Natural Environment Research Council

British Geological Survey

Onshore Geology Series

TECHNICAL REPORT WA/99/02

The stratigraphy of the Chalk Group in Yorkshire and Lincolnshire

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Geographical index
Yorkshire, Humberside, Lincolnshire

Subject Index
Geology, Stratigraphy, Cretaceous
Chalk

Bibliographic reference
Sumbler, M.G. 1999.
The stratigraphy of the Chalk Group
in Yorkshire and Lincolnshire.
British Geological Survey
Technical Report WA/99/02

 Keyworth, Nottingham, British Geological Survey 1999

BRITISH GEOLOGICAL SURVEY

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= C O N T E N T S =

THE STRATIGRAPHY OF THE CHALK GROUP IN YORKSHIRE AND LINCOLNSHIRE

M G Sumbler

1 INTRODUCTION

This open-file report is an updated and amended version of British Geological Survey confidential report No WA/96/26C (Sumbler, 1996). The latter was prepared for the Hydrogeology Group of the BGS, as a contribution towards a hydrogeological memoir for the region, a contract funded by the National Rivers Authority, the predecessor of the Environment Agency. It is based primarily on published maps and accounts of the succession (see References) with some additional information (e.g. boreholes and geophysical information) from BGS archives.

2 OUTCROP, THICKNESS AND STRUCTURE

The Chalk Group, mainly of Late Cretaceous age, forms the bedrock beneath much of East Yorkshire and Lincolnshire (Figure 1). In the western part of this region, it crops out at the surface to form the downland scenery of the Yorkshire and Lincolnshire Wolds, and spectacular cliffs up to 120 m in height where the Wolds meet the coast between Speeton and Bridlington. Farther south in Yorkshire and Lincolnshire, there are no corresponding chalk cliffs because the Chalk is buried beneath drift deposits. These deposits, mainly Late Pleistocene (Devensian) tills, sands and gravels of glacial origin, and post-glacial (Holocene) coastal and marsh sediments, are typically some 20 to 30 m in thickness along the coast, and locally exceed 50 m. They blanket the eastern and southern part of the region, forming the lowland areas of Holderness and Lincoln Marsh. A former sea-cliff, of pre-Devensian age, can be traced beneath this drift cover some kilometres inshore of the present coast; it meets the modern coast at Sewerby, near Bridlington, and can be recognised on the banks of the Humber at Hessle and Barton (Figure 1). Across the Wash, to the south of the region, the Chalk is present in Norfolk. Again, much of the outcrop is concealed beneath drift, but it emerges to form the coastal cliffs at Hunstanton.

In the southern and greater part of the region, the Chalk Group overlies the East Midlands Shelf (Figure 2). This was an area of gradual subsidence in both Jurassic and Cretaceous times, on which moderate thicknesses of sediments built up. The chalk succession developed on the East Midlands Shelf may be regarded as the standard for the region. In this area, the Chalk strata dip fairly uniformly towards the north-east with an average dip of approximately 1° (i.e. some 15 to 20 m per kilometre). The only significant deviation is the Caistor Monocline, a gentle fold seen at outcrop, and which can be traced from borehole data beneath the drift cover from Caistor towards Grimsby (Versey, 1931; Barker , Lloyd and Peach, 1984; Berridge and Pattison, 1994). It is indicated by slight flexures in the structure contours shown on Figure 2. Minor deviations of the contours in the area of the River Humber are probably the result of valley bulging, a non-diastrophic, relatively shallow effect, related to the topography.

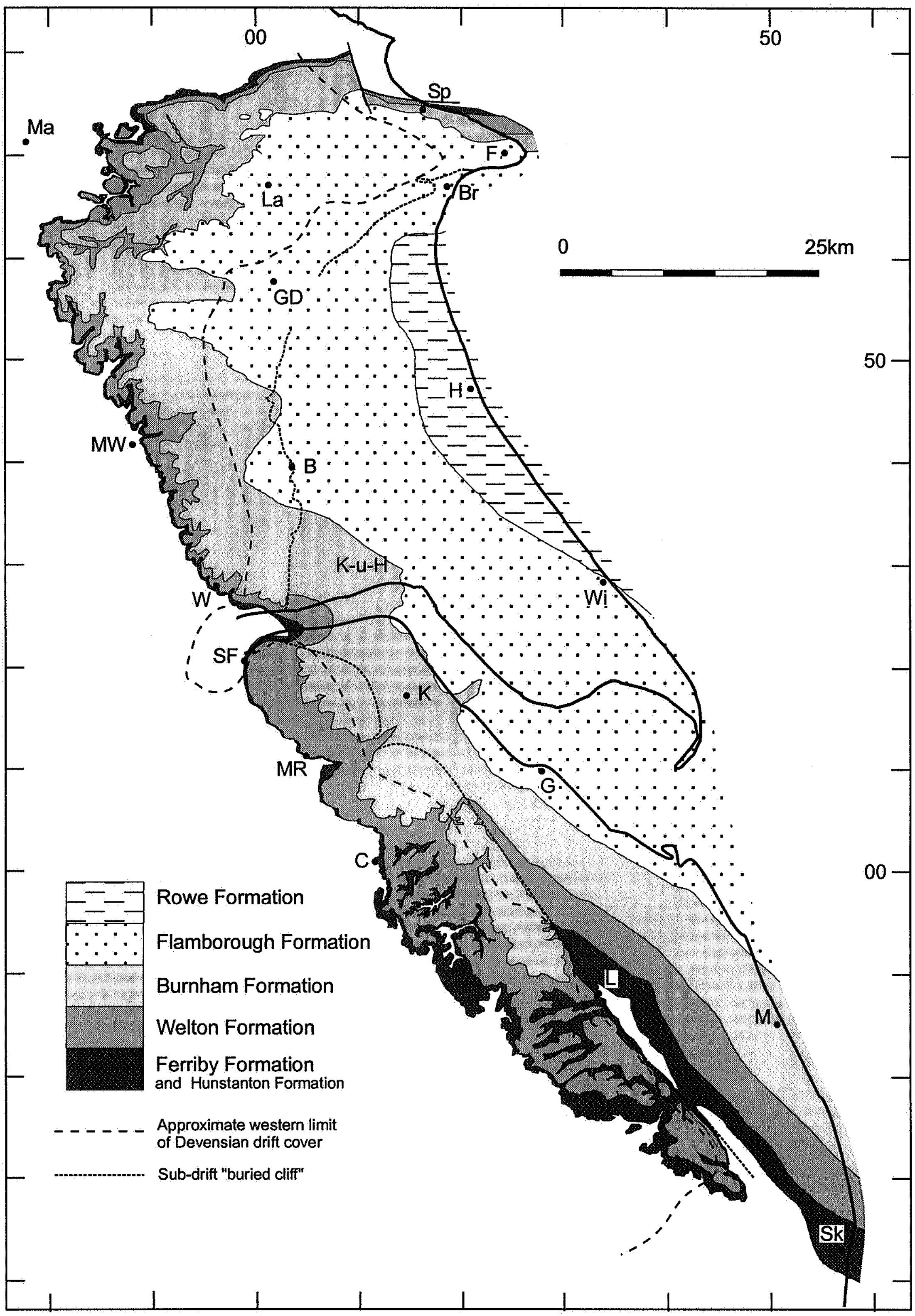

Figure 1. Distribution of the formations of the Chalk Group in Yorkshire and Lincolnshire, and the approximate extent of thick, Devensian Drift cover. Based on published BGS maps with additional data and interpretation. B = Beverley; Br = Bridlington; C = Caistor; F = Flamborough; G = Grimsby; GD = Great Driffield; H = Hornsea; K = Killingholme; K-u-H = Kingston-upon-Hull; L = Louth; La = Langtoft; M = Mablethorpe; Ma = Malton; MR = Melton Ross; MW = Market Weighton; SkK = Skegness; SF = South Ferriby; Sp = Speeton; W = Welton; Wi = Withernsea

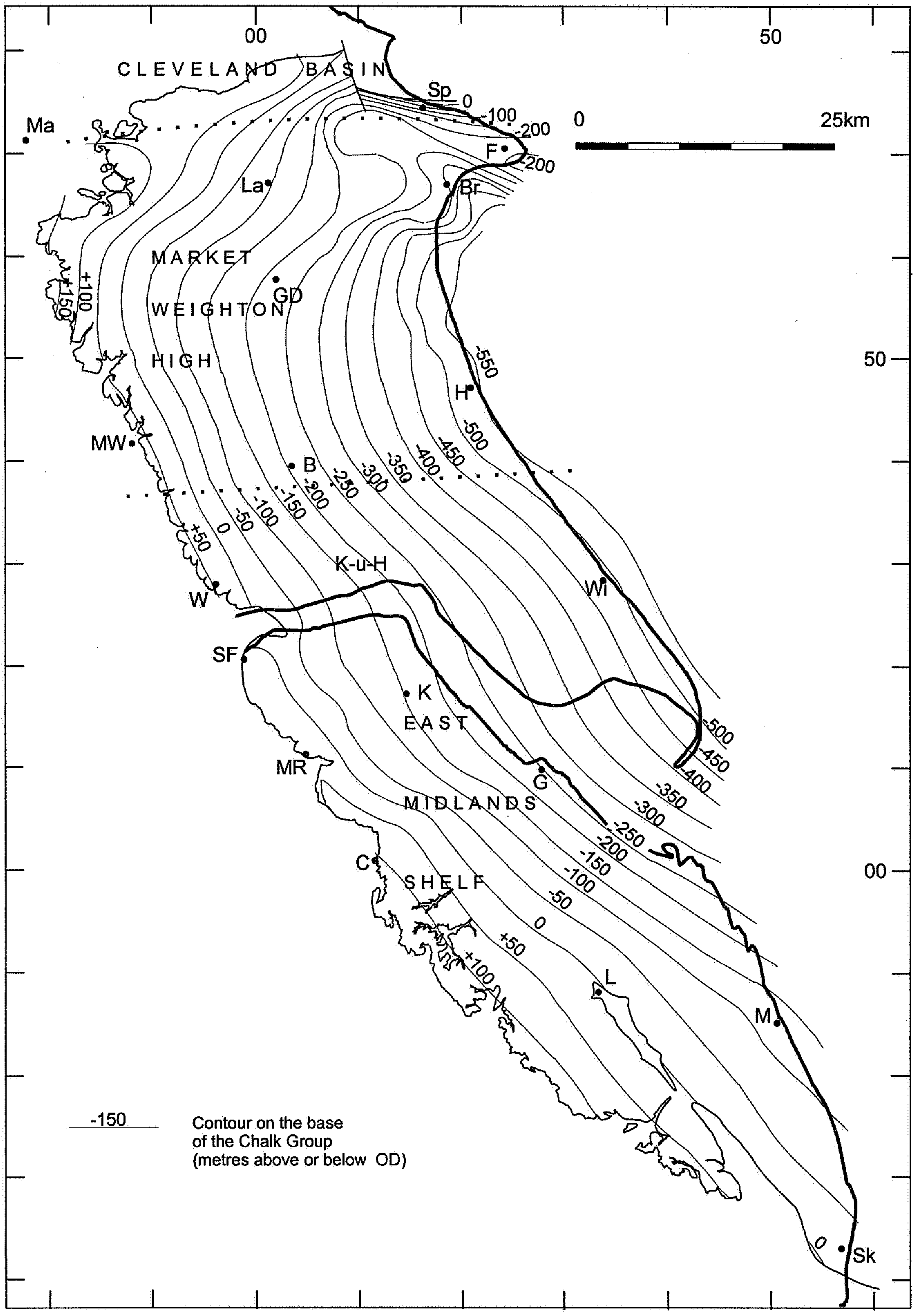

Figure 2. Generalized structure contours on the base of the Chalk Group, in metres above or below sea-level (O.D.). Based on BGS Hydrogeological maps Nos 2 (North and east Lincolnshire), 10 (East Yorkshire) and Evans et al. (1990), with modifications (mainly in the north) based on additional data. The three main Mesozoic structural elements are also indicated; the boundary between the Cleveland Basin and Market Weighton High corresponds with a fault-zone at depth, but the boundary between the Market Weighton High and East Midlands Shelf is gradational and arbitrary.

In Yorkshire, the Market Weighton High (or Axis) marks an area of reduced subsidence or relative uplift which affected Jurassic and Cretaceous sedimentation. In this area, the Chalk Group is somewhat thinner than in the south, the changes being particularly noticeable in the lower part of the Group. Over the High, the dip swings round towards the south-east, and to the north at Flamborough, average dips of 3 to 5° to the south or south-south-west occur. This zone of steeper dips is associated with a zone of minor faulting and flexuring that can be traced westward across the Yorkshire Wolds towards Malton. It relates to the buried southern margin of the Cleveland Basin (Kirby and Swallow, 1987) in which the most northerly chalk outcrops of the region lie. The Cleveland Basin was an area of subsidence during much of Jurassic and Cretaceous times, but was inverted (uplifted) in latest Cretaceous times. The basin contains thick Jurassic and Lower Cretaceous sediments, and the lower part of the Chalk succession also expands significantly into the basin, and is substantially thicker than in the areas of either the Market Weighton High or East Midlands Shelf. Higher parts of the succession may also have been affected, but due to post-Cretaceous erosion, they are no longer preserved.

Because of the predominantly eastward dip (Figure 2), the greatest thickness of Chalk preserved onshore occurs beneath Holderness, with over 500 m present at Hornsea, where the youngest Chalk strata of the region are found. Succeeding beds are represented offshore, where there is also general expansion of the succession, such that a total of over 800 m of Chalk are present some 40 km from the coast in a Late Cretaceous basin adjoining the Sole Pit Trough, an inverted Jurassic basin analogous to the Cleveland Basin. The Chalk is thin or absent due to later erosion over the inverted trough, but is over 1200 m thick to the east, in the central North Sea (Cameron et al., 1992; Lott and Knox, 1994).

3 LITHOLOGY AND FAUNA

The Chalk Group comprises calcium carbonate-rich sediments that were deposited in a shelf sea that covered much of north-west Europe during some 40 million years in the latter part of the Cretaceous period. Chalk, the predominant sediment of the Chalk Group is an extremely fine-grained, micritic limestone, mainly composed of biogenic debris. The principal ingredient is a coccolith mud, made up of the microscopic skeletal calcite plates of coccolithophorids, a type of alga (Hancock, 1975). Other bioclastic components include microscopic calcispheres (from dinoflagellate algae), foraminifera tests, and shell debris from larger creatures such as bivalves and echinoderms. At some current-winnowed horizons, the chalk is composed largely of this coarser shell debris, with little or no coccolith component.

Most of the Chalk succession is extremely pure, but the lower part is characterised by marly (i.e. argillaceous) chalks and marls (i.e. calcareous mudstones) containing a substantial proportion of clay minerals such as montmorillonite and illite, together with small amounts of detrital quartz and feldspar. In the higher and generally purer chalks, non-carbonate contents are typically about 2 per cent. However, clay minerals may be concentrated in discrete marl seams. These, though typically no more than a few centimetres thick, are generally extremely persistent laterally, and so are of great value in correlation, particularly because of the distinctive peaks (high gamma, low sonic, low resistivity) which they produce on downhole geophysical borehole logs (Barker et al., 1984; Murray, 1986). Some of the marl bands represent contemporaneous volcanic ash falls (Pacey, 1984; Wray and Wood, 1998), but others may result from a temporary increase in the supply of terrigenous detritus. The likely correlation between the marls of the Yorkshire-Lincolnshire Chalk succession and those of Southern England is discussed by Mortimore and Wood (1986), Gaunt , Fletcher and Wood (1992, fig. 28) and Wray and Gale (1993).

Flint, a form of cryptocrystalline quartz, is generally associated with the purer chalks. It formed at an early stage of diagenesis, though at some depth below the sea-floor (Clayton, 1984). The silica was derived from the skeletons of sponges, radiolarians and diatoms, which dissolved in the generally alkaline environment on burial. Decomposing organic matter gave rise to localised acidic conditions in which the silica was reprecipitated, replacing calcium carbonate which went into solution. This process occurred preferentially in more permeable parts of the sediment, such as burrowed horizons. Consequently, the majority of flints are replacements of the chalk in and around burrows, and the shape of a flint nodule generally reflects the original burrow morphology. Most common are the irregular and 'knobbly' flints formed around *Thalassinoides* burrows, whilst giant vertical flints known as paramoudras formed around the tiny burrow-trace *Bathichnus*. Flint nodules may be so abundant that they coalesce into a more or less continuous bed, forming a so-called tabular flint. Being related to sedimentary rhythms, many of the flint bands are widespread marker-horizons, and like marl seams, are often very prominent on geophysical logs (low gamma, high sonic, high resistivity). In addition to the nodular and tabular forms, flint may also occur as thin sheets, lining fractures at various angles to the bedding.

The fossils found in the chalk indicate that the sediments were deposited in a fully marine subtropical environment. Much of the succession is relatively barren of macrofossils, and those that do occur are forms such as brachiopods, inoceramid bivalves and echinoids, with calcite shells. Fossils such as gastropods and the biostratigraphically important ammonites, with aragonite-shells, are extremely rare. This is probably a result of early dissolution of their shells and may be an indication of deposition in relatively deep water (perhaps of the order 300 m depth). Because of the rarity of ammonites in much of the higher part of the succession, the traditional zonation of the Chalk is based on a combination of brachiopods, bivalves, crinoids and echinoids (Table 1). Because of provinciality of faunas at some levels, the zonal scheme traditionally used in Yorkshire and Lincolnshire is somewhat different from that used in Southern England, though the latter is now regarded as standard, and is used throughout. In most cases, the boundaries of these zones are poorly defined, and their precise relationship to the international ammonite zones is uncertain. For this reason, detailed correlation is best achieved using lithological marker bands, of which the marl seams appear to be the most reliable, with the potential for identification using mineralogical or geochemical characteristics (Wray and Gale, 1993; Wray and Wood, 1998).

4 NORTHERN VERSUS SOUTHERN CHALK

Within England, the Chalk is best known from its southern outcrops in the Chilterns, North and South Downs, and from the coastal sections of Kent and Sussex, which fall within the so-called Southern, or Anglo-Paris Basin Province. The northern limit of this sedimentary province is gradational and poorly defined, but many workers would place it in south Lincolnshire. However, it is more convenient to consider the boundary to pass through the

STAGE	BIOZONES North (traditional)	BIOZONES South (current standard)	LITHOSTRATIGRAPHY Northern Province Formation	Northern Province Lithology	Southern Province Formation	Southern Province Formation
CAMPANIAN	Belemnitella mucronata	Belemnitella mucronata	ROWE	*chalk with flints*	UPPER CHALK	Portsdown
CAMPANIAN	Sphenoceramus lingua	Gonioteuthis quadrata	FLAMBOROUGH	*chalk without flints*	UPPER CHALK	Culver
CAMPANIAN	Uintacrinus anglicus	Offaster pilula	FLAMBOROUGH	*chalk without flints*	UPPER CHALK	Newhaven
SANTONIAN	Marsupites testudinarius	Marsupites testudinarius	FLAMBOROUGH	*chalk without flints*	UPPER CHALK	Newhaven
SANTONIAN	Uintacrinus socialis	Uintacrinus socialis	FLAMBOROUGH	*chalk without flints*	UPPER CHALK	Newhaven
SANTONIAN / CONIACIAN	Hagenowia rostrata	Micraster coranguinum	BURNHAM	*chalk with flints*	UPPER CHALK	Seaford
CONIACIAN	Micraster cortestudinarium	Micraster cortestudinarium	BURNHAM	*chalk with flints*	UPPER CHALK	Lewes
TURONIAN	Sternotaxis plana [Holaster planus]	Sternotaxis plana [Holaster planus]	BURNHAM	*chalk with flints*	UPPER CHALK	Lewes
TURONIAN	Terebratulina gracilis	Terebratulina lata	WELTON	*chalk with flints*	MIDDLE CHALK	New Pit
TURONIAN	Rhynchonella cuvieri	Mytiloides labiatus	WELTON	*chalk with flints*	MIDDLE CHALK	Holywell
CENOMANIAN	Sciponoceras gracile or Actinocamax plenus	Neocardioceras juddi	Plenus Marls Member	*marly chalk without flints*	MIDDLE CHALK	Holywell
CENOMANIAN	Sciponoceras gracile or Actinocamax plenus	Metoicoceras geslinianum	Plenus Marls Member	*marly chalk without flints*	LOWER CHALK	Plenus Marls Member
CENOMANIAN	Holaster trecensis	Calycoceras guerangeri	FERRIBY	*marly chalk without flints*	LOWER CHALK	Zig Zag
CENOMANIAN	Holaster subglobosus	Acanthoceras jukesbrownei	FERRIBY	*marly chalk without flints*	LOWER CHALK	Zig Zag
CENOMANIAN	Holaster subglobosus	Acanthoceras rhotomagense	FERRIBY	*marly chalk without flints*	LOWER CHALK	Zig Zag
CENOMANIAN	Holaster subglobosus	Mantelliceras dixoni	FERRIBY	*marly chalk without flints*	LOWER CHALK	West Melbury
CENOMANIAN	Holaster subglobosus	Mantelliceras mantelli	FERRIBY	*marly chalk without flints*	LOWER CHALK	West Melbury; Glauconitic Marl Member
ALBIAN			HUNSTANTON	*red chalk*	Upper Greensand and Gault	

Table 1. Chronostratigraphical and lithostratigraphical classification of the Chalk Group of Lincolnshire and Yorkshire (Northern Province) compared with that of southern England (Southern Province). Not to scale. Both the traditional (Jukes-Browne and Hill, 1903; 1904) and newer (Bristow et al., 1997) lithostratigraphical schemes are indicated. Due to diachronism , the relationship of certain lithostratigraphical boundaries to the chronostratigraphical framework is approximate. Under latest recommendations, the Chalk Group is subdivided into a Grey Chalk Subgroup comprising the strata below the Plenus Marls Member, and a White Chalk Subgroup for the strata from the base of the Plenus Marls upwards. Under these recommendations, the Hunstanton Formation is excluded from the Chalk Group.

Wash and to exclude the Chalk of Yorkshire and Lincolnshire, and that beneath the adjoining North Sea. This falls within a loosely defined Northern Province in which the succession has, in some ways, more in common with correlatives in Germany and areas farther east than with the Chalk of the Southern Province. For example, there are significant differences in the fossil faunas in the two provinces, typically with a lower diversity in the north, which may suggest accumulation in generally deeper waters. As already mentioned, at some levels, different zonal index fossils are used in the two provinces. More importantly, there are differences in the lithological characteristics of the strata and in details of the stratigraphy, such that it is appropriate to use different lithostratigraphical classifications, as described below (see Table 1).

Much of the succession in the Northern Province comprises hard and thinly bedded chalks substantially different to the relatively soft, massive chalk of the south. This hardness is a result of pressure-solution of carbonate, and its redeposition as a calcite cement in the pore spaces of the sediment. Stylolites (intricately sutured bed junctions), also common in northern chalks, are another manifestation of solution at specific horizons in an already lithified sediment. These pressure solution effects relate both to overburden pressure (i.e. depth of burial by later rocks) and to local and regional tectonic stresses (e.g. Mimran, 1977), as well as being dependent on the nature of the original sediment. In detail, the causes are complex, for the degree of cementation of the chalk varies both vertically and horizontally, so that relatively soft chalk may be intercalated with, or pass laterally into, units of well-cemented chalk.

Tabular flints, as distinct from bands of flint nodules, are more common in the chalk of the Northern Province than in southern England, and the northern flints are typically pale grey or white in colour, in contrast to the dark grey or black nodules of the south. The flints may also have poorly defined margins, merging with the surrounding chalk, and can be very difficult to see in some sections, particularly in fresh faces.

5 STRATIGRAPHIC BACKGROUND

The Chalk Group of England has traditionally been divided into three major units, the Lower, Middle and Upper Chalk (Table 1; Jukes-Browne and Hill, 1903; 1904). Whilst the Lower Chalk is fairly distinctive, the Middle and Upper Chalk are essentially similar units of white chalk, regarded as a single formation by some workers (see e.g. Rowe, 1904, 1929). The subdivision into Middle and Upper Chalk was based essentially on the recognition of the Chalk Rock, which occurs at the boundary in southern England. Unfortunately, this marker bed does not occur in the Northern Province, and consequently the classification has always been difficult and unsatisfactory to apply to our region. Thus, although the main part of the Chalk succession, as originally mapped by the Geological Survey in the nineteenth Century, was divided into three, the Middle Chalk - Upper Chalk boundary lay at a somewhat indefinite horizon (the base of the *Sternotaxis plana* Zone) within the median unit of 'Chalk with Flints'. To resolve these problems, a revised scheme of classification was introduced by Wood and Smith (1978). The classification used in the present account is based on their scheme, as modified by subsequent work. Table 1 shows the relationship of the Northern Province scheme with the traditional classification for Southern England, and with the newer scheme of Bristow, Mortimore and Wood (1997), in which (with slightly redefined boundaries) the Lower, Middle and Upper Chalk are treated as formations, each divided into a number of members.

Wood and Smith (1978) divided the Chalk Group of the Northern Province into four formations, in ascending order, the Ferriby, Welton, Burnham and Flamborough formations, typically some 25 m, 50 m, 150 m and 260 m in thickness. In the updated scheme used in this account, the basal part of their Ferriby Formation is treated as a separate entity named the Hunstanton Formation (c. 3 m), and above the Flamborough Formation an additional unit, the Rowe Formation, is recognised beneath the drift cover of Holderness (Figure 1). These six units are based on gross lithological characteristics, such as the presence or otherwise of flints, and so the classification can be applied with a minimum of specialist knowledge. Given some initial knowledge of the stratigraphical context, the units (with the local exception of the Hunstanton Formation) are potentially recognisable on the basis of geophysical borehole logs alone.

Because the boundary between the Northern and Southern provinces is somewhat diffuse, in southern Lincolnshire, the Chalk Group acquires many of the characters of the Southern Province succession. Nevertheless, it is convenient to apply the same Northern Province stratigraphical terminology to the whole of our region; in Norfolk, to the south of The Wash, the Southern Province terminology is used. In the thicker Chalk succession offshore in the North Sea, the same basic units can be recognised as on land. A different nomenclature is used there however; the Rødby, Hidra, Herring, Lamplugh and Jukes formations correspond approximately with the Hunstanton, Ferriby, Welton, Burnham and Flamborough formations onshore (Lott and Knox, 1994), and the Rowe Formation is fully developed. BGS Lexicon-style definitions of the component formations of the Chalk Group in Yorkshire and Lincolnshire are presented in Appendix 1.

The outcrop (or subcrop beneath drift) of the component formations of the Chalk Group is indicated in Figure 1. This is the first map to delineate these units throughout the region, and it should be noted that only in the central part of the region (BGS 1:50 000-scale sheets 80, 81, 89, 90, 91; Gaunt et al., 1992; Berridge and Pattison, 1994) have the formations, as defined herein, been surveyed. Elsewhere, the lines are based on a interpretation of BGS maps mostly dating from the nineteenth century, when the succession was classified using different stratigraphical schemes (Table 1), or have been calculated from the interaction of structure contours with topographic, or rockhead contours. The lines on Figure 1 are therefore necessarily approximate, and there are some instances where major inaccuracies are suspected.

6 HUNSTANTON FORMATION

The Hunstanton Formation, commonly known as the Red Chalk, is of Lower Cretaceous (Albian) age, and thus significantly older than the Chalk Group in southern England, which is Upper Cretaceous in its entirety. Partly because of this, its lithostratigraphical classification and nomenclature has been controversial. Wood and Smith (1978), Gaunt et al. (1992), Berridge and Pattison (1994) and Sumbler (1996) all regarded it as a part of the Ferriby Formation (Hunstanton [Chalk] Member), but many other workers have treated it as separate formation (e.g. see discussion of Wood and Smith, 1978) , or even as a member, grouped into one formation with the underlying Carstone (e.g. Kelly and Rawson, 1983). The most recent works (Rawson, 1992; Gallois, 1994; Owen, 1995, Mitchell, 1995a), whilst disagreeing over the precise nomenclature to use or indeed whether or not it forms a part of the Chalk Group, all treat it as a formation in its own right. Accepting this consensus, the unit is here accorded the status of formation, and is regarded as the basal unit of the Chalk Group.

The Hunstanton Formation is present throughout Yorkshire and Lincolnshire, and extends southwards to the type locality of Hunstanton [TF 67 40] on the north Norfolk coast, but only a few kilometres south it passes into mudstones of the Gault Formation (Gallois, 1994). At Hunstanton, it comprises about 1 m of reddish brown sandy chalk or limestone with marl seams; its top is defined by an erosion surface that corresponds with a striking change in colour to the overlying off-white chalks (Owen, 1995).

North of the Wash, the Hunstanton Formation thickens substantially, averaging about 3 m over the East Midlands Shelf, e.g. at South Ferriby Quarry (Gaunt et al., 1992; Figure 3), an important reference section that is more typical of the formation in general than is the type section at Hunstanton. The formation comprises marls and both rubbly and massive chalks that are typically pink to brick-red in colour due to a proportion of iron, mainly as disseminated hematite. It overlies the ferruginous sandstones of the Carstone Formation, its lower part being particularly marly and sandy. The contact between the two formations commonly appears to be gradational, although there may be a non-sequence with phosphatised burrows at the junction. In some places the red coloration of the Hunstanton Formation may extend upwards into higher beds of the Ferriby Formation, or conversely, the upper part of the formation may be grey, rather than red, due to secondary alteration of the iron minerals. For example, around Bigby Quarry [TA 0594 0782] near Brigg, and perhaps elsewhere in the region, the red colour is completely lost (Kent, 1937; Wood and Smith, 1978, Gaunt et al., 1992), and it is difficult to distinguish the formation from the overlying beds, unless the defining non-sequence, commonly developed as a bored hardground, can be identified. This can be a particular problem in uncored boreholes; geophysical logs are of little value in this instance.

A thinner (c. 1m) succession, more like that at Hunstanton, is developed over the Market Weighton High. There, the Carstone is reduced to a few centimetres of sandy material (Jeans, 1973) best included with the Hunstanton Formation, which thus rests unconformably on Jurassic mudstones. A much thicker and more complete succession is developed in the Cleveland Basin, where the formation is 24 m thick in the cliffs at Speeton [TA 165 751] (Wright, 1963, Jeans, 1973; 1980; Neale, 1974; Mitchell, 1995a), and up to about 30 m in boreholes inland around Fordon. In this area, the Hunstanton Formation rests overlies the Speeton Clay, which replaces the Carstone and earlier Cretaceous strata. The contact is sharp, but apparently gradational. The formation comprises more or less marly chalks much like those of the succeeding Ferriby Formation, particularly in the upper part which also tends to be paler coloured and prone to discoloration (Red Cliff Hole Member of Mitchell, 1995a). This factor, to some extent, accounts for the different thicknesses quoted for the 'Red Chalk' in the various records of Speeton, but the top of the formation as now recognised, is marked by a well-defined burrowed bed (Mitchell, 1995a).

The succession at Hunstanton has been divided into a number of beds based on criteria such as lithology and fossil assemblages (Andrews, 1983; Owen, 1995). The sections at South

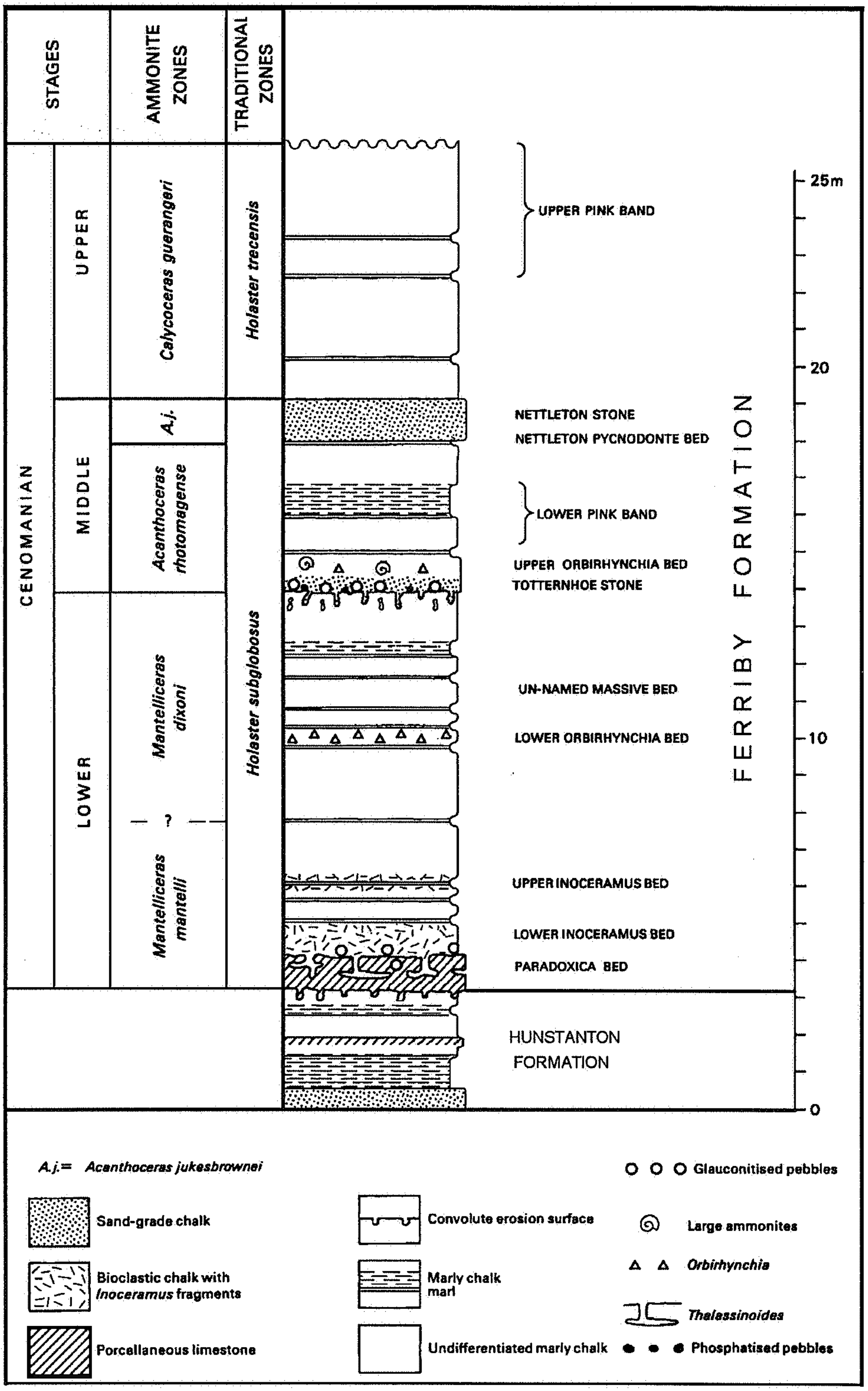

Figure 3. Stratigraphy of the Hunstanton Formation and Ferriby Formation based principally on South Ferriby Quarry (modified from Gaunt et al, 1992, fig. 30).

Ferriby Quarry (Morter, in Gaunt et al., 1992), and Speeton (Mitchell, 1995a) have likewise been subdivided, and a correlation between the three sites is suggested by Mitchell (1995a).

Ammonites are extremely rare in the Hunstanton Formation, and so the chronostratigraphical classification is based mainly on bivalves (*Aucellina, Birostrina* and '*Inoceramus*') and belemnites (*Neohibolites*), the latter often being abundant, though rare in the overlying Ferriby Formation. The biozonation shows that the basal part of the Hunstanton Formation is of Mid Albian age and the overlying and greater part is Late Albian, equating with the Gault and Upper Greensand of southern England, which are together over 100 m thick in some places. The succession is therefore highly condensed and, as might be expected, there is much evidence of reworking and depositional breaks shown by pebbly horizons and erosion surfaces.

7 FERRIBY FORMATION

The Ferriby Formation corresponds approximately with the Lower Chalk of many previous accounts, although the latter included the Black Band marls (now Plenus Marls Member) at the top, which are excluded from the Ferriby Formation (Table 1). It is typically about 20 to 25 m thick throughout the southern part of the region. It thins somewhat over the Market Weighton High (Jeans, 1973); geophysical logs of hydrocarbon exploration boreholes near Hornsea, on the eastward prolongation of the High, indicate that it is of the order 10 to 15 m thick there. It thickens at the margin of the Cleveland Basin to the north, being 33 to 35 m thick on the coast at Speeton (Wright, 1963; Jeans, 1980), and 50 m or more in boreholes inland near Fordon, demonstrating that the influence of the Market Weighton and Cleveland Basin structures continued into the Late Cretaceous. Additional localised thickness variations (in the 'Lower Chalk') were identified by Evans et al. (1990). The Ferriby Formation crops out at the foot of the steep escarpment of the Wolds, and consequently has a relatively narrow outcrop, particularly in Yorkshire (Figure 1). Its type locality is South Ferriby Quarry [SE 9915 2045] (Wood and Smith, 1978; Gaunt et al., 1992; Figure 3) where the beds are worked in conjunction with the underlying Kimmeridge Clay and Ampthill Clay formations (Jurassic) for cement manufacture. The Ferriby Formation differs from the overlying chalk because of its marly (argillaceous) nature, and this enables it to be distinguished readily on downhole geophysical logs (high gamma, low resistivity and sonic). This marly character also restricts its hydrological transmissivity, so that in practical terms the formation does not form a part of the Chalk aquifer.

The Ferriby Formation is dominated by generally grey, predominantly marly chalks, which weather to buff in exposures, and give rise to rather marly soils. It is flint-free throughout, and was mapped as 'Chalk without Flints' by the Geological Survey in the last century. As well as marly chalks with some discrete marl bands, 'gritty' bioclastic chalks and hard, cemented chalks occur. The succession of different lithologies can be interpreted as defining a number of sedimentary rhythms (Jeans, 1980), such as are better developed in the more expanded Lower Chalk succession in southern England. This rhythmicity is thought to have been climatically controlled and related to periodic variations in the earth's orbital and rotational parameters (Milankovitch cycles; e.g. Gale, 1995). A number of named marker beds occur which can be traced throughout the region (Figure 3) including, in most cases, the

Cleveland Basin; these have been used to define seven members (Jeans, 1980), although these have not gained widespread use.

Throughout most of Yorkshire and Lincolnshire, the eroded top surface of the Hunstanton Formation is overlain by a thin bed of iron-stained, silty marl or pink marly chalk which passes up into the **Paradoxica Bed** (or Sponge Bed, the Belchford Member of Jeans, 1980). This comprises hard, cemented pink or yellow chalks, typically penetrated by a ramifying burrow network (*Thalassinoides paradoxica*). The bed is capped by an irregular, often glauconitised erosion surface. In the expanded succession at Speeton, these basal beds are represented by c. 2 m of nodular, chalk with pink, red and purple marl seams and envelopes (Crowe's Shoot Member of Mitchell, 1995a), again capped by the correlative erosion surface. This unit has yielded fossils indicating an earliest Cenomanian (i.e. Late Cretaceous) age, comparable with the basal Chalk Marl of southern England.

Above, two Inoceramus beds contain abundant '*Inoceramus' crippsi* as large fragments or complete shells. The **Lower Inoceramus Bed** is often particularly fossiliferous, and at some localities there is a concentration of glauconitised pebbles at the base. In places there is a glauconitised surface with moulds of turrilitid ammonites at the top of the **Upper Inoceramus Bed**. Within this unit, a nodular brown flint is developed at Speeton (Jeans, 1973). A few metres higher in the succession, the **Lower Orbirhynchia Bed** is a thin but widespread bed characterised by the brachiopod *Orbirhynchia mantelliana*.

The **Totternhoe Stone**, formerly known in this region as the Grey Bed (Hill, 1888), comprises dark grey or brown sand-grade chalk largely composed of inoceramid shell debris. Additionally, it typically contains abundant bivalves, brachiopods, echinoids and ammonites. It locally contains glauconitised pebbles of reworked chalk at the base, which rests non-sequentially on the underlying beds. It is generally about 10 m above the base of the formation but, in the expanded succession at Speeton, lies 20 m above the base. The erosion surface beneath, locally developed as a hardground, can also be recognised in southern England (at the base of the Zig Zag Member).

Just above the Totternhoe Stone, the so-called Ammonite Beds, or **Upper Orbirhynchia Bed** (Jeans, 1980) is a unit of pale nodular chalk yielding *Orbirhynchia mantelliana* and large ammonites (*Austiniceras*). It equates with the Orbirhynchia mantellia Band of southern England (e.g. Kennedy, 1969), and the top marks the so-called mid-Cenomanian non-sequence deduced from foraminifera studies (Carter and Hart, 1977) and thought to mark a sudden deepening of the sea. A metre or so above, the **Lower Pink Band** is typically red or pink colour, but this is absent in some places (e.g. the Kingston upon Hull/Brigg district; Gaunt et al., 1992). Nevertheless, the bed can be recognised from its composition of marly chalk with one or more marl bands in the upper part. It is commonly rich in brachiopods including a terebratulid that was used by Bower and Farmery (1910) to characterise a 'Subzone of *Terebratulina ornata*' in the Louth district.

Above the Lower Pink Band, purer white chalks are capped by a cemented erosion surface. This is overlain by a thin bed of dark grey silty marl known as the **Nettleton Pycnodonte Bed** (formerly Gryphaea Band), from the abundant shells of the oyster *Pycnodonte* (formerly classified as *Gryphaea*). The marl passes up into hard grey sand-grade chalk comprising the **Nettleton Stone** (the Nettleton Member or 'Three-feet-six-inch Bed' of Jeans, 1980) which is commonly prominent in quarry faces. This marks a brief episode of shallowing, which can also be recognised in southern England and elsewhere. The Nettleton Stone is expressed as a high-resistivity spike in downhole logs (the 'Jukes-Browne Band' of Murray, 1986; Figure 3).

The Nettleton Stone is overlain by a unit of marly chalk with thin marl bands and beds of relatively pure chalk (the Louth Member of Jeans, 1980). The upper part is generally stained red or pink, and is known as the **Upper Pink Band**. These beds often contain crushed echinoids, including a form used as the index of the *Holaster trecensis* Zone which is only recognised in the Northern Province (Table 1). The Upper Pink Band is terminated by an erosion surface that marks the top of the Ferriby Formation. It equates with that beneath the Plenus Marls of southern England, which there forms the uppermost unit of the Lower Chalk.

8 WELTON FORMATION

Above the Plenus Marls Member at the base, the Welton Formation is dominated by massive or thickly bedded chalks containing flint nodules (as distinct from tabular flints). It comprises the lower part of the unit of 'Chalk with Flints' shown on early geological maps of the region (Table 1), and corresponds approximately with the Middle Chalk of earlier accounts (Jukes Brown and Hill, 1904), though the latter excluded the basal beds (Plenus Marls Member) of the Welton Formation. The formation is approximately 53 m thick in the Burnham-Melton Ross area in the central part of the region, and at the type locality of Melton Bottoms or Welton Wold Quarry [SE 970 282] (Figure 4). It is perhaps rather thinner in the south, the equivalent beds averaging about 33 m in north Norfolk (Peake and Hancock, 1970). It also may thin slightly across the Market Weighton High, perhaps to as little as 40 m in places, but expands towards the Cleveland Basin, being about 68 m thick in the Bempton and Buckton cliff sections between Flamborough and Speeton (Rowe, 1904; Neale, 1974). The formation crops out on the steep slopes of the Wolds escarpment, and for this reason has a generally rather narrow outcrop particularly in the northern part of the region (Figure 1). Soils on the outcrop are generally brown clayey loams with much flint and subordinate chalk debris.

8.1 The Plenus Marls Member

The Plenus Marls Member could logically be included in the Ferriby Formation on lithological grounds, making the latter the exact equivalent to the Lower Chalk of southern England (Table 1). However, Wood and Smith (1978) treated it as the basal unit of the Welton Formation, and this classification has become generally accepted. Previously, it has been termed the 'Black Band' (e.g. Wright and Wright, 1942), although this term is best applied to a specific part of the succession (see below). Jeans (1980) used the name 'Flixton Member' although Plenus Marls Member (e.g. Whitham, 1991) is now preferred.

The Plenus Marls Member is a thin but complex unit of buff to green and khaki coloured marls and marly chalks that generally forms a topographical slack at outcrop, which facilitates the mapping of the base of the formation. It can also be recognised in boreholes from its distinctive geophysical log signature (e.g. high gamma ray response; Barker et al., 1984). The member is generally about 0.5 m to 0.6 m thick (Figure 4), but is significantly thinner in south Lincolnshire. An unusually complete succession at Melton Ross is over 1.2

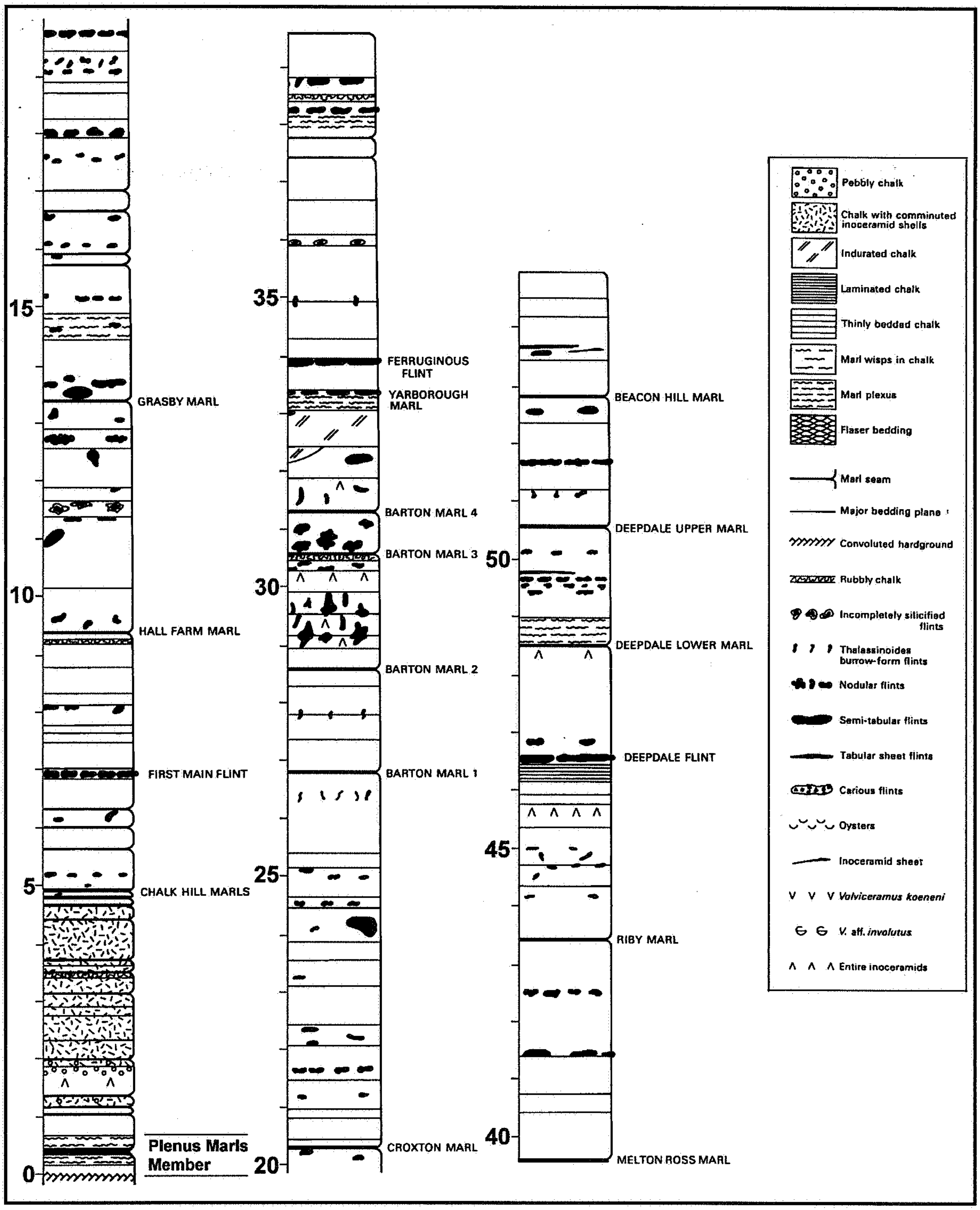

Figure 4. Stratigraphy of the Welton Formation based on the type section (Melton Bottoms Quarry) and exposures in the Humberside area (modified from Gaunt et al, 1992, fig. 33).

m thick (Wood and Mortimore, 1995), and it is also thick in the Cleveland Basin, being 1.4 m thick at Flixton [TA 039 791] where, however, the upper part is rather chalky (Jeans et al., 1991; Dodsworth, 1996). In the cliffs to the south-east of Speeton, it is probably also about 1.4 m thick, although generally only the marly lower part, about 0.7 m thick, has been recognised as belonging to the unit (e.g. Hill, 1888; Wright, 1963), and this is locally squeezed out by thrusting. The succession has been divided into eight units (Beds A to H) by Dodsworth (1996). These can be correlated across the region.

The base of the Plenus Marls (and thus of the Welton Formation) rests upon an erosion surface (see above) that is often highly irregular, and may be stained with iron minerals and glauconite. At the base, Bed A is a nodular chalk with sandy marl seams, which at some localities is capped by a manganiferous layer. Above, Bed B comprises silty and chalky marls. The **Black Band** (Beds C, D and E) in the middle or upper part of the Member, is generally 20 or 30 cm thick, although Dodsworth (1996) recorded 0.75 m at East Knapton in the Cleveland Basin. The Black Band comprises very dark grey to black or purplish bituminous marl. It is often laminated and fissile, and may contain phosphatic fish scales, though otherwise macrofossils are very rare. Microfaunal evidence indicates nearly anaerobic bottom conditions but foraminifera from the associated marls suggest a deep-water environment, and the Black Band succession has been related to a global high sea-level stand with associated depleted oxygen levels (the so-called Oceanic Anoxic Event) at the Cenomanian-Turonian stage boundary (Hart and Bigg, 1981). Above, the upper part of the Plenus Marls Member (Beds F and G) comprises grey and khaki marls which pass into massive chalk in the Cleveland Basin area. Locally developed at the top of the member between Louth and Welton, Bed H is a thin unit of greenish marl, described by Wood and Mortimore (1995) as a sticky, green clay.

At several localities, the belemnite *Actinocamax plenus* has been recorded from the basal beds A and B and in pockets within the underlying erosion surface (Jefferies, 1963; Whitham, 1991, Gaunt et al, 1992). This demonstrates the equivalence of this part of the member to the Plenus Marls as developed in Southern England where they are included in the Lower Chalk. However, higher parts of the member (the Black Band proper and above) post-date the youngest part of the Plenus Marls of the south, being equivalent to the basal part of the Holywell Chalk or Melbourn Rock (Middle Chalk) there (Table 1; Jefferies, 1963; Wood and Mortimore, 1995). The Black Band does not occur south of the neighbourhood of Louth (Bower and Farmery, 1910; Wood, 1980; Dodsworth, 1996), so that the succession in the south of the region is much like that of Southern England

8.2 Welton Formation above the Plenus Marls Member

This unit corresponds with the lower half of the unit of 'Chalk with Flints' shown on early geological maps of the region (Table 1). In fact flints are not generally present in the basal few metres of beds (Figure 4), although in the cliff sections north of Flamborough, flinty chalks are locally in contact with the Plenus Marls Member as a result of tectonism (Rowe, 1904). In undisturbed successions, such as that at the type locality (Figure 4), a thin unit of off-white silty chalk immediately above the Plenus Marls Member is succeeded by several metres of gritty chalks containing abundant shells and shell debris of the inoceramid bivalve *Mytiloides labiatus*, the zonal index fossil. These beds correspond with the upper part of the

Melbourn Rock and the overlying part of the Holywell [Nodular Chalk] Member of Southern England. They contain pebbles of chalk at some levels and a number of thin marl seams.

Above these basal shelly chalks, the bulk of the Welton Formation is composed of extremely pure, white chalks which, in general, are softer than those of the overlying Burnham Formation. Characteristically, this part of the formation contains flints; these flint-bearing beds are some 43 m thick at the type locality (Whitham, 1991) but thicker (c. 64 m; Rowe, 1904; Neale, 1974) on the coast, and probably slightly thinner in the south of the region. These beds correspond approximately with the rather poorly defined *Terebratulina lata* Zone. The zonal brachiopod *T. lata* is very rare except in the upper beds (above the Deepdale Flint), in which it is relatively common. The other fauna is generally sparse, tending to be concentrated at particular horizons. The commonest fossils are inoceramids, but echinoids such as *Sternotaxis* occur sporadically, and more commonly in the upper part of the formation.

In much of the succession, the flints are small and quite sparse (Figure 4). However, a few flint bands are well-developed and conspicuous, and form important marker horizons. Similarly, a number of widespread marl seams are also used as markers (Wood and Smith, 1978; Gaunt et al, 1992; Whitham, 1991). Typically only a few centimetres thick, they are greenish grey where fresh, but weather to orange-brown, and generally have sharp bases whilst grading upwards into the overlying chalks.

The lowest marker is formed by the **Chalk Hill Marls**, comprising three closely-spaced marl seams which rest upon the basal shelly chalks of the formation. The lowest flint band is aptly-named the **First Main Flint**, just above the Chalk Hill Marls and generally about 5 to 7 m above the base of the formation. It comprises closely spaced nodular flints, and locally may form an almost continuous bed (a 'semi-tabular' flint). The **Hall Farm Marl** is a very thin (a few millimetres) marl about 2.5 m above the First Main Flint. It is underlain by a bed of rubbly chalk. About 4 m higher, the **Grasby Marl** is relatively thick marl (up to 4 cm) within a unit of indurated chalk, and so forms a particularly marked peak on geophysical logs. The **Croxton Marl** is thinner (up to 1 cm), but forms a conspicuous peak some 7 m or so above the Grasby Marl.

Roughly in the middle of the formation, the **Barton Marls** are a group of four marl seams within 5 to 7 m or so of strata; they have a readily identified geophysical log signature. Abundant, large, closely spaced burrow-form flint nodules occur in the middle part of the Barton Marls succession. A few metres higher, the **Yarborough Marl** is a marl-chalk complex immediately beneath the **Ferruginous Flint**, otherwise known as the Red Bed. This is a line of flattened flint nodules, developing locally into a semi-continuous flint band (as in parts of the coastal section), in which superficial iron staining produces a characteristic reddish brown colour. Together, the Yarborough Marl and Ferruginous Flint are conspicuous both in exposures and on geophysical logs. The **Melton Ross Marl**, some 5 to 7 m above the Ferruginous Flint, is the thickest marl of the succession (up to 10 cm), and forms a correspondingly prominent peak on geophysical logs. Its identification with the Southerham Marl of Sussex (Mortimore and Wood, 1986) is crucial in the framework of regional correlation. The **Riby Marl**, a few metres higher in the succession, is known from quarries near the Humber, but seems to be less widespread than other marls, and may be absent in the coastal sections.

The **Deepdale Flint**, about 9 m below the top of the formation, is a line of flattened nodules or a semi-tabular flint. It overlies a bed of thinly laminated chalk, and at many localities is succeeded by a bed of nodular flints. This association forms a distinctive peak on geophysical logs. Some 2 m or so above, the **Deepdale Lower Marl** is up to 8 cm thick. The **Deepdale Upper Marl** and the succeeding **Beacon Hill Marl**, together with the Deepdale Lower Marl, form a distinctive group of markers in the uppermost part of the formation.

9 BURNHAM FORMATION

In contrast to the massive chalks of the Welton Formation below, the Burnham Formation is characterised by thinly bedded chalks with common tabular and semi-tabular (discontinuous) flint bands (Figure 5). It forms the upper part of the unit of 'Chalk with Flints' of early geological maps, which comprises the lower part of the Upper Chalk of old accounts (Table 1; Jukes Brown and Hill, 1904). The formation has an extensive outcrop in the north of the region, forming the crest and plateau areas of the Yorkshire Wolds. South of the Humber, however, much of the outcrop is concealed beneath drift deposits (Figure 1). The chalks in the lower part of the formation are particularly hard, and form a conspicuous topographical feature, so that the base of the formation is potentially mappable throughout the drift-free areas. Soils characteristically contain abundant flint debris, often including distinctive pieces of carious flint (i.e. flint with chalk inclusions), together with angular fragments of hard, white chalk.

The type locality for the basal boundary of the formation is the disused Burnham Lodge Quarry [TA 0685 1720] south of Barrow upon Humber. The succession in the overlying beds has been pieced together from various quarries and also boreholes, particularly those drilled at Killingholme [TA 16 19] (Wood and Smith, 1978; Gaunt et al., 1992; Berridge and Pattison, 1994; Whitham, 1991). There, the formation is thought to be about 130 m in thickness. Equivalent beds in Norfolk are approximately 100 m in thickness (based on Wood, Morter and Gallois, 1994), suggesting some thinning of the Burnham Formation in the south of the region. North of the Humber, the Burnham Formation is c. 140 m thick (Whitham, 1991). However, a preliminary interpretion of geophysical logs of boreholes in the area of the Market Weighton High indicates that it is considerably thinner there (85 to 100 m), suggesting the continued influence of this structure. The entire formation is exposed in the cliffs extending north-westwards from Flamborough Head. Rowe (1904) recorded a thickness of 105 m for the beds now included in the formation, but this figure is not necessarily wholly reliable, because of the practical difficulties of measuring this section, much of which is highly dangerous, and is also complicated by faulting. Indeed, bed by bed measurements of the lower part of the formation (up to the Ulceby Oyster Bed; Whitham, 1991; Rawson and Whitham, 1992a) show that, like the Welton Formation, it is actually somewhat expanded (by about 20 per cent) compared with the type section inland, suggesting the possibility of expansion into the area of the Cleveland Basin, perhaps to a thickness of 150 or 160 m.

The flints of the Burnham Formation are mainly tabular types, in some cases up to 0.3 m or more in thickness. Flint nodules such as typify the Welton Formation are relatively scarce, although, large, elongate Paramoudra flints occur at some levels, particularly in the lower part of the succession. As in the Welton Formation, a number of marl seams form widespread

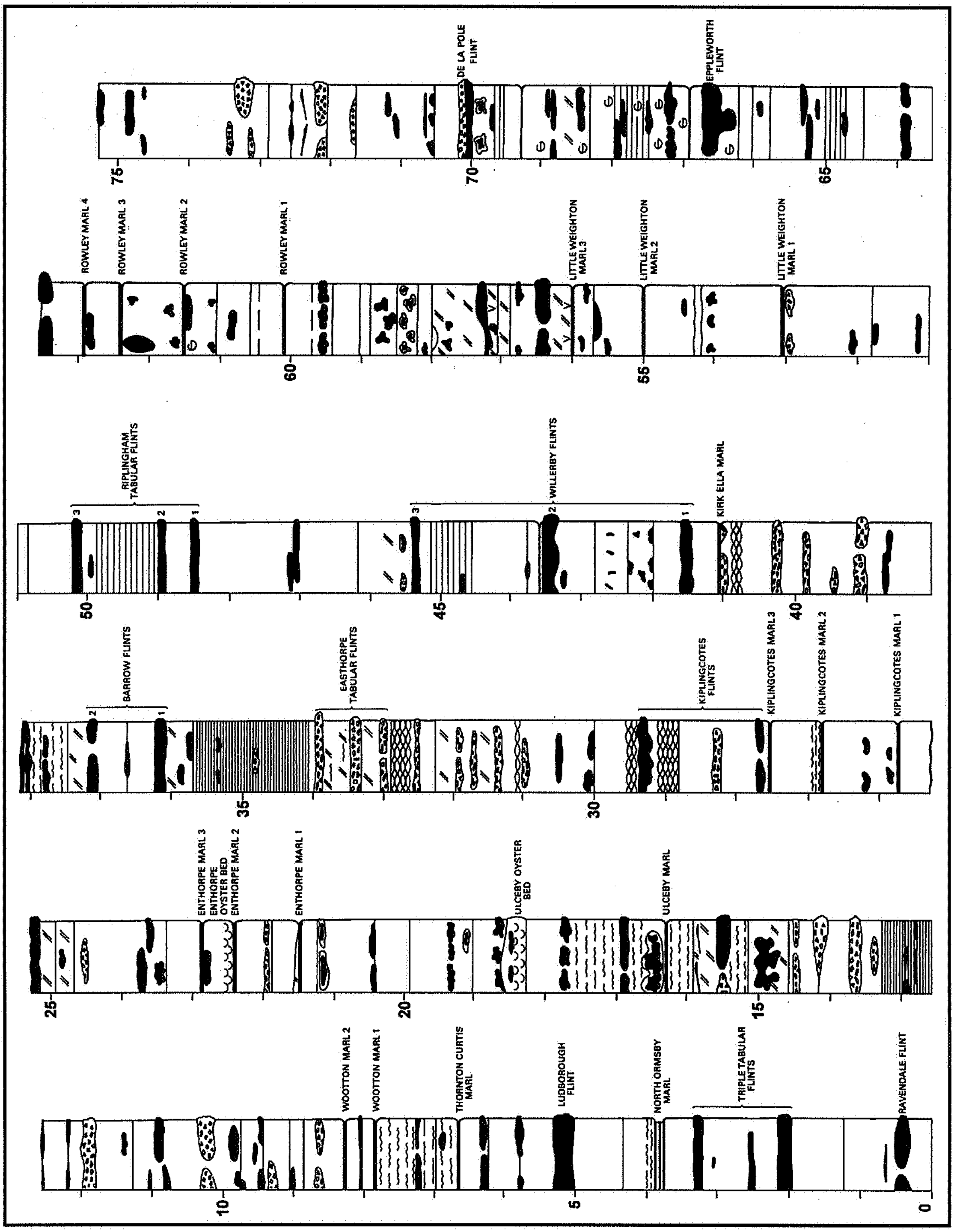

Figure 5. Stratigraphy of the lower part of the Burnham Formation based on sections in the Humberside area (modified from Gaunt et al, 1992, fig. 34). For key see Figure 4.

marker horizons, and in addition, several bands of thinly laminated chalk are also useful for correlation.

The Burnham Formation spans the *Sternotaxis plana, Micraster cortestudinarium* and the lower part of the *Micraster coranguinum* zones. The macrofauna of the formation is more abundant and of higher diversity than in the Welton Formation, particularly in the southern part of the region, where the chalks become somewhat softer than usual, illustrating the transition towards the Southern Province succession.

The lowest few metres of the formation are characterised by hard chalks and thick, closely spaced, tabular flints, and equates with part of the so called 'Brandon Flint Series' of Norfolk, which were mined in Neolithic times for making flint implements. This basal unit, being somewhat more resistant to erosion, produces a minor escarpment by which the base of the formation can be mapped in drift-free areas. It also has a characteristic geophysical log signature enabling its identification in boreholes.

The base of the formation is taken at a bedding plane that corresponds with a marked change from massive, rubbly-weathering chalks below, to harder, thinly bedded or nodular chalk above. This horizon lies just below the **Ravendale Flint** which is a tabular or semi-tabular flint up to 0.25 m thick. A metre or so above, the **Triple Tabular Flints** are a group of three flint bands in about 1.5 m of chalk. The lowest of the three is the thickest and most persistent. Just above the topmost, the **North Ormesby Marl** is a laminated marl up to 11 cm thick, one of the thickest in the Chalk succession, and a key marker, forming a strong peak on geophysical logs. The beds from the base of the formation up to the North Ormsby Marl contain relatively common echinoids, as well as brachiopods and inoceramids.

Just above a succeeding unit of thinly-bedded chalk, the **Ludborough Flint**, about 5 to 6 m above the base of the formation, is a pale grey or white tabular flint up to 25 cm thick. Formerly known as the White Flint (Rowe, 1929), it is one of the thickest flints in the succession, and is thought to be the correlative of the Floorstone at the bottom of the Grimes Graves flint mines of Norfolk (Mortimore and Wood, 1986). In the overlying strata, the **Thornton Curtis Marl** and the paired **Wootton Marls** are thin (1 to 2 cm) marl seams that may be locally impersistent. Rare specimens of the ammonite *Hyphantoceras reussianum* (Orbigny) from the beds just below and above the Wootton Marls (Gaunt et al., 1992; Whitham, 1991), suggest an approximate equivalence with the top of the Chalk Rock at the base of the Upper Chalk in southern England. These beds are also locally rich in echinoids. For several metres above the Wootton Marls, the flints are typically carious. Some metres higher, at about the level of a bed of laminated chalk, the carious flints are replaced by solid, semi-continuous tabular types. These tabular flints are associated with very hard chalks, and together tend to form a second, minor topographical feature at outcrop.

Just above the hard chalks, and about 15 m to 20 m above the base of the formation, the **Ulceby Marl** is an unusually chalky or silty marl, generally about 4 cm thick, often containing crinoid debris, and quite unlike most of the other marl seams in the succession. Some 2 to 3 m higher, the **Ulceby Oyster Bed** is a unit of about 0.2 m of marly chalk with abundant *Pycnodonte* oysters, as well as a diverse brachiopod fauna. Together, the Ulceby Marl and Oyster Bed produce a distinctive double peak on geophysical logs. These beds are succeeded by chalks with flint nodules. Several metres higher in the succession, the

Enthorpe Marls are four marl seams spaced over some 3 m or so of chalk. The lowest marl is generally the thickest (up to 5 cm) and most persistent, whilst the uppermost is often weakly represented or absent. Just above the second marl, a unit of soft chalk with scattered *Pycnodonte* constitutes the **Enthorpe Oyster Bed**, less strongly developed than the Ulceby Oyster Bed. It often contains the burrow trace *Zoophycos* which is particularly characteristic of the beds in this part of the succession (from just beneath the Enthorpe Marls to the top of the Kiplingcotes Marls).

Above the Enthorpe Marls, several metres of massive chalks with some tabular and discontinuous flints are succeeded by the **Kiplingcotes Marls**, three marl seams, each 2 to 3 cm thick, spaced out over some 2 m or so of strata. This sequence is relatively fossiliferous. The base of the *Micraster cortestudinarium* Zone lies between the lower two marls, suggesting that the Kiplingcotes Marls correlate with the Navigation Marls of southern England. The topmost marl is overlain by the lowest of the **Kiplingcotes Flints**, a group of three semi-tabular flint bands in about 1.5 to 2 m of strata. The middle flint is often carious, and the upper of rather nodular habit. At about the level of the uppermost, there is a change to thinly bedded chalks with carious semi-tabular and tabular flints. This part of the succession is often relatively fossiliferous, being particularly rich in echinoids including *Echinocorys* and *Micraster* at some horizons.

About 4 m above the Kiplingcotes Flints, the **Easthorpe Tabular Flints** comprise three tabular flint bands in about 1 m of chalk. They are overlain by a thick unit of laminated chalk with small, flat nodular flints. In contrast to the underlying beds, these laminated chalks are poorly fossiliferous. The latter is succeeded by yellowish, hard, massive chalks with two thick, lenticular or nodular flint bands, known as the **Barrow Flints**. These beds are overlain by a thin unit of relatively soft chalk with marl wisps, succeeded by more massive chalks with incompletely silicified lenticular flints. About 4 m or so above the upper of the two Barrow Flints, the **Kirk Ella Marl** is a very thin (1 cm) marl seam, notable because it immediately overlies a thin, highly carious flint or partly silicified chalk ('incipient flint'). It lies just below the **Willerby Flints**, comprising three tabular flint bands within about 4 m of chalk. The lowest flint, up to 15 cm thick is of a dark grey colour, like most of the flints below, whereas the succeeding flints of the Burnham Formation are mostly pale grey in colour. It is overlain by massive chalks with small flint nodules, and fairly common echinoids. The uppermost flint is underlain by rather thinly bedded chalk, and is overlain by a bed of hard, yellowish chalk, but locally there is a non-sequence cutting out part of the succession at about the level of the Willerby Flints. Above, several metres of relatively thinly-bedded chalks with sporadic flints are capped by the **Riplingham Tabular Flints**, comprising three flint bands within less than 2 m of often hard and thinly bedded chalk. The uppermost flint is the thickest (14 cm) and most persistent. The overlying chalks have yielded a fauna indicating the top of the *Micraster cortestudinarium* Zone.

A few metres higher, the **Little Weighton Marls** (the 'Conoco Marls' of Barker et al., 1984), are three thin (typically 2 cm) marl seams within 2 to 3 m of chalk. The lowest rests on an incipient flint (cf. the Kirk Ella Marl), and the upper is overlain by a hard, yellow, shelly chalk. These marls form a notable marker on geophysical logs, very approximately in the middle of the formation, and generally about 50 to 60 m above the base. The lower two marls are thought to be the correlatives of the paired East Cliff or Shoreham Marls of southern England, the upper of which (corresponding with Little Weighton Marl 2) is taken to mark the base of the *Hagenowia rostrata* Zone, which corresponds approximately with the *Micraster coranguinum* Zone of southern England (Table 1). The topmost marl (Little Weighton Marl 3) is succeeded by hard chalks with variable developments of flint, and at the base, much shell debris (of the inoceramid *Volviceramus*). The **Rowley Marls**, several metres higher in the succession, are four rather variable marls, within a c. 3 m unit of gritty, shell fragmental chalk. They are followed by 3 to 4 m of hard, massive chalks with stylolitic partings, and flints of various types. At the top, the **Eppleworth Flint**, generally about 65 to 70 m above the base of the formation, is a thick irregular semi-tabular flint, made up of coalesced burrow-form nodules. Up to c. 30 cm thick, it is probably the most substantial flint band in the entire succession, possibly equating with the East Cliff Semitabular or Seven Sisters Flint of southern England (Mortimore and Wood, 1986). It lies within a bed of massive chalk, and this association produces a conspicuous peak on resistivity logs.

The succeeding beds are massive chalks with marl partings and small lenticular and nodular flints. About 4 to 5 m above the Eppleworth Flint, the **De la Pole Flint** is a continuous, but rather carious, tabular flint. It is succeeded by beds much like those beneath with, some metres up, a group of several marl seams. The thickest, about 13 m or so above the De la Pole Flint, is the **Middleton Marl** (or East Halton Marl), some 5 cm thick (beyond the upper limit of Figure 5).

The higher part of the Burnham Formation is poorly known inland except from boreholes. These beds typically contain rather thin, pale grey lenticular flints, and bands of small nodular flints, often associated with thin marly horizons. A notable marker proved in a borehole [TA 1732 1905] at Killingholme is a rather carious tabular flint overlain by chalk with *Inoceramus* shell debris, which occurs about 26 m above the Middleton Marl (Berridge and Pattison, 1994). Several boreholes in this area prove a white flint, or incipient flint, some 14 m higher. This appears to be the highest substantial flint in the succession, and as such, defines the top of the formation. The highest beds of the formation are exposed at Flamborough Head, and in the cliffs to the north, where the uppermost flint, known as the **High Stacks Flint** (Whitham, 1991), is a band of grey, yellow-skinned flint nodules 3 to 5 cm thick. The top of the formation is also seen inland in a quarry at Langtoft [SE 973 512] (Whitham, 1991). It remains uncertain whether or not the topmost flint of the formation lies at exactly the same stratigraphical horizon at each of these localities, but it seems most likely that it does not. In Norfolk, and southern England generally, the bulk of the Upper Chalk is to some degree flint bearing, and on this basis it seems probable that the top of the Burnham Formation, defined as a unit of flint-bearing chalk, is somewhat diachronous, becoming younger to the south; this contrasts with the base of the formation (and that of the Welton and Ferriby formations) which are defined at event horizons that are essentially isochronous. To some degree, this diachronous behaviour may account for the thickness variations noted in the Burnham Formation. Additional work on geophysical log correlation would help to resolve these uncertainties.

10 FLAMBOROUGH FORMATION

The Flamborough Formation is the youngest formation recognised in the chalk exposed at outcrop in this region. Unlike the underlying Welton and Burnham formations, it is essentially flint-free, and comprises the upper unit of 'Chalk without flints' mapped by the

Geological Survey in the nineteenth century (Table 1). Much of the succession is also generally less hard than the chalk in the underlying Burnham Formation, being lithologically similar to the chalks of southern England.

The formation is present between Flamborough Head in the north and Grimsby in the south (Figure 1) and extends eastwards beneath the North Sea. The basal 160 m or so of the formation is well exposed in the cliffs between Flamborough Head and Sewerby; this constitutes the type section for the formation. Equivalent, and probably slightly higher beds, (extending up to about 220 m above the base of the formation, according to Whitham, 1993) crop out inland, in the northernmost part of the Yorkshire Wolds, near Driffield. Even higher beds occur beneath drift in the Holderness region where the formation appears to total about 265 m; this figure is based on geophysical logs of boreholes, but the detailed stratigraphy of these beds is unknown.

The cliffs constituting the type section of the Flamborough Formation are described by Lamplugh (1895), Rowe (1904), Neale (1974), Rawson and Whitham (1992b), Whitham (1992; 1993) and Mitchell (1994; 1995b). The succession is difficult to measure accurately, because of cliff falls, minor stuctures and some gaps in exposure, and it is likely that all these accounts contain minor errors. The most complete and detailed description is by Whitham (1993), who introduced names for various marker beds (Figure 6). However, because of the lack of comparative sections elsewhere, it remains uncertain how laterally persistent these named markers are, or to what degree the stratigraphy of the type section is representative of the formation on a regional basis. To help resolve these uncertainties, in 1997, a borehole [TA 16 SE/6; TA 1505 6486] at Carnaby, 6 km south-west of Sewerby, was cored and geophysically logged with the intention of providing a standard by which boreholes elsewhere could be related to the type section. Unfortunately, the lithological and biostratigraphical data obtained were insufficient to allow firm correlation with the coastal exposures (Woods, 1997).

Away from the type area, currently the only cored borehole for which a small amount of published data is available is the BGS Humberside No. 3 Borehole [TA 2756 1677] on the north bank of the Humber at Sunk Island (Berridge and Pattison, 1994). This penetrated the basal c. 120 m of the formation, but the record is insufficiently detailed to make a close comparison with the type section, although it would appear that the succession is relatively condensed. The following detailed discussion of the stratigraphy of the Flamborough Formation (as shown in Figure 6) is therefore based almost entirely on the coastal type section, as described by Whitham (1993) with amendments by Mitchell (1994; 1995b)), together with a small amount of supplementary information from inland exposures and boreholes. As already intimated, it remains uncertain how representative this is of the formation elsewhere.

At the type section, the formation comprises white, flint-free chalks with numerous marl seams typically 1 to 3 cm in thickness; these occur with an average frequency of almost one per metre, far more than in the underlying chalks. Some of the thicker marls named as marker horizons are seen to vary greatly in thickness, or split into multiple bands when traced laterally over fairly short distances, and this inevitably complicates potential correlation with sections elsewhere. It is noteworthy that in the Humberside No. 3 Borehole, only very thin,

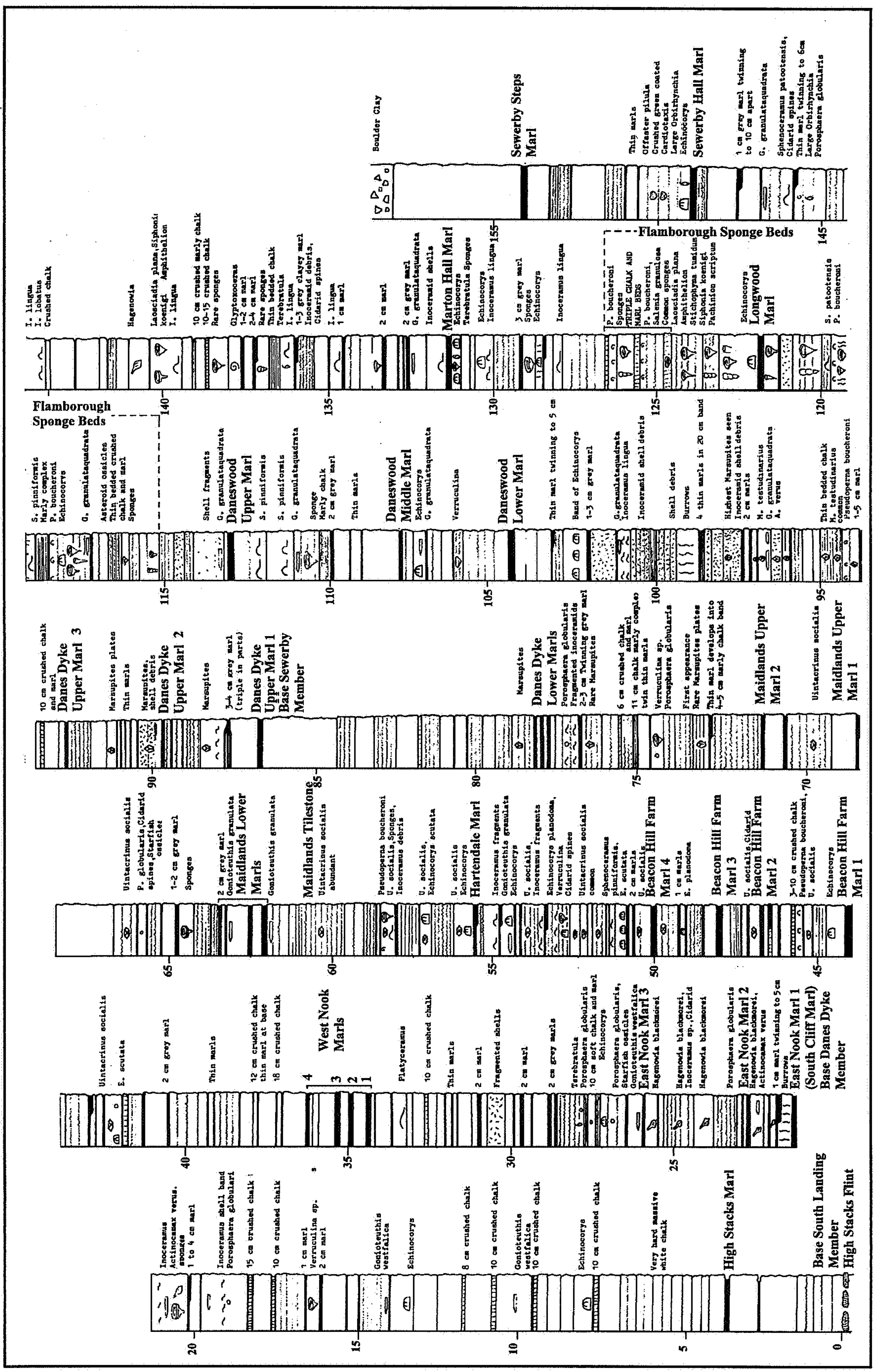

Figure 6. Stratigraphy of the Flamborough Formation at its type section. Modified from Whitham (1993, figs 5, 6, 7, 8, and 9) incorporating the amendments of Mitchell (1994), by permission of the Yorkshire Geological Society.

insignificant marl partings are recorded; whilst this may be merely the result of poor core recovery, it may alternatively indicate that the succession is significantly different there.

Whitham (1993) subdivided the succession at the type section into three members, the South Landing, Danes Dyke and Sewerby members, which have somewhat different lithological characteristics (Figure 6).

10.1 South Landing Member

The South Landing Member, about 21 m thick, comprises hard, massive chalks with sporadic thin marl seams. Some of the chalks are so hard that they have been used locally as a building stone. The base of the member (and of the Flamborough Formation) is marked by the top of the High Stacks Flint, seen on the forehore near High Stacks, Flamborough Head [TA 258 704]. About 3 m above, the **High Stacks Marl** is a 2 cm thick, grey, silty marl, with a thinner marl about 1 m below. This marker has not been observed at Langtoft Quarry [TA 012 661] north of Driffield, which also exposes the basal beds of the Flamborough Formation (Whitham, 1991), but it is unclear whether this indicates that the marl is impersistent, or whether the base of the flint-free Flamborough chalks lies at a different horizon there. About 20 m above the base of the member, a 1m-thick bed of relatively fossiliferous chalk with inoceramids, echinoids, sponges etc, is sandwiched between two marls. The upper was named the South Cliff Marl by Whitham (1993), and regarded as being several metres below the top of the member. However, according to Mitchell (1994), it is the same as the East Nook Marl at the base of the succeeding Danes Dyke Member (see below), the confusion arising because of a gap in the section at South Landing.

10.2 Danes Dyke Member

The Danes Dyke Member, c. 67 m thick, comprises thinly bedded, alternating hard and soft chalks with stylolites, and with common marl seams (86 in total). It is overall less hard than the underlying South Landing Member, and the marls are far more abundant. The lowest are the **East Nook Marls**, three marls which occur in the basal few metres of the member. The base itself is marked by East Nook Marl 1, a grey, rather chalky marl seam, 2 to 3 cm thick. East Nook Marl 2 and East Nook Marl 3 are somewhat thinner, and occur about 2 and 5 m respecively above the basal marl. The peculiarly-shaped echinoid *Hagenowia* occurs fairly commonly in the chalks associated with these three marls, indicating the *H. rostrata* Zone. The base of the succeeding *Uintacrinus socialis* Zone is defined by the first appearance of the zonal crinoid a few metres above.

About 13 to 14 m above the base of the member, the **West Nook Marls** are four grey, silty marls up to 3 cm thick, in a unit of chalk about 2 m thick. Inland, at Bainton Balk [SE 973 512], a band of white flint occurs in the chalks associated with these marls. Fragments of *Uintacrinus socialis* can be found in the overlying 10 m or so of beds. The **Beacon Hill Farm Marls** are the thickest marls in the exposed Flamborough Formation succession. They comprise four marls within a unit of c. 7 m of chalk with some more minor marl and marly chalk seams. Beacon Hill Farm Marl 1, some 23 m above the base of the member, is 8 cm thick, expanding locally to 12 cm with the inclusion of chalky lenses. The higher marls are thinner (4 to 5 cm); the uppermost (Beacon Hill Farm Marl 4) is noticeably greenish and sticky.

The **Hartendale Marl** lies about 5 to 6 m above the Beacon Hill Farm Marl 4, i.e. c. 34 m above the base of the member. It is a 2 to 3 cm grey silty marl expanding laterally into a 10 cm chalk/marl plexus. A bed with abundant inoceramid shell debris occurs about 2.5 m above, and a little higher, the **Maidlands Tilestone** is a 1.8 m unit of thinly bedded chalk with abundant *Uintacrinus*. Just above, the **Maidlands Lower Marls** are a group of three grey marls within 1.5 m of chalk. The lowest marl, up to 5 cm thick, is the thickest. About 5 m higher, the **Maidlands Upper Marls** are a pair of marls roughly 2.5 m apart, and each up to about 4 cm thick. The lower of the two (i.e. Maidlands Upper Marl 1), which is noticeably chalky, lies just above the base of the *Marsupites testudinarius* Zone. About 6 m higher, and about 6 or 7 m below the top of the member, the **Danes Dyke Lower Marls** form a group of three marl seams, each 2 to 3 cm thick, within about 0.5 m of chalk.

10.3 Sewerby Member

The Sewerby Member constitutes the highest chalks exposed on the coast. It is dominated by massive chalks, although the lower part comprises thinly bedded chalks with stylolites, much like the bulk of the underlying Danes Dyke Member. Marl seams are somewhat less common than in the Danes Dyke Member. About 71.5 m of beds are seen on the coast with (probably) slightly higher horizons being represented in quarries inland, although precisely how these inland sections relate to the coast is not certain.

The **Danes Dyke Upper Marls** are three marls seams in the lowest 6 m of the member. Danes Dyke Upper Marl 1, which marks the base of the member, is a 3 to 4 cm rather chalky marl. Danes Dyke Upper Marl 2 and 3 are somewhat thinner. Plates of the zonal crinoid *Marsupites* are common at some levels in the chalks associated with these marls, and in the succeeding 5 m or so. A bed with abundant inoceramid shell debris about 13 m above the base of the member was formerly taken as the base of the *Sphenoceramus (Inoceramus) lingua* Zone, but these beds are now assigned to the *Uintacrinus anglicus* Zone, defined by the range of that crinoid (Mitchell, 1995b), and taken as the basal zone of the Campanian Stage (Table 1). About 18 m above the base of the member, the **Daneswood Lower Marl** is 9 cm thick silty and chalky marl. The base of the *Sphenoceramus lingua* Zone is taken just above. The **Daneswood Middle Marl**, some 3 m above is thinner (4 to 5 cm). **The Daneswood Upper Marl**, about 5 m higher, i.e. some 27 m above the base of the member, is a grey, clayey marl 5 cm thick. About 2 m above, the **Flamborough Sponge Beds**, comprise some 11 m of chalk containing common and well-preserved sponge fossils, together with sporadic echinoids. The **Longwood Marl** in the upper part of the Sponge Beds, about 35 m above the base of the member, is a 6 cm thick grey marl which is succeeded by chalk and marl beds which form the uppermost part of the Sponge Beds. The **Marton Hall Marl**, 45 m above the base of the member, is a 4 cm thick grey marl. In the uppermost part of the exposed section, the **Sewerby Hall Marl** is a 4 to 5 cm marl and chalky marl. Some 5 m higher, the **Sewerby Steps Marl** is a 6 cm brown marl. It is the highest marker in the section, some 68 m above the base of the Sewerby Member, and about 160 m above the base of the Flamborough Formation. About 4 m of chalk are poorly exposed above the Marl at the western end of the section [TA 2015 6865] which terminates where the pre-Devensian cliffline meets the present shore (Figure 1) and the chalk cliffs are replaced by glacial drift.

Inland, quarries at Bessingby [TA 164 669] (Whitham, 1993) and at various localities around Bridlington (Rowe, 1904; Wright and Wright, 1942) expose chalks with marl bands which lie at a slightly higher stratigraphical level than those on the coast. A quarry at Nafferton Grange [TA 049 611] near Driffield is thought, on palaeontological grounds (notably the presence of scaphitid ammonites), to lie at a similar level to those near Bridlington (Whitham, 1993). However, the regional structure as shown in Figure 2 implies that it lies much lower in the Flamborough Formation; this discrepancy may suggest that there are local structural complications in this area. A section at White Hill Reservoir [TA 165 713], Bridlington (Wright and Wright, 1942) is thought to have exposed the youngest chalks represented at outcrop inland. These beds probably belong to the *Gonioteuthis quadrata* Zone (Table 1).

11 ROWE FORMATION

The youngest chalks of the region occur in the coastal area of Holderness, where they are concealed beneath glacial drift deposits up to 50 m thick. Southwards from Hornsea, the total thickness of chalk strata above the Burnham Formation is approximately 300 to 350m. Microfaunal evidence from boreholes indicates that the beds here extend into the *Belemnitella mucronata* Zone, and specimens of the index belemnite have been found in the tills which cover the chalk of this area (Wood, 1980). Chipping and geophysical data from hydrocarbon wells in the Hornsea area would suggest that the the largely flint-free chalks typifying the Flamborough Formation are of the order 260 to 280 m thick. They are apparently overlain by up to 70 m or so of flint-bearing chalks (Figure 1); in geophysical logs, flint bands are indicated by high sonic, low gamma ray peaks, and marls the converse. These flinty strata continue eastwards beneath the North Sea, with still higher beds being present. There, they have been named the Rowe Formation (Lott and Knox, 1994); their base is thought to lie approximately at the base of the *Belemnitella mucronata* Zone.

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Appendix 1 Definitions of lithostratigraphical units

The following definitions of the six formations of the Chalk Group in the Northern Province form the basis for the entries in the British Geological Survey Lexicon of Named Rock Units which, when complete, will provide definitions for all the lithostratigraphical terms found on current, published BGS maps. The BGS Lexicon can be searched via the BGS internet pages (http://www.bgs.ac.uk). Whilst in reality the southern limit of the Northern Province is a poorly defined zone, for practical reasons, only the Hunstanton Formation is used south of the Wash; the other formations are restricted to Yorkshire and Lincolnshire. An alternative nomenclature is used offshore (see main text).

HUNSTANTON FORMATION

BGS Computer code HUCK

BGS Map code HCk

Chronostratigraphy
Lower Cretaceous, middle to upper Albian

Lithology
Rubbly to massive chalks with marl bands; typically pink to brick-red in colour (due to disseminated hematite), but locally upper part grey due to secondary alteration of the iron minerals. Commonly somewhat sandy, particularly in lower part.

Definition of lower boundary
Sharp or [apparently] gradational boundary of marly chalk with ferruginous sandstones of Carstone Formation or (in Cleveland Basin) with mudstone of Speeton Clay Formation; commonly marked by a line of phosphatic nodules (burrow-fills).

Definition of upper boundary
Erosion surface, locally developed as a hardground, overlain by nodular chalk (lowest Cenomanian) of Paradoxica (or Sponge) Bed or (in Cleveland Basin) Crowe's Shoot Member (Mitchell, 1995); this horizon (the base of the Lower Chalk in Norfolk, or elsewhere of the Ferriby Formation) may or may not correspond with the upper limit of red chalks.

Thickness
c. 1 m at type section in Norfolk, typically 3 m in Lincolnshire and south Yorkshire, thinning over Market Weighton High but expanding up to c. 30 m in Cleveland Basin with c. 24 m in cliffs at Speeton..

Previous names

Red Chalk; Hunstanton Limestone; Hunstanton Red Rock; Hunstanton Chalk Formation; Hunstanton Red Chalk Formation (Owen, 1995); Hunstanton Chalk Member (Wood and Smith, 1978)

Where definition published
Owen (1995), as modified herein.

Type section
Hunstanton Cliff [TF 6725 4130 to TF 6786 4238], north Norfolk (Owen, 1995; Gallois, 1994)

Primary Reference Section
South Ferriby Quarry [SE 9915 2045], Lincolnshire (Gaunt et al., 1992)

FERRIBY FORMATION

BGS Computer code FYCK

BGS Map code FyCk

Chronostratigraphy
Upper Cretaceous, Cenomanian (Mantelli to Guerangeri Zone)

Lithology
Grey, soft, marly, flint-free chalk, typically weathering buff in exposures; locally includes pinkish bands; some harder, gritty, shell-debris-rich beds, and thin discrete marl seams.

Definition of lower boundary
Erosion surface, locally developed as a hardground, overlain by nodular chalk (lowest Cenomanian) of Paradoxica (or Sponge) Bed or, in the Cleveland Basin, the Crowe's Shoot Member (Gaunt et al., 1992; Mitchell, 1995).

Definition of upper boundary
Uneven erosion surface that may be stained with iron minerals and glauconite, at the top of a succession of marly chalk (Ferriby Formation); succeeded by Plenus Marls Member (Welton Formation), a thin unit of marls and marly chalks which generally forms a topographical slack at outcrop; this facilitates the mapping of the top of Ferriby Formation which is also readily recognised from geophysical log signature in boreholes.

Thickness
Typically 20 to 25 m, thinning over Market Weighton High (c. 10 to 15 m) but expanding into Cleveland Basin, being c. 35 m in cliffs at Speeton and c. 50 m inland.

Previous names
'Chalk without Flints' or 'Lower Chalk' of early Geological Survey maps, but excluding Plenus Marls; Ferriby Chalk Formation (in some cases this includes the basal unit now separated as the Hunstanton Formation).

Where definition published
Wood and Smith (1978), expanded by Gaunt et al. (1992) and Whitham (1991) as modified herein.

Type section
South Ferriby Quarry [SE 9915 2045] (Gaunt et al., 1992)

Reference Section
Speeton Cliffs [TA 162 752 to TA 192 744] (Wright, 1968; Mitchell, 1995)

WELTON FORMATION

BGS Computer code WCK

BGS Map code WCk

Chronostratigraphy Upper Cretaceous, Cenomanian (Geslinianum Zone) to Turonian (Lata Zone)

Lithology
White, massive or thickly-bedded chalk with common flint nodules ('burrow-form flints') but generally lacking tabular flint bands; sporadic marl seams including the Plenus Marls Member ('Black Band' sensu lato) at the base.

Definition of lower boundary
Base of Plenus Marls Member, a unit of buff to green and grey marls and marly chalks, typically 0.5m thick but up to 1.4 m in Cleveland Basin. This rests on an uneven erosion surface that may be stained with iron minerals and glauconite, at the top of a succession of marly chalk (the Ferriby Formation). The marly basal beds generally form a topographical slack at outcrop, which facilitates the mapping of the base of the formation, and can also be recognised from their geophysical log signature in boreholes

Definition of upper boundary
Marked change from massive, rubbly-weathering chalks below, to harder, thinly bedded or nodular chalk (Burnham Formation) above. This horizon lies just below the Ravendale Flint, a tabular or semi-tabular flint up to 0.25 m thick, which is the lowest such flint in the Chalk Group and base of the chalk unit in which such flint bands are common.

Thickness
About 53 m in type area; thinner in south and over Market Weighton High but may expand towards Cleveland Basin in northernmost part of outcrop, being (reportedly) 68 m in Bempton/Buckton Cliffs.

Previous names
'Chalk with Flints' (lower part) of early Geological Survey maps; Middle Chalk plus uppermost part (Plenus Marls) of Lower Chalk; Welton Chalk Formation

Where definition published

Wood and Smith (1978), expanded by Gaunt et al. (1992)

Type section
Melton Bottoms (Welton Wold) Quarry [SE 970 282] near North Ferriby, Yorkshire (Gaunt et al., 1992; and Whitham, 1991)

Reference Section
Bempton and Buckton coastal cliffs between North Landing and Speeton [TA 239 721to TA 165 750] (because of inaccessibility and structural complications, the section has never been described in detail, but see e.g. Rowe, 1904; Neale, 1974; Rawson and Whitham, 1992)

BURNHAM FORMATION

BGS Computer code BCK

BGS Map code BCk

Chronostratigraphy
Upper Cretaceous, Turonian to Santonian (Plana to Coranguinum zones)

Lithology
White, thinly-bedded chalk with common tabular and discontinuous flint bands; sporadic marl seams.

Definition of lower boundary
Marked change from massive, rubbly-weathering chalks below, to harder, thinly bedded or nodular chalk above. This horizon lies just below the Ravendale Flint, a tabular or semi-tabular flint up to 0.25 m thick which is the lowest such flint in the Chalk Group and base of the chalk unit in which such flint bands are common.The lowest few metres of the formation comprises hard chalks and thick, closely spaced, tabular flints; which produce a topographic feature by which the base of the formation can be mapped, and a characteristic geophysical log signature enabling its identification in boreholes

Definition of upper boundary
Top of highest flint band of thick, flint-rich unit of chalk (i.e. Burnham Formation) succeeded by flint-free chalks (i.e. Flamborough Formation); at Flamborough Head, this is the High Stacks Flint, but elsewhere may be at a somewhat different horizon. Change particularly marked on borehole sonic velocity logs.

Thickness
Generally about 140 m; possibly significantly thinner (85 to 100 m) over Market Weighton High; 105 m reported on Yorkshire coast, but possibly much thicker (up to c. 160 m).

Previous names
'Chalk with Flints' (upper part) of early Geological Survey maps; Upper Chalk (lower part); Burnham Chalk Formation

Where definition published
Wood and Smith (1978), expanded by Gaunt et al. (1992) and Whitham (1991)

Type section
Burnham Lodge Quarry [TA 0685 1720] near Barrow upon Humber, Lincs (Gaunt et al., 1992)
Reference Section
Coastal cliffs between north-west of Flamborough Head [TA 259 705 to c. TA 175 748] (this section has never been described in detail, but see e.g. Rowe, 1904; Neale, 1974; Rawson and Whitham, 1992, a, b)

FLAMBOROUGH FORMATION

BGS Computer code FCK

BGS Map code FCk

Chronostratigraphy
Upper Cretaceous, Santonian to Campanian (Quadrata Zone)

Lithology
White, well-bedded, flint-free chalk with common marl seams (typically about one per metre). Common stylolitic surfaces and pyrite nodules.

Definition of lower boundary
Top of highest flint band of underlying thick, flint-rich unit of chalk (i.e. Burnham Formation); in type section this is the High Stacks Flint but elsewhere may be at a somewhat different horizon.

Definition of upper boundary
Base of lowest flint of succeeding thick, flint-rich unit (i.e. Rowe Formation)

Thickness
Up to about 265 m (onshore); basal c. 160 m exposed in type section

Previous names
'Chalk without Flints' of early Geological Survey maps
Upper Chalk (pars)
Flamborough Chalk Formation

Where definition published
Wood and Smith (1978) expanded by Whitham (1993); Mitchell (1994)

Type section
Cliff section between Sewerby Steps and High Stacks, Flamborough Head [TA 201 687 to TA 259 705] (Whitham, 1993; Mitchell, 1994, 1995b)

Reference Section
Atwick No 2 (1973) borehole (TA 15 SE/9) [TA 1835 5171], c. 122 m to c. 385 m

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Name **ROWE FORMATION**

BGS Computer code ROWE

BGS Map code ROWE

Chronostratigraphy
Upper Cretaceous, Campanian (Mucronata Zone) onshore, extending into Maastrichtian offshore

Lithology
White, flint-bearing chalk with sporadic marl bands

Definition of lower boundary
Basal flint band of thick unit of flint-bearing chalk above thick flint-free unit of Flamborough Formation; recognised on the basis of downhole geophysical logs.

Definition of upper boundary
Unconformably overlain by Quaternary deposits onshore: offshore also succeeded by Palaeogene deposits (Lott and Knox, 1994)

Thickness
About 80 m preserved onshore; up to c. 380 m offshore

Previous names
Not previously named onshore, thus implicitly included in Flamborough Formation.

Where definition published
Onshore usage Sumbler (1996), based on Lott and Knox (1994)

Type section
Borehole 49/24-1, 635 m to 840 m depth (Offshore, southern North Sea; see Lott and Knox, 1994)

Reference Section
Atwick No 2 (1973) borehole (TA 15 SE/9) [TA 1835 5171], c. 41 m to c. 122 m

Appendix 2 Component BGS maps, and stratal thicknesses

BGS 1:50 000 and 1:63 360-scale Geological Sheets covering the region (January 1999). Asterisk indicates old or reprinted map which utilises obsolete stratigraphical subdivisions. Provisional maps are based on old maps without modern resurvey. Thicknesses of formations, where given, are in metres, and are an approximation based principally on the generalised vertical section on the map, and from the corresponding memoirs. in some cases more meaningful figures may be derived from a consideration of the structural information given in Figure 2 (H = Hunstanton Formation; Fy = Ferriby Formation, W = Welton Formation; B = Burnham Formation; F = Flamborough Formation; R = Rowe Formation)

53 Pickering 2000 (provisional)	H 12, Fy 20
54 Scarborough 1998 (provisional)	H 12-30; Fy 38-60; W, B 170; F 71+
55 and 65 Flamborough and Bridlington 1985 (Provisional)	H 12.5, Fy 40; W 68; B 104; F 265; R 70
63 York 1983*	H, Fy,W, B
64 Great Driffield 1993 (Provisional)	H, Fy 30; W, B 150; F 265
65 (see 55)	
71 Selby 1973 (Provisional)*	H, Fy, W
72 Beverley 1995 (Provisional)	H, Fy 28; W, B 180; F 215+
73 Hornsea 1998 (Provisional)	H, Fy 10-15; W 55-60; B 95; F265; R 80+
80 Kingston upon Hull 1983	H, Fy 25; W 44-53; B 140; F 20+
81 and 82 Patrington 1991	H, Fy 20; W 50; B 130 ; F 340+
89 Brigg 1982	H, Fy 22; W 64; B 45+
90 and 91 Grimsby 1990	H, Fy 22-32; W 48 to 53; B 130 ; F 300+
103 Louth in press (Provisional)	H, Fy 22-32; W 48-53; B 40+
104 Mablethorpe 1996 (Provisional)	H, Fy 30; W, B, F 175+
115 Horncastle 1995 (Provisional)	H, Fy 30; W 15+
116 Skegness 1996 (Provisional)	H, Fy 20 to 30; W 25+