratigraphy. Secondly, it has provided a key section for integrated geochemical (stable isotope), sedimentological (cyclostratigraphy) and biostratigraphical studies, which have been applied throughout northern Europe.

Lithostratigraphy

The succession (Figure 5.21) at Speeton Cliff comprises the Hunstanton Red Chalk Formation (Albian-basal Cenomanian), 24 m thick (Mitchell, 1995a), overlain by the re-defined Ferriby Chalk Formation (Cenomanian), about 33 m thick. Above the Ferriby Chalk, the largely inaccessible cliffs expose the Welton Chalk Formation, with the Black Band at the base, and the lower part of the Burnham Chalk Formation.

Mitchell (1995a) gave a comprehensive historical review of the usage of the stratigraphical term 'Red Chalk'. He assigned the Red Chalk formally to the Hunstanton Red Chalk Formation and divided the succession at Speeton Cliff into five members, which he described and illustrated in detail. He also reviewed previous work on the Albian–Cenomanian stratigraphy at Speeton Cliff, and provided a correlation table to show the nomenclature of the various units adopted by previous workers.

Speeton Cliff provides a continuous expanded basinal succession across the Albian–Cenomanian boundary (see details below). The actual boundary falls within the Weather Castle Member of the Hunstanton Red Chalk Formation. There is an up-section change from the marly chalks of this member to the more nodular chalks of the Red Cliff Hole Member. Jeans (1980) defined the top of his Red Chalk at this change, but primarily on a palaeontological, rather than on a lithostratigraphical basis. The top of the Hunstanton Red Chalk Formation is taken at the top of the Red Cliff Hole Member, at a conspicuous bed (RCH5d of Mitchell) of brownish chalk with vertical 2 mm diameter burrows (*Skolithos?*) filled with red clay. Above this bed there is a decrease in clay content and a change to less strongly coloured chalks. The base of the re-defined Ferriby Chalk Formation (i.e. excluding the Red Chalk component), is taken at the base of the Crowe's Shoot Member, which marks a change from rhythmically-bedded, red chalks to white flaser-bedded chalks with thin red or purple marls. There is also a marked reduction in the clay content. The Crowe's Shoot Member corresponds to the thin Paradoxica Bed limestone of the condensed platform sucessions. The type locality is in the low cliffs near Dulcey Dock [TA 168 749].

1.2: Ferriby Chalk Formation (Speeton Cliff–Buckton Cliffs)

The lower part of the Ferriby Chalk Formation, from the base of the Paradoxica Bed up to the base of the Totternhoe Stone, is relatively expanded at Speeton Cliff (20.3 m). This contrasts with its development at Melton Bottom Chalk Pit (9.8 m), Middlegate Quarry South Ferriby (10.5 m), and the extremely condensed succession at Hunstanton Cliffs (5.8 m) and in the nearby Hunstanton No. 1 Borehole (6.3 m). It is also very thin compared with the same interval in the 'Lower Chalk' of Barrington Chalk Pit (27 m in Jeans, 1980, fig. 1) (see (Figure 5.9)) and (Figure 5.22).

Part of the Ferriby Chalk Formation at Speeton Cliff, consisting of the higher part of the Lower Cenomanian and the Middle Cenomanian strata, was published by Mitchell (1996, fig. 2). In this log, the succession is divided into numbered units designated by the prefix 'SLC' (Speeton Lower Chalk) and the individual marl-limestone couplets are assigned couplet letters and numbers according to the scheme introduced by Gale (1995). The standard section given here (Figure 5.22) is based on an unpublished log of the entire Ferriby Chalk by Professor A.S. Gale, which has been checked against photographs of the sections taken by Dr C.V. Jeans (Figure 5.23) and (Figure 5.24). Additional details of the basal part of the Ferriby Chalk are taken from a log published by Mitchell (1995a, fig. 11).

Biostratigraphy

Speeton Cliff is critical to the international correlation of the Albian–Cenomanian boundary because of the apparent unbroken sedimentary record across this interval (see below). Inoceramid bivalves belonging to the group of *Inoceramus anglicus* Woods range through the higher part of the Red Cliff Hole Member and the overlying Crowe's Shoot Member, up to the base of the Lower Inoceramus band. *Aucellina* sp., showing the striate microsculpture characteristic of forms from the Cenomanian strata (Morter and Wood, 1983), are common throughout the Red Cliff Hole Member. Continuing the distribution pattern seen in the condensed Paradoxica Bed equivalent elsewhere, the genus appears to become extinct in the higher part of the Crowe's Shoot Member. The appearance of the thick-shelled *Inoceramus crippsi* Mantel in the coarse-grained shell-detrital chalks of the Lower Inoceramus Bed chalks, can be used, by analogy with the Hunstanton Cliffs succession, to mark the base of the *Sharpeiceras schlueteri* Subzone of the Lower Cenomanian *Mantelliceras mantelli* Zone.

The reappearance of inoceramid bivalve shell debris in the Upper Inoceramus Bed has been inferred (Mitchell *et al.,* 1996) to correspond to the transgressive sediments at the base of the *Mantelliceras dixoni* Zone. This assignment is supported by the occurrence of *Inoceramus* ex gr. *virgatus* Schlüter in a conspicuous group of six pale limestones (the '6 Band Group' of Jeans, 1980; SLC6A–F of Mitchell, 1996). This equates with the *Inoceramus virgatusacme* that is found throughout northern Europe in a group of noticeably more calcareous beds (marker horizon A of Mitchell *et al.,* 1996) in the lower part of the *dixoni* Zone; the highest of these limestones has yielded a single specimen of *Mantelliceras dixoni* Spath. These limestones are followed by a unit of marly chalk containing the rhynchonellid brachiopod *Orbirhynchia mantelliana* (J. de C. Sowerby). This marker event (B of Mitchell *et al.,* 1996), called by Jeans (1980) the 'Lower Orbirhynchia Band', correlates with the lowest of the three *mantelliana* bands of the Southern Province ((Figure 2.8), Chapter 2) and is followed by a conspicuous pale, massive limestone, SLC8.

The Middle Cenomanian section is situated about 100 m beyond the large fallen mass of Middle Turonian cliff (Weather Castle, [TA 176 748]). All the beds have well-developed ferroan calcite cements. The section described by Mitchell (1996) is situated below Buckton Cliffs [TA 183 747].

The critical stratigraphy and correlation of the lower part of the Middle Cenomanian Substage at Speeton Cliff has been discussed in detail (Paul *et al.,* 1994; Mitchell *et al.,* 1996; Mitchell and Carr, 1998). The Totternhoe Stone here rests on a burrowed chalk, rather than on a well-developed erosion surface, as in the case of the condensed successions on the Market Weighton

Axis and the East Midlands Shelf. The Totternhoe Stone itself is complex, comprising silty marls, passing up into calcarenitic chalks and then into normal chalks. Its base lies below the base shown by Mitchell. This succession consists of the condensed components of four marl-limestone couplets (B41–43; C1) of the standard Cenomanian cyclostratigraphy established by Gale (1995). The main calcarenitic part of the Totternhoe Stone largely consists of couplet 42 of Gale.

The position of the Arlesiensis Bed (marker E and the marl of Couplet B41 of Gale (1996)) of the Southern Province (e.g. Southerham Grey Pit and Folkestone to Kingsdown. GCR sites), can be inferred from the position of the lower (MCE1a) of the pair of Middle Cenomanian positive $\delta^{13}C$ excursions recognized throughout northern Europe by Mitchell *et al.* (1996). This 10 cm-thick silty marl has yielded specimens of (Paul *et al.,* 1994, fig. 11) the diagnostic lower Middle Cenomanian inoceramid bivalve index species, *Inoceramus schoendorfi* Heinz, and a single specimen of the rhynchonellid brachiopod *Orbirhynchia mantelliana,* but not the eponymous *Lyropecten (Aequipecten) arlesiensis* (Woods).

The equivalent of the Cast Bed (couplet C1) rests on a burrowed limestone that equates with the Tenuis Limestone of the Southern Province. This boundary at Speeton Cliff therefore corresponds to the base of the Zig Zag Chalk Formation of that province (Bristow *et al.,* 1997), but it probably cannot be mapped out. The silty Cl marl contains the two belemnites *Praeactinocamax primus* (Arkhangelsky) and *Belemnocamax boweri* Crick, indicating the position of marker horizon F and the *primus* event (Ernst *et al.,* 1983; Christensen, 1990) of the northern European scheme. Other fossils recorded from this bed include *Inoceramus schoendorfi* and the thin-shelled pectinacean bivalve *Entolium orbiculare* (J. Sowerby) as well as the ammonites *Acanthoceras rhotomagense* (Brongniart), *Turrilites costatus* Lamarck (indicating the *costatus* Subzone of the *rhotomagense* Zone) and *Sciponoceras baculoides* (Mantell). *Belemnocamax boweri* ranges up above the marl, into the limestone of couplet Cl and the overlying C2 couplet. The higher and more strongly developed of the two Middle Cenomanian positive $\delta^{13}C$ excursions (MCE1b), as elsewhere, lies at the level of the C1 marl-limestone couplet.

Orbirhynchia mantelliana is restricted here to a single couplet (C4), compared with its greater range in the Southern Province, for example couplets C6–C11 at Southerham Grey Pit, constituting the highest of the three *Orbirhynchia mantelliana* bands. The so-called P(lanktonic)/B(enthic) break (marker horizon G), which is marked by a sudden increase in planktonic foraminifera as a percentage of the total foraminiferal assemblage, falls here at the base of a thick marl seam (SLC13), which weathers back in the cliff.

Jukes-Browne Bed 7 of the Southern Province successions is represented here by the 1 m-thick calcarenitic Nettleton Stone (SLC17B) with its basal Nettleton Pycnodonte Bed marl (SLC17A), which contains the small oyster *Pycnodonte.* This oyster-rich marl equates with the *Pycnodonte* event (Ernst *et al.,* 1983; Ernst and Rehfeld, 1997) of the northern European scheme.

The succession from the top of the Nettleton Stone to the sub-Plenus erosion surface at the top of the Ferriby Chalk (the Louth Member of Jeans, 1980, fig. 3), is lithologically and faunally similar to the succession at Melton Bottom Chalk Pit and also to the so-called 'Arme *rhotomagense* Schichten' of northern Germany. This interval consists of much more calcareous, rhythmically bedded, poorly fossiliferous chalks, and tends to maintain a more or less constant thickness throughout the Northern Province (cf Jeans, 1980, fig. 1). The development of the marl-limestone couplets here, and also at the Middlegate Quarry, South Ferriby, is virtually identical to that in northern Germany, and the same short-term exogyrine oyster occurrences (the *Amphidonte* events of Ernst *et al*., 1983) can be recognized.

The Albian–Cenomanian boundary and division of the Cenomanian Stage

At Speeton Cliff, in an apparently unbroken sedimentary record across the Albian–Cenomanian boundary, the base of the Cenomanian Stage can be exactly located. The boundary is drawn through the trough between the top two of a well-marked triplet of closely spaced positive 8^{13}C peaks (Figure 5.21). The expanded Speeton Cliff equivalent (Crowe's Shoot Member) of the Paradoxica Bed of the Hunstanton Cliffs GCR site, is separated from the extrapolated base of the Cenomanian strata by nearly 6 m of red sediments, including marls, marly chalks and chalks with marl flasers (Figure 5.21), comprising the highest beds of the Weather Castle Member and the entire Red Cliff Hole Member of the Hunstanton Red Chalk Formation. It is these beds (and part of the underlying Dulcey Dock Member) that are absent from the thin platform successions, for example at Melton Bottom Chalk Pit, Middlegate Quarry, South Ferriby and Hunstanton Cliffs, where there is always a major hiatus at the top of the Hunstanton Red Chalk Formation. The top of this succession at Speeton Cliff consisting of 1.3 m of alternating thin marls and marly chalks, constituting the upper part of the Red Cliff Hole Member, equates with the thin dark red marl beneath the Paradoxica Bed at Hunstanton Cliffs, and rests on a deeply burrowed erosion surface.

The extrapolated base of the Cenomanian Stage lies approximately 0.5 m beneath the top of the Weather Castle Member. It is situated just below the upper limit of forms of the thin-shelled bivalve *Aucellina* with coarse-reticulate microsculpture, (Morter and Wood, 1983) and just below the entry of the terebratulid brachiopod *Concinnithyris subundata (*J. Sowerby). The occurrence of the latter species in abundance at the base of the Red Cliff Hole Member was the palaeontological criterion used by Jeans (1973, 1980) to define the base of the Lower Chalk. No ammonites or inoceramid bivalves have been found at Speeton Cliff in the boundary succession, but the base of the Cenomanian strata falls within the range of the belemnite *Neohibolites praeultimus* Spaeth, which hitherto was believed to be restricted to the highest Albian succession. It also lies just below the first local appearance of the ostracod *Rehacythereis bemerodensis* (Bertram and Kemper), which occurs later here than in southern England (Mitchell, 1995a).

The Lower–Middle Cenomanian boundary transition is also more complete at Speeton Cliff than in the platform successions to the south, for example Melton Bottom Chalk Pit on the Market Weighton Axis, and the Middlegate Quarry, South Ferriby, on the East Midlands Shelf At the latter localities, the equivalent of the basal Middle Cenomanian *Cunningtoniceras inerme* ammonite Zone of the Southern Province is completely missing at the hiatus marked by the sub-Totternhoe Stone erosion surface (cf. Mitchell, *et al., 1996,* fig. 3).

Part 2: Welton Chalk and Burnham Chalk formations (Buckton Cliffs to Stottle Bank)

At the eastern end of Buckton Cliffs, the dip brings the boundary between the Ferriby Chalk and Welton Chalk formations down to sea level, close to a wave-washed point known as 'Kit Pape's Spot' [TA 1886 7454]. To the west of this point [TA 1868 7460], there is considerable tectonic complication, with the base of the flinty Welton Chalk being locally thrust over the Black Band. The flintless, shell-detrital chalk that normally intervenes between the Black Band and the lowest flinty chalk is here represented merely by fragments incorporated in the crush-zone associated with the thrust plane. A conspicuous vertical fault recorded by Rowe (1904) in the cliff near this point had a throw of only about 4 ft (1.2 m), but exhibited horizontal slickensiding aligned S20°E, indicating a predominantly lateral displacement. This sense of movement is the same as that shown by the thrust. Nearby sections here (e.g. Rowe, 1904, pl. 19) show a normal succession above the Black Band, although the flintless chalk component appears to be somewhat thinner (*c.* 3.5 m) than the 4–5 m found elsewhere. However, Rowe suggested that this reduction in thickness was due to compaction.

Sherborn's longitudinal cliff section (Rowe, 1904, pl. 38) showed that chalk with tabular flints (identified as the *Holaster planus* Zone) occupied the higher part of the cliffs between the eastern end of Buckton Cliffs and a point, Gull Nook [TA 218 728]. Beyond Gull Nook, the cliff reduced in height towards Little Thornwick Bay, so that successively lower levels of the underlying (Welton) Chalk appeared in the top of the cliff. This is partly confirmed from oblique aerial photographs, in which the up-section change, from the massive-bedded chalks of the Welton Chalk Formation, to the thin-bedded chalks with closely spaced tabular flints of the Burnham Chalk Formation, can be clearly seen (Figure 5.25), as can two closely spaced crevices some distance below which represent the paired Deepdale Marls (Figure 5.26). However, the succession may extend much higher than in Sherborn's interpretation. Somewhat higher than the base of the thin-bedded chalks, and only two-thirds of the way up the cliff, the lithological change (within the *Sternotaxis plana* Zone) at the Ulceby Marl from darker, very hard chalks, to paler and relatively softer chalks, can be confidently identified at a conspicuous recess on top of a ledge. Above this marl an additional *c.* 30 m of chalk can be inferred.

This suggests, on the basis of data from outcrop and subcrop successions (cf. Wood, 1992, fig. 34; Berridge and Pattison, 1994, fig. 19) that the topmost beds in the 90–100 m high cliffs to the north-west of the nature reserve may actually lie close to the top of the *Micraster cortestudinarium* Zone. A thin capping of the post-Ulceby Marl succession can be traced to some 300 m southeast of Danes Dyke. Sherborn's interpretation that the chalk with tabular flints (Burnham Chalk) could be traced only as far as Gull Nook is also incorrect. Whilst the cliff height reduces to the south-east, bringing in successively lower beds at the top of the cliff, the basal beds of the Burnham Chalk are actually still present in Sanwick Bay.

2.1: The Staple Nook (adjacent to Scale Nab) zone of deformation

In an embayment known as 'Staple Nook' (Newk), at the south-east end of Bempton Cliffs, the Welton Chalk strata, which dip at 10°–15° to the south, are interrupted by a narrow zone, 200 m wide [TA 2046 7370]–[TA 2060 7358], within which the Chalk in the cliff and rock platform has undergone intense deformation. This famous example of localized tectonism in the Chalk, which is also known, less correctly, as 'Old Dor' (after the broad fold at the southeast end of the zone of deformation) and 'Scale Nab' (after the headland at the north-west end), was first described by Phillips (1829). It was later the subject of three photographs published by the Yorkshire Geological and Polytechnic Society, together with a description (Davis, 1885); two of these photographs were used by Rowe in reduced form (1904, p1.24). Lamplugh (1895) described the deformed strata in vivid detail and, noting that similar contorted strata existed inland, for example at the Foxholes Pit [TA 012 735], made the far-sighted observation that it might be possible to identify zones of pressure and movement.

Starmer (1995b) gave a modern structural interpretation based solely on the photographs, and related the deformation to late-stage reactivation of the underlying deep-seated Bempton Fault, which had been previously recognized by Kirby and Swallow (1987) in seismic profiles. Oblique aerial photographs show that the structurally simple Old Dor fold comprises only the more massively bedded Welton Chalk Formation; the intensely deformed strata to the north-west belong to the relatively thin bedded Burnham Chalk Formation, which here occupies what was initially a simple syncline between Old Dor and the undeformed Scale Nab headland.

2.2: Little Thornwick Bay–Great Thornwick Bay–North Landing

Annotated photographs (Rawson and Whitham, 1992a, fig. 33) of the cliff sections in Little Thornwick Bay, and photographs of the cliffs in Chatterthrow [TA 2308 7239], immediately to the west, and of the inaccessible sections in Sanwick Bay [TA 2288 7245] (Lamplugh, 1896, fig. 4; Rowe, 1904, pls 26, 27), all appear to show the key Ferruginous Flint marker horizon (of the Welton Chalk Formation) low in the cliffs. There is also a crevice marking the position of the Melton Ross Marl some distance above, and the Barton Marls are seen at sea level.

Lithostratigraphy

The Barton Marls are seen at low water at the base of the headland in Little Thornwick Bay, and at the base of Thornwick Nab' (Rawson and Whitham, 1992a, fig. 33). On the west side of Great Thornwick Bay, the deeply dissected headland known as 'Thornwick Nab' exposes the Ferruginous Flint and the underlying Barton Marls (Rawson and Whitham, 1992a, fig. 33). A huge expanse of rock platform is exposed at low water in the centre of the bay, and the iron-stained flint provides a useful marker horizon. It is much more tabular and continuous here than it is in the Melton Bottom Chalk Pit (see GCR site report, this volume), and Melton Ross Quarry sections, in other words, it is more like a Burnham Chalk flint. On the east side of the bay, the Melton Ross Marl forms a deep crevice near the foot of the cliffs at low water, and the Deepdale Marls can be recognized by two crevices halfway up the cliff. The latter can be readily traced in the aerial photographs of the inaccessible cliffs between Great Thomwick Bay and North Landing.

In the latter bay, the Ferruginous Flint is found on the scars near the north-west headland. The basal beds of the Burnham Chalk, with their distinctive grouping of large flints and the North Ormsby Marl, can be seen halfway up an arch on the west side of the bay, but the flints are much less well developed than in the type sections in Lincolnshire, and the marl is represented merely by a thin crevice (Figure 5.4). The overlying beds are extremely hard, veined by calcite, and contain numerous closely spaced tabular flints, including paramoudras. At the head of the bay, the Ulceby Marl forms a conspicuous crevice on each side of the slipway. Part of the section was published by Wood and Smith (1978, fig. 5). The overlying beds include two horizons with oysters, 2 m and 4 m above the marl respectively. The upper of these, rather than the lower (as in Rawson and Whitham, 1992a, fig. 32), is the correlative of the Ulceby Oyster Bed. On the basis of this interpretation, the succession above the Ulceby Marl here appears to be relatively expanded, and similar to that in Enthorpe Railway Cutting (see GCR site report, this volume), although only one oyster bed has been identified at this level in the latter locality. The marl seam near the top of the section is inferred to be the lowest of the Enthorpe Marls.

Mortimer (1878) first drew attention to the vertical columns of flint (paramoudras) at the base of the cliffs on the east side of the bay. Rowe (1904) stated that six such flints could be seen from the sea to the south-east of North Landing, noting that they characterized a level in the upper part of his *Holaster planus* Zone. It is now known that paramoudras are relatively common everywhere in the *Sternotaxis plana* Zone at this level, i.e. in the interval with closely spaced thick tabular flints between the Wootton Marls and the Ulceby Marl. However, they are relatively inconspicuous in the degraded inland quarry sections, and North Landing is by far the best place to study them. Some of the detached, wave-rounded, paramoudras lying on the beach here display a complex internal structure. Paramoudras reappear low in the *Micraster cortestudinarium* Zone, above the Kiplingcotes Marls, notably the famous flint formerly seen in Ashby Hill Quarry [TA 2405 0060] in Lincolnshire (Toynton and Parsons, 1990).

Biostratigraphy

Barrois (1876) was the first geologist (28 years earlier than Rowe) to use fossils to subdivide this composite section into zones. His pioneering work was remarkably correct by today's standards. He recognized that the chalk in Little and Great Thornwick Bay must belong to the *Terebratulina gracilis* (i.e. *lata*) Zone because of the general rarity of macrofossils, apart from the inoceramid bivalve *Inoceramus brongniarti* (i.e. I. ex gr. *lamarcki* Parkinson). Even more importantly, he appreciated that the 'very hard, siliceous, crystalline chalk' in North Landing, with 'closely-spaced, smokey-grey, predominantly tabular flints' (his 'Chalk with grey flints of North Sea') contained fossils indicative of the *Holaster planus* Zone, including the zonal index fossil. Rowe (1904) actually recorded 30 examples of *Sternotaxis plana* from here, noting that it was 'common'. It is surprising that there are no records of *Micraster,* since *M. corbovis* Forbes occurs regularly at this level in inland pits in Yorkshire and in Lincolnshire. Barrois noted this same distinctive flinty unit (i.e. basal Burnham Chalk Formation) at the top of the Bempton cliffs, and also in the highest part of the quarries at Hessle (Sheppard, 1903, fig. 38), west of Hull. On the basis of the latter observation, he named the underlying, less flinty, *gracilis* Zone Chalk in the quarries, the 'Chalk of Hessle'.

2.3: North Landing–Stottle Bank

From the eastern headland of North Landing, for 1.8 km to Stottle Bank, 0.5 km north of Selwicks Bay, there is no access to the shore, although it is feasible, if extremely dangerous, to land from a boat at low water on the scars that extend out some distance from the cliffs near the headland known as 'Breil Nook' on modern maps (Figure 5.27). Rowe (1904) described doing this, but there has been no subsequent report of anybody else landing here in the intervening one hundred years!

Inspection of a set of oblique aerial photographs of this coastal stretch, in conjunction with telephoto photographs taken from the top of the cliffs, and photographs of the cliff section on the east side of North Landing, suggests that it may be possible to begin to interpret the stratigraphy. The Ulceby Marl is near the top of the headland on the east side of North Landing, and appears to come down to near sea level to the east of the recess known as 'Newcombe'. Farther to the east, the record (Rowe, 1904) of specimens of *Micraster, Sternotaxis placenta* (Agassiz) and common inoceramid bivalves from the foot of the cliffs east of Breil Nook points to the interval, low in the *Micraster cortestudinarium* Zone, between the Kiplingcotes Marls and the Easthorpe Tabular Flints (cf. Enthorpe Railway Cutting GCR site), in which case, the strong crevices seen at the foot of Breil Nook itself could be the Kiplingcote Marls. This interpretation agrees with the 6 inch to 1 mile longitudinal section of this coastal stretch section (Sherborn in Rowe, 1904, pl. 38), which places the base of the *M. cortestudinarium* Zone at about this position.

In this same longitudinal section, a 'well-marked line of holes' was used to indicate the approximate boundary between the *Micraster cortestudinarium* and *M. coranguinum* zones. This marker horizon was said to be traceable from a little east of Breil Nook, where it appeared in the top of the cliff below the drift (Rowe, 1904, pls 29, 38), to a point just south of Stottle Bank, where it reached sea level. It is actually improbable that this 'line of holes' is at or even near the base of the *coranguinum* Zone, since there is no evidence at Stottle Bank of the common thick-shelled inoceramid bivalves (*Volviceramus* and *Platyceramus*) that characterize the basal 15 m of this zone in inland sections (see Whitham, 1991; Wood, 1992). In view of the fact that another 'line of holes' (i.e. karst development over a marl seam) at Stottle Bank marks the approximate position of the base of the Santonian portion of the *coranguinum* Zone (see below), it is more likely that Rowe and Sherborn's marker is the Middleton Marl (i.e. near the top of the Coniacian portion of the zone), or that the latter marl is represented by the deep crevice, seen 13 m beneath the basal Santonian marker marl, at the base of the deep water gully at Stottle Bank itself. This latter interpretation fits with the record of *Cladoceramus* in NIREX Borehole 37 in north Lincolnshire, 12 m above the Middleton Marl.

Part 3: Stottle Bank–Selwicks Bay–Flamborough Head (High Stacks)

Stottle Bank to Flamborough Head crosses the complex tectonic structures related to faulting in Selwicks Bay (Figure 5.28), (Figure 5.29), (Figure 5.30). The faulting and folding is related to east–west thrusts initiated as frontal movements from the offshore Dowsing Fault.

Lithostratigraphy and tectonic structures

The previously unpublished *c.* 30 m section (Figure 5.29) begins in the Burnham Chalk at the lowest point that can be seen in the water-filled gully at the base of Stottle Bank, and extends to the High Stacks Flint, which is found near the base of Kindle Scar, and at the base of the West Cliff in Selwicks Bay. The High Stacks Marl (Whitham, 1993, fig. 5), 3.3 m above this flint, forms a conspicuous crevice at the foot of the cliff at the back of the bay. Above this level, extensive faulting breaks up the basal Flamborough Chalk succession. In the centre of the bay, a complex, brecciated, calcite-veined fault zone is seen in the cliffs, and can be traced seawards on the scars. This is the Selwicks Bay Fault of the earlier literature. On the south side of the bay, on the far side of this fault, flinty chalk of the Burnham Chalk Formation is seen at the base of the scars at low water, and chalk with flints continues to the top of the cliff, although some of the flints are relatively inconspicuous.

The early workers (e.g. Lamplugh, 1880, 1895), presented a relatively simple structural picture of Selwicks Bay, in which flintless (i.e. Flamborough Chalk Formation) chalk was brought into juxtaposition with flinty (Burnham) chalk by the Selwicks Bay Fault, the extent of the vertical downthrow being determined as about 80 ft (24 m) to the north. However, Starmer (1995a) has demonstrated that Selwicks Bay itself (as well as the cliffs to the north) is structurally extremely complex, with the chalk having undergone four temporally widely separated phases of deformation, including folding, faulting and thrusting (Figure 5.28) and (Figure 5.30). In his analysis, he claimed to have traced the highest flint (High Stacks Flint) close to the main fault, which he termed the 'Frontal Faults' (of the entire complex), and assigned to the fourth phase of deformation. He considered that there was actually no significant vertical displacement, and that the apparent displacement resulted from a combination of synclinal folding and faulting. However, the succession on the far side of the Frontal Faults can be correlated in detail with that exposed to the south of Stottle Bank (see (Figure 5.28), (Figure 5.29) and (Figure 5.30)). In particular, a thick (unnamed) marl seam at Selwicks Bay, from which water issues, is represented at Stottle Bank by a crevice and associated solution-enlarged (karst) caves (a 'line of holes') in which kittiwakes nest. The lowest flint on the rock platform on the south side of the Frontal Faults is actually 21 m beneath the High Stacks Flint.

In (Figure 5.29), previously unpublished logs of the cliff sections from Stottle Bank to Kindle Scar, from the south side of Selwicks Bay on the south side of the Selwicks Bay Fault, and at Flamborough Head, are correlated.

Thin, poorly developed white flints are found in the Selwicks Bay section in the basal Flamborough Chalk Formation, some metres above the terminal Burnham Chalk flint (High Stacks Flint), but are absent from the section at High Stacks at Flamborough Head. The correlation of the higher Burnham Chalk Formation succession between Flamborough Head and the section immediately north of Kindle Scar (*c.* 0.5 km) is unequivocal. In each an unnamed pair of marls, 0.3 m apart, and a semi-continuous nodular flint, are seen 1.5 m and 3.7 m below the High Stacks Flint respectively. There is also a very tight correlation between the Burnham Chalk section on the south side of Selwicks Bay and that at Stottle Bank, although there is some problem with correlating the flints in the higher part of the Selwicks Bay section. These section details and correlations differ significantly from those presented by Whitham (1993, fig. 4).

Biostratigraphy

The biostratigraphy of the highest Burnham Chalk in these sections is extremely poorly known. Professor A.S. Gale (unpublished data) has collected specimens of the thin-shelled inoceramid bivalve *Cladoceramus undulatoplicatus* (Roemer) (now at the British Geological Survey, Keyworth) at two horizons beneath the unnamed marl seam on the south side of Selwicks Bay, allowing this part of the succession to be assigned to the basal Santonian *Cladoceramus undulatoplicatus* Zone of the standard European zonal scheme. About 1 m above the highest occurrence of *Cladoceramus,* he collected specimens of the echinoid *Infulaster infulasteroides* (Wright and Wright) (common over 1 m), terebratulid brachiopods (*Gibbithyris* sp.) and other inoceramid bivalves that are possibly *Sphenoceramus cardissoides* (Goldfuss). About 10 m above the marl, in the section immediately north of Kindle Scar, the occurrence of *Cordiceramus cordiformis* (J. de C. Sowerby) (British Geological Survey collections, unpublished) in fossiliferous, inoceramid bivalve-rich chalk over about 4 m suggests a correlation with the *Cordiceramusacme* in the Middle Santonian strata of northern Germany (Ernst, 1966; Ernst and Schulz, 1974), and indicates a possible upper limit to the Lower Santonian succession. This would fall in the higher part of the *coranguinum* Zone of the Southern Province. It is not possible at present to identify the Burnham–Flamborough boundary on a faunal basis. However, since it is known that the base of the *Uintacrinus socialis* Zone is situated 70 m above the High Stacks Flint, it is clear that the higher part of the equivalent of the *coranguinum* Zone, both the flinty (Burnham) and flintless (Flamborough) components, is enormously expanded here compared to its development in the Southern Province (about 87 m compared with 32 m from the base of the Santonian to Buckle Marl 1 at Seaford Head (Cuckmere to Seaford GCR site), (Figure 3.100) and (Figure 3.101), Chapter 3.

Part 4: Flamborough Head (High Stacks) [TA 257 704] to Sewerby Steps [TA 205 687]

The coast section from Flamborough Head (High Stacks) to Sewerby Steps can be divided into three separate parts by the structurally controlled inlets of South Landing and Danes Dyke, which provide the only access to the shore between High Stacks and Sewerby Steps. Excellent descriptions were given by Rowe (1904), Rawson and Whitham (1992b), Whitham (1992a,b, 1993) and Mitchell (1995b).

Lithostratigraphy

The composite lithostratigraphical section (Figure 5.31) of the flintless chalk is deliberately skeletal, in view of the thin bedding, complex sedimentology and the large number of minor marl seams. It is based on the stratotype Flamborough Chalk section published by Whitham (1993), but incorporates the corrections and additions made by Mitchell (1994, 1995b). The highest preserved Flamborough Chalk Formation at Sewerby Steps, which is approximately 5 m above OD, can be inferred from structural contours (Sumbler, 1996, fig. 2) to be about 380 m above the base of the Chalk Group. Whitham (1993) suggested that, in addition to the 165 m section in the cliffs, an additional 45–50 m of Flamborough Chalk, including sections no longer extant, cropped out on the top of the Wolds near Bridlington and Great Driffield. Even greater thicknesses of between 260 and 280 m of flintless chalk were proved in uncored wells near the coast of Holderness. Here the flintless (inferred Flamborough Chalk Formation) was overlain by up to 70 m of flinty chalk (assigned to the Rowe Formation by Sumbler, 1996).

Biostratigraphy

The Flamborough Chalk of the coast section extends from a horizon within the equivalent of the Middle Santonian part of the *Micraster coranguinum* Zone of southern England to low in the equivalent of the (Lower Campanian) *Offaster pilula* Zone. The entire equivalent of the *M. coranguinum* Zone, which spans the terminal Burnham Chalk and the basal Flamborough Chalk, was placed by Rowe (1904) in the local zone of *Infulaster rostratus.* This was based on the misunderstanding that, in view of the extreme rarity of the southern zonal index fossil, the flood occurrences, in the lower part of the Flamborough Chalk, of *Hagenowia anterior* Ernst and Schulz (mistakenly identified by him and later workers as *Infulaster rostratus* Forbes) could be used to characterize both the flinty (Burnham) and flintless (Flamborough) parts of the zone.

Little information is available on the biostratigraphy of the equivalent of the higher part of the *Micraster coranguinum* Zone. In the lower beds, there are few fossils, apart from sporadic occurrences of thin-shelled inoceramid bivalves and oysters, belemnites (*Gonioteuthis),* and sponges poorly preserved in limonite. Rowe (1904) recorded an 'almost obliterated ammonite, about 4 inches in diameter, from the base of the flintless chalk at High Stacks'. Some 20 m above the High Stacks Flint, a highly fossiliferous 1.5 m bed of chalk (first recognized by Lamplugh, 1895), containing abundant specimens of *Hagenowia anterior,* together with the small spherical calcareous sponge *Porosphaera globularis* (Phillips), can be traced in the lower part of the cliff for over 2 km. Whitham (1993) additionally recorded specimens of *Gonioteuthis westfalica* (Schlüter), the small rhynchonellid brachiopod *Orbirhynthia pisiformis* Pettitt, small corals and echinoid spines from this bed and, at an unspecified level near South Landing, both he and Rowe (1904) noted large ammonites tentatively assigned to *Parapuzosia (P.) leptophylla* (Sharpe).

In the highest part of the *pre-Uintacrinus socialis* Zone Flamborough Chalk succession, small crinoid plates and columnals attributed to the comatulid crinoid *Amphorometra* are not uncommon (Mitchell, 1994).

The Upper Santonian *Uintacrinus socialis* Zone (39 m) and *Marsupites testudinarius* Zone (27.5 m) are very well developed here, although their original recorded lower limits (Rowe, 1904) have been revised downwards (Whitham, 1993; Mitchell, 1994, 1995b) on the basis of bed-by-bed collecting, in the case of the *Uintacrinus socialis* Zone, by as much as 6 m. The thicknesses of the two zones are very much greater than in the Southern Province, where, at Seaford Head (Cuckmere to Seaford GCR site), they are 8 m and 10.6 m respectively (Mitchell, 1995b). They are also thicker here than in the correlative chalk facies standard section at Lägerdorf in northern Germany (Schonfeld and Schulz, 1996). This expansion of the Santonian, and also of the overlying Lower Campanian, successions compared with those in other areas is one of the most remarkable features of the higher part of the Chalk of the Northern Province.

There is a small overlap between the highest occurrences of *Uintacrinus socialis* and the lowest occurrences of *Marsupites testudinarius.* In the *M. testudinarius* Zone, Mitchell (1995b) recorded five discrete flood occurrences of the index crinoid (Figure 5.31), and recognized a stratigraphical separation between lower, unornamented or weakly ornamented calyx plates and higher, ornamented calyx plates, which could be used to divide the zone into two sub-zones. The higher part of the zone, as everywhere throughout northern Europe, is characterized by shell-detrital chalks made up of fragments and complete shells of oysters (mainly *Pseudoperna boucheroni* (Woods *non* Coquand)) and inoceramid bivalves (*Sphenoceramus):* this is the Grobkreide (coarse chalk) of German geologists.

The beds between the upper limit of *Marsupites* and the top of the section by Sewerby Steps, including the famous Flamborough Sponge Beds, were assigned by Rowe (1904) to the local zone of *Inoceramus* (now *Sphenoceramus) lingua,* which replaced the lower part of the Zone of *Actinocamax quadratus* then applied in the south. *Sphenoceramus lingua* (as used in England and Germany) is an unfortunate choice as zonal index fossil: as shown by Seitz (1965), this species concept can strictly be applied only to the holotype, which is an incomplete specimen that does not preserve the adult ornament. The interval in question is characterized by *S. patootensiformis* (Seitz) and *S. angustus* (Beyenburg), and is commonly assigned to the *S. patootensiformis* inoceramid bivalve Zone ((Figure 2.27), Chapter 2). Mitchell (1995b) sepa rated the basal beds of Rowe's *lingua* Zone as an independent zone of *Uintacrinus anglicus,* on the basis of recognizing two discrete minor floods of the eponymous crinoid. His one was defined as the 9 m interval between the disappearance of *Marsupites* and the highest *Uintacrinus anglicus* Rasmussen and approximately corresponds to the *Gonioteuthis granulataquadrata* belemnite Zone of northern Germany.

The Flamborough Sponge Beds consist of just over 10 m of chalk, with the basal beds lying some 15.5 m above the base of the *lingua* Zone (Whitham, 1993). These beds contain a spectacular, abundant, mixed assemblage of three-dimensionally preserved lithistid and hexactinellid siliceous sponges, in which the lithistids predominate (Reid, 1968). It is one of the most important and most diverse Upper Cretaceous sponge assemblages in Britain, apart from that of the Chalk Rock.

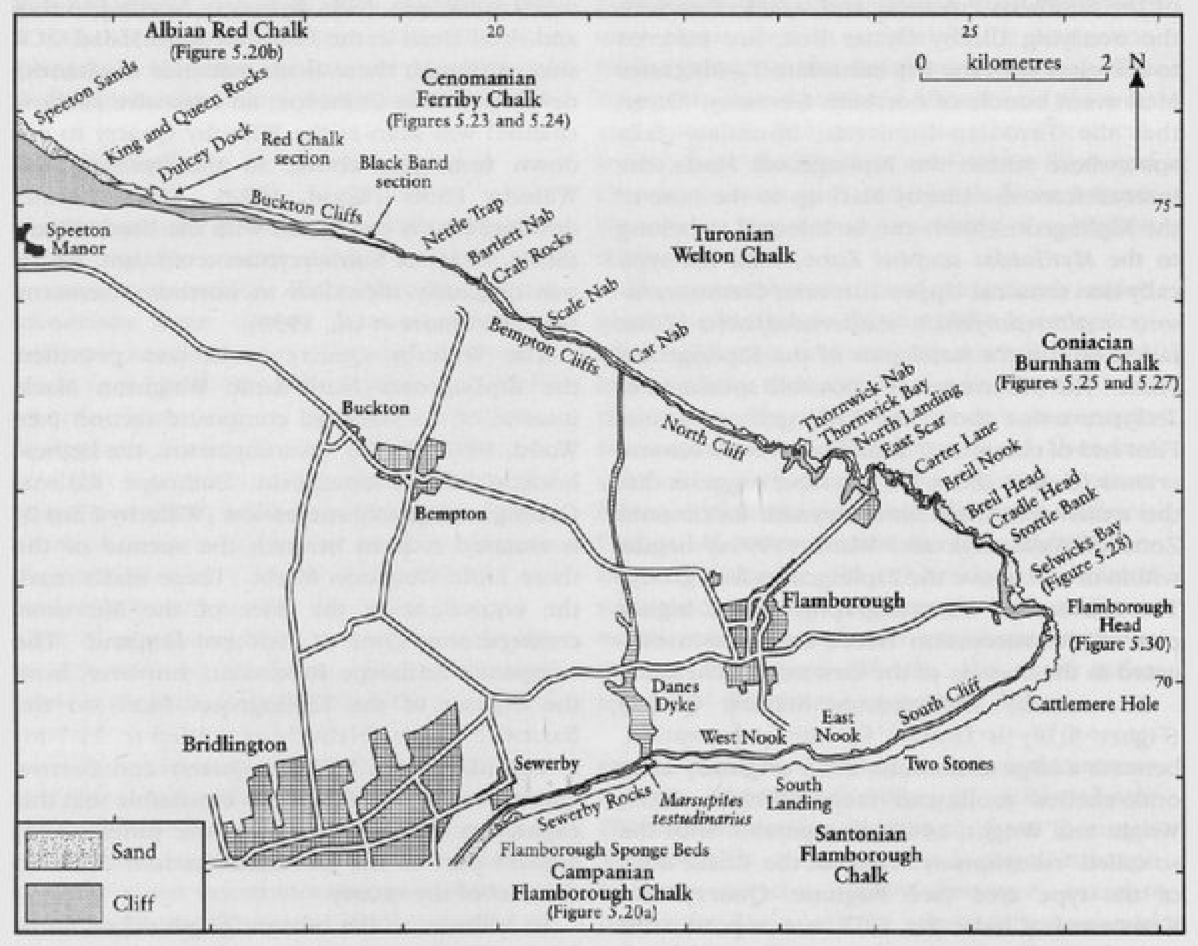
Offaster pilula (Lamarck) is recorded from one bed in the succession above the Sponge Beds and is the only evidence for the *O. pilula* Zone in the Northern Province.

Whitham (1993) recorded the appearance, in the highest beds of Flamborough Chalk preserved at Sewerby Steps, of the heteromorph ammonite *Discoscaphites* (now *Scaphites) binodosus* (Roemer), which he took to mark the base of the *Discoscaphites binodosus* Subzone (Wright and Wright, 1942) of the *Inoceramus (Sphenoceramus) lingua* Zone. This ammonite, together with common *Sphenoceramus* spp., characterizes the fauna of the flintless chalk succession exposed in the quarries on top of the Wolds. *Scaphites binodosus,* which was originally described from Westphalia in Germany, is restricted there to the Lower Campanian *lingua/quadrata* Zone (Kennedy and Kaplan, 1995b), which equates approximately with the *Echinocorys depressula* Subzone of the *Offaster pilula* Zone of the Southern Province. On the basis of the ammonite and inoceramid bivalve faunas, there is no evidence that the currently exposed inland chalk in Yorkshire extends any higher than this. However, faunas recorded (Wright and Wright, 1942; Whitham, 1993) from now backfilled pits north of Bridlington, including the only known specimen from the Yorkshire Chalk of the belemnite *Belemnitella* from the White Hill Reservoir section, may indicate a higher horizon, but the occurrence of *Scaphites binodosus* still places these sections in the lower part of the *pilula* Zone.

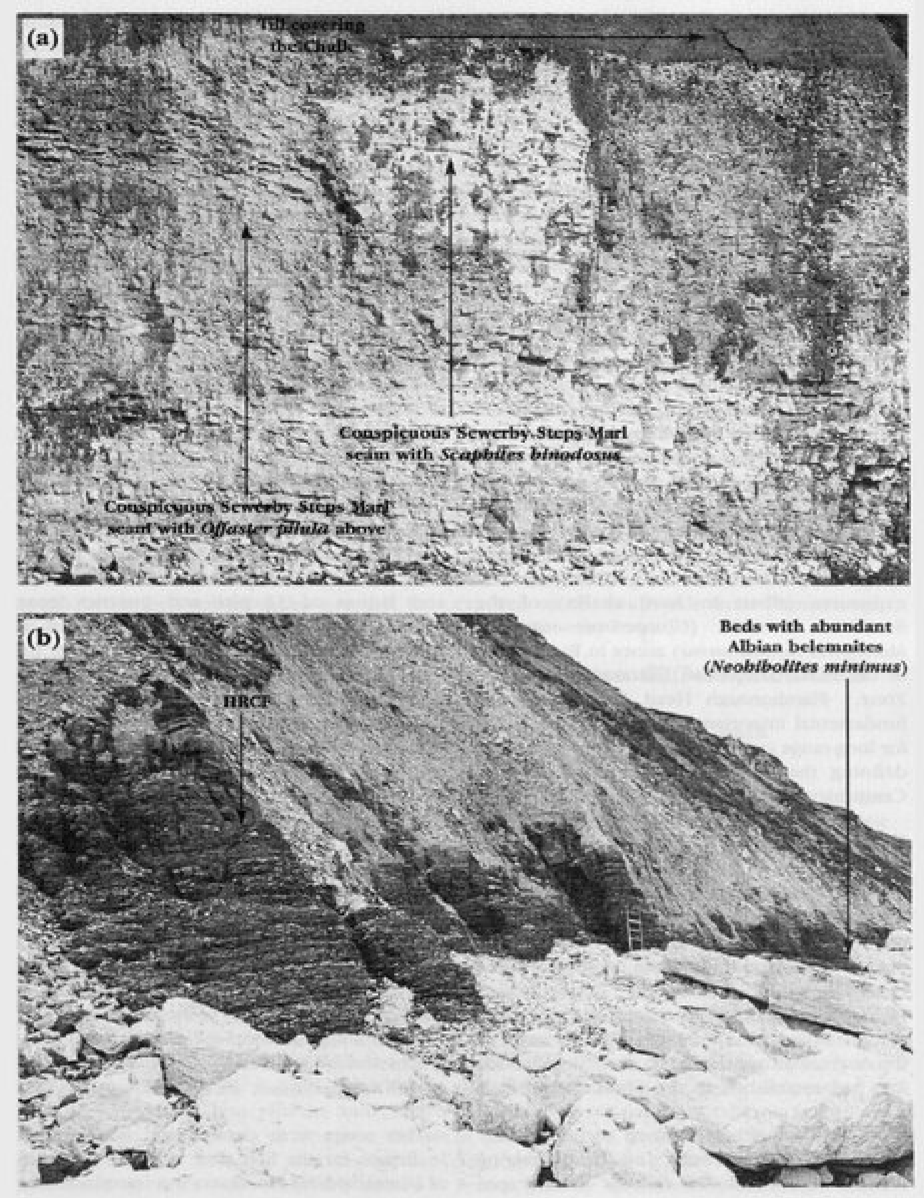
Conclusions

The Flamborough Head site spans the entire Northern Province Upper Cretaceous succession and is therefore crucial to the interpretation of the successions in the adjacent North Sea Basin. The site is unique in its exposures of a very complete and expanded Lower–Upper Cretaceous boundary succession in red chalk facies at Speeton Cliff. The base of the Cenomanian Stage can be recognized on the basis of stable isotope stratigraphical correlation with the boundary stratotype section in southern France. The greatly expanded Cenomanian succession (compared with other Northern Province sections) has been investigated in respect of macrofossil and microfossil biostratigraphy, cyclostratigraphy and stable isotope stratigraphy and compared with the standard successions in the Southern Province, such as those found at the Southerham Grey Pit and Folkestone to Kingsdown GCR sites. The Santonian–Lower Campanian succession is more expanded here than anywhere else in the UK and provides a key reference section for the base of the Campanian Stage. Parts of the Dowsing Fault structure intersect the coast in the northern part of the site, illustrating the influence of such structures on the deformation of the Chalk.

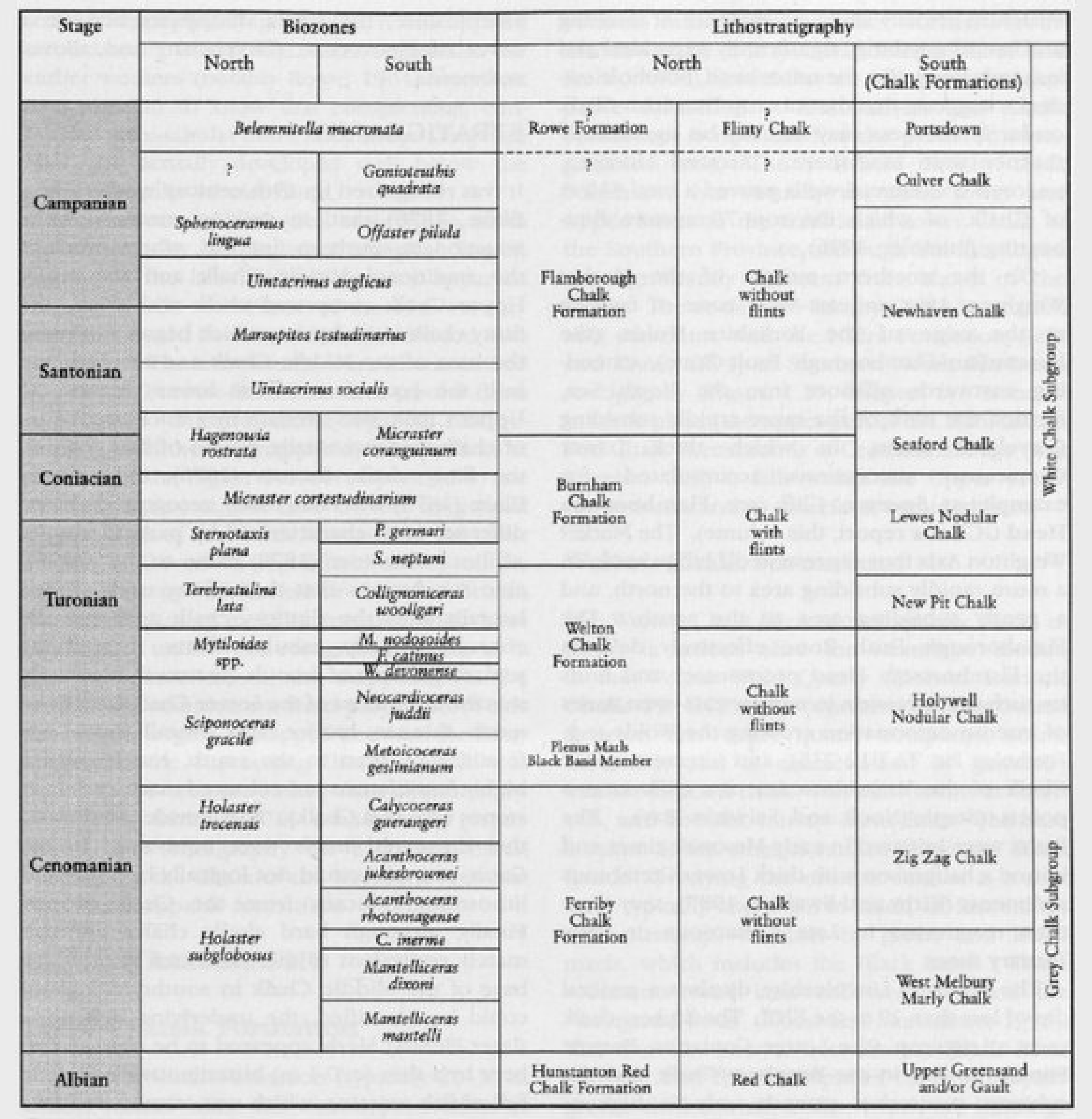
[References]



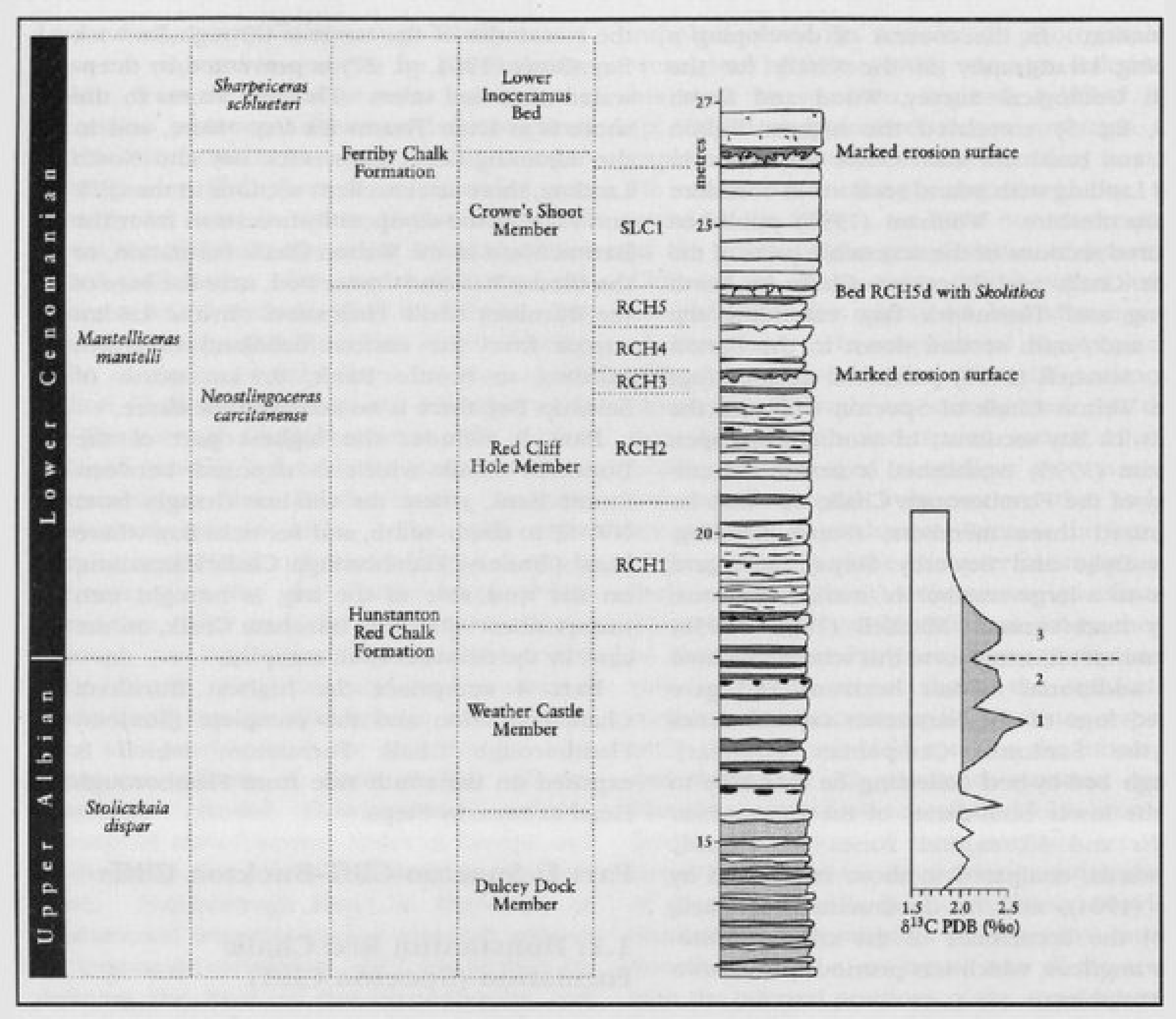
(Figure 5.19) Location of key sections in the Flamborough Head GCR site.



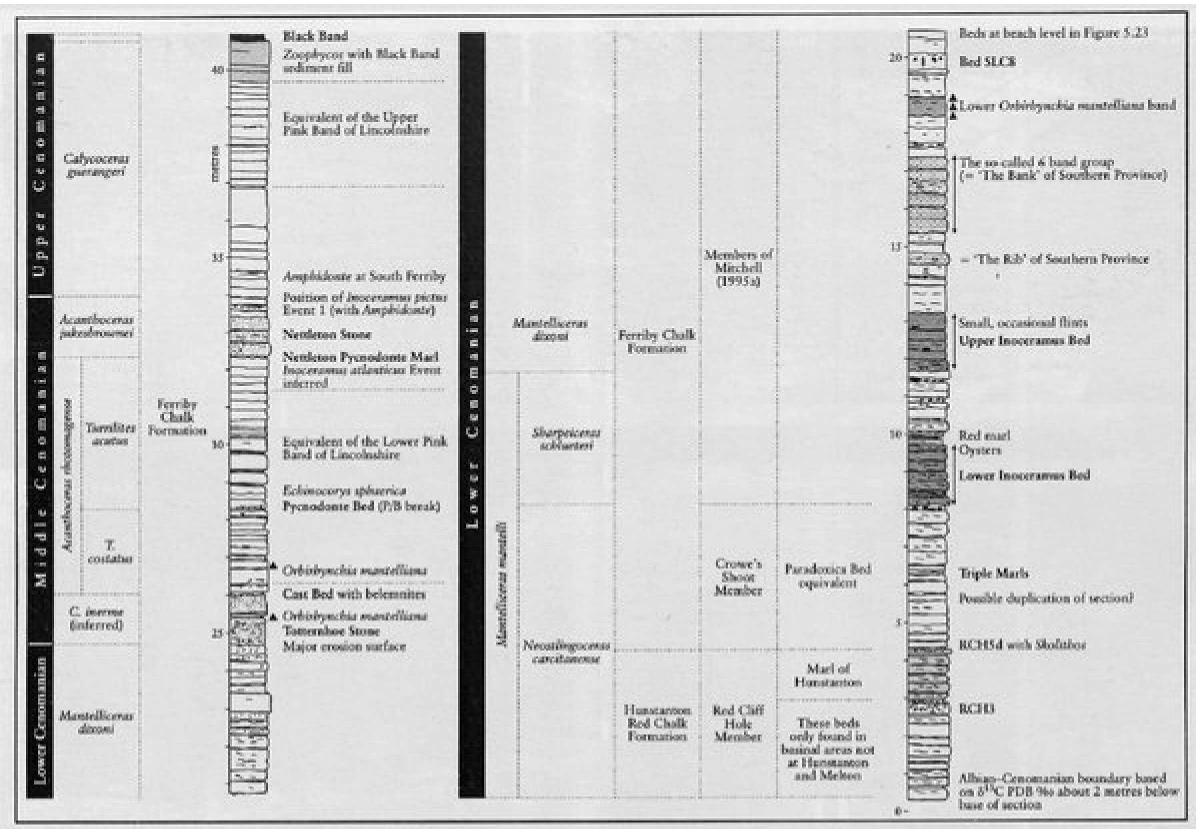
(Figure 5.20) The oldest and youngest Chalk exposed on the Yorkshire coast of Flamborough Head. (a) The youngest chalk south of Sewerby Steps in the Flamborough Chalk Formation. This chalk is flintless but contains numerous marl seams. (b) The oldest chalk is at the base of Speeton Cliff in the Hunstanton Red Chalk Formation (HRCF, labelled). This chalk is flintless, but contains numerous flaser marl seams and nodular chalk layers. (Photos: R.N. Mortimore.)



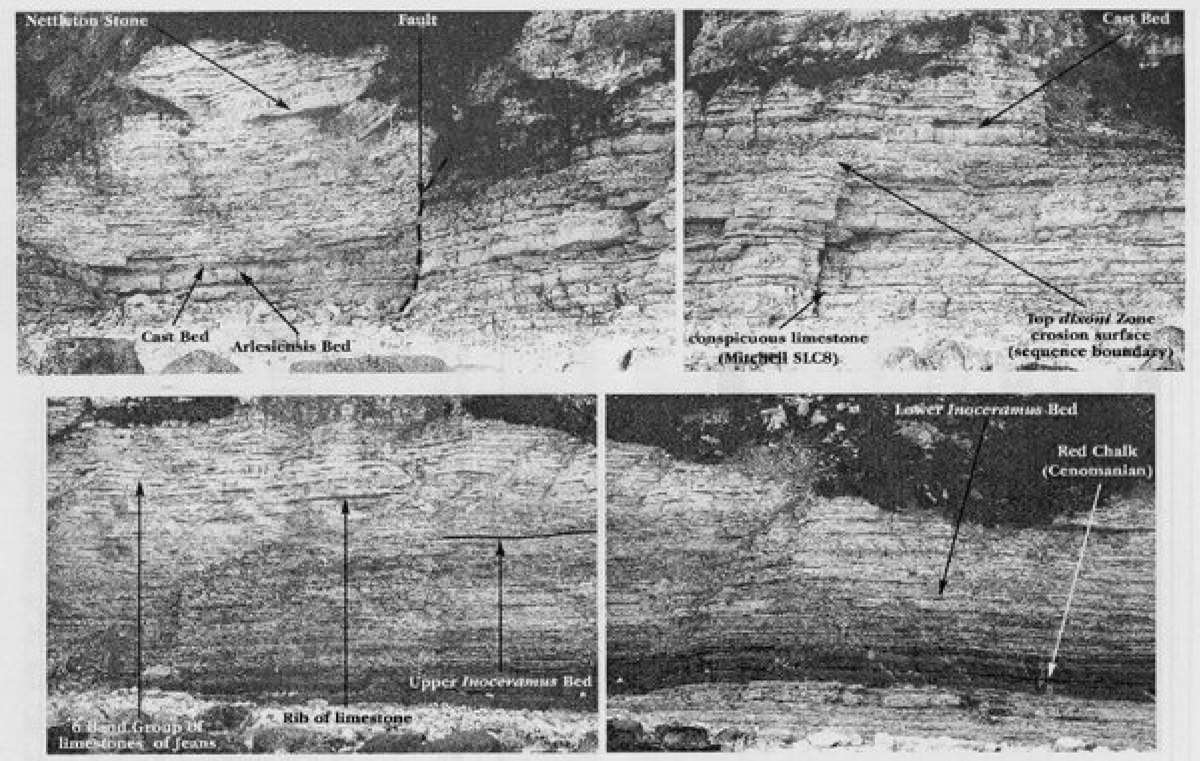
(Figure 5.3) The stratigraphy of the Northern Province Chalk (compare with (Figure 1.5), Chapter 1 and Figures 2.8, 2.9, 2.21, 2.22 and 2.27, Chapter 2).



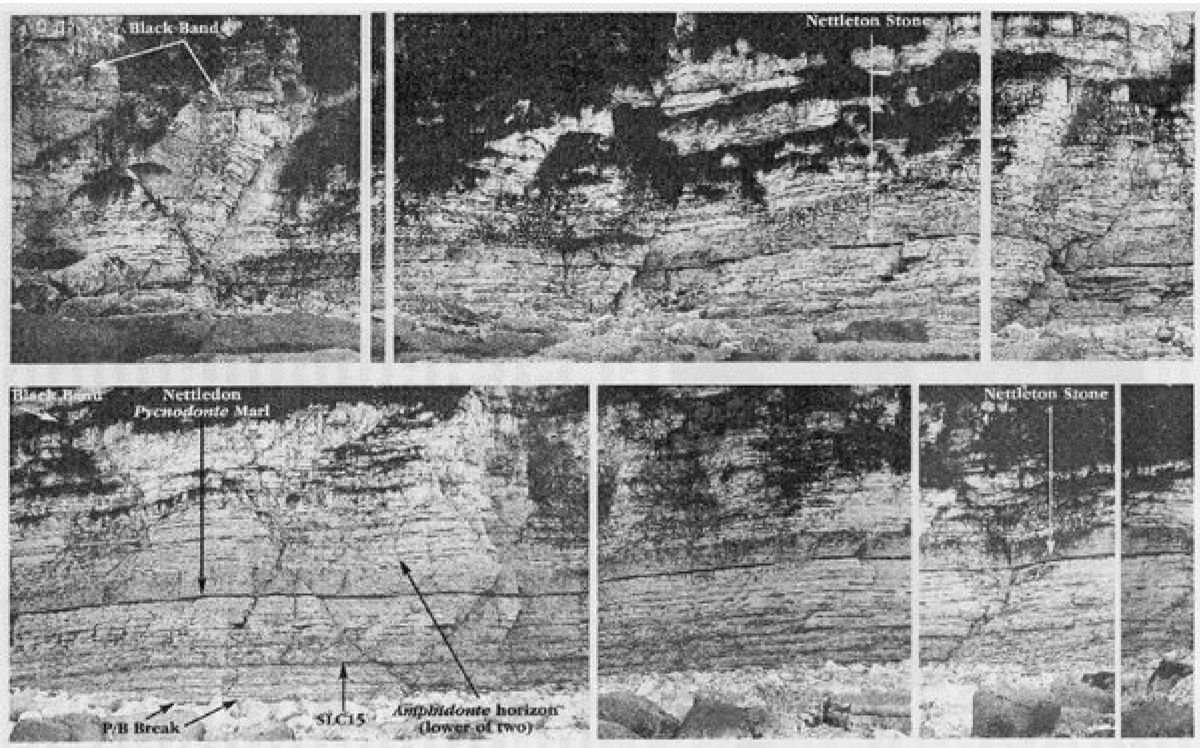
(Figure 5.21) The Hunstanton Red Chalk and Ferriby Chalk formations at Speeton Cliff, Yorkshire, showing the stable isotope $S^{13}C$ curve used to identify the Albian–Cenomanian boundary, between peaks 2 and 3. (Modified from Mitchell, 1995a, fig. 11.)



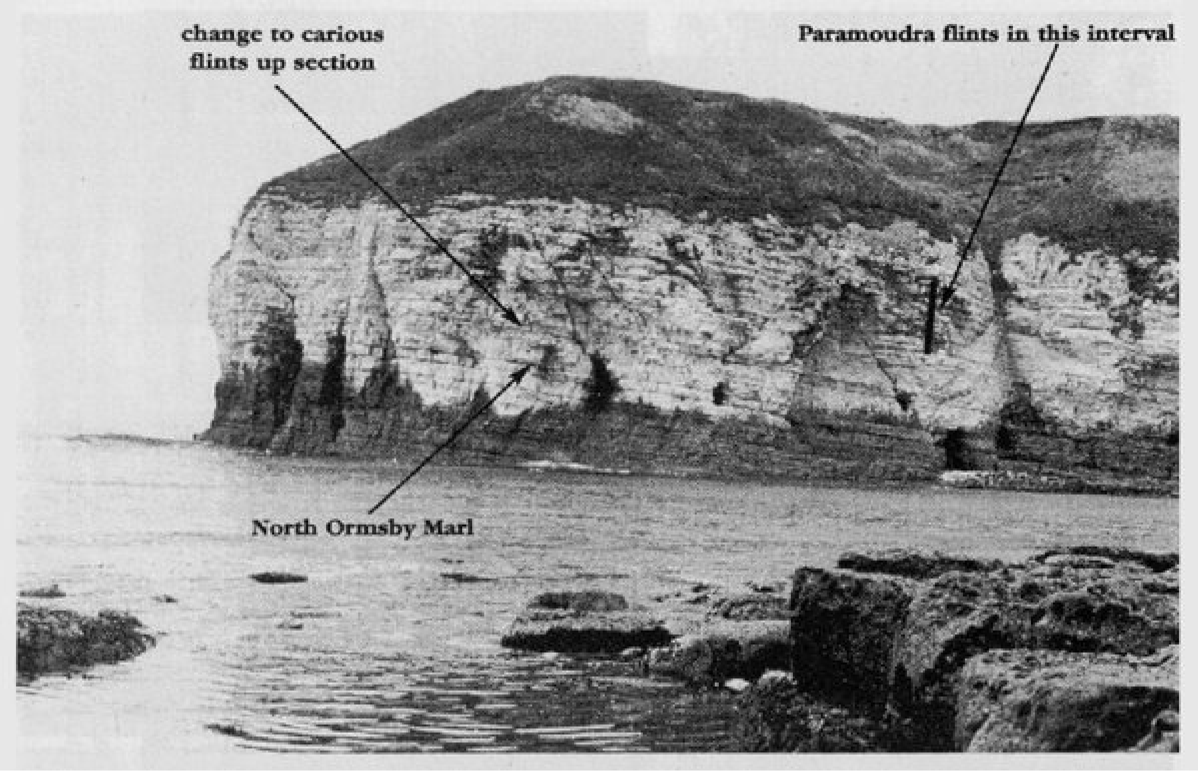
(Figure 5.22) The Cenomanian Ferriby Chalk Formation at Speeton Cliff-Buckton Cliffs, Yorkshire (compare with Figures 5.20b, 5.21, 5.23 and 5.24). For explanations of bed abbreviations, see text.



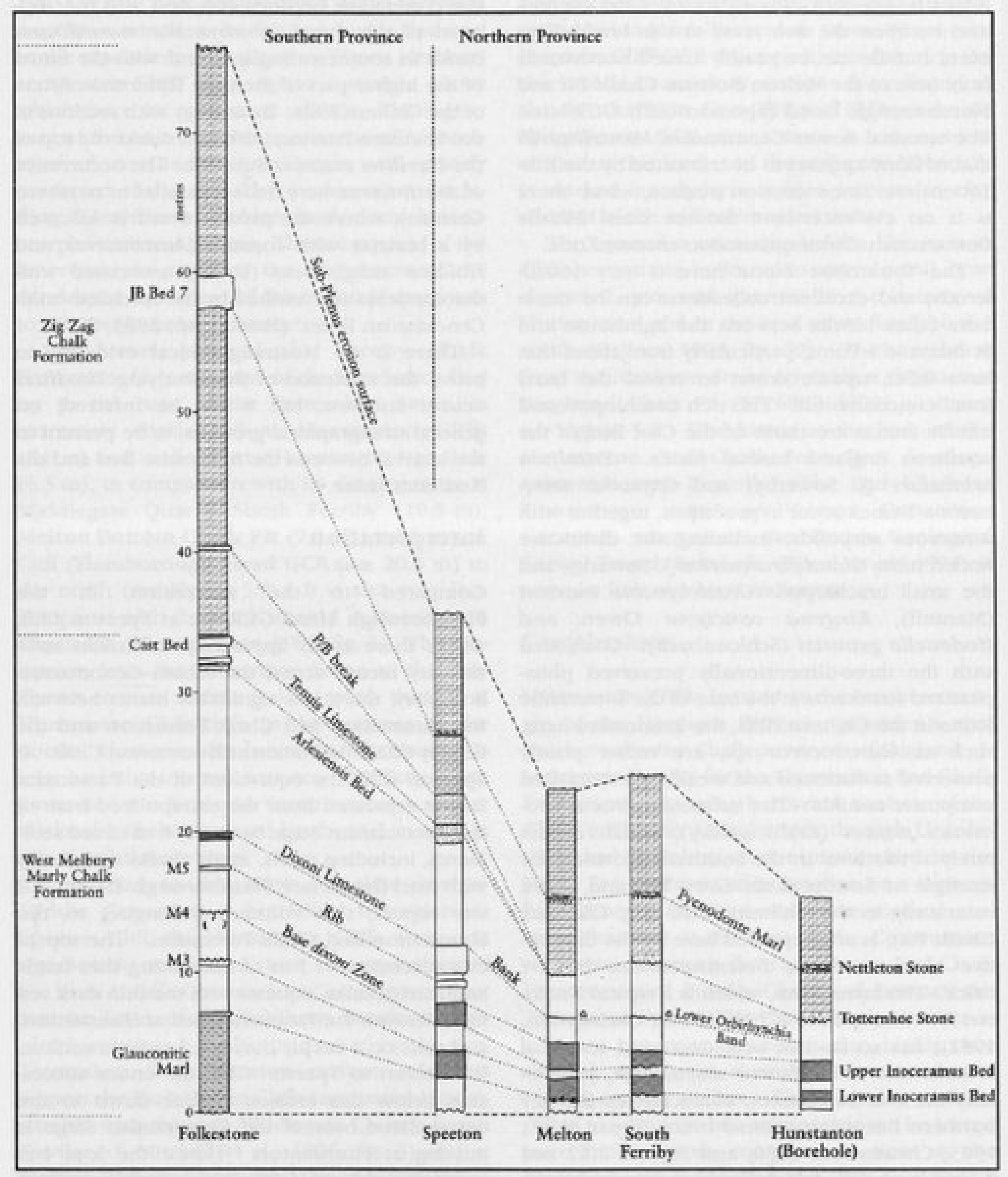
(Figure 5.23) Lower and central part of the Ferriby Formation at Buckton Cliffs, Flamborough, East Yorkshire. (The '6 Band Group' of limestones of Jeans = 'The Bank' at Southerham Grey Pit; the rib of Limestone = 'The Rib' of Southerham Grey Pit.) (Photos: Dr C.V. Jeans, University of Cambridge.)



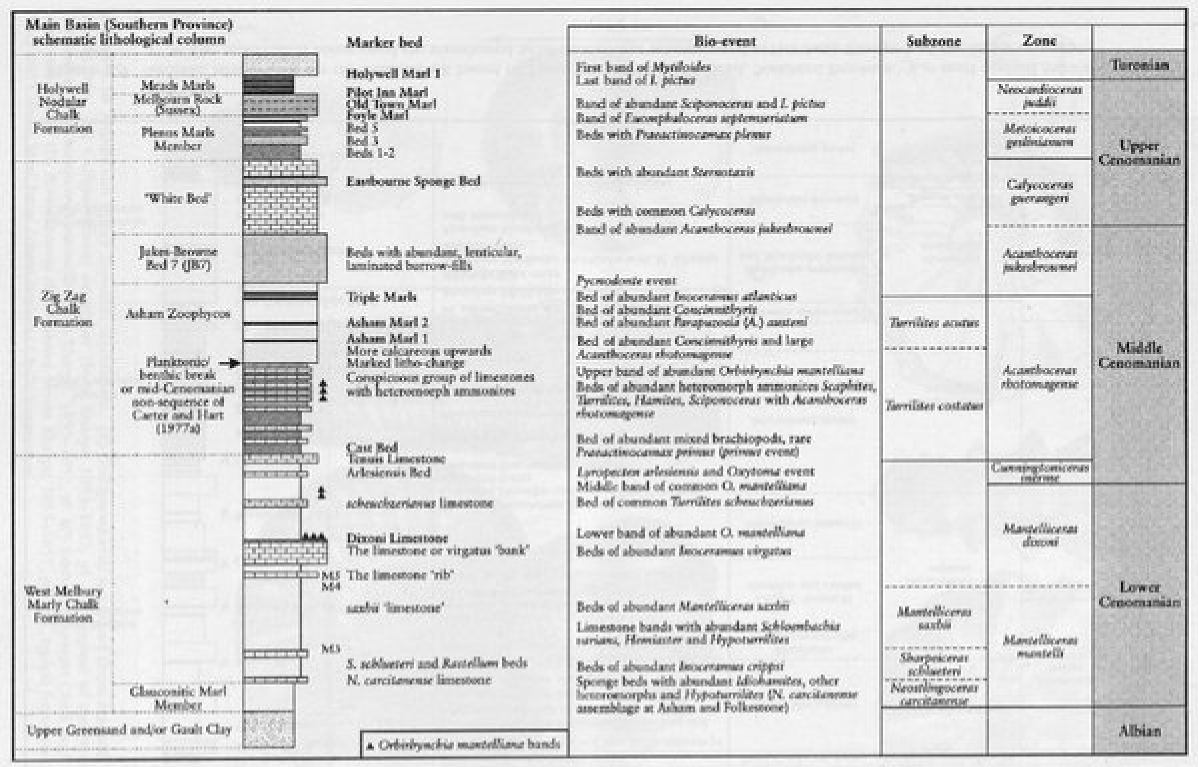
(Figure 5.24) Upper part of the Ferriby Chalk Formation (Cenomanian) at Buckton Cliffs, Flamborough, East Yorkshire. (Nettleton Stone = approximate position of the base of the Acanthoceras jukesbrownei Zone; P/B Break = Plantonic/Benthic ratio change, the approximate position of the Turrilites costatusacutus sub-zonal boundary) (Photos: Dr C.V. Jeans, University of Cambridge.)



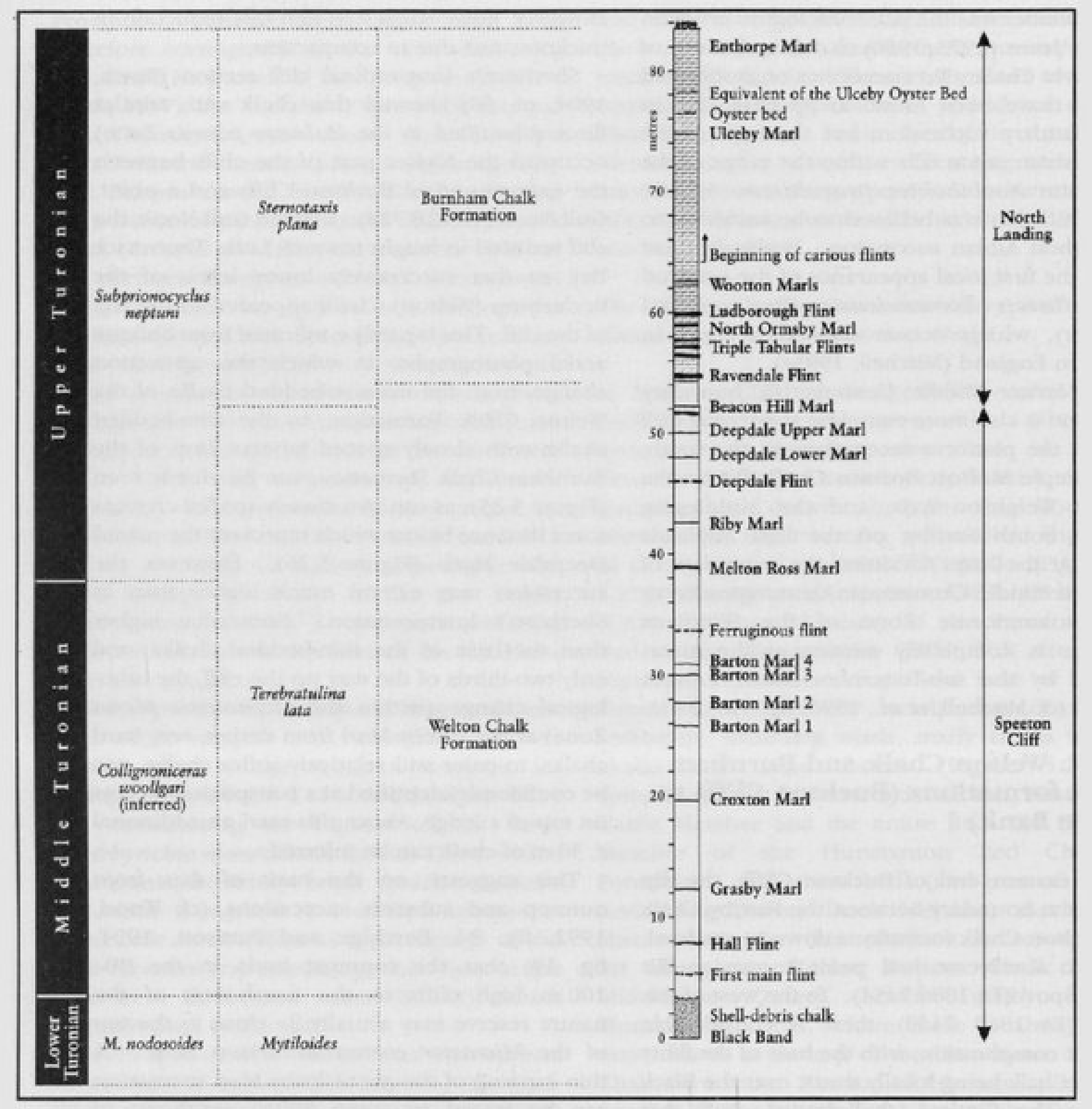
(Figure 5.25) Looking east onto the cliffs at North Landing, Flamborough Head, Yorkshire, where the Welton-Burnham Chalk boundary is well exposed. Spectacular Paramoudra flints are present in the basal unit of the Burnham Chalk Formation. (Photo: C.J. Wood.)



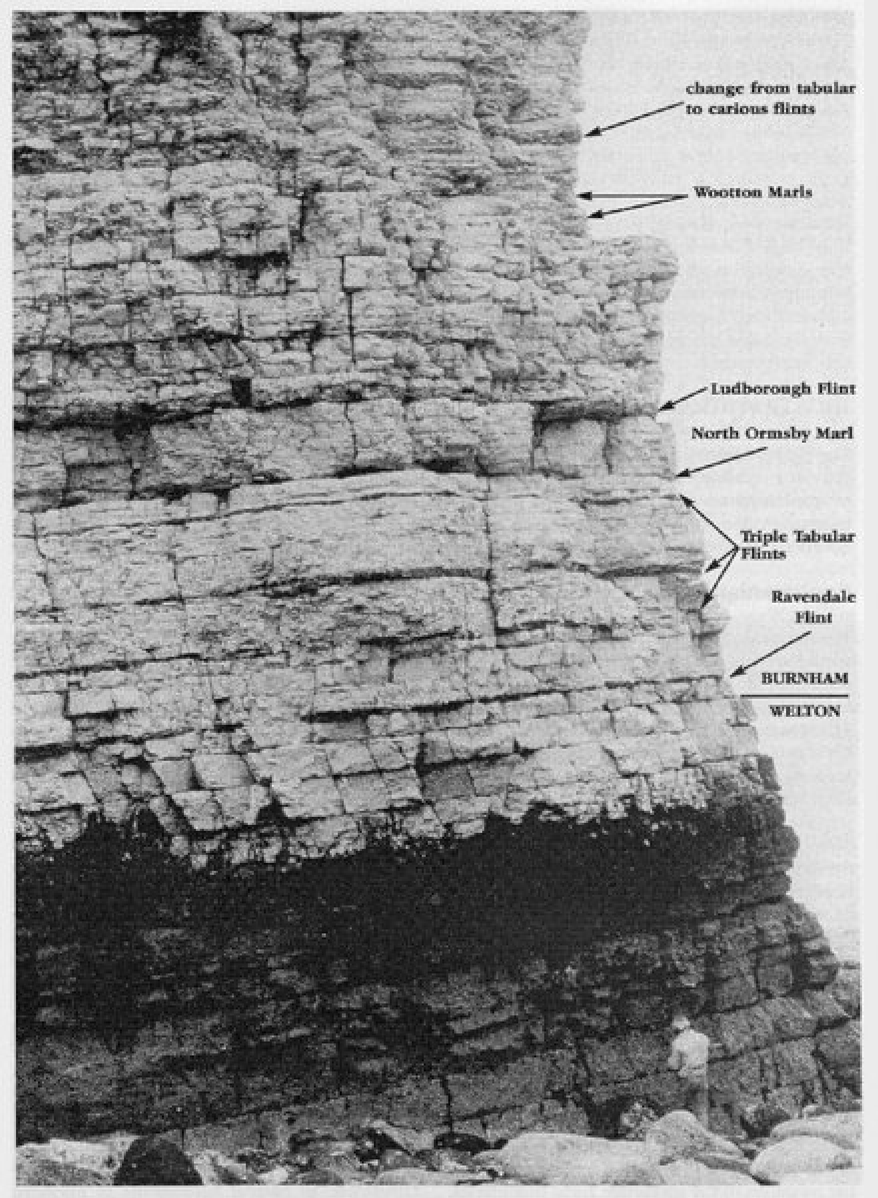
(Figure 5.9) Correlation of key marker beds in the Cenomanian Grey Chalk Subgroup between the Southern Province (West Melbury Marly Chalk and Zig Zag Chalk formations), and the Northern Province (Ferriby Chalk Formation).



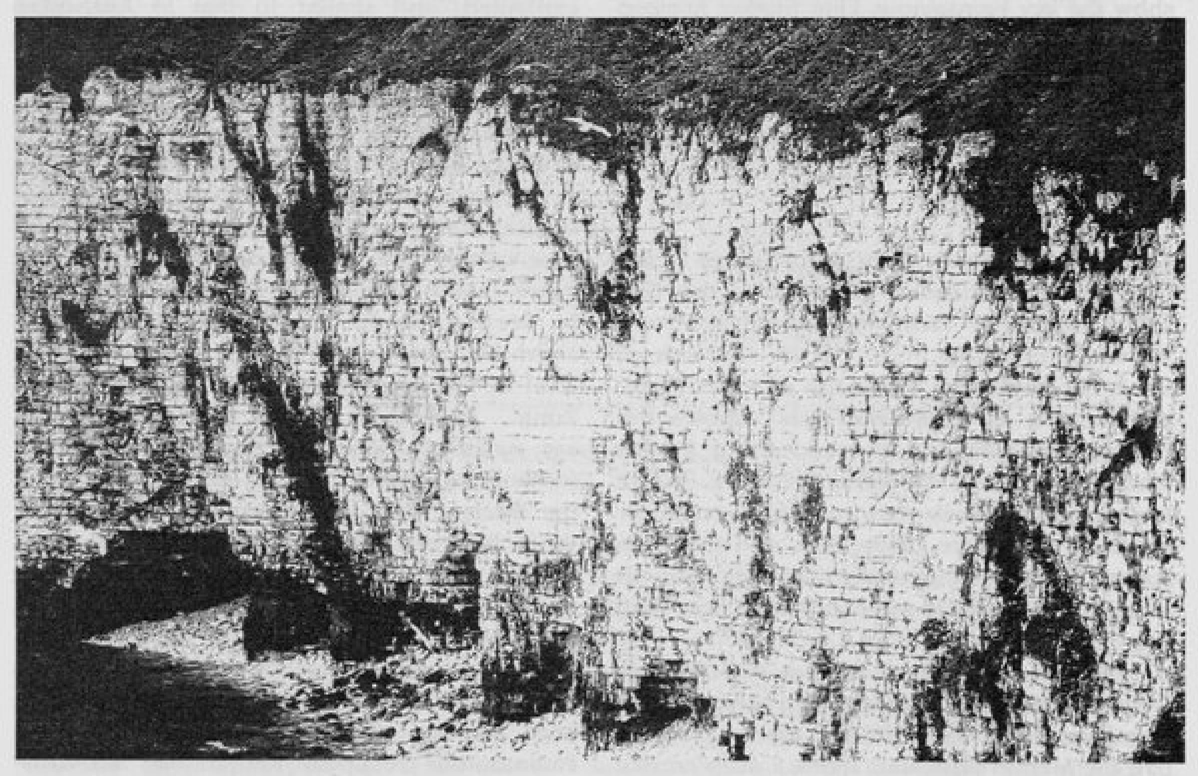
(Figure 2.8) Cenomanian stratigraphy for the onshore UK based on Southerham, Asham, Beachy Head and Folkestone. M2, M4 and M5 are Marker Beds of Gale (1995).



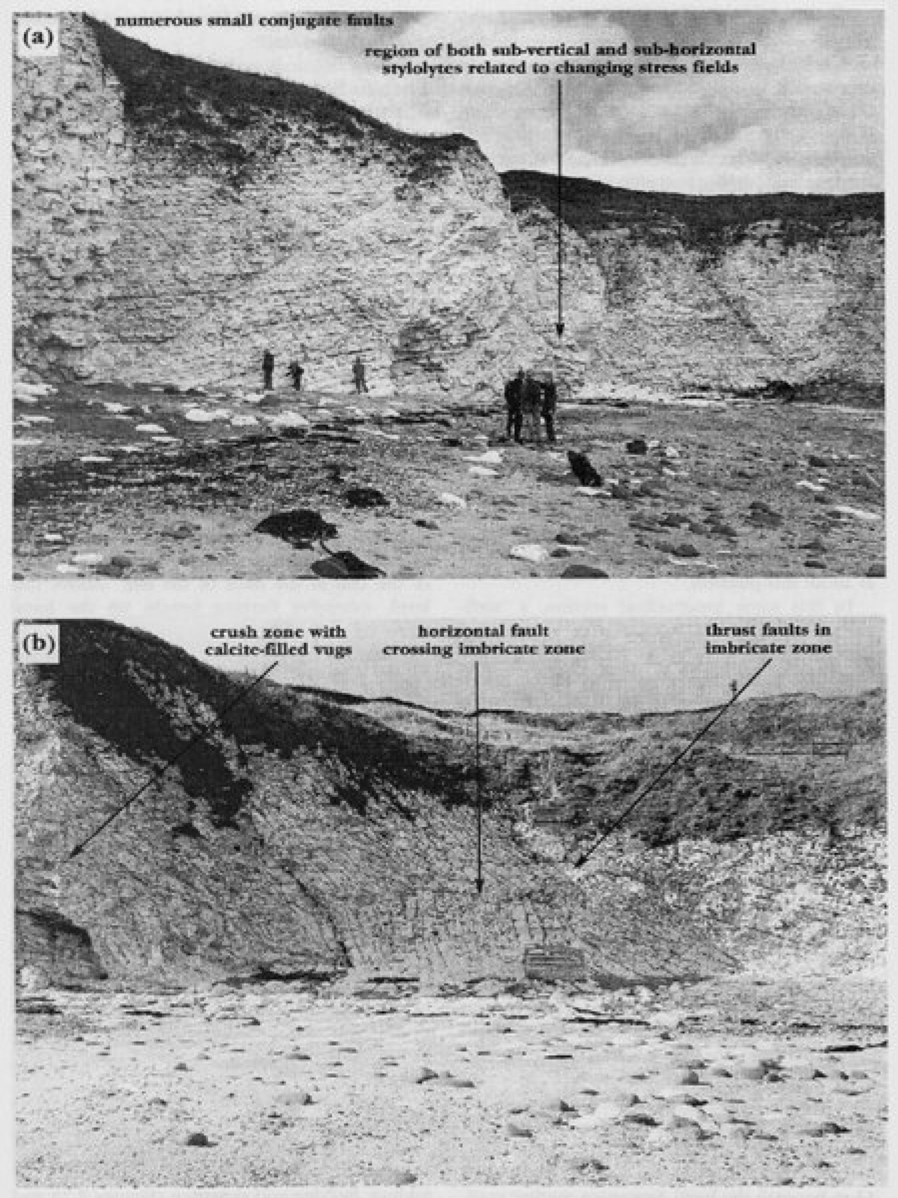
(Figure 5.26) The Welton Chalk and basal Burnham Chalk formations at the Flamborough Head GCR site between Speeton Cliff and North Landing. (After Mitchell, 2000; and unpublished logs of C.J. Wood.)



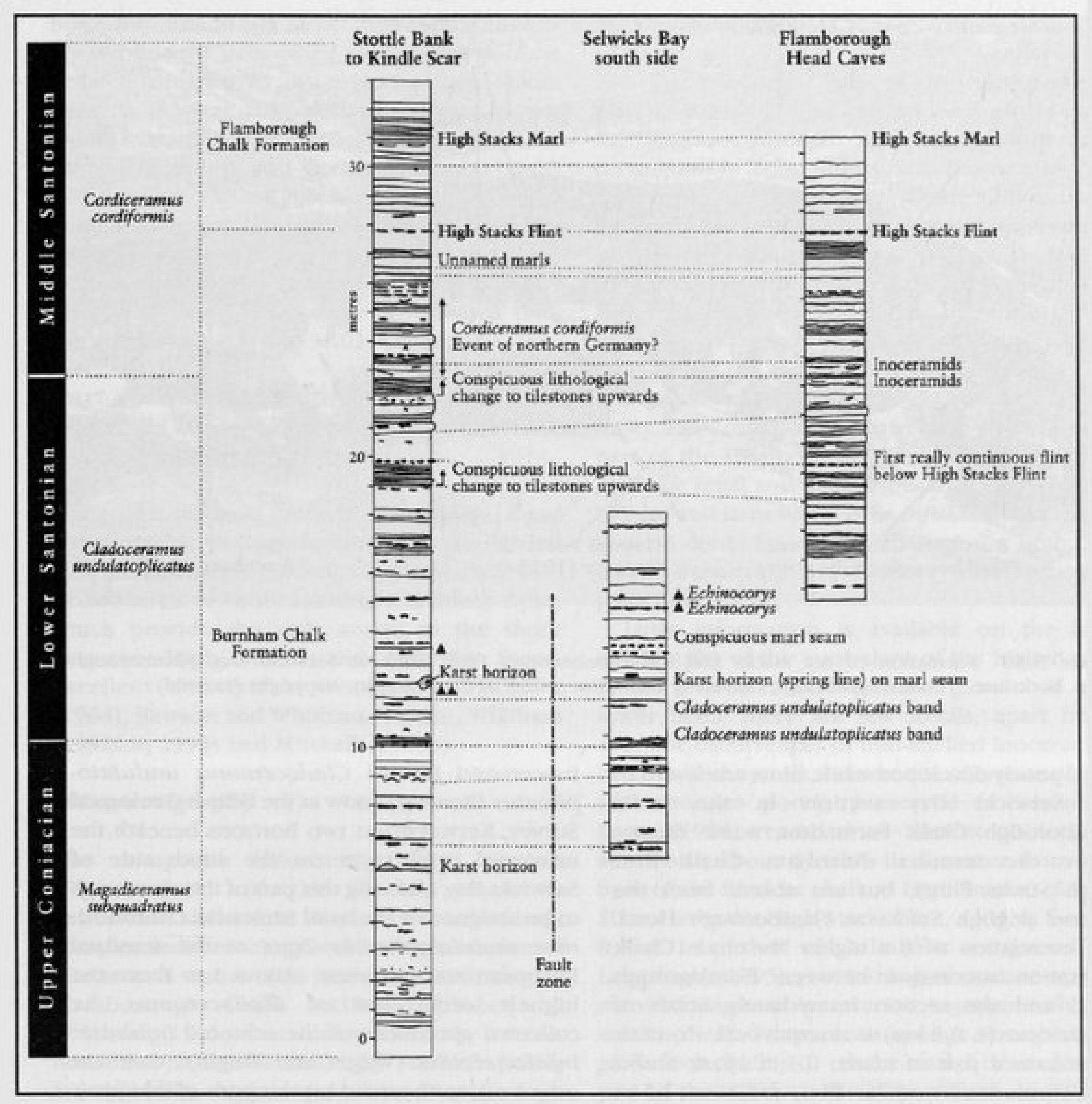
(Figure 5.4) Key marker beds at the Welton-Burnham Chalk boundary, North Landing, Flamborough Head GCR site, Yorkshire. (Photo: C.J. Wood.)



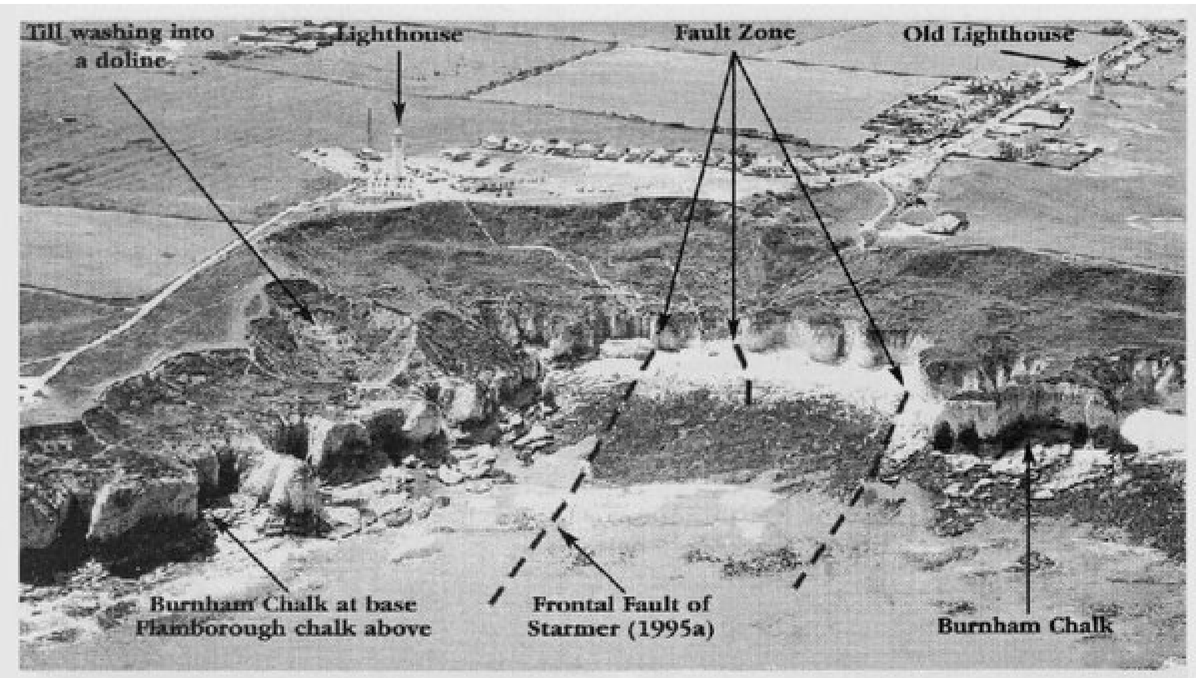
(Figure 5.27) Chalk cliffs on the east side of Breil Nook, Flamborough Head, Yorkshire, illustrating rhythmically bedded Burnham Chalk Formation with flint bands (Micraster cortestudinarium and M. coranguinum zones). These inaccessible cliffs have never been measured or properly interpreted. (Photo: A.A. Morter.)



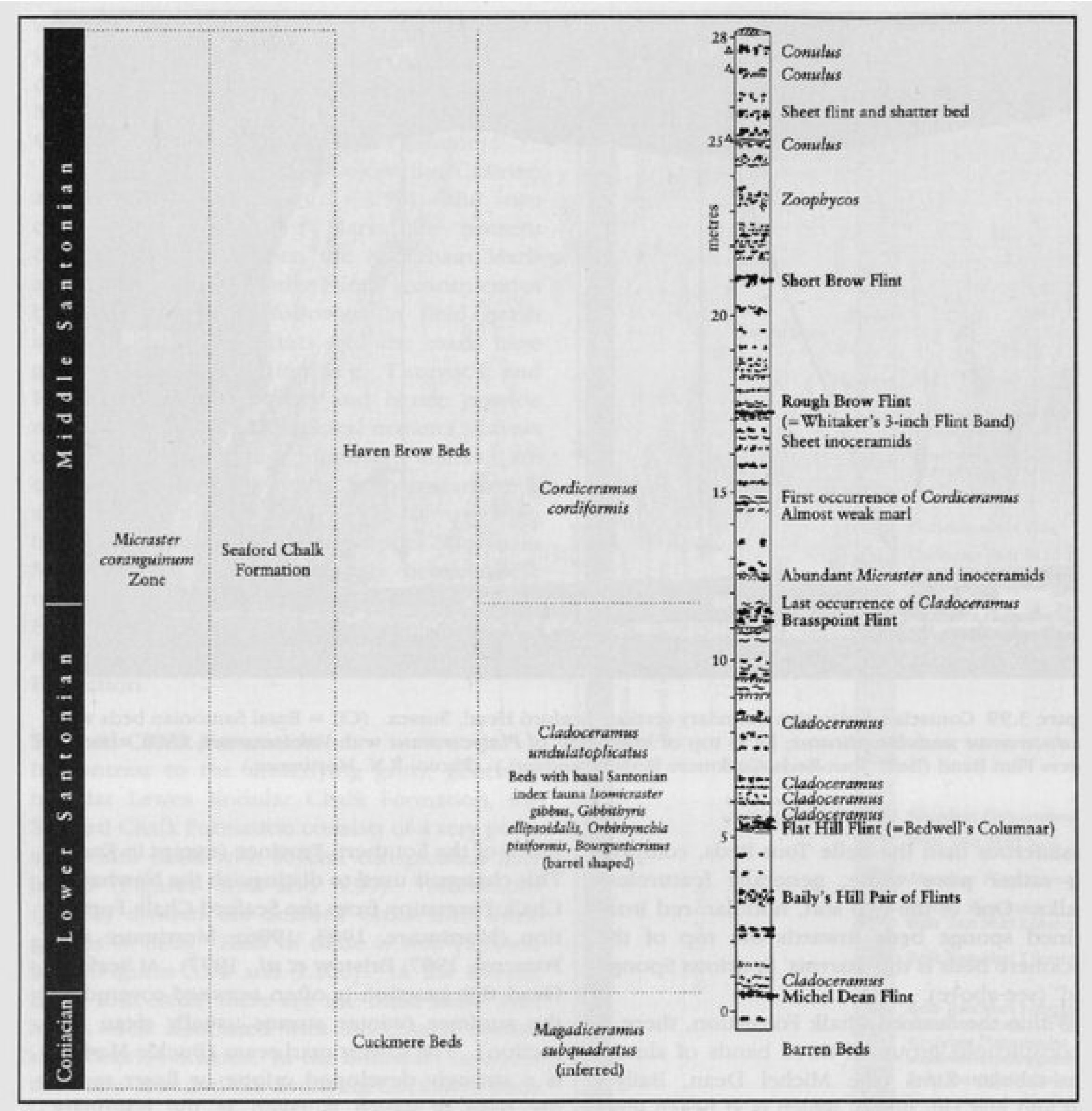
(Figure 5.28) The 'disturbed zone' at Selwicks Bay, Flamborough Head, Yorkshire. The series of faults displaces the chalk by 23 m down to the south, bringing Flamborough Chalk against Burnham Chalk. (Photos: R.N. Mortimore.)



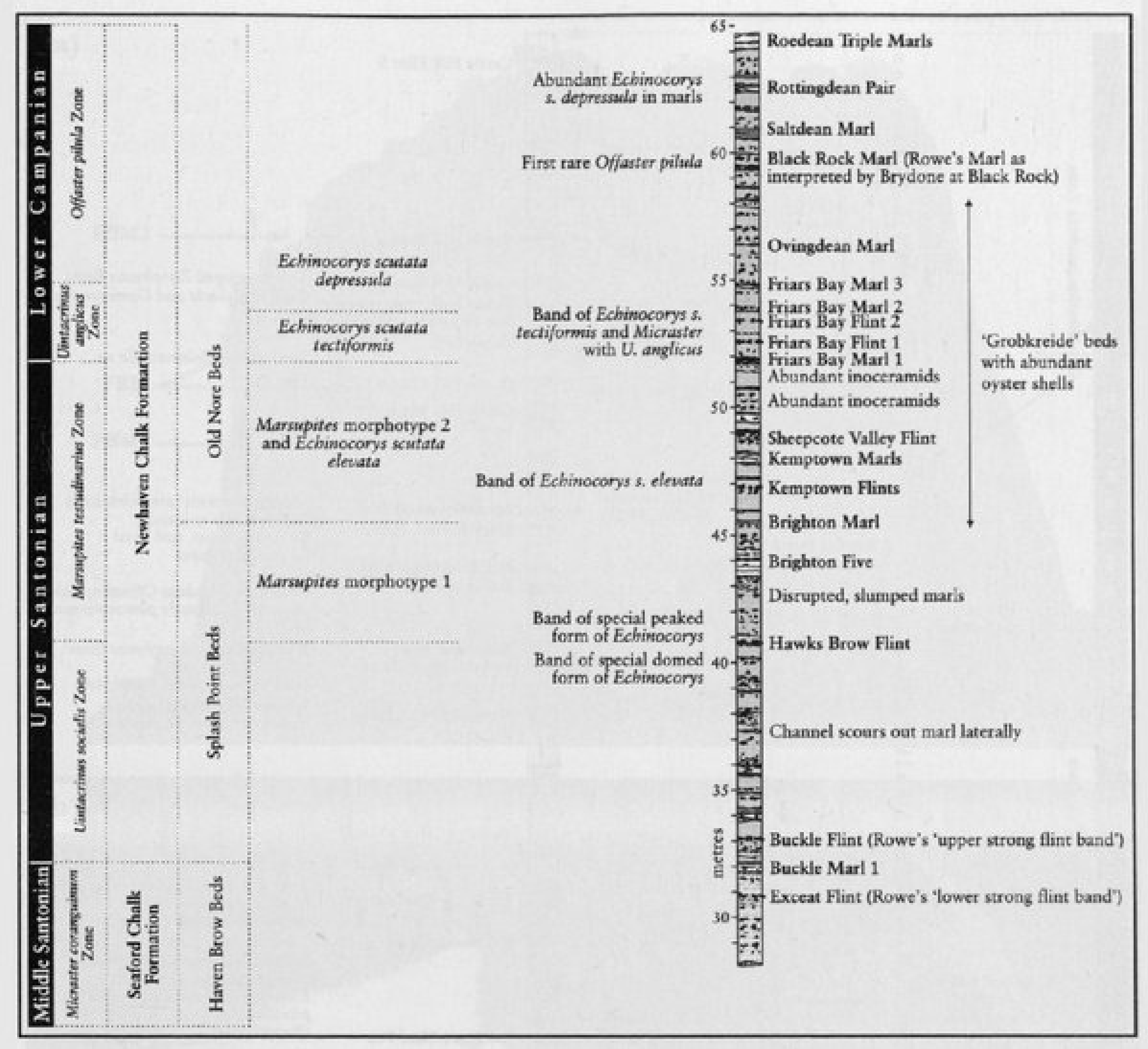
(Figure 5.29) Correlation from Stottle Bank across the Selwicks Bay Fault to Flamborough Head (High Stacks) with inferred biostratigraphy.



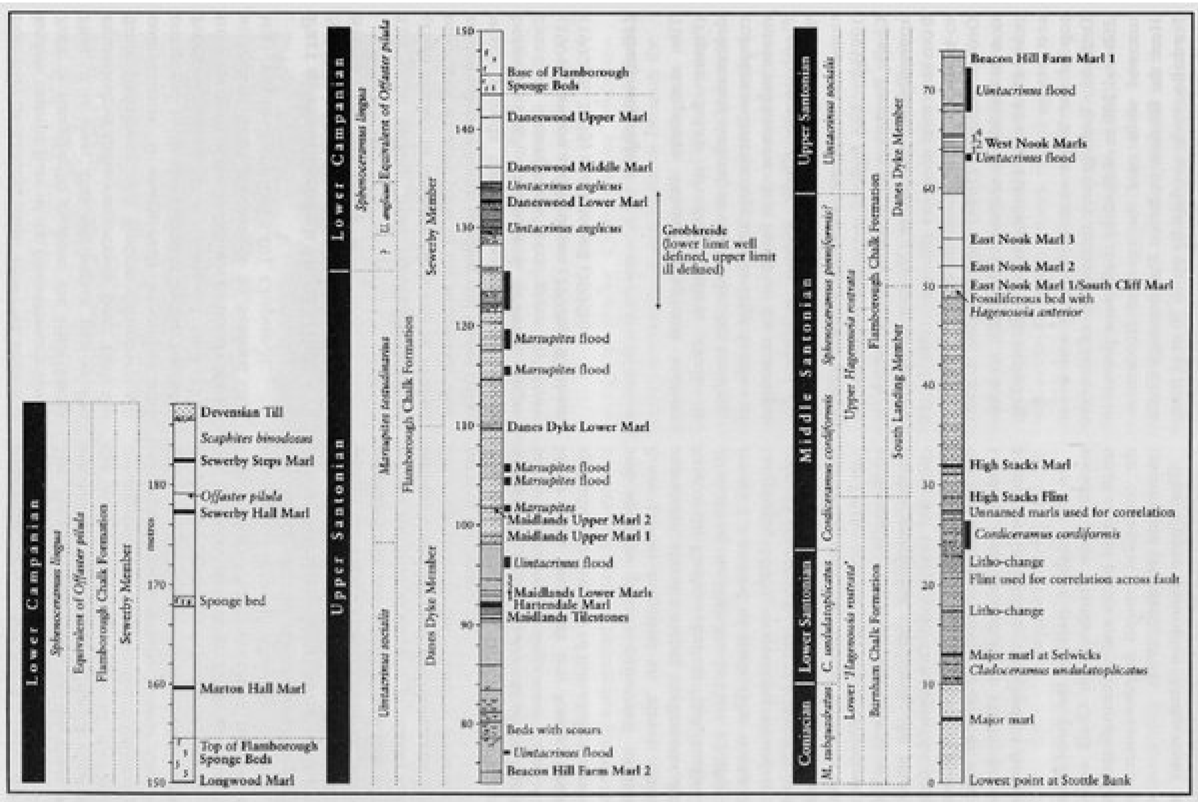
(Figure 5.30) Formation of sea stacks and the Flamborough Fault Zone at Selwicks Bay, Flamborough Head, Yorkshire. (Photo: Cambridge University Collection of Aerial Photography: copyright reserved).



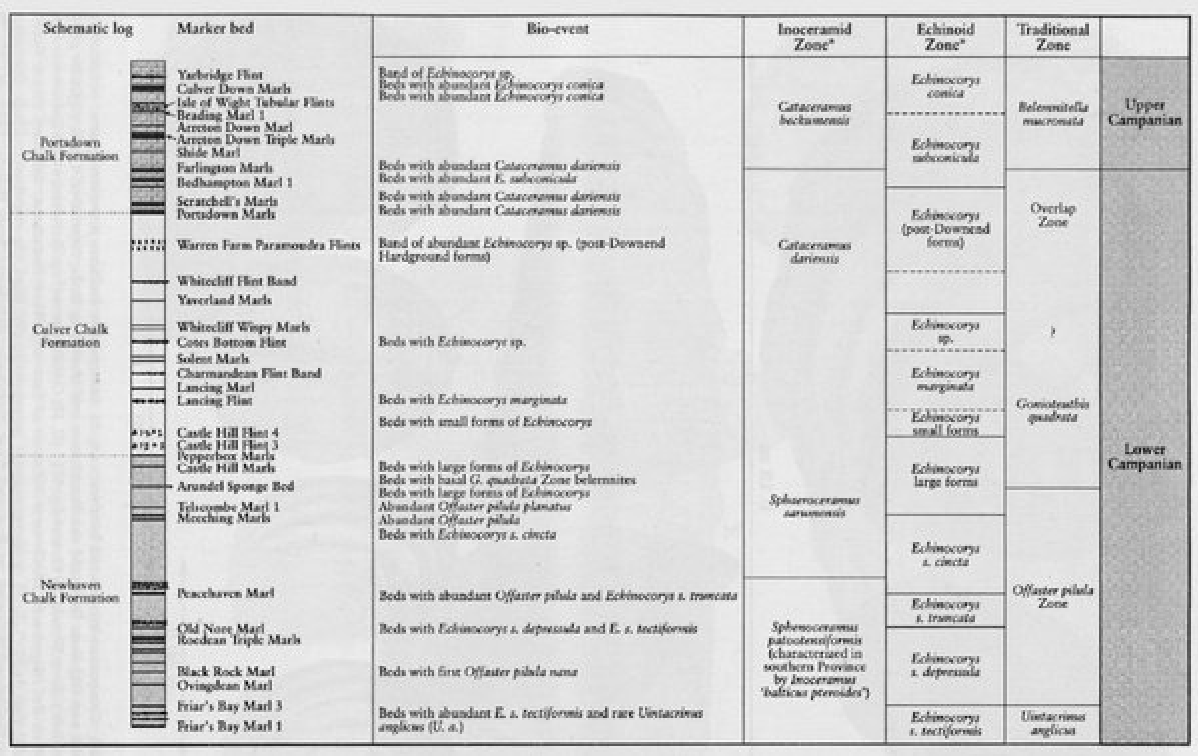
(Figure 3.100) Seaford Head: the Coniacian–Santonian boundary and the higher part of the Seaford Chalk Formation.



(Figure 3.101) Seaford Head: the lower half of the Newhaven Chalk Formation, including the Santonian–Campanian boundary



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



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