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The stratigraphy of the Chalk Group in Yorkshire, Humberside and Lincolnshire

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THE STRATIGRAPHY OF THE CHALK GROUP IN YORKSHIRE, HUMBERSIDE AND LINCOLNSHIRE

M G Sumbler

1. INTRODUCTION

This report was prepared for the Hydrogeology Group of the British Geological Survey, as a contibution towards their hydrogeological memoir for the region, a contract funded by the Nation Rivers Authority. 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 of Cretaceous age, forms the bedrock present beneath much of North Yorkshire, Humberside and Lincolnshire (Figure 1). In the western part of this region, it crops out at the surface, forming the downland scenery of the Yorkshire and Lincolnshire Wolds, and forming spectacular cliffs up to 100m in height where the Wolds meet the coast at Flamborough. However, in the eastern part of the region, the Chalk is buried beneath drift deposits, mainly Late Pleistocene (Devensian) tills, sands and gravels of glacial origin, and post-glacial (Holocene) coastal and marsh sediments. These drift deposits, forming the lowland areas of Holderness and Lincoln Marsh, are commonly some 20 to 30m in thickness along the coast, and locally exceed 50m in the southern part of Holderness. 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 on the banks of the Humber at Hessle and Barton (Figure 1). To the south of the region, the Chalk re-emerges from beneath the drift cover on the Norfolk coast at Hunstanton.

In the southern and greater part of the region, the Chalk Group overlies the East Midlands Shelf (Figure 2), an area of gradual subsidence in both Jurassic and Cretaceous times, on which moderate thicknesses of sediments built up. The chalk succession dveloped 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 20m 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 et al., 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 relatively shallow effect related to the topography.

In north Humberside, the Market Weighton High (or "Axis") marks an area of relative uplift which affected Jurassic and Early Cretaceous sedimetation. 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. In this area, the dip swings round towards the south-east, and 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 Wolds towards Malton. It relates to the buried southern margin of the Cleveland Basin (Kirby and Swallow, 1987), in which a thick succession of Jurassic and Lower Cretaceous sediments accumulated; it was uplifted (inverted) in later Cretaceous times. The most northerly chalk outcrops of the region lie on the margins of this basin; the lower part of the Chalk Group expands significantly into the basin, and are substantially thicker than in the areas of the Market Weighton High or East Midlands Shelf. Higher parts of the succession may also have been affected, but 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 500m 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 800m of Chalk are present some 40km 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 1200m thick to the east, in the central North Sea.

3. LITHOLOGY AND FAUNA

The Chalk Group comprises 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, 1985). 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 chalks and marls 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 probably represent contemporaneous volcanic ash falls (Pacey, 1984), but others may result from a temporary increase in the supply of terrigenous detritus. The likely correlation between the marls of our region and those of the Southern England succession is discussed by Mortimore and Wood (1986) and Gaunt et al.(1992, fig. 28).

Flints, a form of cryptocrystalline quartz, are generally associated with the purer chalks. Flint 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, particularly *Thalassinoides*, and the shape of a flint nodule reflects the original burrow morphology. 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 rhyhmicity, 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 sheets, lining fractures at various angles or 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 300m depth). Because of the rarity of ammonites in much 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). 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, notably the marl seams.

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 Chalk of Yorkshire, Humberside and Lincolnshire, and beneath the adjoining North Sea, falls within a loosely defined Northern Province. In many ways, the northern succession has more in common with correlatives in Germany and areas farther east than with the Chalk of the Southern Province. There are significant differences in the fossil faunas in the two provinces, with a generally lower diversity in the north, which may suggest accumulation in generally deeper waters. In some cases, 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 (see below).

The chalks of the Northern Province are typically hard and thinly bedded compared with 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 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 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 are often difficult to see in some sections.

5. STRATIGRAPHIC BACKGROUND

The Chalk Group of England has traditionally been divided into three `formations', the Lower, Middle and Upper Chalk (Table 1; Jukes-Browne and Hill, 1903; 1904). These units are based essentially on the recognition of marker beds (Melbourn Rock and Chalk Rock) which occur at their boundaries in southern England. Unfortunately, these marker beds do not occur in the Northern Province, and consequently the classification has always been difficult and unsatisfactory to apply to our region; 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/Upper chalk boundary lies at a somewhat indefinite horizon (the base of the *Sternotaxis plana* Zone) within the median unit of `Chalk with Flints' (Table 1). To resolve these problems, a revised scheme of classification was introduced by Wood and Smith (1978), and the classification used in the present account is based on their scheme, as modified by subsequent work.

The scheme divides the Chalk Group of the Northern Province into four formations, in ascending order, the Ferriby, Welton, Burham and Flamborough formations, typically some 25m, 50m, 150m and 300m+ in thickness. A fifth formation may be present in the youngest chalks present at depth beneath Holderness. These 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 intial knowledge of the stratigraphical context, the units are potentially recognisable on the basis of geophysical borehole logs alone. The boundary between the Northern and Southern provinces is somewhat diffuse, and so in southern Lincolnshire, the Chalk Group acquires many of the characters of the Southern Province succession. Nevertheless, it is convenient to apply the 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 Hidra, Herring, Lamplugh and Jukes fomations correspond approximately with the Ferriby, Welton, Burham and Flamborough formations onshore (Lott and Knox, 1994).

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 formations throughout the region, and it should be noted that only in the central part of the region (BGS 1:50 000 sheets 80, 81, 89, 90, 91; Gaunt et al., 1992; Berridge and Pattison, 1994) have they been surveyed. Elsewhere, the lines are based on a interpretation of BGS maps mostly dating from the nineteenth century, and/or have been calculated from the interaction of structure contours with topographic, or rockhead contours. The lines are therefore necessarily approximate, and there are some instances where major inaccuracies are suspected.

6. FERRIBY FORMATION

The Ferriby Formation, corresponding approximately with the Lower Chalk plus Red Chalk of previous accounts, is typically about 25 to 30m 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 15m thick there. It thickens very suddenly and considerably at the margin of the Cleveland Basin to the north, as seen on the coast at Speeton where it totals some 55m or so. Additional localised 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 and Humberside (Figure 1). Its type locality is South Ferriby Quarry [SE 9915 2045] (Wood and Smith, 1978; Gaunt et al., 1992) where the beds are worked in conjunction with the underlying Kimmeridge and Ampthill Clay formations (Jurassic) for cement manufacture. The Formation differs from the overlying chalk because of its marly (argillaceous) nature, and this enables it to be distinguished readily on downhole geophysical logs. This marly character also restricts its hydrological transmissivity, so that in practical terms the formation is excluded from the Chalk aquifer.

6.1 Hunstanton Member

The Hunstanton Member, formerly 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. Because of this, its lithostratigraphical classification and nomenclature is controversial. Wood and Smith (1978) regarded it as a part of the Ferriby Formation, but 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), all treat it as a formation in its own right, but disagree over the precise nomenclature to use, and whether or not the it should be included in the Chalk Group.

In the region discussed in this account, the unit is predominantly of chalk lithology, and so is logically classified as part of the Chalk Group and, because there is commonly some difficulty in separating it from the overlying chalks of the Ferriby Formation, it is best treated as part of that formation, rather than a separate entity. Thus, it is herein classified as the basal member of the Ferriby Formation (c.f. Wood and Smith, 1978). The name Hunstanton Member is used to highlight its equivalence to the Hunstanton [Red Chalk]

Formation of the type locality at Hunstanton [TF 67 40] on the Norfolk Coast. Important reference sections within our region include South Ferriby Quarry (Gaunt et al., 1992), and the sea cliffs near Speeton [TA 165 751] in Yorkshire (Mitchell, 1995a).

The Hunstanton Member is typically about 3m thick over the East Midlands Shelf in the southern part of the region (Figure 3), though thinner (c. 1m) over the Market Weighton High. A much thicker and more complete succession is devleoped in the Cleveland Basin; it is 24m thick at Speeton and 27m in a borehole inland at Fordon (Jeans, 1973; 1980; Neale, 1974; Mitchell, 1995a). It 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. In some places the red colouration may extend upwards into higher beds, or conversely, the upper part of the Hunstanton Member may be grey, rather than red, due to secondary alteration of the iron minerals. For example, in the area 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 member from the overlying beds.

Ammonites are extremely rare in the Hunstanton Member, 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 part of the Ferriby Formation. The biozonation shows that the basal part of the Hunstanton Member 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 100m 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.

In the south of the region, the Hunstanton Member overlies the ferruginous sandstones of the Carstone Formation, and generally appears to grade down into it, the lower and greater part of the Hunstanton Member being particularly marly and sandy. There may, however, be a phosphatised, burrowed horizon at the junction. In the region of the Humber, the Carstone is very thin, and to the north, over the Market Weighton High, it is either absent, or reduced to a few centimetres of sandy material (Jeans, 1973) best included in the Hunstanton Member, which there rests unconformably on Jurassic mudstones. In the Cleveland Basin area to the north of the High, the Hunstanton Member overlies the Speeton Clay, which replaces the Carstone and earlier Cretaceous strata in this area; the contact is sharp, but apparently gradational (Mitchell, 1995a). The upper part of the member is less marly and more massive than the lower part, and tends to be paler coloured and prone to discoloration. There may be thus be some difficulty in drawing the upper boundary, although strictly it is defined by a non-sequence, which may be developed as a bored hardground.

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

6.2 Ferriby Formation above the Hunstanton Member

The remainder and greater part of the Ferriby Formation comprises generally grey, predominantly marly chalks, which weather to buff in exposures, and give rise to rather marly soils. The succession is flintless throughout. It corresponds approximately with the Lower Chalk of many previous accounts, which was mapped as `Chalk without Flints' by the Geological Survey in the last century, although the Lower Chalk included the Black Band marls (now Plenus Marls Member) at the top, which are excluded from the Ferriby Formation (Table 1). The succession is approximately 20 to 25m thick throughout most of the region, but thinner (10 to 15m) over the Market Weighton High, and thicker to the north (c. 30 to 40m at Speeton., and perhaps 60m in the Vale of Pickering), demonstrating that the influence of the Market Weighton and Cleveland Basin structures continued into the Late Cretaceous.

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. A number of named marker beds occur which can be traced throughout much of the region (Figure 3).

The eroded top surface of the Hunstanton Member is overlain by a thin bed of iron-stained, silty marl or pink marly chalk, which at Speeton expands to c. 2m of nodular, chalk with pink red and purple marl seams and envelopes (Crowe's Shoot Member of Mitchell, 1995a). It has yielded fossils indicating an earliest Cenomanian (i.e. Late Cretaceous) age, comparable with the basal Chalk Marl of southern England. These basal beds are overlain by the Paradoxica (or Sponge) Bed which 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 (marking the top of the Crowe's Shoot Member at Speeton).

Above, the 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. 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 (Jukes-Browne and Hill, 1903), 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 pebbles of reworked chalk at the base, which rests non-sequentially on the underlying beds. The erosion surface beneath, locally developed as a hardground, can also be recognised in southern England.

Immediately 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, which is commonly a prominent bed 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 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 form the uppermost unit of the Lower Chalk.

7. WELTON FORMATION

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 excuded 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 33m in north Norfolk (Peake and Hancock, 1970). It also may thin slightly across the Market Weighton High, perhaps to as little as 40m in places, but expands towards the Cleveland Basin, being about 70m 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.

7.1 The Plenus Marls Member

The base of theWelton Formation is defined by an erosion surface (see above) that is often highly irregular, and may be stained with iron minerals and glauconite. Above, is a complex unit of buff to green and khaki coloured marls and marly chalks, generally less than than 0.5m thick (Figure 4). An unusually complete succession at Melton Ross is over 1.2m thick (Wood and Mortimore, 1995). In the north of the region, it is up to about 0.7m in the cliffs to the south-east of Speeton, but is there locally squeezed out by thrusting. These marly beds generally form a topographical slack at outcrop, which facilitates the mapping of the base of the formation, and they can also be recognised in boreholes from their distinctive geophysical log signature (Barker et al., 1984). Near the top of this unit, a few centimetres of very dark grey to black or purplish, bituminous marl constitutes the **Black Band**, although this term is commonly applied to the whole of the marly succession. This Black Band 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). The grey and khaki marls above the Black Band terminate in a sticky, green clay, which marks the top of the unit of marls (Wood and Mortimore, 1995).

At several localities, the belemnite *Actinocamax plenus* has been recorded from the basal marly bed, 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 unit to the Plenus Marls of Southern England. However, the Black Band proper post-dates the youngest part of the Plenus Marls, being equivalent to the basal part of the Holywell Chalk or Melbourn Rock of the south (Table 1; Jefferies, 1963; Wood and Mortimore, 1995). Nevertheless, the term Plenus Marls Member (e.g. Whitham, 1991) is an appropriate name for these beds. The Black Band proper dies out in the neighbourhood of Louth, in the south of the region (Bower and Farmery, 1910; Wood, 1980), so that there the succession is much like that of Southern England where, however, the Plenus Marls are included in the Lower Chalk.

7.2 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 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 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 43m thick at the type locality (Whitham, 1991) but thicker (c.

64m; 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 *Terabratulina 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 the aptly-named **First Main Flint**, just above the Chalk Hill Marls and generally about 5 to 7m above the base of the formation. It comprises closely spaced nodular flints, and locally may form an almost continuous bed. 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 4m higher, the **Grasby Marl** is relatively thick marl (up to 4cm) 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 7m 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 7m 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 tabular 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 7m above the Ferruginous Flint, is the thickest marl of the succession (up to 10cm), 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 9m 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 2m or so above, the **Deepdale Lower Marl** is up to 8cm 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.

8. 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 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 earlier 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 (including carious flints, which are common at some levels), 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 130m in thickness. Equivalent beds in Norfolk are of the order 100m in thickness (based on Wood et al., 1994), suggesting some thinning of the Burnham Formation in the south of the region. North of the Humber, the Burnham Formation is c. 140m (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 100m), suggesting the continued influence of this structure. The entire formation is exposed in the cliffs at and just to the north of Flamborough Head. There, it is apparently also relatively thin; Rowe (1904, plates 38 and 39) and Neale (1974) recorded thicknesses of 90m and 105m respectively for the beds now included in the formation, but neither figure is necessarily reliable, because of the practical difficulties of measuring this section, parts of which are inaccessible and complicated by faulting. Indeed, bed by bed measurements of the lower part of the formation (Whitham, 1991; Rawson and Whitham , 1992a) show that it is actually somewhat expanded compared with the sections inland, suggesting the possibility of expansion into the area of the Cleveland Basin..

The flints of the Burnham Formation are mainly tabular types, in some cases up to 0.3m 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 marker horizons, and in addition, several bands of thinly laminated chalk are also useful for correlation.

The Burham 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 the Neolithic period 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 0.25m thick. A metre or so above, the **Triple Tabular Flints** are a group of three flint bands in about 1.5m 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 11cm 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 6m above the base of the formation, is a pale grey or white tabular flint up to 25cm 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 **Wooton Marls** are thin (1 to 2cm) marl seams that may be locally impersistent. Rare specimens of the ammonite *Hyphantoceras reussianum* (Orbigny) from the beds just below and above the Wooton Marls (Gaunt et al., 1992; Whitham, 1991), suggest an approximate equivalence with the top of the Chalk Rock of southern England. These beds are also locally rich in echinoids. For several metres above the Wooton Marls, the flints are typically `carious', containing chalk inclusions, because of incomplete amalgamation of the flint developed around burrows. Some metres higher, at about the level of a bed of laminated chalk, the carious flints are replaced by solid, semicontinuous 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 15m to 20m above the base of the formation, the **Ulceby Marl**, is an unusually chalky or silty marl, generally about 4cm thick, often containing crinoid debris, and quite unlike the volcanigenic marl seams in of other parts of the succession. Some 2 to 3m higher, the **Ulceby Oyster Bed** is a unit of about 0.2m 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 sucession, the **Enthorpe Marls** are four marl seams spaced over some 3m or so of chalk. The lowest marl is generally the thickest (up to 5cm) 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 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 3cm thick, spaced out over some 2m over 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 semitabular flint bands in about 1.5 to 2m 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 semitabular 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 4m above the Kiplingcotes Flints, the **Easthorpe Tabular Flints** comprise three tabular flint bands in about 1m of chalk. They are overlain by a thick unit of laminated chalk with small, flat nodular flints. In contrast to the underlying beds, these laminate chalks are poorly fossiliferous. The latter is succeeded 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 4m or so above the upper of the two Barrow Flints, the **Kirk Ella Marl** is a very thin (1cm) 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 4m 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 2m of often hard and thinly bedded chalk. The uppermost flint is the thickest (14cm) 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 2cm) marl seams within 2 to 3m 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 of geophysical logs, very approximately in the middle of the formation, and generally about 60m 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. 3m unit of gritty, shell fragmental chalk. They are followed by 3 to 4m of hard, massive chalks with stylolitic partings, and a flints of various types. At the top, the **Eppleworth Flint**, generally about 70m above the base of the formation, is a thick irregular semi-tabular flint, made up of coalesced burrow-form nodules. Up to c. 30cm 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 5m 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 13m or so above the De la Pole Flint, is the **Middleton Marl** (or East Halton Marl), some 5cm thick.

The higher part of the Burnham Formation (not shown in Figure 5) 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 [Borehole 37; TA 1732 1905] at Killingholme is a rather carious tabular flint overlain by chalk with *Inoceramus* shell debris, which occurs about 26m above the Middleton Marl (Berridge and Pattison, 1994). Some 14m higher, a white flint (or incipient flint) found in several boreholes appears to be the highest substantial flint in the succession, and as such, defines the top of the formation. These uppermost beds are exposed at Flamborough Head, where the uppermost flint, known as the **High Stacks Flint** (Whitham, 1991), is a band of grey, yellow-skinned flint nodules 3 to 5cm thick.

The top of the fomation 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 in each case, butIn Norfolk, and southern England generally, the bulk of the Upper Chalk is to some degree flint bearing, and on this basis it seems likely that the top of the Burnam Formation, defined as a unit of flint-bearing chalk, is somewhat diachronous, becoming younger to the south. This may account to some degree for the thickness variations noted. Additional work on geophysical log correlation would help to resolve the uncertainties, and it may ultimately prove preferable to redefine the top of the formation at some appropriate isochronous horizon such as a convenient marl seam.

9. FLAMBOROUGH FORMATION

The Flamborough Formation is the youngest formation recognised in the chalk at outcrop in this region. By comparison with 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). It is also generally less hard than the underlying chalks, being lithologically similar to the chalks of southern England.

The formation is present between Flamborough in the north and Grimsby in the south (Figure 1) and extends eastwards beneath the North Sea. The basal 160m or so of the formation is well exposed in the cliffs between Flamborough Head and Sewerby, which constitutes the type section for the formation. Equivalent, and perhaps slightly higher beds (totalling c. 220m according to Whitham, 1993) crop out inland, in the northernmost part of the Yorkshire Wolds, near Driffield. Elsewhere in the region, the formation is concealed beneath drift, and for this reason, the stratigraphy of the Flamborough Formation, particularly of its unexposed, higher beds, is poorly known.

The cliffs constituting the type section of the Flamborough Formation are described by Lamplugh (1895), Rowe (1904), Neale (1974) and Whitham (in Rawson and Wright, 1992; 1993). The sections are difficult to measure in detail, because of faulting and other factors, and it is likely that all these accounts contain minor errors. The most detailed and reliable description is by Whitham (1993), who introduced names for various marker beds (Figure 6). However, because of the lack of comparative sections elsewhere, it is difficult to determine how regionally significant some of these named markers are. This situation is aggravated by a general paucity of geophysically logged boreholes, particularly close to the type section. The only cored borehole for which a small amount of 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, 1992), which penetrated the basal c. 120m of the formation. 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 is therefore based largely on the coastal type section (principally from Whitham (1993) as modified by Mitchell (1994; 1995b)), with a small amount of supplementary information from inland exposures and boreholes. As already intimated, further research is necessary to establish the degree to which the stratigraphy of the type section is representative of the formation on a regional basis.

At the type section, the formation comprises white, flint-free chalks with numerous marl seams typically 1 to 3cm 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, 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 different gross lithological characters (Figure 6).

9.1 South Landing Member

The South Landing Member, about 21m 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 3m above, the **High Stacks Marl** is a 2cm thick, grey, silty marl, with a thinner marl about 1m 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 20m 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.

9.2 Danes Dyke Member

The Danes Dyke Member, c. 67m 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 4m of the member. The base itself is marked by East Nook Marl 1, a grey, rather chalky marl seam, 2 to 3cm thick. East Nook Marl 2 and East Nook Marl 3 are somewhat thinner, and occur about 2 and 5m 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 14m above the base of the member, the **West Nook Marls** are four grey, silty marls up to 3cm thick, in a unit of chalk about 2m 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 10m 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. 7m of chalk with some more minor marl and marly chalk seams. Beacon Hill Farm Marl 1, some 23m above the base of the member, is 8cm thick, expanding locally to 12cm with the inclusion of chalky lenses. The higher marls are thinner (4 to 5cm); the uppermost (Beacon Hill Farm Marl 4) is noticeably greenish and sticky.

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

9.3 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 71.5m 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 6m of the member. Danes Dyke Upper Marl 1, which marks the base of the member, is a 3 to 4cm 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 5m or so. A bed with abundant inoceramid shell debris about 13m 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 18m above the base of the member, the **Daneswood Lower Marl** is 9cm silty and chalky marl. The base of the *Sphenoceramus lingua* Zone is taken just above. The **Daneswood Middle Marl**, some 3m above is thinner (4 to 5cm). **The Daneswood Upper Marl**, about 5m higher, i.e.some 27m above the base of the member, is a grey , clayey marl 5cm thick. About 1.5m above, the **Flamborough Sponge Beds** , comprise some 11m 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 35m above the base of the member, is a 6cm thick grey marl which is succeeded by chalk and marl beds which form the uppermost part of the Sponge Beds. The **Marton Hall Marl**, 45m above the base of the member, is a 4cm thick grey marl. In the uppermost part of the exposed section, the **Sewerby Hall Marl** is a 4 to 5cm marl and chalky marl. Some 5m higher, the **Sewerby Steps Marl** is a 6cm brown marl. It is the highest marker in the section, some 68m above the base of the Sewerby Member, and about 160m above the base of the Flamborough Formation. About 4m of chalk are poorly exposed above the Marl at the western end of the section [TA 2015 6865].

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). Regional structure (Figure 2) would suggest that it lies much lower in the Flamborough Formation. A section at White Hill Reservoir [TA 165 713], Bridlington (Wright and Wright, 1942) is said to have exposed the youngest chalks, probably in the *Gonioteuthis quadrata* Zone or the lowest part of the *Belemnitella mucronata* Zone (Table 1).

10. 'ROWE FORMATION"

Still younger chalks are represented in the drift-covered coastal area of Holderness. 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 would suggest that the the largely flint free chalks typifying the Flamborough Formation are of the order 260 to 280m thick in the Hornsea area. They are apparently overlain by some 70m or so of flint bearing chalks (Figure 1); in geophysical logs, flint bands may be 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 recently 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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TABLES AND FIGURES

Table 1. Chronostratigraphical and lithostratigraphical classification of the Chalk Group of North Yorkshire, Humberside and Lincolnshire (Northern Province) compared with that of southern England (Southern Province). Not to scale.

Figure 1. Distribution of the formations of the Chalk Group in North Yorkshire, Humberside and Lincolnshire, and the approximate extent of 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; SK = Skegness; SF = South Ferriby; Sp = Speeton; W = Welton; Wi = Withernsea

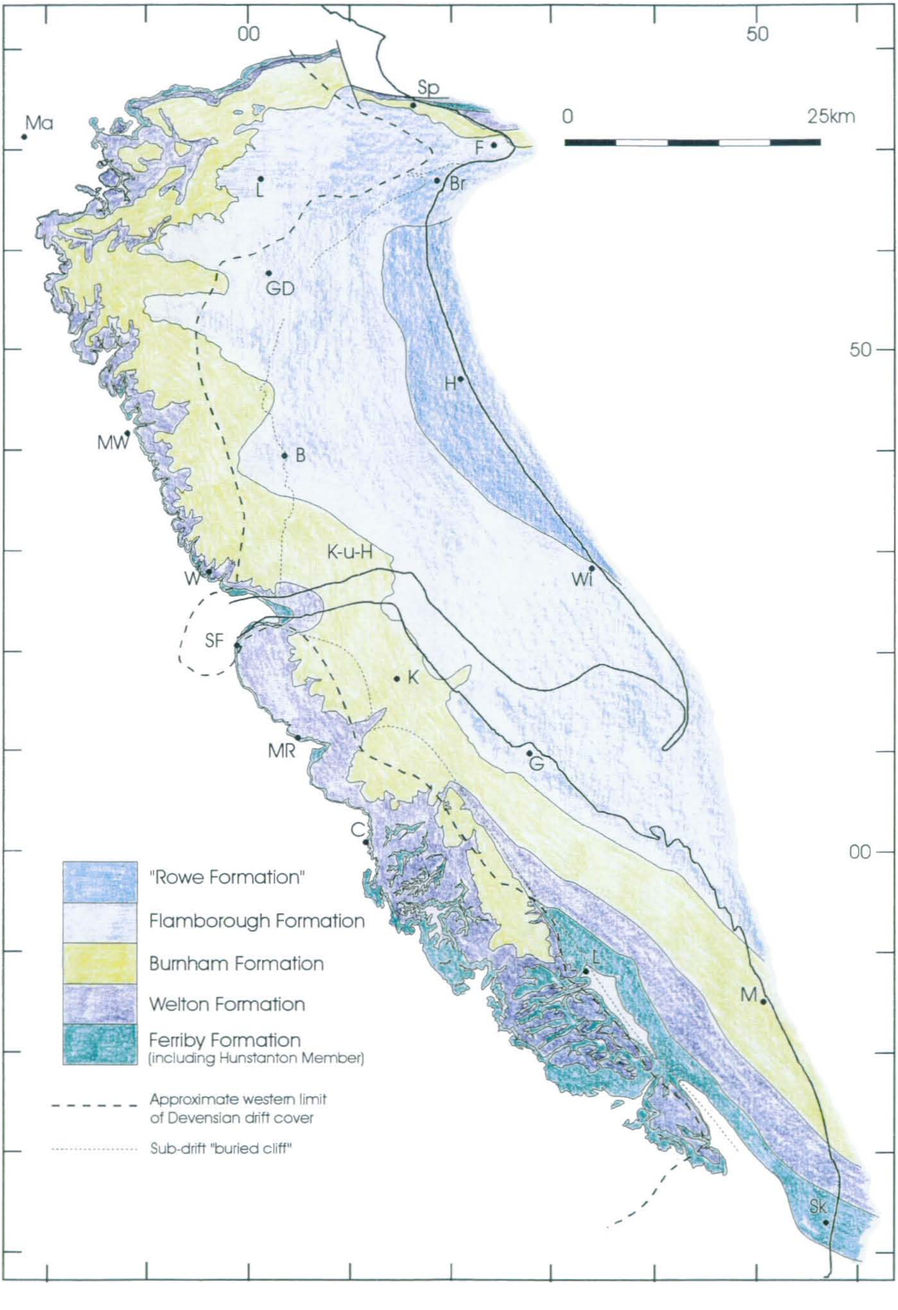
Figure 2. Structure contours on the base of the Chalk Group, in metres above or below sea-level (O.D.). Based on BGS Hydrogeological maps Nos 2 (North and east Lincolnshire) and 10 (East Yorkshire); Evans et al (1990), with modifications (mainly in the north) based on additional data. The three main 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.

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

Figure 4. Stratigraphy of the Welton Formation based on sections in the Humberside area (modified from Gaunt et al, 1992, fig. 33).

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).

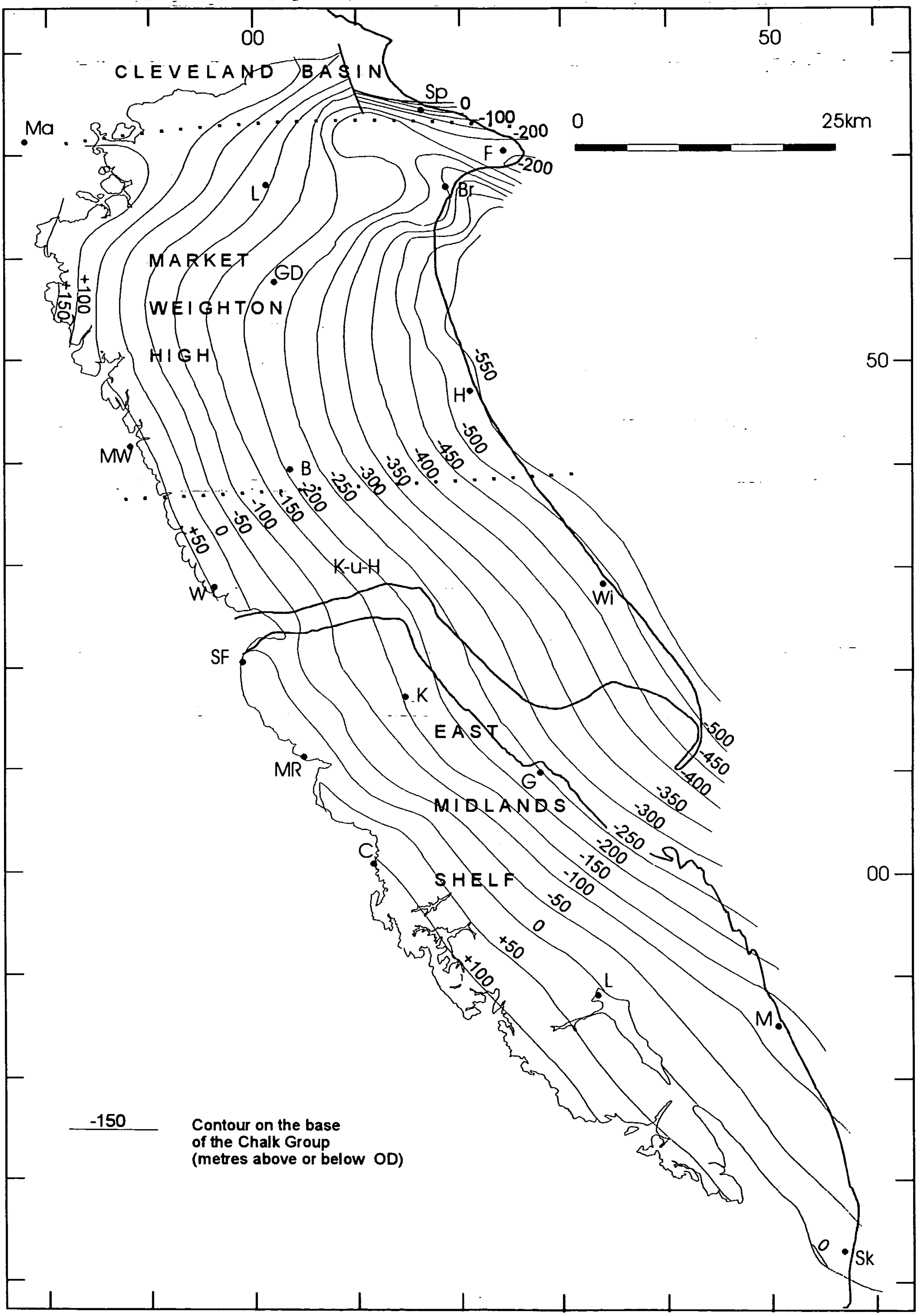
Figure 6. Stratigraphy of the Flamborough Formation between Flamborough Head and Sewerby (modified from Whitham, 1993, fig. 3). Marl bands not to scale.



00
50
Sp
0
25km
Ma
F
Br
L
GD
50
H
MW
B
K-u-H
W
Wi
SF
K
MR
G
C
00
"Rowe Formation"
Flamborough Formation
Burnham Formation
Welton Formation
Ferriby Formation
(including Hunstanton Member)
Approximate western limit
of Devensian drift cover
Sub-drift "buried cliff"
L
M
Sk

Fig 1

STAGE	BIOZONES North	BIOZONES South	LITHOSTRATIGRAPHY Northern Province	LITHOSTRATIGRAPHY Northern Province	LITHOSTRATIGRAPHY Southern Province
CAMPANIAN	Belemnitella mucronata	Belemnitella mucronata	"ROWE"	Flinty Chalk?	UPPER CHALK
	Sphenoceramus lingua	Gonioteuthis quadrata	FLAMBOROUGH	Chalk without Flints	
	Uintacrinus anglicus	Offaster pilula			
SANTONIAN	Marsupites testudinarius	Marsupites testudinarius			
	Uintacrinus socialis	Uintacrinus socialis			
	Hagenowia rostrata	Micraster coranguinum	BURNHAM	Chalk with Flints	
CONIACIAN	Micraster cortestudinarium	Micraster cortestudinarium			
TURONIAN	Sternotaxis plana	Sternotaxis plana			
	Terebratulia lata	Terebratulia lata	WELTON		MIDDLE CHALK
	Mytiloides labiatus	Mytiloides labiatus			
CENOMANIAN	Sciponoceras gracile	Neocardioceras juddi	Plenus Marls Mbr	Chalk without Flints	
		Metoicoceras geslinianum			Plenus Marls Mbr
	Holaster trecensis	Calycoceras guerangeri	FERRIBY		LOWER CHALK
	Holaster subglobosus	Acanthoceras rhotomagense			
		Acanthoceras jukesbrownei			
		Mantelliceras dixoni			
		Mantelliceras mantelli			
ALBIAN			Hunstanton Mbr	Red Chalk	U Greensand and Gault



00
50
CLEVELAND BASIN
Sp
0
-100
-200
-200
0
25km
Ma
F
Br
L
MARKET
WEIGHTON
HIGH
GD
+100
+150
50
-550
H
-500
-450
-400
-350
-300
-250
-200
-150
-100
-50
0
+50
MW
B
W
K-u-H
Wi
SF
K
EAST
MIDLANDS
SHELF
G
MR
-500
-450
-400
-350
-300
-250
-200
-150
-100
-50
0
+50
+100
C
00
L
M
0
Sk
-150
Contour on the base of the Chalk Group (metres above or below OD)

Fig 2

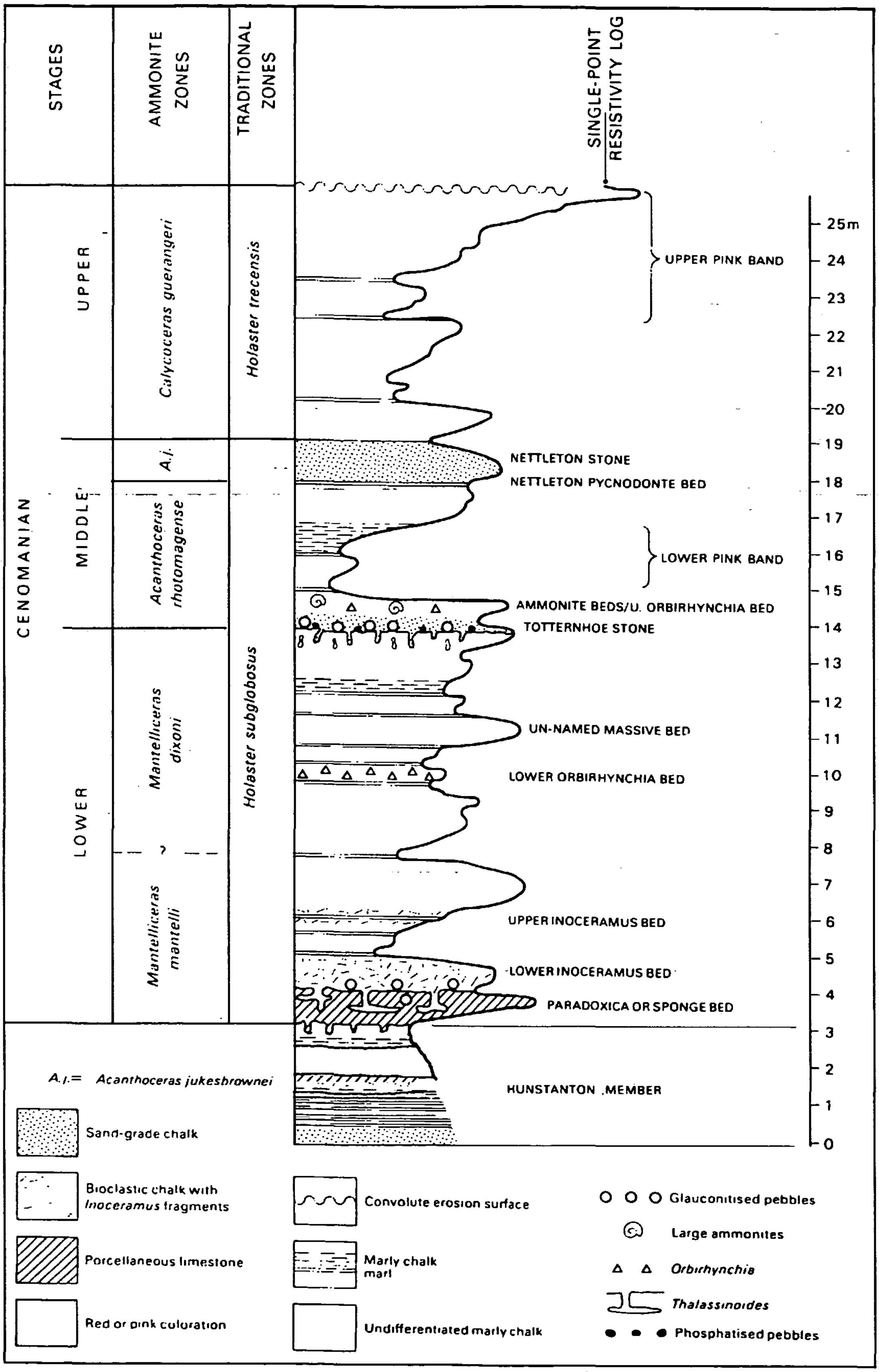
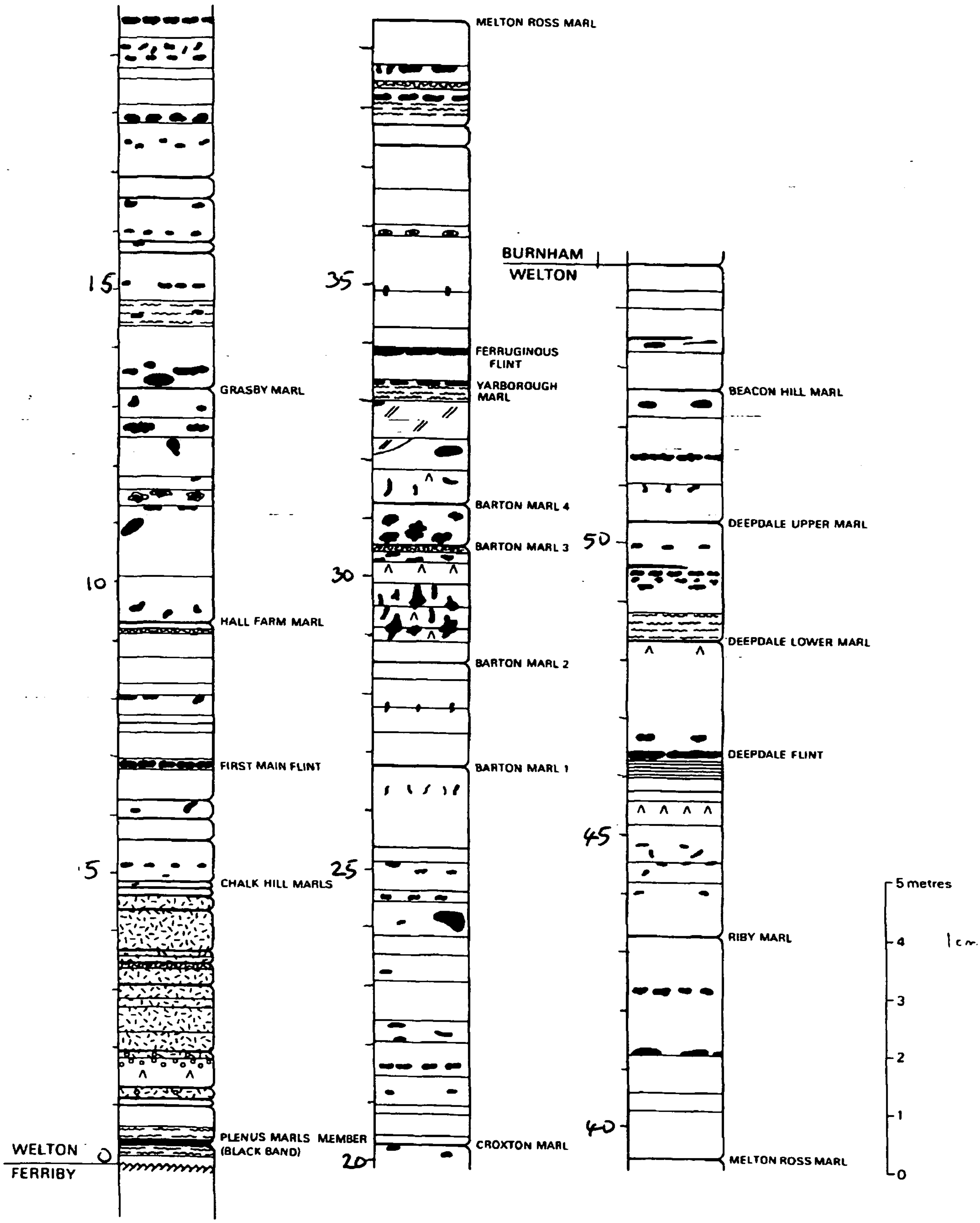
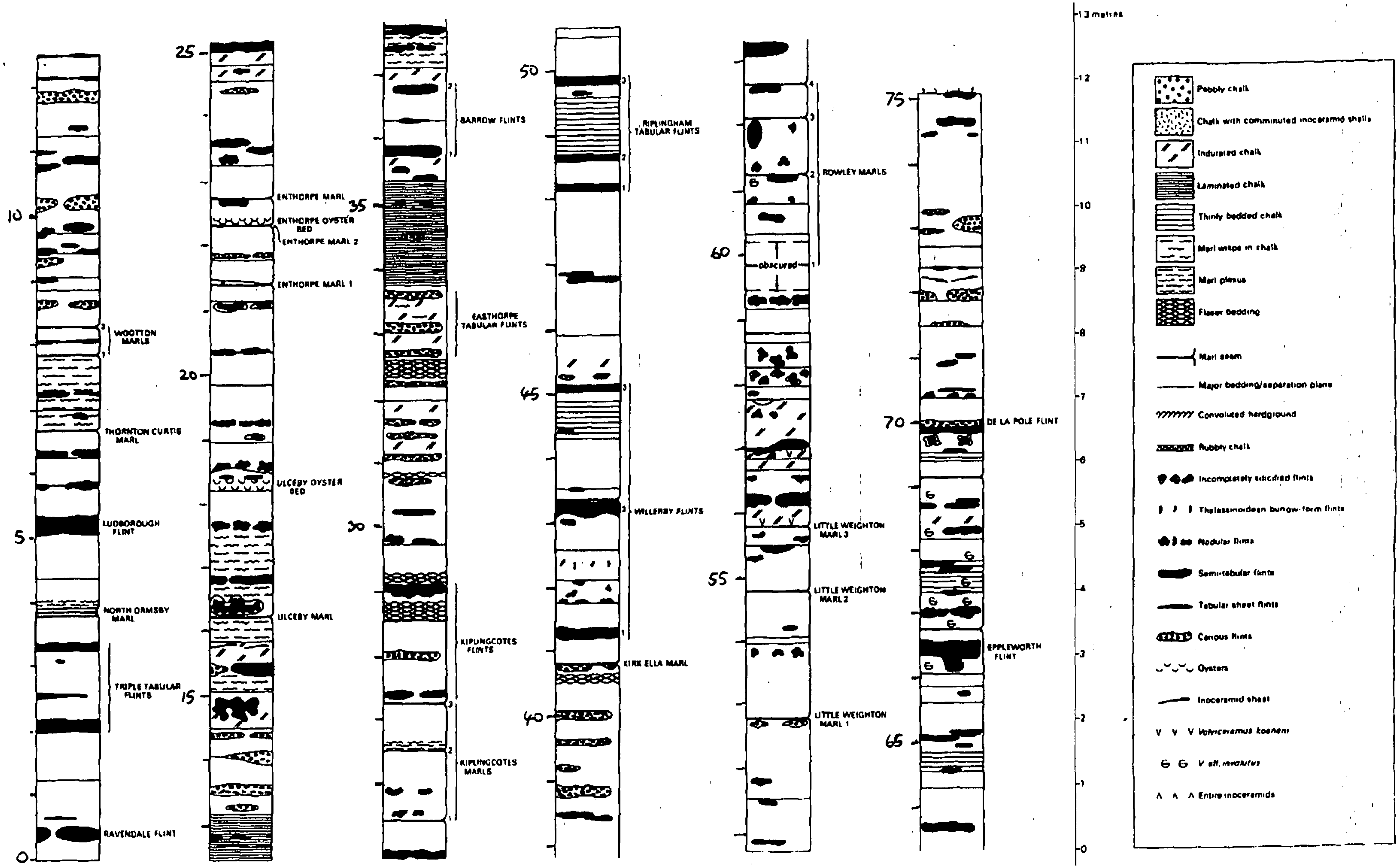

STAGES
AMMONITE ZONES
TRADITIONAL ZONES
SINGLE-POINT RESISTIVITY LOG
CENOMANIAN
UPPER
MIDDLE
LOWER
Calycoceras guerangeri
A.j.
Acanthoceras rhotomagense
Mantelliceras dixoni
Mantelliceras mantelli
Holaster trecensis
Holaster subglobosus
UPPER PINK BAND
NETTLETON STONE
NETTLETON PYCNODONTE BED
LOWER PINK BAND
AMMONITE BEDS/U. ORBIRHYNCHIA BED
TOTTERNHOE STONE
UN-NAMED MASSIVE BED
LOWER ORBIRHYNCHIA BED
UPPER INOCERAMUS BED
LOWER INOCERAMUS BED
PARADOXICA OR SPONGE BED
HUNSTANTON MEMBER
25m
24
23
22
21
20
19
18
17
16
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
0
A.j. = Acanthoceras jukesbrownei
Sand-grade chalk
Bioclastic chalk with Inoceramus fragments
Porcellaneous limestone
Red or pink coloration
Convolute erosion surface
Marly chalk
marl
Undifferentiated marly chalk
Glauconitised pebbles
Large ammonites
Orbirhynchia
Thalassinoides
Phosphatised pebbles

Fig 3



MELTON ROSS MARL
FERRUGINOUS FLINT
YARBOROUGH MARL
BARTON MARL 4
BARTON MARL 3
BARTON MARL 2
BARTON MARL 1
CROXTON MARL
GRASBY MARL
HALL FARM MARL
FIRST MAIN FLINT
CHALK HILL MARLS
PLENUS MARLS MEMBER (BLACK BAND)
WELTON
FERRIBY
BURNHAM
WELTON
BEACON HILL MARL
DEEPDALE UPPER MARL
DEEPDALE LOWER MARL
DEEPDALE FLINT
RIBY MARL
MELTON ROSS MARL
5 metres
4
3
2
1
0
1cm

Fig 4



RAVENDALE FLINT
TRIPLE TABULAR FLINTS
NORTH ORMSBY MARL
LUDBOROUGH FLINT
THORNTON CURTIS MARL
WOOTTON MARLS
ULCEBY MARL
ULCEBY OYSTER BED
ENTHORPE MARL 1
ENTHORPE MARL 2
ENTHORPE OYSTER BED
ENTHORPE MARL
KIPLINGCOTES MARLS
KIPLINGCOTES FLINTS
EASTHORPE TABULAR FLINTS
BARROW FLINTS
KIRK ELLA MARL
WILLERBY FLINTS
RIPLINGHAM TABULAR FLINTS
LITTLE WEIGHTON MARL 1
LITTLE WEIGHTON MARL 2
LITTLE WEIGHTON MARL 3
obscured
ROWLEY MARLS
EPPLEWORTH FLINT
DE LA POLE FLINT
13 metres
Pebbly chalk
Chalk with comminuted inoceramid shells
Indurated chalk
Laminated chalk
Thinly bedded chalk
Marl wisps in chalk
Marl plexus
Flaser bedding
Marl seam
Major bedding/separation plane
Convoluted hardground
Rubbly chalk
Incompletely silicified flints
Thalassinoidean burrow-form flints
Nodular flints
Semi-tabular flints
Tabular sheet flints
Carious flints
Oysters
Inoceramid sheet
Volviceramus koeneni
V. aff. involutus
Entire inoceramids

Fig 5

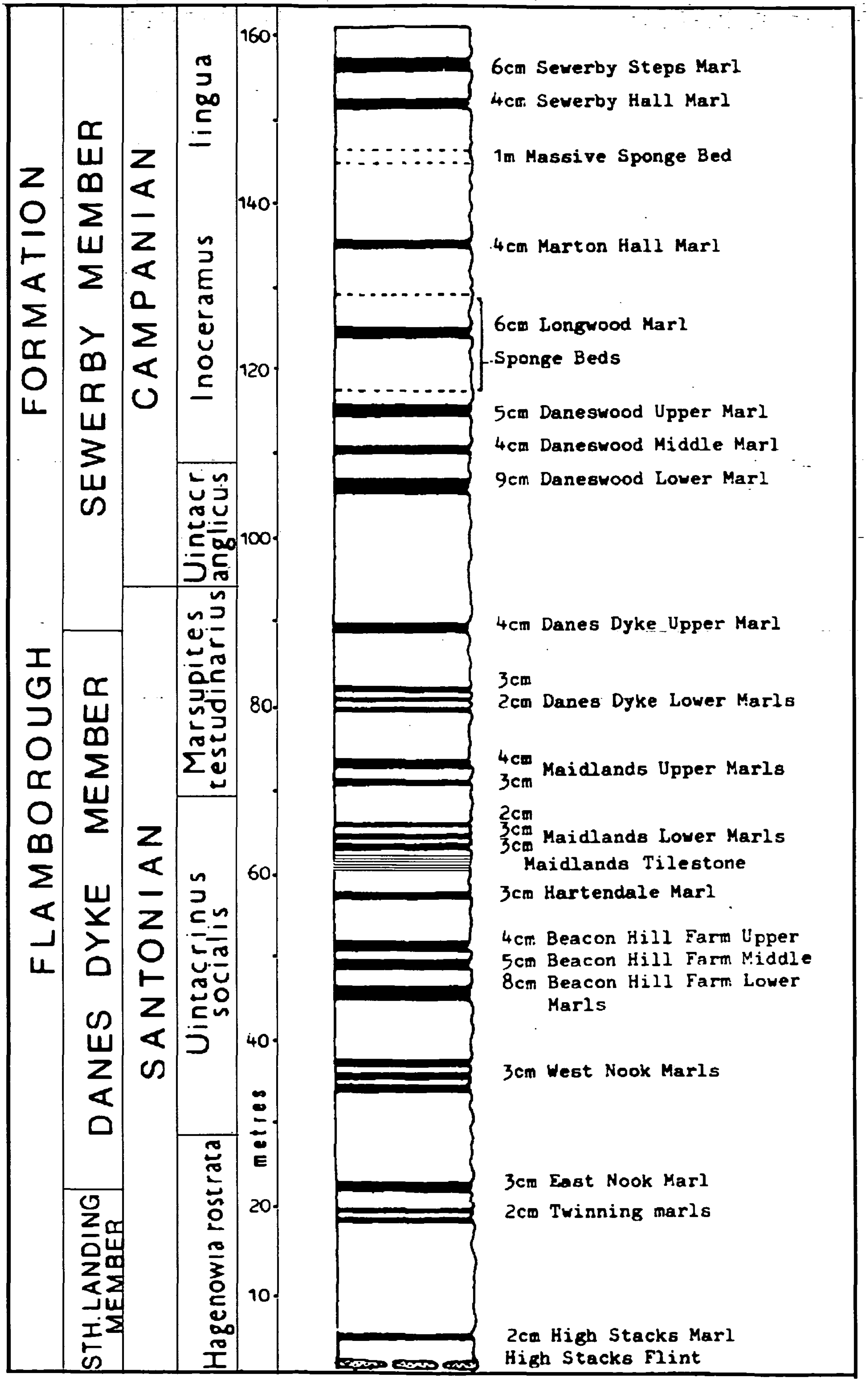

FLAMBOROUGH FORMATION
STH. LANDING MEMBER
DANES DYKE MEMBER
SEWERBY MEMBER
SANTONIAN
CAMPANIAN
Hagenowia rostrata
Uintacrinus socialis
Marsupites testudinarius
Uintacr. anglicus
Inoceramus lingua
metres
10
20
40
60
80
100
120
140
160
6cm Sewerby Steps Marl
4cm Sewerby Hall Marl
1m Massive Sponge Bed
4cm Marton Hall Marl
6cm Longwood Marl
Sponge Beds
5cm Daneswood Upper Marl
4cm Daneswood Middle Marl
9cm Daneswood Lower Marl
4cm Danes Dyke Upper Marl
3cm
2cm Danes Dyke Lower Marls
4cm
3cm Maidlands Upper Marls
2cm
3cm
3cm Maidlands Lower Marls
Maidlands Tilestone
3cm Hartendale Marl
4cm Beacon Hill Farm Upper
5cm Beacon Hill Farm Middle
8cm Beacon Hill Farm Lower Marls
3cm West Nook Marls
3cm East Nook Marl
2cm Twinning marls
2cm High Stacks Marl
High Stacks Flint

Fig 6

Appendix 1

BGS 1:50 000 and 1:63 360-scale Geological Sheets covering the region. Asterisk indicates old or reprinted map which utilises obselete 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 consiration of the structural information given in Figure 2 (H= Hunstanton Member; F= Ferriby Formation (excluding H), W = Welton Formation; B= Burnham Formation; F = Flamborough Formation; R = "Rowe Formation")

53 Pickering 1973 (reprint of 1880 map) * H, Fy
54 Scarborough 1881* H, Fy 50; W, B 170; F 27+
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 Beverly 1995 Provisional H, Fy 28; W, B 180; F 215+
73 Hornsea 1990* (reprint of 1883 map) H, Fy, W, B, F, R 500+
80 Kingston upon Hull 1983 H, Fy 25; W 44-53; B 140; F 20+
81 and 82 Patrington 1991H, 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 to 32; W 48 to 53; B c. 130 ; F c. 300+
103 Louth 1980* Provisional H, Fy, W, B
104 Mablethorpe (in press) Provisional H,Fy 30; W, B, F 175+
115 Horncastle 1995 Provisional H, Fy 30; W 15+
116 Skegness (in press) Provisional H, Fy c. 20 to 30; W 25+

[129, 145 King's Lynn and The Wash; North Norfolk LCk 16- 43 MCk 33; UCk or: H, Fy 16; W30 ;B 90; F 275+]