Chapter 4 Transitional Province, England

Introduction

From the Vale of Pewsey in Wiltshire to the north coast of Norfolk is a region known as the 'Transitional Province' (Figure 4.1), which is given this name because it contains elements of the litho- and biostratigraphy of both the Southern and Northern Provinces. The region is bounded to the south and south-west by the Vale of Pewsey, which has formed along a major fault structure (see p. 87, Chapter 3), and encompasses the Chalk hills from the Berkshire Downs, through the Chiltern Hills to East Anglia. Both the Berkshire Downs and the Chiltern Hills have a well-defined northerly-facing scarp with a dip-slope south-eastwards into the London Basin, where the Chalk is buried by Palaeogene sediments. At the northern end of the Chiltern Hills, there is another significant structural line, the Utley Bottom structure (see (Figure 1.15), Chapter 1), a probable fault-controlled monocline that seems to have exerted some control on sedimentation. This structure appears to follow the north-east edge of the deep-seated Midlands microcraton (Hopson *et al.,* 1996). Beyond that point there is still a Chiltern Hills scarp, but more subdued. The region then grades through the gently rolling Gog Magog Hills into East Anglia where any sort of feature in the Chalk is lost except for the Melbourn Rock feature at the base of the White Chalk Subgroup. Here the remainder of the outcrop is glacially degraded and largely drift-covered. This loss of features is related to lithological changes in the Grey Chalk Chalk Subgroup, to the complete loss of major hardgrounds forming the Chalk Rock and Top Rock lithologies, and to a very gentle dip of perhaps 0.5° to the east.

The Chalk of East Anglia overlies the northern extension of the buried Anglo-Brabant Massif ((Figure 1.8), Chapter 1), and the western margin of the North Sea Basin. A positive area in north Norfolk, has been related to the existence of an inferred igneous intrusive body at depth ((Figure 1.15), Chapter 1; Smith, 1985; Gallois, 1994), and is considered to be the cause of the condensed successions that are developed there.

The northern boundary of the province in East Anglia shifted over time. It appears to have been particularly well marked during Turonian and Early Coniacian times, when it lay in the vicinity of Swaffham. Here it is expressed by the change from the black, burrow-form flints of the Southern and Transitional provinces, to the grey, tabular and semi-tabular flints, within well-bedded chalks, that characterize much of the flinty succession in the Northern Province. In contrast, the higher part of the succession in northern East Anglia has a more Southern Province character.

Apart from East Anglia, in contrast to the adjoining provinces, post-Cretaceous erosion levels have cut deeper into the Chalk in the Transitional Province. Consequently the preserved Chalk succession over the greater part of the province goes up only to the Santonian part of the *Micraster coranguinum* Zone. Local pockets of unusual sediment such as the phosphatic chalks north-east of Newbury (e.g. Winterbourne Chalk Pit) and at Taplow (e.g. South Lodge Pit) near Maidenhead, preserve beds as high as the *Marsupites* (Upper Santonian) and *Offaster pilula* (Lower Campanian) zones. Around the Winterbourne–Kintbury area of Berkshire the preserved level of 'normal' Chalk is somewhere within the *O. pilula* Zone.

The Transitional Province is a region that presents an apparent simplicity that belies a complex geological structure that has had a major influence on Chalk sedimentation. As a result there are several major controversies. The first relates to the lithostratigraphical subdivision of the Chalk for geological mapping, notably the extent to which the standard mapping stratigraphy of the Southern Province can be applied in the Transitional Province. The second controversy is the representation of the facies changes that occur towards adjoining regions, and the third is the age and correlation of the component hardgrounds and associated marl seams of the Chalk Rock in relation to the basinal successions of the Southern Province. The relationship between the Chalk Rock of the type area and the Spurious Chalk Rock of the Isle of Wight and Dorset is not entirely resolved.

Post-Cretaceous geological history of the region involved sub-Palaeogene erosion, Palaeogene sedimentation, tectonic movements, weathering to form Clay-with-flints and glacial and periglacial processes. A long-running controversy has been the cause of apparently 'out-of-place' Chalk blocks with anomalously dipping Chalk at the northern end of the Chiltern Hills around Reed and Barkway. Hopson (1995) has recently interpreted the origin of these blocks as the result of excavation by ice and subsequent rafting. One result of weathering has been the development of 'Sarsen' stones, which include the stone-runs of the Marlborough Downs, the Hertfordshire Pudding Stone and the more than 80 tonne-blocks excavated during construction of the M40 through the Aston Rowant Cutting (see GCR site report, this volume). Dissolution pipes are another weathering feature of the region and excellent examples are found at Kensworth Chalk Pit (see GCR site report, this volume) where the Chalk Rock has also acted as an aquiclude and karst features have developed along it.

Tectonic structure and sedimentation history

The Upper Cretaceous sediments of the Transitional Province formed on a platform that was itself subdivided by faults, causing local thickness and lithological changes. The Marlborough Downs–Chiltern Hills area occupies an intermediate position between the basinal chalks of the Southern Province and the successions in East Anglia and the Northern Province (Figure 4.1). At the northern end of the Chiltern Hills, the Glauconitic Marl at the base of the Chalk is replaced across the Lilley Bottom structure by the Cambridge Greensand, which can be traced thence eastwards into East Anglia.

Compared with those of the Southern Province, the Grey Chalk Subgroup successions in the Chiltern Hills and in the southern part of East Anglia (Cambridgeshire, Suffolk) are characterized by thick basal Chalk (West Melbury Marly Chalk Formation). In contrast, from about mid-Cenomanian times, the entire Berkshire Downs–Chiltern Hills area intermittently constituted a structural high on which developed thin condensed calcarenitic successions such as the Totternhoe Stone in the Grey Chalk Subgroup (Middle Cenomanian), and, in the Turonian–Coniacian strata, extremely condensed successions with hardgrounds such as the Chalk Rock and Top Rock. The Marlborough Downs in Wiltshire constitute the type area for the Chalk Rock, for it is here that it attains its maximum development. The area immediately to the east of the Chiltern Hills is the type area for the Melbourn Rock, a unit of hard chalks, at the base of the traditional Middle Chalk, incorporating the Cenomanian–Turonian boundary transition.

Other aspects of the lithology, related to the broad tectonic setting, include flints at the top of the Holywell Nodular Chalk Formation over an area extending from the central Chiltern Hills (Ivinghoe–Aston Pit, Totternhoe) to the east of Hitchin. In the southern Chiltern Hills, the equivalent succession is not known to be flint-bearing. The Upper Santonian–Lower ampanian successions (crinoid zones to *Offaster pilula* zones inclusive) are locally represented by thin units of phosphatic chalk. Channels and deep troughs ('cuvettes') are associated with these deposits and slump beds are present at Boxford Chalk Pit (see GCR site report, this volume) in the Upper Coniacian–Santonian succession.

The Mundford investigations in Norfolk (Ward *et al.,* 1968), illustrated the presence of channels in the equivalent of the Turonian New Pit Chalk Formation. Other channels may also be present in the buried high chalks of East Anglia since there is evidence of local anomalous stratigraphies in the Campanian succession. Within the Overstrand to Trimingham Cliffs chalk masses there is an internally disrupted stratigraphy related to to intra-Late Cretaceous events (see GCR site report, this volume).

Stratigraphy

Subdivision of the stratigraphy of the Transitional Province into formations, members and beds follows the scheme now established in the Southern Province ((Figure 3.3), Chapter 3; Bristow *et al.,* 1997; Rawson *et al.,* 2001) for the greater part of the region up to the northern end of the Chiltern Hills. The Northern Province stratigraphy applies in the most northerly part of East Anglia around the Wash at Hunstanton Cliffs ((Figure 5.3), Chapter 5). In between, the stratigraphical units are gradational. There are several distinct features of the stratigraphy, such as the presence of the Totternhoe Stone in the Grey Chalk Subgroup.

Grey Chalk Subgroup

The Grey Chalk Subgroup of the Chiltern Hills has been traditionally divided into four standard lithostratigraphical units, namely the Chalk Marl, Totternhoe Stone, Grey Chalk and Plenus Marls. The Plenus Marls Member is now included in the White Chalk Subgroup. In this area, the Totternhoe Stone provides a simple means of delimiting the traditional Chalk

Marl from the Grey Chalk. Recent stratigraphical schemes have treated the Totternhoe Stone either as a unit intercalated between the Chalk Marl and the Grey Chalk (e.g. Shephard-Thorn *et al.,* 1994), or as the basal unit of the Grey Chalk (e.g. Horton *et al.,* 1995). The Chalk Marl, as developed in the Chiltern Hills, represents the preserved remnant of the West Melbury Marly Chalk Formation of the Southern Province. The Totternhoe Stone equates with the basal part of the Zig Zag Chalk Formation, the overlying Grey Chalk constituting the equivalent of the remainder of the redefined Zig Zag Chalk Formation (see Rawson *et al.,* 2001 for further discussion).

The Grey Chalk Subgroup, still relatively thick in the southern part of East Anglia (e.g. over 70 m near Cambridge and *c.* 40 m near Thetford), progressively reduces in thickness at outcrop northwards to a minimum of 14 m at Heacham and 11 m in the subcrop in the Trunch Borehole. Both the latter localities probably overlie a structural high that influenced Albian (Red Chalk) and Cenomanian (Grey Chalk Subgroup) sedimentation. This reduction in thickness particularly affects the lower part of the succession below the Totternhoe Stone. As the Grey Chalk Subgroup thins, it takes on the typical characteristics of the Ferriby Chalk Formation of the Northern Province. These condensed successions have very well-defined bedding and contain lower diversity faunas than successions in southern England. Ammonites, in particular, are relatively uncommon, whereas echinoids become more significant. The succession is closely similar to the equivalent, but thicker, successions in northern Germany (cf. Ernst *et al.,* 1983, 1996; Ernst and Rehfeld, 1997; Kaplan *et al.,* 1998). As in Germany, the condensed successions in eastern England are marked by a sequence of lithostratigraphical and/or biostratigraphical events, which provides a useful framework for correlation.

Glauconitic Marl Member and Cambridge Greensand

The basal beds of the Chalk Group in the western part of the Transitional Province and in the southern Chiltern Hills constitute a thin unit of glauconite-rich marls, the Glauconitic Marl Member, which is locally thick enough to be mapped. To the north, in the area of Totternhoe and Sundon, the Glauconitic Marl locally disappears, and only a few grains of glauconite are found at the contact between the Grey Chalk Subgroup and the Upper Greensand (Shephard-Thorn *et al.,* 1994). Even farther to the north, near Barton-le-Clay, where the Chiltern Hills scarp weakens significantly and changes to a generally east–west direction, thin Glauconitic Marl is replaced by the Cambridge Greensand. This is a unit of micaceous, glauconitic marls rich in phosphatized pebbles, including many fossils reworked from the (Albian) Gault mudstones, on which it rests with erosive contact (Morter and Wood, 1983). The replacement of the Glauconitic Marl by the Cambridge Greensand is apparently structurally controlled, and takes place in the vicinity of a NW–SE fault or monoclinal structure (Liffey Bottom structure), with a downthrow in the Chalk of up to 10 m to the north-east (Shephard-Thorn *et al.,* 1994; Hopson *et al.,* 1996). This structural line also marks the south-west edge of the so-called Anglian Trough', a depositional low revealed by the isopachytes of the Plenus Marls Member at the base of the White Chalk Subgroup (Hart, 1973, fig. 1). Although the Cambridge Greensand development is concentrated in this 'trough', it actually extends as far north as Ely and east into the East Anglian subcrop.

West Melbury Marly Chalk Formation (Chalk Marl)

The lowest part of the West Melbury Maly Chalk Formation (Figure 4.2) in the Chiltern Hills comprises relatively dark grey, silty sediments, which, apart from their different macrofossil content, are not always easy to distinguish from the underlying Gault when wet. These beds are characterized by a low-diversity fauna dominated by small, predominantly crushed, thin-shelled bivalves belonging to the genus *Aucellina,* and are known informally as the 'Aucellina Beds' for this reason (Figure 4.3).

In East Anglia, the lowest part of the Chalk, above the Cambridge Greensand, comprises buff-coloured, rather chalky beds, many metres thick, with a low-diversity fauna dominated by the bivalve *Aucellina.* These so-called 'Porcellaneous Beds' (Morter and Wood, 1983) correlate with the basal Cenomanian Aucellina Beds of the Channel Tunnel boreholes and the Chiltern Hills. Towards the top, they yield poorly-preserved assemblages of ammonites, including heteromorphs such as *Algerites.* The Porcellaneous Beds thin and become more lithified when traced northwards; a little to the south of the Hunstanton Cliffs GCR site they condense to a unit, less than 0.5 m thick, of intensely hard limestone, the 'Paradoxica Bed', with several superimposed glauconitized hardgrounds penetrated by *Thalassinoides* (formerly *Spongia paradoxica*) burrows. Throughout much of East Anglia, these basal beds are overlain by two units of inoceramid bivalve shell-detrital chalk, each with an erosional base (the Lower and Upper Inoceramus Beds), separated by a bed without shells. These beds also become thinner, more lithified and better defined towards Hunstanton Cliffs. Once the Porcellaneous Beds have passed into the Paradoxica Bed there is a standard (Northern Province) Ferriby Chalk succession.

Within the higher part of the West Melbury Marly Chalk Formation, above the Aucellina Beds, two variably cemented, highly fossiliferous limestone beds provide useful marker horizons. The lower of these, named the 'Doolittle Limestone' after a locality near Totternhoe in the northern Chiltern Hills (Shephard-Thorn *et al.,* 1994), is locally feature-forming and may equate in part with the spring-forming, so-called 'Marl-Rock' of the earlier literature. This bed contains abundant specimens of well-preserved three-dimensional ammonites, predominantly *Schloenbachia,* associated with *Inoceramus crippsi* Mantell. It has also been informally called the 'Crippsi Limestone' (e.g. Wood, 1996, fig. 23), and it equates with a similarly fossiliferous bed in the Folkestone to Kingsdown section (see GCR site report, this volume; marker horizon M3 of Gale, 1989), where it marks the top of the Lower Cenomanian *Sharpeiceras schlueteri* Subzone (Gale, 1996) of the *Mantelliceras mantelli* Zone. (Figure 4.3) shows that this marker horizon can be used to demonstrate how the underlying part of the West Melbury Marly Chalk Formation thickens from the Folkestone to Kingsdown GCR site (*c.* 12 m) to Chinnor Chalk Pit (15 m), to the north of which (Pitstone, Totternhoe, Sundon), this unit increases dramatically in thickness to *c.* 35 m. The northern limit of this thickening also appears to be linked to the position of the Lilley Bottom structure.

The higher of the two cemented limestones is known informally as the 'Dixon Limestone', because it locally (but only rarely in the Chiltern Hills) yields well-preserved specimens of the Lower Cenomanian ammonite zonal index fossil *Mantelliceras dixoni* Spath. This bed is characterized by the occurrence of abundant large specimens of *Inoceramus virgatus Schlüter*, commonly with the valves articulated, associated with subordinate *I. crippsi.* It equates with a closely-spaced pair of thin spongiferous limestones (marker horizon M6 of Gale, 1989) in the Folkestone to Kingsdown standard section, and it similarly marks the top of a unit, some 3 m thick, of rather calcareous beds containing common *I. virgatus.* As in Kent, the Dixoni Limestone is overlain by manly beds with small brachiopods, including *Orbirhynchia mantelliana* (J. de C. Sowerby), constituting the lowest of the three distinct *Orbirhynchia mantelliana* bands in the Grey Chalk Subgroup, and is succeeded by a conspicuous dark marl. (Figure 4.3) shows that the Dixoni Limestone can also be used to demonstrate the same trend for the lower part of the West Melbury Marly Chalk Formation to thicken towards the central and northern Chiltern Hills.

Totternhoe Stone

The middle part of the Grey Chalk Subgroup, comprising the lower Middle Cenomanian *Turrilites costatus* Subzone of the *Acanthoceras rhotomagense* Zone, is represented, in condensed form, by a brown or buff-coloured, coarse-grained, calcarenitic unit of variable thickness, which is known as the 'Totternhoe Stone' after the isolated hill situated in front of the main scarp in the northern Chiltern Hills, near Dunstable, where it has been for centuries, and still is, exploited for building stone. The Totternhoe Stone is first encountered at the eastern end of the Berkshire Downs, in the disused Chilton railway cutting [SU 496 858], south of Oxford. In the southern Chiltern Hills, it is well exposed at the Chinnor Chalk Pit GCR site.

To the east of Hitchin, for example at Barrington Chalk Pit and, in the Northern Province, Hunstanton. Cliffs, the Totternhoe Stone more or less equates with the 'Cast Bed' of the Folkestone to Kingsdown GCR site, and correlative successions, and is overlain by a thin 'ammonite limestone' containing specimens of large, weakly glauconitized ammonites *Parapuzosia (Austiniceras),* together with *Orbirhynchia mantelliana,* which represents the third and highest of the three *Orbirhynchia mantelliana* bands of the Southern Province.

Jukes-Browne Bed 7/Buckinghamshire Rag

In the Chiltern Hills, Jukes-Browne Bed 7 (upper Middle Cenomanian *Acanthoceras jukesbrownei* Zone) of the Southern Province is represented by a poorly-developed equivalent of the Nettleton Stone of the Northern Province. This bed typically (e g Chinnor Chalk Pit; part of the Totternhoe Quarry complex) has a thin marl containing small pycnodonteine oysters at the base, which rests on a burrowed surface. The marl is the correlative of the Nettleton Pycnodonte Marl of the Northern Province (see below). Locally, the marl becomes calcarenitic (e.g. adjacent to the Stone Pit in the

Totternhoe Quarry), and may elsewhere (e.g. Pitstone Quarry 2) contain glauconitized and phosphatized pebbles, up to several centimetres across (Figure 4.3). This latter development constitutes the so-called 'Buckinghamshire Rag' of the earlier literature.

In East Anglia, the Jukes-Browne Bed 7 event is represented by the Nettleton Stone of the Northern Province, with its basal dark grey, silty marl full of small oysters (*Pycnodonte),* the Nettleton Pycnodonte Marl — the 'Gryphea Band' of Bower and Farmery (1910). The marl rests here, with conspicuous colour contrast, on intensely hard, creamy-white chalk.

White Chalk Subgroup

As in the Southern Province, the base of the White Chalk Subgroup is taken at the sub-Plenus erosion surface (Figure 4.3) which also marks the base of the Holywell Nodular Chalk Formation. The division of the traditional Middle and Upper Chalk in the Southern Province into formations and members also applies in the Transitional Province with some modifications as units are traced into Norfolk. Two units at the base of the Subgroup, the Plenus Marls Member and Melbourn Rock, have their type localities in this Province.

Plenus Marls Member

It was in the Chiltern Hills and immediately adjacent areas that the Plenus Marls (originally called the 'Belemnite Marls' after the occurrence, in the higher part of the unit, of the belemnite now known as *Praeactinocamax* (formerly *Actinocamax) plenus* (Blainville)), were first recognized (Hill and Jukes-Browne, 1886). Throughout the Chiltern Hills, for example at the Chinnor Chalk Pit GCR site, Pitstone Quarry 2 RIGS site [SP 949 148] and Sewell Quarry [SP 9945 2236] near Totternhoe, the standard sequence of eight beds established in the Southern Province by Jefferies (1963), can be recognized without difficulty, but significant changes appear near Hitchin. Here the manly Bed 2 may virtually disappear, while the limestone (Bed 3) and the overlying silty Bed 4 may locally become merged to produce the conglomeratic, so-called 'marbled rock' of the earlier literature (e.g. Hill and Jukes-Browne, 1886), which incorporates reworked fossils from both lower (*Orbirhynchia multicostata* Pettitt, *Pycnodonte*) and higher (*Praeactinocamax plenus*) assemblages (see Hopson *et al.,* 1996). In addition, the occurrence in the Plenus Marls of tere-bratulid brachiopods (*Ornatothyris),* possibly associated with the sub-Bed 2 erosion surface (Jefferies, 1962) here, and throughout eastern England, suggests a change to a shallower water, higher-energy environment. This area falls well within the Anglian Trough' (Jefferies, 1963; Hart, 1973) of increased Plenus Marls thicknesses, but some of the sections around Hitchin are highly condensed (see Hopson *et al.,* 1996, fig. 12), and contradict the evidence for this thickness trend.

The Plenus Marls Member thins steadily northwards from Cambridge to Hunstanton Cliffs (see GCR site report, this volume). With increasing condensation, the succession (particularly the upper part) becomes more and more difficult to interpret (cf. Jefferies, 1962, fig. 3; 1963, fig. 10). Bed 2 tends to disappear, and Bed 3 retains the nodular character first seen at Hitchin. At Marham [TF 702 078], a conglomeratic bed at the base of Bed 3 contains abundant specimens of *Ornatothyris,* and a thin rusty marl, 0.15 m above the top of Bed 3, is inferred to represent Bed 8. Where most condensed, for example at Hillington Quarry [TF 723 244], SSE of Hunstanton, the Plenus Marls are represented by a manly unit, only a few centimetres thick, resting on a hardground corresponding to the sub-Plenus erosion surface and containing sediment-filled pockets with a fauna of *Ornatothyris latissima* (Sahini), *Orbirhynchia multicostata* and small, depressed forms of the echinoid *Camerogalerus cylindricus* (Lamarck).

Melbourn Rock

In its type area in south Cambridgeshire and north Hertfordshire, the Melbourn Rock crops out on the crest of a prominent feature that was used to survey the newly defined Lower–Middle Chalk boundary on the earliest [British] Geological Survey maps of the region (Penning and Jukes-Browne, 1881). Because part of the Plenus Marls (notably Jefferies' Bed 3) may be extremely indurated in this area, the 'Belemnite Marls' were included in the original concept of the Melbourn Rock, but were later (Hill and Jukes-Browne, 1886) excluded, when the distinctive, essentially many, character of the Belemnite Marls elsewhere became apparent.

The original named localities were Melbourn (Cambridgeshire), as well as a quarry at Ashwell, and Hitchin railway cutting [TL 196 295]. Of these sections, only the Ashwell section [TL 2687 3945] (Hopson *et al.,* 1996, fig. 13) remains, and it is now taken as the stratotype (see discussion by Hopson *et al.,* 1996). The lower part of the type Melbourn Rock includes the group of three intensely cemented marl-limestone rhythms that overlies the Plenus Marls in the Southern Province (the 'Sussex Melbourn Rock' of Mortimore, 1986a; or the Ballard Cliff Member of Gale, 1996).

Although the Melbourn Rock is recognizable thoughout the Chiltern Hills, the upper limit in the earlier literature was applied inconsistently to the west and south of the type area. However, the Melbourn Rock was generally perceived to be poorly fossiliferous, with its top being marked by a gradation to fossiliferous chalks containing inoceramid bivalves (*Mytiloides*) and rhynchonellid brachiopods (*Orbirhynchia cuvieri).* Using the sections in Chinnor Chalk Pit and the Pitstone Quarry 2 RIGS site as links, it has proved possible, on a basis of lithostratigraphical and macrofaunal criteria, to correlate the stratotypic Melbourn Rock at Ashwell with successions in the lower part of the Holywell Nodular Chalk Formation at Dover and Eastbourne (Wood, 1993). This correlation shows that the Melbourn Rock represents, in highly condensed form, the terminal Cenomanian strata (upper *Metoicoceras geslinianum* and *Neocardioceras juddii* ammonite zones) and the basal part of the Turonian succession (*Watinoceras devonense* and *Fagesia catinus* ammonite zones).

Holywell Nodular Chalk and New Pit Chalk formations

In the Chiltern Hills and East Anglia the Holywell Nodular Chalk Formation is readily recognizable, albeit relatively condensed, as it is in the North Downs and at Dover. There is, likewise, the usual lithological change at the top of the Holywell Nodular Chalk Formation, marked by the sharp upper limit of shell-detrital chalk. Locally (northern Chiltern Hills and north Hertfordshire) highly flinty chalk is present at the top of the Holywell Nodular Chalk and base of the equivalent of the New Pit Chalk Formation. In the type area of the Chalk Rock, the sub-Chalk Rock succession (e.g. the Fognam. Quarry GCR site) can be broadly assigned to the New Pit Chalk Formation, although it is much more flinty than in correlative Southern Province successions (cf. Gale, 1996, fig. 5).

To the east of Hitchin, the most shell-detrital part of the Holywell Nodular Chalk, incorporating the equivalent of the beds at, and immediately below, the *Filograna avita* event of the Anglo-Paris Basin (Gale *et* ed., 1993; Gale, 1996), becomes highly cemented, and comparable in its degree of induration with the Melbourn Rock, with which it has been confused by quarry operators. This distinctive unit, which is delimited by marl seams, and which in the Chiltern Hills is relatively friable, has been formally designated the 'Morden Rock' by the British Geological Survey after the type locality at the Steeple Morden Plantation Quarry [II 298 402], near Ashwell (Hopson *et al.,* 1996). The overlying succession, up to the top of the Holywell Nodular Chalk Formation, is characterized in the central Chiltern Hills, for example at the Ivinghoe-Aston Pit [SP 960 176], Totternhoe, and in north Hertfordshire (Steeple Mordern Plantation Quarry), by a remarkable development of flint, producing flinty (albeit shell-detrital) chalks that are reminiscent of parts of the traditional Upper Chalk. The flinty chalk begins above a marl seam (the Aston Marl) that is named after the Ivinghoe-Aston Pit and locally includes a more strongly developed flint (Morden Flint) that preserves valves of *Mytiloides.* This occurrence of flinty chalk is demonstrably structurally controlled, for it is absent from the thinner, more condensed, successions developed over minor anticlines (cf. Hopson *et al.,* 1996, fig. 14). The flinty chalk in this area continues into the overlying basal part of the equivalent of the New Pit Chalk Formation of the Southern Province.

With the exception of the Holywell Nodular Chalk at the top of the Grey Chalk Subgroup escarpment, the Holywell Nodular Chalk and New Pit Chalk formations are poorly exposed in East Anglia, where they occupy mostly low-relief ground. The full succession, and also the lower part of the Lewes Nodular Chalk, was penetrated in cored boreholes and shafts at Mundford, south Norfolk and the composite section proved there provides a standard stratigraphy (Ward *et al.*, 1968) that is applicable throughout East Anglia. This comprises a framework of laterally persistent marl seams, fossil horizons and variably developed beds of flint. The marl seams have been tentatively correlated with marl seams in other depositional areas. In ascending order the Mount Ephraim, Twin Marls, Grimes Graves Marl and West Tofts Marl of Mundford can be equated with the Southerham Marl 1, Caburn Marl, Bridgewick Marl 1 and Lewes Marl of the Southern Province succession; and with the Melton Ross Marl, Deepdale Marl 1, North Ormsby Marl and Ulceby Marl of the Northern Province succession (cf. Mortimore and Wood, 1986, figs 2.3, 2.6). Correlation of the marl seams below the Mount Ephraim Marl (e.g. Pilgrims Walk, Denton Lodge), with named marl seams elsewhere is more controversial. The Northern Province stratigraphy, rather than that of the Transitional Province applies in north Norfolk (e.g. see Hunstanton

Cliffs GCR site report, this volume).

Lewes Nodular Chalk Formation

In the Transitional Province, the Lewes Nodular Chalk Formation with its nodular beds and/or coarse, gritty chalks can be traced through the Chiltern Hills into southern East Anglia. Within the region are the type localities for both the Chalk Rock and the Top Rock. The development of both the Chalk Rock and the Top Rock varies to such an extent that the Lewes Nodular Chalk Formation is, in places, only a few metres thick and in others expands up to several tens of metres.

Chalk Rock Member

The Chalk Rock is a complex of hardgrounds and condensed successions that varies stratigraphically from place to place. Its type locality is in the Marlborough Downs at Ogbourne Maizey, Wiltshire [SU 180 716] on the southern margin of the Transitional Province. Here the Chalk Rock comprises three groups of named hardgrounds, the so-called Bottom, Middle and Top suites (Bromley and Gale, 1982, fig. 3; (Figure 4.4); (Figure 3.41), Chapter 3). The pebble bed associated with the terminal hardground of the top suite, named the 'Hitch Wood Hardground' after a locality in Hertfordshire, yields the so-called '*reussianum* fauna' of well-preserved phosphatized and glauconitized moulds of originally aragonite-shelled molluscs (notably ammonites and gastropods) for which the Chalk Rock is justifiably famous. The remaining hardgrounds are virtually devoid of fossils in this type of preservation. At the type locality, the two lower hardground suites are separated by a conspicuous grey marl seam, the Fognam Marl, which is named after the type locality at Fognam Quarry. At its maximum development, the Chalk Rock Member represents, in a condensed form, the whole of the lower Lewes Nodular Chalk Formation and possibly part of the topmost New Pit Chalk Formation (i.e. a large part of the *Terebratulina lata* Zone (Middle and basal Upper Turonian) and the lower part of the overlying *Sternotaxis plana* Zone (Upper Turonian), see Mortimore, 1983; Gale, 1996).

Traced westwards, the bottom and middle hardground suites coalesce, occluding the Fognam Marl. On the other side of the Vale of Pewsey, at the western termination of Salisbury Plain, the top and middle suites also progressively coalesce and, at its extreme development on the Cley Hill outlier near Warminster [ST 839 447], the entire Chalk Rock condenses to a complex unit of chalkstones less than 1 m thick (Bromley and Gale, 1982, fig. 12; Gale, 1996, fig. 6).

To the east, in the direction of the Chiltern Hills, the bottom suite disappears, and the Chalk Rock comes to be represented only by the two higher suites, these being underlain in most localities by a marl seam that is generally inferred to be the Fognam Marl. Extreme condensation of the middle and top suites is found in the area around Henley, producing a unit, less than 1 m thick, of closely spaced hardgrounds that was termed by Hill (1886) the 'Henley Rock'. This type of development is seen in the nearby Aston Rowant Cutting GCR site.

Traced laterally into the Chiltern Hills, the middle suite of hardgrounds also disappears, and the Chalk Rock is eventually represented only by the top suite (i.e. the Hitch Wood Hardground and the subjacent chalkstone) underlain by several widely spaced marl seams, for example at Kensworth Chalk Pit, and the Hill End Pit, [TL 197 240]. This type of development of the Chalk Rock is known as the 'Hitch Wood facies' (Hopson *et al.,* 1996). In north Hertfordshire, apparently under structural control, the complex phosphatized and glauconitized Hitch Wood Hardground, and its associated pebble bed, weakens and divides into two closely-spaced mineralized, fossiliferous hardgrounds; a glauconitized (green) hardground, followed by a phosphatized (brown) hardground. This development is termed the 'Reed facies', after the Reed Chalk Pit RIGS site [TL 359 371], where it is best seen (Bromley and Gale, 1982, fig. 13; Gale, 1996, fig. 7; Hopson *et al.,* 1996, fig. 17).

The Chalk Rock in the southern part of East Anglia is represented only by one or more closely spaced beds of patchily indurated nodular chalk containing small-sized elements of the characteristic *reussianum* fauna (Hewitt, 1924, 1935). The underlying giant grey flints (0.2–0.4 m thick) of the Grimes Graves and other flint mines in the vicinity of Brandon, constituting the so-called 'Brandon Flint Series' (Skertchly, 1879; Hewitt, 1935), and long exploited first for tools and latterly for gun-flints, were used by the British Geological Survey (Wood and Bristow in Bristow, 1990, fig. 8) to map the base of the traditional Upper Chalk. These flints are transitional in morphology between the large, black, irregularly shaped nodular flints associated with the Bridgewick Marls of the Southern Province (the 'Basal Complex') and the group of giant, predominantly tabular, grey flints (Ravendale, Triple Tabular and Ludborough) at the base of the Burnham Chalk Formation of the Northern Province (Mortimore and Wood, 1986, figs 2.3, 2.6; Wood, 1992; (Figure 5.4), Chapter 5).

Swaffham railway cutting exposed a historically important section ranging from the higher part of the New Pit Chalk Formation to the upper Lewes Nodular Chalk Formation. The now extensively degraded, and partly backfilled, railway cuttings west of Swaffham [TF 799 094]–[TF 804 094], exposed key sections in the *T. lata, S. plana* and *M. cortestudinarium* zones, in ascending order, from west to east. There are no published sections of the cuttings, but descriptions by Rowe (in manuscript) refer to thick, semi-continuous tabular flints of Northern Province type and also to paramoudras. The characteristic Northern Province echinoid genus, *Infulaster,* is relatively common here in the Turonian strata. The easternmost cutting yielded rich faunas of Upper Turonian and, particularly, Lower Coniacian inoceramid bivalves, including specimens figured by Woods (1912), for example the zonal index fossil *Cremnoceramus crassus inconstans* (Woods) ((Figure 2.18), Chapter 2) and of *C. waltersdorfenis waltersdorfensis* (Andert) ((Figure 2.19), Chapter 2). The adjacent quarry, which presumably exposed a slightly higher Coniacian section, was the source of a mixed assemblage of southern and northern species of the echinoid *Micraster.*

Understanding of the relationship between the basinal chalk successions and the highly condensed successions (Bromley and Gale, 1982; Mortimore, 1983a; Mortimore and Pomerol, 1987; Gale, 1996) comprising the various developments of the Chalk Rock remains one of the major unsolved problems of English Chalk stratigraphy. The solution to this problem depends on successfully tracing the marl seams of the basinal successions, as they progressively disappear, via the transitional nodular chalk facies, into the condensed hardground facies of the platforms and structural highs. For example, the Lewes Marl is occluded throughout much of the North Downs and Chiltern Hills but is present in boreholes in the Thames, through Essex and through much of East Anglia.

Top Rock

In much of the Transitional Province the Chalk Rock forms the base of the Lewes Nodular Chalk Formation and is overlain by coarse-grained flinty chalks that can be assigned to the upper Lewes Nodular Chalk Formation. Beginning in the southern Chiltern Hills, condensation of the Navigation, Cliffe, Hope Gap and Beeding hardgrounds of the Southern Province forms the strongly glauconitized Top Rock hardground. In the northern Chiltern Hills and in Hertfordshire, the interval from the top of the Chalk Rock up to the top of the Top Rock is extremely condensed (< 3 m) and contains several glauconitized hardgrounds and nodular chalks, the Kensworth Nodular Chalk Member (Hopson *et al.,* 1996). The Top Rock of the Transitional Province, therefore, includes the greater part of the (Lower Coniacian) *Micraster cortestudinarium* Zone. The dominant hardground is overlain by glauconitized fossils including sponges in pebble preservation and internal moulds of echinoids, such as *Micraster* and *Echinocorys.*

The Top Rock is well exposed in the Aston Rowant Cutting and Kensworth Chalk Pit (see GCR site reports, this volume). The most northerly proved occurrence of the Top Rock is in the shafts near Mundford, Norfolk (Ward *et al.,* 1968), and it has been proved in road cuttings and trial pits as far east as Bury St Edmunds (Wood and Bristow, 1990). Some of the latter were remarkably fossiliferous: they yielded the same terebratulid brachiopods and Lower Coniacian inoceramid bivalves as the Top Rock at Kensworth Chalk Pit and Redbournbury Quarry, Hertfordshire [TL 123 103] ((Figure 4.1), and p. 347), together with a diverse assemblage of sponges, corals, the rhynchonellid brachiopod *Cretirhynchia subplicata* (Mantell), echinoids and elements of a fauna of *reussianum* type, including moulds of small gastropods and bivalves. The sponges and the echinoids (*Echinocorys gravesi* (Desor), *Micraster cortestudinarium* (Goldfuss)) are heavily glauconitized, and tend to be concentrated on the terminal hardground, whereas the inoceramid bivalves, which include *Cremnoceramus* ex gr. *waltersdorfensis* (Andert), are variably phosphatized (for details see Wood and Bristow, 1990). Farther to the east, in the cored Stowlangtoft Borehole [TL 9475 6882], the Top Rock is represented by several beds of nodular chalk. There is no evidence of Top Rock in the essentially Northern Province-type succession in the Swaffham railway cutting. In the Trunch Borehole, a strongly glauconitized hardground overlain by chalks with the same inoceramid bivalves as occur in the Top Rock elsewhere is inferred (Wood *et al.,* 1994) to represent the Navigation Hardground of the Southern Province; here the extreme condensation represented by the Top Rock is not developed.

Overlying the Top Rock are rather coarse-grained, flinty and partly nodular chalks that can be assigned satisfactorily to the upper part of the Lewes Nodular Chalk Formation. The lithological change at this level to highly flinty chalks is particularly conspicuous. However, the highest part of the interval up to the correlative of the Shoreham Marls at the base of the Seaford Chalk Formation, although gritty, is not as nodular as its Southern Province correlative but it does contain the conspicuous Beachy Head Zoophycos Beds.

Seaford Chalk and Newhaven Chalk formations

Over much of the region, the sub-Palaeogene surface lies at a relatively high level in the Seaford Chalk Formation. For an apparently homogeneous soft, white chalk unit, the Seaford Chalk Formation is extraordinarily variable in the Transitional Province. In the vicinity of Newbury, higher chalks stratigraphically equivalent to the Newhaven Chalk Formation of the Southern Province are preserved beneath the Palaeogene sediments. In the same area, and near Maidenhead, deep channels cut into the Seaford Chalk, and presumably initiated under structural control, are filled by non-flinty phosphatic chalk. There are several conspicuous features including the presence locally of well-developed hardgrounds (e.g. Clandon Hardground) and the development of phosphatic chalks and slump folds.

Clandon Hardground

In an area stretching from the North Downs westward to the Berkshire Downs, a significant hardground is locally developed over structural highs at the boundary between the *Micraster coranguinum* Zone and the overlying crinoid zones. This strongly mineralized hardground, which is the indurated lateral equivalent of the Barrois' Sponge Bed of the Thanet Coast, forms the floor of the Chislehurst chalk caves in south London, and takes its name of Clandon Hardground (Robinson, 1986) from the West Clandon Quarry [TQ 038 508], east of Guildford. The same hardground is inferred to correlate with the Whitway Rock, described by Hawkins (1918) from the area south of Newbury, and it is also found below the phosphatic chalks (see below) north of Newbury, and at South Lodge Pit, Taplow; near Maidenhead (see GCR site report, this volume).

Phosphatic chalks in the Newhaven Chalk Formation

In the Newhaven Chalk Formation of the Transitional Province (Upper Santonian–Lower Campanian crinoid zones to *Offaster pilula* Zone inclusive) several different lithologies are found. One lithology found in the east around Sudbury and Ipswich is a very strange, homogeneous, poorly flinty, creamy soft chalk. None of the usual marker beds are present and there may be evidence of severe truncation by channels (F. Wright, pers. comm.). In the Berkshire Downs (Boxford Chalk Pit and Winterbourne Chalk Pit GCR sites), and Chiltern Hills (South Lodge Pit GCR site), are highly condensed successions, only a few metres thick, of brown, flintless, highly fossiliferous chalks rich in pelletal phosphate. These phosphatic chalks are of only very limited areal extent, and they typically rest on a lithified erosion surface or on a glauconitized and/or phosphatized hardground. They have been compared with similar phosphatic chalks in northern France. On the northern edge of the Province on the Norfolk coast the Newhaven Chalk is represented by chalks with marl seams (Wells Quarry) which may correlate to both the Southern and Northern provinces.

The 'High Chalk' of East Anglia

Above the Top Rock in the Transitional Province, particularly in East Anglia, there are only discontinuous inland exposures of the overlying interval up to the Upper Campanian strata. There were formerly numerous small pits and quarries throughout East Anglia (see Peake and Hancock, 1961, 1970; Wood, 1988 for review and comprehensive references).

It is probable that at least the Seaford Chalk Formation will be mapped through this region in the future (but see comments above). The biostratigraphical equivalent of the Seaford Chalk, the *M. coranguinum* Zone, is known in several places. The basal beds of the *coranguinum* Zone are exposed in the partly filled Titchwell Parish Pit [TF 762 433]: here flinty chalk with marl seams (equivalent to the Belle Tout Beds of the Southern Province), has yielded the basal Middle Coniacian inoceramid bivalve zonal index fossil, *Volviceramus koeneni* (Müller). This species was also identified in the Trunch Borehole (Wood *et al.,* 1994). A chalk pit (T, 895 776) south of Thetford, exposing chalk higher in the *coranguinum* Zone (upper part of the Belle Tout Beds and base of the overlying Cuckmere Beds), contains some of the most prolific Middle Coniacian inoceramid bivalve assemblages to be found anywhere in Britain. In addition to *Platyceramus mantelli* and *Volviceramus* spp., the assemblage includes undescribed forms that may be conspecific with coeval taxa described from North America. An important section of the top of the *coranguinum* Zone and, questionably, the base of the overlying *Uintacrinus socialis* Zone, is exposed east of Bury St Edmunds, at Stowlangtoft Quarry (11 9475 6882) (Wood and Bristow, 1990, pp. 27–8, fig. 10). The Stowlangtoft Borehole, sunk in the floor of this pit, cored 211 m of Chalk down to the base of the Cambridge Greensand (Bristow, 1990).

Large, sparsely fossiliferous sections in almost flintless, very soft chalk inferred to span the boundary between the *Uintacrinus socialis* Zone and overlying *Marsupites testudinarius* Zone are exposed in Sudbury beneath the Palaeocene Thanet Beds (Pattison *et al.,* 1993). Parts of the Lower Campanian succession (*Offaster pilula* and basal *Gonioteuthis quadrata* zones) were reported to be formerly exposed in large quarries in and adjacent to the Gipping valley, north of Ipswich (Jukes-Browne, 1904; Boswell, 1913; Brydone, 1932a,b; Markham, 1967) but with the exception of Great Blakenham [TM 112 499] these have been back-filled. There are no detailed published sections of any of these quarries, and this part of the succession consequently remains poorly understood.

A key section of chalk with marl seams (Newhaven Chalk Formation), through the higher part of the *O. pilula* Zone and the basal part of the *quadrata* Zone is exposed in the abandoned quarry at Wells [TF 928 429]. It yields the zonal index fossil *Offaster pilula* and, in the higher beds, common specimens of *Echinocorys* and *Gonioteuthis quadrata.* The section is also important because it includes an unnamed marl seam that was also found in the Trunch Borehole. This marl seam has previously been correlated on macrofaunal grounds (Wood *et al.,* 1994) with the vulcanogenic Old Nore Marl of the Southern Province and the M1 marl of the northern German standard succession at Lagerdorf (Schonfeld and Schulz, 1996). However, the microfaunal evidence (Swiecicki, 1980) suggests that this interpretation may be incorrect, and that the marl seam may perhaps correlate with a stratigraphically higher marl close to the top of the *pilula* Zone.

The *quadrata* Zone succession is very poorly exposed. The only complete succession is in the Trunch Borehole and this cannot readily be correlated with that in the south. Two closely spaced, weakly phosphatized hardgrounds at the top of the zone were inferred (Wood *et al.,* 1994) to reflect the same tectonic event (Peine) that is expressed, in southern England, by the Downend Hardgrounds at the Downend Chalk Pit GCR site (Mortimore and Pomerol, 1997; Mortimore *et al.,* 1998).

The Upper Campanian Chalk (traditional *Belemnitella mucronata* Zone) has been extensively worked in and around the city of Norwich in numerous pits and shallow mines. The early collectors of fossils recognized that these exposures yielded a rich, prolific and superbly preserved fauna that was distinctly different from that of the remainder of the English Chalk, and comparable with that of the Chalk of Meudon near Paris. This composite succession came to be known as the 'Norwich Chalk' (see (Figure 4.5)). Most of these sections are now backfilled, but there are discontinuous exposures of parts of the succession in the cliffs and foreshore between Weybourne Hope and Cromer.

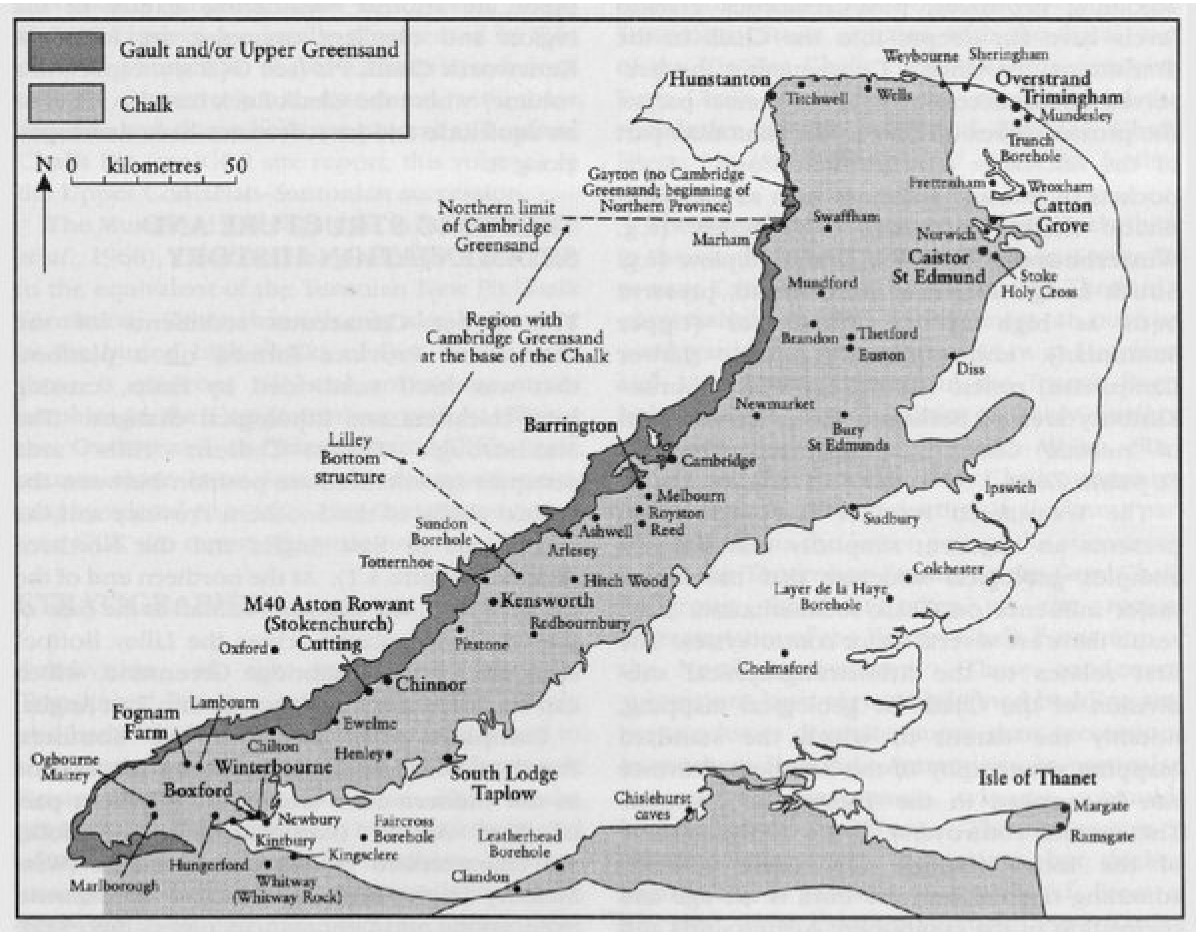
Peake and Hancock (1961, 1970) divided the Norwich Chalk into several loosely delimited faunal units based largely on macrofossil collections and field observations made by Rowe (in manuscript) and a series of key papers by Brydone (1922, 1930, 1938). These were, in ascending order: Basal *mucronata* Chalk, Eaton Chalk, Weybourne Chalk, Catton Sponge Bed, Beeston Chalk and Paramoudra Chalk. This nomenclature was subsequently modified by Wood (1988) who, recognizing that the stratotype Eaton Chalk included the basal beds of the Weybourne Chalk, combined the Basal *mucronata* Chalk and Eaton Chalk to form the pre Weybourne Chalk; and divided the Weybourne Chalk into three faunal belts and the Paramoudra Chalk into two. Johansen and Surlyk (1990) gave formal lithostratigraphical member status to the units from the Eaton Chalk upwards. The two 'Norwich Chalk' GCR sites (Caistor St Edmund Chalk Pit and Catton Grove Chalk Pit) provide a partial composite section through the highest part of the Weybourne Chalk and part of the Beeston Chalk Formation.

The onshore Maastrichtian Chalk (traditional *Belemnella lanceolata* Zone *sensu lato*) is exposed only in cliff and foreshore sections cut through isolated glacio-tectonic deformed erratic masses in the Anglian Till on the Norfolk coast Overstrand to Trimingham Cliffs GCR site. It is present *in situ* beneath the glacial deposits in the Trunch Borehole (Wood *et al.,* 1994), and it can be traced in the subcrop as far south as Wroxham (Whittlesea, 1991) and the valley of the Yare, east of Norwich (Arthurton *et al.,* 1994). The stratigraphically highest successions in the glacial erratics collectively constitute the informally named 'Trimingham Chalk' of earlier workers, and represent the youngest Chalk preserved onshore in England.

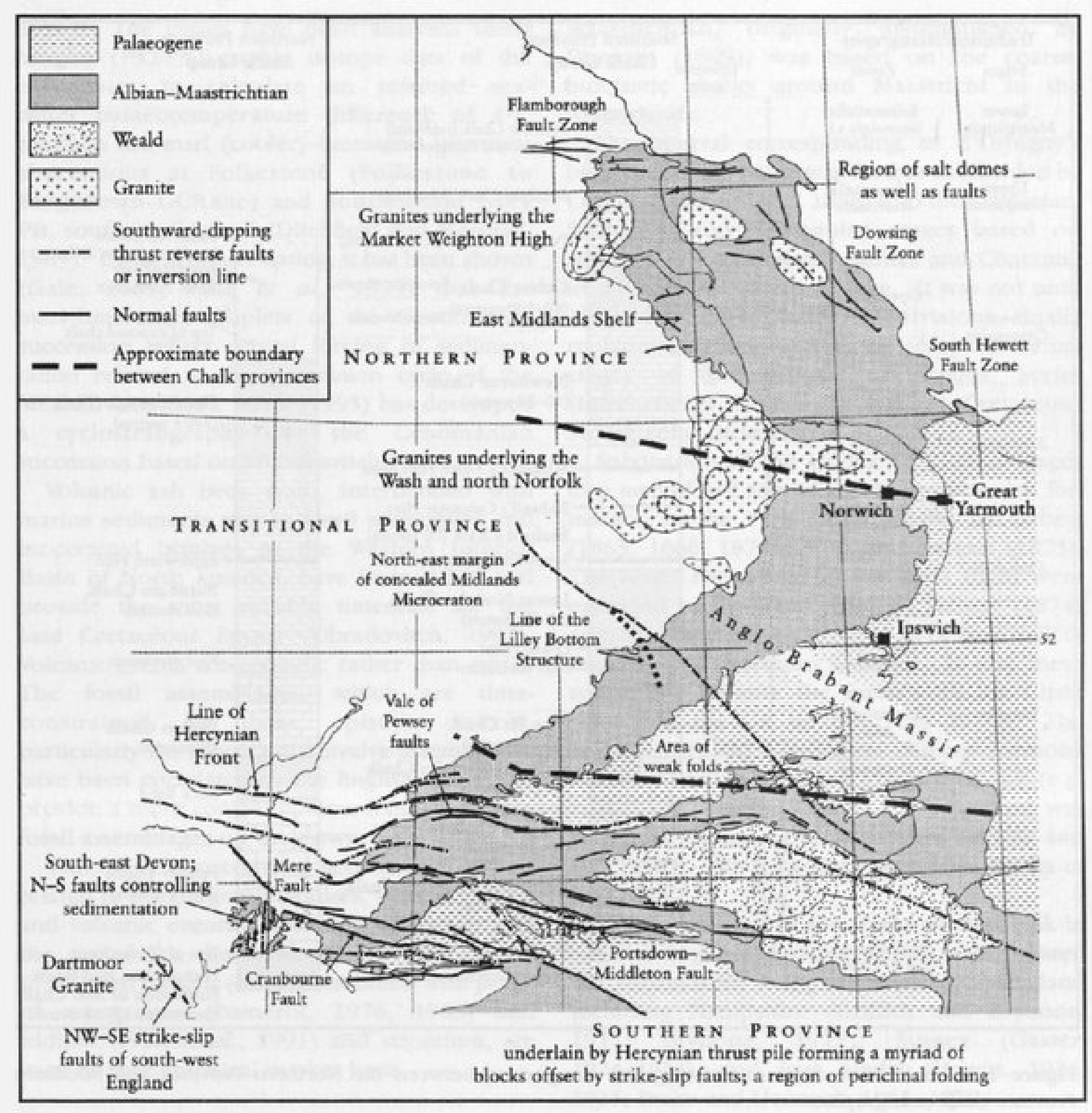
As in the case of the 'Norwich Chalk', the early workers appreciated the distinct nature of the Trimingham fauna, recognizing that many of the fossils had been described from the glacio-tectonic masses exposed in the cliffs of the island of Rügen in the Baltic. They inferred that the Trimingham Chalk lay above the Norwich Chalk. Belemnites are very common in the former, and extensive collections were made by Brydone. Jeletzky (1951) realized that these belemnites belonged not to the Upper Campanian zonal index fossil *Belemnitella mucronata,* as previously thought, but to the diagnostic Maastrichtian genus *Belemnella,* including forms related to the then standard European zonal index fossil *B. lanceolata.* He thereby broadly confirmed Brydone's own ideas (1900, 1906), based largely on bryozoa and serpulids, regarding the similarity between the Trimingham and the Lower Maastrichtian Rügen faunas.

Brydone (1906) subdivided the Maastrichtian succession into, in ascending order, the *Porosphaera* Beds; the Sponge Beds; the White Chalk without *Ostrea lunata;* the White Chalk with *Ostrea lunata;* and the Grey Beds. Wood (1967) split off the lower part of the *Porosphaera* Beds exposed in the glacio-tectonic masses at Overstrand as the *pre-Porosphaera* Beds. Johansen and Surlyk (1990), placed the entire succession in the glacio-tectonic slices that lay stratigraphically beneath the Sponge Beds, irrespective of whether or not it included Upper Campanian strata, into a formally defined 'Sidestrand Chalk Member'. In addition, they introduced the 'Trimingham Sponge Beds Member' for the Sponge Beds; the 'Little Marl Point Chalk Member' for the bipartite White Beds; and the 'Beacon Hill Grey Chalk Member' for the Grey Beds.

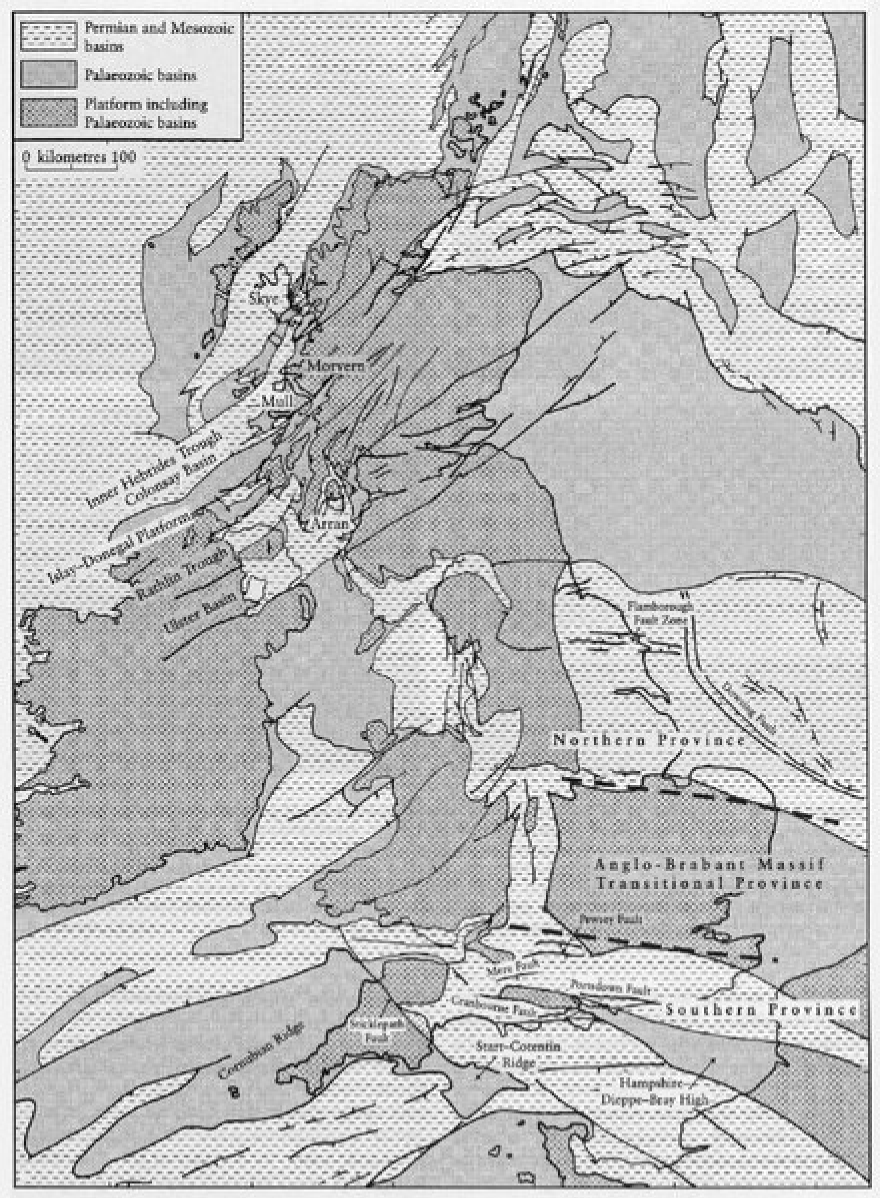
References



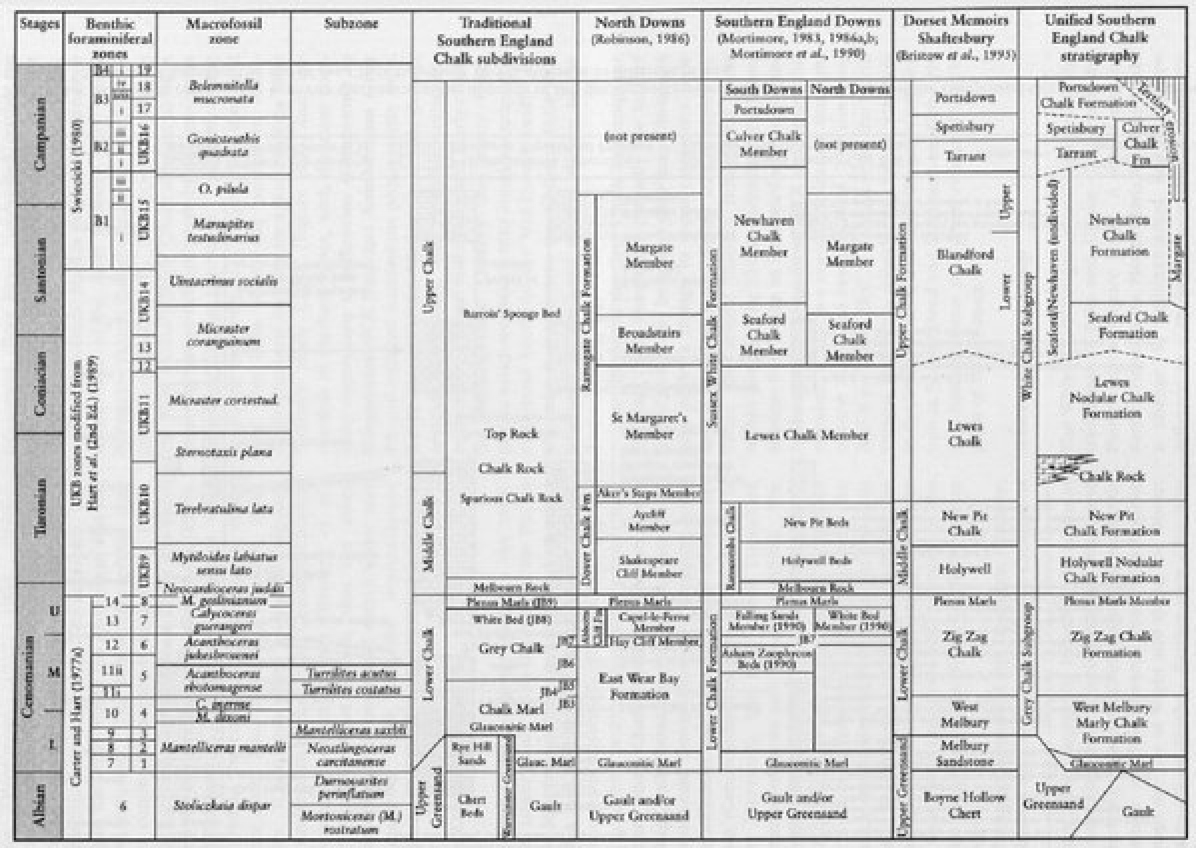
(Figure 4.1) Location of GCR sites (bold type), and other sites also mentioned in the text, in the Transitional Chalk Province of England.



(Figure 1.15) Simplified structural map showing the main features affecting sedimentation of the Upper Cretaceous deposits of England.



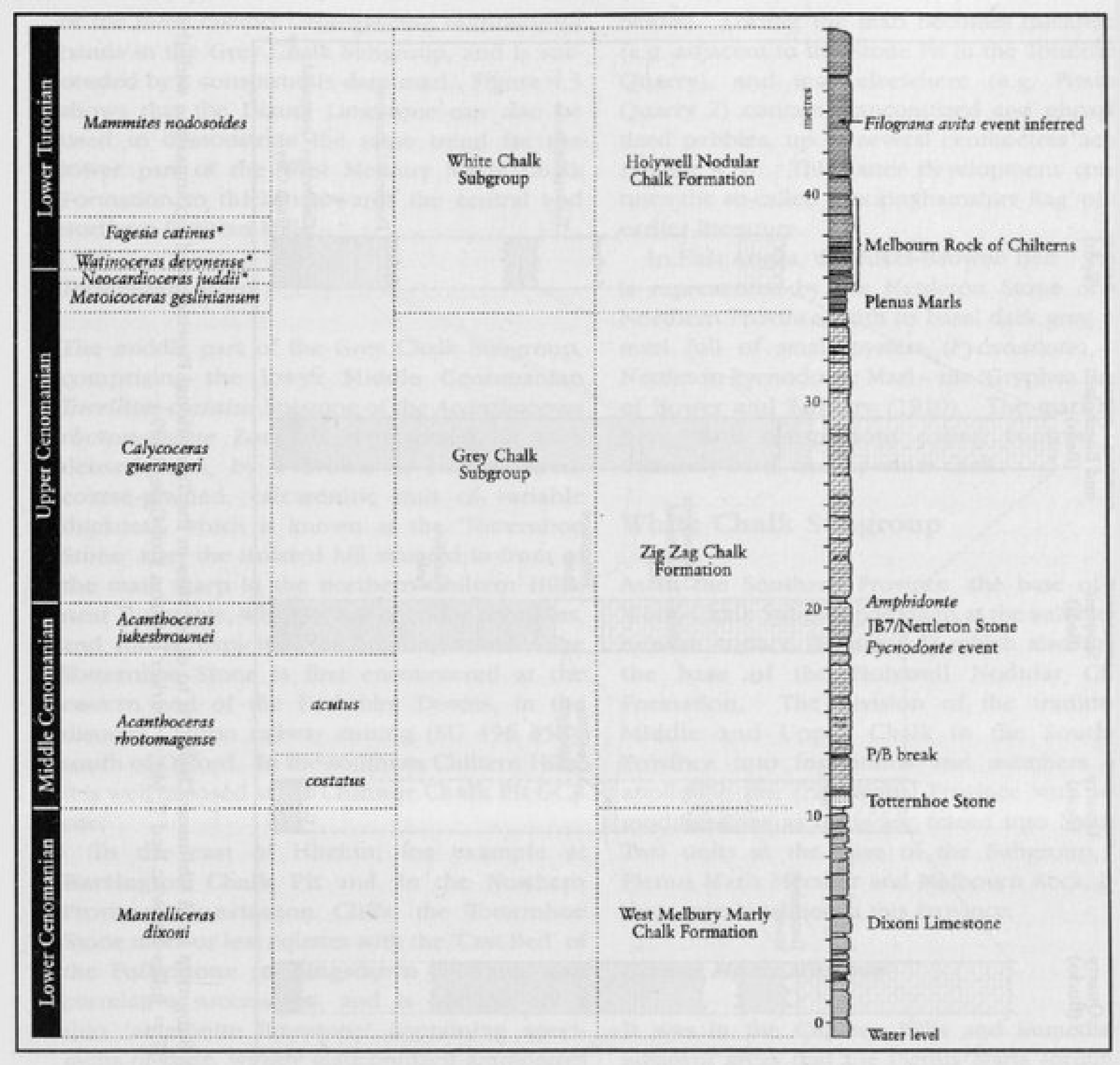
(Figure 1.8) Broad structural features affecting sedimentation of the Upper Cretaceous deposits in the British Isles. (Based on British Geological Survey 1:1 000 000 maps of the Geology of the UK, Ireland and Continental Shelf; North and South Sheets.)



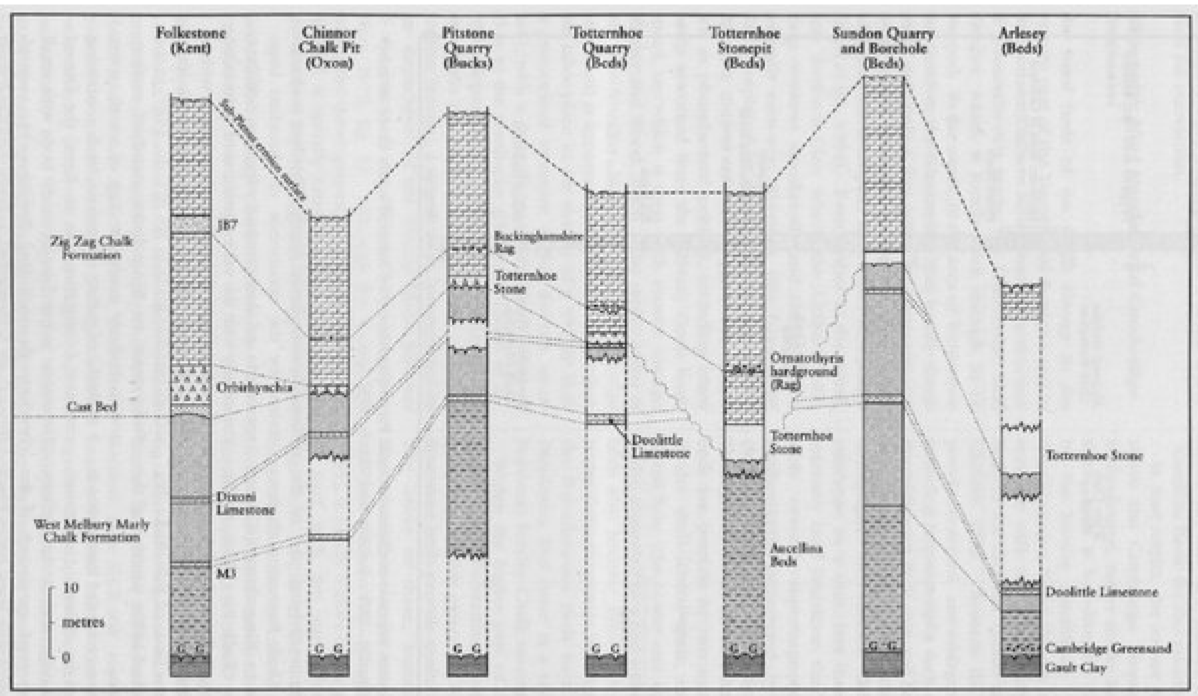
(Figure 3.3) Unified stratigraphy for the Upper Cretaceous successions of the Southern Province. (JB = Jukes-Browne bed numbers.) (Based on Bristow et al., 1997.)

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

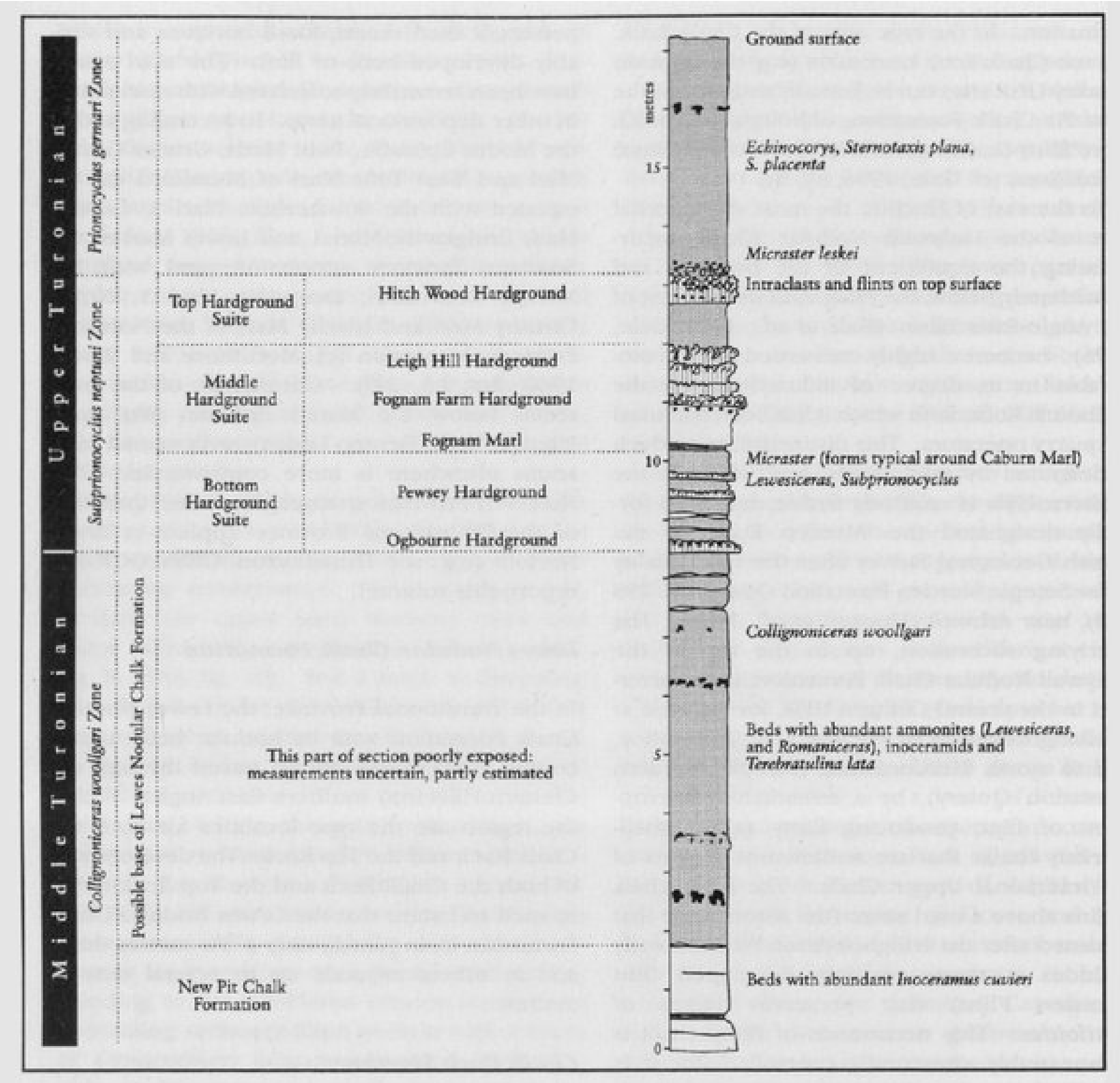
(Figure 5.3) The stratigraphy of the Northern Province Chalk (compare with (Figure 1.5), Chapter 1 and Figures 2.8, 2.9, 2.21, 2.22 and 2.27, Chapter 2).



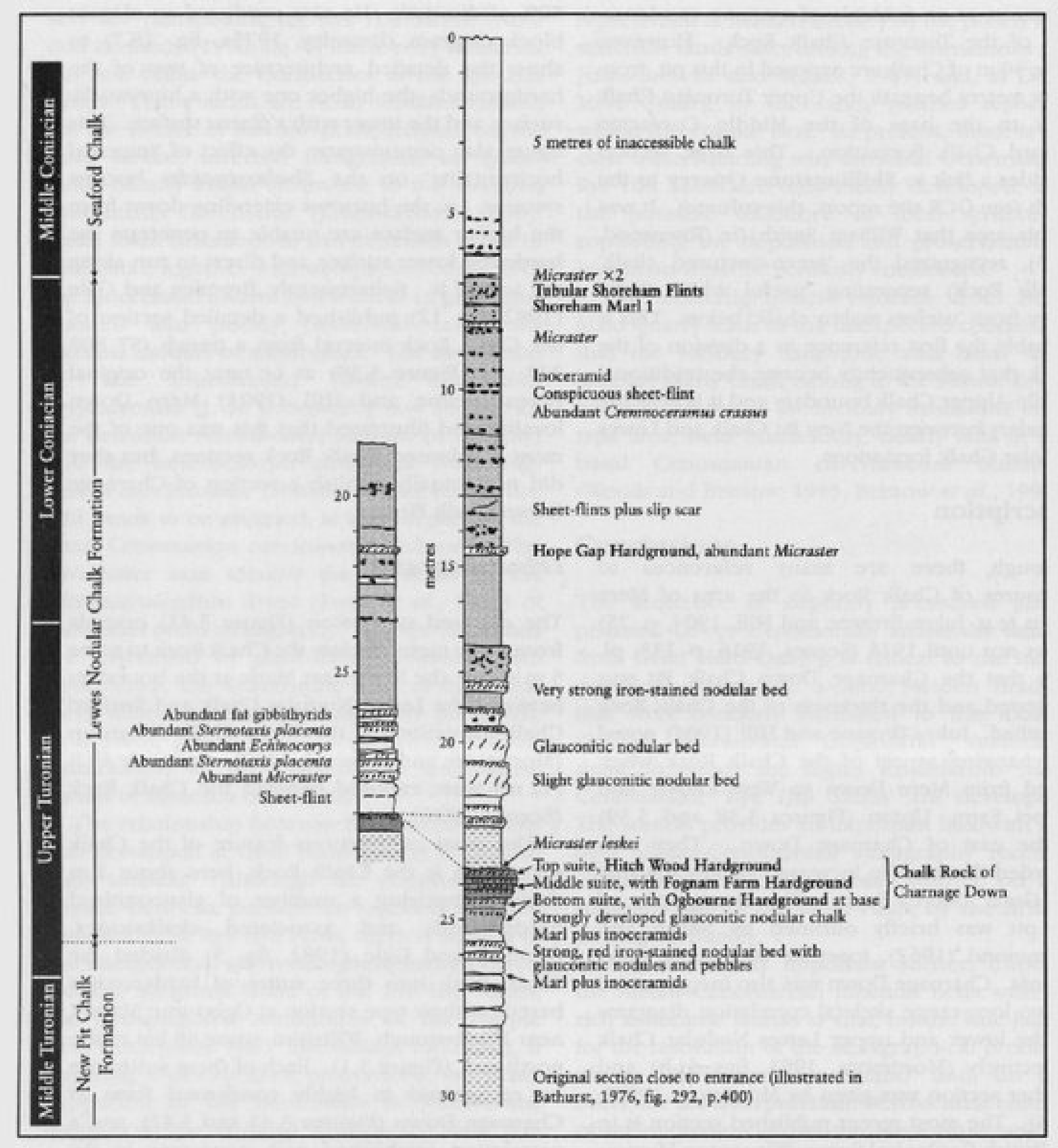
(Figure 4.2) Chalk succession exposed in Chinnor Chalk Pit, Oxfordshire (* = inferred zones based on other sections and associated fossils). (After Sumbler and Woods, 1992.)



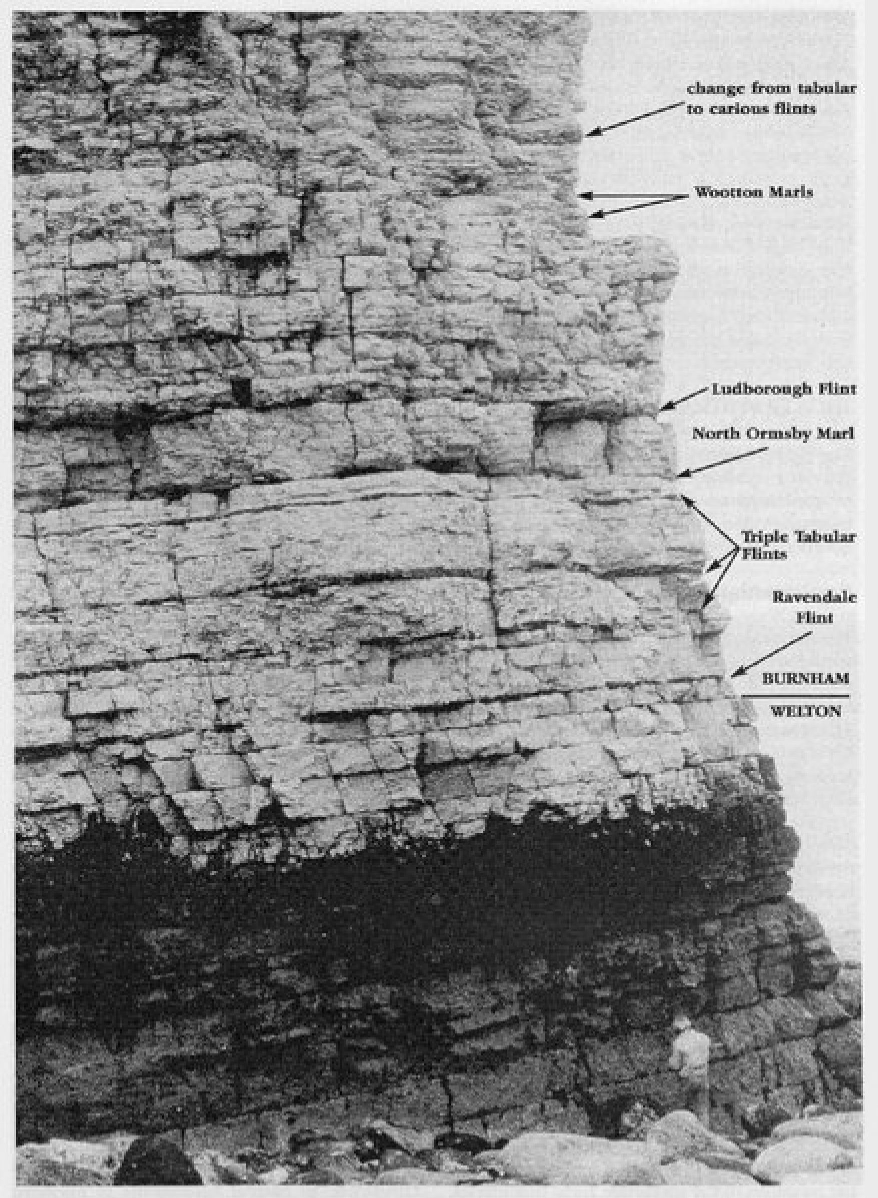
(Figure 4.3) Correlation of the Cenomanian Grey Chalk Subgroup from Chinnor Chalk Pit to other sites in the Transitional Province and a comparison with the Folkestone standard section. (G = Glauconitic Marl; JB7 = Jukes-Browne Bed 7; M3 = marker horizon 3 of Gale, 1989.)



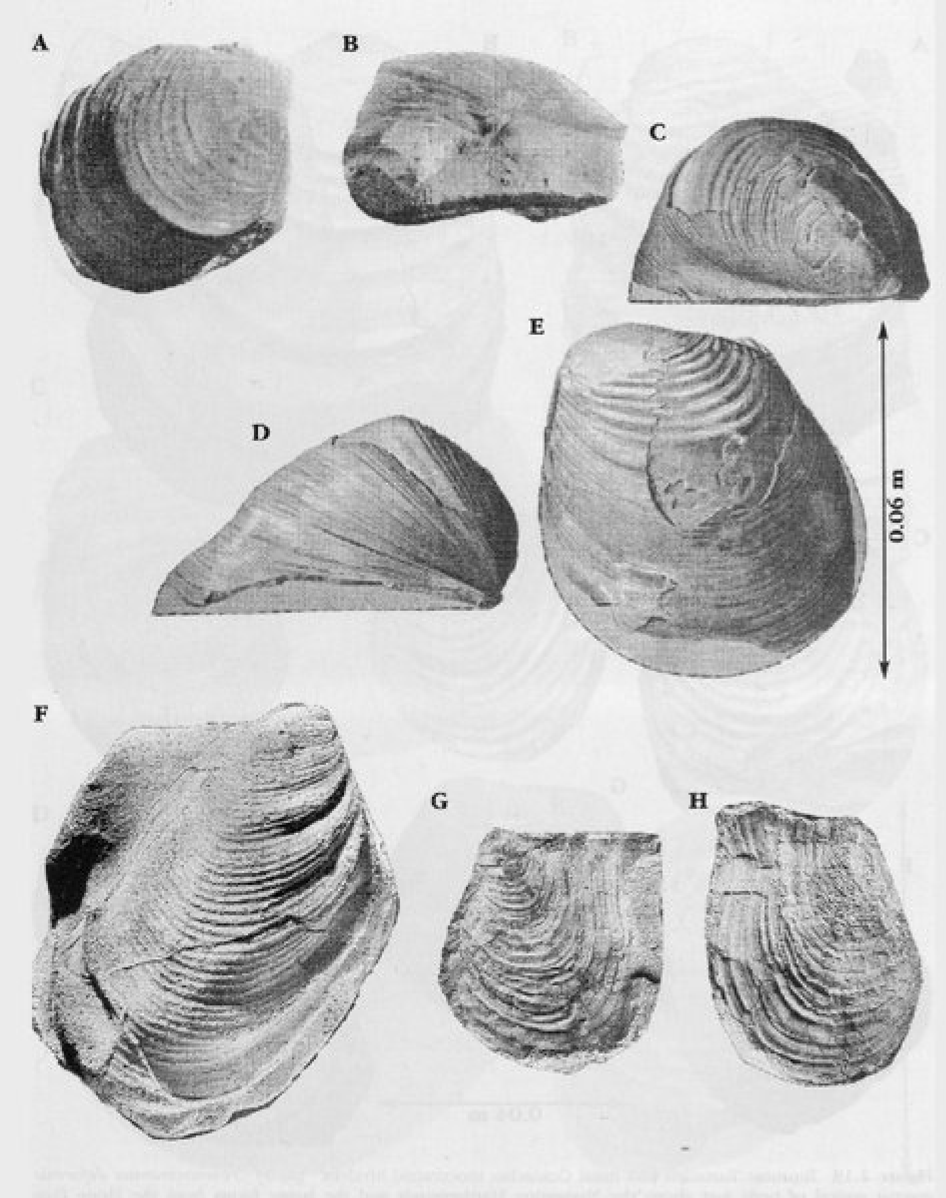
(Figure 4.4) The Chalk succession exposed at Fognani Quarry, a key section for Chalk Rock stratigraphy. Compare with Charnage Down Chalk Pit ((Figure 3.41), Chapter 3) and Kensworth Chalk Pit (Figure 4.21).



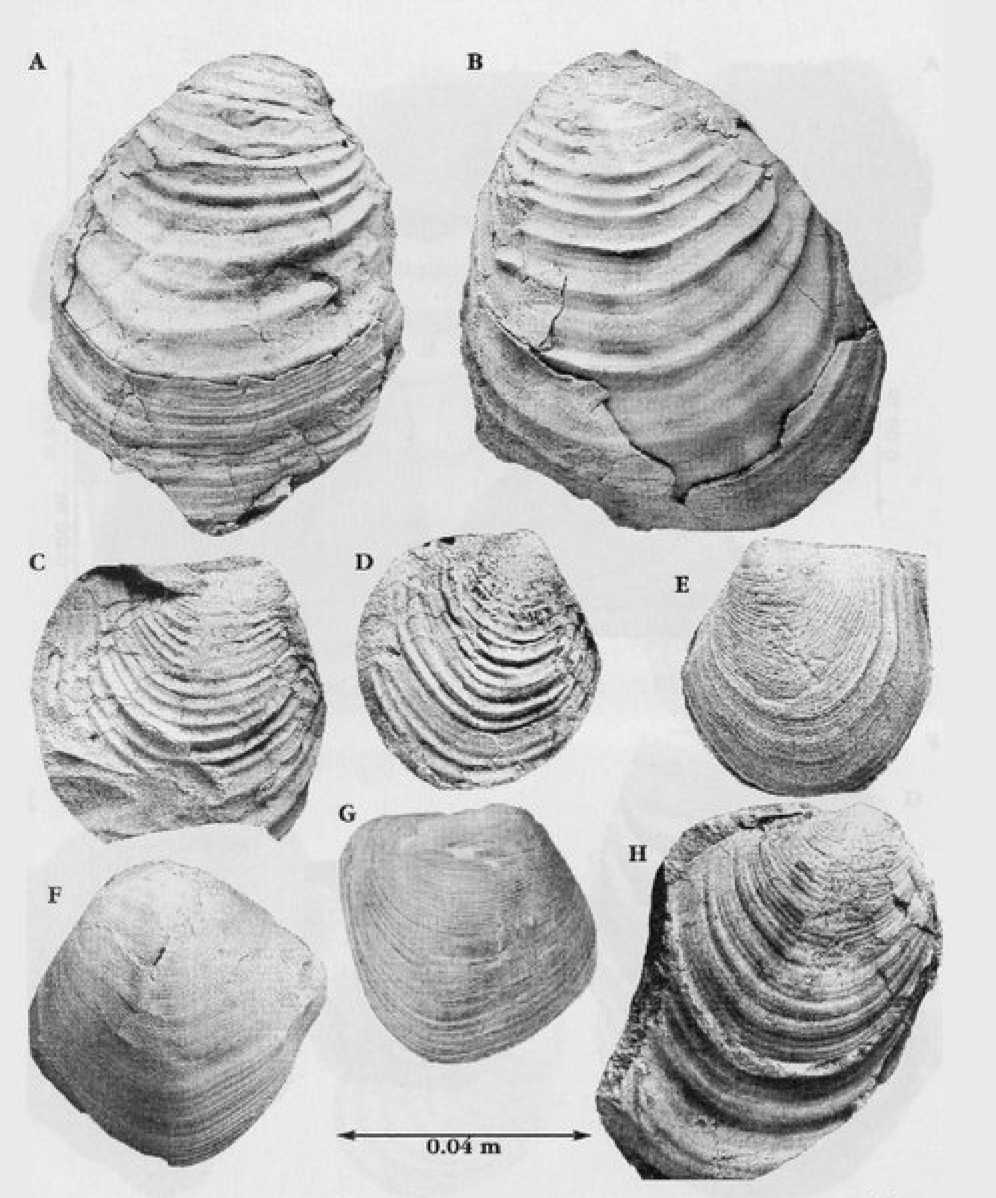
(Figure 3.41) The succession of Chalk at Charnage Down Chalk Pit, Mere, Wiltshire, showing lateral variation along section.



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



(Figure 2.18) Upper Turonian and Lower Coniacian inoceramid bivalves. (A–E) Cremnoceramus crassus inconstans; (A, B) the lectotype, the original of Inoceramus sp., Mantell, 1822 (from Woods, 1912, text-fig. 42); (C–E) from Woods, 1912, text-fig. 43. (F) Inoceramus lusatiae, holotype: typical of the Navigation Hardgrounds (from Walaszczyk and Wood, 1999b, pl. 2, fig. 4). (G, H) Mytiloides herbichi, probably typical of the beds around the Cuilfail Zoophycos (from Walaszczyk and Wood, 1999b, p1. 1, fig. 5). Scale bar applies to all specimens.



(Figure 2.19) Topmost Turonian and basal Coniacian inoceramid bivalves. (A, B) Cremnoceramus deformis erectus typical of beds just above the Navigation Hardgrounds and the larger forms from the Hope Gap Hardground (from Walaszczyk and Wood, 1999b, pl. 7, figs 7, 8). (C, D) Cremnoceramus deformis erectus, typical of Navigation Marls, (from Walaszczyk and Wood, 1999b, p1. 7, figs 1, 2). (E-G) Cremnoceramus waltersdorfensis waltersdorfensi; (E) typical of the Southern Province (from Walaszczyk and Wood, 1999b, pl. 15, fig. 2); (F) typical of beds below the Navigation hardgrounds (from Walaszczyk and Wood, 1999b, pl. 17, fig. 3); (G) typical of beds between Navigation and Cliffe hardgrounds in the Southern Province (from Woods, 1912, pl. 52, fig. 1). (H) Cremnoceramus waltersdorfensis hannovrerzsis typical of beds between Cliffe and Hope Gap hardgrounds (from Walaszczyk and Wood, 1999b, pl. 11, fig. 2). Scale bar applies to all specimens.

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

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