British Upper Cretaceous Stratigraphy

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Chapter 5

Northern Province, England

INTRODUCTION

At Hunstanton, on the eastern shores of the Wash, a marked change takes place in the Chalk successions representing the Upper Cretaceous Series in England, emphasized by the conspicuous red chalk at the base of the cliffs in contrast to the white cliffs of the south coast. Northwards from the Wash, the Upper Cretaceous Chalk forms the treeless rolling hills of the Lincolnshire and Yorkshire Wolds, where it is exposed in large working quarries. In East Yorkshire, the Chalk forms forbidding and inaccessible sea cliffs, inhabited only by kittiwakes and fulmars. In plough, along the base of the Wolds escarpment, is the conspicuous brick-red Hunstanton Red Chalk Formation, a unit not present in the Southern Province or Transitional Province, but one which is a vital marker bed in North Sea boreholes. There are major lithological and sedimentological differences between the Northern Province and areas south of the Wash. Not only is the Chalk red at the base in this province, but chalk sediment begins in the Upper Albian succession, rather than at the base of the Cenomanian. The Cenomanian succession is conspicuously thinner, there is no Plenus Marls Member or Melbourn Rock, the higher part of this interval being replaced by the Black Band. Regular flint bands occur lower, at the base of the equivalent of the New Pit Chalk Formation of the Southern Province, and there are huge thicknesses of marly Upper Santonian–Lower Campanian Flamborough Chalk Formation (an expanded Newhaven Chalk Formation) without flint. The Chalk succession of the Northern Province (Figures 5.1 and 5.2) is, therefore, sufficiently different from that in southern England that it requires a separate lithostratigraphical classification (Figure 5.3).

As in the Southern and Transitional provinces, the Chalk Group is divided into the Grey Chalk and White Chalk subgroups. Within these subgroups, the Northern Province Chalk comprises four mappable formations, the Ferriby Chalk, Welton Chalk, Burnham Chalk and Flamborough Chalk formations, in ascending order. The Ferriby Chalk Formation has virtually the same lower and upper boundaries as the Grey Chalk Subgroup. Above the Ferriby Chalk Formation, only the Holywell Nodular Chalk Formation and the lithological change at its top to the white, smooth chalks of the equivalent of the New Pit Chalk Formation, are recognizable. However, the equivalent of the Holywell Nodular Chalk is extremely condensed, and the immediately overlying chalk contains conspicuous flints. The latter are much more strongly developed than the approximately correlative Glyndebourne Flints of the Southern Province; the only other areas in the UK where flints are so strongly developed at the base of the equivalent of the New Pit Chalk are in the northern Chiltern Hills and in south-east Devon.

There are also major faunal differences throughout the succession compared with regions south of the Wash. In contrast, there is a strong similarity both lithostratigraphically and faunally to the limestone and chalk successions of northern Germany. Sections in the Cenomanian succession in the two areas are virtually interchangeable. The main bio-events and lithofacies changes can be correlated readily. The continuous Cenomanian to Lower Campanian succession exposed in the sea cliffs and inland sections is of fundamental importance in the understanding and interpretation of

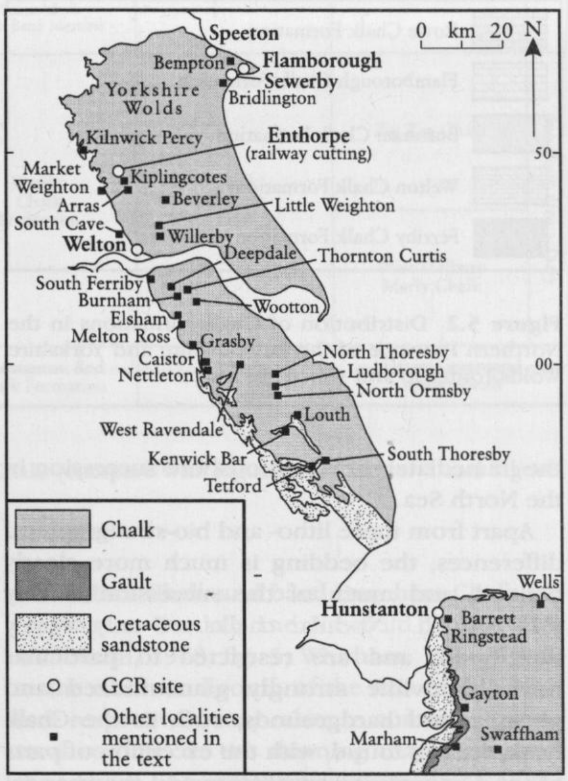


Figure 5.1 Location of GCR sites and other sites mentioned in the text in the Northern Chalk Province of England.

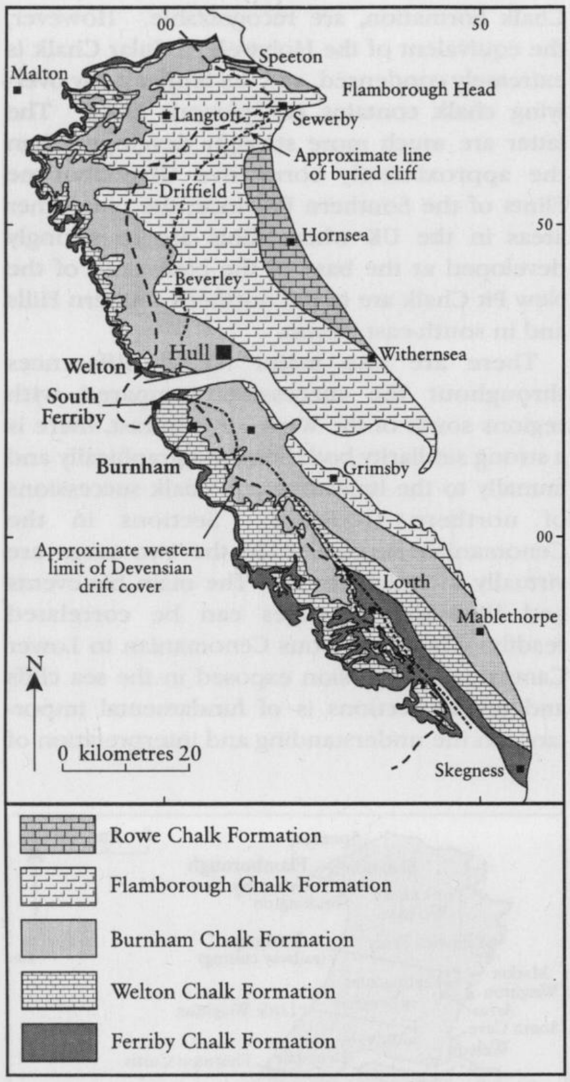


Figure 5.2 Distribution of Chalk formations in the Northern Province of the Lincolnshire and Yorkshire Wolds (outcrop and subcrop).

the immediately adjacent offshore succession in the North Sea.

Apart from these litho- and bio-stratigraphical differences, the bedding is much more clearly defined, and much of the succession is very thin bedded. Nodular chalks are only weakly developed, and are restricted to particular horizons, while strongly glauconitized and phosphatized hardgrounds, such as the Chalk Rock, are not found, with the exception of parts of the Cenomanian succession and the channel floor hardground in the basal Coniacian strata. The flints at Willerby Quarry, Hull, are typically grey, predominantly tabular, poorly delimited from the chalk, and relatively inconspicuous, in contrast to the generally black nodular flints of the south. All of these features are commonly, if controversially, attributed to deposition in a deeper-water environment. The chalk is pervasively indurated north of Louth, Lincolnshire, as a result of overgrowth cements and the way calcite crystals interlock (Mimran, 1978; Mortimore and Fielding, 1990). Concomitant with this greater hardness, sub-horizontal, hard-rock stylolites are a marked feature of the northern chalk.

The hardening is variously interpreted as resulting from deep burial, the effect of superincumbent ice during the last glaciations, and even mild regional hydrothermal metamorphism connected with the Whin Sill and other igneous intrusions (Scholle, 1974). Mimran (1978) concluded that the hardening of the Yorkshire Chalk took place after the end of the Cretaceous Period through the introduction of carbonate from an external source at some time between the Palaeocene and the Eocene epochs. Part of the explanation for the hardening must, however, be due to differences in the original sediment, and even to different depositional situations, for relatively softer chalks are found intercalated between the hard chalks, and hard chalks may pass laterally into soft chalks. In addition, the lower part of the succession in Lincolnshire becomes less hard and, at the same time, more fossiliferous, as it progressively thickens southwards. The idea that up to 50% of the Yorkshire Chalk at **Flamborough Head** may have been lost by dissolution is not supported by the litho- and bio-stratigraphical evidence (see GCR site report, this volume).

TECTONIC STRUCTURE AND SEDIMENTOLOGICAL SETTING

The Chalk of the Northern Province belongs to three main structural units that shifted their positions over time. Throughout the Mesozoic Era, the area of present-day Lincolnshire constituted a slowly subsiding platform, known as the 'East Midlands Shelf' (see Figure 1.15, Chapter 1). To the north, the Market Weighton Axis acted as an intermittently positive area. Jurassic and Lower Cretaceous strata thinned towards this structure, and became eroded over it. Recent work has shown that, just as in the case of north Norfolk, the presence of an inferred buried granite at or about the position

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

of the Market Weighton structure, and also offshore, to the east (Donato and Megson, 1990; Donato, 1993), may have exerted some control on chalk sedimentation, but probably did not contribute to the pervasive hardening. This structural control continued until at least the end of the Cenomanian Age, since the Hunstanton Red Chalk Formation and Ferriby Chalk Formation exhibit reduced thicknesses in this area. The markedly reduced thicknesses of the Welton Chalk and basal Burnham Chalk successions at Burdale and Newbald Wold (Wood and Smith, 1978, fig. 5; Whitham, 1991, fig. 6), to the north and south of the axis of this structure respectively, may relate to continuing structural control, or the thinning may conform to the pattern of generally smaller thicknesses that is found in the western part of the Wolds. Higher Burnham Chalk successions (Upper Turonian–Lower Coniacian in age) over the structure actually show no evidence of thinning and are, if anything, significantly expanded and less indurated. On the other hand, borehole evidence suggests that the subcrop Burnham Chalk under Holderness may actually be significantly thinner than elsewhere. Around Hornsea, uncored commercial wells proved a total 510 m of Chalk, of which the top 70 m were flint-bearing (Sumbler, 1996).

On the northern margin of the Market Weighton Axis, an east–west zone of faulting at the edge of the Yorkshire Wolds (the Howardian–Flamborough Fault Zone), extending eastwards offshore into the North Sea, formed the limit of the more rapidly subsiding Cleveland Basin, in which thick Lower Cretaceous successions accumulated, for example at Speeton Cliff (see **Flamborough Head** GCR site report, this volume). The Market Weighton Axis thus represented a hinge between a more rapidly subsiding area to the north, and a gently subsiding area to the south. The Flamborough Fault Zone effectively delimits the Flamborough Head promontory and finds its surface expression in narrow east–west zones of intense deformation crossing the Wolds (e.g. Foxholes Pit, TA 012 735), and intersecting the Chalk of the Yorkshire coast sea cliffs at two points (Staple Nook and Selwicks Bay). The faults were initiated in early Mesozoic times and bound a halfgraben with thick Lower Cretaceous sediments (Kirby and Swallow, 1987); they were then reactivated in Late Cretaceous or Early Tertiary times.

The Chalk in Lincolnshire displays a general dip of less than 1° to the ENE. The highest chalk seen at outcrop (the Lower Coniacian Barrow Flints) lies low in the Burnham Chalk, and the subcrop succession extends only as high as the lower part (Santonian) of the Flamborough Chalk. In the Yorkshire Wolds, the Chalk is folded into a gentle broad syncline, plunging south-east. In the **Flamborough Head** area, dips are generally of the order of 5°– 10° to the south, but locally attain 20°. The entire Upper Cretaceous succession, with the exception of the highest beds of the Flamborough Chalk, is exposed in the sea cliffs of **Flamborough Head**, between Speeton Cliff and Sewerby Steps. The highest Chalk seen at outcrop (Lower Campanian Flamborough Chalk) is found in quarries on the top of the Wolds inland from Bridlington. Beneath Holderness, and also on the east side of Lincolnshire, the Chalk disappears beneath a cover of Pleistocene (Devensian) and alluvial sediments.

STRATIGRAPHY

It was recognized by 19th century workers (e.g. Blake, 1878) that, in striking contrast to the situation in southern England, where much of the traditional Middle Chalk and the entire Upper Chalk comprised chalk with flints, the flinty chalk in Yorkshire, which began at or near the base of the Middle Chalk and extended up into the equivalent of the lower part of the Upper Chalk, was overlain by a thick succession of chalk that was totally devoid of flint. Within the flinty chalk, Barrois (1876), followed by Blake (1878) and Hill (1888), recognized several different units characterized by particular types of flint. Mortimer (1878) came to the remarkable conclusions that these flinty units graded laterally into the flintless chalk and that the characteristically tabular flints formed by replacing sheets of fucoids (seaweed). Not only was the equivalent of the Lower Chalk seen to be much thinner, harder, and overall much less fossiliferous than in the south, but it overlay highly fossiliferous red-coloured marls and limestones (the Red Chalk). Fossil evidence showed that these red marls were equivalent to the Gault, but they could not logically be separated lithostratigraphically from the Chalk proper. Finally, although hard shelly chalks approximately equivalent to the Melbourn Rock at the base of the Middle Chalk in southern England could be identified, the underlying Belemnite (later Plenus) Marls appeared to be represented here by a thin (*c.* 0.1 m) bituminous black shale full of fish remains, which was termed by Rowe (1904), the 'Black Band', only 15 ft (4.3 m) above which the first flints were found.

Early classifications took the base of the Middle Chalk variously either at the Black Band and/or the base of the inferred equivalent of the immediately overlying Melbourn Rock; or else at the onset of flint. Although the [British] Geological Survey geologists formally took the base at the Black Band, it was clearly stated in the memoirs that they used the first flints for mapping purposes. The base of the Upper Chalk was taken originally at the lower limit of flintless chalk, but later (Jukes-Browne and Hill, 1903, 1904), at the onset of tabular flints. Whilst it was appreciated that the latter criterion had some stratigraphical significance, it was applied inconsistently in the field. This is because the earlier workers (notably Rowe, 1904) were not in a position to know that conspicuous, continuous semi-tabular flints, such as the Deepdale Flint, are actually developed well below the onset of regular tabular flints.

In the course of geological mapping in north Lincolnshire by the British Geological Survey, starting in the late 1960s, it became apparent that the 'Chalk with Flints' of the 19th century surveyors could be consistently subdivided into two units. These two units were characterized by nodular burrow-form flints and tabular flints respectively. Massive, closely spaced, feature-forming (and, hence, mappable) tabular flints at the base of the higher unit corresponded to the Basal Complex at the base of the traditional Upper Chalk of the North Downs, and the coast section at Dover. A rapid field survey of the Chalk outcrop of Yorkshire by the British Geological Survey in 1974 revealed that these lithological units were recognizable and, to a greater or lesser extent, also mappable. In the structurally complex northern part of the Wolds the contact originally mapped between the flinty chalk and the succeeding flintless chalk was found to be tectonic rather than sedimentary. Wood and Smith (1978) consequently established this stratigraphy on a formal basis, subdividing the Chalk of the Northern Province into four mappable formations.

LITHOSTRATIGRAPHY

Ferriby Chalk Formation

The Ferriby Chalk Formation (typically 20–30 m thick), named after the stratotype section at Middlegate Quarry (Rugby plc), South Ferriby, north Lincolnshire, originally comprised the traditional Red Chalk and the equivalent of the Lower Chalk. The upper limit is taken at the erosion surface below the thin unit (Variegated Beds of Wood and Mortimore, 1995) that includes the Black Band. This surface is interpreted as being equivalent to the sub-Plenus erosion surface of southern England.

The basal (Red Chalk) component of this formation was controversially separated by the British Geological Survey (Wood and Smith, 1978) as the 'Hunstanton Chalk Member', named after the stratotype section at **Hunstanton Cliffs**, Norfolk (see GCR site report, this volume) rather than, as other workers recommended at the time (see discussion in Wood and Smith, 1978), treated as an independent mappable formation. 'Hunstanton Red Chalk Formation' is now used as the preferred stratigraphical term. The re-defined 'Ferriby Chalk Formation' has virtually the same lower and upper limits as the traditional Lower Chalk of the Southern Province, although the lithologies are significantly different from those of the south. The re-defined Ferriby Chalk Formation also correlates with the Hidra Formation (Lott and Knox, 1994) of Southern North Sea Basin stratigraphy (Figure 1.17, Chapter 1). Because in some places the upper part of the Hunstanton Red Chalk Formation is of Cenomanian age (e.g. Speeton Cliff) it falls within the Upper Cretaceous Series and is, therefore, included here.

Welton Chalk Formation

The Welton Chalk Formation (typically 44–53 m thick) is named after the stratotype section in the Welton Wold Quarry (**Melton Bottom Chalk Pit** GCR site) (operated by the Omnia Croxton and Garry quarry company), south Yorkshire, and is characterized by generally massive-bedded chalk with marl seams at intervals, and nodular, burrow-form flints. The base is taken at the erosion surface below the Black Band. Overlying the erosion surface is a thin unit, typically about 0.5 m thick, of limestones and siltstones, overlain by green and khaki marls, which includes the Black Band. These sediments were later collectively named the 'Variegated Beds' (Wood and Mortimore, 1995). The 3 to 4 m interval between the Black Band and the first flints comprises impure, greyish-green, shell-detrital chalks, which are lithologically identical to the chalks of the Holywell Nodular Chalk Formation of the Southern and Transitional provinces. These shelly chalks terminate in a closely spaced group of three dark marl seams within 0.25 m (the Chalk Hill Marls). Above this, there is a conspicuous abrupt lithological change to white, flinty chalks.

The Welton Chalk Formation extends from the base of the Upper Cenomanian *Metoicoceras geslinianum* Zone to the top of the Upper Turonian *Terebratulina lata* Zone of the traditional scheme. The faunas are of generally low diversity, comprising brachiopods, inoceramid bivalves and echinoids. Except in the basal (Lower Turonian) beds, ammonites are extremely rare, presumably due to their low preservation potential.

The Welton Chalk Formation approximately equates with the Herring Formation of Southern North Sea Basin stratigraphy (Lott and Knox, 1994), the base of which is also marked by the Black Band.

Burnham Chalk Formation

The (composite) Burnham Chalk Formation (inferred to be 130–150 m thick) is based on a large number of sections in both north Lincolnshire and Yorkshire. It is named after the basal boundary stratotype at the Burnham Lodge Quarry (TA 0685 1720), near the hamlet of Burnham, north Lincolnshire (Figures 5.1 and 5.2).

The onset of nodularity, which marks the base of the Lewes Nodular Chalk Formation in the Southern Province, cannot be recognized in the Northern Province. However, the approximately equivalent horizon can be located by recognizing the correlation with the immediately underlying Glynde Marls, which here correlate to the Barton Marls; this boundary cannot be mapped. In fact, the next higher mappable level in the Northern Province above the base of the Welton Chalk Formation (the base of the Burnham Chalk Formation), is taken at the entry of large tabular flints (Figure 5.4). This is the level formerly mapped as the base of the traditional Upper Chalk in the North Downs, i.e. at the Basal Complex of closely spaced marl seams and large flints, and its East Anglian correlative, the 'Brandon Flint Series'. There is, likewise, no obvious lithological change at the horizon equivalent to the base of the Seaford Chalk Formation, which falls within the Burnham Chalk Formation, although the equivalent of the Belle Tout Beds can be recognized without difficulty.

The Burnham Chalk Formation is relatively thin bedded, and is much more flinty overall than the underlying Welton Chalk, although towards the top the flints become thin and inconspicuous, as well as being irregularly and only very sparsely developed. Marl seams are present throughout. Tabular and semi-tabular flints predominate over nodular burrow-form flints, and the huge vertical flints known as paramoudras are found at two levels. In some parts of the succession many of the flints are markedly carious, leading to the expression 'intermingled chalk and flints' (e.g. Jukes-Browne and Hill, 1903, 1904).

The Burnham Chalk Formation approximately equates with the Lamplugh Formation and the lower part of the Jukes Formation of the Southern North Sea Basin stratigraphy (Lott and Knox, 1994; and see Figure 1.17, Chapter 1).

Flamborough Chalk Formation

The onset of persistent (and relatively closely spaced) marl seams, which marks the base of the Newhaven Chalk Formation of the Southern Province occurs much lower in the Northern Province, at the base of the Flamborough Chalk Formation, and within the higher part of the equivalent of the Seaford Chalk Formation. The Flamborough Chalk Formation (260–280 m thick, on the basis of logs of uncored deep commercial wells drilled through the Chalk subcrop beneath Devensian sediments under Holderness) is named after **Flamborough Head**, and is characterized by flintless, relatively marly chalk with numerous marl seams. It is not possible at present to identify the Burnham–Flamborough boundary on a faunal basis. However, since the base of the *Uintacrinus socialis* Zone lies 70 m above the High Stacks Flint (at the top of the Burnham Chalk Formation; see **Flamborough Head** GCR site report, this volume), it is clear that the higher part of the equivalent of the *Micraster coranguinum* Zone is enormously expanded here compared to its development in southern England. The base of the offshore Jukes Formation (Lott and Knox, 1994) approximates to the base of the Santonian Stage, which is situated only a short distance below the base of the Flamborough Chalk.

A detailed graphic section through the entire Flamborough Chalk Formation was given by Whitham (1993); the Upper Santonian and basal Campanian succession was subsequently revised by Mitchell (1994, 1995b).

Rowe Formation

The logs of the Holderness wells (Sumbler, 1996) show that the flintless chalk is overlain by up to 70 m of flinty chalk. This latter unit has been recognized in offshore wells, where it has been given the name 'Rowe Formation' (Lott and Knox, 1994). However, nannofossil evidence indicates (Bailey, pers. comm., 1999) that

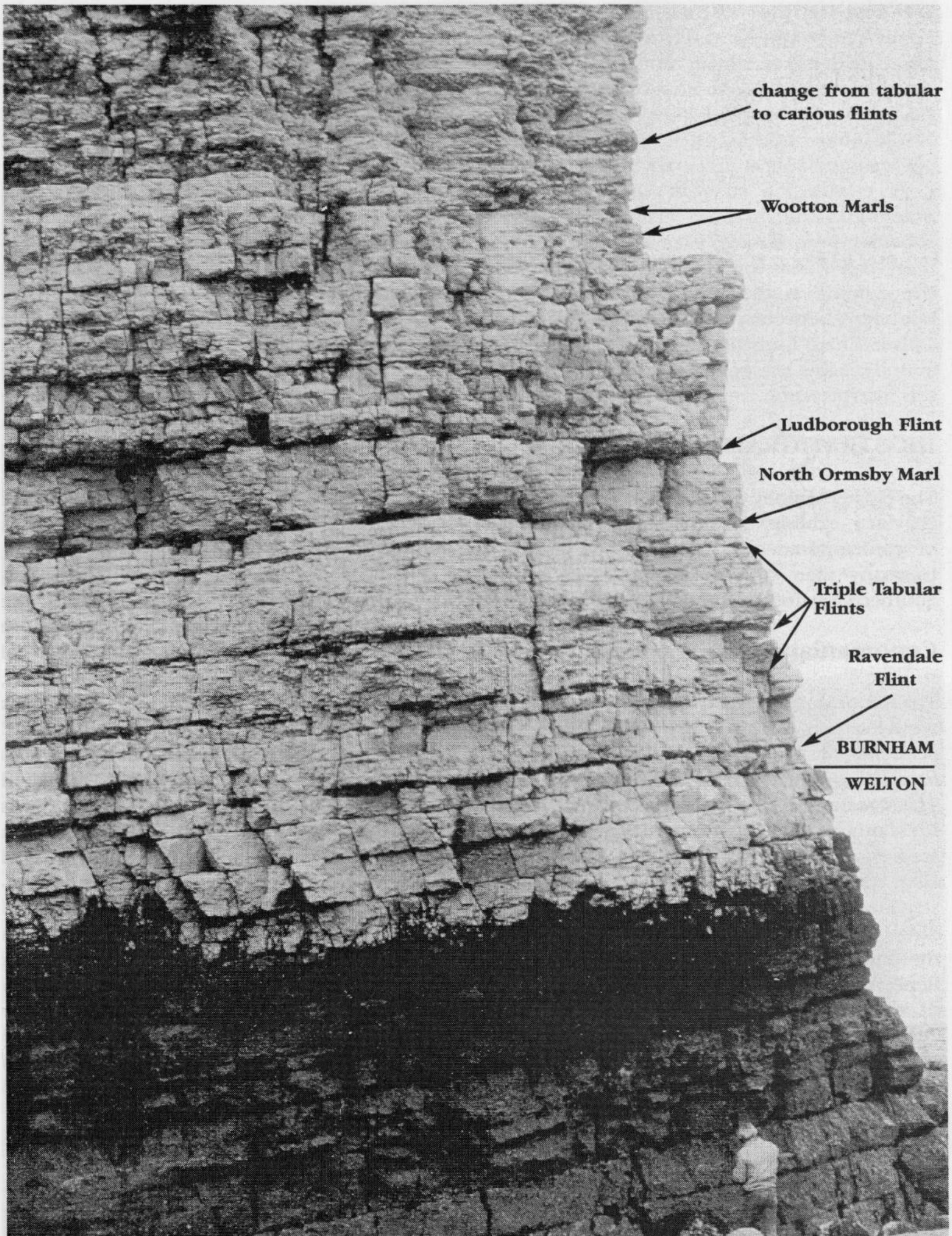


Figure 5.4 Key marker beds at the Welton–Burnham Chalk boundary, North Landing, **Flamborough Head** GCR site, Yorkshire. (Photo: C.J. Wood.)

the base of the offshore Rowe Formation appears to be approximately coincident with the Campanian–Maastrichtian boundary as recognized in the glacio-tectonic successions in north Norfolk at Sidestrand (see **Overstrand to Trimingham Cliffs** GCR site report, this volume) and not, as suggested by Lott and Knox (1994) with the base of the *Belemnitella mucronata* Zone. The up-section change, in the subcrop, from flintless Flamborough Chalk to flinty chalk may correspond to the change in the subcrop in the Southern Province at the boundary between the Newhaven Chalk and Culver Chalk formations. Unfortunately there are no reliable biostratigraphical data to confirm this interpretation.

BIOSTRATIGRAPHY

The biostratigraphy of the Chalk of the Northern Province exhibits greater similarities to that of contemporaneous successions in northern Germany than to the basinal chalks of the Southern Province and Anglo-Paris Basin.

Cenomanian Stage

The Cenomanian strata of the Northern Province were formerly traditionally divided by means of echinoids into a lower Zone of *Holaster subglobosus* and a higher Zone of *Holaster trecensis*. This contrasted with the parallel zonal scheme for southern England, which recognized a lower *Schloenbachia varians* Zone, succeeded by a *Holaster subglobosus* Zone. However, both schemes were based on misconceptions of the range and occurrence of *H. subglobosus*: on the one hand, the small *Holaster* (*H. bischoffi* Renevier) in the Lower Cenomanian deposits of the Northern Province were incorrectly attributed to *H. subglobosus* (Leske) and, on the other, in neither province does *H. subglobosus* range above the Nettleton Stone, or its equivalent (Jukes-Browne Bed 7). The Cenomanian strata of the Northern Province are relatively poorly fossiliferous, particularly in respect of ammonites. However, they can be successfully correlated with the more fossiliferous equivalents in northern Germany, and with the successions in the Southern Province by means of bio-events. On this basis, it is possible to infer the positions of the ammonite zonal boundaries, even though the zonal index fossils themselves are largely absent.

The Albian–Cenomanian boundary and, hence, the base of the Upper Cretaceous Series, falls near the top of the expanded Hunstanton Red Chalk Formation in the basinal succession developed at Speeton Cliff in the Cleveland Basin. Full biostratigraphical data, and details of the stable isotope correlation that allows the base of the Cenomanian Stage to be exactly located in this succession are given under the description of this section (see **Flamborough Head** GCR site report, this volume). It is only in the platform successions, for example **Melton Bottom Chalk Pit**, Middlegate Quarry, South Ferriby and **Hunstanton Cliffs**, where there is a hiatus at the boundary, involving both upper Albian and basal Cenomanian strata. In these cases, the base of the Upper Cretaceous succession (i.e. the base of the Cenomanian Stage) is taken at the thin dark marl beneath the Paradoxica Bed, and thus approximately at the base of the restricted Ferriby Chalk/Lower Chalk Formation.

The Cenomanian–Turonian boundary falls in or just above the 'Black Band' in the Northern Province. Wood and Mortimore (1995) described this variable succession of extremely condensed thin limestones and silts, within which there may be one or more black bands and marl seams, as the 'Variegated Beds' (Figure 5.5). The type locality is Melton Ross Quarry, Lincolnshire, where the Variegated Beds contained at least two black bands. Beds immediately below the Black Band proper can be correlated with the Plenus Marls Member of the Southern Province (*Metoicoceras geslinianum* ammonite Zone) at least up to and including Jefferies' Bed 4. The Black Band itself may equate with the basal part of the Sussex Melbourn Rock–Meads Marls of the Southern Province. The Cenomanian–Turonian boundary falls between the Black Band and the terminal green clay of the Variegated Beds (see Wood and Mortimore, 1995). It is, therefore, incorrect to treat the Variegated Beds as the correlative of the Plenus Marls, as has been done by Whitham (1991) and by Jeans *et al.* (1991). The equivalent of the Black Band is, rather, to be sought in the lower part of the thick terminal Cenomanian (*Neocardioceras juddii* Zone)–basal Turonian (*Mytiloides* spp. Zone) black shales that overlie the so-called 'Plenus Limestone' in basinal successions in northern Germany (cf. Ernst *et al.*, 1984; Hilbrecht and Dahmer, 1994; Wood and Ernst, 1998). The

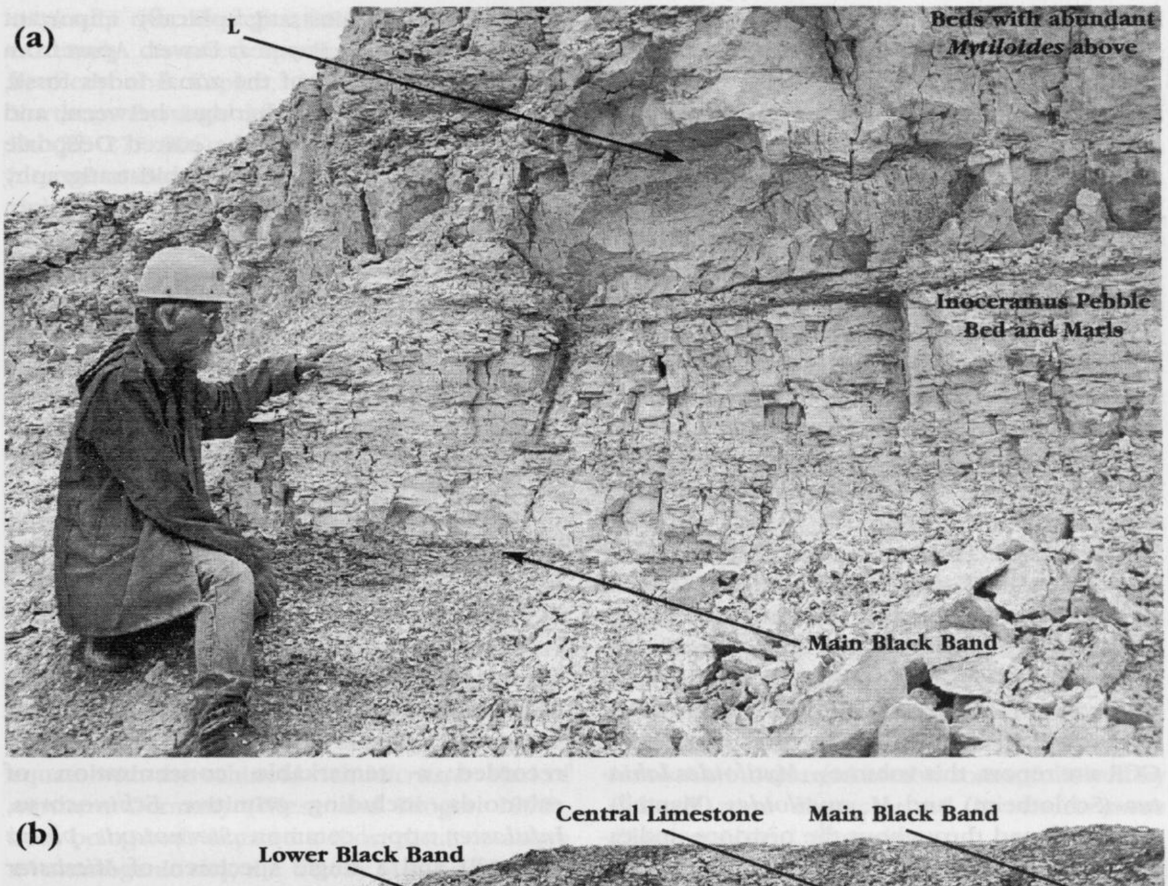


Figure 5.5 The Black Band of the Northern Province at the base of the White Chalk Subgroup and the Welton Chalk Formation. (a) The top of the Black Band to the twin marls (Inoceramus Pebble Bed) in Bigby Quarry, Lincolnshire. Note the mould of a very large ammonite (*Lewesiceras*, labelled 'L'). (b) The Black Band succession of Variegated Beds in Melton Ross Quarry, Lincolnshire. (Photos: R.N. Mortimore.)

Black Band also equates with the (Lower Turonian) Black Band at the base of the Herring Formation of Southern North Sea Basin stratigraphy.

Turonian Stage

The limits and diagnostic faunas of the traditional *Mytiloides* spp., *Terebratulina lata* and *Sternotaxis plana* zones of the Turonian Stage of southern England can be recognized without difficulty. However, the echinoid genus *Infulaster*, which is virtually absent from the Southern Province, is a characteristic and common faunal element throughout the higher part of the *lata* Zone and the entire *plana* Zone.

As yet there is no unequivocal evidence for the existence of the *Fagesia catinus* Zone in the Northern Province. However, the Lower Turonian *Mammites nodosoides* (ammonite) Zone is widely represented by *Mammites nodosoides* (Schlotheim) and *Morrowites wingi* (Morrow) (see **Melton Bottom Chalk Pit** GCR site report, this volume). *Mytiloides labiatus* (Schlotheim) and *M. mytiloides* (Mantell), are also found throughout the province, indicative of the *Mytiloides* spp. Zone (*Inoceramus labiatus* Zone of earlier zonal schemes).

The basal Middle Turonian zonal marker fossils *Collignoniceras woollgari* and *M. subhercynicus* have not been recorded in the Northern Province. Proxies for this boundary, the brachiopods *Concinnithyris* and *Terebratulina lata*, are recorded a short distance below the Grasby Marl (see **Melton Bottom Chalk Pit** GCR site report, this volume) in the Welton Chalk Formation.

Inoceramid bivalves of the *Inoceramus lamarcki* Parkinson and *I. cuvieri* J. Sowerby complex (*I. brongniarti* in the earlier literature on this area) first become conspicuous above the Grasby Marl, and are abundant in the interval between Barton Marls 2 and 3. The latter acme-occurrence corresponds in northern Germany to the *lamarcki/cuvieri* event 2, above tuff T_C (cf. Ernst *et al.*, 1998, figs 6.1, 6.2), the equivalent of Barton Marl 1. *Sternotaxis plana* (Mantell) first appears below Barton Marl 3, and in the Ferruginous Flint, a short distance above. A thin bed midway between this flint and the Melton Ross Marl, containing specimens of *Inoceramus lamarcki sensu stricto*, corresponds approximately to the type horizon of this biostratigraphically important species, at Langdon Bay near Dover. Apart from a relative abundance of the zonal index fossil, *Terebratulina lata* R. Etheridge, between, and for some distance above, the paired Deepdale Marls, little is known about the biostratigraphy of the highest part of the Welton Chalk.

The basal Upper Turonian ammonite zonal index species *Subprionocyclus neptuni* (Geinitz) is represented by a single find from below Deepdale Marl 1, a horizon inferred to be the equivalent of the basal Upper Turonian *costellatus/plana* event of northern Germany. The rich *neptuni* Zone ammonite fauna of the Chalk Rock is represented only by rare, poorly preserved specimens from the equivalent of the Kingston nodular beds (*S. plana* Zone), including the rare species *Pseudojacobites farmeryi* (Crick) (cf. Kennedy and Kaplan, 1995a).

The *Sternotaxis plana* Zone (Upper Turonian) is located at the base of the Burnham Chalk Formation. In the very condensed section at Newbald Wold Pit, Whitham (1991) recorded a remarkable concentration of echinoids, including primitive *Echinocorys*, *Infulaster* spp., common *Sternotaxis plana* (Mantell) and a single specimen of *Micraster michelini* (Agassiz), in and just above a bed of marly, nodular flaser-chalk at the base of the Burnham Chalk Formation. Wood (1992) noted that the association of *M. michelini* and common *S. plana* supported the correlation with the basal beds of the *S. plana* Zone of Dover, i.e. the Bridgewick Flints.

The Chalk Rock *reussianum* fauna of southern England is represented in the north by extremely rare, poorly preserved ammonites, including *Allocrioceras angustum* (J. de C. Sowerby), *Hyphantoceras reussianum* (d'Orbigny), *Lewesiceras mantelli* Wright and Wright and *Pseudojacobites farmeryi*. These ammonites come mainly from unspecified levels in the interval between the Wootton Marls and the Ulceby Marl, although Whitham (1991) recorded the eponymous *H. reussianum* from immediately beneath the Wootton Marls, and large, smooth ammonites occur in the bed beneath the Ulceby Marl at several localities. *P. farmeryi*, which belongs to the highest of the three ammonite faunas described from the contemporaneous 'Scaphitenschichten' of northern Germany (Kaplan and Kennedy, 1996), is extremely rare in the Chalk Rock, and was originally described on the basis of a single, extremely distorted specimen (Crick, 1910b; Kennedy and Kaplan, 1995a, pl. 4) from a Northern Province locality, the Boswell Farm Pit (TF 279 906) north of Louth. This same interval at Boswell Farm is highly fossiliferous, yielding a rich and well-preserved echinoid fauna, including common specimens of the large, thin-tested, primitive *Micraster corbovis* Forbes and subordinate, smaller *Micraster leskei* Desmoulins, which are typically Northern, and Southern, Province forms respectively.

The Ulceby Oyster Bed, in which small pycnodonteine oysters are abundant, marks a significant faunal change, with the entry of a diverse brachiopod fauna of Chalk Rock type, for example *Cretirhynchia cuneiformis* Pettit and *Gibbithyris subrotunda* (J. Sowerby), together with 'advanced' *Micraster* of the *bucailli* group. Immediately beneath this bed there is a sponge bed characterized by the typically Northern Province sponge species, *Cystispongia bursa* Quenstedt (Wood, 1992; Wiese and Wood, 2001). The Ulceby Oyster Bed is inferred to equate with the echinoid-rich *Micraster* Marl of northern Germany (Wiese and Kröger, 1998), both being beds situated a short distance above a vulcanogenic clay, the Ulceby Marl and Tuff T_F respectively (Wray and Wood, 1998).

Coniacian Stage

The Turonian–Coniacian boundary is present at the **Enthorpe Railway Cutting** GCR site and falls somewhere in the interval containing the three Kiplingcotes Marls. The biostratigraphy of the remainder of the Coniacian Stage was documented by Whitham (1991) and Wood (1992). A feature of particular note in the lower part of the Northern Province equivalent of the *Micraster cortestudinarium* Zone is the co-occurrence of *Micraster normanniae* and *M. corbovis*, together with a diverse *Cremnoceramus* assemblage, including *C. crassus inconstans* (Woods) and *C. c. crassus* (Petrascheck). In the higher part of the zone, the Southern Province zonal index species is also absent, being replaced here by the characteristically Northern Province *Micraster* of the *bucailli* group. Here, a lower *Cremnoceramus crassus–Inoceramus annulatus* Goldfuss assemblage is succeeded by a monospecific *I. annulatus* assemblage, a faunal change which has so far not been recognized in the Southern Province, but which has been recently identified in northern Germany (Walaszczyk and Wood, 1999c).

In the *M. cortestudinarium* Zone, echinoids are common, but the Northern Province form *Micraster bucailli* Parent replaces the Southern Province *M. cortestudinarium* (Goldfuss) and *M. decipiens* (Bayle) forms. The zone could be readily subdivided by means of echinoids, and the European Lower Coniacian inoceramid bivalve zones (Walaszczyk and Wood, 1999a,b) can also be identified. The rarity of *Micraster* in the equivalent of the *Micraster coranguinum* Zone (with the exception of the lower beds) has led to the introduction of a local Zone of *Hagenowia rostratus*. This zone, introduced by Rowe (1904), is based on a misconception that the common *Hagenowia* (actually *H. anterior* Ernst and Schulz) in the Flamborough Chalk, ranged throughout the interval in question. There is no suitable Northern Province zonal index species for this zone. However, the basal beds can be assigned to the European *Volviceramus koeneni* and *V. involutus* inoceramid bivalve zones, followed by a local zone characterized by *Inoceramus digitatus* J. de C. Sowerby.

The basal beds of the equivalent of the *Micraster coranguinum* Zone yield rich mixed *Platyceramus–Volviceramus* inoceramid bivalve faunas, as in southern England. The basal Middle Coniacian inoceramid zonal index species, *V. koeneni* (Müller), which is uncommon in the south, occurs in a shell-bed close to the base of the zone. Noteworthy occurrences at this level are *Inoceramus gibbosus* Schlüter, which is common in the *koeneni* Zone in Germany, but has not so far been recorded from the Southern Province; and a single specimen of the extremely rare belemnite *Actinocamax bohemicus* Stolley (Christensen, 1982) from the now backfilled Little Weighton Quarry. The succeeding zonal index fossil, *V. involutus* (J. de C. Sowerby), is found in proximity to a giant flint, the Eppleworth Flint, above which *Platyceramus* dominates the inoceramid bivalve assemblage. This faunal change parallels that found in the Southern Province at and above the level of the Seven Sisters Flint.

The beds below the Middleton Marl at Middleton-on-the-Wolds Quarry (SE 942 501), and in the Killingholme boreholes in Lincolnshire, contain specimens of the very large inoceramid bivalve *Inoceramus digitatus* J. de

C. Sowerby, which has a thick, tyically purple-coloured, strongly corrugated shell, with radiating ribs and a massive hinge. This fossil was originally described from a flint internal mould found in gravels in Essex, and is not known from the correlative level in southern England. Siliceous sponges, three-dimensionally preserved in limonite, are also common in these beds. In the higher part of the section, above the marl, *Volviceramus* re-appears, perhaps indicating the lower part of the Upper Coniacian succession of the European scheme.

Santonian Stage

By comparison with the Southern Province, the basal Santonian echinoids such as *Micraster coranguinum sensu stricto*, *M. gibbus*, and *Conulus albogalerus* are very rare or absent in the Northern Province. Even the stage boundary index inoceramid bivalve *Cladoceramus undulatoplicatus* (Roemer) is difficult to find. *C. undulatoplicatus*, found in only two horizons at Selwicks Bay (see **Flamborough Head** GCR site report, this volume), allows recognition of the basal Santonian Zone. *Cladoceramus* is also recorded about 12 m above the Middleton Marl in the Killingholme Borehole NIREX BH 37 (Berridge and Pattison, 1994, fig. 19). Other index fossils of the Lower Santonian Substage in the Northern Province found about 1 m above the higher *Cladoceramus* horizon are the echinoid *Infulaster infulasteroides* (Wright and Wright), together with terebratulid brachiopods (*Gibbithyris*) and inoceramid bivalves that are possibly *Sphenoceramus cardissoides* (Goldfuss). The occurrence of *Cordiceramus cordiformis* in inoceramid bivalve rich, fossiliferous chalk over about 4 m suggests a correlation with the *Cordiceramus*-acme in the Middle Santonian strata of northern Germany (Ernst and Schulz, 1974), and indicates a possible upper limit to the Lower Santonian succession in the Northern Province. In terms of the Southern Province, this would fall in the higher part of the *Micraster coranguinum* Zone.

The entire equivalent of the *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 rarity of the Southern Province zonal index fossil, the flood occurrences in the Flamborough Chalk of *Hagenowia anterior* (mistakenly identified by him and later workers as *Infulaster* (now *Hagenowia*) *rostratus*(*a*)) could be used to characterize both the flinty (Burnham) and flintless (Flamborough) parts of the zone.

The *Uintacrinus socialis* and *Marsupites testudinarius* zones are well developed here, although their original limits (Rowe, 1904) have been revised (Whitham, 1993; Mitchell, 1994, 1995b) on the basis of bed-by-bed collecting.

Campanian Stage

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* (Figure 2.25, Chapter 2), which replaced the Zone of *Actinocamax quadratus* then applied in the Southern Province. Mitchell (1995b) separated 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. The *S. lingua* Zone is characterized by *S. patootensiformis* Seitz (Figure 2.25, Chapter 2) and *S. angustus* Beyenburg and is commonly assigned to the *S. patootensiformis* inoceramid Zone (Figure 2.27, Chapter 2).

At Sewerby Steps, the occurrence of the heteromorph ammonite *Scaphites binodosus* Roemer, was taken by Whitham (1993) to mark the base of the *Discoscaphites binodosus* Subzone (Wright and Wright, 1942) of the *lingua* Zone. On the basis of the ammonite and inoceramid bivalve faunas, there is no evidence that the currently exposed coastal and inland Chalk in Yorkshire extends any higher than the lower part of the equivalent of the *Offaster pilula* Zone of southern England. However, faunas recorded from now vanished pits by Wright and Wright (1942) and by Whitham (1993), including *Micraster schroederi* and the belemnite *Belemnitella*, are significantly different from those of the extant quarries, and may indicate a higher horizon, but still within the *Offaster pilula* Zone. None of the typical *Echinocorys* of the *Offaster pilula* Zone of the Southern Province has been found in Yorkshire and it is not, therefore, possible to apply the Southern Province zonal and subzonal scheme to the Northern Province.

HUNSTANTON CLIFFS, THE WASH, NORFOLK (TF 672 413–TF 679 424)

Introduction

The Hunstanton Cliffs GCR site is a west-facing sea cliff, up to 18 m high, that extends 1.3 km NNE from Hunstanton promenade to St Edmund's Point, Old Hunstanton (Figure 5.6). The site provides a continuous, long and beautifully weathered section (Figure 5.7) through the lower two-thirds of the redefined Ferriby Chalk Formation, the equivalent in the Northern Province of the Grey Chalk Subgroup of the Southern Province. This is the first outcrop locality where the stratigraphical terminology of the Northern Province can be applied. The Hunstanton Cliffs GCR site is the next link northwards in the network of GCR sites after **Chinnor Chalk Pit** in the southern Chiltern Hills and **Barrington Chalk Pit** (Cambridgeshire). Parts of the succession, notably the basal Paradoxica Bed, the overlying Lower Inoceramus Bed and the Totternhoe Stone are very fossiliferous. The macrofossils from here are critical in the correlation between the relatively condensed successions of the Northern Province and the expanded, basinal successions of the Southern Province. The Ferriby Chalk Formation here, and in the type area, is directly comparable with the Cenomanian successions in northern Germany.

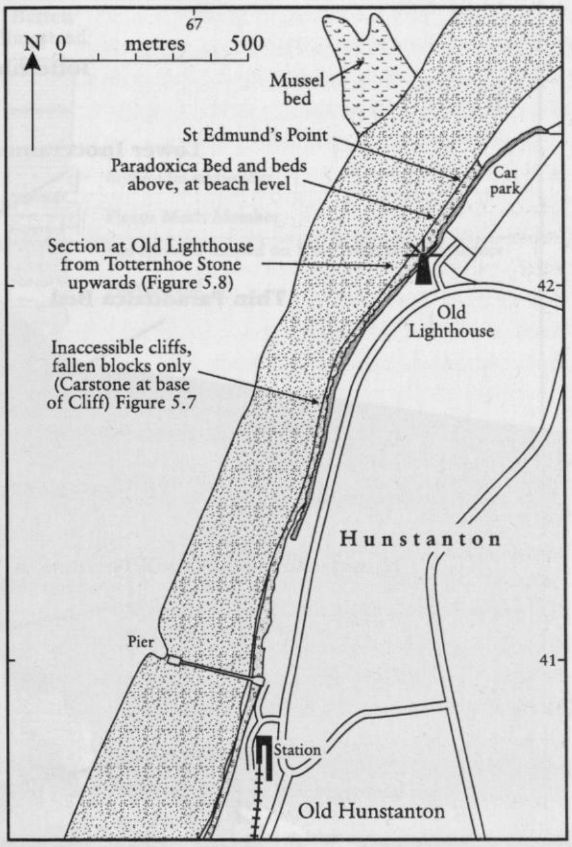


Figure 5.6 Map of the Hunstanton Cliffs GCR site (also see Figure 5.7).

Description

At Hunstanton Cliffs the strata are superbly exposed, and there is a spectacular and dramatic colour contrast between the rusty brown Carstone, the brick-red Hunstanton Red Chalk Formation ('Red Chalk'), and the overall white and grey colours of the Ferriby Chalk Formation (Figure 5.7). A very gentle easterly dip brings the base of the Upper Cretaceous succession to beach level at St Edmund's Point. Between here and New Hunstanton, the Ferriby Chalk is generally inaccessible, except beneath the lighthouse, where it is possible to reach weathered exposures of most of the succession by climbing a former cliff-fall. The various components of the succession can, however, be readily examined in huge fallen blocks on the beach, many of which are sea-washed and reveal sedimentary details that are not easily seen in the cliffs.

The richly fossiliferous nature of the Red Chalk and Ferriby Chalk at Hunstanton Cliffs has attracted the attention of numerous geologists. William Smith included both formations in his 'Table of Strata' (1815a,b) and both were delineated on his map of Norfolk (1819). Early descriptions of the cliffs include those by Taylor (1823), S. Woodward (1833) and Fitton (1836). The most comprehensive account of the stratigraphy of the Ferriby Chalk of the site is given in a British Geological Survey Memoir (Gallois, 1994). Owen (1995) studied the Red Chalk and Jeans (1980) investigated the contact between the Red Chalk and Ferriby Chalk. It was, however, Mitchell (1995a) who identified the extent of the hiatus at the Lower–Upper Cretaceous boundary in the context of the expanded and more complete basinal succession in Yorkshire at Speeton Cliff. Mitchell *et al*. (1996), Gale (1996) and Mitchell and Veltkamp (1997) discussed the correlative succession at Middlegate Quarry and South Ferriby, Lincolnshire.

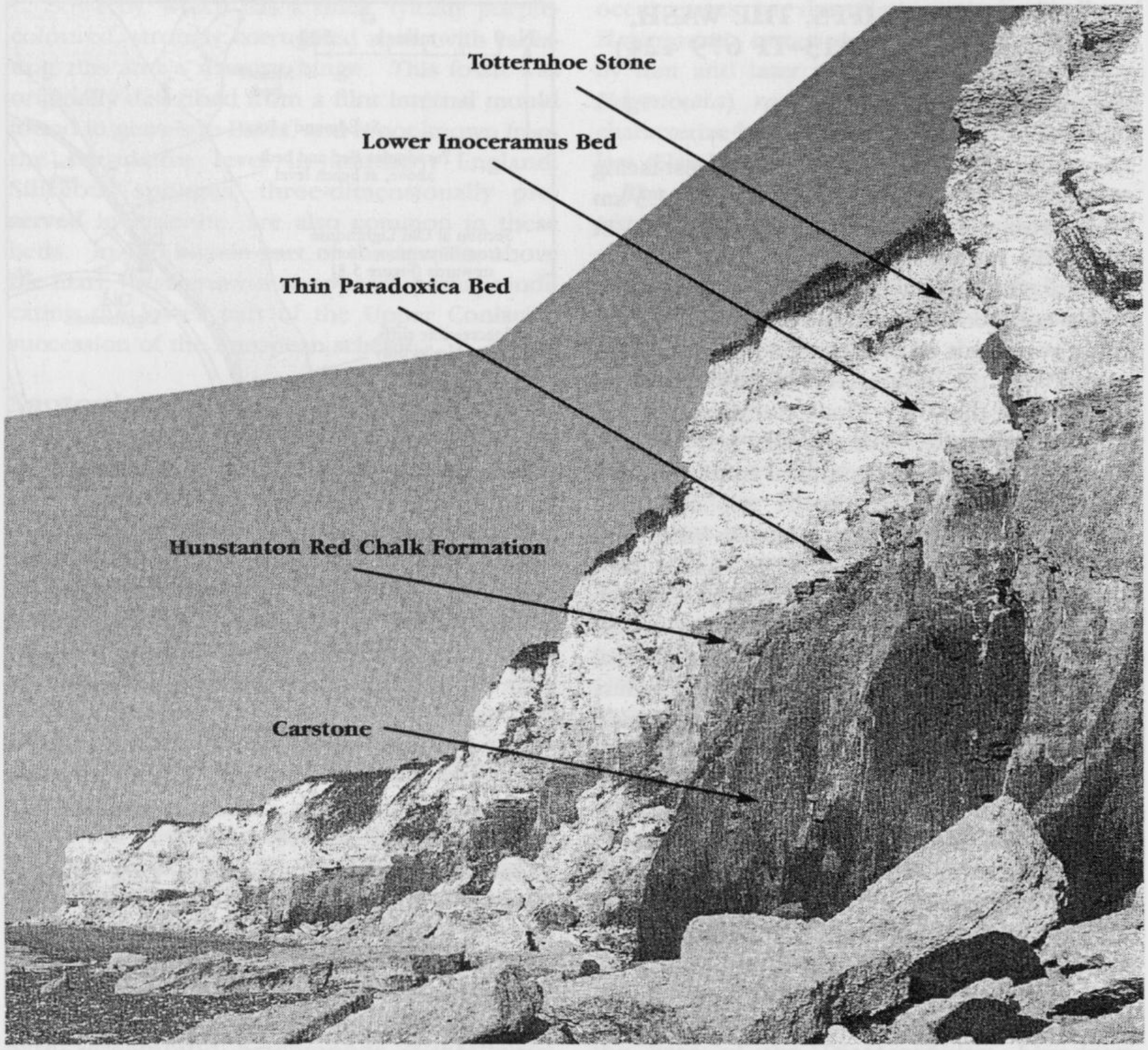


Figure 5.7 Hunstanton Cliffs, north Norfolk coast. (Photo: A. Hutchinson.)

Lithostratigraphy

The Ferriby Chalk Formation, about 10 m thick (Figure 5.8), extends from the contact with the underlying Hunstanton Red Chalk Formation up to the hard-bed beneath the Nettleton Pycnodonte Marl and overlying Nettleton Stone. Both these markers just fail to be preserved at the top of the cliff adjacent to the lighthouse, but are found in nearby sections inland.

The original lithostratigraphical scheme for the Northern Province (Wood and Smith, 1978) treated the Red Chalk as a member (Hunstanton Chalk Member) of the Ferriby Chalk Formation. Later workers (Whitham, 1991; Mitchell, 1995a; and Owen, 1995) have redefined the Ferriby Chalk by classifying the Red Chalk as a formation in its own right. Owen's revised name, 'Hunstanton Red Chalk Formation', is used in the present volume in accordance with the recent standardized stratigraphical nomenclature.

The pink and cream colours of the thin (up to 0.45 m thick) Paradoxica Bed, at the base of the Ferriby Chalk, contrasts vividly with the red coloration of the Hunstanton Red Chalk Formation beneath, and the grey Lower Inoceramus Bed above. The contact between the Hunstanton Red Chalk Formation and the Paradoxica Bed is extremely complex (Jeans, 1980, fig. 12). Depressions in the eroded top of the Hunstanton Red Chalk Formation are filled by laminated structures, which may be algal stromatolites.

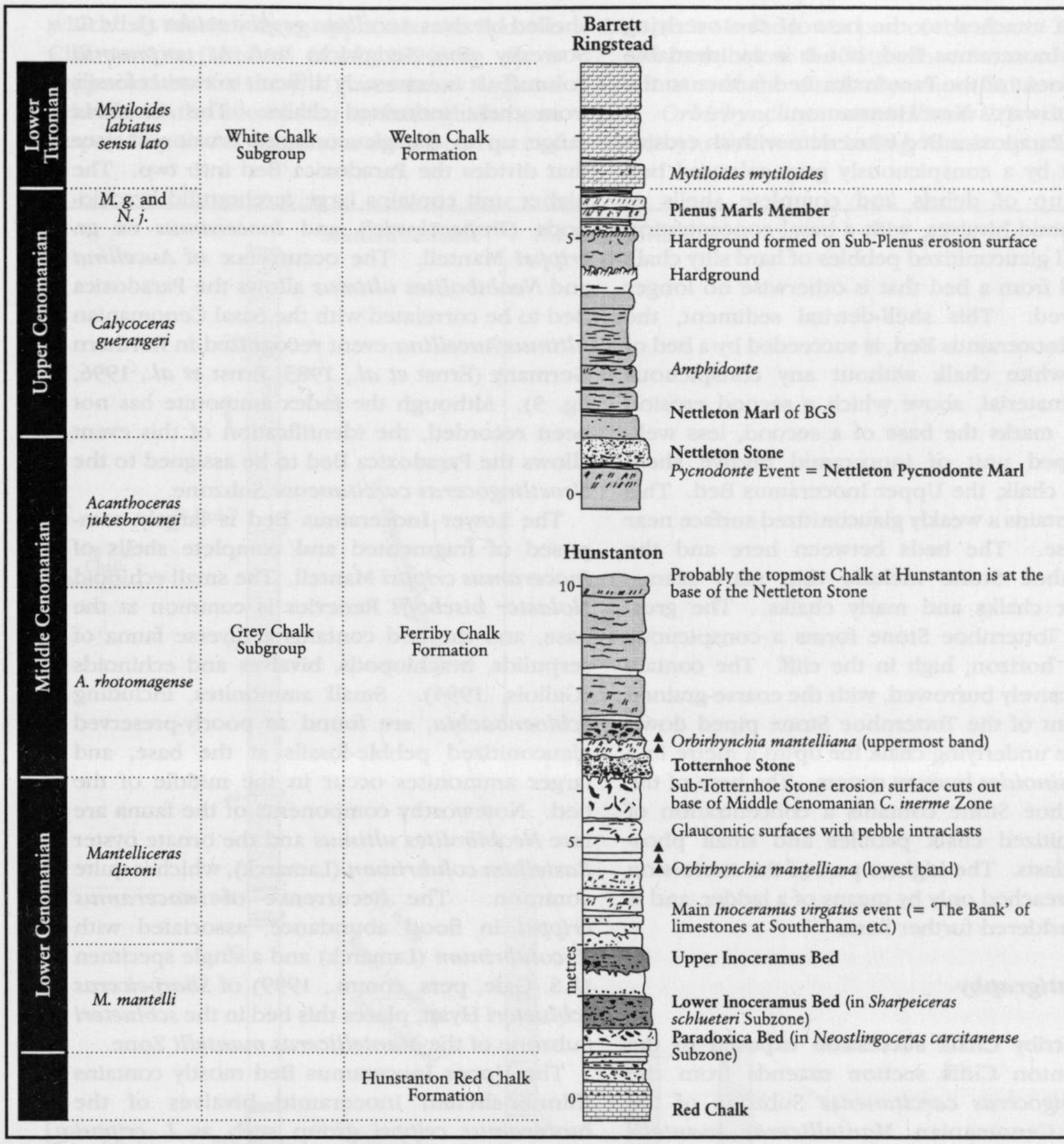


Figure 5.8 The Chalk succession at Hunstanton Cliffs (compare with Figure 5.7). The higher Cenomanian beds are not present at Hunstanton, these are seen at Barrett Ringstead Chalk Pit. (*M. g. = Metoicoceras geslinianum*; *N. j. = Neocardioceras juddii*.)

These are overlain by a thin, dark red marl, from which arise laminated columnar structures that are larger than those below. These may also be stromatolites, which would indicate very shallow, possibly intertidal conditions.

The Paradoxica Bed proper comprises several closely spaced, welded, glauconitized hardgrounds, penetrated by sediment-filled, anastomosing *Thalassinoides* burrow systems (Jeans, 1980, fig. 9). It is these complex branching burrows, superbly illustrated by Kennedy (1967, pls 2, 3), and misidentified by 19th century workers as a sponge (*Spongia paradoxica*) that give the name to this distinctive bed. The Paradoxica Bed is divided into two parts at a glauconitized surface. The thinner, upper part, is scarcely preserved in the vicinity of St Edmund's Point, where it is represented by small patches attached to the base of the overlying Lower Inoceramus Bed, but it is an invariable component of the Paradoxica Bed farther to the south, towards New Hunstanton.

The Paradoxica Bed is overlain with an erosive contact by a conspicuously grey coloured bed made up of debris and complete shells of inoceramid bivalves, with a basal concentration of small glauconitized pebbles of hard silty chalk derived from a bed that is otherwise no longer preserved. This shell-detrital sediment, the Lower Inoceramus Bed, is succeeded by a bed of hard, white chalk without any conspicuous shelly material, above which a second erosion surface marks the base of a second, less well-developed unit of inoceramid bivalve shell-detrital chalk, the Upper Inoceramus Bed. This bed contains a weakly glauconitized surface near the base. The beds between here and the Totternhoe Stone include thin marl seams, nodular chalks and marly chalks. The grey-brown Totternhoe Stone forms a conspicuous marker horizon, high in the cliff. The contact is extensively burrowed, with the coarse-grained sediment of the Totternhoe Stone piped down into the underlying chalk for up to a metre in a *Thalassinoides* burrow system. The base of the Totternhoe Stone contains a concentration of glauconitized chalk pebbles and small phosphate clasts. The highest part of the succession can be reached only by means of a ladder, and is not considered further here.

Biostratigraphy

The Ferriby Chalk succession exposed in the Hunstanton Cliffs section extends from the *Neostlingoceras carcitanense* Subzone of the Lower Cenomanian *Mantelliceras mantelli* Zone up to a horizon inferred to be near the base of the Middle Cenomanian *Acanthoceras jukesbrownei* Zone.

The thin marl immediately underlying the Paradoxica Bed, (and representing the highest unit of the Hunstanton Red Chalk), contains a distinctive fauna of small terebratulid brachiopods, associated with the belemnite *Neohibolites ultimus* (d'Orbigny). Some of the brachiopods are forms that were described by d'Archiac (1847) from the basal Cenomanian condensed 'Tourtia' of the Ardennes in Belgium.

The Paradoxica Bed contains small brachiopods (see Gallois, 1994), the belemnite *Neohibolites ultimus* (d'Orbigny) and the thin-shelled bivalves *Aucellina gryphaeoides* (J. de C. Sowerby *non* Sedgwick) and *A. uerpmanni* Polutoff. It is extremely difficult to extract fossils from these indurated chalks. The *Aucellina* range up to the glauconitized erosion surface that divides the Paradoxica Bed into two. The higher unit contains large terebratulid brachiopods (*Tropeothyris*?) and *Inoceramus* ex gr. *crippsi* Mantell. The occurrence of *Aucellina* and *Neohibolites ultimus* allows the Paradoxica Bed to be correlated with the basal Cenomanian *ultimus/Aucellina* event recognized in northern Germany (Ernst *et al.*, 1983; Ernst *et al.*, 1996, fig. 5). Although the index ammonite has not been recorded, the identification of this event allows the Paradoxica Bed to be assigned to the *Neostlingoceras carcitanense* Subzone.

The Lower Inoceramus Bed is largely composed of fragmented and complete shells of *Inoceramus crippsi* Mantell. The small echinoid *Holaster bischoffi* Renevier is common at the base, and the bed contains a diverse fauna of serpulids, brachiopods, bivalves and echinoids (Gallois, 1994). Small ammonites, including *Schloenbachia*, are found as poorly-preserved glauconitized pebble-fossils at the base, and larger ammonites occur in the middle of the bed. Noteworthy components of the fauna are rare *Neohibolites ultimus* and the ornate oyster *Rastellum colubrinum* (Lamarck), which is quite common. The occurrence of *Inoceramus crippsi* in flood abundance, associated with *R. colubrinum* (Lamarck) and a single specimen (A.S. Gale, pers. comm., 1999) of *Sharpeiceras schlueteri* Hyatt, places this bed in the *schlueteri* Subzone of the *Mantelliceras mantelli* Zone.

The Upper Inoceramus Bed mostly contains thinner-shelled inoceramid bivalves of the *Inoceramus crippsi* group such as *I. crippsi hoppenstedtensis* Tröger. A glauconitized surface near the base (the 'Turrilitoid Plane' of Jeans, 1980), overlain by very large and poorly preserved, glauconitized heteromorph ammonites (*Hypoturrilites* and/or *Mariella*), can be followed from here to Yorkshire, and is probably equivalent to the *Mariella* event recognized throughout northern Germany (Ernst and Rehfeld, 1997). This re-appearance of coarse, shell-detrital chalks in Hunstanton Cliffs and correlative Northern Province sections, is now considered to correspond to the coarser chalks with associated phosphates that mark the base of the *Mantelliceras dixoni* Zone in southern England (see Figure 5.9). This interpretation, which has recently been applied to the Speeton Cliff section (Mitchell *et al.*, 1996, fig. 5), is supported by the entry of *Inoceramus virgatus* Schlüter in the succeeding nodular chalks, corresponding to the ubiquitous acme-ocurrence of this species in the lower part of the *dixoni* Zone.

The beds below the Totternhoe Stone contain specimens of the small rhynchonellid brachiopod *Orbirhynchia mantelliana* (J. de C. Sowerby), bivalves including *Limea* sp., and a

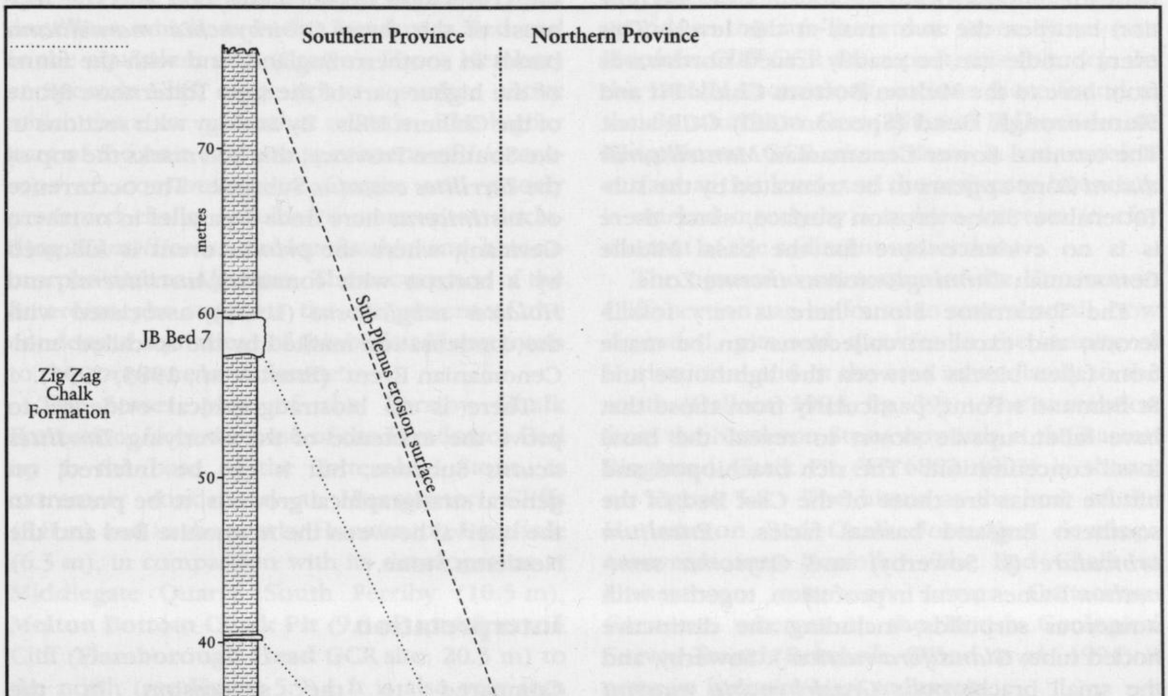


Figure 5.9 Correlation of key marker beds in the Cenomanian Grey Chalk Subgroup between the Southern Province (West Melbury Marly Chalk and Zig Zag Chalk formations), and the Northern Province (Ferriby Chalk Formation).

diverse echinoid fauna. This brachiopod occurrence (Orbirhynchia Band 1 of Jeans, 1968) equates with the lowest of the three *Orbirhynchia mantelliana* bands developed in the Southern Province (e.g. at Folkestone; see Figure 5.9) and, together with the *virgatus*-acme beneath, unequivocally establishes the correlation between the two areas at this level. This event bundle can be readily traced northwards from here to the **Melton Bottom Chalk Pit** and **Flamborough Head** (Speeton Cliff) GCR sites. The terminal Lower Cenomanian *Mantelliceras dixoni* Zone appears to be truncated by the sub-Totternhoe Stone erosion surface, since there is is no evidence here for the basal Middle Cenomanian *Cunningtoniceras inerme* Zone.

The Totternhoe Stone here is very fossiliferous, and excellent collections can be made from fallen blocks between the lighthouse and St Edmund's Point, particularly from those that have fallen upside down to reveal the basal fossil concentration. The rich brachiopod and bivalve faunas are those of the Cast Bed of the southern England basinal facies. *Entolium orbiculare* (J. Sowerby) and *Oxytoma seminudum* Dames occur in profusion, together with numerous serpulids, including the distinctive noded tube, *Glandifera rustica* J. Sowerby, and the small brachiopods *Grasirhynchia martini* (Mantell), *Kingena concinna* Owen and *Modestella geinitizi* (Schloenbach). Compared with the three-dimensionally preserved phosphatized steinkerns at the base of the Totternhoe Stone in the Chiltern Hills, the ammonites here, such as *Acanthoceras* sp., are rather poorly preserved as flattened and weakly glauconitized composite moulds. The belemnite *Praeactinocamax primus* (Arkhangelsky), which occurs rarely at this level in the Southern Province, for example at **Southerham Grey Pit**, and, more commonly, in the Chiltern Hills, (e.g. **Chinnor Chalk Pit**), is accompanied here by the diminutive aberrant form, *Belemnocamax boweri* Crick. This latter form, which is a typical Northern Province species (Crick, 1910a; Christensen, 1992), has so far not been recorded south of Hunstanton. This faunal assemblage, particularly the two belemnites, characterizes the key northern European *primus* event (Ernst *et al.*, 1983; Christensen, 1990; and Figures 2.12 and 2.13, Chapter 2), which has been shown by stable isotope data (Mitchell *et al.*, 1996, Paul *et al.*, 1994) possibly to mark a short-term cooling phase in early Mid-Cenomanian times.

The Totternhoe Stone is overlain by a hard white chalkstone, the 'Ammonite Bed', which contains large, uncrushed and weakly glauconitized ammonites, including *Parapuzosia* (*Austiniceras*) *austeni* (Sharpe). The occurrence of *Orbirhynchia mantelliana* establishes the correlation between this bed and the topmost of the three *Orbirhynchia mantelliana* bands in southern England, and with the fauna of the higher part of the type Totternhoe Stone of the Chiltern Hills. By analogy with sections in the Southern Province, this bed marks the top of the *Turrilites costatus* Subzone. The occurrence of *Austiniceras* here finds a parallel in northern Germany, where the *primus* event is followed by a horizon with common *Austiniceras* and *Holaster subglobosus* (Leske), associated with the condensation marked by the so-called 'mid-Cenomanian Event' (Ernst *et al.*, 1983, 1996).

There is no biostratigraphical evidence to prove the existence of the overlying *Turrilites acutus* Subzone, but it can be inferred, on general stratigraphical grounds, to be present in the interval between the Ammonite Bed and the Nettleton Stone.

Interpretation

Compared to the succession in the **Flamborough Head** GCR site at Speeton Cliff, where there is an apparently unbroken sedimentary record across the Albian–Cenomanian boundary, there is a significant hiatus between the Hunstanton Red Chalk Formation and the Ferriby Chalk Formation at Hunstanton Cliffs. At Speeton Cliff, the equivalent of the Paradoxica Bed is separated from the extrapolated base of the Cenomanian Stage by nearly 6 m of red sediments, including marls, marly chalks and chalks with marl flasers (see **Flamborough Head** GCR site report, this volume) belonging to the Hunstanton Red Chalk Formation. The top of this succession, 1.3 m of alternating thin marls and marly chalks, equates with the thin dark red marl beneath the Paradoxica Bed at Hunstanton, and rests on a deeply burrowed erosion surface. In contrast to Speeton Cliff, the entire succession below this erosion surface down to the extrapolated base of the Cenomanian Stage is missing at Hunstanton. Hence the low, but certainly not basal, Cenomanian Paradoxica Bed rests here with major hiatus on a level in the Upper Albian (*Stoliczkaia dispar* ammonite Zone) Hunstanton Red Chalk Formation (cf.

Mitchell, 1995a, fig. 12; and Figure 5.8).

The Paradoxica Bed, when traced southwards from Hunstanton Cliffs in cored boreholes, thickens and becomes progressively less indurated, passing into buff-coloured chalks known as the 'Porcellaneous Beds' (Morter and Wood, 1983). These beds contain few fossils apart from *Aucellina*, which, as in the Paradoxica Bed and in the equivalent unit (Crowe's Shoot Member) at Speeton Cliff, range up to a surface above which there are no further records. The higher part of the unit contains specimens of *Inoceramus* cf. *comancheanus* Cragin and poorly preserved chalky moulds of ammonites, including *Mantelliceras*, *Schloenbachia* and heteromorphs such as *Algerites*. The occurrence of the heteromorphs supports the assignment of the condensed equivalent of this bed at Hunstanton to the *carcitanense* Subzone.

The lower part of the Ferriby Chalk Formation, from the base of the Paradoxica Bed up to the base of the Totternhoe Stone, is extremely condensed at Hunstanton Cliffs (5.8 m) and in the nearby Hunstanton Borehole (6.3 m), in comparison with its development at Middlegate Quarry, South Ferriby (10.5 m), **Melton Bottom Chalk Pit** (9.8 m) and Speeton Cliff (**Flamborough Head** GCR site; 20.3 m) to the north (see Figure 5.9). It is also very thin compared with the same interval at **Barrington Chalk Pit** (27 m in Jeans, 1980, fig. 1). The succession from the Totternhoe Stone to the sub-Plenus erosion surface is also much thinner at Hunstanton Cliffs than in the sections to the north. However, the proportional thinning is less, and the interval between the Totternhoe Stone and the Nettleton Stone retains a similar thickness, albeit increased by about 1 m only in the correlative sections.

Compared to the more complete Lower–Middle Cenomanian boundary transition at Speeton Cliff, the Hunstanton Cliffs section is significantly condensed, with the equivalent of the basal Middle Cenomanian *Cunningtoniceras inerme* Zone of the Southern Province completely missing at the hiatus marked by the sub-Totternhoe Stone erosion surface. In this respect the Hunstanton Cliffs succession is comparable with those at Middlegate Quarry, South Ferriby (cf. Mitchell et al., 1996, fig. 3) and at **Melton Bottom Chalk Pit**. The sub-Totternhoe Stone erosion surface in these platform successions, including those discussed earlier in the Chiltern Hills sections, for example **Chinnor Chalk Pit**, represents a sequence boundary located at a very high level in the terminal Lower Cenomanian *Mantelliceras dixoni* Zone. The hiatus between the Hooken Member (Bed A2) and the Little Beach Member (Bed B) in the highly condensed Beer Head Limestone Formation succession of south-east Devon also corresponds to this sub-Totternhoe Stone hiatus (see **Hooken Cliff** GCR site report, this volume). In the basinal successions, such as those found at the **Southerham Grey Pit** and **Folkestone to Kingsdown** GCR sites, there is no erosion surface at this level, and the sequence boundary is marked merely by a sudden increase in clay content of the sediment up-section.

The upward continuation of the Hunstanton Cliffs section can be found in several small, now degraded, pits and quarries in the vicinity of Hunstanton, and in the area immediately to the south (Gallois, 1994, fig. 39). The succession from the Nettleton Stone upwards at the Barrett Ringstead Chalk Pit (TF 6892 4003) is shown on Figure 5.8. The hiatus at the base of the Hunstanton Red Chalk Formation develops eastwards into Norfolk. The Red Chalk at Hunstanton rests on Lower Cretaceous Carstone, whereas in the British Geological Survey Trunch Borehole (Wood *et al.*, 1994) it rests on Jurassic (Lias) sediments.

Conclusions

Hunstanton Cliffs, located at the southern margin of the Northern Province, provides a vital link between the Chalk provinces of England. It is the type locality for the Hunstanton Red Chalk Formation, a mapping horizon at the base of the Chalk escarpment northwards through Lincolnshire and Yorkshire, and a marker bed in the North Sea. Because of its location on a tectonic high beneath the Wash there are marked erosional hiatuses at the base of the Cenomanian succession between the Hunstanton Red Chalk Formation and Ferriby Chalk and beneath the Totternhoe Stone. The Plenus Marls Member in adjacent quarry exposures is also highly condensed, resting on a strongly developed sub-Plenus erosion surface. These erosion surfaces relate to sequence boundaries that can be traced into thicker, more complete, sections at the **Flamborough Head** (Speeton Cliff) GCR site, in the Northern Province and the **Folkestone to Kingsdown** and **Southerham Grey Pit** GCR sites in the Southern Province.

MELTON BOTTOM CHALK PIT, EAST YORKSHIRE (SE 970 277–SE 970 272)

Introduction

The Melton Bottom Chalk Pit GCR site consists of two quarries. The southern quarry (SE 970 272–SE 973 273), to which the name Melton Bottom Chalk Pit should strictly be applied, is a narrow quarry, aligned NW–SE. The quarry is now abandoned and the sides have been graded, obscuring the section. It formerly provided an excellent *c.* 30 m Cretaceous section, from the unconformable contact between the Lower Albian Carstone with the Upper Jurassic (basal Upper Oxfordian) mudstones of the Ancholme Clay Group, up to the basal 6 m of the Welton Chalk Formation of the Chalk Group.

To the north of the Melton Bottom Chalk Pit is an enormous working quarry cut into the hillside, extending back to Welton Wold, which is the name by which this upper quarry is known. This quarry is the stratotype section for the Welton Chalk Formation and additionally exposes the basal few metres of the Burnham Chalk Formation. The Melton Bottom Chalk Pit GCR site is currently, with the exception of the Black Band at the base, the only inland section exposing the entire formation. It is also the best inland exposure of the higher part of the formation, from the Melton Ross Marl upwards.

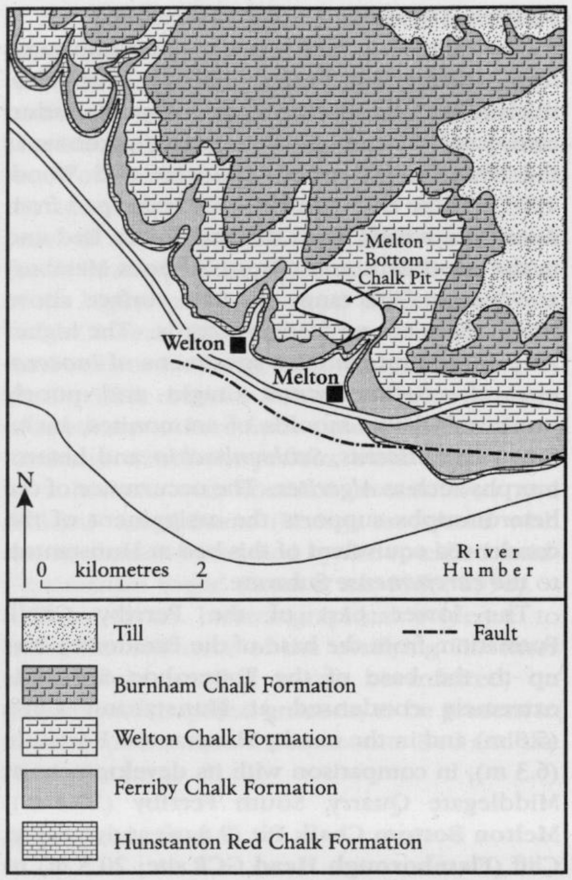


Figure 5.10 The Melton Bottom Chalk Pit GCR site, East Yorkshire; type locality of the Welton Chalk Formation. (Based on British Geological Survey Sheet 80, Kingston upon Hull.)

Description

The two Melton Bottom Chalk Pit site quarries (Figures 5.10 and 5.11) are described separately. Previous published records of this site are limited to general descriptions and a photograph (Sheppard, 1903, fig. 39). The first and only measured sections are those of Whitham (1991, fig. 4).

Melton Bottom Chalk Pit

Lithostratigraphy

A skeletal log of the Ferriby Chalk Formation in Melton Bottom Chalk Pit (the 'Lower Pit' on Figure 5.11) showing the main beds and marker horizons is given in Figure 5.12, which is largely based on Whitham's log (1991, fig. 4). The extra descriptions and interpretations of this log are those of the present authors, based on correlative sections at Middlegate Quarry, South Ferriby. As this quarry is now backfilled, no further details can be obtained and the present authors are indebted to Dr Whitham for his information.

Biostratigraphy

The biostratigraphy of the Ferriby Chalk Formation, based on Lincolnshire localities, was reviewed by Wood (1992). Records relating specifically to Melton Bottom Chalk Pit were given by Whitham (1991). Of particular interest is the reported occurrence there of *Aucellina* in the Lower Inoceramus Bed, which, if correctly identified, would represent the highest record of *Aucellina* in the UK, i.e. within the *Sharpeiceras schlueteri* Subzone. The previous highest record was in the lower part of the Paradoxica Bed (basal Cenomanian *Neostlingoceras carcitanense* Subzone).

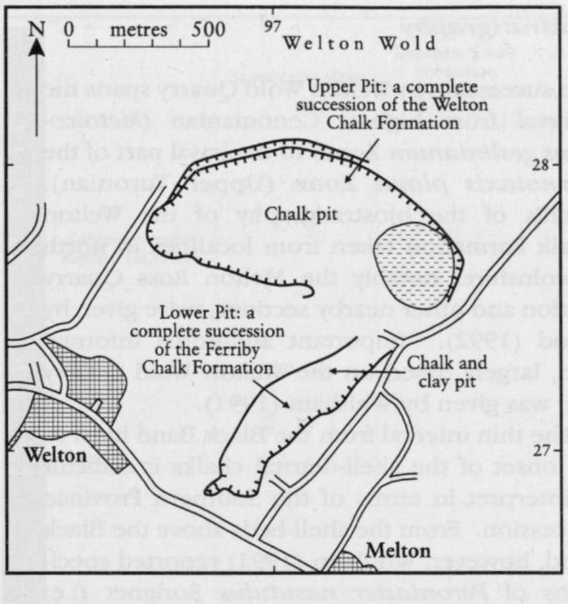


Figure 5.11 The Melton Bottom Chalk Pit GCR site, represented by the 'Lower Pit' (Melton Bottom Chalk Pit, and the 'Upper Pit' (Welton Wold Quarry).

Melton Bottom Chalk Pit yields specimens of crushed ammonites (*Schloenbachia* sp.) in shaly beds overlying the Upper Inoceramus Bed. These have not been recorded from other correlative sites. Whitham (1991) noted four specimens of the belemnite *Praeactinocamax primus* (Arkhangelsky) in the Totternhoe Stone and, surprisingly, additionally recorded the small pectinacean bivalve *Lyropecten* (*Aequipecten*) *arlesiensis* (Woods). In Southern Province basinal successions, this latter species is usually restricted to a bed (Arlesiensis Bed) in the basal Middle Cenomanian *Cunningtoniceras inerme* Zone, below the level of the Cast Bed and hence below the equivalent of the Totternhoe Stone. In the Chiltern Hills, this species is entirely absent from the Totternhoe Stone, although it is known from the channel facies of the Stone at Arlesey (see p. 340, Chapter 4), north of Hitchin, which is the type locality for the species. Current evidence (e.g. Mitchell *et al.*, 1996, fig. 3) suggests that the bed in question is missing

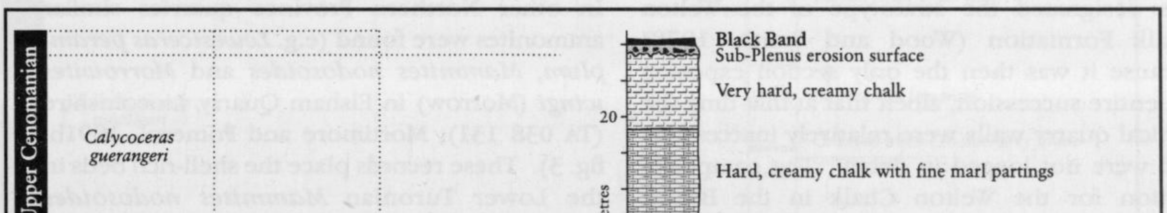


Figure 5.12 The Red Chalk and Ferriby Chalk succession at Melton Bottom Chalk Pit (the 'Lower Pit' at Melton, Figure 5.11) (*N.* = *Neostlingoceras*). (After Whitham, 1991.)

here and in all other platform successions (e.g. Middlegate Quarry, South Ferriby; **Hunstanton Cliffs**) in the sub-Totternhoe Stone hiatus. The higher part of the Totternhoe Stone yields specimens of undescribed large *Holaster* sp., *Acanthoceras rhotomagense* (Brongniart), *Parapuzosia* (*Austiniceras*) sp. and moulds of large *Turrilites*; at the nearby Rifle Butts section (SE 901 427) the diminutive aberrant belemnite *Belemnocamax boweri* Crick has been collected from the same level.

Welton Wold Quarry

Welton Wold Quarry (the 'Upper Pit' on Figure 5.11) is located to the north of the abandoned Melton Bottom Chalk Pit.

Lithostratigraphy

The section extends from the Black Band at the base of the Welton Chalk Formation to the basal part of the Burnham Chalk Formation. It was designated the stratotype of the Welton Chalk Formation (Wood and Smith, 1978) because it was then the only section exposing the entire succession, albeit that at that time the vertical quarry walls were relatively inaccessible and were not logged in detail. The composite section for the Welton Chalk in the British Geological Survey Memoir (Wood, 1992, fig. 33) was actually constructed from the section in the Melton Ross Quarry (TA 082 112) in north Linconshire for the succession from the Grasby Marl up to the Melton Ross Marl at the top of the quarry (for which this is the stratotype), with the remainder of the succession being taken from other sections in the same area. Subsequently the style of quarrying at Welton Wold Quarry has changed, and sloping roadways provide easy access to most parts of the section. The section (Figure 5.13) is modified from the skeletal log given by Whitham (1991, figs 5, 6), supplemented with information from the relevant part of the Melton Ross section. The basal Variegated Beds, including the Black Band (see Figure 5.5), and overlying shell-detrital chalks equivalent to the Holywell Nodular Chalk Formation of the Southern and Transitional provinces, are only 3.3 m thick here. The stratotype Welton Chalk Formation is 54 m thick, and an additional 2 m of basal Burnham Chalk, up to the lowest of the Triple Tabular Flints, is exposed at the top of the quarry, by the access road.

Biostratigraphy

The succession in Welton Wold Quarry spans the interval from highest Cenomanian (*Metoicoceras geslinianum* Zone) to the basal part of the *Sternotaxis plana* Zone (Upper Turonian). Details of the biostratigraphy of the Welton Chalk Formation taken from localities in north Lincolnshire, notably the Melton Ross Quarry section and other nearby sections, were given by Wood (1992). Important additional information, largely based on the Welton Wold Quarry site, was given by Whitham (1991).

The thin interval from the Black Band itself to the onset of the shell-detrital chalks is difficult to interpret in terms of the Southern Province succession. From the shell-beds above the Black Band, however, Whitham (1991) reported specimens of *Peroniaster nasutulus* Sorignet (i.e. *Hemiaster minimus* (Agassiz)), as well as the ammonites *Lewesiceras peramplum* (Mantell), *Mammites nodosoides* (Schlotheim) and *Parapuzosia* (*Austiniceras*) *austeni* (Sharpe). In other Northern Province quarries similar ammonites were found (e.g. *Lewesiceras peramplum*, *Mammites nodosoides* and *Morrowites wingi* (Morrow) in Elsham Quarry, Lincolnshire (TA 038 131); Mortimore and Pomerol, 1991b, fig. 3). These records place the shell-rich beds in the Lower Turonian *Mammites nodosoides* Zone. This is supported by the occurrence of abundant *Mytiloides* spp., including *M. labiatus* (Schlotheim) and *M. mytiloides* (Mantell), which are indicative of the provisional *Mytiloides* spp. inoceramid bivalve Zone, (the *Inoceramus labiatus* Zone of earlier zonal schemes).

Towards the top of the shell-rich beds there is a thin (*c.* 0.4 m), orange-brown bed of pebbly, shelly chalk full of flattened valves of large *Mytiloides* spp., which rests on an erosion surface and is overlain by a silty marl passing up into silty chalks with abundant *Mytiloides* sp., the Inoceramus Pebble Bed of Hart *et al.* (1991). This bed is inferred to correlate with the acme-level of shell detritus in the Holywell Nodular Chalk Formation, and with the associated *Filograna avita* marker horizon. However, no trace of the diagnostic sepulid-encrusted shells has been found at any locality in the Northern Province, which follows the trend seen in the Chiltern Hills, where this event is virtually undetectable north of the Pitstone Quarry 2 RIGS site. The Inoceramus Pebble Bed is also

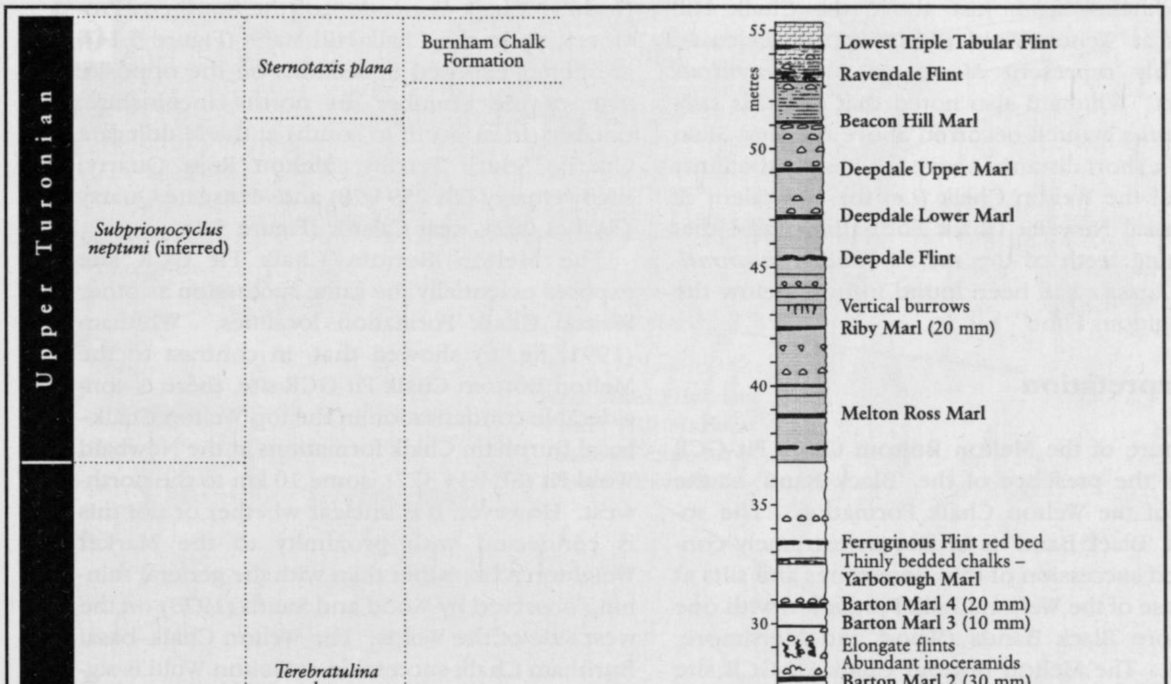


Figure 5.13 The stratotype section for the Welton Chalk Formation at Welton Wold Quarry (the 'Upper Pit' at Melton, Figure 5.11). (After Whitham, 1991, fig. 5.)

inferred to equate with the so-called 'Violet Marl' marker horizon in the Rotpläner red limestones in northern Germany (Ernst *et al.*, 1983, 1998; Hilbrecht and Dahmer, 1994).

The change from *Mytilodes* shell-rich chalks to smooth chalks with brachiopods and few *Mytiloides* in southern England (the change from Holywell Nodular Chalk to New Pit Chalk formations) is similarly well developed here, and *Terebratulina lata* R. Etheridge is first recorded a short distance below the Grasby Marl. However, the records of *Mytiloides labiatus*

(Schlotheim) from just above the Chalk Hill Marls at Welton Wold (Whitham, 1991) could possibly represent *M.* ex gr. *subhercynicus* (Seitz). Whitham also noted that *Conulus subrotundus* Mantell occurred above the First Main Flint, a short distance above the base of the flinty part of the Welton Chalk (i.e. the equivalent of the basal New Pit Chalk Formation), and that crushing teeth of the ray *Ptychodus mammillaris* Agassiz had been found in beds below the Ferruginous Flint.

Interpretation

A feature of the Melton Bottom Chalk Pit GCR site is the presence of the 'Black Band' at the base of the Welton Chalk Formation. The so-called 'Black Band' is in fact an extremely condensed succession of thin limestones and silts at the base of the Welton Chalk Formation with one or more Black Bands (Wood and Mortimore, 1995). The Melton Bottom Chalk Pit GCR site section of the 'Black Band' has not been studied in the same detail as pits south of the Humber where the relationship of these beds to the Plenus Marls–Meads Marls interval of the Southern Province has been worked out (see references in Wood *et al.*, 1997; and **Southerham Grey Pit** GCR site report, this volume). Beds immediately below the Black Band, down to the sub-Plenus erosion surface can be correlated, on the basis of the occurrence of the belemnite *Praeactinocamax plenus* (Blainville) and the rhynchonellid brachiopod *Orbirhynchia multicostata* Pettitt, with the Plenus Marls Member of the Southern Province, at least up to and including Jefferies' Bed 4. The stratigraphical correlation of the Black Band itself is highly controversial, and remains unresolved; stable isotope and other evidence suggests that it may equate with the basal part of the Melbourn Rock–Meads Marls of the Southern Province and that the Cenomanian–Turonian boundary falls between the Black Band and the terminal green clay of the Variegated Beds (see Wood and Mortimore, 1995). The Black Band succession of variegated beds is more complete in the Melton Ross Quarry (Figures 5.5 and 5.14).

The Welton Wold Quarry section of the Melton Bottom Chalk Pit GCR site was originally designated the stratotype for the entire Welton Chalk Formation. However, the basal shell-detrital beds (the Buckton Member of Mitchell (2000), and the equivalent of the Holywell Nodular Chalk Formation of the Southern Province), up to the Chalk Hill Marls (Figure 5.14), are better exposed in sections on the opposite side of the Humber, in north Lincolnshire, notably (from north to south) at the Middlegate Quarry, South Ferriby; Melton Ross Quarry; Bigby Quarry (TA 059 078) and Mansgate Quarry (TA 123 002), near Caistor (Figure 5.1).

The Melton Bottom Chalk Pit GCR site exposes essentially the same succession as other Welton Chalk Formation localities. Whitham (1991, fig. 6) showed that, in contrast to the Melton Bottom Chalk Pit GCR site, there is considerable condensation in the top Welton Chalk–basal Burnham Chalk formations at the Newbald Wold Pit (SE 934 377), some 10 km to the north-west. However, it is unclear whether or not this is connected with proximity to the Market Weighton Axis, rather than with the general thinning observed by Wood and Smith (1978) on the west side of the Wolds. The Welton Chalk–basal Burnham Chalk succession at Welton Wold is significantly thinner than the equivalent interval at Thornwick Bay and North Landing (Whitham, 1991, fig. 7; Mitchell, 2000, fig. 3) in the **Flamborough Head** GCR site. On the other hand, the 54.8 m thickness of the Welton Chalk Formation at Speeton Cliff (Mitchell, 2000) is virtually identical to that of the stratotype.

The only feature of particular interest in the basal Burnham Chalk at the Melton Bottom Chalk Pit GCR site is that there is more evidence of preserved brecciated chalk at and around the Ravendale Flint than elsewhere.

Conclusions

The Melton Bottom Chalk Pit GCR site formerly exposed a complete Ferriby Chalk Formation and is the type locality for the Welton Chalk Formation. It is only recently (Whitham, 1991), however, that a detailed stratigraphy has been established and linked to previously more accessible sections in north Lincolnshire. A feature of the stratigraphy is the Black Band at the Cenomanian–Turonian boundary. Black Band successions across the Humber in north Lincolnshire provide additional evidence for the correlation of this succession with the Plenus Marls Member and the Cenomanian–Turonian boundary in the Southern Province. The Melton Bottom Chalk Pit GCR site is a key locality for assessing the causes of thickness variations in the Welton Chalk and Burnham Chalk formations, possibly

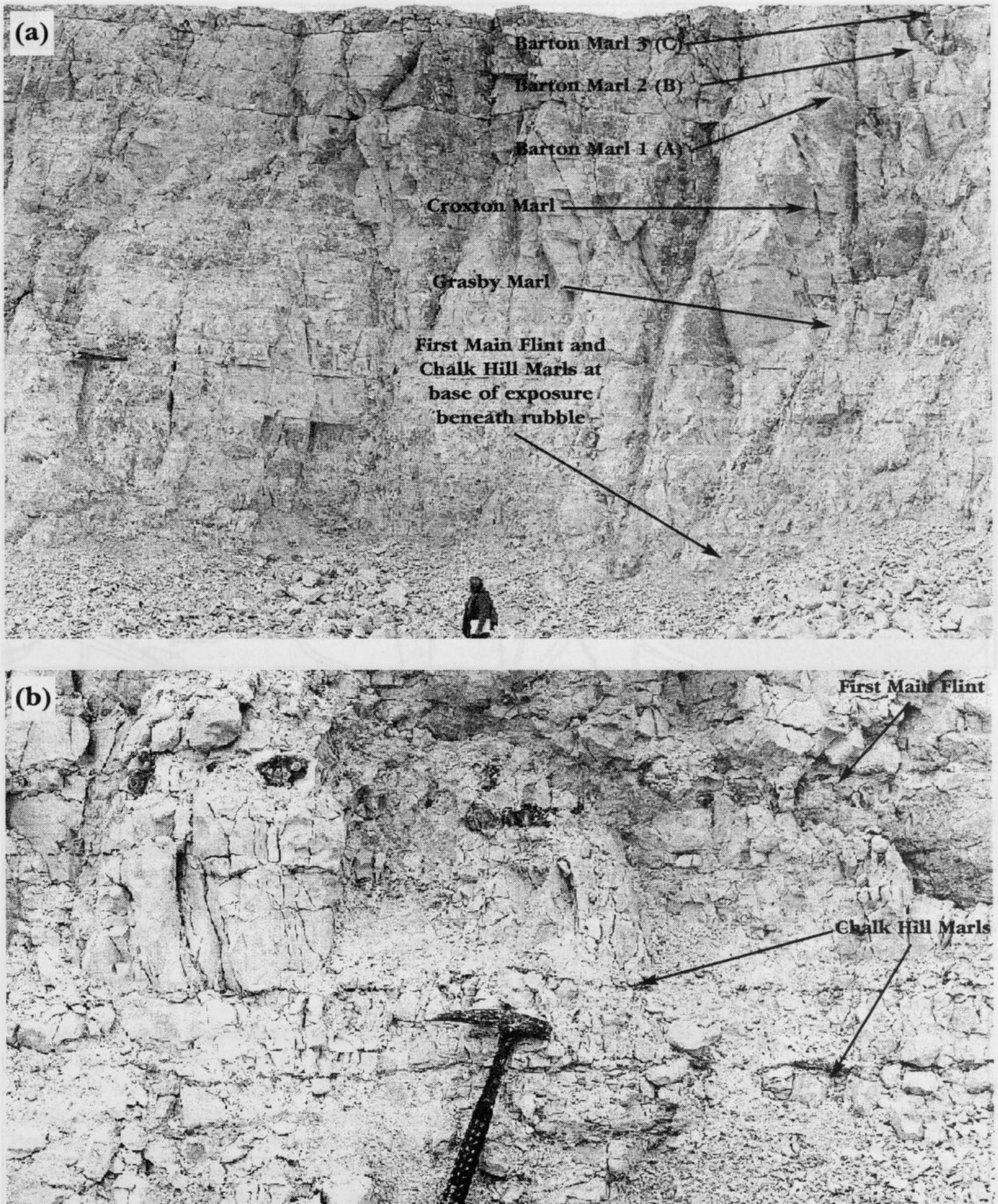


Figure 5.14 The Welton Chalk Formation in the Northern Province, Melton Ross Quarry, Lincolnshire. (a) The lower part of the Welton Chalk Formation marker marl seams. Note the typical conjugate fractures characteristic of this Chalk. (b) The Chalk Hill Marls and the First Main Flint at the boundary between the *Mytiloides* spp. and *Terebratulina lata* zones. This is effectively correlated to the boundary between the Holywell Nodular Chalk and New Pit Chalk formations of the Southern Province. (Photos: R.N. Mortimore.)

related to structural control of sedimentation on the Market Weighton or a Humber axis.

ENTHORPE RAILWAY CUTTING, YORKSHIRE WOLDS (SE 906 456–SE 914 459)

Introduction

The Enthorpe Railway Cutting GCR site is an abandoned railway cutting trending ENE–WSW, some 0.75 km long, with steep, partly degraded sections, up to 15 m high on both sides (Figures 5.15–5.18). The cutting is a key section for understanding the lithostratigraphy and biostratigraphy of the lower part of the Burnham Chalk Formation, providing the stratotype section for the Enthorpe Marls and the Enthorpe Oyster Bed. It is one of the most fossiliferous localities in the Chalk of Yorkshire. The unusually soft chalk here has yielded many well-preserved fossils, notably echinoids and inoceramid bivalves, the latter being of critical importance in long-range correlation to contemporaneous successions in Germany and Poland, and even to North America. The section has yielded an undescribed species of the characteristically boreal echinoid genus *Infulaster*. The excellent

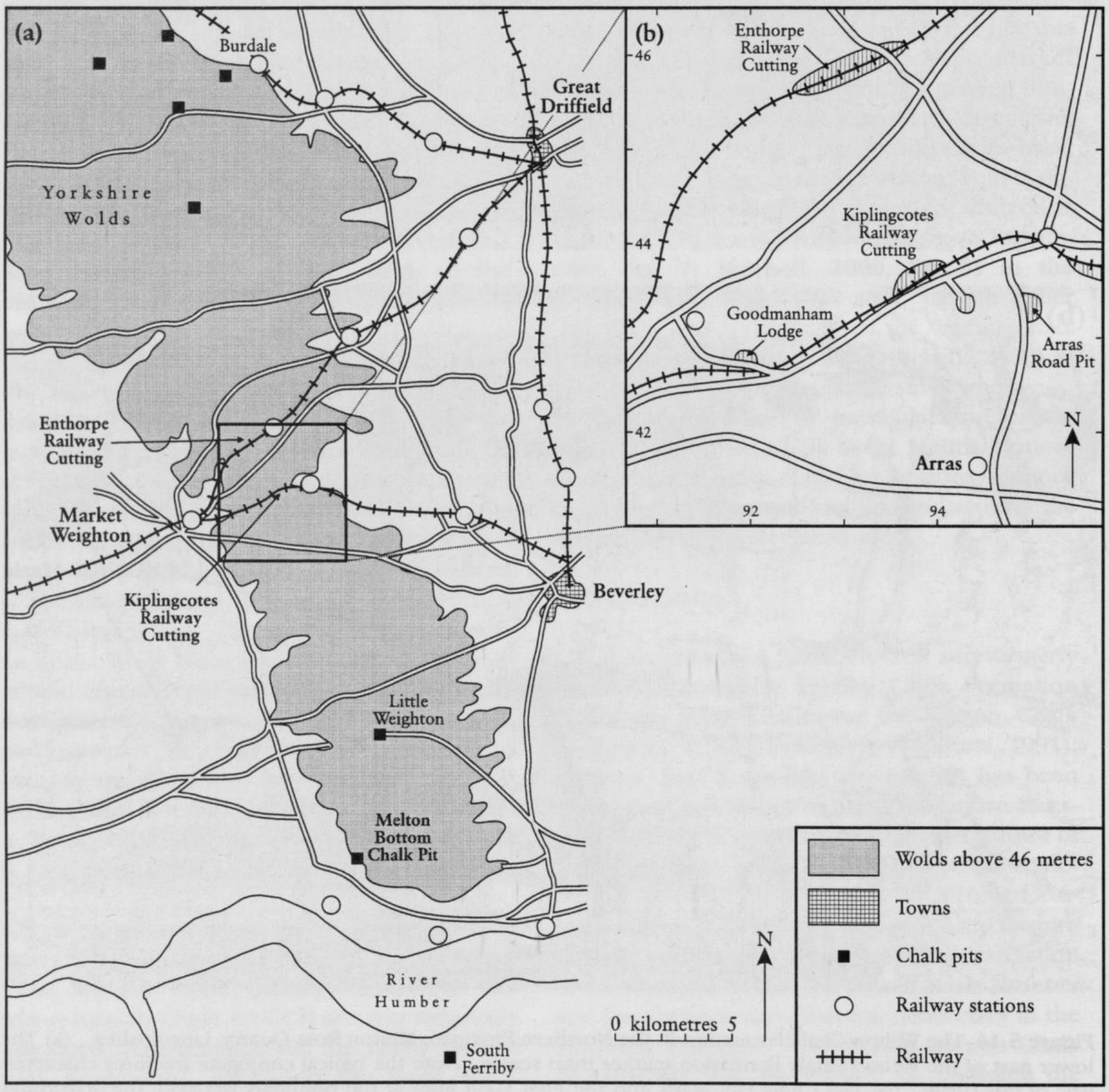


Figure 5.15 The location of Enthorpe Railway Cutting and other field sections in the Yorkshire Wolds.

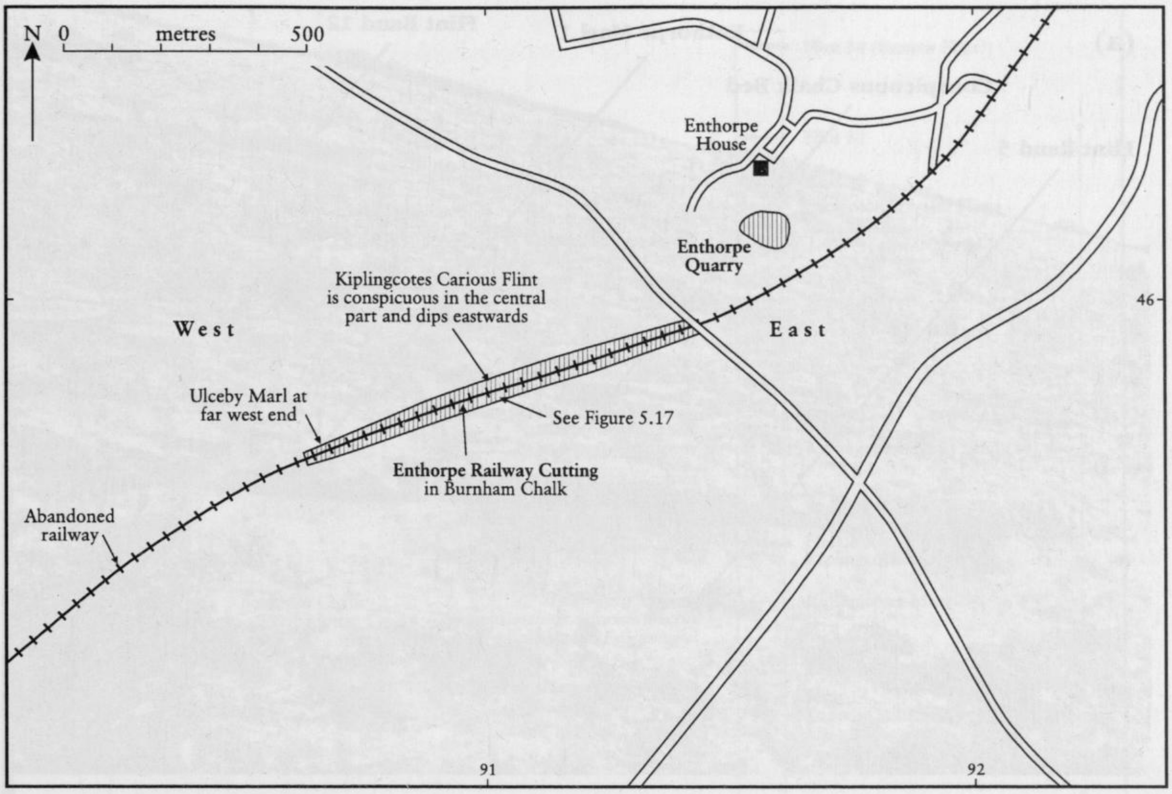


Figure 5.16 The Enthorpe Railway Cutting GCR Site, exposing the Burnham Chalk Formation from just above the Ulceby Marl to a level above the Easthorpe Tabular Flints in the Beachy Head Zoophycos Beds.

exposure of the Kiplingcotes Marls is crucial to the interpretation of the Turonian–Coniacian boundary succession in the Northern Province, and its correlation to successions in the Southern Province.

Description

At the Enthorpe Railway Cutting GCR site the strata dip at a low angle to the east, and are displaced by several small faults. The 'Upper Chalk' stratigraphy was first recorded by Jukes-Browne and Hill (1904), but the site was then apparently ignored for many decades until it was exhaustively investigated by the local amateur geologist, Dr Felix Whitham of Willerby. A skeletal lithological log was provided by Whitham (1991, fig. 8), together with extensive biostratigraphical data based on his own bed-by-bed collecting. Whitham (1994) also gave a brief account and a locality map of this and other nearby localities in the Yorkshire Geological Society field guide. Additional biostratigraphical information was given by Wood (1992). The rare earth element mineralogy of the marl seams and their classification into vulcanogenic bentonites (tuffs) and detrital marls was reviewed by Wray and Wood (1998). The litholological log and the lithostratigraphical classification given here is based on hitherto unpublished work carried out by Wood for the British Geological Survey.

Lithostratigraphy

The two sides of the cutting (Figures 5.16 and 5.17) provide a composite, more or less continuous near-dip section in the lower part of the Burnham Chalk Formation (Figure 5.18), extending from the Ulceby Marl up to the Easthorpe Tabular Flints. Above the highest accessible tabular flints, two continuous, thick (i.e. > 0.30 m) tabular flints (the Barrow Flints) can be observed projecting from the inaccessible highest 3 m of the section near the top of the cutting. The Ulceby Marl itself is not exposed, but it can be revealed by digging into the talus at the base of the western end of the cutting (SE 9138 4594).

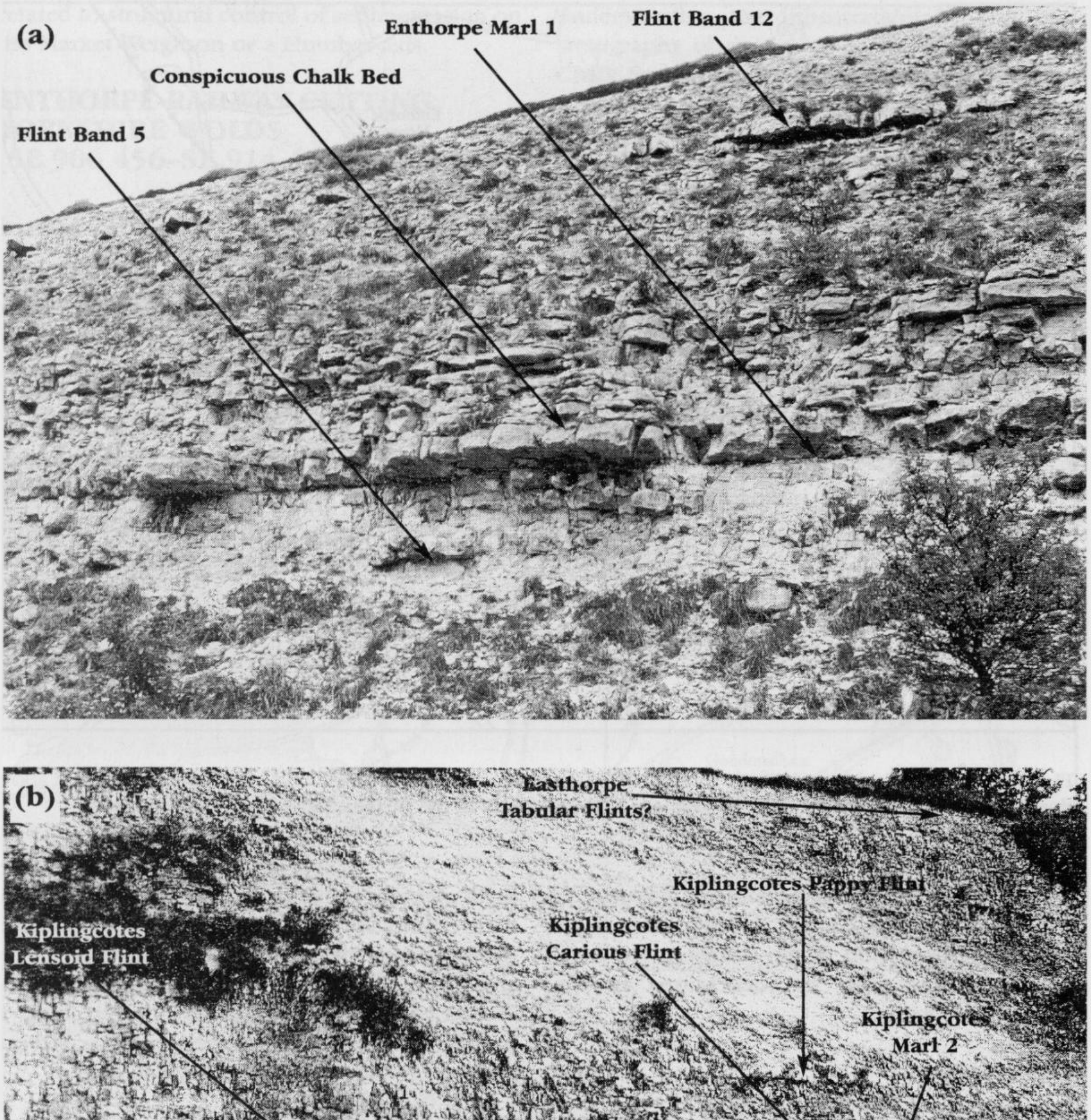


Figure 5.17 Enthorpe Railway Cutting in the highest Turonian and Lower Coniacian Burnham Chalk Formation. (a) North side of cutting looking NNW. (b) South side of cutting looking south-east. (Photos: C.J. Wood.)

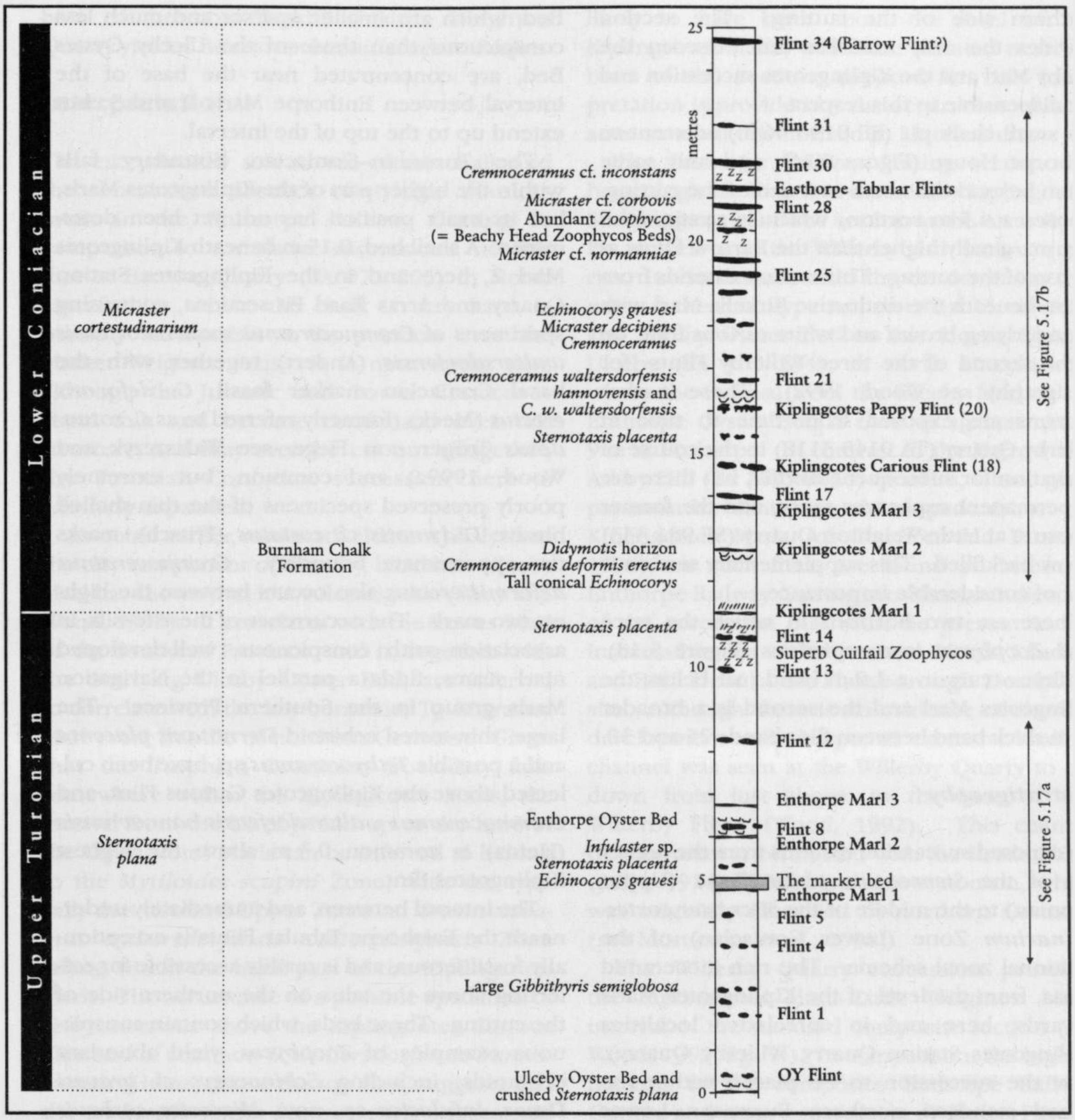


Figure 5.18 The Burnham Chalk Formation section exposed in the abandoned Enthorpe Railway Cutting, Yorkshire Wolds.

This locality is the stratotype section for the Enthorpe Marls, and for the Enthorpe Oyster Bed, which is situated in the interval between Enthorpe Marls 2 and 3. However, the topmost of the four Enthorpe Marls, which is 5 mm thick at the Arras Road Pit (SE 9286 4322), some 2 km to the south (Figure 5.15), is represented here by a bedding plane only. Enthorpe Railway Cutting is also currently one of the best-available sections through the three Kiplingcotes Marls and the immediately overlying Kiplingcote Flints, for which the stratotype section is the abandoned Kiplingcotes Station Quarry, Kiplingcotes Cutting (SE 9322 4376; Figure 5.15). The characteristic triple grouping of a basal smooth, lenticular flint, followed by a thick, semicontinuous irregular carious flint and an irregularly shaped 'pappy' flint with protuberances projecting downward from the base, forms a conspicuous feature on the southern side of the cutting. The section provides the only available link between the Ulceby Marl and the Kiplingcotes succession and is indispensible in this respect.

A small chalk pit (SE 9196 4640) adjacent to Enthorpe House (Figure 5.16), and only some 200 m beyond the north-east end of the cutting, exposes a 4.5 m section, which is stratigraphically marginally higher than the Barrow Flints at the top of the cutting. This section extends from *c.* 2 m beneath the distinctive Kirkella Marl with its underlying brown and white carious flint, up to the second of the three Willerby Flints (for stratigraphy see Wood, 1992). These marker horizons are exposed from time to time at Willerby Quarry (TA 0148 3118) in the course of excavation for subsequent landfill, but there are no permanent exposures there, and the former exposure at Little Weighton Quarry (SE 981 333) is now backfilled. This supplementary section is thus of considerable importance.

There are two horizons in which the trace fossil *Zoophycos* is conspicuous (Figure 5.18). the first occurs in a 1.0 m band just below the Kiplingcotes Marl and the second is a broader 2.5 m thick band between flint bands 25 and 30.

Biostratigraphy

The exposed succession extends from the higher part of the *Sternotaxis plana* Zone (Upper Turonian) to the middle of the *Micraster cortestudinarium* Zone (Lower Coniacian) of the traditional zonal scheme. The rich inoceramid faunas, from the level of the Kiplingcotes Marls upwards, here and in correlative localities (Kiplingcotes Station Quarry, Willerby Quarry), allow the succession to be placed within the revised standard northern European Lower Coniacian inoceramid bivalve zonation (Figures 2.9 and 2.18–2.21, Chapter 2; Walaszczyk and Wood, 1999b,c; Appendix, this volume).

The Ulceby Oyster Bed, as elsewhere, is silty and rich in bioclastic debris, particularly small crinoid columnals. It has yielded the usual well-preserved medium-sized pycnodonteine oysters, as well as specimens of the brachiopods *Cretirhynchia cuneiformis* Pettitt, *Gibbithyris subrotunda* (J. Sowerby) and *Orbirhynchia* sp.. An undescribed large species of the echinoid *Infulaster* is not uncommon between Enthorpe Marls 1 and 2, and Whitham (1991) recorded the first ocurrence of *Sternotaxis placenta* (Agassiz) at this level. The oysters of the Enthorpe Oyster Bed, which are smaller, sparser and much less conspicuous than those of the Ulceby Oyster Bed, are concentrated near the base of the interval between Enthorpe Marls 2 and 3, but extend up to the top of the interval.

The Turonian–Coniacian boundary falls within the higher part of the Kiplingcotes Marls, but its exact position has not yet been determined. A shell bed, 0.15 m beneath Kiplingcotes Marl 2, here and in the Kiplingcotes Station Quarry and Arras Road Pit sections, containing specimens of *Cremnoceramus waltersdorfensis waltersdorfensis* (Andert) together with the basal Coniacian marker fossil, *C. deformis erectus* (Meek) (formerly referred to as *C. rotundatus* Tröger *non* Fiege: see Walaszczyk and Wood, 1999a) and common, but extremely poorly preserved specimens of the thin-shelled bivalve *Didymotis* cf. *costatus* (Fritsch), marks the approximate boundary. *Cremnoceramus deformis erectus* also occurs between the highest two marls. The occurrence of these fossils, in association with conspicuous, well-developed marl seams, finds a parallel in the Navigation Marls group in the Southern Province. The large, thin-tested echinoid *Sternotaxis placenta* and a possible *Tethyoceramus* sp. have been collected above the Kiplingcotes Carious Flint, and *Cremnoceramus waltersdorfensis hannovrensis* (Heinz) is common 0.3 m above the highest Kiplingcotes flint.

The interval between, and immediately underneath the Easthorpe Tabular Flints is exceptionally fossiliferous, and is readily accessible for collecting above the talus on the northern side of the cutting. These beds, which contain conspicuous examples of *Zoophycos*, yield abundant echinoids, including *Echinocorys* cf. *gravesi* Desor, *Infulaster* sp. nov., *Micraster corbovis* Forbes, *M. normanniae* Bucaille and *Sternotaxis* aff. *placenta*. The echinoids are associated with medium-sized inoceramids such as *Cremnoceramus* ex gr. *deformis* and *Cremnoceramus crassus inconstans* (Woods), the zonal index species of the *crassus inconstans* Zone).

The section has yielded specimens of *Inoceramus annulatus* Goldfuss and *Cremnoceramus crassus* Petrascheck (the *C. schloenbachi* (Böhm) of earlier literature) from beneath Willerby Flint 2, placing this highest Enthorpe horizon in the *Cremnoceramus crassus-deformis* Zone of the revised inoceramid scheme (see Walaszczyk and Wood, 1999b,c). The same horizon at Willerby Quarry and at the base of the now backfilled Little Weighton Quarry yielded *Micraster bucaillei sensu* Stokes.

Interpretation

The exceptionally soft nature of the chalk and the concomitant absence of stylolite development in the Enthorpe Railway Cutting in comparison to correlative successions, notably that at Barrow Quarry (TA 071 203) in North Lincolnshire, where the chalk is very hard, is possibly attributable to its position over the Market Weighton Axis. It is noteworthy that, although the Jurassic and Lower Cretaceous strata thin and become condensed over this structure, and may even be cut out altogether, the Turonian–Coniacian succession here is relatively expanded.

As noted earlier, rare earth element analysis of the clay component of the silty, bioclastic Ulceby Marl has shown that it is vulcanogenic (Wray and Wood, 1998). It correlates with the Lewes Marl of the Southern Province, and it, together with the overlying Ulceby Oyster Bed, are inferred to correlate with the key bentonite T_F–Micraster Marl event bundle of northern Germany. Given that the Turonian–Coniacian boundary falls somewhere within the Kiplingcotes Marls, the interval from the Ulceby Marl up to the base of the Kiplingcotes Marls can be inferred to belong to the *Mytiloides scupini* Zone, with the typically thin terminal Upper Turonian *Cremnoceramus waltersdorfensis waltersdorfensis* Zone falling within the basal part of the Kiplingcotes Marls. The occurrence of a possible specimen of *Tethyoceramus* above the Kiplingcotes Carious Flint and of common *C. waltersdorfensis hannovrensis* (Heinz) above the top flint, suggests that the *waltersdorfensis hannovrensis* inoceramid Zone of Walaszczyk and Wood (1999a) begins within or just above the Kiplingcotes flint group. The inoceramid biostratigraphy of the higher part of the succession needs to be re-investigated in the context of the new zonal scheme.

The nearby Kiplingcotes Station Quarry (Figure 5.16) is famous for the preservation, beneath a large ammonite, of an originally aragonite-shelled molluscan fauna (Wright, 1935; Wright and Wright, 1942), comparable with the so-called '*reussianum* fauna' of the Chalk Rock of the type area (see **Fognam Quarry** and **Kensworth Chalk Pit** GCR site reports, this volume), albeit at a higher stratigraphical level. The actual horizon was not recorded, but it is likely to have been about the level of the Kiplingcotes Marls, which are situated near the base of the section; support for this interpretation is provided by the occurrence of large ammonites at this horizon in Lincolnshire.

The Enthorpe Railway Cutting section can be geologically linked to the nearby Kiplingcotes Station Quarry and the section at the Arras Road Pit, as well as to the Willerby and Barrow quarries. It also demonstrates the condensation that exists at the stratotype section of the Ulceby Marl and Ulceby Oyster Bed at Vale House Quarry, Ulceby (TA 107 134), in north Lincolnshire, where the interval from the Ulceby Marl to the Enthorpe Oyster Bed is 6 m, as against nearly 9 m at Enthorpe. In contrast to the Barrow and Ashby Hill (TA 2405 0060) quarries, where giant paramoudra flints are developed above the Kiplingcotes Marls (cf. Toynton and Parsons, 1990), no such flints are found at Enthorpe. Enthorpe Railway Cutting provides an indication of the succession that must be present in the inaccessible sea cliffs between North Landing and Breil Head in the **Flamborough Head** GCR site. Although there is no evidence of channel development at Enthorpe, an extensive shallow channel was seen at the Willerby Quarry to cut down from just above, to the base of, the Willerby Flints (Wood, 1992). This channel development is connected with the Ilsede Phase (Stille, 1924) of Subhercynian tectonism, which was originally identified in northern Germany (see Mortimore *et al.*, 1998).

The Willerby Quarry succession provided the Kiplingcotes Marls–Little Weighton Marls interval of the standard composite section (see Wood, 1992, fig. 34). In comparison, the highest horizon of the composite Enthorpe Railway Cutting and quarry succession (Willerby Flint 2) is situated *c.* 12 m beneath the second of the three Little Weighton Marls. These marls mark the equivalent of the base of the *Micraster coranguinum* Zone of southern England. The composite Enthorpe succession, however, from the highest of the Kiplingcotes Marls to the Barrow Flints, is relatively expanded (*c.* 11.7 m) in relation to the Willerby Quarry and Barrow Quarry sections (*c.* 8.5 m). It is possible that this expansion may also apply to the (unexposed) highest part of the *cortestudinarium* Zone to the east of the quarry.

In addition to the biostratigraphical evidence for correlations, and the presence of north-west European-wide marker marl seams, the two conspicuous *Zoophycos* trace fossil horizons correlate with the equivalent Southern Province Cuilfail and Beachy Head Zoophycos (Figure 5.18; Figure 2.3, Chapter 2). The Cuilfail Zoophycos are particularly well developed and preserved at the Arras Road Pit and also occur widely across north-west Europe (Mortimore and Pomerol, 1991b).

Conclusions

The abandoned Enthorpe Railway Cutting, located close to the Market Weighton Axis, is one of the few exposures of unusually soft chalk in Yorkshire. These soft chalks yield many well-preserved and some unique fossils. This exposure is also the only link in the Northern Province succession in the Upper Turonian–Lower Coniacian strata between the Ulceby Marl and the beds at Kiplingcotes. The Upper Turonian–Lower Coniacian inoceramid bivalve collections in particular are crucial to correlations with Europe and the establishment of the Turonian–Coniacian boundary in English Chalk successions.

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 (Figures 5.19 and 5.20). Even higher (low

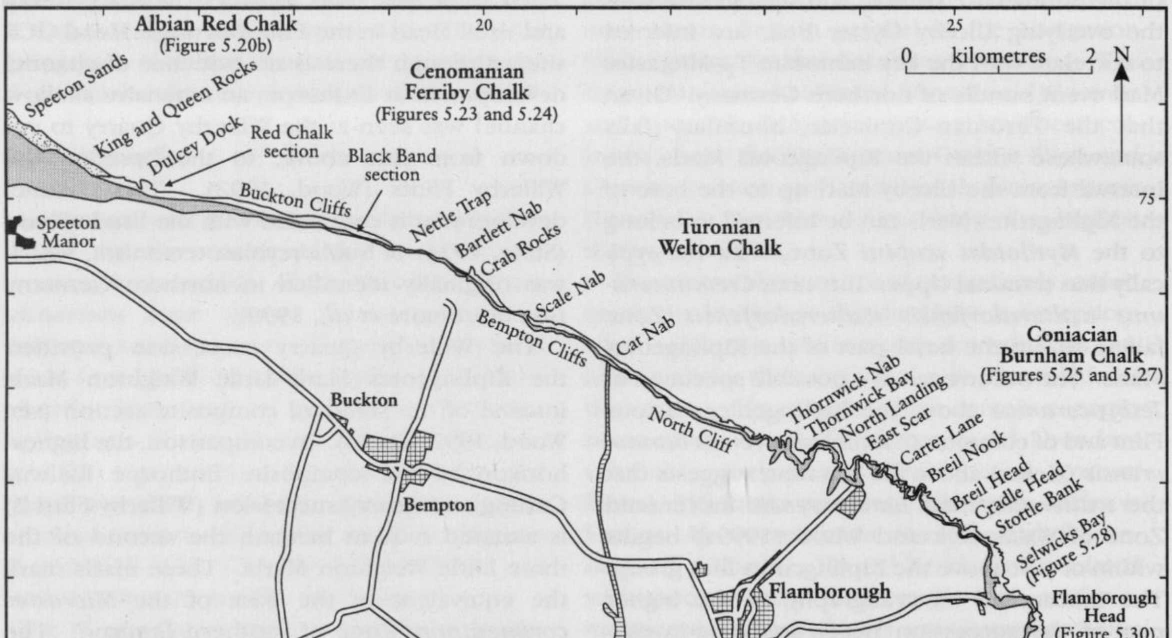


Figure 5.19 Location of key sections in the Flamborough Head GCR site.

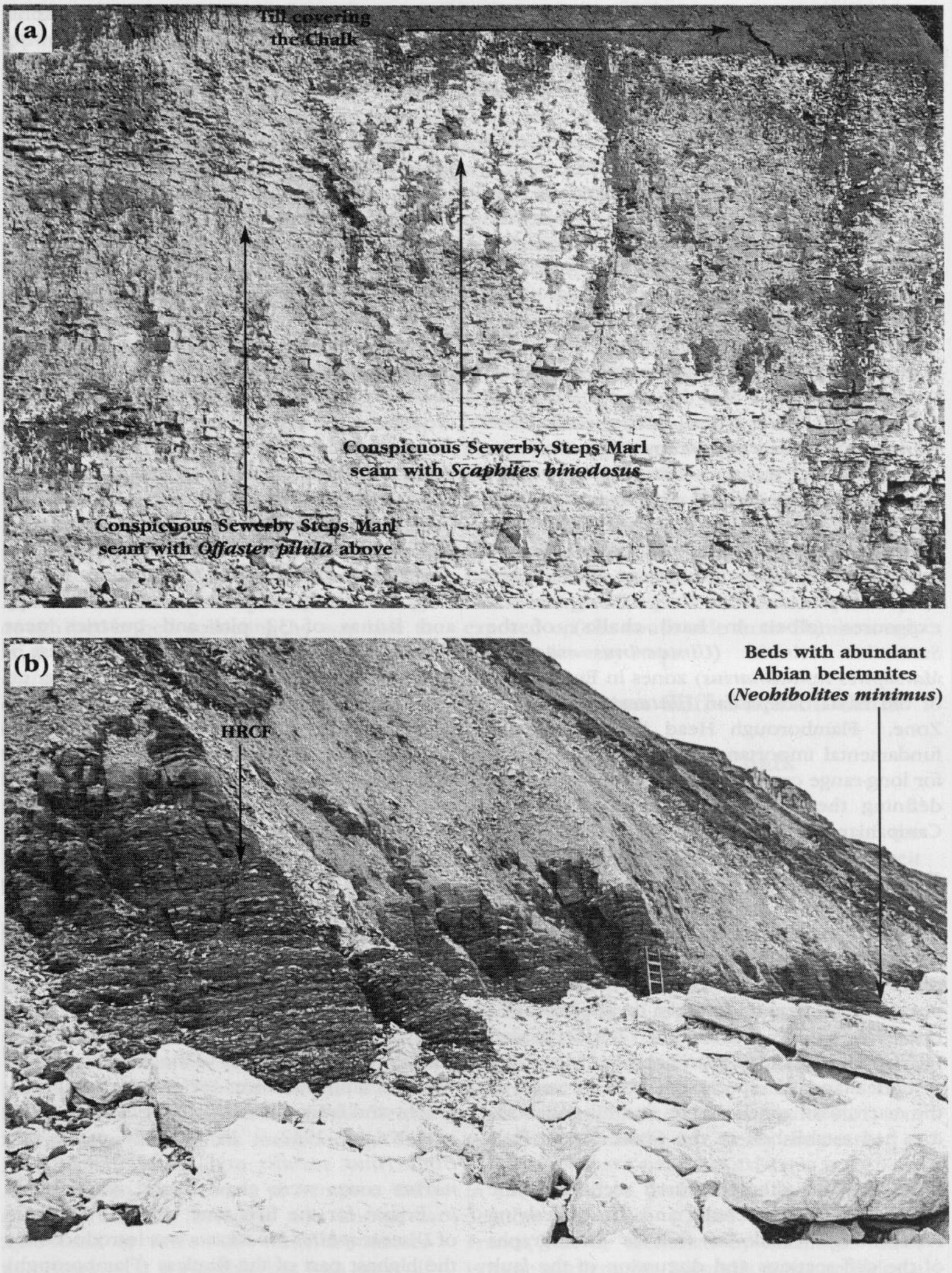


Figure 5.20 The oldest and youngest Chalk exposed on the Yorkshire coast of Flamborough Head. (a) The youngest chalk south of Sewerby Steps in the Flamborough Chalk Formation. This chalk is flintless but contains numerous marl seams. (b) The oldest chalk is at the base of Speeton Cliff in the Hunstanton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

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 (Figures 5.3, 5.20–5.25), 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.

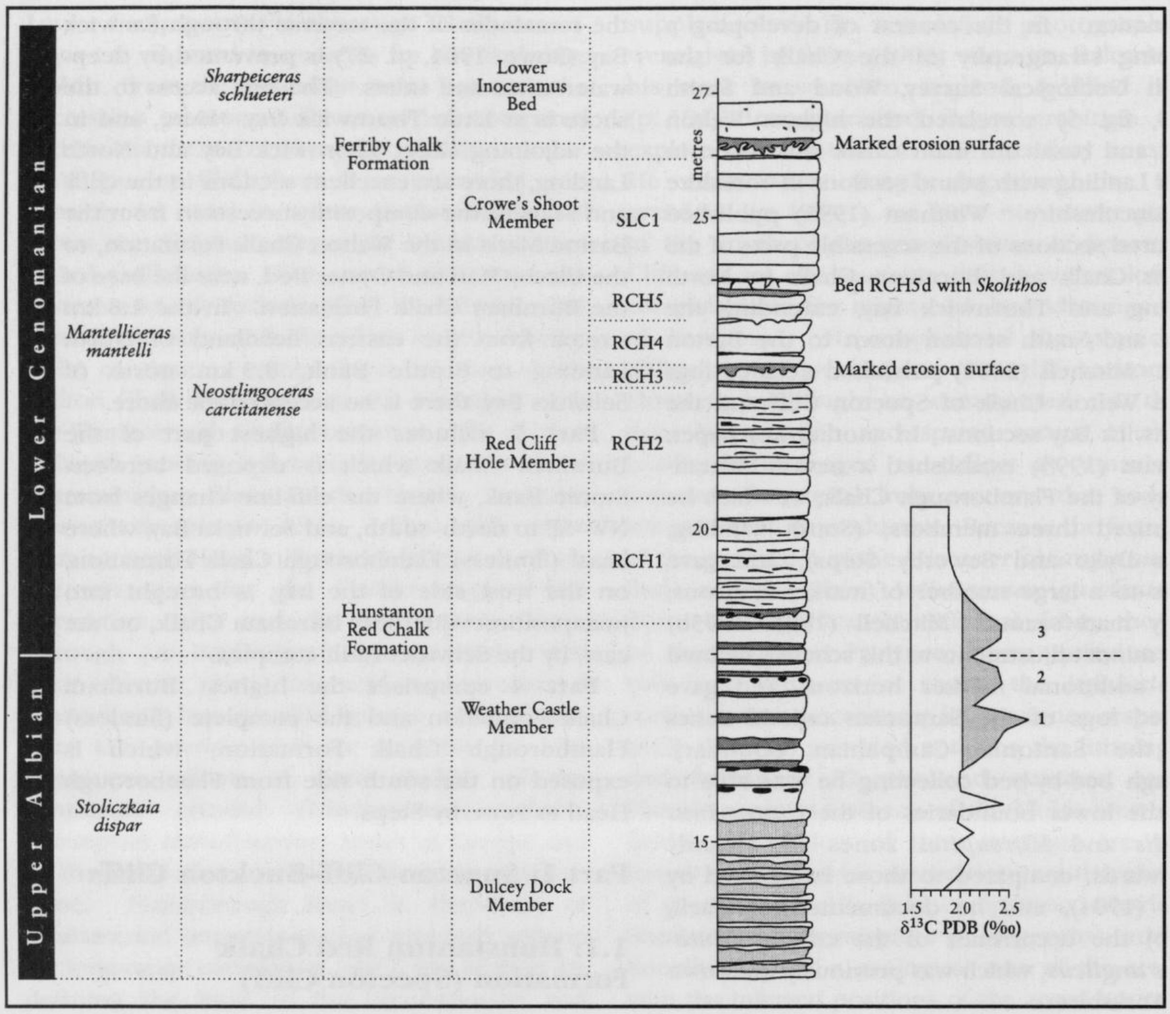


Figure 5.21 The Hunstanton Red Chalk and Ferriby Chalk formations at Speeton Cliff, Yorkshire, showing the stable isotope $\delta^{13}C$ curve used to identify the Albian–Cenomanian boundary, between peaks 2 and 3. (Modified from Mitchell, 1995a, fig. 11.)

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

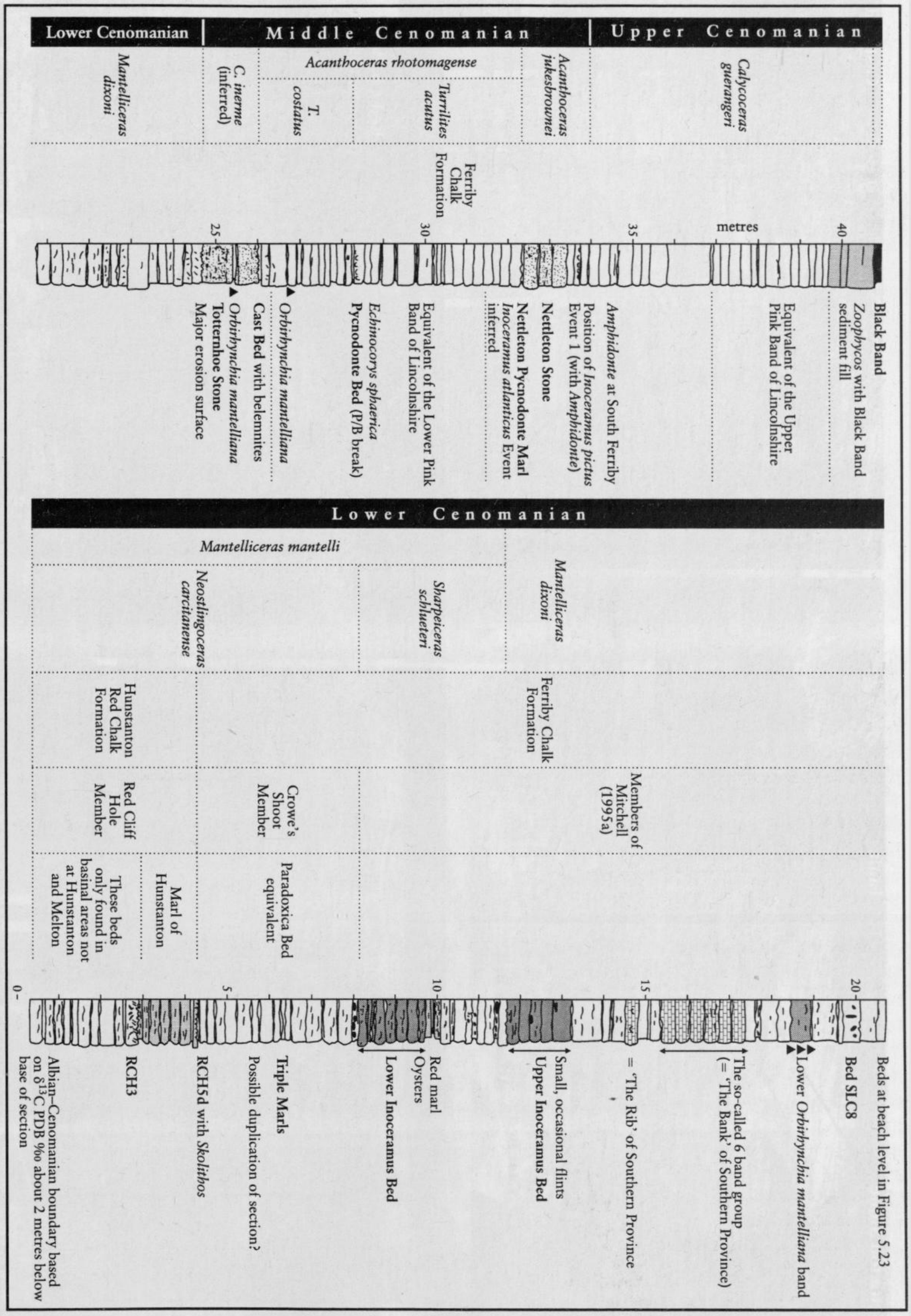


Figure 5.22 The Cenomanian Ferriby Chalk Formation at Speeton Cliff–Buckton Cliffs, Yorkshire (compare with Figures 5.20b, 5.21, 5.23 and 5.24). For explanations of bed abbreviations, see text.

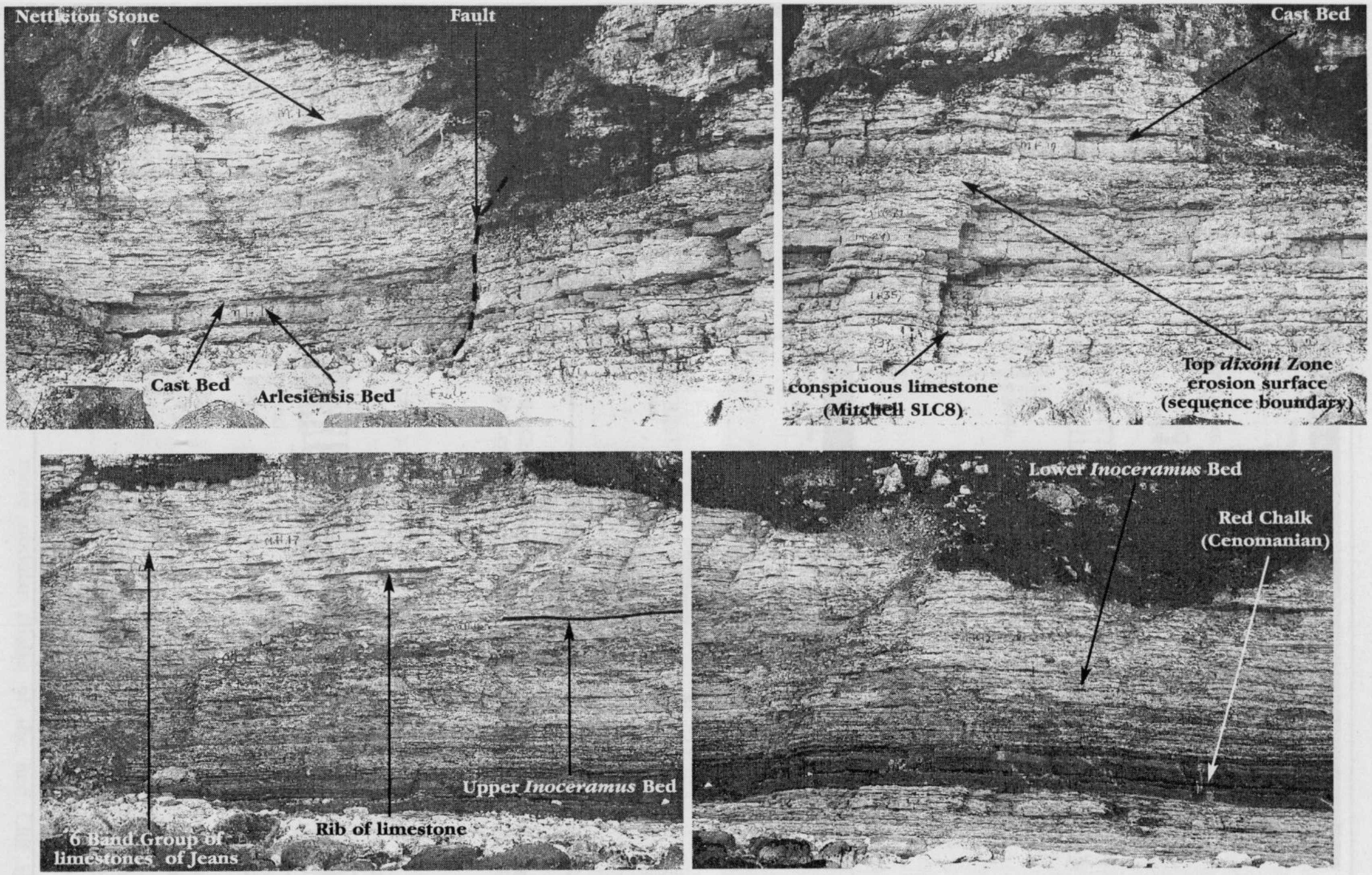


Figure 5.23 Lower and central part of the Ferriby Formation at Buckton Cliffs, Flamborough, East Yorkshire. (The '6 Band Group' of limestones of Jeans = 'The Bank' at **Southerham Grey Pit**; the rib of Limestone = 'The Rib' of **Southerham Grey Pit**.) (Photos: Dr C.V. Jeans, University of Cambridge.)

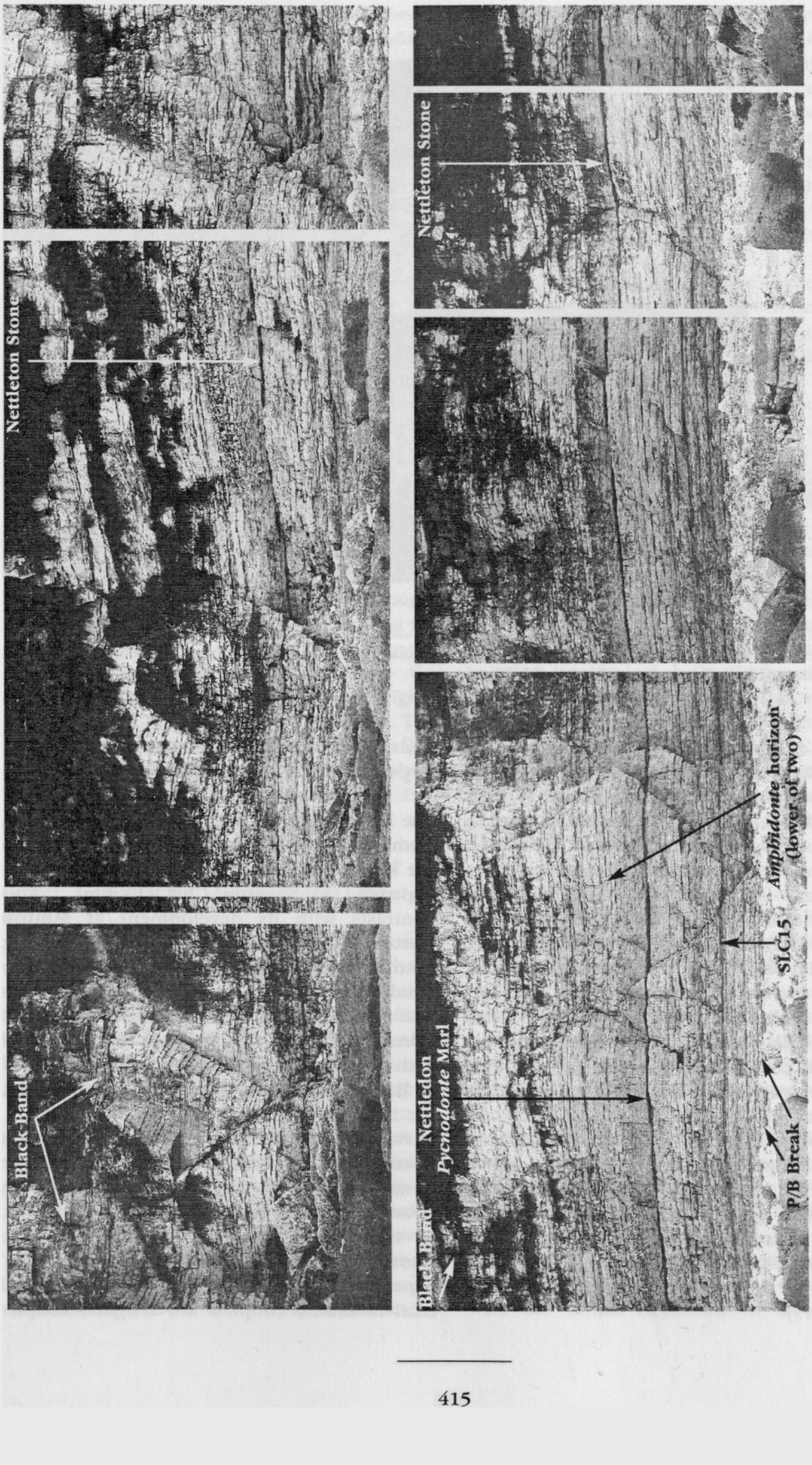


Figure 5.24 Upper part of the Ferriby Chalk Formation (Cenomanian) at Buckton Cliffs, Flamborough, East Yorkshire. (Nettleton Stone = approximate position of the base of the *Acanthoceras jukesbrownei* Zone; P/B Break = Plantonic/Benthic ratio change, the approximate position of the *Turrilites costatus–acutus*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

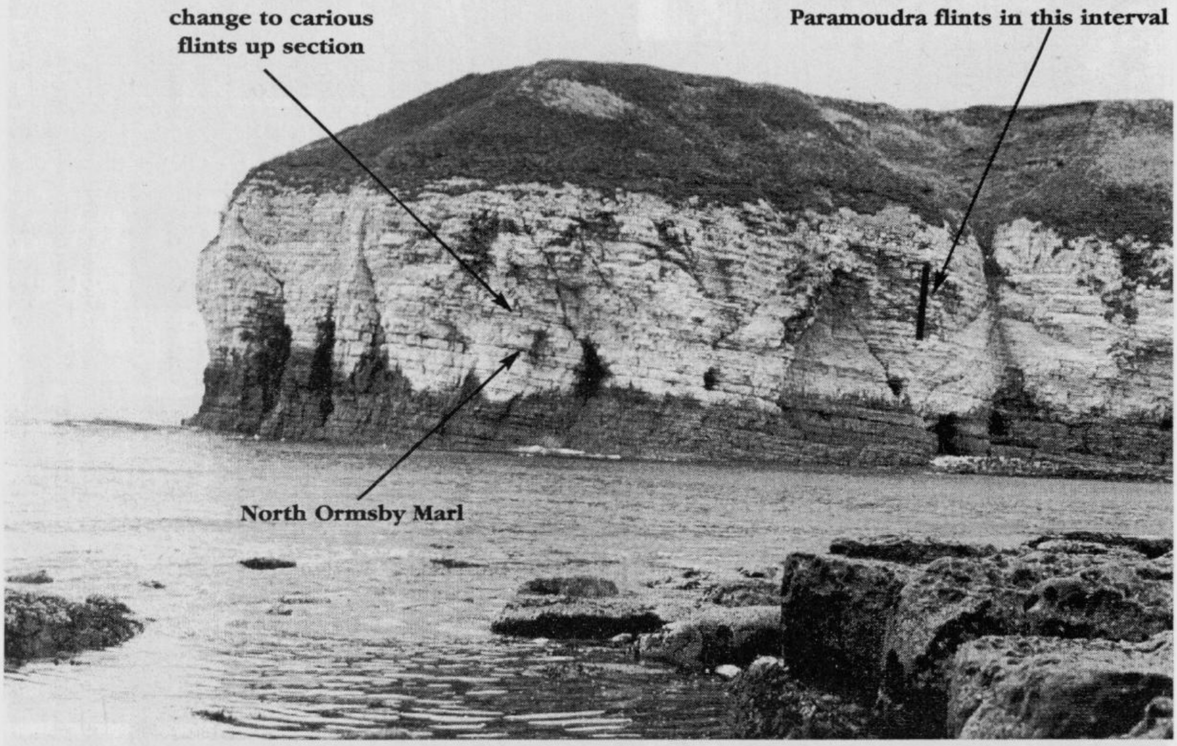


Figure 5.25 Looking east onto the cliffs at North Landing, Flamborough Head, Yorkshire, where the Welton–Burnham Chalk boundary is well exposed. Spectacular Paramoudra flints are present in the basal unit of the Burnham Chalk Formation. (Photo: C.J. Wood.)

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 Figures 5.9 and 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 (Figures 5.23 and 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* Mantell 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 virgatus*-acme 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 C1 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 C1 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 $\delta^{13}C$ 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

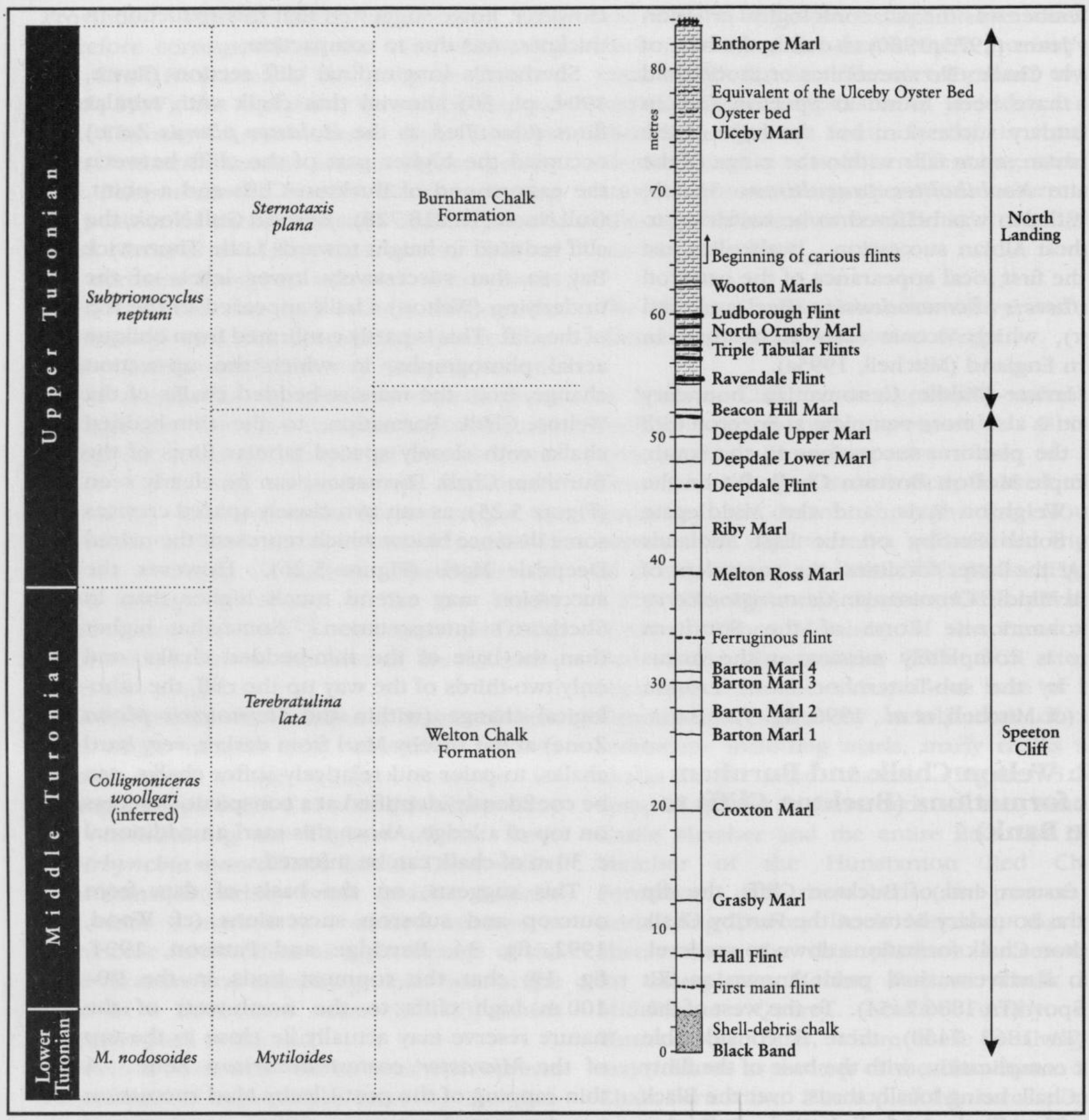


Figure 5.26 The Welton Chalk and basal Burnham Chalk formations at the Flamborough Head GCR site between Speeton Cliff and North Landing. (After Mitchell, 2000; and unpublished logs of C.J. Wood.)

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 south-east 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, pl. 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 Thornwick 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!

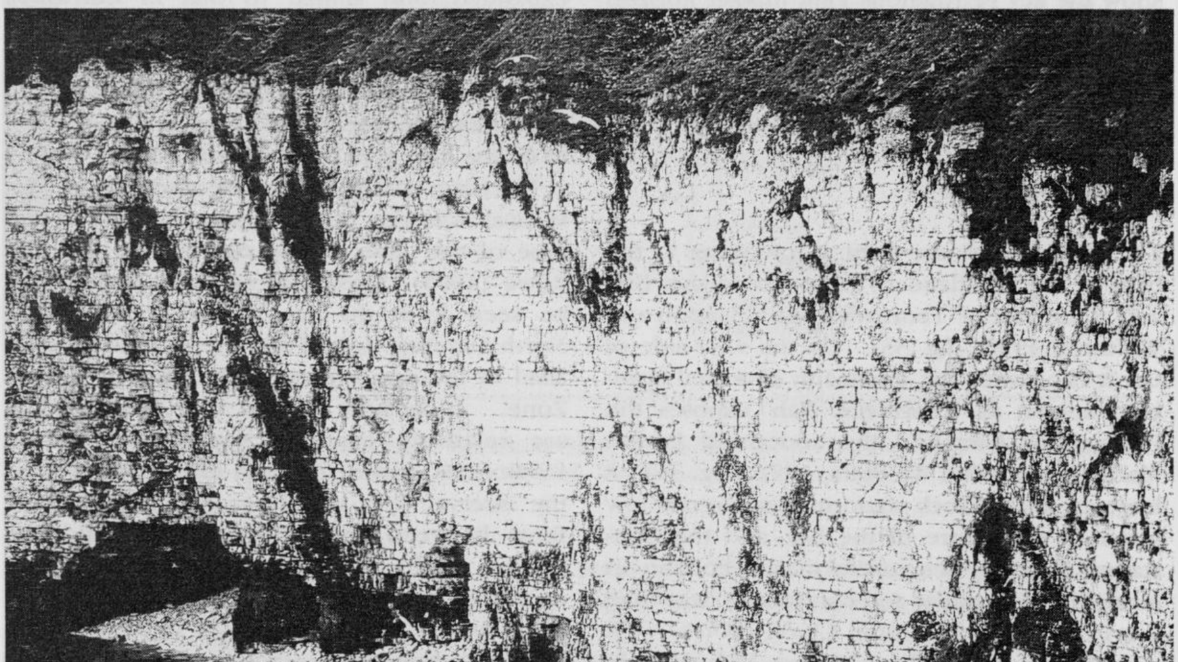


Figure 5.27 Chalk cliffs on the east side of Breil Nook, Flamborough Head, Yorkshire, illustrating rhythmically bedded Burnham Chalk Formation with flint bands (***Micraster cortestudinarium*** and ***M. coranguinum*** zones). These inaccessible cliffs have never been measured or properly interpreted.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

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.

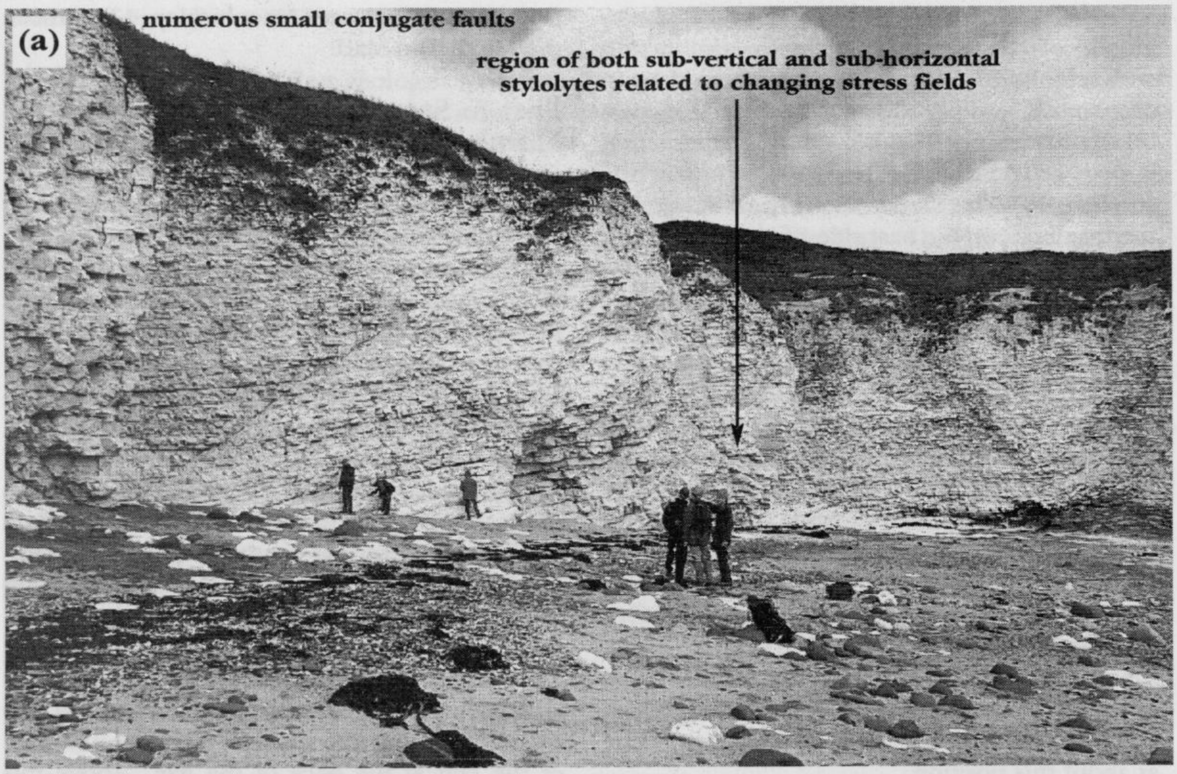
Part 3: Stottle Bank–Selwicks Bay–Flamborough Head (High Stacks)

Stottle Bank to Flamborough Head crosses the complex tectonic structures related to faulting in Selwicks Bay (Figures 5.28–5.30). 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 (Figures 5.28 and 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'



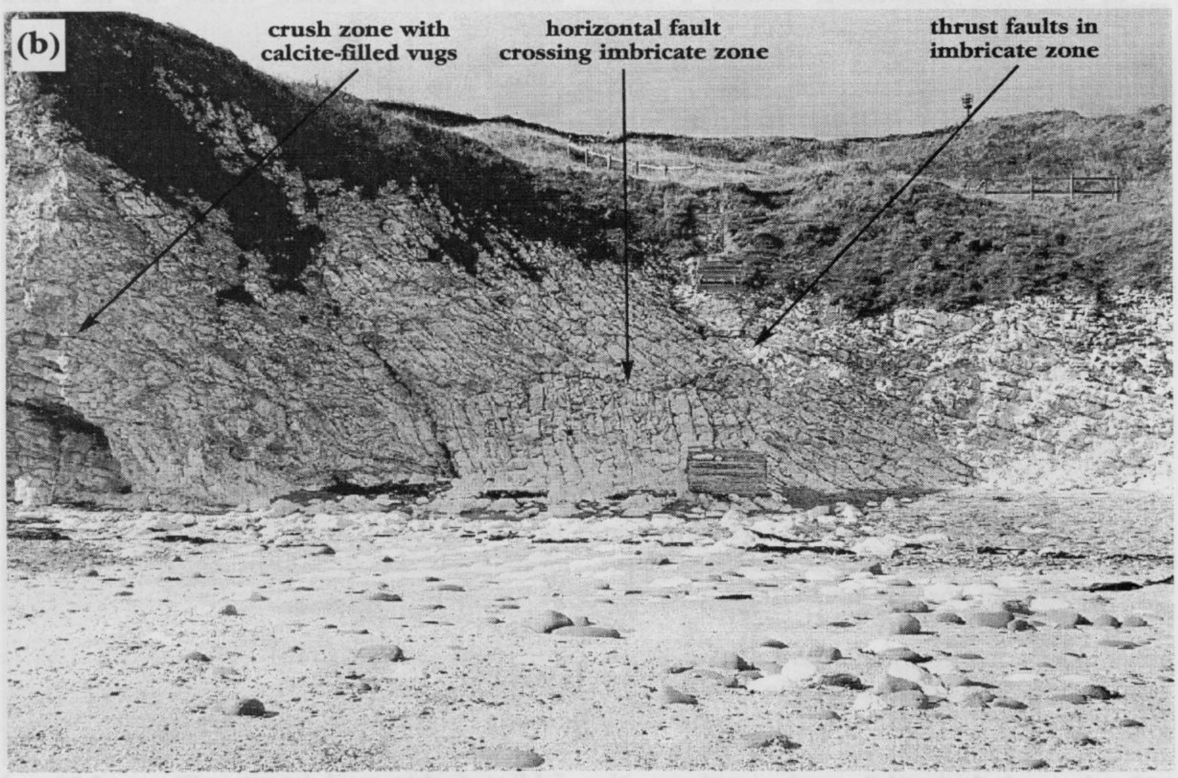


Figure 5.28 The 'disturbed zone' at Selwicks Bay, Flamborough Head, Yorkshire. The series of faults displaces the chalk by 23 m down to the south, bringing Flamborough Chalk against Burnham Chalk. (Photos: R.N. Mortimore.)

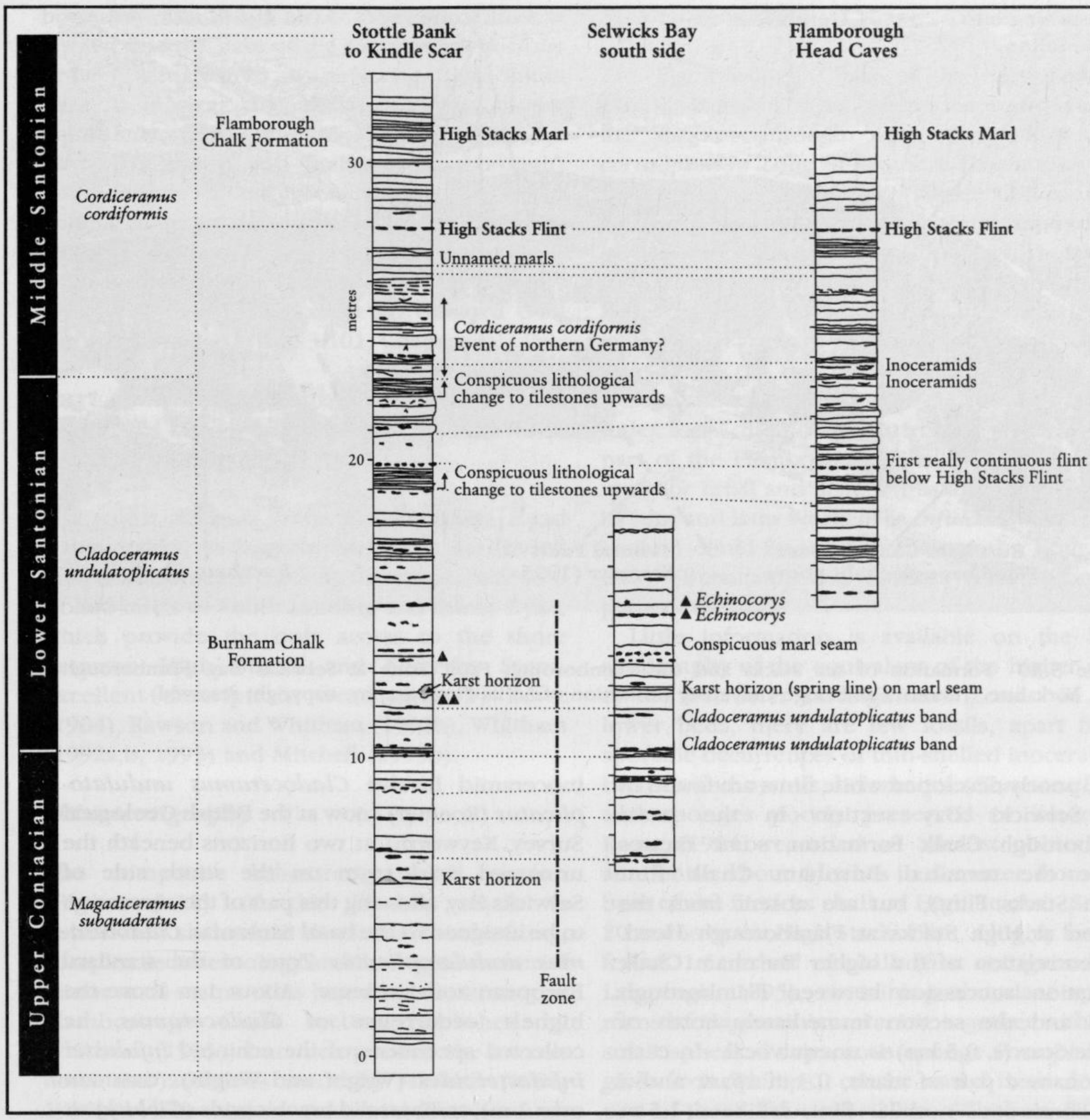


Figure 5.29 Correlation from Stottle Bank across the Selwicks Bay Fault to Flamborough Head (High Stacks) with inferred biostratigraphy.

(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 Figures 5.28, 5.29 and 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.

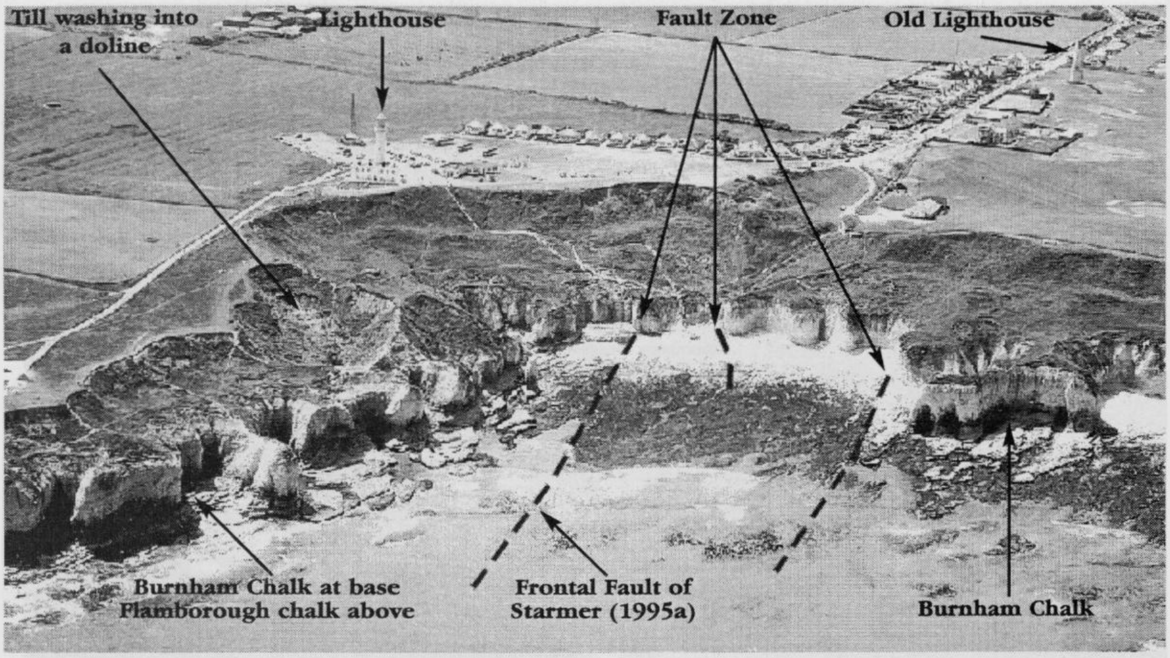


Figure 5.30 Formation of sea stacks and the Flamborough Fault Zone at Selwicks Bay, Flamborough Head, Yorkshire. (Photo: Cambridge University Collection of Aerial Photography: copyright reserved).

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 *Cordiceramus*-acme 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), Figures 3.100 and 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 *Orbirhynchia 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

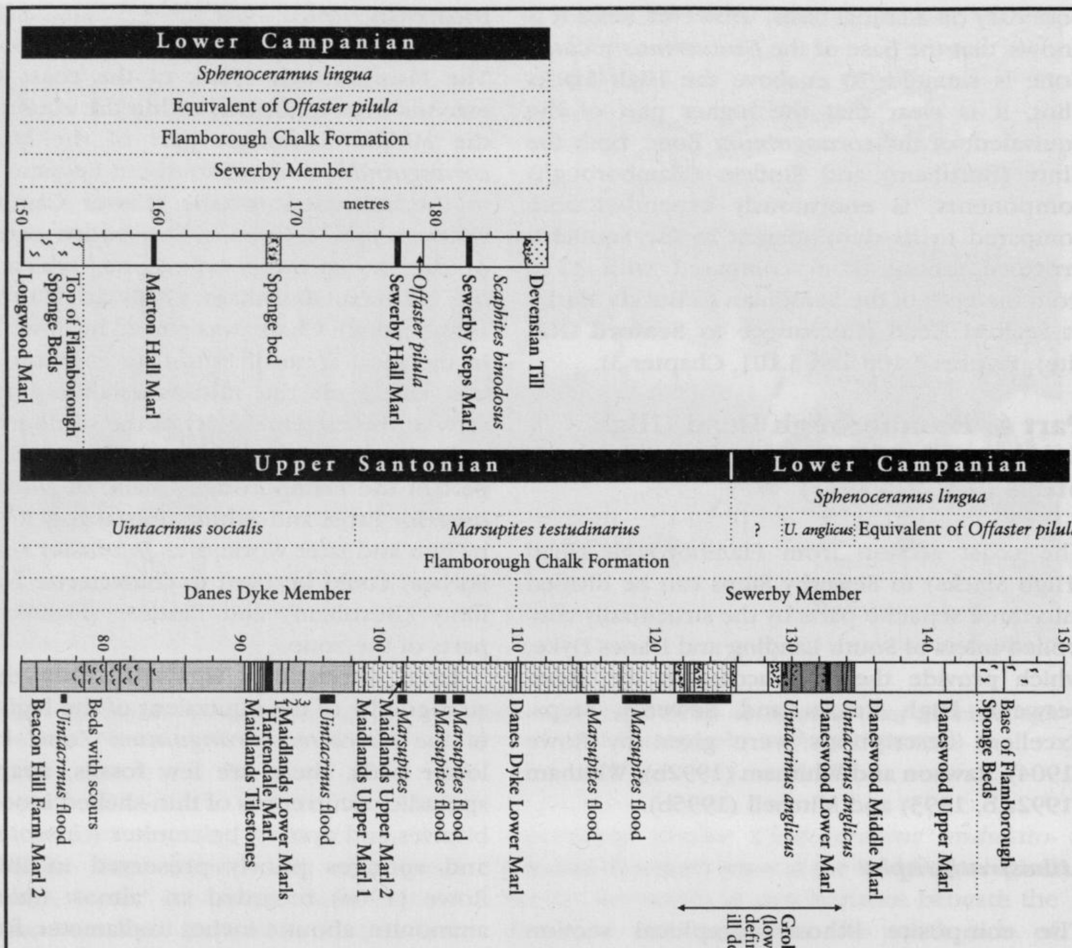


Figure 5.31 A simplified true scale section of the highest Burnham Chalk Formation and Flamborough Chalk Formation from Stottle Bank to the Sewerby Steps Quaternary cliff section. For details of the highest Burnham Chalk and basal Flamborough Chalk formations, see Figure 5.29.

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 (Schönfeld 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 subzones. 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) separated 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 granulata-quadrata* 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.