British Upper Cretaceous Stratigraphy

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Chapter 3

Southern Province, England

INTRODUCTION

Upper Cretaceous rocks in the Southern Province occur as small outliers in south-west England and form the rolling Chalk downland and cliffs of Wessex and the Weald regions (Figure 3.1). The lowest Upper Cretaceous deposits in south-west England are shallow-water, richly fossiliferous glauconitic greensands, and highly condensed, fossiliferous limestones. In contrast, to the east, these pass into deeper water chalks. The chalks thicken eastwards into Sussex, and continue across the Channel as far as the eastern side of the Paris Basin. The whole of this region is known as the 'Anglo-Paris Basin'. The Chalk successions in the southern English part of this basin belong to the Southern Province (Figure 1.16, Chapter 1).

Movement of deep-seated faults has uplifted and folded the younger cover rocks, including the Chalk. Folding results in the Chalk dipping north in the North Downs into the London Basin and south in the South Downs into the Channel. There is a general structural plunge to the west, taking the Chalk under the Hampshire Basin. Chalk is brought to the surface again by a number of smaller, fault-controlled anticlines on the Isle of Wight and along the south Dorset coast. One of these folds brings high Chalk to the surface on Portsdown, where unusual sedimentary structures are exposed at **Downend Chalk Pit.** Another of these folds is the pronounced topographical feature corresponding to the Dean Hill Anticline, south-east of Salisbury, with Pepperbox Hill Quarry towards its western end (Figure 3.1). The general plunge westwards of the folds into Wessex preserves progressively younger chalks in that direction. The youngest chalks are exposed in the Isle of Wight and in Studland Bay, Dorset, where they extend into the Upper Campanian. In contrast, the most complete earliest Upper Cretaceous deposits are found in the east at Lewes, Beachy Head and Folkestone.

Along the south coast, through the Isle of Wight and **Handfast Point to Ballard Point**, to **White Nothe** in Dorset, the Chalk forms a long, narrow rib of downland, dipping steeply north (Figure 3.2). The cliff sections along this rib are spectacular, producing the Needles and Old Harry Rocks, and these sections are crucial to understanding how the basin evolved during the Late Cretaceous Epoch.

In central Dorset there are open expanses of downland in younger Campanian Chalk, which here forms several small but conspicuous escarpments related to the lithostratigraphy. These escarpments are readily identifiable on satellite imagery and can be traced through Hampshire into Sussex (Bristow *et al.*, 1997). Interpreting the stratigraphy of these mapped topographical features, geophysical borehole logs and general geology, relies on a number of very small chalk pits, and extrapolation to the better coastal sections or quarries to the south and east (i.e. the GCR sites).

Two major fault-controlled re-entrants into the western Chalk escarpment in Wiltshire, the Vale of Wardour and Vale of Pewsey, bound Salisbury Plain to the south and north respectively. There are few exposures of Chalk in this area and **Shillingstone Quarry** in north Dorset, on the south side of the Vale of Wardour, and Beggars Knoll, Westbury, on the south side of the Vale of Pewsey provide critical sections in the Cenomanian, Turonian and Coniacian stages. A number of small pits around Salisbury expose the higher Chalk, including an excellent section in the Lower Campanian Newhaven Chalk Formation at **West Harnham Chalk Pit**. On the north side of the Vale of Pewsey, controlled by the Mere Fault, is found the highly condensed Turonian–Coniacian succession at **Charnage Down Chalk Pit**.

In the south-west region, chalks and Chalk-equivalent 'greensands' and limestones are found as small erosional remnants on the dissected Upper Greensand plateau that extends westwards from Lyme Regis in Dorset and Chard in Somerset to Salcombe and Wilmington in east Devon (see Figure 3.19, p. 109). Farther west, capping the Haldon Hills in south Devon, the Upper Greensand is locally overlain by Cenomanian 'greensands' (the Cullum Sands-with-Cherts (Hamblin and Wood, 1976)) and by Palaeocene and Eocene flint-rich gravels (Tower Wood, Buller's Hill and Aller gravels). The characteristically grey flints in these gravels are unusually fossiliferous and contain well-preserved moulds of Turonian to Campanian fossils, notably echinoderms, brachiopods and inoceramid bivalves (Selwood *et al.*, 1984) that indicate the former presence of parts of the Chalk succession that are no longer preserved. Similar faunas are preserved in flint-rich gravels around the edges of the tectonically down-faulted Bovey Basin, and at Orleigh Court, North Devon, on the extension of the Bovey structure (Figure 3.1).

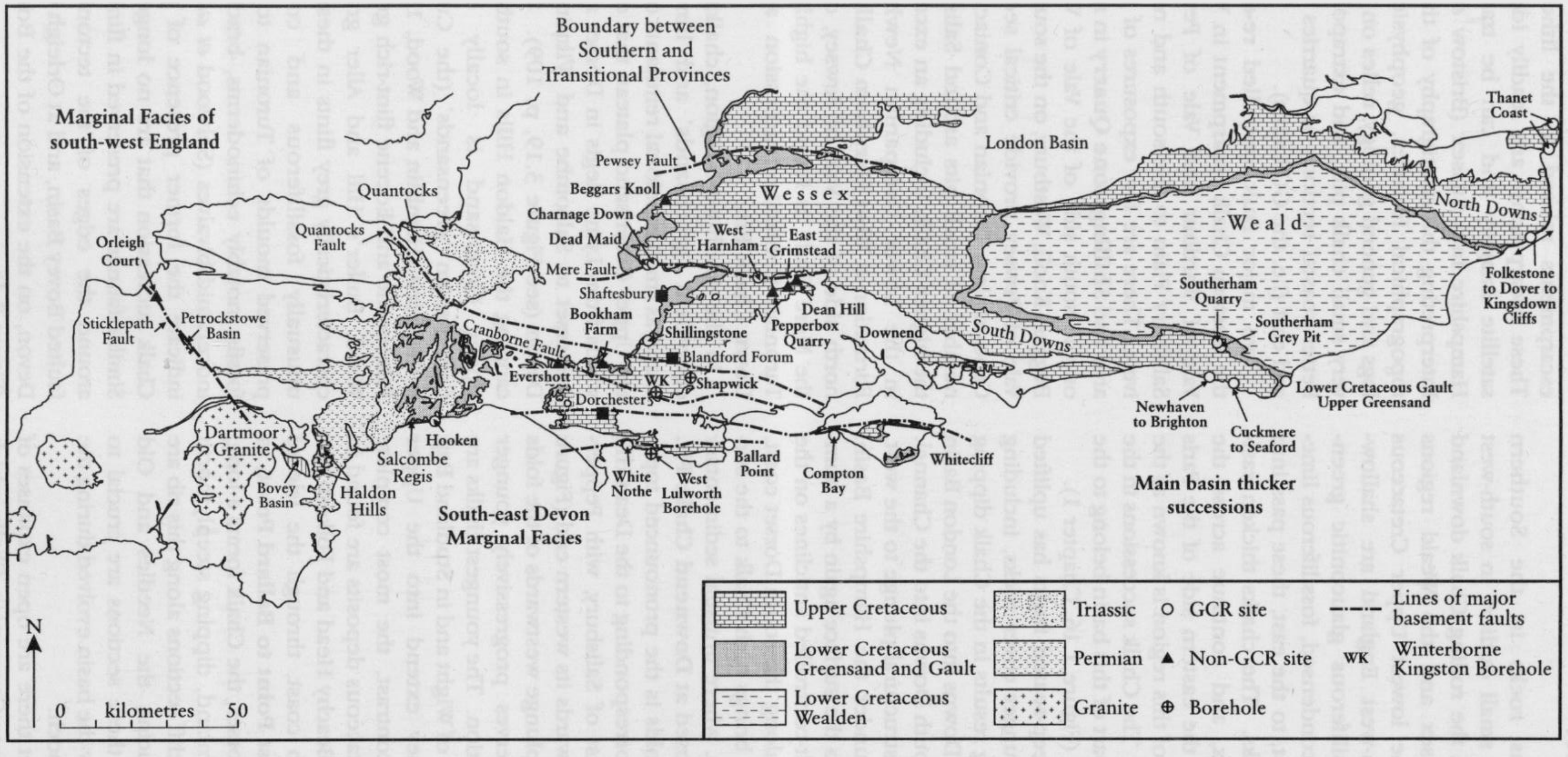


Figure 3.1 Southern Province GCR localities in relation to the Upper Cretaceous outcrop and major tectonic lineaments. For south-east Devon GCR sites, see also Figure 3.19, p. 109.

Figure 3.2 Long narrow rib of the Chalk Downs along the Dorset coast east of Lulworth. (Photo: Cambridge University Collection of Aerial Photography; copyright reserved.)

Preservation of the higher part of the Upper Cretaceous succession is largely dictated by the Laramide phase of tectonism at the end of the Cretaceous Period and in the early part of the Palaeogene Period. Erosion of the Chalk beneath the Palaeogene deposits has cut more deeply in the North Downs, typically to levels high in the *Micraster coranguinum* Zone (Seaford Chalk Formation), but elsewhere only down as far as the top of the *Marsupites testudinarius* Zone (e.g. M25 Leatherhead–Reigate section and the British Geological Survey Fetcham Mill Borehole near Leatherhead (Gray, 1965; Murray, 1986)). In east Kent, the basal beds of the *Offaster pilula* Zone are found in Thanet (Shephard-Thorn, 1994) but they are not preserved in the main mass of the Downs. In the South Downs, the preservation level beneath the Palaeogene surface lies in the basal *Gonioteuthis quadrata* Zone in East Sussex, whereas it lies in the *Belemnitella mucronata* Zone in West Sussex, Hampshire and central Dorset.

TECTONIC STRUCTURE AND SEDIMENTATION HISTORY

The structural line along the Vale of Pewsey forms a natural boundary with the Marlborough Downs–Berkshire Downs–Chiltern Hills region to the north. The significance of this structural boundary is demonstrated by the difficulty of correlating successions across it. To the south and south-west are a series of structural lines, the South Downs Axis (Allen, 1975, 1981; Young and Monkhouse, 1980), the Mid-Dorset Swell (Drummond, 1970) along the Fordingbridge–Cranbourne Fault block, the St Valéry–Bembridge line and the Cotentin line of Smith and Curry (1975). The Cotentin Line was considered by Curry and Smith (1975) to form a boundary between a Western Approaches Basin and basins to the east in the Channel. Other workers have identified sub-basins, such as the 'Channel' Basin (Chadwick, 1986), but these do not readily correspond to the sedimentary pattern during the Late Cretaceous Epoch. In the Southern Province the pattern of Chalk sedimentation closely relates to the fault-controlled fold lineaments (e.g. the Cranbourne–Fordingbridge fault block), and even to the subtleties of individual folds (Mortimore, 1986b; Mortimore and Pomerol, 1987, 1991a, 1997).

The Late Cretaceous sedimentation history reflects both the broad tectonic setting of shelves and basins, and the local effects of growth tectonics on folds and faults. The broad tectonic structure of the Southern Province is subdivided (e.g. Drummond, 1970) into a 'Wessex Shelf', including south-east Devon, Somerset and west Dorset; and a 'Wessex Basin', which continues eastwards into the Weald Basin, forming one large basin system. The old concept of a 'Cenomanian Transgression' (Suess, 1883–1888), as applied to this region, actually refers to the progressive overstep of the Albian Upper Greensand onto pre-Cretaceous rocks westwards in Dorset and Devon. The Greensand rests on the Middle Jurassic strata at Bridport, the Lower Jurassic succession at Lyme Regis, the Triassic System in east Devon, and on Devonian to Permian rocks in south-west Devon (Figure 3.1).

The most westerly Cenomanian deposits in Dorset, between Eggardon and Litton Cheyney, expose about 30 m of typical Grey Chalk Subgroup lithologies (Wilson *et al.*, 1958), whereas their nearest correlative in east Devon consists of less than 1 m of highly condensed nodular limestone. The Upper Cretaceous deposits in the south-west region are themselves cut by north–south-trending faults (Kellaway and Welch, 1948) that were active in

Cenomanian and early Turonian times, resulting in rapid lateral lithological variations in the east Devon successions. This faulted shelf contains a richness and diversity of echinoderm and crustacean faunas (especially crabs) that is unmatched at this stratigraphical level elsewhere in the Southern Province. By the Turonian, the whole of south-west England was probably inundated by the sea, and chalks were deposited throughout the region and beyond.

In contrast to the shelf, the main basin was a complex submarine trough, with its apex in the west in Wiltshire and north Dorset, opening eastwards across the Anglo-Paris Basin (Drummond, 1970; Mortimore, 1979, 1983; Mortimore and Pomerol, 1987). This contrasts with the earlier Mesozoic palaeogeographical model comprising a 'Wessex Trough' and a local 'Wealden' Basin (Whitaker, 1985; Chadwick, 1985, 1986). Within this submarine trough, a relationship between the deep faulting, surface folding and Upper Cretaceous sedimentation has been suggested (Mortimore, 1986b; Mortimore and Pomerol, 1987, 1991b, 1997), including changes in thickness of Chalk strata, and the occurrence of channel scours at particular places and stratigraphical intervals (e.g. the **Southerham Grey Pit** Channel and Strahan's Hardground in the **Southerham Pit**). In addition, the Newhaven Chalk Formation contains a particular fracture style, including faults that are confined to that level and do not continue upwards into the overlying Culver Chalk Formation (e.g. at Castle Hill, part of the **Newhaven to Brighton** GCR site).

The evidence for intra-Chalk tectonic movements, channel scour and slumping events is further supported by the large-scale growth structures and slump folding at **Downend Chalk Pit**, Portsdown, in the Early Campanian and by the slumping seen on Solent marine seismic lines in Late Turonian–Early Campanian times (Mortimore and Pomerol, 1991a, 1997). Evans and Hopson (2000), have provided the first onshore seismic sections showing the scale of channels in the Chalk in Dorset and Hampshire. Big coastal exposures such as **Whitecliff**, Isle of Wight, provide evidence for *episodic* movements closely associated with well-known tectonic lines over which condensed or anomalous sediments recur. Similar evidence is found at **White Nothe**, Dorset. As a result of deep intra-Chalk channel scour in particular, the stratigraphy preserved at any one locality can be very variable. The presence of large-scale channels helps explain many stratigraphical anomalies in the province.

STRATIGRAPHY

The stratigraphy of the Southern Province contains two distinct developments, one relating to the Chalk Group of the main basin (Figure 3.3) and the other to the condensed Cenomanian deposits of the south-west marginal shelf of Devon, Somerset and west Dorset (Figure 3.4).

Lithostratigraphy of the Chalk in the Southern Province

Evolution of the lithostratigraphy in the Chalk Group towards the present subdivision into two subgroups and nine mappable formations in the Southern Province (Figure 3.3) has been long and tortuous (Bristow *et al.*, 1997; Rawson *et al.*, 2001).

Many 19th century observers (e.g. Evans, 1870) had recognized that marker beds existed that could be used for local correlation and for recording the distribution of fossils. Whitaker (1872) described a 'Three Inch Flint Band' that he could trace around the coast of Kent. Similarly Bedwell (1874), in addition to Whitaker's flint band, identified two marker flint beds on the **Thanet Coast**. Rowe (1900) coined the names 'Whitaker's 3-inch tabular flint-band', 'Bedwell's columnar band' and the 'Bedwell-line' for these marker beds, but he did not identify them outside the Kent coast sections. Price (1874, 1877) introduced identified horizons such as the 'Cast Bed' in the Lower Chalk, a key marker horizon on top of the Tenuis Limestone (see **Folkestone to Kingsdown** GCR site report, this volume).

Work on a detailed modern lithostratigraphy for the Southern Province really began with the subdivision of the Plenus Marls into eight beds by Jefferies (1962, 1963), who nominated the Merstham Quarry, Surrey, as the stratotype section. This section no longer exists and the Holywell, Eastbourne section, figured by Jefferies (1963) is taken as the replacement stratotype section because of its completeness. A study of the detailed lithostratigraphy for the White Chalk Subgroup (Middle and Upper Chalk) of the province was undertaken in the

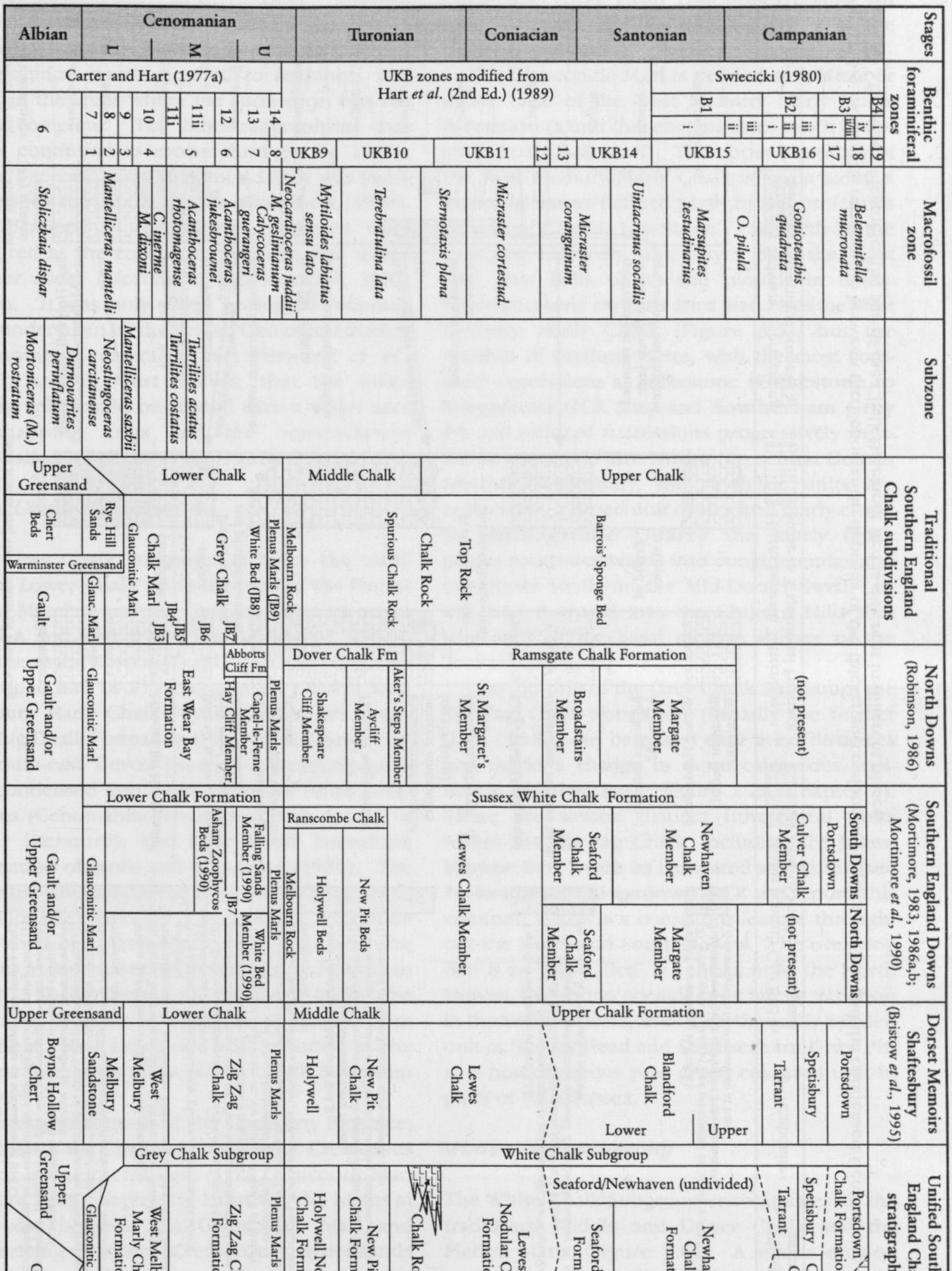


Figure 3.3 Unified stratigraphy for the Upper Cretaceous successions of the Southern Province. (JB = Jukes-Browne bed numbers.) (Based on Bristow *et al.*, 1997.)

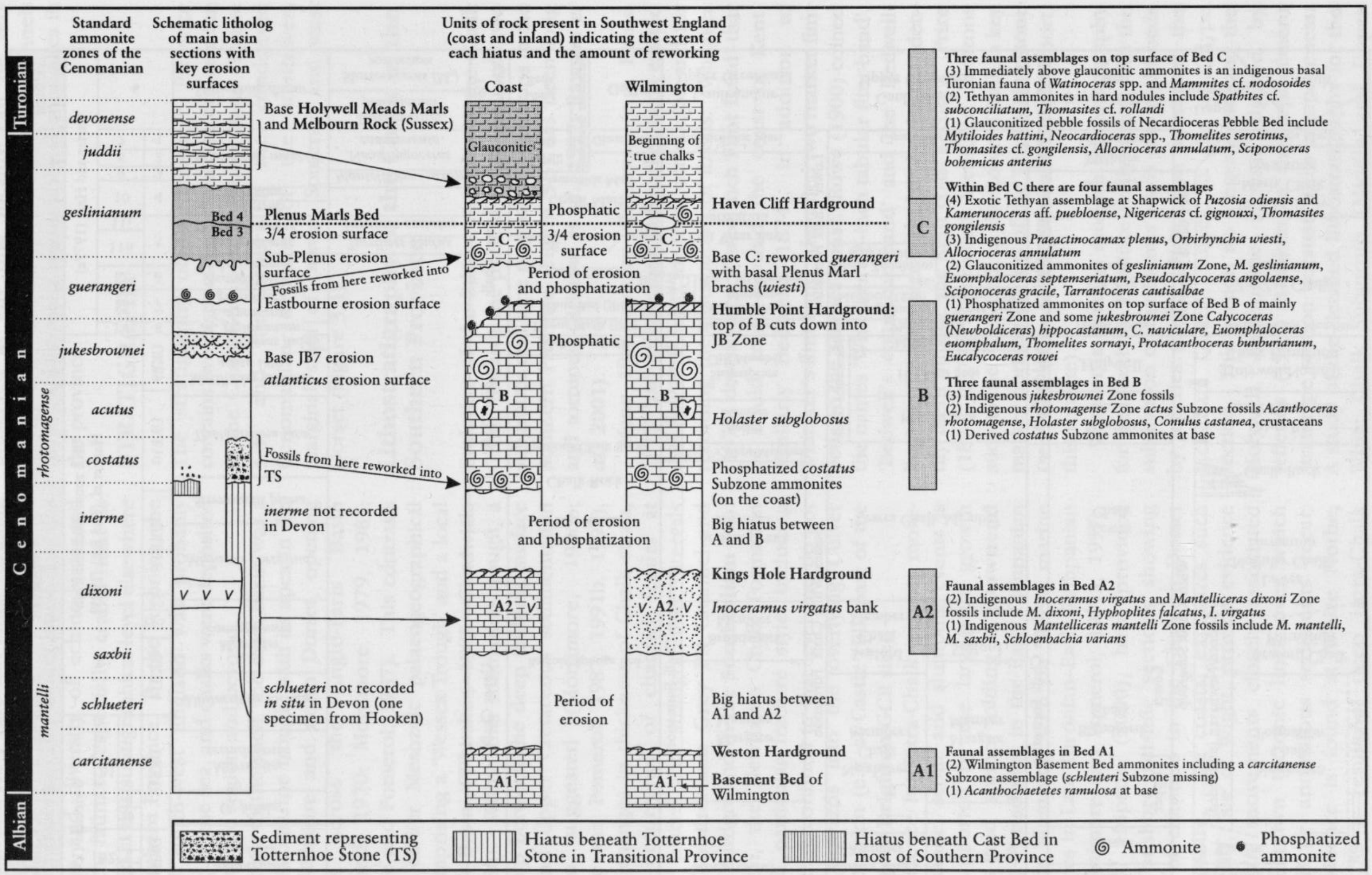


Figure 3.4 Schematic relationship between the Cenomanian deposits of the thicker successions in Sussex and Kent and the condensed Cenomanian Limestone (A, B, C). Because of tectonics the age of the Chalk Basement Bed is different in different places.

1970s (Mortimore, 1977, 1983, 1986b). Sections were nominated as stratotypes for the lithology, boundary markers were identified, and geographical names applied to members and beds in the areas where the succession was the most complete. The lithostratigraphical concepts continued to evolve through the 1980s, when a second, parallel nomenclature was introduced for the North Downs (Robinson, 1986). Modifications to the existing schemes were required as the correlation of units was tested farther afield (Mortimore and Pomerol, 1987, 1996). It was only when geological mapping was undertaken by the British Geological Survey, beginning in central Dorset (Bristow *et al.*, 1995) and in West Sussex, that the lithostratigraphy could be related over a wider area to mapping units and the nomenclature rationalized (Bristow *et al.*, 1997).

Grey Chalk Subgroup

The Grey Chalk Subgroup includes the traditional Lower Chalk up to the base of the Plenus Marls Member and the Cenomanian Limestone (Bed A and Bed B only) in south-east Devon. For the main Wessex–Weald basin the subgroup is divided into two mapping units, a lower West Melbury Marly Chalk Formation and an upper Zig Zag Chalk Formation (Figure 2.8, Chapter 2). In south-east Devon these two mapping units are condensed into a few metres of sandy limestones (Cenomanian Limestone Beds A to C of older literature), the Beer Head Limestone Formation of Jarvis and Woodroof (1984). The topmost division of the Beer Head Limestone, the Pinnacles Member (Cenomanian Limestone Bed C of older literature), correlates with the Plenus Marls–Sussex Melbourn Rock of the main basin. To conform with the main basin, the Pinnacles Member is, therefore, separated from the Beer Head Limestone and included in the lowest formation of the White Chalk Subgroup above.

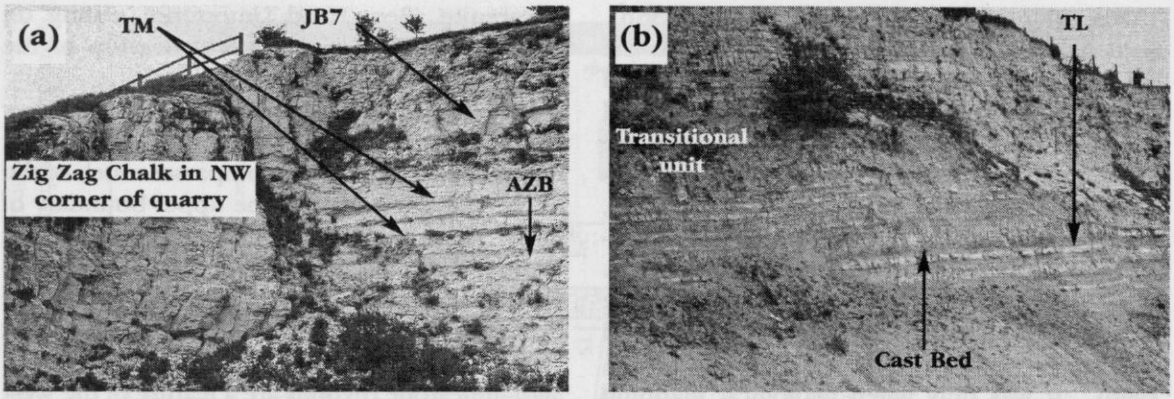
Throughout most of the Southern Province, the base of the Chalk, and the Upper Cretaceous Series, is taken at the base of the Glaucontic Marl (Figure 2.2b, Chapter 2). However, the hiatus at the base between the Glauconitic Marl and underlying Lower Cretaceous greensands increases south-westwards from Eastbourne through the Isle of Wight and along the Dorset coast to **White Nothe**. Farther west (**Hooken Cliff**), the hiatus is marked by a bioclastic calcarenite (Beer Head Limestone) resting on the Small Cove Hardground at the top of the Upper Greensand.

The Glauconitic Marl is defined as a Member at the base of the West Melbury Marly Chalk Formation (a unit that encompasses much of the traditional Chalk Marl). The upper boundary of the West Melbury Marly Chalk is taken along a mapping feature defined partly by a conspicuous limestone ('Tenuis Limestone') and partly by the overlying markedly silty, clayey bed, the 'Cast Bed' that balls up in the plough in fields. Marl–limestone rhythms are a feature of the West Melbury Marly Chalk (Figure 3.5), but the number of rhythms varies, with the most complete successions at Folkestone (**Folkestone to Kingsdown** GCR Site) and **Southerham Grey Pit** and reduced successions progressively westwards towards **White Nothe**. In central Dorset, around Shaftesbury, the rhythmic units are replaced by a broad unit of silty and marly chalk. At **Shillingstone Quarry** the marly chalk passes south-westwards into conglomerates and calcareous sands on the Mid-Dorset Swell. As this unit is traced into the Chiltern Hills it is truncated by the basal erosion surface of the Totternhoe Stone.

The top unit of the Grey Chalk Subgroup, the Zig Zag Chalk Formation (broadly the former Grey Chalk), can be traced over great distances and marks a change to more calcareous sediments with less marl (Figure 2.2a, Chapter 2). There are several distinct lithological units within the Zig Zag Chalk, including the Jukes-Browne Bed 7 with its laminated structures (see **Folkestone to Kingsdown** GCR site report, this volume), which is a consistent feature throughout the North and South Downs. The overlying Bed 8 or 'White Bed' is consistent in the North Downs, but shows considerable lateral variation in the South Downs, from a rhythmically bedded unit at Beachy Head and **Southerham Grey Pit**, to a homogeneous pale green coloured unit in parts of West Sussex.

White Chalk Subgroup

The White Chalk Subgroup encompasses all the traditional Middle and Upper Chalk and the Plenus Marls (Figure 3.6). A major erosion surface beneath the Plenus Marls Member marks a change in sedimentation across Europe reflected in a marked colour change from the White Bed beneath to the green hues of the



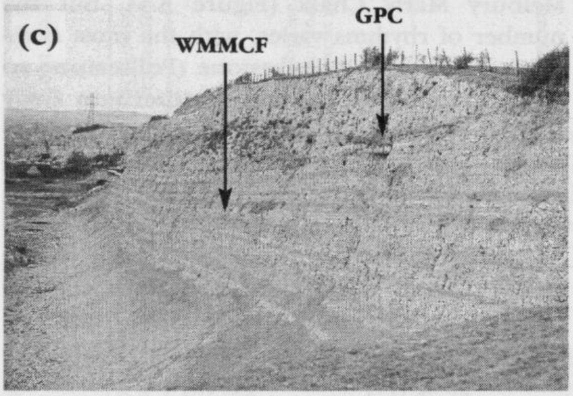


Figure 3.5 Southerham Grey Pit, Lewes, Sussex, showing the transition from West Melbury Marly Chalk rhythms below to Zig Zag Chalk above.

AZB = Asham Zoophycos Beds;
GPC = Grey Pit Channel;
JB7 = Jukes-Browne Bed 7;
TL = Tenuis Limestone forming the mapping base of the Zig Zag Chalk Formation;
TM = Triple Marls and the *Inoceramus atlanticus* event;
WMMCF = West Melbury Marly Chalk Formation.
(Photos: R.N. Mortimore.)

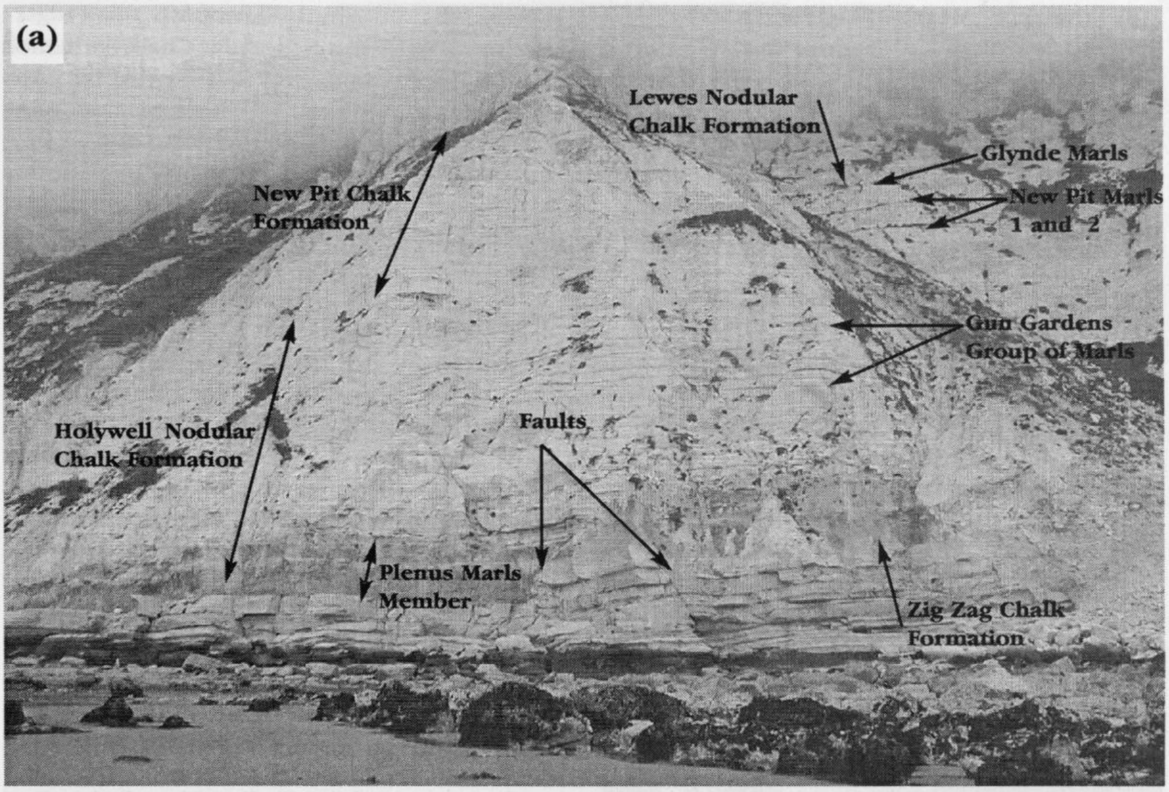
Plenus Marls and overlying nodular beds of the Holywell Nodular Chalk Formation. This sub-Plenus erosion surface is, therefore, taken as the base of the White Chalk Subgroup and the base of the Holywell Nodular Chalk Formation, the lowest mapping unit of the subgroup. The White Chalk Subgroup is marked by the presence of purer chalks and the general entry of flint in formations above the Holywell Nodular Chalk. Seven mapping formations and two mapping members are recognized (Figure 3.3). Numerous marker beds are also recognized (Figures 2.8, 2.9, 2.21, 2.22 and 2.27, Chapter 2).

Holywell Nodular Chalk Formation and New Pit Chalk Formation

The basal unit of the White Chalk Subgroup and the Holywell Nodular Chalk Formation, the Plenus Marls Member, is recognized everywhere except in south-east Devon. The thickness of this unit also varies greatly, being thickest and most complete at Eastbourne (Beachy Head). Above the Plenus Marls, the Holywell Nodular Chalk Formation is gritty and nodular in contrast to the smoother chalks of the New Pit Chalk Formation, which contains numerous marker marl seams (Mortimore and Pomerol, 1996; Bristow *et al*., 1997). These two formations change thickness dramatically across the Southern Province (Mortimore, 1986a; Mortimore and Pomerol, 1987, 1996). The Holywell Nodular Chalk thins onto the southern edge of the Anglo-Brabant Platform at Dover and through the North Downs, and thickens along the south-west margin in Dorset and Devon. In contrast, the overlying New Pit Chalk is thicker in the North Downs and almost completely disappears along the south-west margin in Dorset (Mupe Bay) and in parts of south-east Devon.

Marker Beds in the Holywell Nodular and New Pit Chalk formations: Numerous lithostratigraphical marker beds are recognized in the Holywell Nodular Chalk and New Pit Chalk formations (Mortimore, 1983, 1986a, 1990; Mortimore and Pomerol, 1990, 1991b, 1996). These include:

(i) beds numbered 1 to 8 in the Plenus Marls Member (Jefferies, 1963);



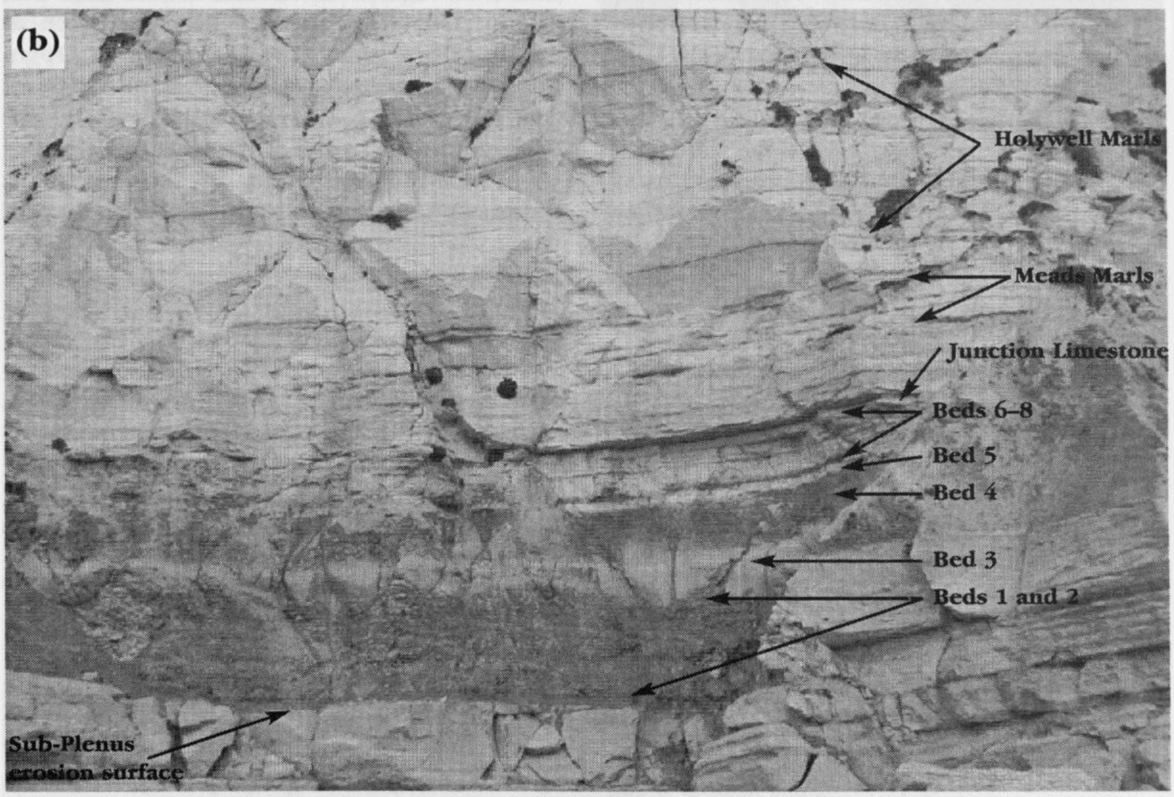


Figure 3.6 (a, b) Grey Chalk Subgroup and White Chalk Subgroup boundary at the base of the Plenus Marls at Beachy Head, Sussex. (Beds 1–8 are those of Jefferies, 1963.) (Photos: R.N. Mortimore.)

(ii) the six Meads Marls that span the Cenomanian–Turonian boundary, and;
(iii) the Holywell Marl and Gun Gardens Marl within the Holywell Nodular Chalk Formation.

The Gun Gardens Main Marl is the boundary between the Holywell Nodular Chalk and New Pit Chalk formations, and has a very distinctive finger-flint horizon above, the Glyndebourne Flints. This marl and overlying flint band has been recognized in Kent at the Halling Pit; at **Southerham Pit**, Lewes; on the Dorset coast; and at Beggars Knoll Quarry, Westbury, Wiltshire. Lithological marker beds in the New Pit Chalk include the Malling Street Marls, the New Pit Marls and the Glynde Marls. These marls have been recognized throughout the main basin axis, in the shelf successions of south-east Devon and have been correlated north through the London Basin and parts of the adjoining Transitional Province (Mortimore, 1986a,b, 1987; Mortimore and Wood, 1986; Mortimore and Pomerol, 1987, 1996). These marl seams, and those in the lower Lewes Nodular Chalk above, are critical markers in determining the amount of condensation and erosion involved in the Chalk Rock.

Gale (1996) studied the cyclostratigraphy of the Turonian Chalk, using the newly introduced Lulworth Marl and Robinson's (1986) Round Down Marl as key markers. These are the correlatives of the Gun Gardens Main Marl and Malling Street Marl 2, respectively. Hence these extra names are unnecessary.

The level of entry of persistent flint bands in the Southern Province varies. In West Sussex (Duncton Quarry) through Hampshire (M3 Cuttings, Twyford Down), and in Wiltshire (Beggars Knoll Quarry), flint bands are present in the New Pit Chalk. Flints are progressively more common in south Dorset and south-east Devon, even occurring in the basal Holywell Nodular Chalk of Worbarrow Bay. In contrast, in Kent and East Sussex, flint bands generally enter in the Glynde Beds at the base of the Lewes Nodular Chalk Formation. This pattern of flint distribution probably reflects the basin geometry, with flint entering earlier along the west and south-west margin and on the north-east shelf (Mortimore and Pomerol, 1987).

Lewes Nodular Chalk Formation

The base of the Lewes Nodular Chalk Formation (Mortimore, 1983, 1986a) is defined at the entry of persistent nodular chalk beds, which occurs above the Glynde Marls (Bristow *et al.*, 1997) throughout most of the province including south-east Devon. Caburn Pit, Lewes, and Beachy Head, Eastbourne, are the basal boundary stratotype sections. In the western part of the Southern Province the base of the formation is taken at the base of the 'Spurious Chalk Rock' of Rowe (1908), which has been correlated with the Ogbourne Hardground at the base of the standard Chalk Rock stratigraphy (Bromley and Gale, 1982), as seen at **Charnage Down Chalk Pit**, Mere, Wiltshire. The Spurious Chalk Rock is well developed along the southern margin of the basin at **Compton Bay**, Isle of Wight, Ballard Head (**Handfast Point to Ballard Point** GCR site), Mupe Bay, and **White Nothe**, Dorset. Exactly how the Spurious Chalk Rock relates to the basal Lewes Nodular Chalk of the expanded sections in Sussex and the North Downs is still under discussion.

The Lewes Nodular Chalk is 80 m thick in East Sussex and may be only 20–30 m thick at **Shillingstone Quarry** and **Charnage Down Chalk Pit**, Mere. Mortimore and Pomerol (1996), divided the Lewes Nodular Chalk into lower and upper parts at the Lewes Marl, a key basin-wide and inter-basinal marker bed and a vulcanogenic marl. This marl is associated with the conspicuous Lewes Tubular Flints (Figure 3.9b, p. 96), which are also present even in the condensed sections where the Lewes Marl may be locally occluded (e.g. Dover, Kent, Figure 3.7) or very thin (Chapel Rock, south-east Devon). Within the lower Lewes Nodular Chalk are a number of conspicuous marker marl seams named after localities around Lewes, Sussex. These include, in ascending order, the Southerham, Caburn, Bridgewick and Lewes marls, some of which are derived from decomposed volcanic ash (tuffs, Wray, 1999). Each of these marls is lost in the condensed hardgrounds comprising the Chalk Rock at **Charnage Down Chalk Pit**, Mere and Cley Hill, Warminster, Wiltshire (Bromley and Gale, 1982; Mortimore, 1983). The lower Lewes Nodular Chalk, 40 m thick around Lewes, East Sussex, probably represents the expanded stratigraphy of the Chalk Rock, which is only 1 m thick at Cley Hill.

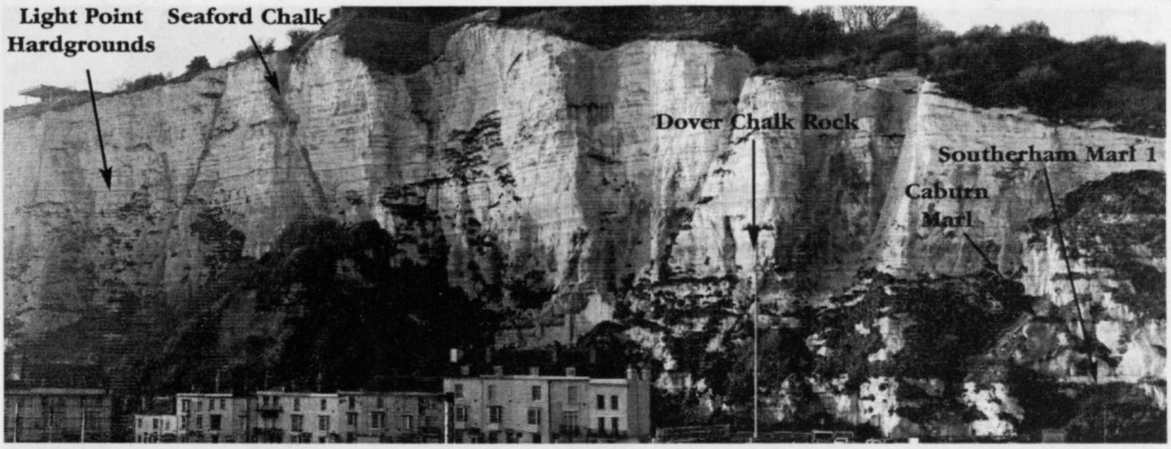


Figure 3.7 Part of the Chalk cliffs at Dover above Athol Terrace exposing the entire Lewes Nodular Chalk Formation and the basal Seaford Chalk Formation. (Photomosaic: R.N. Mortimore.)

Also in the lower Lewes Nodular Chalk is a unit known as the 'Basal Complex', which is particularly clearly seen in the Dover coast sections (Figure 3.8; Jukes-Browne and Hill, 1904; Mortimore and Wood, 1986). This unit comprises a succession of conspicuous flint bands and marl seams named the Bridgewick Flints, Bridgewick Marls and Bopeep Flints, in ascending order (Mortimore, 1986a, 1997). The Basal Complex is traceable through the North Downs, where it was formerly used by the British Geological Survey to map the base to the traditional Upper Chalk. It is a flint maximum in the Upper Turonian of the Transitional Provinces (Mortimore and Wood, 1986), where it corresponds to the horizon of the Brandon Flints at Grimes Graves Flint Mines, Brandon, Norfolk. This same horizon is taken as the mapping base of the Burnham Chalk Formation (Wood and Smith, 1978) in the Northern Province. This horizon can also be identified in south-east Devon (at **Hooken Cliff**; Figures 3.9–3.11).

The upper Lewes Nodular Chalk continues the character of the lower Lewes Nodular Chalk, comprising a number of cyclic packages of hardgrounds and nodular, gritty chalks. One of the best known marker beds is the traditional Top Rock, which equates with the Navigation Hardground (Mortimore, 1983, 1986a; Bailey *et al.*, 1983, 1984). Elsewhere in the Southern Province, the Top Rock may represent either the Cliffe or Hope Gap hardgrounds (e.g. **Charnage Down Chalk Pit**), while in the Transitional Province (e.g. **Aston Rowant Cutting** and **Kensworth Chalk Pit** in the Chiltern Hills) it

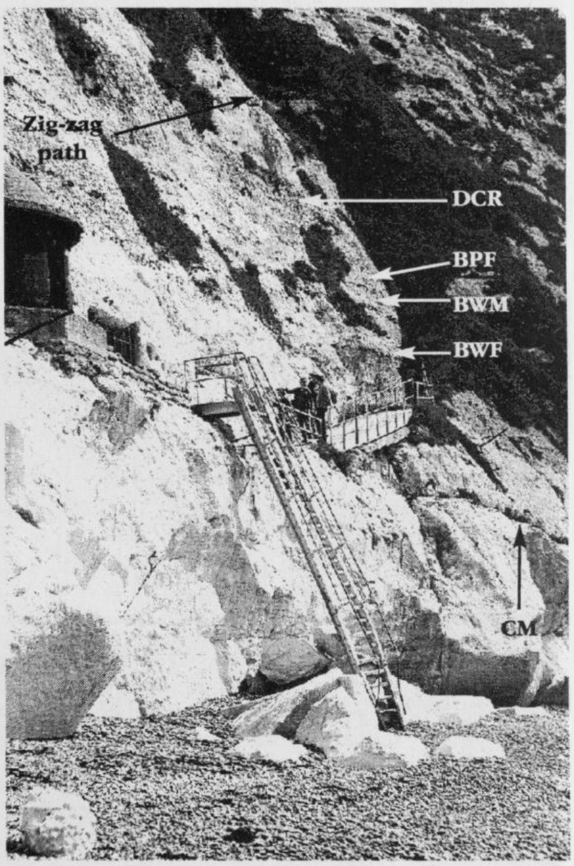


Figure 3.8 The bottom sections of Langdon Stairs, Dover, exposing the 'Basal Complex'.
BWM = Bridgewick Marls;
BWF = Bridgewick Flints;
BPF = Bopeep Flints;
CM = Caburn Marl;
DCR = Dover Chalk Rock.
(Photo: R.N. Mortimore.)

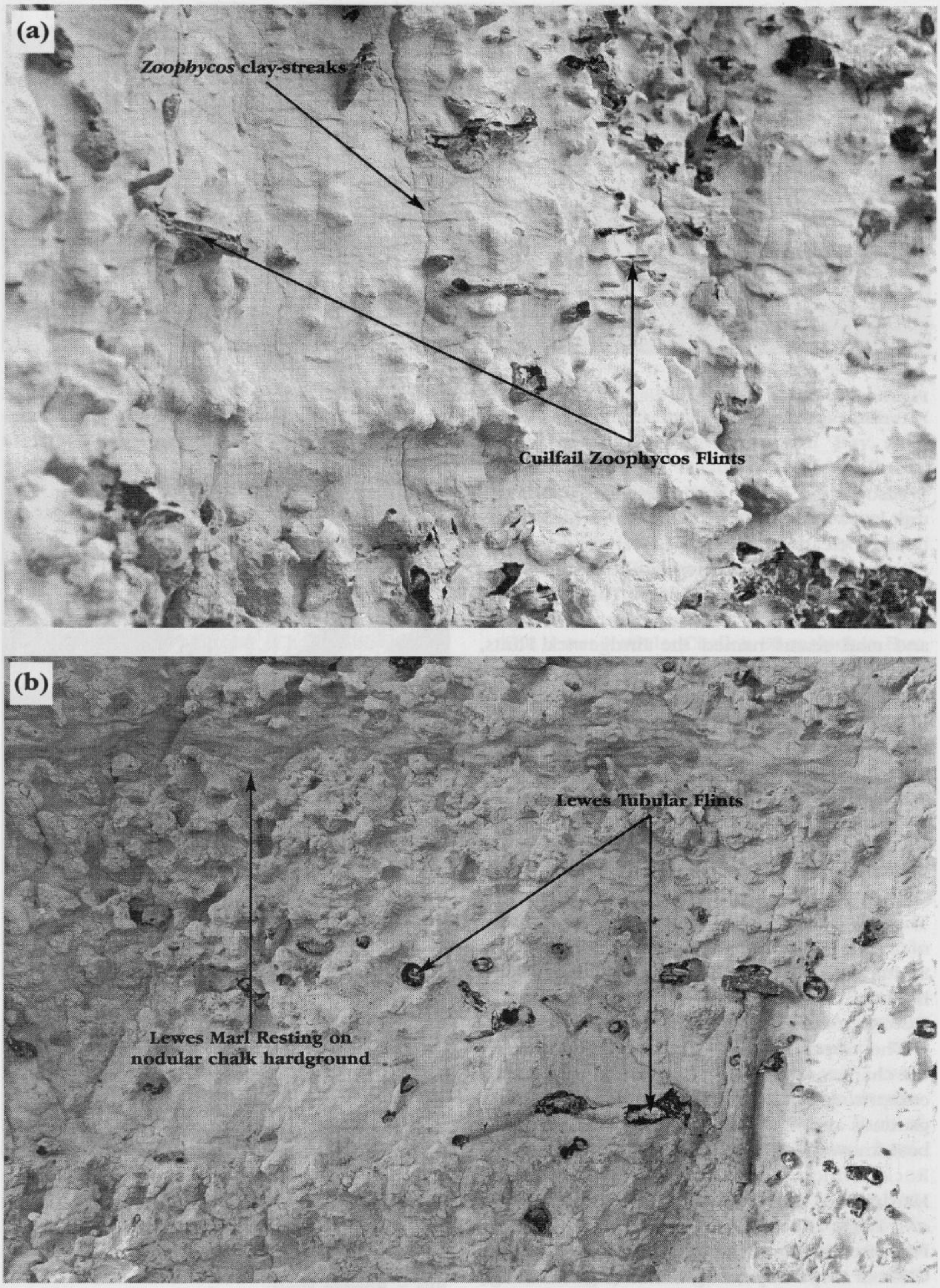


Figure 3.9 (a, b) Basin-wide marker beds in the Upper Turonian part of the Lewes Nodular Chalk Formation present in the Hooken succession at **Hooken Cliff**. (Photos: R.N. Mortimore.)

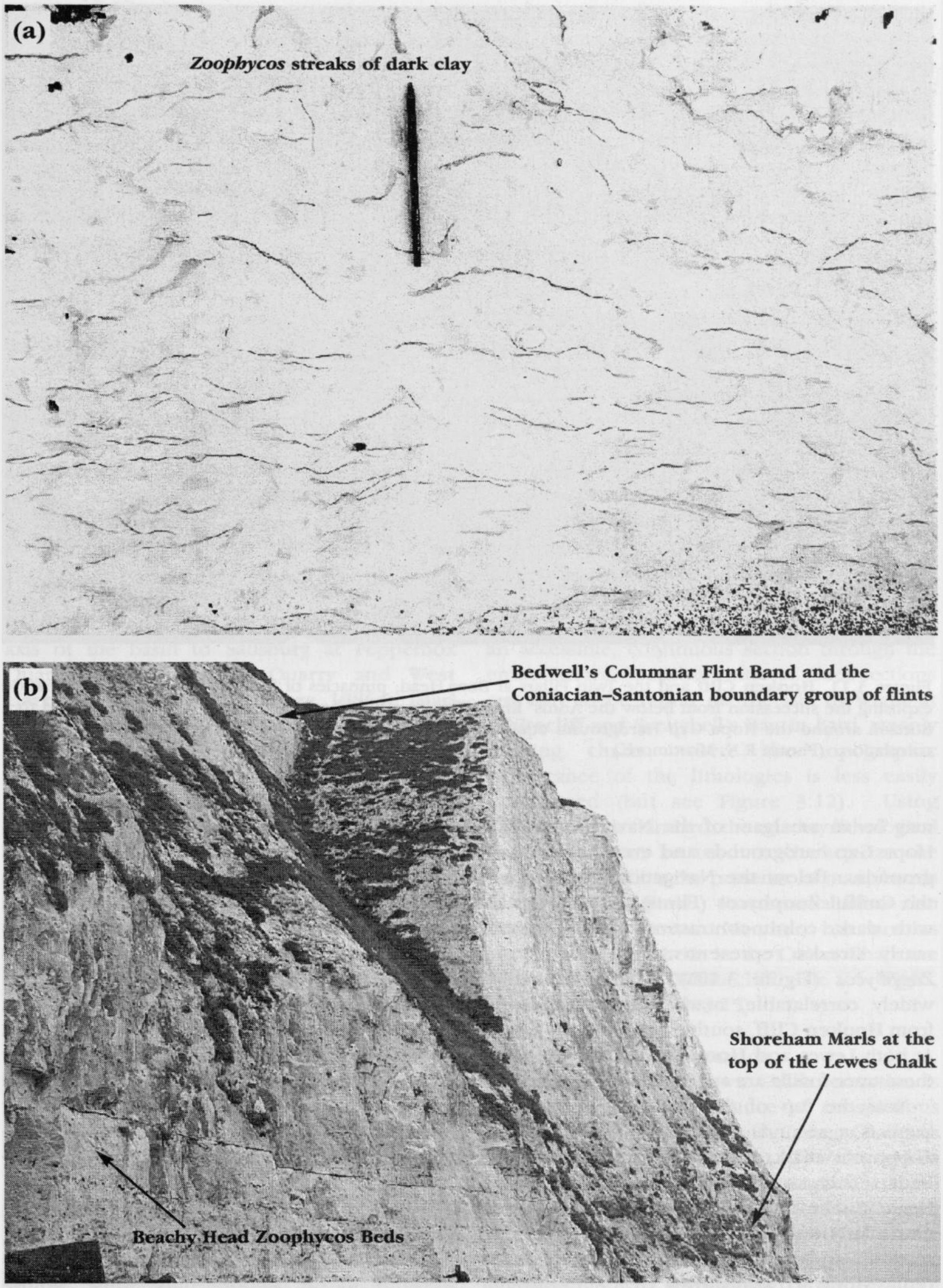


Figure 3.10 Chalk adjacent to St Margaret's Bay, Dover. (a) South side of St Margaret's Bay beyond the South Foreland, showing the Cuilfail Zoophycos in the topmost Turonian strata. (b) North side of St Margaret's Bay, showing the topmost Lewes Nodular Chalk and basal Seaford Chalk formations. (Photos: R.N. Mortimore.)

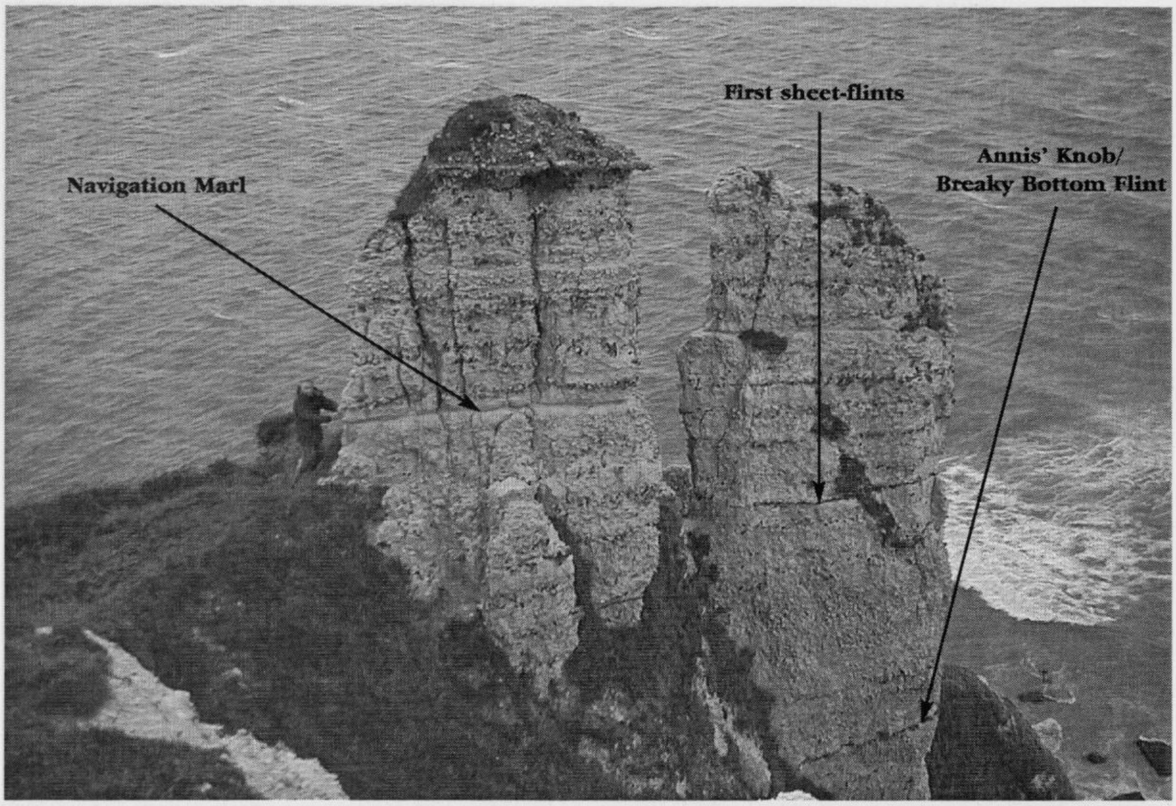


Figure 3.11 **Hooken Cliff** and the Twin Pillars at Beer Head; pinnacles of Lewes Nodular Chalk Formation exposing the succession from below the Annis' Knob Flint, through the Lewes Marl and Navigation Marl to a horizon around the Hope Gap Hardground equivalent. The first sheet-flints were used by Rowe (1903) for correlation. (Photo: R.N. Mortimore.)

may be an amalgam of the Navigation, Cliffe, Hope Gap hardgrounds and even higher hardgrounds. Below the Navigation Hardground, the Cuilfail Zoophycos (Flints), a unit of chalk with dark, colour-contrasting, millimetre-thin marly streaks representing the trace fossil *Zoophycos* (Figure 3.10a), is a conspicuous, widely correlatable, marker horizon present from **Hooken Cliff**, south-east Devon, to Dover. At both Lewes and **Hooken Cliff** (Figure 3.9a) these trace fossils are spectacularly silicified.

Near the top of the Lewes Nodular Chalk there is a second, equally distinctive, unit of Zoophycos chalk, the Beachy Head Zoophycos Beds. This marker, which is seen at Seaford Head (**Cuckmere to Seaford** GCR site) and is particularly well developed in the Beachy Head section, can be traced northwards from Dover (**Folkestone to Kingsdown** GCR site) through the London Basin, where the unit is conspicuous in borehole cores (Mortimore *et al.*, 1990), and westwards into flaser or griotte marly chalk in south-east Devon (e.g. Chapel Rock and, less accessibly, at **Hooken Cliff**). The Beachy Head Zoophycos Beds are overlain by the two Shoreham Marls, between which the Shoreham Tubular Flints (Figure 3.10) are conspicuous markers in both borehole core and exposures (e.g. Seaford Head (**Cuckmere to Seaford Head** GCR site) and **Charnage Down Chalk Pit**, Mere), as well as forming a distinctive field brash for mapping. Over structural highs, either or both of the Shoreham Marls may be occluded in the development of strong hardgrounds, for example the Bar End Hardgrounds of Winchester (Mortimore, 1986a) and the Rochester Hardground (Robinson, 1986) of Kent and Surrey.

Seaford Chalk Formation

Coarse, gritty Lewes Nodular Chalk changes abruptly to the smooth pure white, homogeneous Seaford Chalk Formation, which produces a quite distinct, slabby-chalk field brash. The basal boundary marker is the Shoreham

Marl 2 at Seaford Head, Sussex (**Cuckmere to Seaford** GCR site) which has been shown to be a vulcanogenic marl (Wray, 1999). Within the Seaford Chalk there are again numerous lithological marker beds that have been widely correlated (Mortimore, 1986a, 1997; Mortimore and Pomerol, 1987). Of these, the most conspicuous are the big flint bands, the Seven Sisters, Michel Dean, Baily's Hill, Flat Hill/Bedwell's Columnar and Whitaker's 3-inch flint bands. There are many more flint bands along the southern margin of the Basin in Sussex, Hampshire and Dorset and Devon, compared to the northern margin in Kent. As the flints are traced westwards through the Isle of Wight and south Dorset coast sections many of the individual flints in the marker bands also increase in size.

Newhaven Chalk Formation

Regular marl seams in white chalk with flint bands characterize the Newhaven Chalk and the basal boundary marker is taken at the lowest of these, Buckle Marl 1 at Seaford Head (**Cuckmere to Seaford** GCR site). Individual marl seams have been traced through the main axis of the basin to Salisbury at Pepperbox Quarry, East Grimstead Quarry and **West Harnham Chalk Pit** (Mortimore, 1986a). Marl seams and many flint bands disappear over local tectonically controlled highs such as the Hollingbury Dome near Brighton, Shawford near Winchester (Mortimore and Pomerol, 1997) and on the Dean Hill Anticline at Dean Hill near Salisbury (see Figure 3.1 and Figure 3.43, p 157). The marl seams strengthen and thicken into more basinal areas. At **Whitecliff**, Isle of Wight, there is a special section of condensed Newhaven Chalk with a number of hardgrounds and associated phosphatic chalks. The key marker beds in the Newhaven Chalk Formation are identified and defined in the **Newhaven to Brighton** and **Cuckmere to Seaford** GCR sites, Sussex.

The Culver Chalk Formation

The Culver Chalk Formation can locally be subdivided into the Tarrant Member and the Spetisbury Member (Bristow *et al.*, 1995). These two members comprise white chalks with numerous flint bands, and correspond to the Sompting Beds and Whitecliff Beds of Mortimore (1983, 1986a). They were introduced in central Dorset for the mappable topographical features present in that area. Subsequently the topographical feature representing the Tarrant–Spetisbury boundary was traced through West Sussex to Warningcamp Chalk Pit near Arundel, and was found to correlate with the Warningcamp–Whitecliff Flint of Mortimore (1986a,b). This suggests that the same basal boundary marker chosen for the base of the Whitecliff Beds can be used for the base of the Spetisbury Chalk Member, at least in the South Downs into Hampshire.

The base of the Tarrant Chalk is not so easily defined, as it appears to be at different levels in the South Downs compared to Dorset. In West Sussex, the basal Tarrant Chalk topographical feature has been traced into the Black Rabbit Pit at Arundel, where it corresponds to the entry of the large Castle Hill Flints 4 and 5 of Mortimore (1986a). This is just above the Pepperbox Marls, at the boundary between Mortimore's Newhaven Chalk and Culver Chalk formations. Biostratigraphical evidence from Dorset suggests that the base of the Tarrant topographical feature is lower there, around the Arundel Sponge Bed or even at the level of the Meeching Marls (Bristow *et al.*, 1997). A key problem is finding an accessible, continuous section through the entire Tarrant–Spetisbury interval. Such sections are only to be found on the Isle of Wight at **Whitecliff** and Scratchell's Bay, in hard, steeply dipping chalks, where the topographic significance of the lithologies is less easily determined (but see Figure 3.12). Using **Whitecliff** as a standard, the one key lithological feature that can be used to characterize the Spetisbury Chalk is the presence of many bands of paramoudra flints. Paramoudra flints also occur in the Tarrant Member, but not as regularly. Marker beds in the Culver Chalk are identified in the **Whitecliff**, Isle of Wight, sections (Figures 3.13–3.15).

Portsdown Chalk Formation

The base of the Portsdown Chalk Formation is marked by the reappearance of conspicuous marl seams, following a unit (Culver Chalk) in which they are virtually absent. This change is a conspicuous feature in the high chalk on Portsdown and along the coast between **Whitecliff**, Isle of Wight, and Bats Head on the Dorset coast. The basal boundary marker is the Portsdown Marl 1 at Farlington, Portsdown and at **Whitecliff**. In central Dorset, the marl seams characteristic of this unit are largely absent, except for the Almer Marl, but the chalk still

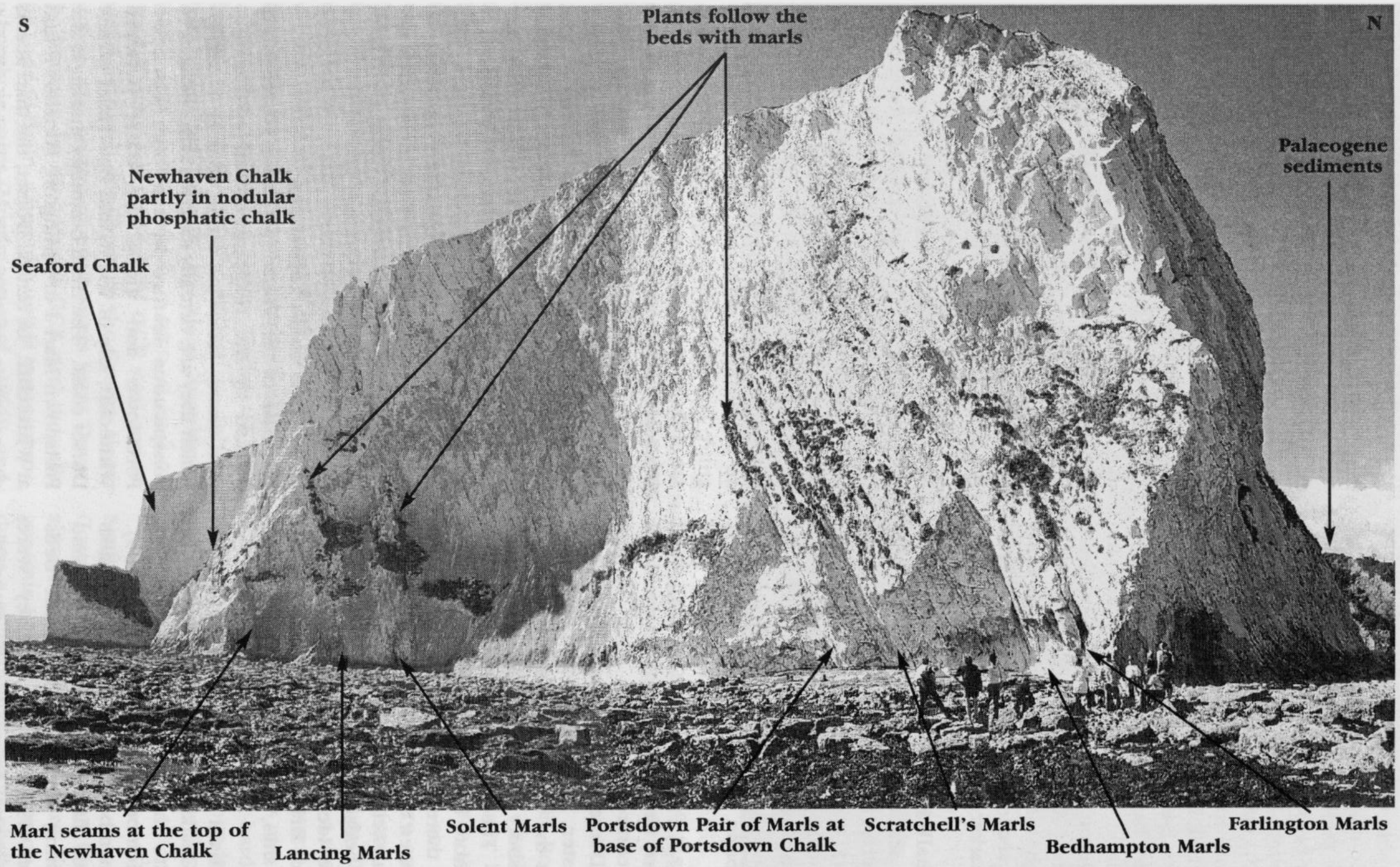
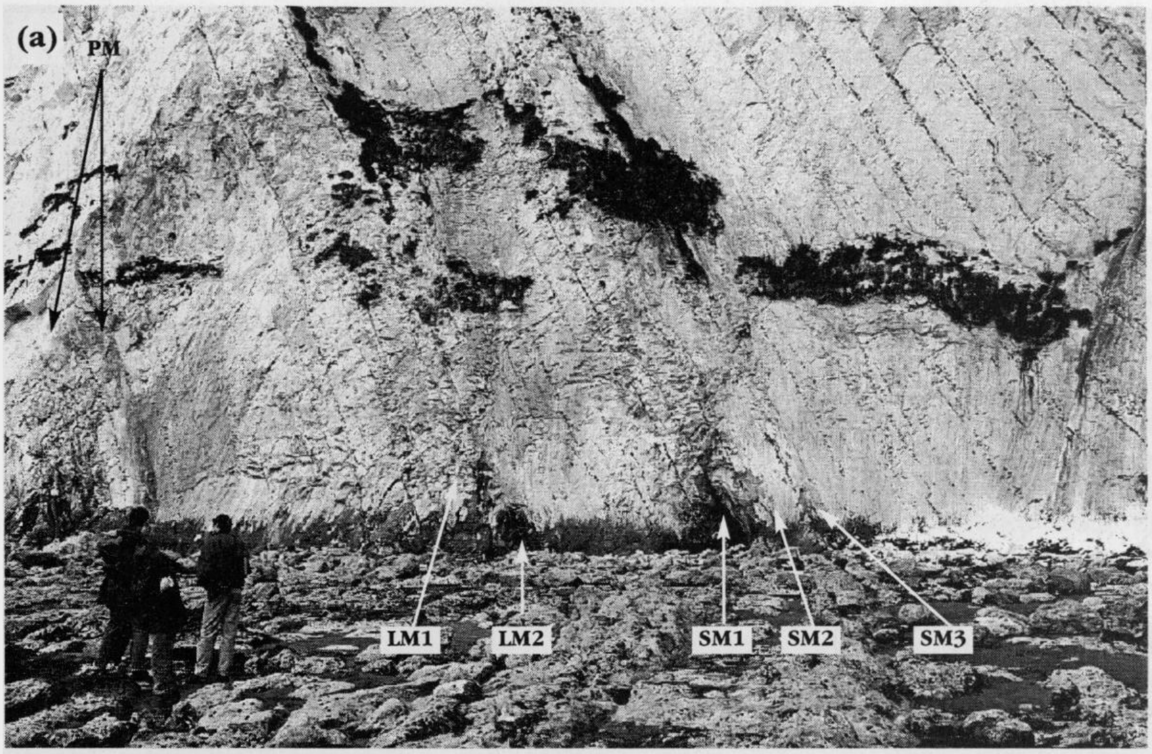


Figure 3.12 **Whitecliff**, Isle of Wight, showing the Seaford Chalk, Newhaven Chalk, Culver Chalk and Portsdown Chalk formations. The Bedhampton Marls and Farlington Marls both contain abundant inoceramid bivalve shell debris. This is the type section for the Culver Chalk Formation. Note the marly units stand out as bluffs even in the Culver Chalk Formation, which can be recognized as the unit between the top Newhaven marls and basal Portsdown marls. Compare with Figure 3.65, p.188. (Photomosaic: R.N. Mortimore.)



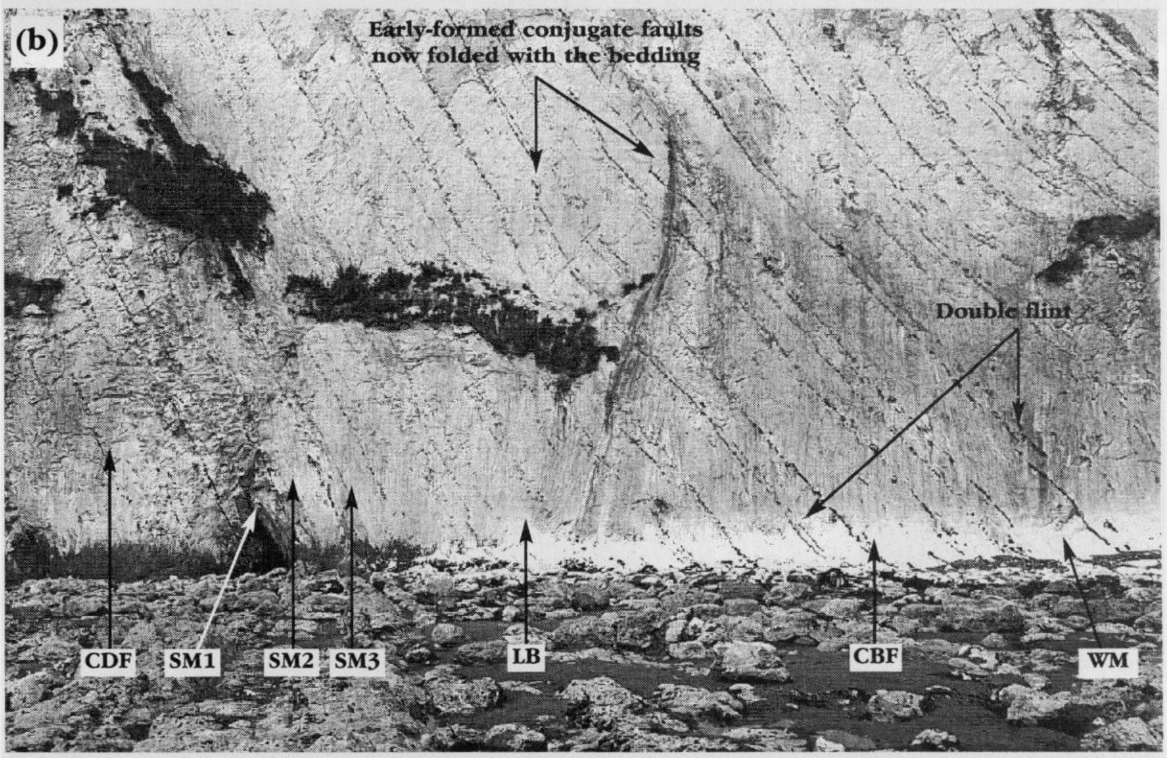


Figure 3.13 The Culver Chalk Formation at **Whitecliff**, Isle of Wight. (a) The basal part of the formation. (b) The central part of the formation, the boundary between the Tarrant Member below and the Spetisbury Member above is taken at the Whitecliff Marls. (CBF = Cote's Bottom Flint; CDF= Charmandean Flint; LB = Laminated beds; LM1, LM2 = Lancing Marls 1 and 2; PM = Pepperbox Marls at top of Newhaven Chalk Formation; SM1, SM2, SM3 = Solent Marls 1, 2 and 3; WM = Whitecliff Marls.) (Photos: R.N. Mortimore.)

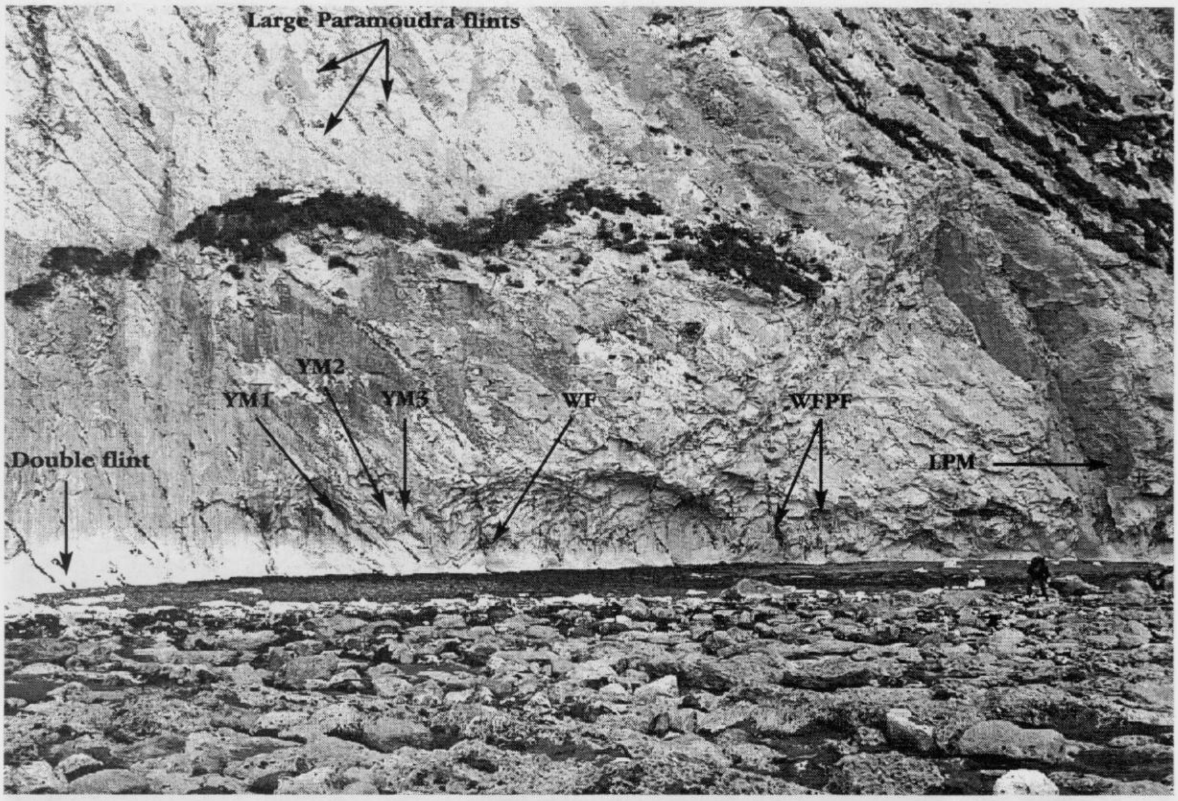


Figure 3.14 The upper part of the Culver Chalk Formation, **Whitecliffe**, Isle of Wight (Spetisbury Member) containing numerous Paramoudra flints. (LPM = Lower Portsdown Marls; WF = Whitecliffe Flint; WFPF = Warren Farm Paramoudra Flints; YM1, YM2, YM3 = Yaverland Marls 1, 2 and 3.) (Photo: R.N. Mortimore.)

produces a very fine topographical feature that is mappable into Hampshire and West Sussex (Bristow *et al.*, 1997).

Above the Portsdown Chalk with many marl seams, up to the Palaeogene surface on the Isle of Wight and at Studland, is another unit without marls informally named the 'Alum Bay Beds' (Mortimore, 1979, 1983) but later formally designated the 'Studland Chalk Member' (Gale *et al.*, 1988).

South-west England (south-east Devon, Somerset and west Dorset)

The lowest parts of the Upper Cretaceous deposits of south-west England are so different from those of the main basins to the east that they require separate treatment (Figure 3.4). In particular, most of the Cenomanian deposits consist not of chalks, but instead comprise highly condensed, fossiliferous sands and sandy limestones. These form the Beer Head Limestone Formation of the Grey Chalk Subgroup. The Holywell Nodular Chalk, New Pit Chalk, Lewes Nodular Chalk, and Seaford Chalk formations of the White Chalk Subgroup can be recognized, albeit the New Pit Chalk Formation is conspicuously flinty (the Beer Roads Member of Jarvis and Woodruff, 1984) compared with its development elsewhere in the Southern Province.

The top Pinnacles Member (Bed C) of the Beer Head Limestone is included in the White Chalk Subgroup as the basal member of the Holywell Nodular Chalk Formation. The preserved and exposed succession in south-east Devon goes up only to the basal Seaford Chalk Formation, the highest beds being present in **Hooken Cliff** (Figure 3.16). The lower part of the White Chalk Subgroup in east Devon shows considerable lateral variation over short distances, and contains numerous minor sedimentary breaks represented by hardground surfaces. It consists of gritty and nodular chalks that can be broadly correlated on lithological and faunal grounds with the Holywell Nodular Chalk of the standard Southern Province succession. These beds include lithologies not seen elsewhere in southern Britain, notably the calcarenitic Beer Stone made up of inoceramid debris. The top of the Holywell Nodular Chalk is marked in **Hooken Cliff** and in Beer Cliffs by a laterally persistent hardground (the Branscombe Hardground of Jarvis and Woodroof, 1984), which represents a significant sedimentary break.

Biostratigraphy and chronostratigraphy

The current biostratigraphical and chronostratigraphical division of the Late Cretaceous deposits of the Southern Province is a mixture of traditional assemblage zones from the Anglo-Paris Basin and internationally agreed zonal and subzonal divisions of the Late Cretaceous stages (Figure 1.5, Chapter 1; Figures 2.8, 2.9, 2.21, 2.22 and 2.27, Chapter 2). The boundary stratotypes for the stages are mostly based outside the UK (see Appendix, this volume).

The biotratigraphy has largely evolved from the work of many great amateur

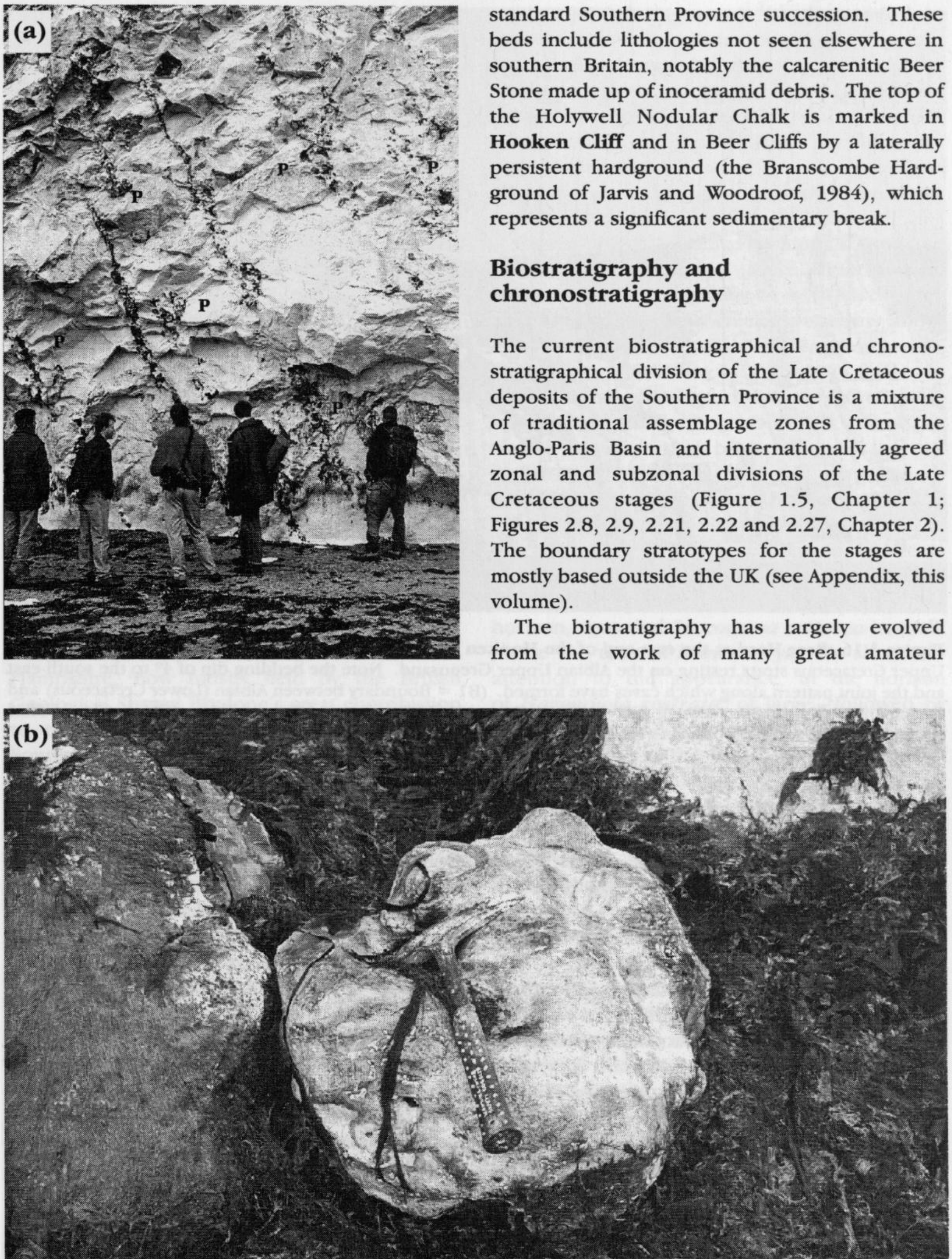


Figure 3.15 (a) Large Paramoudra flints (P) from the Warren Farm Paramoudra horizon, **Whitecliff**, Isle of Wight. (b) Large Paramoudra flint fallen to the beach, **Whitecliff**, Isle of Wight. (Photos: R.N. Mortimore.)

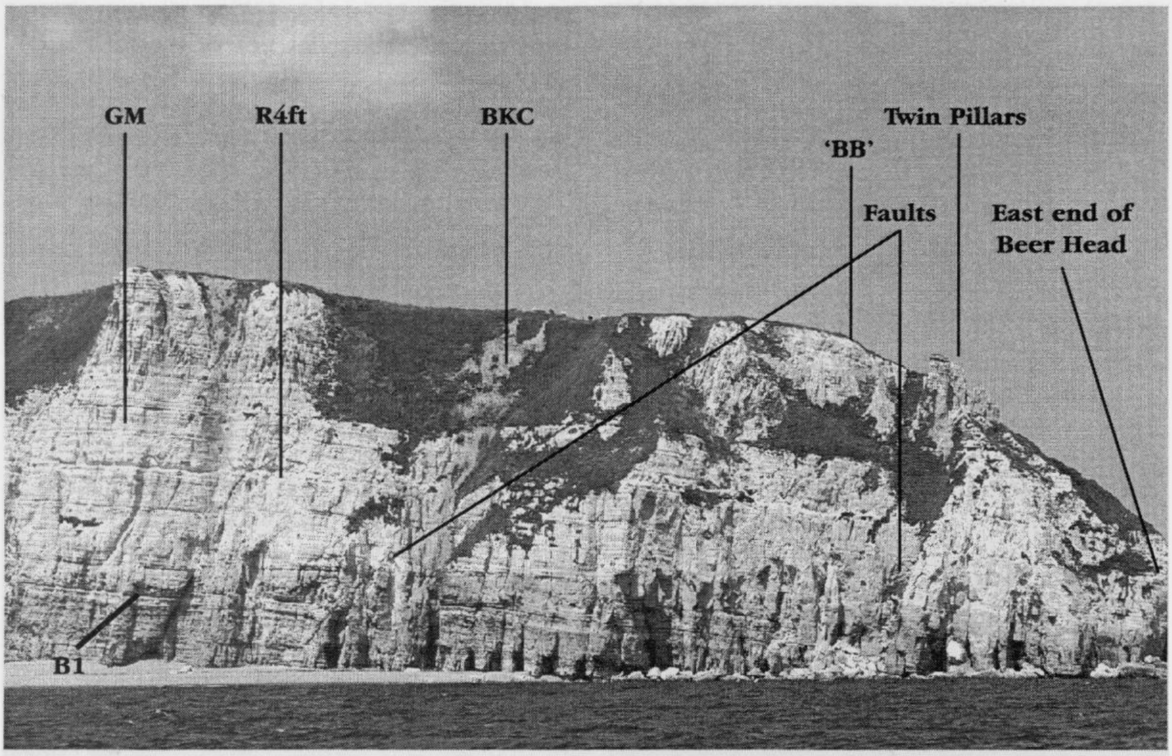


Figure 3.16 Beer Head at the east end of the **Hooken Cliff** site, south-east Devon, showing the base of the Upper Cretaceous strata resting on the Albian Upper Greensand. Note the bedding dip of 4° to the south-east and the joint pattern along which caves have formed. (B1 = Boundary between Albian (Lower Cretaceous) and Cenomanian (Upper Cretaceous); 'BB' = 'Belay Buttress'; BKC = base of Karst collapse; GM = Glynde Marl (Dowlands Marl and base of Lewes Nodular Chalk); R4ft = Rowe's 4-ft band.) (Photo: R.N. Mortimore.)

palaeontologists working in the 19th and early 20th centuries. A Lewes surgeon, Mantell, published his studies in *The Fossils of the South Downs or Illustrations of the Geology of Sussex* (1822). This work can be compared with the description at the same time of the *Geology around Paris* (which actually included a huge area of the Paris Basin), by Cuvier and Brongniart (1822). These wonderful books were the first to illustrate the extraordinary range of fossils in the rocks of the region and they must have stimulated others to investigate further. Like Mantell's publications, Dixon's *Geology of Sussex* (1850) is a source of many type and figured specimens, for example the *Micraster corbovis* of *plana* Zone type (Forbes, Stokes, 1975) (the *Forbesaster forbesi* of Drummond, in manuscript; Drummond, 1983).

The information accumulated by Mantell, Dixon, and others contributed to d'Orbigny's (1847, 1850–1852) worldwide synthesis in lists of fossils contained within Upper Cretaceous stages. This work was further developed by Hébert (1866, 1874) and Barrois (1876), who both deserve a special mention for their application to England of the familiar Chalk *zones* from the Chalk of the Paris Basin (Figure 2.8, Chapter 2). These are the zones that were applied by Rowe (1900–1908) to the coast sections and later mapped by both Brydone (1912) and Gaster (1924–1951) in Hampshire and Sussex respectively.

Rowe concentrated on the well-exposed coastal sections (Rowe, 1900–1908), whereas the [British] Geological Survey paid more attention to the inland sections. This led to wide discrepancies in zonal concepts because of the different nature of exposures and preservation of fossils between the coast and inland pits, and the absence of a good lithostratigraphical framework. Rowe (1899) also published the first modern study of a fossil group, the Chalk heart-shaped urchin *Micraster*. This paper has had a great influence on evolutionary thought, and is still widely used for teaching. In his papers on the coastal sections (but not in his posthumous paper on the Chalk of Lincolnshire, Rowe, 1929), Rowe did not accept the principle of lithostratigraphical correlation in the Chalk. Nevertheless his 'zoological boundaries' invariably conveniently coincided with lithological marker horizons at any one locality, which, despite his stated philosophy, led him to make serious mistakes in correlation.

Brydone (in Griffith and Brydone, 1911; Brydone, 1912, 1914, 1915) not only mapped the Chalk zones in Hampshire but also provided an immense amount of information on the numerous chalk pits in that county. Brydone's map illustrated the extent of folding in the Chalk, including the strongly developed Warnford Dome and numerous subsidiary folds in south Hampshire from Winchester to the Sussex border. Brydone was exceptional in providing some measured sections and details of marl seams in the *Marsupites testudinarius* and *Offaster pilula* zones on the Sussex coast and in Hampshire. He recognized the two-inch marl that could be traced from Seaford Head to Rottingdean on the Sussex coast, now named the 'Old Nore Marl' (Mortimore, 1986a).

Apart from the vast collection of fossils from Hampshire, now mostly held by the British Geological Survey, Brydone's great contribution to the biostratigraphy of the Chalk of the Southern Province was the description of many of the stratigraphically distinctive shape changes in the echinoid genus *Echinocorys* (Figure 2.3, Chapter 2). Brydone (1912, 1939), following previous suggestions by Rowe (1900) and Jukes-Browne (1912), formally separated off the lower part of the existing *Actinocamax quadratus* Zone as an independent zone of *Offaster pilula.*

Gaster, a local solicitor, mapped the zones of the Chalk in Sussex (1924–1951). In 1920 he introduced his '*Trochiliopora* bed' in the '...lower portion of the *Micraster coranguinum* Zone...', based on the small bryozoan *Trochiliopora gasteri* (Gregory), and later indicated (Gaster, 1929) that it could be traced from Beachy Head to the Adur. Gaster had been struck by the differences of opinion between Rowe (1900), Jukes-Browne (1912) and Brydone (1912, 1914) on the zonal divisions of the Chalk above the *Marsupites* Zone (i.e. where to place the *Offaster pilula* Zone and whether to introduce other divisions). By washing blocks and pieces of chalk Gaster (1924, 1929) obtained abundant small fossils (mesofossils). He found numerous rostra of the delicate and very fragile small echinoid *Hagenowia blackmorei* Wright and Wright (then misidentified as *H. rostrata* (Forbes)) and suggested that this could also be used as a guide fossil for the highest unit of his revised concept of the *Offaster pilula* Zone. He inferred the position of this zone in other exposures from Hampshire and the Isle of Wight based on published lists of fossils from those exposures.

Gaster (1924) modified Brydone's restricted Zone of *Gonioteuthis* (then *Actinocamax*) *quadrata* with a Subzone of *Saccocoma cretacea* (now *Applinocrinus cretaceus*) about 40 m thick, and a horizon of *Hagenowia rostrata* (now *H. blackmorei*), 15–20 m thick. In doing so, he added greatly to the list of guide fossils, particularly the mesofossils. In 1929, Gaster revised the biostratigraphy of his '*Offaster pilula* Zone' (not that used today), establishing two subzones of *Echinocorys scutatus* var. *depressa* and *E. scutatus* var. *cincta*, in ascending order. Within the second, he recognized the two horizons of abundant *Offaster pilula* and *Hagenowia rostrata* and, in the latter horizon, recorded *Saccocoma cretacea* in chalk inside the tests of *Echinocorys.* He also drew attention to the appearance, in the horizon of *Hagenowia rostrata*, of large – followed by small – forms of *Echinocorys*. These are generally referred to as the 'large and small forms of Gaster' respectively.

Jefferies (1962, 1963) began the modern approach by describing in detail the lithology and fossils in the Plenus Marls. He was followed by Kennedy (1969, 1970) who gave a detailed account of the Lower Chalk in the region, using the Folkestone sections as a reference. Kennedy (1969) assigned letters to beds in measured sections containing particular groups of fossils that he then used for correlation within the south-east part of the region (1969, fig. 16). He employed the broad French ammonite-based zonation for the Cenomanian Stage introduced to the region by Hancock (1959), to establish a number of ammonite assemblages and subzones capable of being widely correlated. Kennedy (1970) extended this work to the western margin of the Southern Province, an area studied in detail by Drummond (1967, 1970). Both researchers provided measured sections with descriptions of fossil assemblages, illustrating the age of the deposits and the influence of condensation across the Mid-Dorset Swell and the shelf area of south-east Devon.

Drummond (1970) added to the discussion of fossil assemblages and sedimentology of the south-western margin. Detailed litho- and biostratigraphical work on the Middle and Upper Chalk was not undertaken until later (Mortimore, 1983, 1986a,b; Robinson 1986).

Carter and Hart (1977a) introduced a microfossil zonation for the Gault and Lower Chalk comprising benthic foraminiferal zones designated by numbers; these zones were extensively used in investigations connected with the construction of the Channel Tunnel (Harris *et al.*, 1996b). Hart's co-workers, Bailey and Swiecicki, extended the microfossil stratigraphy to the whole of the Chalk (Bailey *et al.*, 1983).

The biostratigraphy of the Upper Cretaceous Chalk for the region is now based upon detailed measured sections. First occurrences, last occurrences and ranges of macro-, meso-, micro- and nanno-fossils are plotted in relation to lithological marker beds (e.g. Bailey *et al.*, 1983, 1984; Mortimore, 1986a). For this purpose, the most complete sections are essential. Within the region there are several potential basal boundary stratotype sections for the international Stages or Substages. These include the base of the Middle Cenomanian Substage at **Southerham Grey Pit**, Lewes, the base of the Santonian Stage and the base of the Campanian Stage, both at Seaford Head, Sussex (see **Cuckmere to Seaford** GCR site report, this volume).

There are two major regional variations in the biostratigraphy in the Southern Province. In the first, fossils that are common on the **Thanet Coast**, for example Late Santonian belemnites at Margate, are rare at similar horizons in Sussex. These differences may reflect palaeogeographical settings, Kent being on the edge of the Anglo-Brabant Massif and Sussex in a more basinal setting. Local anomalies also occur. The second relates to the marginal facies of south-west England. Detailed studies of the faunas, notably of the ammonites by Kennedy (1971) and Wright and Kennedy (1981, 1984) and of the echinoderms by Smith *et al.* (1988), have shown that the Cenomanian faunas of south-west England are not only extraordinarily diverse, but that they include species not recorded elsewhere in Britain. This makes detailed correlation between the two facies difficult, but adds to the international importance of the Devon faunas.

The GCR sites in the Southern Province cover the entire stratigraphical range of the preserved Upper Cretaceous Series in the region, beneath the Palaeogene erosion surface. These sites also serve to illustrate the influence of sea level and tectonics on the formation of the Chalk. The localities are arranged in geographical order from Devon to Dorset and Hampshire, and through Sussex to Kent. Many of the sections form the classic white Chalk cliffs of Albion.

HOOKEN CLIFF, SOUTH-EAST DEVON (SY 210 881–SY 227 878)

Introduction

The Hooken Cliff GCR site includes the Hooken Cliffs, Beer Head and Branscombe East Cliff. The vertical cliffs of Beer Head and the great Hooken Cliffs landslip (Figures 3.16–3.18) expose the most complete Upper Cretaceous succession in south-east Devon. These are also the westernmost exposures of Chalk in England and illustrate what happens to the Upper Cretaceous sediments as they approach the basin margin. At the base of the succession, the earliest (Cenomanian) deposits are highly condensed sandy limestones about 5 m thick, compared with more than 80 m for the same interval in the main basin in Sussex and Kent. Despite this condensation there is a remarkable preservation of fossils, particularly ammonites, that aids correlation with the main basin to the east, with Europe and with North America. As the seas deepened and chalks formed, key basinal lithological markers such as the Turonian marl seams and flint bands can be recognized and the main basin lithostratigraphy can be applied. These chalk units form the main high cliffs at Beer Head.

Within a relatively small outcrop, Hooken Cliff illustrates extraordinary lateral changes in sedimentation, which include onlapping of higher Turonian beds over earlier ones onto the Albian Upper Greensand. The Cenomanian deposits pass from thin sandy limestone facies, on the margins of the site, to calcarenitic ('Wilmington Sand') facies in the centre of the site. This lateral variation, which is also seen in the lenticular development of a calcarenitic freestone (Beer Stone) near the base of the Lower Turonian Holywell Nodular Chalk Formation, is attributable to the site traversing a narrow, north–south, fault-bounded depositional trough ('Hooken–Wilmington trough', Figures 3.17 and 3.19), which controlled sedimentation. A

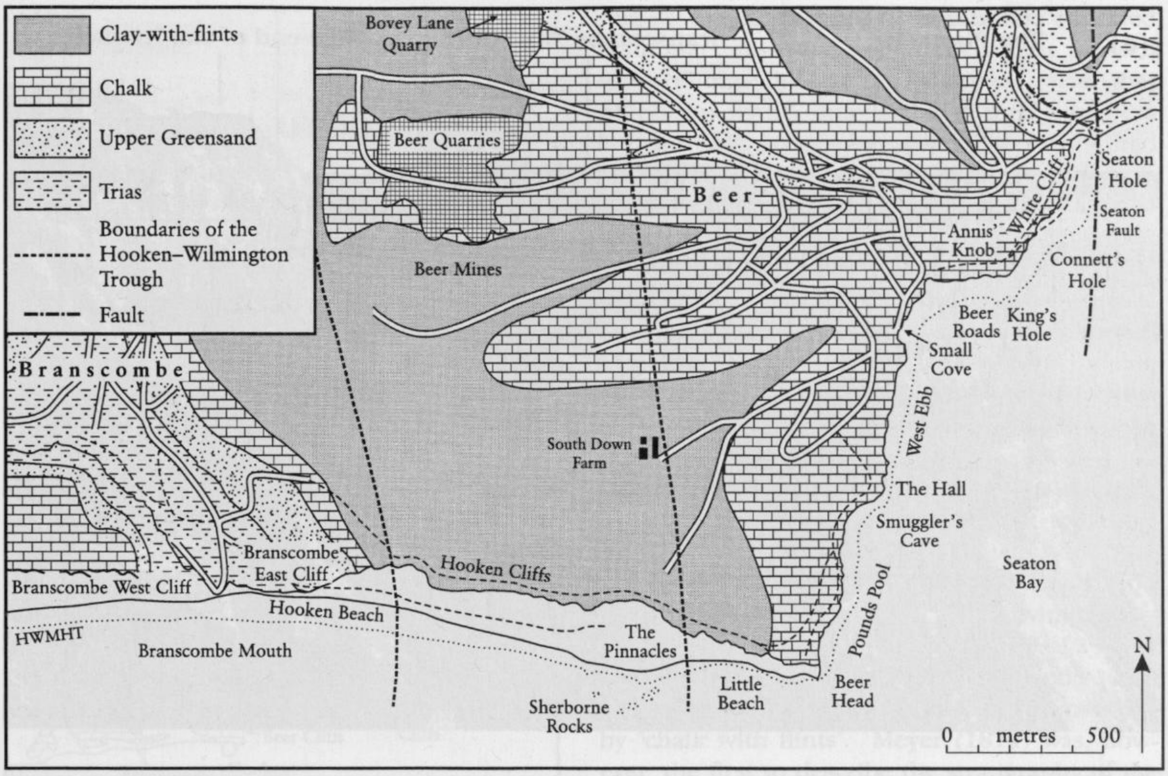


Figure 3.17 The Hooken Cliff GCR site in relation to nearby sections and the local geology.

combination of tectonic fault control and sea-level rise is used to explain the sedimentary variations.

The site and, particularly, the sections immediately to the west, are famous for the rich Lower Turonian echinoid faunas in the Holywell Nodular Chalk Formation.

Description

Hooken Cliff comprises several components (see Figure 3.20):

1. The continuous cliff section landward of the landslip, from Branscombe East Cliff to Hooken Cliffs, including the Beer Stone adit.
2. Slipped masses from these cliffs in the landslip area including, from west to east, Mitchell's Stile Rock, Martin's Rock, and the three Pinnacles.
3. The cliff section east of the landslip area extending from Little Beach to Beer Head, and fallen blocks therefrom. This was described by Rowe (1903, p. 20): 'there is no section on the English coast which gives so much zonal detail, or tells the story of zonal succession in so convincing and graphic a manner'.
4. High-level slipped masses at and near Beer Head, which preserve the highest Chalk: these include the so-called 'Belay Buttress' and a karstic collapse structure.

The beds dip gradually eastwards at 4°, bringing Upper Cretaceous strata from near the top of the cliff in Branscombe East Cliff down to sea level at Beer Head.

Between the Beer and Branscombe valleys the Chalk caps a ridge of high ground known as South Down (Figures 3.17 and 3.20). Prior to 1790, this ridge terminated in a line of Upper Greensand and Chalk cliffs up to 150 m high, but in March 1790 failure along a thin bed of sandy clay at the base of the Upper Greensand caused a mass 1300 m long, and up to 250 m wide, to subside seawards. Dawson *et al.* (1840) provided the following graphic description, based on local accounts.

'... in the middle of the night, a tract of from

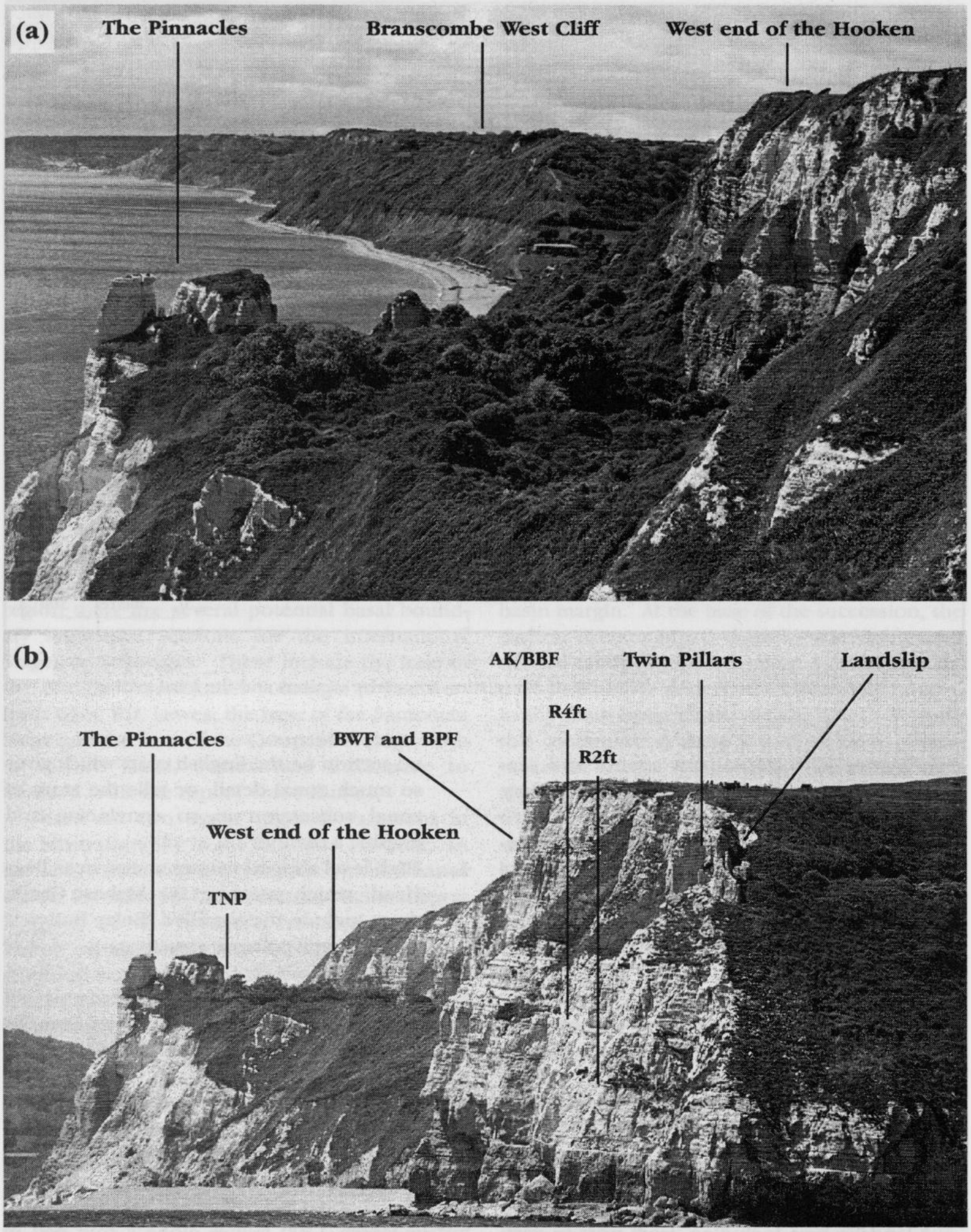


Figure 3.18 (a) Beer Head looking west; the west end of the Hooken Cliff GCR site shows the overstep of Chalk onto Upper Greensand. (b) Hooken Landslip looking north-west. The Twin Pillars are composed of Annis' Knob Flint, Lewes Flint, Lewes Marl, Cuilfail Zoophycos and Navigation Marl; the Landslip displays the stratigraphically highest chalk on the Devon coast with *Platyceramus/Volviceramus* and the Seven Sisters Flint Band. (AK/BBF = Annis' Knob/Breaky Bottom Flint; BWF and BPF = Bridgewick Flints and Bopeep Flints; R2ft = Rowe's 2-ft band; R4ft = Rowe's 4-ft band; TNP = Turonian New Pit Chalk section in landslip with abundant spiky flints.) (Photos: R.N. Mortimore.)

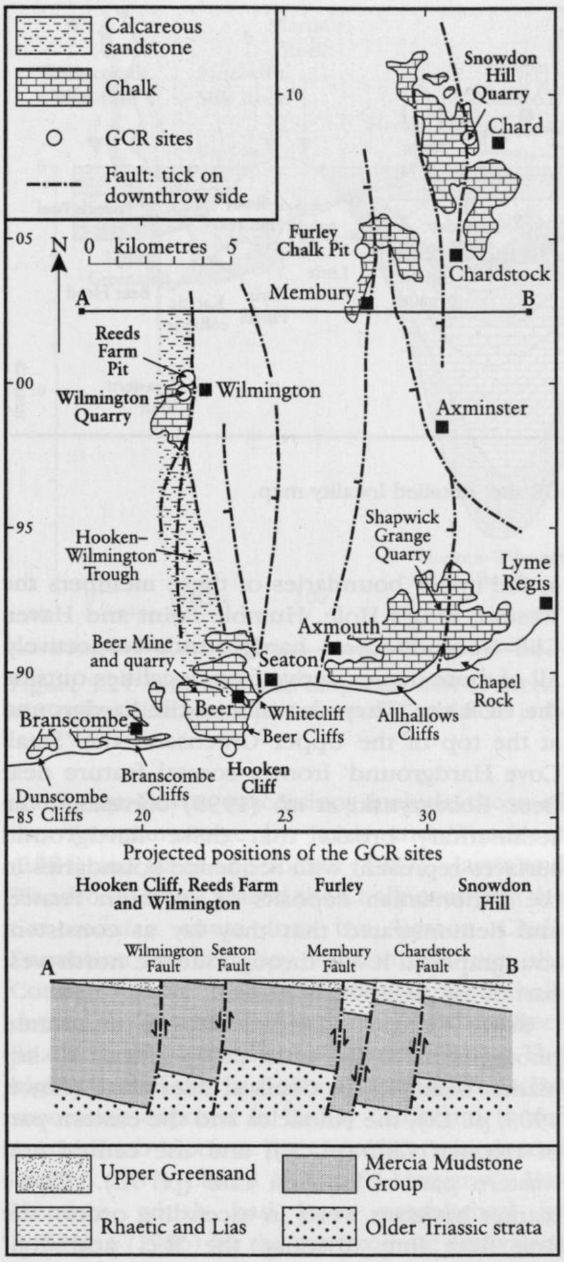


Figure 3.19 Geological sketch map and section showing the position of the Upper Cretaceous GCR sites in relation to outcrop and structure.

seven to ten acres, ranging along the brow of a steep cliff immediately overhanging the sea, suddenly sank down from 200 to 260 feet, presenting a striking group of shattered pinnacles and columns of chalk entangled with the sunken fragments of the fields thus torn away from their native site; the remains of hedges still traversed these fragments, and a stile was seen undisturbed on the summit of one of the subsided columnar masses. The subsided mass pressed forward into the sea ... fishermen relate that points on which they had laid their crab-pots beneath the water, and over which they had sailed the night before ... were raised ... on a reef at a height of fifteen feet in the air'

No-one witnessed the event, but fishermen out at sea were alarmed by the noise of it. The fields, hedges and the stile have long since gone, but the pinnacles of remarkably undisturbed Upper Greensand and Chalk remain, rising above a sea of tangled vegetation that now separates them from the Hooken Cliffs in the back face of the landslip.

De la Beche (1826) was the first to describe the Upper Cretaceous succession of the coast sections including the Hooken. He noted the anomalous nature of the oldest Chalk and recorded the presence of 'chalk with quartz grains' underlain by up to 3 ft (*c.* 1 m) of a richly fossiliferous 'compact pebbly basal bed'. This was succeeded by 'chalk without flints' overlain by 'chalk with flints'. Meyer (1874) was, however, the first to describe the stratigraphy of the Chalk of Hooken Cliff. Barrois (1876) was then the first to recognize the presence of the Paris Basin macrofossil assemblage zones of *Rhynchonella cuvieri*, *Terebratulina gracilis* and *Holaster planus* (Turonian), and *Micraster cortestudinarium* (Coniacian). Jukes-Browne and Hill (1903, 1904) and, particularly, Rowe (1903) described the stratigraphy and fauna of the traditional Middle and Upper Chalk successions of the coastal and inland quarry sections in considerable detail.

Jukes-Browne and Hill (1903; Jukes-Browne 1896, 1903) gave detailed descriptions of the Cenomanian sediments at Hooken Cliff. They termed these collectively the 'arenaceous beds', or 'Zone of *Ammonites mantelli*', and subdivided the succession into two distinct beds, which they designated A and B, in ascending order. In the sections west of Branscombe, i.e. west of the site, they noted (1903) that the lower part of Bed A (A1) was characterized by the common occurrence of what they took to be a giant coral-like bryozoan, *Ceriopora ramulosa* (Michelin), which was absent from the higher part (A2) of the same bed. The bed overlying Bed B (Bed C), which they described as chalk and excluded from the arenaceous beds, was particularly well developed at Humble Point, between Lyme Regis and Axmouth. They

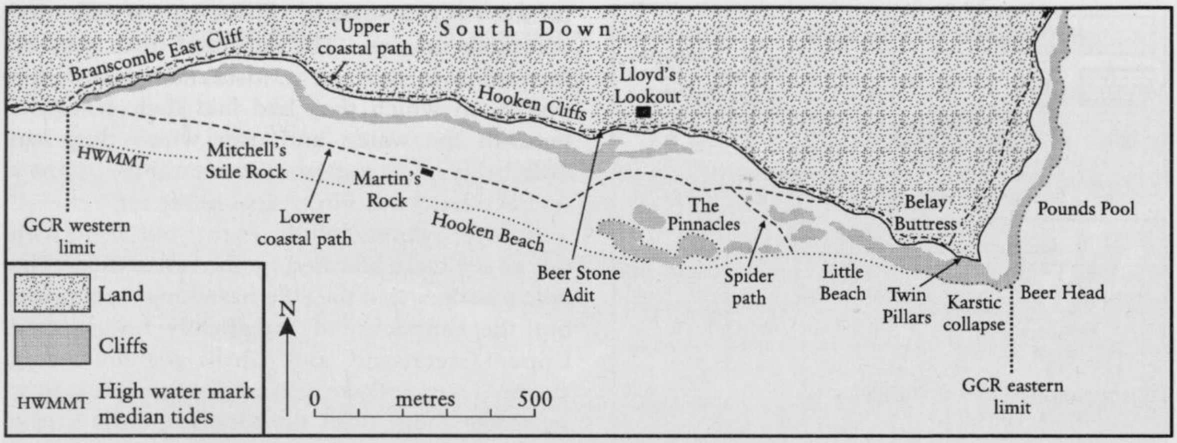


Figure 3.20 The Hooken Cliff GCR site, detailed locality map.

inferred that Bed C, which was represented by glauconitic sands in Hooken Cliff, correlated with the Plenus Marls of areas to the east, and emphasized the considerable hiatus between Beds B and C (Figure 3.4).

Smith (1957a) gave formal formation status to the previously (e.g. Rowe, 1903) informally named 'Cenomanian Limestone'. At first he accepted the subdivisions A1, A2, B and C, but he later (1965) renamed Bed C the 'Orbirhynchia Bed' because he considered that it was of Turonian rather than Cenomanian age, and excluded it from the Cenomanian Limestone. In a series of papers, following and adding to the the earlier work by Jukes-Browne (1898) and Jukes-Browne and Hill (1903), he described the lateral variation of the Cenomanian deposits between Sidmouth and Lyme Regis. Two of these papers (Smith, 1957a, 1961) are of particular relevance to the Hooken Cliff GCR site.

Jarvis and Woodroof (1984) renamed Smith's original 'Cenomanian Limestone Formation' the 'Beer Head Limestone Formation' and gave formal member status to the four subdivisions (A1, A2, B and C), which were then in general usage (see Figure 3.21). In ascending order, these became the 'Pounds Pool Sandy Limestone Member', 'Hooken Nodular Limestone Member', 'Little Beach Bioclastic Limestone Member' and 'Pinnacles Glauconitic Limestone Member'. With the exception of the Pounds Pool Member, the type section of which lies to the north of the site, these members are named after the Hooken Cliff GCR site and localities within it. They named the hardground surfaces at the upper boundaries of these members the Weston, King's Hole, Humble Point and Haven Cliff Neocardioceras hardgrounds respectively. All of these names derive from localities outside the GCR site. They also named the hardground at the top of the Upper Greensand the 'Small Cove Hardground' from a coastal feature near Beer. Robaszynski *et al.* (1998) correlated the sedimentary breaks that these hardground surfaces represent with sequence boundaries in the Cenomanian deposits of northern France, and demonstrated that they lay at consistent stratigraphical levels throughout the north-west part of the Anglo-Paris Basin.

Rowe (1903) provided superb annotated photographs to illustrate the positions of key marker bands in the Chalk at Beer Head (Rowe, 1903, pl. IX); the Pinnacles and the eastern part of Hooken Cliff (pl. X); and the central and western part of Hooken Cliff (pl. XI). These marker horizons were, in ascending order: 'the first flint line dividing the R.c. and T.g.' (*Rhynchonella cuvieri* and *Terebratulina gracilis* zones); two conspicuous marl-rich bands (the '2-ft band' and the '4-ft band') in the *gracilis* Zone; and a 'marl seam dividing T.g. and H.p.' (*Holaster planus* Zone). In the highest part of the succession, he recognized a 'strong double flint line'; a 'strong nodular flint line in the *Holaster planus* Zone'; a 'thin tabular band dividing the *planus* Zone from the *Micraster cortestudinarium* Zone'; and a 'marl seam within the *cortestudinarium* Zone'. His zonation of these sections has proved to be remarkably accurate.

More recent descriptions of all or part of the

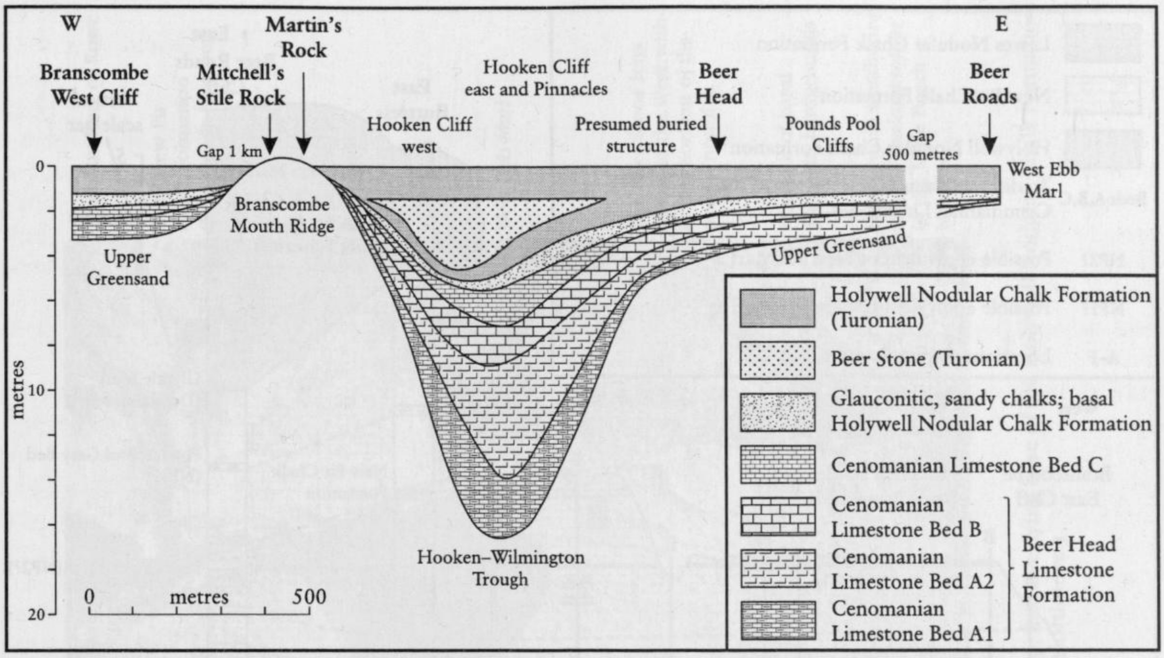


Figure 3.21 Schematic and simplified view of lateral variation in the Cenomanian and Early Turonian deposits of Hooken Cliffs and adjacent areas. The datum is the West Ebb Marl.

south-east Devon successions include those of the Turonian Stage by Jarvis and Woodroof (1984) and Jarvis and Tocher (1987). Jarvis and Woodroof (1984) placed the Chalk overlying the Cenomanian strata into the Seaton Chalk Formation, which they subdivided into the Connett's Hole Member (nodular and shell-detrital chalk, with flints at the top) and the Beer Roads Member (marly chalks with flints). The higher part of the Turonian and basal Coniacian succession exposed in Pinhay Cliffs and in the Annis' Knob block at Beer was later (Jarvis and Tocher, 1987) placed in the St Margaret's Bay Member, which had been established by Robinson (1986) for the approximate equivalent in the North Downs of the Lewes Nodular Chalk Formation.

Jarvis *et al*. (1988a) documented in detail the foraminiferal and dinoflagellate cyst biostratigraphy and the stable isotope stratigraphy across the Cenomanian–Turonian boundary succession at the Beer Stone adit section. Their study complemented previous work on the foraminifera of the Pinnacles section by Carter and Hart (1977a).

Hooken Cliff is particularly famous for the remarkable thinning of the thick Cenomanian arenaceous deposits (Wilmington Sand facies of the Cenomanian Limestone) and the cutting out of the basal Turonian (Holywell Nodular Chalk Formation) chalks westward from the centre of the site onto a positive structure, and the progressive onlap in the same direction of flinty Turonian Chalk (New Pit Chalk Formation) (Figures 3.21 and 3.22). This thinning and overstep, first illustrated by Whitaker (1871), and subsequently described by Rowe (1903), Jukes-Browne and Hill (1903, fig. 80) and Smith (1961, fig. 4b), is further discussed below.

Lithostratigraphy

The site exposes an almost complete section through the Upper Greensand Formation, overlain by up to 80 m of Upper Cretaceous deposits that extend in a continuous succession from the base of the Cenomanian sediments (Cenomanian Limestone Formation) up to a horizon low in the Seaford Chalk Formation of the White Chalk Subgroup. The extensive cliff sections, and their continuation in Branscombe and Salcombe cliffs to the west, and in Beer Cliffs to the east (Figures 3.16, 3.18 and 3.20–3.24), enable the lateral variations to be studied in detail. The exposures within the site provide a transect through the thick Albian to Turonian succession developed in the 'Hooken–Wilmington Trough'.

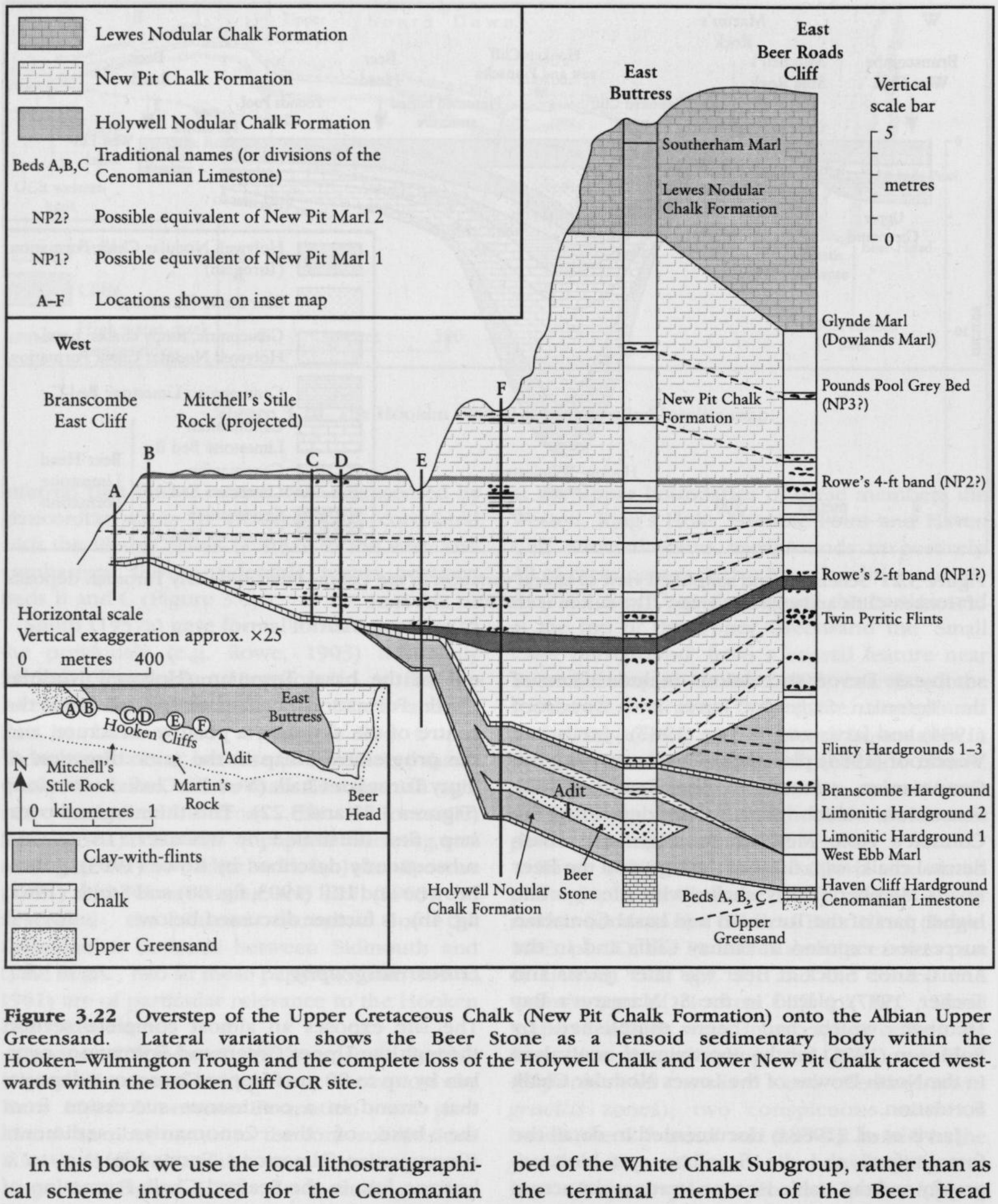


Figure 3.22 Overstep of the Upper Cretaceous Chalk (New Pit Chalk Formation) onto the Albian Upper Greensand. Lateral variation shows the Beer Stone as a lensoid sedimentary body within the Hooken–Wilmington Trough and the complete loss of the Holywell Chalk and lower New Pit Chalk traced westwards within the Hooken Cliff GCR site.

In this book we use the local lithostratigraphical scheme introduced for the Cenomanian Stage by Jarvis and Woodroof (1984), treating the thicker arenaceous developments of Bed A (Pounds Pool and Hooken members) as the arenaceous or 'Wilmington Sand' facies. We choose to use the member names, rather than the traditional beds A1–C in order to reflect the sedimentological complexity of these units. However, we consider that the Pinnacles Member (Bed C) should be regarded as the basal bed of the White Chalk Subgroup, rather than as the terminal member of the Beer Head Limestone Formation (see Figure 3.23). This follows the observations of Wright *et al.* (1984) who stated that Bed C is simply Chalk Basement Bed. In fact, at some localities, for example White Cliff and Haven Cliff, the lithology of Bed C was described by Wright and Kennedy (1981) as quartzose chalk. Except in the centre of Hooken Cliff, the Pinnacles Member is largely co-extensive with the Plenus Marls Member of

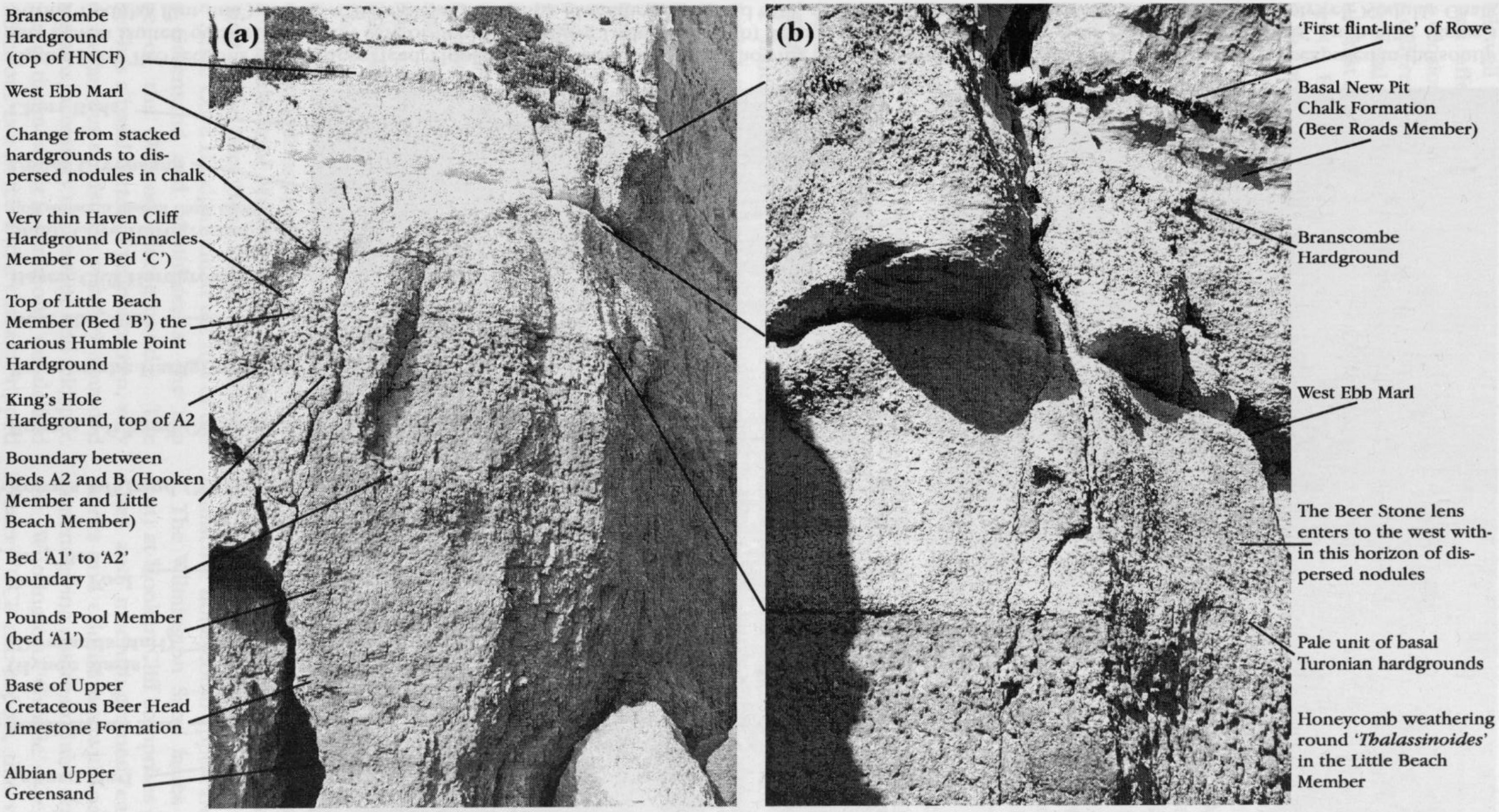


Figure 3.23 (a, b) Beer Head Limestone Formation (Cenomanian Limestone), Grey Chalk Subgroup, and overlying base of the Holywell Nodular Chalk Formation (HNCF) and White Chalk Subgroup at Beer Head, Hooken Cliff, south-east Devon. (Photos: R.N. Mortimore.)

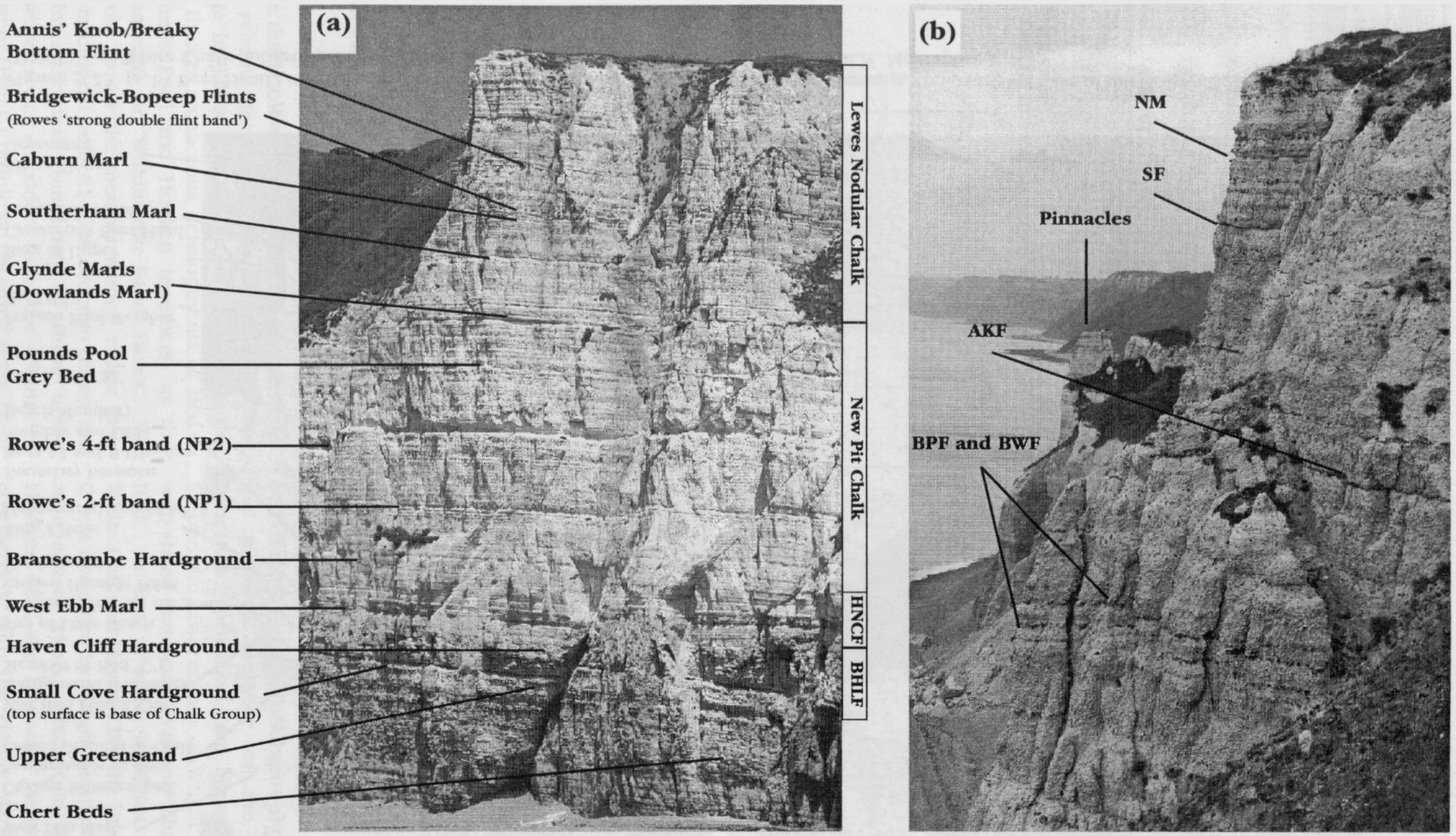


Figure 3.24 Two sections west of Beer Head, Hooken Cliff, south-east Devon, showing the entire undisturbed Upper Cretaceous succession exposed in the south-east Devon faulted outliers. (a) West side of Beer Head above Little Beach. (b) Section on 'Belay Bluff' above Beer Head. (AKF = Annis' Knob Flint (Rowe's 'strong nodular flint line'); BHLF = Beer Head Limestone Formation; BPF and BWF = Bopeep Flints and Bridgewick Flints; HNCF= Holywell Nodular Chalk Formation; NM = Navigation Marl, (Rowe's 'marl in M.c.t.'); NP1, NP2= New Pit Marls 1 and 2; SF = sheet-flint (Rowe's 'Tabular at Base M.c.t.').) (Photos: R.N. Mortimore.)

the Holywell Nodular Chalk Formation, and its base can effectively be regarded as the sub-Plenus erosion surface. However, in view of its totally different lithological character we adopt for this basal unit of the White Chalk Subgroup in south-east Devon the existing name 'Pinnacles Member'. For reasons explained below, we choose to apply the standard lithostratigraphical classification of the lower part of the White Chalk Subgroup into Holywell Nodular Chalk, New Pit Chalk and Lewes Nodular Chalk formations (Rawson *et al.*, 2001), rather than accept the local lithostratigraphical nomenclature introduced by Jarvis and Woodroof (1984), and further modified by Jarvis and Tocher (1987) and Tocher and Jarvis (1987). The highest preserved Chalk belongs to the Seaford Chalk Formation.

Grey Chalk Subgroup: Beer Head Limestone Formation (Cenomanian Limestone Beds A and B and the Wilmington Sand facies)

At the base of the Upper Cretaceous succession, the richly fossiliferous Cenomanian Limestone is exposed at the eastern end of the site at Beer Head (Figure 3.23). It can be traced westwards into a much thicker succession of sandy limestones, calcarenites and calcareous sandstones (Wilmington Sand facies and transitional lithologies) over a distance of a few hundred metres at Little Beach. The Cenomanian Limestone facies reappears at the western end of the site.

The type section for Meyer's (1874) beds 10, 11, 12 and 13 and for the Beer Head Limestone Formation lies within the site, where the succession is thickest and most arenaceous, adjacent to the Beer Stone adit. The descriptions below illustrate the principal features of the end members of the laterally variable succession. The full thickness of the limestone facies of the Beer Head Limestone is perfectly exposed at the foot of Beer Head (SY 227 879), where the following descriptions apply.

The Pounds Pool Member (Bed A1) is the basal unit of the Beer Head Limestone. It rests on the Small Cove Hardground at the top of the Upper Greensand and terminates at the top surface of the Weston Hardground. The member has a basal metre of yellow-brown, very coarse, calcareous sandstone with 50% rounded quartz grains, accessory tourmaline and feldspar. This part of the member is commonly decalcified to weather out as a notch and it contains ripped up blocks of Upper Greensand hardground at the base. These coarse sands are overlain by pale brown, sandy bioclastic limestones containing 35% subangular to rounded quartz grains and *c.* 30% bioclasts. The sandy limestones become more shelly and weakly nodular upwards, and terminate either in a locally developed mineralized hardground (the Weston Hardground), or in a weakly glauconitized and limonite stained surface producing a weak parting penetrated by a *Thalassinoides* burrow system. This basal unit of the formation contains common coralline sponges, *Acanthochaetetes ramulosus* (Michelin) (the '*Ceriopora ramulosa*' of the old literature).

The Hooken Member (Bed A2) is up to 5 m thick at the adit, thinning to 0.9 m at Beer Head. It rests on the underlying Pounds Pool Member and terminates in the well-developed King's Hole Hardground. The basal part is a grey nodular shell-detrital limestone characteristically rubbly, with intraclasts on scour surfaces in thicker sections. Pebble-grade nodules and intraclasts are often cemented together to form larger 100–150 mm complex nodules. Nodules become reworked and weakly glauconitized and/or limonite stained as the member thins towards Beer Head. The unit contains about 30% bioclasts and many large silicified shell fragments. The terminal-intraclastic King's Hole Hardground contains a closely spaced succession of phosphatized surfaces, of which the top one is the most strongly phosphatized and near planar.

The Little Beach Member (Bed B) is about 1.75 m thick at the adit, and slightly thicker at Little Beach. It contains a complex stratigraphy with a basal heavily mineralized convolute hardground at Beer Head (a cavernous hardground). Elsewhere this hardground is replaced by white pebbles and contains many *Holaster subglobosus* (Leske) in sandy biomicrites. These beds are overlain by light grey biomicrites with 30% bioclasts penetrated by a *Thalassinoides* burrow system with a fill of glauconitic sand from the base of the overlying member, giving rise to a distinctive honeycomb appearance.

The Wilmington Sand facies (Bed A equivalent) at Hooken Cliff comprises gritty, shell-rich, fine- and medium-grained calcareous sandstones and calcarenites with patchy calcareous cement giving rise to nodular textures similar to the Wilmington 'Grizzle' (see **Wilmington Quarry** GCR site report, this volume). These pass down into softer (decalcified?) calcarenites and calcareous sands with mostly comminuted shells and common oyster fragments up to 0.05 m across. The base is irregular and rests on the mineralized surface of the Upper Greensand calcarenite (i.e. the Small Cove Hardground).

White Chalk Subgroup

The White Chalk Subgroup at Hooken Cliff includes the Pinnacles Member (Bed C of the traditional Cenomanian Limestone succession) and all of the overlying Chalk (Figures 3.9, 3.11, 3.23 and 3.24).

The Pinnacles Member is 2.3 m thick at the adit, thinning to less less than 0.1 m at Little Beach (Figure 3.20). The basal few centimetres contain 40% quartz sand and 15–20% glauconite in a biomicrite matrix. The succession continues with white nodules, a limonitic nodule hardground with phosphatized surface that in turn is overlain by friable sandy glauconitic limestones. As the member thins towards Beer Head, the limonitic nodule hardground converges with the Humble Point Hardground and, at Beer Head itself, the member is represented only by the massively indurated terminal Haven Cliff Hardground.

The Pinnacles Member is thicker and more complex in the centre of Hooken Cliff than elsewhere in the region (see '**Interpretation**' below).

Above the Pinnacles Member is an unbroken succession of Lower Turonian to Middle Coniacian chalks (Holywell Nodular Chalk, New Pit Chalk, Lewes Nodular Chalk and Seaford Chalk formations). The most westerly lower New Pit Chalk Formation is preserved on top of the cliffs at Salcombe Regis (Figure 3.1). The Chalk successions in the eastern (more accessible) parts of Hooken Cliff and Beer Head are illustrated in Figures 3.9, 3.11, 3.16, 3.23 and 3.24. When traced westwards through Hooken Cliff into Branscombe East Cliff (Figure 3.17), the oldest beds (Holywell Nodular Chalk Formation) are cut out, as younger strata (New Pit Chalk Formation) onlap the structural high ('Branscombe Mouth Ridge' of the literature) that here forms the western boundary of the southern end of the Hooken–Wilmington Trough (Figures 3.21 and 3.22). A low easterly dip causes the higher part of the succession to be cut out in the same direction by the erosion surface at the base of the overlying Clay-with-flints. The stratigraphically highest Chalk at Hooken Cliff (Seaford Chalk Formation), is preserved within a large karstic (solution) collapse feature above Beer Head (Figure 3.16).

Holywell Nodular Chalk Formation: This formation also shows rapid lateral facies variations within the Hooken–Wilmington Trough. It comprises a series of nodular beds described in detail by Jarvis and Woodroof (1984). In the lower part of the formation, a variably developed marly bed, the West Ebb Marl, provides an important marker horizon for correlation (Figures 3.21–3.24).

The lower part of the Holywell Nodular Chalk Formation, below the West Ebb Marl, displays a marked thickening towards the centre of the site owing to the development of the lenticular Beer Stone (Figures 3.21 and 3.22). This is a grey, fine-grained calcarenite, up to 3 m thick, composed largely of fragmented echinoderm (micro-crinoid) plates which sparkle in the sun. It is virtually the only true 'freestone' in the British Chalk, for although it contains some patches with bioturbation and a few fossils, it is largely homogeneous in grain-size and texture. The stone has been worked almost continuously since Roman times, and has been used in the cathedrals at Exeter, Winchester and Norwich, and in many churches and houses in east Devon. The conspicuous adit, high in the cliff in the centre of the site, marks the position of a former working for Beer Stone.

The Holywell Nodular Chalk Formation within the site is capped by a prominent iron-stained massive hardground, the Branscombe Hardground (Figure 3.24; Jarvis and Woodroof, 1984), for which this site is the type locality (Tocher and Jarvis, 1987). The hardground here marks a major break in sedimentation, and a sudden change from nodular, non-flinty chalks to the smooth-textured, marly chalks with numerous flint-rich bands that characterize the local equivalent of the New Pit Chalk Formation, the 'Beer Roads Member' of Jarvis and Woodroof (1984). However, this hardground rests on a relatively low level in the Holywell Nodular Chalk Formation, with much of the higher part of the formation being absent here.

New Pit Chalk Formation: From a distance (Figure 3.24), the New Pit Chalk Formation looks exactly like the smoother chalk, seamed with marl, that is characteristic of it in the main basin. Close to, this chalk is seen to contain many flint bands. At the Pinnacles, these flints are often small, finger- and *Zoophycos*-like at the base (reminiscent of the Glyndebourne Flints (see **Southerham Pit** GCR site report, this volume)), while others have a columnar arrangement. Within the New Pit Chalk at Hooken Cliff are several conspicuous marker bands, seen particularly well on photographs (Figures 3.16, 3.18, 3.23 and 3.24). These include the marl-rich '2-ft' and '4-ft' bands identified by Rowe (1903) (and also recognized by Meyer, 1874 and by Jukes-Browne and Hill, 1903), which weather-out as conspicuous grooves that can be traced almost continuously in the cliffs from Beer to Beer Head and through part of Hooken Cliff. The '2-ft' band (= New Pit Marl 1) progressively oversteps the lower part of the New Pit Chalk Formation and the underlying Holywell Nodular Chalk Formation westwards within the site, and comes to rest at Mitchell's Stile Rock on the merged Branscombe and Haven Cliff hardgrounds and the underlying Pounds Pool Member of the Beer Head Limestone (Figures 3.22 and 3.24). At this point, the composite succession above the Pounds Pool Member up to the Haven Cliff Hardground, and from the Haven Cliff Hardground up to the Branscombe Hardground, has been cut out. Farther to the west, Turonian chalk actually rests on the Upper Greensand.

The so-called '4-ft band' (= New Pit Marl 2) is actually about 3.5 m thick in the central part of the site; the base of the bed can be recognized immediately beneath the Clay-with-flints as far west as Branscombe East Cliff (Figure 3.22). The highest bed of the New Pit Chalk, the Glynde or Dowlands Marl (Rowe's 'marl seam at the base of the *Holaster planus* Zone'), can also be traced as a conspicuous groove high in the cliff; marking the approximate base of nodular chalk. Over much of the section it forms the lower limit of karstic (solution) action at the base of the Clay-with-flints. All of these marl seams were also formerly seen in inland quarry sections west of Beer (Jukes-Browne and Hill, 1903, 1904).

The conspicuous marker beds in the New Pit Chalk Formation are considered to be correlatives of the main basin markers, specifically the New Pit and Glynde marls.

Lewes Nodular Chalk Formation: This formation enters above the Dowlands (Glynde) Marl and is composed of nodular and very nodular chalks and chalkstones with numerous hardgrounds and flint-rich beds (some with very large flints), as well as several thin, but laterally persistent marl seams that enable the Hooken Cliff succession to be correlated with the sections at Allhallows (SY 312 906) and Chapel Rock (SY 291 899), west of Lyme Regis (Figure 3.19). These marl seams also corrrespond to basin-wide marker beds including the Southerham, Caburn, Lewes and Navigation marls (Figure 2.9, Chapter 2). The Lewes Nodular Chalk Formation at Hooken Cliff is capped by a strongly mineralized hardground, the Chapel Rock Hardground (Jarvis and Tocher, 1987). This hardground marks a major lithological change from nodular chalks to the soft white chalks of the overlying Seaford Chalk Formation with many horizons of medium-sized flints, thick tabular flints and, in the stratigraphically highest preserved beds, paramoudra flints.

Biostratigraphy

The Upper Cretaceous succession of the site extends from the basal Cenomanian *Neostlingoceras carcitanense* Subzone of the ammonite *Mantelliceras mantelli* Zone up to the lower part of the traditional *Micraster coranguinum* Zone (Middle Coniacian), the equivalent of the *Volviceramus koeneni* and *V. involutus* zones of the inoceramid bivalve zonal scheme. Equivalents of the traditional *Mytiloides* spp., *Terebratulina lata*, *Sternotaxis plana* and *Micraster cortestudinarium* zones can also be recognized.

The Cenomanian strata (Figure 3.4; Figure 2.8, Chapter 2) of the coastal sections contain a diverse and commonly well-preserved fauna, which is well represented in museum and other collections. Most of this material has been systematically collected using the traditional subdivision into beds A1, A2, B and C. In-situ sections (Figure 3.19) of the condensed Cenomanian succession, east of Hooken Cliff, at Whitecliff (Seaton) (SY 235 895), Shapwick Grange Quarry (Uplyme) (SY 312·918) and in fallen blocks below the Undercliff Landslip (notably below Haven Cliff, SY 262 896) and at Humble Point (SY 307 899) have yielded an extraordinarily diverse ammonite fauna that forms the basis for the current zonation. The Cenomanian deposits exposed at the eastern end of Hooken Cliff have yielded few of these species, largely because of its tough, unweathered state and its relative inaccessibility. The lithological correlation is, however, sufficiently clear to suggest that the same zones and subzones are present.

The Pounds Pool Member (Bed A1) at Hooken Cliff has yielded ammonites including *Mantelliceras cantianum* Spath, *M.* spp., *Mariella cenomanensis* (Schlüter) and *Schloenbachia* spp. (Kennedy, 1970), some of which show signs of intraformational reworking (Wright *et al.*, 1984). The small rhynchonellid brachiopod *Cyclothyris schloenbachi* (Davidson), terebratulid brachiopods, fragmentary oysters and pectinacean bivalves, several species of echinoid, including *Catopygus columbarius* (Lamarck) and *Holaster* spp., and crustacean remains are locally common. The Pounds Pool Member has also been known as the 'Ceriopora Limestone' because of the abundance in it, particularly towards the base, of broken, rolled and bored fragments of the coralline sponge *Acanthochaetetes ramulosus*, which was formerly regarded as a giant bryozoan, and referred to the genus *Ceriopora* (see Hart and Johnson, 1984). This sponge also occurs in the Basement Bed of the Wilmington Sand at **Wilmington Quarry** and **Reeds Farm Pit** (see GCR site reports, this volume). At the latter locality, the bed contains a rich basal Lower Cenomanian *Neostlingoceras carcitanense* Subzone ammonite fauna.

In the Hooken Member (Bed A2), the diverse ammonite fauna includes species of *Hyphoplites*, *Hypoturrilites*, *Mantelliceras* and *Schloenbachia*, and was assigned (Wright *et al.*, 1984) to the *Mantelliceras saxbii* Subzone of the *Mantelliceras mantelli* Zone; locally the overlying *M. dixoni* Zone was also represented. Apart from a record (Wright and Kennedy, 1987) of a specimen of the zonal index ammonite from the Cenomanian Limestone ('precise horizon unknown') of the Hooken Landslip, there is no evidence for the *Sharpeiceras schlueteri* Subzone. The Hooken Member is sedimentologically complex and some of the apparently well-preserved ammonites are reworked limestone pebble fossils incorporated in a limestone matrix. The occurrence of the inoceramid bivalve *Inoceramus virgatus* Schlüter (recorded by Jukes-Browne and Hill (1903) from Hooken Cliff as *I. striatus*) and *Mantelliceras dixoni* Spath at many localities clearly points to the fauna belonging largely to the *dixoni* Zone (see Figure 3.4). The higher part of the member at Hooken Cliff is characterized by the large, highly ornate pectinacean bivalve *Merklinia aspera* (Lamarck) (the *Pecten asper* of earlier literature).

In the Little Beach Member (Bed B), phosphatic and limestone pebbles at the base contain a phosphatized ammonite assemblage derived from the Middle Cenomanian *Turrilites costatus* Subzone of the *Acanthoceras rhotomagense* Zone, including *Acanthoceras rhotomagense* (Brongniart), *Calycoceras* (*Newboldiceras*) *asiaticum asiaticum* (Jimbo) and *Turrilites costatus* Lamarck (A.S. Gale, pers. comm., 2000). There is also some evidence from localities east of Beer for reworked *dixoni* Zone ammonites, including *Hyphoplites*, *Mantelliceras* ex gr. *dixoni* Spath, *M. lymense* (Mantell) and *Schloenbachia* (Kennedy, 1970). As noted by Wright *et al.* (1984), it is difficult in some cases to distinguish between material from the top of Bed A2 and that from the base of Bed B, particularly where the boundary between the two units is ill-defined. Between the Hooken Member and Little Beach Member there is a major hiatus comprising the higher part of the *dixoni* Zone, the basal Middle Cenomanian *Cunningtoniceras inerme* Zone and the sediment of the *costatus* Subzone. The abundance of the echinoid *Holaster subglobosus*, together with smaller numbers of *Conulus castanea* (Brongniart), above the pebble bed at the base of the Little Beach Member at Hooken Cliff is indicative of the *Turrilites acutus* Subzone. The higher part of the member here has yielded to Professor Gale rare indigenous examples of the zonal index fossil, *Acanthoceras jukesbrownei* (Spath), together with *Calycoceras* (*Newboldiceras*) *tunetanum* (Pervinquière) and *C.* (*N.*) *planecostum* (Kossmat), indicating that the sediment itself is of *jukesbrownei* Zone age. This interpretation of the ammonite biostratigraphy of this member corrects that presented by Robaszynski *et al.* (1998).

At the base of the Pinnacles Member the rich phosphatized ammonite assemblage has been largely derived from the *Calycoceras guerangeri* Zone, with a few of the more strongly phosphatized specimens coming from the underlying *Acanthoceras jukesbrownei* Zone. Knowledge of this assemblage is mainly based on extensive collections made from fallen blocks, particularly at Humble Point, that have split open along this surface; and also from **Wilmington Quarry** (see GCR site report, this volume) and Shapwick Grange Quarry. Some of these *guerangeri* zonal elements, for example *Thomelites sornayi* (Thomel) and the zonal index fossil itself, have been collected ***in situ*** in chalk facies 3 to 4 m and 7 to 8 m below the Plenus Marls Member at Ballard Cliff, Dorset (see **Handfast Point to Ballard Point** GCR site report, this volume) and Beachy Head, Eastbourne (see Figure 3.112, p. 251) respectively (Wright and Kennedy, 1996). Wright and Kennedy (1987) recorded four specimens of *Protacanthoceras tuberculatum devonense* Wright and Kennedy from the Hooken Cliff GCR site. The main mass of the Pinnacles Member contains a glauconitized Upper Cenomanian *Metoicoceras geslinianum* Zone ammonite fauna. This includes *Euomphaloceras septemseriatum* (Cragin), *M. geslinianum* (d'Orbigny), *Pseudocalycoceras angolaense* Spath, *Sciponoceras gracile* (Shumard) and *Tarrantoceras* (*Sumitomoceras*) *cautisalbae* Wright and Kennedy, together with non-glauconitized elements including *Allocrioceras annulatum* (Shumard), the belemnite *Praeactinocamax plenus* (Blainville), the rhynchonellid brachiopods *Orbirhynchia multicostata* Pettitt and *O. wiesti* (Quenstedt) and the echinoid *Camerogalerus cylindricus* (Lamarck). In the Hooken Cliff GCR site, *Praeactinocamax plenus* and *Orbirhynchia wiesti* are well represented, but there seem to be no published ammonite records. Uniquely at this site, the Pinnacles Member succession is thicker and more complex, and may possibly include a pre-*geslinianum* Zone, i.e. a *guerangeri* Zone component, in the lower part of the bed (see below). At Shapwick Grange Quarry, the highest part of the Pinnacles Member contains an exotic Tethyan ammonite assemblage that includes *Puzosia odiensis* Kossmat, *Kamerunoceras* aff. *puebloense* (Cobban and Scott), *Nigericeras* cf. *gignouxi* Schneegans, *Thomasites gongilensis lautus* (Barber) and *T. gongilensis tectiformis* (Barber).

The Haven Cliff Hardground, at the top of the Pinnacles Member, contains moulds of ammonites belonging to the terminal Cenomanian *Neocardioceras juddii* Zone assemblage, including the zonal index fossil and *Sciponoceras* sp., as well as spines of the regular echinoid *Hirudocidaris hirudo* (Sorignet). At Haven Cliff, these fossils, together with *Thomelites serotinus* Wright and Kennedy and the inoceramid bivalve *Mytiloides hattini* Elder, are concentrated as glauconitized pebbles on the surface of the hardground, forming the so-called '*Neocardioceras* Pebble-Bed'.

In comparison with the Cenomanian deposits, the basal Turonian Chalk successions are sparsely fossiliferous. With the exception of relatively common *Watinoceras devonense* and *Mammites nodosoides* (Schlotheim), immediately above the Haven Cliff Hardground and in the lower part of the Holywell Nodular Chalk Formation respectively, ammonites are rare. *Lewesiceras peramplum* (Mantell), *Metasigaloceras rusticum* (J. Sowerby), *Morrowites wingi reveliereoides* Wright and Kennedy and *M. wingi wingi* (Morrow) have been recorded from low in the Holywell Nodular Chalk Formation of the coast sections adjacent to the site, and the same level at Haven Cliff has yielded *Fagesia catinus* (Mantell), *Kamerunoceras turoniense* (d'Orbigny), and the only known British record of *Lecointriceras fleuriausianum* (d'Orbigny). These last three species are typically Tethyan in their distribution and also occur in the type Turonian section of Touraine.

The Holywell Nodular Chalk Formation at Hooken Cliff contains a rich fauna of (predominantly small) echinoids, notably *Camerogalerus minimus* (Desor) (*Discoidea dixoni* Forbes of the older literature), *Hemiaster nasutulus* Sorignet (*H. minimus* Agassiz), *Cardiaster truncatus* (Goldfuss) (*C. pygmaeus*), *Cardiotaxis cretacea* (Sorignet), *Conulus castanea*, *Hirudocidaris hirudo* and *Tylocidaris sorigneti* (Desor). Rowe (1903, p. 2) commented that 'This coast affords a scope for the study of Echinoderma which alone would render any section famous.', and noted (p. 33) that he had collected 30 specimens of *Conulus castanea* (13 from a single block) at Hooken Beach. *Micraster* also appears at this level, which is unusually low compared with its first occurrence elsewhere in the Southern Province. Immediately west of Branscombe Mouth, just outside the site limits, the echinoid assemblage in the equivalent beds is dominated by abundant spines and tests of *Hirudocidaris hirudo* and *Tylocidaris sorigneti*, together with ossicles of the asteroid *Metopaster cornutus* Sladen.

Apart from echinoids, inoceramid bivalves are the most common fossils in the Holywell Nodular Chalk Formation. They include *Mytiloides labiatus* (Schlotheim) and *M. mytiloides* (Mantell), indicative of the Lower Turonian '*Mytiloides* spp.' Zone or *Mammites nodosoides* ammonite Zone. The occurrence of *Mytiloides* shells encrusted by the serpulid

Filograna avita (J. Sowerby) ('*Filograna avita* event'), first observed here and in Dorset by Rowe (1901, 1903), and found in the middle part of the Holywell Nodular Chalk Formation (*M. nodosoides* Zone) throughout the Southern Province and the Anglo-Paris Basin, has been identified in the very condensed succession above the West Ebb Marl at West Ebb, north of Beer Head (Gale, 1996, fig. 4). In the Hooken Cliff sections, the erosive Branscombe Hardground has presumably cut out this key marker horizon (cf. Jarvis and Woodroof, 1984, fig. 4). *Terebratulina lata* R. Etheridge, the zonal index fossil of the *T. lata* Zone, which elsewhere in the Southern Province enters in the lower part of the New Pit Chalk Formation, appears in the thick Lower Turonian succession at Beer at the level of the 'first flint-line' (Rowe, 1903), i.e. at the base of the higher (flinty) part of the Holywell Nodular Chalk Formation. The inoceramid bivalves at this level appear to belong to the *M. subhercynicus* (Seitz)–*hercynicus* (Petrascheck) group and these are also common at the base of the New Pit Chalk Formation (see Glyndebourne Pit description in the **Southerham Pit** GCR site report, this volume).

Terebratulina lata is common throughout the New Pit Chalk Formation and is reported (Rowe, 1903) to be larger here than elsewhere. Other common macrofaunal elements (for a full list see Rowe, 1903) are *Micraster corbovis* Forbes of *lata* Zone type, and the inoceramid bivalves *Inoceramus cuvieri* J. Sowerby and *I. lamarcki* Parkinson.

The Lewes Nodular Chalk Formation of Hooken Cliff is richly fossiliferous; echinoderms, brachiopods and bivalves are abundant at many levels. The fauna is similar to that of the type area, comprising echinoids (abundant *Micraster* spp., including *M. corbovis* Forbes, *M. leskei* Desmoulins and *M. normanniae* Bucaille, *Sternotaxis plana* (Mantell)), inoceramid bivalves (common thick-shelled *Inoceramus* spp. in the lower and middle parts and *Cremnoceramus,* indicative of the Coniacian, in the highest part, above the Annis' Knob Flint), common *Orbirhynchia* and terebratulid brachiopods.

The lower part of the Seaford Chalk Formation is well exposed at the eastern end of the site, but in sections that are mostly deeply weathered and difficult to access. The only common fossils are large shell pieces, many being several centimetres across, of the inoceramid bivalve genera *Platyceramus* and *Volviceramus.*

Micropalaeontology

The foraminiferal biostratigraphy of the Cenomanian–Turonian succession at the Pinnacles was described by Carter and Hart (1977a) and that of the nearby Beer Stone adit section by Jarvis *et al.* (1988a).

By extrapolation from the Beer Roads section (Hart and Weaver, 1977; Hart, 1997, fig. 2), the condensed Holywell Nodular Chalk Formation of the Hooken Cliff GCR site belongs to the *Helvetoglobotruncana helvetica* Interval Zone of the planktonic foraminifer zonal scheme, with the basal beds, i.e. up to just above the West Ebb Marl, falling in the *Hedbergella archaeocretacea* Partial Range Zone. The overlying *Marginotruncana sigali* Interval Zone extends from the base of the New Pit Chalk Formation up to a horizon *c.* 2 m above the '4-ft band'. The overlying succession belongs in part to the *Marginotruncana pseudolinneiana* Interval Zone (Figure 2.41, Chapter 2). The giant agglutinating foraminifer, *Labyrinthidoma southerhamensis* Hart (recorded by Rowe (1903) as *Haplophragmium*, and usually cited as '*Coskinophragma*' sp. (see Hart, 1993)), occurs in large numbers in several thin bands, mostly marl seams, over a similar stratigraphical range to that in the New Pit Chalk Formation of the type area around Lewes, Sussex, but enters here in the higher (flinty) part of the Holywell Nodular Chalk Formation. The tests of this microfossil are larger in Devon than elsewhere. At Hooken Cliff, *Labyrinthidoma* is first seen at the base of the New Pit Chalk Formation. By extrapolation from the Annis' Knob section, Beer (Bailey, 1975; Hart and Weaver, 1977; Hart, 1997), the highest preserved Lewes Nodular Chalk Formation at Beer Head (*Sternotaxis plana* and *Micraster cortestudinarium* macrofossil zones) belongs to the *Marginotruncana coronata* and overlying *Whiteinella baltica* interval zones (Figure 2.41, Chapter 2).

The dinoflagellate cyst biostratigraphy of the Holywell Nodular and New Pit Chalk formations at Hooken Cliff, Beer Roads cliffs and Beer Quarry, has been documented by Tocher and Jarvis (1987).

Interpretation

The 'Cenomanian Limestone' (see Figures 3.21 and 3.23), can be traced eastwards, as a continuous hard bed at the foot of the cliffs, for 2 km from Beer Head to Beer Roads. At the latter locality, it consists of a highly condensed, splintery limestone that is only 0.4 to 0.6 m thick and contains several coalescing hardground surfaces. Eastwards from Beer to its most easterly known occurrence near Lyme Regis, the Beer Head Limestone remains highly condensed and less than 1 m thick. It can also be traced westwards from Hooken Cliff in discontinuous cliff sections and fallen bocks, as far as Salcombe Regis (Figure 3.1).

Inland, the full thickness of the arenaceous facies of the Cenomanian succession was formerly exposed in Bovey Lane Quarry (SY 217 899), 2 km north of the site; the upper part is exposed from time to time in the floor of the nearby working Beer quarries (Figure 3.17). The published records (Smith, 1961; Smith and Drummond, 1962) of the faunal and lithological succession at Bovey Lane Quarry provide a useful link between the successions at Hooken Cliff and **Wilmington Quarry** (see GCR site report, this volume).

The Pinnacles Member (Bed C) succession is thicker and more complex in the centre of the Hooken Cliff GCR site than elsewhere in the region. The lower part of the member includes two accumulations of white nodules and phosphatized intraclasts in a glauconitic sand matrix. Towards the top of the member there is a phosphatized and limonitized hardground (the informally named 'limonitic nodule hardground' of Jarvis and Woodroof, 1984), overlain by a concentration of phosphatized intraclasts including fossils. The occurrence of unphosphatized specimens of the eponymous belemnite of the Plenus Marls, *Praeactinocamax plenus,* at this level suggests that the hardground probably correlates with the erosion surface at the top of Bed 3 of the standard Plenus Marls succession of Jefferies (1963). However, carbon stable isotope (Jarvis *et al.*, 1988a, fig. 4) and microfaunal (foraminiferal) data point to a significant hiatus at this level, involving the equivalent of the lower part (Jefferies' beds 1–3) of the Plenus Marls and the top few metres of the underlying Zig Zag Chalk Formation. It is therefore probable that the terminal Bed 3 erosion surface is superimposed directly on the sub-Plenus erosion surface. The lower (glauconitic) part of the Pinnacles Member was considered by Jarvis *et al.* (1988a) to pre-date the (*geslinianum* Zone) Plenus Marls, i.e. to be of *Calycoceras guerangeri* Zone age, but this interpretation is controversial.

Towards Beer Head, following the Jarvis *et al.* (1988a) interpretation, the superimposed Bed 3 and sub-Plenus erosion surfaces converge to rest on the Humble Point Hardground at the top of the Little Beach Member. This hardground and the accumulation of phosphatized fossils that is associated with, and overlies it, may represent a sequence boundary that has recently been identified in the Upper Cenomanian succession (equivalent of the *guerangeri* Zone) of northern Spain (Wiese and Wilmsen, 1999). It may also equate with the Eastbourne Sponge Bed at Beachy Head in Sussex (see Figure 3.112, p. 251). Where the member is thin, the basal glauconitic sand is preserved only in the fills of the burrows that penetrate the Little Beach Member. The higher part of the Pinnacles Member also thins in this direction, so that the member is eventually represented merely by a thin composite bed comprising the Haven Cliff Hardground and the subjacent nodular chalk (Jarvis and Woodroof, 1984, fig. 2).

The thicker, more arenaceous sequences at the Hooken Cliff and **Wilmington Quarry** GCR sites, and at intermediate sites, lie within a 'Hooken–Wilmington' depositional trough (Figures 3.17, 3.19 and 3.21), which is bounded by deep-seated faults that strongly influenced sedimentation in the Cenomanian and Turonian ages. The dominant structure consists of a series of approximately north–south faults, which are closely related to the boundaries of the Cretaceous outliers (Figure 3.19). Local thickening of the Cenomanian strata into the Hooken–Wilmington Trough (Figure 3.21) is associated with a change from, the margins, where limestones with mineralized surfaces are present, to calcarenites (Wilmington Sand facies) in the centre of the trough. In the lower part of the Lower Turonian Holywell Nodular Chalk Formation, the calcarenitic Beer Stone, is developed only in the same structural feature. The trough extends northwards, through the area to the west of Beer with the Beer Stone quarries and the Bovey Lane Quarry, to the Wilmington outlier; its eastern boundary, in particular, parallels the Wilmington Fault, with its downthrow to the west. At **Wilmington**

Quarry and **Reeds Farm Pit** (see GCR site reports, this volume), the Hooken Member is represented by the highly fossiliferous Wilmington Sand; nearby, the Beer Stone was formerly quarried as the 'Sutton Stone'. The Beer Stone is generally inferred to equate with the similarly bioclastic (microcrinoid debris) sediment of the bed between Holywell Marls 2 and 3 of the expanded Southern Province sections. The latter bed belongs to the *Fagesia catinus* ammonite Zone (Gale, 1996).

The stratotype Branscombe Hardground, as seen in and immediately adjacent to the Hooken Cliff GCR site only, actually represents a convergence of all the hardgrounds from the higher (flinty) part of the Holywell Nodular Chalk Formation onto a hardground overlain by marly chalk, to form a single massively indurated hardground (see Jarvis and Woodroof, 1984, figs 4–6). Those authors also show that this hardground further converges with the two highest 'limonitic hardgrounds' in the non-flinty lower part of the Holywell Nodular Chalk Formation above the West Ebb Marl. Some 9 m of sediment at Beer Roads are represented by a hiatus at the surface of the Branscombe Hardground (Tocher and Jarvis, 1987). The flinty part of the Holywell Nodular Chalk Formation, which is best developed and thickest in the sections immediately east of Beer, has cut out completely in the Pounds Pool cliffs, to the north of Beer Head, and is not represented at all at Hooken Cliff (see Figure 3.22). It follows that Rowe's 'first flint line' at the base of the *gracilis* (i.e. *lata*) Zone in the site is not equivalent to his 'first flint line' in the cliffs east of Beer, since these flints are located in the basal New Pit Chalk Formation and Holywell Nodular Chalk Formation respectively.

The New Pit Chalk Formation is more flinty in Devon than elsewhere in southern England, which led Jarvis and Woodroof (1984) to introduce the term 'Beer Roads Flinty Chalk Member'. However, the flints apart, the gross lithologies of the member are not dissimilar to those of the type sections in Sussex. In view of the fact that it was recently decided (Rawson *et al.*, 2001) to accept lateral lithological variations within the standard lithostratigraphical framework of formations, there is no need to retain the new name. The same argument applies in the case of the Connett's Hole Nodular Chalk Member (Jarvis and Woodroof, 1984), which differs from the standard Holywell Nodular Chalk Formation only in the fact that the higher part is flinty. Even this difference is not particularly significant, for the Holywell Nodular Chalk Formation contains flints towards the top on the Dorset coast, and is markedly flinty in the northern Chiltern Hills. The introduction, by those authors, of the new term 'Seaton Chalk Formation' for an interval that essentially comprises the Holywell Nodular and New Pit Chalk formations of the standard scheme (Rawson *et al.*, 2001), is likewise not followed here.

Subsequent work has largely confirmed the correctness of Rowe's (1903) zonation of the Chalk in and adjacent to the Hooken Cliff GCR site. The 'first flint line' lies just above the Branscombe Hardground, which marks the base of the modern *Terebratulina lata* Zone, and the 'marl seam' (Dowlands Marl = Glynde Marl after the section in the Dowlands Landslip between Axmouth and Lyme Regis) marks (albeit somewhat below) the approximate base of the *Sternotaxis plana* Zone. This marl seam is also close to a rapid upward change from the smooth-textured marly chalks of the New Pit Chalk Formation to the nodular chalks of the Lewes Nodular Chalk Formation.

The Chalk successions at Hooken Cliff can be matched in detail with those to the east in Beer Cliffs, Allhallows Cliffs and at Chapel Rock. There are, however, significant local lithological variations, especially in the Holywell Nodular Chalk and the New Pit Chalk formations, that are probably due to penecontemporaneous fault activity.

Conclusions

The extensive exposures in the Hooken Cliff GCR site, including Hooken Cliffs, Branscombe East Cliff, Beer Head and the Pinnacles, provide continuous exposures through some of the most unusual facies variations in the Cenomanian and Lower Turonian strata that can be observed anywhere in the Southern Province. The site includes the stratotype section for the arenaceous limestones and sands comprising the Cenomanian deposits of Devon. The westward thinning of these Cenomanian arenaceous sediments, and the overlying Lower Turonian chalks, onto a structural high, and their progressive onlap by Middle Turonian (New Pit Chalk Formation) flinty chalks, is unique in Britain. The preservation in a karstic collapse structure of an Upper Turonian and Coniacian Chalk succession, extending up to the lower part of the

Seaford Chalk Formation, indicates the former extension of these beds to the west of the exposures in the landslip between Lyme Regis and Seaton. The rich echinoid faunas in the Lower Turonian Holywell Nodular Chalk Formation are of critical importance in evolutionary studies, notably the classic example of the heart-urchin *Micraster*.

WILMINGTON QUARRY, SOUTH-EAST DEVON (SY 209 997)

Introduction

The entrance to the Wilmington Quarry ('White Hart Sandpit') is situated opposite the White Hart Inn, Wilmington (Figure 3.25). The quarry was worked for calcareous sands and calcarenites (Wilmington Sand), which had become largely decalcified. The sands occur beneath a thin capping of Beer Head Limestone Formation and basal White Chalk Subgroup (Holywell Nodular Chalk Formation) and, on the southern and western sides of the quarry, Clay-with-flints. In the south-west corner, where the Clay-with-flints is at its thickest, it infills deep, wide dissolution pipes separated by isolated pillars of Wilmington Sand calcarenites overlain by the Chalk. The sand workings consisted of a number of small, hand-dug pits at the time of Jukes-Browne's (1898) visit, but these subsequently became amalgamated and the workings now cover about 5 hectares (Figure 3.25). They were dug to a depth of 12 to 15 m, but are now mostly backfilled and only the upper part of the succession has been exposed in recent years.

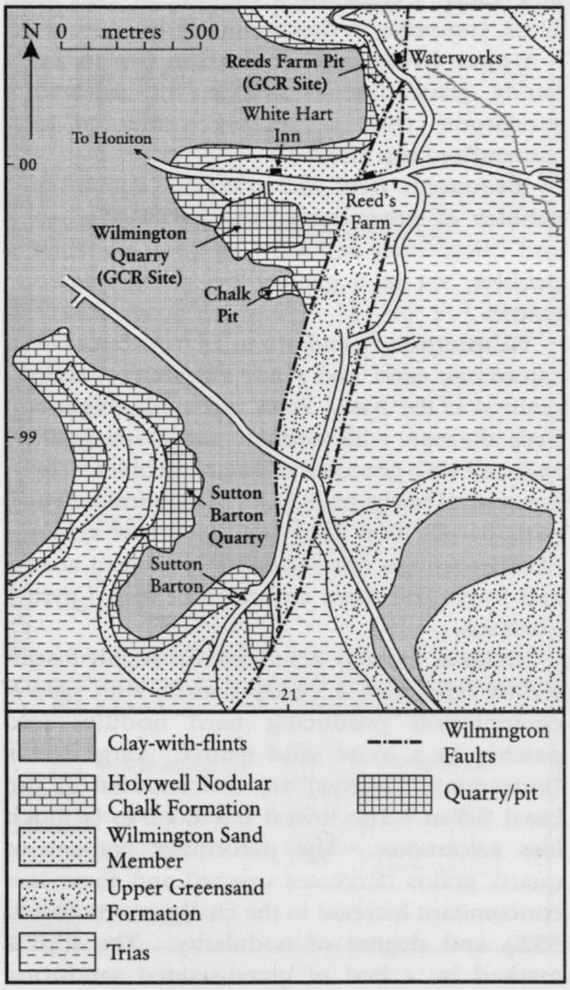


Figure 3.25 Geological setting of Wilmington Quarry, **Reeds Farm Pit** and adjacent sections, south-east Devon.

Wilmington Quarry has yielded over 300 fossil species, one of the most diverse Cenomanian faunas recorded anywhere in the Anglo-Paris Basin. The site is especially rich in fossil brachiopods, bivalves, echinoderms and crabs, and includes many species that are unknown elsewhere in Britain. Fossil crabs are rare in the Upper Cretaceous Series in Britain except in the sandy Cenomanian deposits of Devon. Of the 28 recorded species, 24 are present at Wilmington. The echinoderms recorded by Smith *et al.* (1988) comprise 36 species of echinoid, 10 of which had not previously been recorded in Britain, 18 species of asteroid and 7 species of crinoid. This richness in fossils is partly explained by the geological setting of the site within the structurally controlled 'Hooken–Wilmington Trough' (Figures 3.19 and 3.21), within which the arenaceous facies of the Cenomanian and the Lower Turonian Beer Stone is developed. It exposes a key section that complements that of **Hooken Cliff** (see GCR site report, this volume). The quarry provides the best remaining inland exposures of the Lower Cenomanian Wilmington Sand facies of the Hooken Member (Bed A2) of the Beer Head Limestone Formation. It is also the most northerly exposure of the Beer Stone.

Description

Wilmington Quarry was worked for building sand from the early part of the 19th Century until 1993. The section was first recorded by Fitton (1836, p. 234), who noted that 'a stone called 'Grizzle' by the quarry-men is dug ... about 5 feet (1.5 m) in thickness ... it contains green particles and does not burn to lime'. Jukes-Browne (1898) recorded a diverse Cenomanian fauna from the Wilmington Sand that he subsequently correlated with that of Bed A2 of the 'arenaceous beds' or Zone of *Ammonites mantelli* of the coastal sections (Jukes-Browne and Hill, 1903, p. 129). The unusual lithologies and the highly fossiliferous nature of the Wilmington section attracted numerous later researchers, who have made it one of the most studied and best-documented Cenomanian successions in the Southern Province. The more important works include Jukes-Browne and Hill's (1903) and Smith's (1957b) descriptions of the stratigraphy as a whole, Kennedy's (1970, 1971) and Wright and Kennedy's (1981, 1984) descriptions of the lithostratigraphy and the ammonite sequence, and Smith *et al.*'s (1988) description and analysis of the echinoderm faunas. Hart (1983) described the foraminiferal biostratigraphy and used it to correlate the succession with that in the Grey Chalk Subgroup succession at Folkestone (see **Folkestone to Kingsdown** GCR site report, this volume). Figures of sections showing lateral variations within the quarry are given by Kennedy (1970, fig. 18), Jarvis and Tocher (1987, fig. 6) and by Smith *et al.* (1988, fig. 3).

Jukes-Browne (1898) described over 30 ft (9 m) of Wilmington Sand with loose blocks of 'Grizzle' in the overlying soil. An attempt to dig below the floor of the quarry was stopped when a dense, calcareous-cemented bed of pebbly sandstone, presumed to be a Chalk Basement Bed, was encountered. The quarry workers said that this bed had previously been exposed in an excavation in the village where it had been 15 ft (4.5 m) thick (Jukes-Browne, 1898). Subsequent descriptions by Smith (1957b), Smith and Drummond (1962), Kennedy (1970), Jarvis and Tocher (1987), Hart (1983) and Smith *et al.* (1988), all of whom saw the full thickness of the Wilmington Sand, showed the basal pebble bed (i.e. Basement Bed) to be less than 1 m thick.

In contrast to the Wilmington Sand, the Little Beach Member of the Beer Head Limestone Formation, and the overlying basal White Subgroup strata (Holywell Nodular Chalk Formation) show marked variations in lithology; several authors have drawn attention to and have illustrated this feature. The highest bed seen in the quarry at present is the deeply weathered gritty Beer Stone, crowded with tiny echinoderm prisms. Previously, several metres of shell-rich chalk were locally preserved above this stone. Jukes-Browne (1898) recorded the stone in another quarry (now backfilled) adjacent to Wilmington Quarry. This had reputedly supplied the stone for Widworthy Court, which overlooks Wilmington Quarry. A petrologically identical stone was formerly worked at Sutton Barton Quarry to the south of Wilmington Quarry (Figure 3.25), under the name 'Sutton Stone' (Jukes-Browne, 1898).

Lithostratigraphy

The lithologies present in the Cretaceous succession at Wilmington Quarry (Figure 3.26 and Table 3.1) below a capping of Clay-with-flints, comprise, in descending order:

Upper Greensand Formation (up to 2 m): Sandy, glauconitic calcarenite and calcareous sandstone with a densely cemented and mineralized top surface.

'Basement Bed' (0.2 to 0.3 m): Pebbles and cobbles of green-coated calcareous sandstone and calcarenite, and hard and soft phosphatic pebbles, set in a glauconitic sandy limestone matrix.

Wilmington Sand (4 to 14 m): Decalcified calcareous sand and sandy calcarenite, coarse-grained at the base. Fine- and medium-grained beds alternate with medium- and coarse-grained beds, all with granules and small pebbles. There are several horizons of laterally impersistent and partially silicified thalassinoid burrow systems. Shallow trough cross-bedding is present at several levels and there are traces of rotted pyritic horizons.

'Grizzle' (mostly 2.5 to 3.5 m): Highly fossiliferous sand with a chalky matrix; with patchy cementation producing hard nodules and patches in a loose sand matrix. Large shells (inoceramid bivalves) are concentrated in the basal 0.5 m. The lowest 0.8 to 1.0 m is much less calcareous. The percentage content of quartz grains decreases upward and there is a concomitant increase in the chalky matrix (up to 35%) and degree of nodularity. The top is marked by a bed of green-stained sandstone pebbles.

Little Beach Member (Bed B) (= Wilmington Limestone of Smith *et al.*, 1988): This varies laterally from a hard quartzose

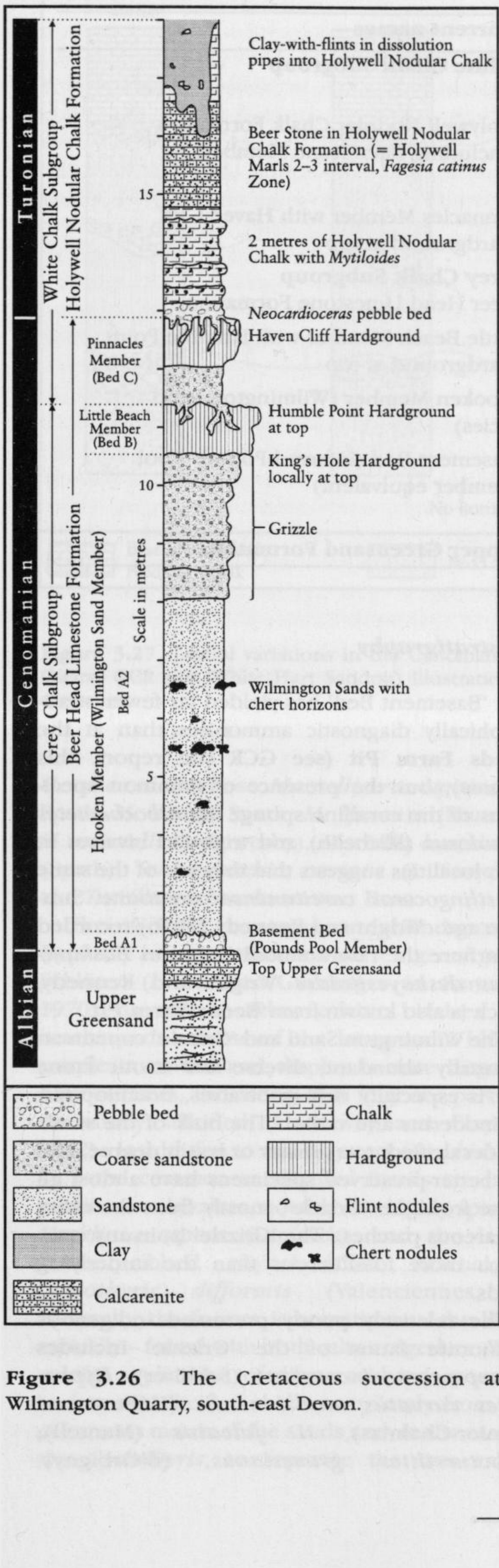


Figure 3.26 The Cretaceous succession at Wilmington Quarry, south-east Devon.

bioclastic limestone in the northern part of the quarry to a highly bioturbated mixture of quartz sand, glauconite and chalky mud; locally calcareously cemented to dense calcarenite/calcareous sandstone. In the upper 0.3 m there is a concentration of phosphatized and glauconitized nodules. The top surface is glauconite-impregnated and penetrated by a ramifying *Thalassinoides* burrow system, which is also green-stained. The burrows pipe down glauconitic calcareous sands and small phosphate clasts from the overlying Pinnacles Member. The surface and the burrow walls are coated with a shiny chocolate-brown veneer of phosphate. There is a rich fauna of encrusting organisms, which is also phosphatized. This complex surface corresponds to the Humble Point Hardground (Jarvis and Woodroof, 1984) at the top of the member in the coastal exposures.

The Little Beach Member thins and disappears laterally, resulting in the Pinnacles Member coming to rest directly on the top mineralized surface of the 'Grizzle' (Figure 3.27).

Pinnacles Member (Bed C): The Little Beach Member is overlain in this section by a laterally extremely variable unit of glauconitic sediments. All of the descriptions of this unit differ significantly.

Wright and Kennedy (1981) recorded a basal conglomerate of unlithified phosphate clasts overlain by 0.6 m of soft quartzose glauconitic bioturbated chalk with scattered phosphates and small quartz pebbles. This graded up into 0.8 m of intensely hard splintery and nodular quartzose and glauconitic chalk. The unit ended in a hardground with green-coated pebbles in and welded to the surface, which was penetrated by a ramifying *Thalassinoides* burrow system. This description is similar to that of Kennedy (1970), but differs in that he did not report the higher unit of quartzose chalk.

Smith *et al.* (1988), on the other hand, reported that the Humble Point Hardground was overlain by 0.2 to 0.23 m of glauconitic sand (with a basal phosphate pebble conglomerate). This sand thinned westwards to a point where it was represented merely by a thin veneer capping the Little Beach Member and infilling fissures and burrows. These sections were mainly in the north-east corner of the quarry.

The present section in the south-west corner of the quarry, where there are residual pillars of Cretaceous rock surrounded by solution

Table 3.1 Lithostratigraphy of the Upper Cretaceous at Wilmington Quarry.

Former names of units	Current names
Middle and Upper Chalk (only Middle Chalk was ever present here)	**White Chalk Subgroup**
Middle Chalk (*Inoceramus labiatus* Zone)	Holywell Nodular Chalk Formation (including Beer Stone Member)
Cenomanian Limestone (Beds A–C)	
Bed C of Cenomanian Limestone of authors	Pinnacles Member with Haven Cliff Hardground at top
	Grey Chalk Subgroup
	Beer Head Limestone Formation
(Bed B)	Little Beach Member with Humble Point Hardground at top
Grizzle and Wilmington Sand (Bed A2)	Hooken Member (Wilmington Sand facies)
Basement Bed (Bed A1)	Basement Bed (inferred Pounds Pool Member equivalent)
Lower Cretaceous	
Upper Greensand Formation	**Upper Greensand Formation**

hollows, resembles that originally described by Kennedy (1970). The Pinnacles Member consists of up to 0.9 m of white and greyish white, porcellanous, nodular, highly bioturbated, glauconitic limestone. At the base, resting on the glauconitized and phosphatized hardground at the top of the Little Beach Member, there is locally a pebble bed with green-coated limestone and phosphate pebbles. The top of the unit is glauconitized, forming the Haven Cliff Hardground of coastal sections, and is penetrated by a *Thalassinoides* burrow system filled with sandy glauconitic chalk piped down. This hardground is intensely glauconitized and indurated in nearly inaccessible sections in the present north-east corner of the quarry.

The Haven Cliff Hardground is overlain by up to 2 m of gritty, glauconitic chalk, with common phosphatic pebbles and green-coated limestone pebbles in the basal 0.2 m (the Haven Cliff *Neocardioceras* Pebble-Bed of coastal sections).

Beer Stone Member (up to 2 m): Comprises deeply weathered, bioturbated, very sparsely shelly gritty chalk composed largely of sand-grade echinoderm prisms.

The Beer Stone Member is overlain by up to 3 m of deeply weathered, slightly marly, gritty chalk with common inoceramid bivalve debris as well as whole and fragmentary shells.

Biostratigraphy

The 'Basement Bed' has yielded far fewer stratigraphically diagnostic ammonites than at the **Reeds Farm Pit** (see GCR site report, this volume), but the presence of common specimens of the coralline sponge *Acanthochaetetes ramulosus* (Michelin) and trigoniid bivalves at both localities suggests that they are of the same *Neostlingoceras carcitanense* ammonite Subzone age. Wright and Kennedy (1996) recorded from here the rare ammonite species *Baskaniceras deshayesitoides* Wright and Kennedy, which is also known from **Reeds Farm Pit**.

The Wilmington Sand and 'Grizzle' contain an unusually abundant, diverse and exotic fauna that is especially rich in bivalves, brachiopods, echinoderms and crabs. The bulk of the sands are decalcified, to a greater or lesser degree, and the better-preserved specimens have almost all come from the 'Grizzle', mostly from the more calcareous patches. The 'Grizzle' is, in any case, much more fossiliferous than the underlying sands.

The relatively poorly preserved indigenous ammonite fauna of the 'Grizzle' includes *Acompsoceras inconstans* (Schlüter), *Hypoplites curvatus arausionensis* (Hébert and Munier-Chalmas), *H. falcatus* (Mantell), *Hypoturrilites gravesianus* (d'Orbigny),

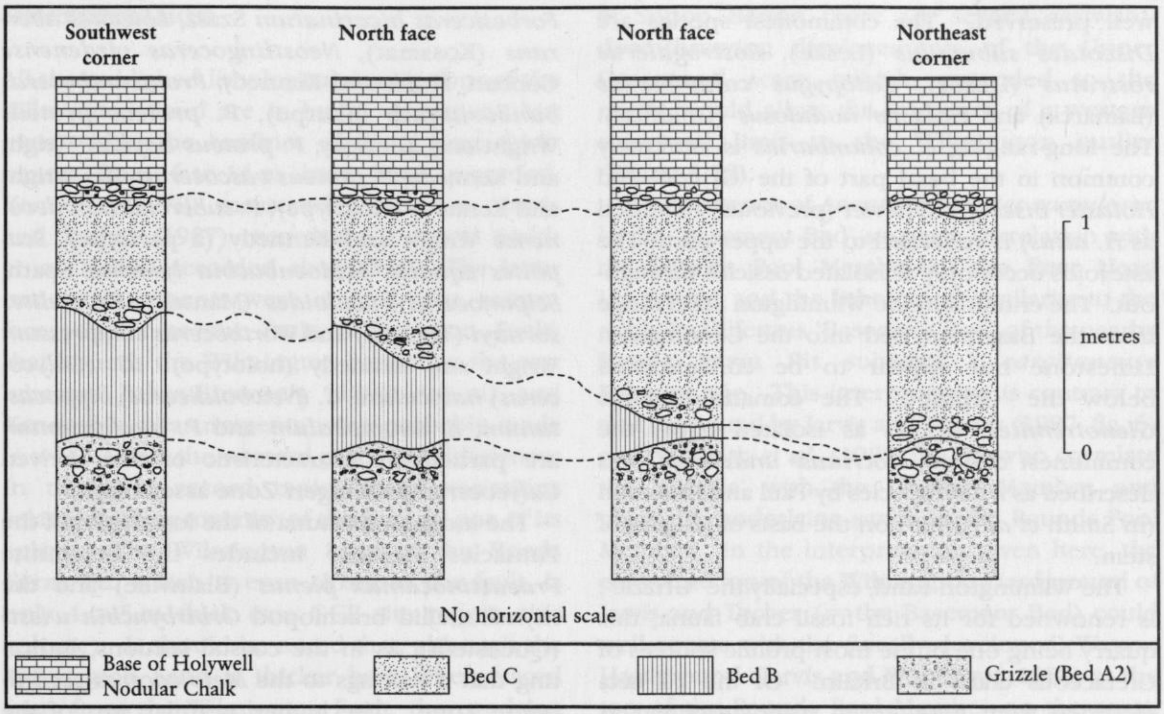


Figure 3.27 Lateral variations in the Cenomanian Limestone equivalent (see Table 3.1) in the Wilmington Quarry GCR site (White Hart Sandpit) illustrating the reason for the near absence of Bed B in parts of the exposure.

H. tuberculatus Bosc, *Mantelliceras cantianum* Spath, *M. dixoni* Spath, *M. lymense* (Mantell), *M. mantelli* (J. Sowerby), *Mariella lewesiensis* (Spath), *Schloenbachia varians* (J. Sowerby) and *Turrilites scheuchzerianus* Bosc.

The 'Grizzle' contains an abundance of (typically bivalved) *Inoceramus* ex gr. *virgatus* Schlüter (*I. conicus* Guéranger in Kennedy, 1970), as well as other calcitic bivalves and brachiopods. Some of the latter are a bluish-purple in colour and display beekite rings on their surfaces, indicating that they are partially or wholly silicified (Holdaway and Clayton, 1982). In addition to small oysters (*Amphidonte* sp.), the commonest silicified fossils are large pectinacean bivalves, notably the highly spinose *Merklinia aspera* (Lamarck), and the large, coarsely-ribbed rhynchonellid brachiopod *Cyclothyris difformis* (Valenciennes, in Lamarck); the former is sometimes – the latter typically – found with both valves together. With careful application of dilute acid it is possible to free the silicified shells completely from the calcareous matrix of the sands and, in the case of the *Cyclothyris*, to separate the two valves sufficiently to reveal the brachial apparatus.

The rich brachiopod fauna also includes *Arcuatothyris arcuata* (Roemer), *Arenaciarcula beaumonti* (d'Archiac), *Burrirhynchia devoniana* Owen, *Dereta pectita* (J. Sowerby), *Grasirhynchia grasiana* (d'Orbigny), *Kingena arenosa* (d'Archiac), *Orbirhynchia wilmingtonensis* Owen, *Ovatathyris ovata* (J. Sowerby), *Rectithyris wrightorum* Owen, and *Terebrirostra lyra* (J. Sowerby). Some of these are robustly ornamented forms that characterize coarse-grained sediments and are absent from the Cenomanian chalks of other parts of England. The holotypes and paratypes of *B. devoniana* and *O. wilmingtonensis*, and the only known specimen (holotype) of *R. wrightorum* (Owen, 1988) came from here.

The Wilmington Sand is particularly rich in echinoderms. Smith *et al.* (1988) recorded 37 species of echinoid, 18 of asteroid and 7 of crinoid. No new species of echinoid were described, but ten species had not previously been reported from Britain. The fauna is extraordinarily diverse, and comprises both 'regular' and 'irregular' taxa, much of it very well preserved. The commonest species are *Discoides subuculus* (Leske), *Rostrogalerus rostratus* (Desor), *Catopygus columbarius* (Lamarck) and *Holaster nodulosus* (Goldfuss). The long-ranging *C. columbarius* is extremely common in the basal part of the 'Grizzle' and *Holaster bischoffi* Renevier (previously recorded as *H. altus*) is restricted to the upper part. The asteroids occur only as isolated ossicles throughout. The crinoids in the Wilmington Sand range from the Basement Bed into the Cenomanian Limestone but appear to be concentrated below the 'Grizzle'. The comatulid genus *Glenotremites*, occurs as isolated cups; the commonest crinoid, *Isocrinus? undulatus*, was described as a new species by Paul and Donovan (in Smith *et al.*, 1988) on the basis of lengths of stem.

The Wilmington Sand, especially the 'Grizzle', is renowned for its rich fossil crab fauna, this quarry being one of the most prolific sources of Cretaceous crabs in Britain. Of the 24 taxa recorded from here, seven were described as new by Wright and Collins (1972), one new genus appropriately being given the name *Wilmingtonia*. The new species described from the 'Grizzle' are *Notopocorystes ornatus*, *Paranecrocarcinus biscissus*, *P. digitatus*, *P. foersteri*, *Pithonoton cenomanense*, *Wilmingtonia satyrica* and *Xanthosia fossa*. Three species, *Plagiophthalmus oviformis* Bell, *Diaulax oweni* (Bell) and *Necrocarcinus labeschei* (Deslongchamps) are relatively common, the remainder are rare. The holotype of *Plagiophthalmus? nodulosus* Wright and Collins came from the overlying Cenomanian Limestone (see Table 3.1).

The fauna of the Little Beach Member is sparse, and echinoids, mostly *Conulus castanea* (Brongniart) and *Holaster subglobosus (*Leske), and crustacean debris are the only common fossils. Wright and Kennedy (1987, pl. 49, fig. 5) illustrated a well-preserved, incomplete specimen of *Acanthoceras rhotomagense* (Brongniart) from here.

The phosphatized *Calycoceras* (*Proeucalycoceras*) *guerangeri* Zone ammonite fauna from the base of the Pinnacles Member (Bed C) recorded from here includes *Calycoceras* (*C.*) *naviculare* (Mantell), *C.* (*Newboldiceras*) *hippocastanum* (J. de C. Sowerby), *C.* (*Proeucalycoceras*) *picteti* Wright and Kennedy, *Eucalycoceras pentagonum* (Jukes-Browne), *E. rowei* (Spath), *Euomphaloceras euomphalum* (Sharpe), *Forbesiceras bicarinatum* Szasz, *Lotzeites aberrans* (Kossmat), *Neostlingoceras virdenense* Cobban, Hook and Kennedy, *Protacanthoceras bunburianum* (Sharpe), *P. proteus proteus* Wright and Kennedy, *P. proteus baylissi* Wright and Kennedy, *P. proteus vascoceratoides* Wright and Kennedy (holotype), *P. tuberculatum devonense* Wright and Kennedy (a paratype), *Scaphites equalis, Schloenbachia lymense* Spath, *Sciponoceras baculoides* (Mantell), *Thomelites sornayi* (Thomel) and *Worthoceras compressum* Wright and Kennedy (holotype). *C.* (*Calycoceras*) *naviculare*, *C.* (*Newboldiceras*) *hippocastanum*, *E. euomphalum* and *P. bunburianum* are particularly characteristic of this derived *Calycoceras guerangeri* Zone assemblage.

The indigenous fauna of the lower part of the Pinnacles Member includes the belemnite *Praeactinocamax plenus* (Blainville) and the rhynchonellid brachiopod *Orbirhynchia wiesti* (Quenstedt), as in the coastal sections, indicating that it belongs to the *Metoicoceras geslinianum* Zone. The higher, nodular part of the member has yielded *Euomphaloceras euomphalum.* The puzzling record of *ollignoniceras* (Wright and Kennedy, 1981, fig. 5; pl. 8, fig. 17) may refer to another genus. The Haven Cliff Hardground contains *Sciponoceras* sp. and common spines of the regular echinoid *Hirudocidaris hirudo* (Sorignet). The overlying glauconitized pebble-fossils include *Sciponoceras bohemicum anterius* Wright and Kennedy and *Neocardioceras* sp., belonging to the terminal Cenomanian *Neocardioceras juddii* ammonite Zone; the surrounding quartzose glauconitic chalk contains indigenous *Watinoceras devonense* Wright and Kennedy, the zonal index fossil of the basal Turonian ammonite zone.

The indigenous fauna of the Holywell Nodular Chalk Formation includes the echinoids *Cardiaster truncatus* (Goldfuss) (*Cardiaster pygmaeus* in the older literature), *Cardiotaxis cretacea* (Sorignet), *Conulus subrotundus* (Mantell), *Camerogalerus minimus* (Desor) (*Discoidea dixoni*), *Hemiaster nasutulus* (Sorignet), *Prionocidaris granulostriata* (Desor) and common specimens of the inoceramid bivalve *Mytiloides labiatus* (Schlotheim). The overlying beds of the Holywell Nodular Chalk are deeply weathered and the fossils are mostly poorly preserved. A specimen of the ammonite *Spathites* (*Jeanrogericeras*) cf. *subconciliatus* (Choffat) from here was figured by Wright and Kennedy (1981, pl. 22, fig. 3).

Interpretation

All the published lithological descriptions of the Wilmington Sand are in broad agreement, but even within the confines of the quarry, thicknesses from 6 to 14 m have been recorded. Kennedy (1970) measured 12 to 14 m, Jarvis and Tocher (1987) recorded 6.2 m and Smith *et al*. (1988) recorded about 8 m. The latter two measurements were made in the eastern face, closest to the fault (Wilmington Fault) that bounds the Wilmington outlier to the east whereas Jukes-Browne's (1898: 9+ m) and Kennedy's measurements were probably made in what is now the western part. The differences in thickness record rapid lateral variations related to the proximity of the fault or one of its splays. The Wilmington Sand at the **Reeds Farm Pit**, which is even closer to the fault, is only 4 to 5 m thick (see GCR site report, this volume). It should be noted that, although the Wilmington Sand is thicker here when traced away from the Wilmington Fault, the overlying Little Beach (Bed B) and Pinnacles members (Bed C) are thin in comparison with the developments of these members in the **Hooken Cliff** sections.

The development of the thick arenaceous (Wilmington Sand) facies of the Lower Cenomanian sandy Beer Head Formation limestones, and of the lenticular Beer Stone (locally called 'Sutton Stone') in the lower part of the Holywell Nodular Chalk Formation, is of critical importance in structural terms. It allows the key postulation of an approximately north–south aligned 'Hooken–Wilmington Trough', extending from Hooken Cliff, through the Beer Stone quarries and nearby sections such as Bovey Lane Quarry (Figure 3.17), to the sections in the fault-controlled Wilmington outlier. This outlier is delimited to the east by a major fault (Wilmington Fault), which seismic reflection surveys show to have a westerly downthrow of more than 0.3 m in the Trias close to Wilmington. As noted above, the Cenomanian sediments thicken significantly westwards away from the fault, and the structural situation is broadly similar to that described from the **Hooken Cliff** GCR site between the Beer Head and Beer Stone adit sections. Because of the loss of Cretaceous strata beneath the Clay-with-flints cover to the west of Wilmington, there is no clear evidence for the existence of the other side of the trough. However, to the south of Sutton Barton there are several eastward-downthrowing displacements of the Upper Greensand scarp, which, extended to the north, would allow the inference of a western structural limit to the Wilmington outlier (Figure 3.19).

The presence of *Acanthochaetetes ramulosus* in the 'Basement Bed' suggests correlation with the Pounds Pool Member of the Beer Head Limestone, and the lithological similarity to the richly fossiliferous 'Basement Bed' of the nearby **Reeds Farm Pit** suggests a *carcitanense* Subzone age. This interpretation is contrary to that presented by Jarvis and Tocher (1987, fig. 6) and by Smith *et al*. (1988, fig. 5), who correlate the 'Grizzle' with the Hooken Member, and place the underlying sands in the Pounds Pool Member. In the interpretation given here, the convolute top of the Wilmington Hardground of Jarvis and Tocher (= the Basement Bed) could well equate with the (locally developed) Weston Hardground (Jarvis and Woodroof, 1984) at the top of the Pounds Pool Member on the coast. Our interpretion is supported by the occurrence of *Inoceramus virgatus* at the base of the Wilmington Sand at the **Reeds Farm Pit,** indicative of the *Mantelliceras dixoni* Zone.

The coarse grain-size of the sands and their sedimentary (cross-bedding) features suggest rapid deposition, and the whole of the Wilmington Sand above the 'Basement Bed' is probably of a similar age. The presence of lines of cherts indicates that the sediments were formerly much more calcareous. The association of *Mantelliceras dixoni* with an abundance of the bivalve *Inoceramus* ex gr. *virgatus* places the 'Grizzle' in the *Mantelliceras dixoni* Zone and suggests correlation with the Hooken Member (Bed A2). This is supported by the abundance in the 'Grizzle' of *Merklinia aspera*, which is common at the top of the arenaceous Hooken Member at **Hooken Cliff**. The ocurrence of *I*. ex gr. *virgatus* suggests correlation with the *I. virgatus*-acme that characterizes the lower third of the *dixoni* Zone in the 'Chalk Marl' facies of the Grey Chalk Subgroup, for example at **Southerham Grey Pit**, Lewes (see GCR site report, this volume), and at Folkestone (see **Folkestone to Kingsdown** GCR site report, this volume). They typically occur as bivalved specimens in both successions and, in both cases, in relatively calcareous sediments. The abundance of the rhynchonellid brachiopod

Orbirhynchia wilmingtonensis in the 'Grizzle' suggests possible correlation with the *O. mantelliana* band that immediately follows the *I. virgatus*-acme. However, the presence in the 'Grizzle' of *Acompsoceras inconstans* and *Turrilites scheuchzerianus* additionally indicates the highest of the three ammonite assemblages recognized in the *dixoni* Zone by Gale (1996), the *Mesoturrilites boerssumensis* Subzone of Kaplan *et al.* (1998).

Conclusions

Wilmington Quarry (White Hart Sandpit) has exposed, from time to time, the greatest thickness of the unusual Cenomanian deposits within the Hooken–Wilmington Trough. The sections have yielded an abundant and exceptionally diverse fauna of ammonites, echinoids and crustaceans, many of which have only been recorded from east Devon, and some of which are unique to Wilmington Quarry.

REEDS FARM PIT, WILMINGTON, SOUTH-EAST DEVON (ST 213 003)

Introduction

Reeds Farm Pit is about 600 m north-east of **Wilmington Quarry**, (Figure 3.25; see GCR site report, this volume), and has also been referred to as 'Hutchin's Pit' (e.g. Kennedy, 1970, p. 661) after a previous owner, 'the pit in a field near the lane to Haynes Farm' (Jukes-Browne, 1898), and the 'Waterworks Pit' (being opposite a pumping station). The decalcified Wilmington Sand was worked for building sand, as at the Wilmington Quarry. Reeds Farm Pit provided a complete section through the Wilmington Sand, a condensed representative of the Little Beach Member of the overlying Beer Head Limestone Formation, and the basal beds (Turonian Age) of the Holywell Nodular Chalk Formation. The pit lies closer to the Wilmington Fault than the Wilmington Quarry and the succession is consequently more condensed (Figure 3.28).

Description

The earliest description of the section is that of Jukes-Browne (1898), which was repeated and expanded by Jukes-Browne and Hill (1903). The pit was at that time in work (Figure 3.29). Its small size suggests that it is more recent than the extensive Wilmington Quarry section, and that it was probably opened some time after Fitton's visit to the latter workings. The section was partially overgrown when examined by Kennedy (1970), who was able to collect enough fossils from the Cenomanian Limestone and the basal Turonian Chalk to confirm Jukes-Browne's correlations with the succession at **Wilmington Quarry**. In particular, he collected ammonites and other fossils from the richly fossiliferous Basement Bed of the Wilmington Sand, which has not been well exposed subsequently. Re-examination of the ammonites from this bed enabled Kennedy (1971) and Wright *et al.* (1984) to apply the modern ammonite zonal scheme for the Cenomanian Stage to the succession and to correlate it with successions on the Devon coast and, farther to the east, in Grey Chalk Subgroup facies. Hart (1983) noted that the section was in such a poor state that further collecting was unlikely to add anything to earlier micropalaeontological studies (Carter and Hart, 1977a, fig. 41).

Lithostratigraphy

Jukes-Browne (1898) recorded 5 ft 9 in (1.75 m) of Middle Chalk (i.e. Holywell Nodular Chalk Formation) resting on 2 ft (0.6 m) of Cenomanian Limestone and 6 ft (1.83 m) of nodular calcareous sandstone (the 'Grizzle' at the top of the Wilmington Sand; Figure 3.29), faulted against 18 ft (5.5 m) of sand with siliceous concretions. Smith (1957b, p. 152) recorded a richly fossiliferous bed at the base of the Wilmington Sand. The succession summarized in Figure 3.28 and below is a composite based on the authors cited above.

Biostratigraphy

The Basement Bed of the Wilmington Sand at Reeds Farm Pit has yielded superbly preserved three-dimensional moulds of ammonites belonging to the *Neostlingoceras carcitanense* Subzone of the *Mantelliceras mantelli* Zone. Many of the better specimens were figured by Wright and Kennedy (1984). The following list has been updated from Kennedy (1970, 1971) and Wright and Kennedy (1984): *Algerites ellipticum* (Mantell), *A. sayni* Pervinquière, *Anisoceras* sp., *Baskaniceras deshayesitoides* Wright and Kennedy, *B. smithi* Wright and Kennedy, *Forbesiceras beaumontianum*

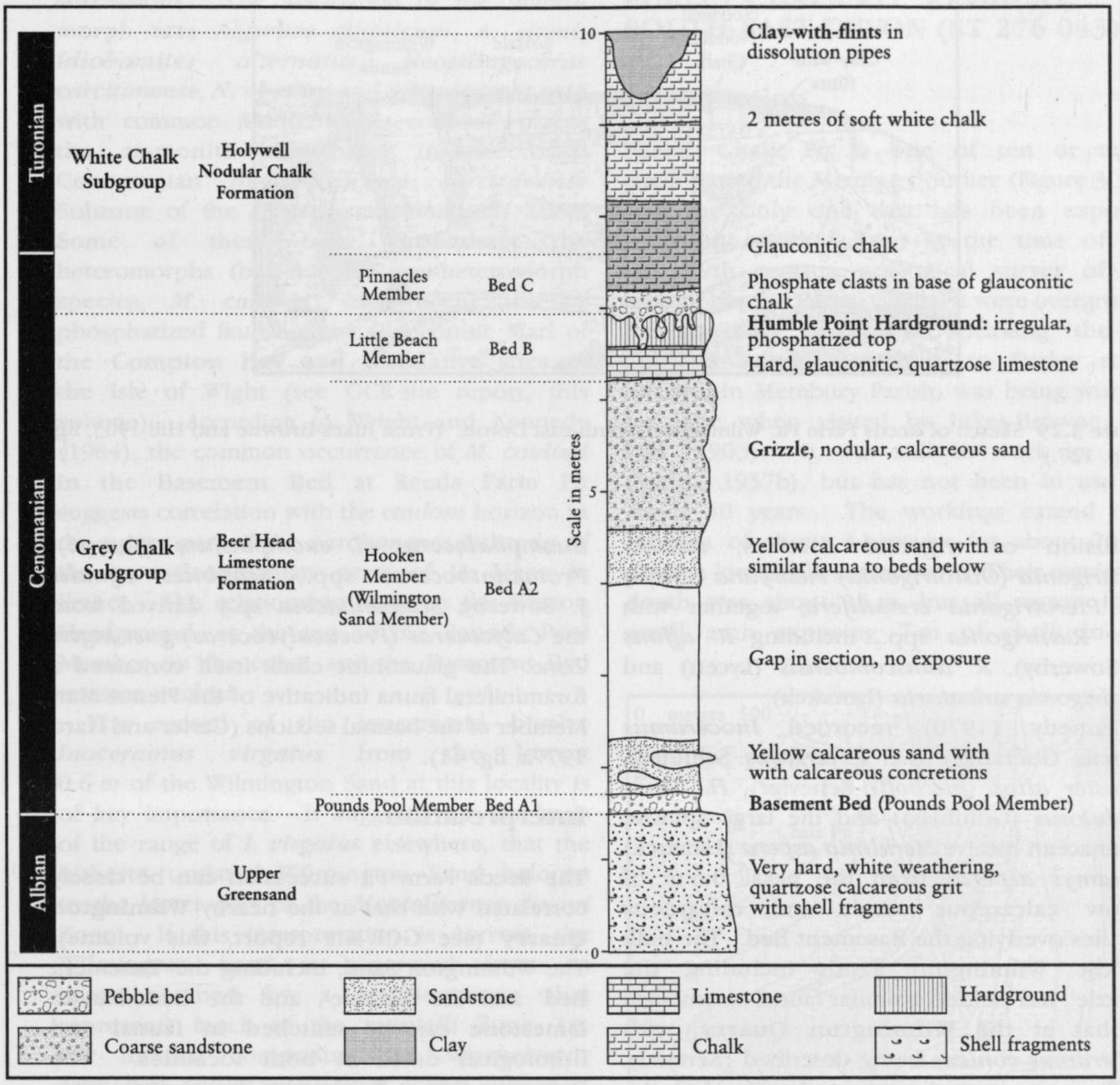


Figure 3.28 The former section at Reeds Farm Pit, Wilmington, south-east Devon (also known as 'Hutchins Pit' or 'Haynes Lane Pit').

(d'Orbigny), *F. lagilliertianum* (d'Orbigny), *Hyphoplites campichei* Spath, *H. curvatus curvatus* (Mantell), *H. curvatus arausionensis* (Hébert and Munier-Chalmas), *H. curvatus pseudofalcatus* (Semenov), *Hypoturrilites betraitaensis* Collignon, *H. mantelli* (Sharpe), *H. collignoni* Wright and Kennedy, *Idiohamites alternatus* (Mantell), *Mariella quadrituberculata* (Bayle), *M. torquatus* Wright and Kennedy, *M. dorsetensis* Spath, *Neostlingoceras carcitanense* (Matheron), *N. oberlini* (Dubourdieu), *Mantelliceras couloni* (d'Orbigny), *M. lymense* (Mantell), *M. saxbii* (Sharpe), *Schloenbachia varians*, *Sciponoceras roto* Cieslinski and *Stoliczkaia (Lamnayella) juigneti* Wright and Kennedy. Of these, this pit provided the holotype and/or paratype of four new species: *Baskaniceras smithi*, *Hypoturrilites collignoni*, *Mariella torquatus* and *Stoliczkaia (Lamnayella) juigneti* (Wright and Kennedy, 1984). The Basement Bed also yielded the holotype of the crab *Glaessneria kennedyi* Wright and Collins.

The Basement Bed contains the coralline sponge *Acanthochaetetes ramulosus* (Michelin). It is also characterized by a

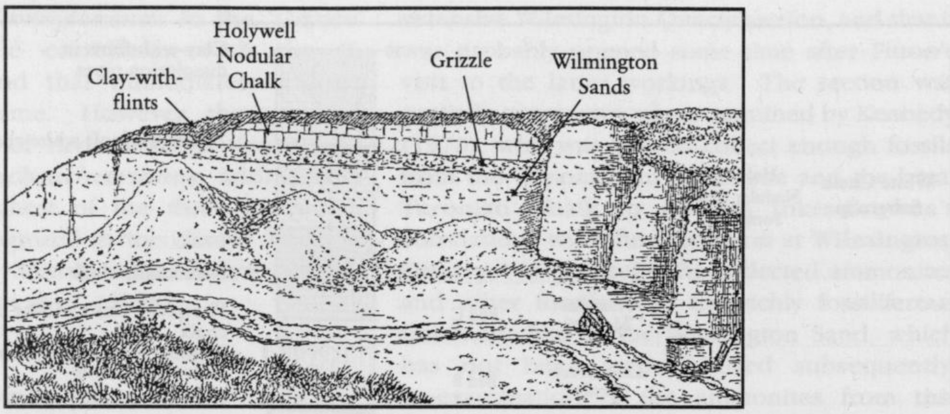


Figure 3.29 Sketch of Reeds Farm Pit, Wilmington, south-east Devon. (From Jukes-Browne and Hill 1903, fig. 31, p. 127.)

profusion of trigoniid bivalves, notably *Linotrigonia* (*Oistotrigonia*) *vicaryana* (Lycett) and *Pterotrigonia crenulifera*, together with rarer *Rutitrigonia* spp., including *R. affinis* (J. Sowerby), *R. dunscombensis* (Lycett) and *Apiotrigonia sulcataria* (Lamarck).

Kennedy (1970) recorded *Inoceramus conicus* Guéranger (i.e. *I. virgatus* Schlüter), *Holaster altus* (*bischoffi* Renevier), *H. laevis* (*nodulosus* (Goldfuss)) and the large spinose pectinacean bivalve *Merklinia aspera* (Lamarck) (*Chlamys aspera*) from the basal 0.6 m of yellow calcareous sands and calcareous nodules overlying the Basement Bed. The bulk of the Wilmington Sand, including the 'Grizzle', has yielded a similar faunal assemblage to that at the **Wilmington Quarry**, with *Inoceramus conicus* being described (Kennedy, 1970) as 'common'. As at that locality, the most prolific and better preserved specimens occur in the more cemented patches within the 'Grizzle'. Wright and Kennedy (1984) reported rare *Austiniceras* from the lower part of the Wilmington Sand and noted that the 'Grizzle' contained a *dixoni* Zone ammonite fauna.

The Little Beach Member (Bed B) has yielded (Kennedy, 1970) ammonites (*Protacanthoceras* sp., *Schloenbachia* sp.), echinoids (*Conulus castanea* (Brongniart) and common *Holaster subglobosus* (Leske)) and crustacean fragments. Phosphatized fossils from the base of the overlying glauconitic chalk of the Pinnacles Member (Bed C) at the base of the Holywell Nodular Chalk include ammonites (*Eucalycoceras* cf. *pentagonum* (Jukes-Browne), *Euomphaloceras* cf. *euomphalum* (Sharpe), *Protacanthoceras* spp., *Scaphites equalis* J. Sowerby, *Schloenbachia* sp.) derived from the *Calycoceras* (*Proeucalycoceras*) *guerangeri* Zone. The glauconitic chalk itself contained a foraminiferal fauna indicative of the Plenus Marl Member of the basinal sections (Carter and Hart, 1977a, fig. 41).

Interpretation

The Reeds Farm Pit succession can be closely correlated with that at the nearby **Wilmington Quarry** (see GCR site report, this volume). The Wilmington Sand, including the 'Basement Bed' and the 'Grizzle', and the Cenomanian Limestone can be matched in faunal and lithological detail at both localities. The Basement Bed at Reeds Farm Pit is much more fossiliferous and the pit has yielded far fewer specimens from the Little Beach and Pinnacles members. Differences in overall thickness between the two sections probably reflect their distances from the Wilmington Fault, the thinner Reeds Farm Pit succession being closer to the fault. The structural relationships between this and the other extant and former Wilmington quarries and pits and the 'Hooken–Wilmington trough' (Figure 3.21) is discussed above.

The diverse trigoniid bivalve assemblage, together with the coralline sponge *Acanthochaetetes ramulosus*, suggest that the Basement Bed is the correlative of the Pounds Pool Member (Bed A1) of the Beer Head Limestone Formation of **Hooken Cliff** (see GCR site report, this volume), and other coastal successions. The association of the heteromorph taxa *Algerites ellipticum*, *A. sayni*, *Idiohamites alternatus*, *Neostlingoceras carcitanense*, *N. oberlini* and *Sciponoceras roto* with common *Mantelliceras couloni*, places the ammonite assemblage in the basal Cenomanian *Neostlingoceras carcitanense* Subzone of the *Mantelliceras mantelli* Zone. Some of these taxa, particularly the heteromorphs (but not the non-heteromorph species, *M. couloni*) also occur in the phosphatized fauna of the Glauconitic Marl of the **Compton Bay** and correlative sites in the Isle of Wight (see GCR site report, this volume). According to Wright and Kennedy (1984), the common occurrence of *M. couloni* in the Basement Bed at Reeds Farm Pit suggests correlation with the *couloni* horizon in the upper part of the *carcitanense* Subzone of the type Cenomanian strata of Le Mans in France. The relationship between the Weston Hardground, at the top of the Pounds Pool Member on the coast, and the Basement Bed remains unclear.

The record of the inoceramid bivalve *Inoceramus virgatus* from the lowest 0.6 m of the Wilmington Sand at this locality is of key importance. It suggests, on the basis of the range of *I. virgatus* elsewhere, that the hitherto undated Wilmington Sand belongs to the lower part of the *Mantelliceras dixoni* Zone. If this interpretation is correct, the Wilmington Sand is separated from its basement bed by a non-sequence that represents much of the *mantelli* Zone, i.e. the interval comprising the *Sharpeiceras schlueteri* and *Mantelliceras saxbii* subzones. As at **Wilmington Quarry**, the abundance of *I. virgatus* in the overlying 'Grizzle' here enables correlation with the *I. virgatus* acme-event that is developed throughout northern Europe in the middle part of the *dixoni* Zone.

Conclusions

The Reeds Farm Pit section complements the section at **Wilmington Quarry**. The Basement Bed here (unlike that at the latter locality) has yielded the best preserved and most diverse basal Cenomanian *Neostlingoceras carcitanense* Subzone ammonite fauna in Britain, including many type and figured specimens.

FURLEY CHALK PIT, MEMBURY, SOUTH-EAST DEVON (ST 276 043)

Introduction

Furley Chalk Pit is one of ten or more chalk pits in the Membury outlier (Figure 3.30), and the only one that has been exposed in recent years. Even at the time of the late 19th century geological survey of the area all but the Furley Chalk Pit were overgrown. Furley Chalk Pit, strictly speaking 'the pit adjacent to the Membury to Furley road' but within Membury Parish, was being worked for lime when visited by Jukes-Browne and Hill (1903). It was still in work in 1955 (Smith, 1957b), but has not been in use for about 40 years. The workings extend over an area of about 3 hectares for about 200 m along a low Chalk escarpment. Their maximum depth was about 15 m, but all except for a small area exposing 7 m of chalk in the

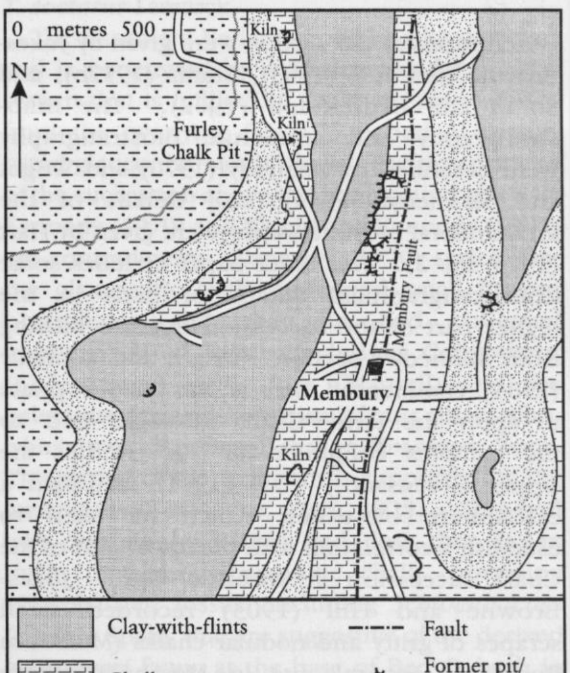


Figure 3.30 The geological setting of the Furley Chalk Pit GCR Site.

highest (eastern) face has now been backfilled. The pit has provided the only information on the Upper Cretaceous (Cenomanian–Lower Turonian) deposits and their relationship to the underlying Lower Cretaceous (Albian) Upper Greensand in the fault-bounded Membury outlier (Figure 3.31). As elsewhere in the region, the Cenomanian deposits are highly condensed and richly fossiliferous, with several different reworked faunas. The stratigraphy differs in detail from that of the other Upper Cretaceous outliers. The overlying Turonian Holywell Nodular Chalk Formation succession is lithologically different from that of the nearest coastal sections and the successions in the Wilmington and Chard outliers. The individual character of the Furley succession testifies to the continuing influence of nearby deep-seated faults throughout the Cenomanian and Turonian ages.

Description

Descriptions of the section were given by Jukes-Browne and Hill (1903), Smith (1957b), and Smith and Drummond (1962). The litho-stratigraphy and ammonite biostratigraphy were described by Kennedy (1970) and Wright and Kennedy (1984), and details of the foraminiferal biostratigraphy were given by Hart (1975, fig. 2). This latter paper includes some lithostratigraphical details of beds in the higher part of the succession that are missing from Kennedy's section. Wright and Kennedy (1984) commented that it was inappropriate to apply the term 'Chalk Basement Bed' to the complex conglomerate that overlies the Upper Greensand. Hart (1991) identified a calcisphere bio-event, which he used to establish a correlation with the lower part of the Chalk succession at **Hooken Cliff**. Jukes-Browne and Hill (1903) recorded small scrapes of gritty and nodular chalks (Melbourn Rock?) in several pits in Membury village and concluded that, in contrast to the successions in the surrounding areas, much of the Cenomanian strata were in Lower Chalk facies. Despite the absence of faunal confirmation of this observation, the Membury outlier has been commonly quoted as an abnormal local development of Lower Chalk, and the most westerly in England.

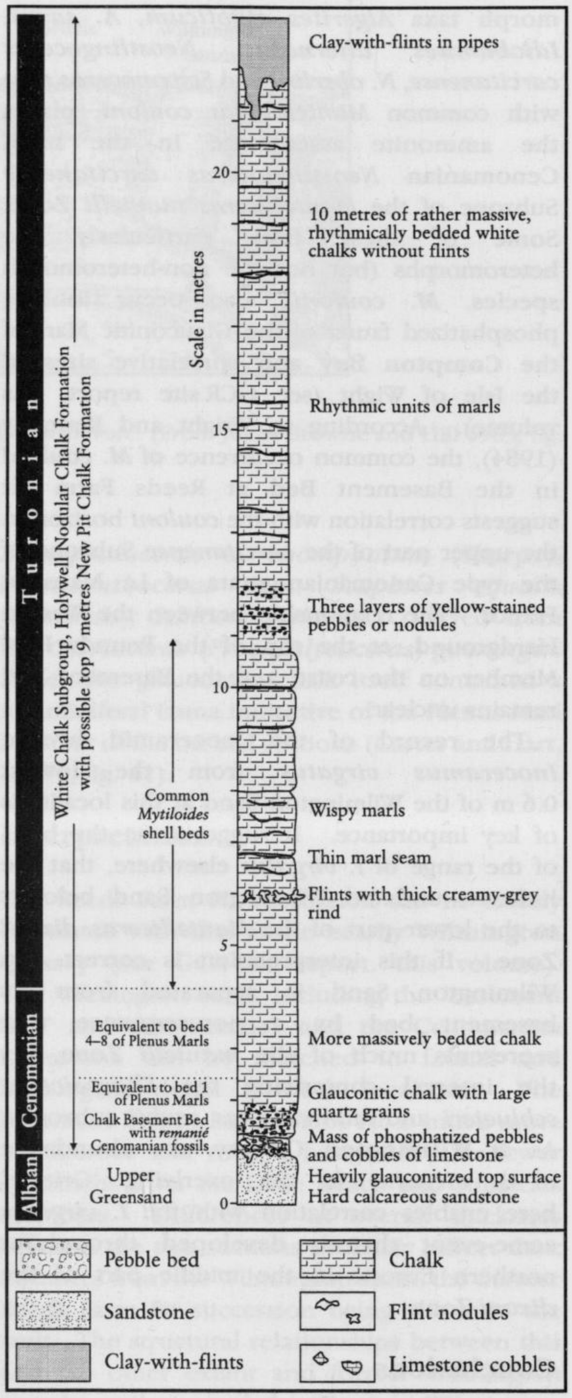


Figure 3.31 Furley Chalk Pit, south-east Devon, showing an unusual development of Chalk without hardgrounds and only one flint band in contrast to all other known localities at this horizon in Devon, more like a Sussex succession. (Based on Kennedy, 1970, fig. 14; and Hart 1975, fig. 2.)

Lithostratigraphy

Smith (1957b) recorded that the pit was floored by hard calcareous grit at the top of the Upper Greensand. The junction with an overlying pebbly 'Basement Bed' and glauconitic chalk was exposed in an excavation. Smith and Drummond (1962) and Kennedy (1970) also described these basal beds. The section summarized in Figure 3.31 is based on the references cited above, with some additional observations.

The Upper Greensand is succeeded by a 0.3 m complex conglomerate, which has been termed the 'Chalk Basement Bed', although Wright *et al.*, (1984, p. 14) regarded the use of this term (e.g. by Kennedy, 1970) as inappropriate. However, they were prepared to apply this term to the similar bed at **Snowdon Hill Quarry** (see GCR site report, this volume), presumably on the basis that the clasts there are incorporated in a soft glauconitic chalk matrix. The conglomerate terminates in a hardground penetrated by a *Thalassinoides* burrow system.

Biostratigraphy

Several different derived faunas can be recognized in the complex conglomeratic 'Basement Bed'. Weakly phosphatized pebbles of sandy limestone at the base contain glauconitized Lower Cenomanian ammonites, including *Hyphoplites curvatus arausionensis* (Hébert and Munier-Chalmas), *Hypoturrilites gravesianus* (d'Orbigny), *Mantelliceras* spp. and *Schloenbachia varians* (J. Sowerby). Kennedy (1970) correlated this fauna with the '*Mantelliceras saxbii* assemblage' of Bed A2 of the Cenomanian Limestone (Figures 3.4 and 3.21) and indicated that elements of the '*Mantelliceras* gr. *dixoni* assemblage' (i.e. *dixoni* Zone) were absent. The absence of heteromorph ammonites from the list preclude correlation with the *carcitanense* Subzone Wilmington Sand Basement Bed fauna, while the apparent absence of *Inoceramus virgatus* Schlüter suggests that this derived fauna is indicative of the *mantelli* Zone rather than the *dixoni* Zone. However, Wright and Kennedy (1984) suggested that fossils derived from the *dixoni* Zone might also be present.

The *remanié* phosphatized fauna of the higher part of the Basement Bed appears to include ammonites from several different zones/subzones of the Middle Cenomanian Substage. The assemblage contains representatives of the *Turrilites costatus* Subzone and, particularly, of the *T. acutus* Subzone of the *Acanthoceras rhotomagense* Zone, including the subzonal indices, as well as common examples of the zonal index fossil of the overlying *Acanthoceras jukesbrownei* Zone. It includes: *Acanthoceras jukesbrownei* (Spath) (specimens from here were illustrated by Kennedy, 1971), *A. rhotomagense* (Brongniart) (one specimen illustrated by Kennedy, 1971), *Anisoceras plicatile* (J. Sowerby), *Calycoceras* (*Newboldiceras*) *asiaticum asiaticum* (Jimbo), *C.* (*N.*) *a. spinosum* (Kossmat), *C.* (*Calycoceras*) *bathyomphalum* (Kossmat), *Calycoceras* (*Proeucalycoceras*) *picteti* Wright and Kennedy (a paratype), *Lechites* cf. *gaudini raricostatus*, *Lotzeites* sp., *Parapuzosia* (*Austiniceras*) sp., *Schloenbachia coupei* (Brongniart), *Scaphites equalis* J. Sowerby (common), *Turrilites acutus* Passy and *T. costatus* Lamarck.

The Basement Bed is capped by a hardground and is penetrated by a *Thalassinoides* burrow system that is infilled by sediment piped down from the overlying 0.6–0.75 m bed of bioturbated glauconitic sandy chalk. The descriptions of the succession above the hardground given by Kennedy (1970) and Wright and Kennedy (1984) are contradictory. Kennedy (1970) stated that the glauconitic chalk contained small broken phosphates and that he had collected unphosphatized fossils including *Calycoceras* (*Calycoceras*) *naviculare* (Mantell) and the belemnite *Praeactinocamax plenus* (Blainville), which would indicate the *geslinianum* Zone. This dating of the sediment is supported by the foraminiferal evidence (Hart, 1975). This bed was overlain by a thin bed, less than 0.2 m thick, of highly glauconitic chalk containing phosphatized fossils, including *Schloenbachia lymense* Spath, that are suggestive of the derived *guerangeri* fauna at the base of Bed C, both in the coastal sections and at **Wilmington Quarry** (see GCR site report, this volume). This apparent inversion of the usual succession does not make sense. However, in Westphalia, northern Germany, *S. lymense* is recorded as ranging up into the *geslinianum* Zone (Kaplan *et al.*, 1998), so perhaps this apparent inversion is a normal succession. On the other hand, Wright and

Kennedy (1984) stated that it was the 0.6–0.75 m unit that had yielded the phosphatized ammonites, and attributed these to both the *jukesbrownei* and *guerangeri* zones.

The higher part of the Furley Chalk Pit succession, still partly exposed, is unusually unfossiliferous, and Jukes-Browne and Hill (1903) commented on this. Hart (1991) reported a flood occurrence of the calcisphere *Pithonella* in the interval from 1.5 m beneath, to 3 m above the flint, and suggested that this could be correlated with a near-global bio-event that had been recognized in the Lower Turonian deposits of southern England at **Hooken Cliff** (see GCR site report, this volume) and Dover (see **Folkestone to Kingsdown** GCR site report, this volume). This interval at Furley Chalk Pit corresponds to a significant increase and a concomitant decrease in the proportions of benthic and planktonic foraminifera respectively (cf. Hart 1975, fig. 2). An ammonite collected from an unspecified horizon 'well above the basement bed' was identified as a *Schloenbachia* of Upper Cenomanian character (Smith and Drummond, 1962), implying that the higher part of the succession belonged to the Lower Chalk, but this critical specimen was subsequently redetermined (Kennedy, 1970), as a Turonian *Watinoceras*. Kennedy (1970) recorded *Inoceramus* (i.e. *Mytiloides*) *labiatus* (Schlotheim) below the lowest nodule bed, confirming that the lower part of this succession falls in the Lower Turonian *Mytiloides* spp. Zone. Comparison of the microfaunal data from Furley Chalk Pit (Hart, 1975, fig. 2) and from the section at Beer Roads, to the north-east of the **Hooken Cliff** GCR site (Hart and Weaver, 1977; Hart, 1997, fig. 2), indicates that that the highest part of the Furley succession falls within the *Helvetoglobotruncana helvetica* planktonic foraminiferal Interval Zone. No macrofossils have been recorded from the highest part of the succession.

Interpretation

There is a remarkable change in the Cenomanian and Turonian successions between the Wilmington and Membury outliers. At Furley Chalk Pit, there is apparently no evidence of the thick Lower Cenomanian (*dixoni* Zone) Wilmington Sand and 'Grizzle' seen 6 km to the south-west in the **Wilmington Quarry** and **Reeds Farm Pit** GCR sites. The pebbles of sandy limestones with glauconitized Lower Cenomanian ammonites in the lower part of the Basement Bed could perhaps represent a lateral equivalent of either the basal Cenomanian (*carcitanense* Subzone) Basement Bed of the Wilmington Sand, or of the *dixoni* Zone 'Grizzle', but the absence of records of the biostratigraphically diagnostic coralline sponge *Acanthochaetetes ramulosus* (Michelin) and the inoceramid bivalve *Inoceramus virgatus* respectively means that these pebbles cannot be dated. A similar problem is found at **Snowdon Hill Quarry** although there a bed of sandy limestone is actually intercalated between the Upper Greensand and the Basement Bed (see GCR site report, this volume).

The ammonite assemblage in the green-coated pebbles is Lower Cenomanian in age (cf. that of the Hooken Member, Bed A2). The assemblage in the phosphatic pebbles is Middle Cenomanian in age, and it probably correlates in part with the (derived *costatus* Subzone) assemblage at the base of the Little Beach Member (Bed B) in the coastal sections. However, it appears to belong largely to the *acutus* Subzone, as at **Snowdon Hill Quarry**. The derived *Acanthoceras jukesbrownei* Zone faunal elements form part of the indigenous fauna of the higher part of the Little Beach Member of the coastal sections. The succeeding glauconitic sandy limestone is lithologically and faunally similar to the Pinnacles Member (Bed C) at the base of the Holywell Nodular Chalk Formation.

The overlying succession, up to the base of the beds of nodular chalk, can be unequivocally assigned to the Holywell Nodular Chalk Formation (i.e. the Connett's Hole Member of Jarvis *et al*., 1988) on microfloral, microfaunal and macrofaunal evidence. The calcisphere (*Pithonella*) flood above and below the flint horizon enables correlation with at least the lower part of this formation. The record of *Mytiloides labiatus* below the lowest of the nodular beds also supports correlation with this formation. The absence of any records of the keeled planktonic species *Marginotruncana sigali* (Reichel), indicative of the succeeding *M. sigali* Interval Zone, or of the giant agglutinating foraminifer *Labyrinthidoma* (formerly *Coskinophragma*), suggests, but does not prove, that the highest beds in the quarry do not reach the top of the *Helvetoglobotrunca belevetica* Interval Zone, i.e. that they lie below the base of the *sigali* Interval Zone. In the Beer Roads section on the coast (Hart, 1997, fig. 2), the boundary between the Holywell Nodular Chalk and flinty New Pit Chalk formations is more or less coincident with the base of the *sigali* Interval Zone. This implies, by extrapolation, that the preserved thickness of Holywell Nodular Chalk Formation at Furley Chalk Pit could be as much as 14 m. However, it is noteworthy that there is no evidence here, in this apparently expanded section, for the development of the Beer Stone lithology found in the Hooken–Wilmington Trough. On lithological grounds alone, ignoring the microfaunal evidence, the description of the highest beds as being chalk with marl seams suggests that they may belong to the New Pit Chalk Formation.

The Membury outlier is delimited to the east by a major fault (the Membury Fault) that cuts through the underlying Trias (Figures 3.19 and 3.30). Jukes-Browne and Hill (1903) considered that the Upper Cenomanian succession in the outlier was in typical Lower Chalk facies, an observation that has led subsequent authors to state that this was the most westerly Lower Chalk in Britain. However, the faunal evidence shows that there is no Lower Chalk (i.e. Grey Chalk Subgroup) at Furley Chalk Pit, the apparent 'Lower Chalk' here being actually an expanded succession of the basal White Chalk Subgroup (Holywell Nodular Chalk Formation). However, it is possible that 'Lower Chalk' is actually present in the outlier, but close to the Membury Fault in Membury village. Jukes-Browne and Hill (1903, p. 122) believed that there were up to 60 ft (15 m) of Lower Chalk exposed in a line of pits close to the fault (Figure 3.30). Even at that time these pits were overgrown and there was no supporting faunal evidence for this interpretation. However, comparison with the rapid lateral variation in the Cenomanian sediments at the **Hooken Cliff** GCR site, close to tectonic structures weaker than the Membury Fault, suggests the possibility that the condensed Cenomanian sequence at the Furley site may pass into Grey Chalk facies adjacent to the fault.

Conclusions

This site has provided the only detailed information on the Upper Cretaceous (Cenomanian–Turonian) deposits of the fault-bounded Membury outlier, and their relationship to the underlying Upper Greensand. The succession here differs significantly from those of the Chard and Wilmington outliers to the east and west respectively, and from those on the Devon coast. The individual character of the succession in this outlier testifies to the continuing influence on sedimentation of nearby deep-seated faults throughout the Cenomanian and Turonian ages.

SNOWDON HILL QUARRY, CHARD, SOMERSET (ST 312 089)

Introduction

Snowdon Hill Quarry and an adjacent mine, known as 'Snowdon Caves', were last worked over 100 years ago for building materials and lime. At their maximum extent, the workings exposed a continuous section (Figure 3.32), cut by several small faults, through the highest part of the Upper Greensand (Whitecliff Chert and Eggardon Grit of the modern lithostratigraphical scheme), a Cenomanian 'Basement Bed' and overlying white chalks with siliceous nodules ('Lower Chalk') (Jukes-Browne and Hill, 1903, fig. 28). The beds dip at 5° to the west, and the main face shows two parallel north–south-trending faults, 9 m apart, with the block between them being upthrown by nearly 2 m. The faulted nature of the section can be seen in the engraving from Jukes-Browne and Hill (1903, fig. 28; Figure 3.33). The rich phosphatized ammonite fauna from the Basement Bed has provided much illustrated material, including type and figured specimens.

Description

The sections were first documented by Wiest (1852), who recognized three beds above the Upper Greensand, of which the lowest (his 'Scaphites Bed') was described as 'a compact accumulation of fossils'. Wiest carefully recorded the brachiopod faunas from each of his three beds. The Upper Cretaceous succession was described in detail by Jukes-Browne and Hill (1903, pp. 118–20), who recorded 101 species in a faunal assemblage that was dominated by ammonites (40 species), bivalves and brachiopods with common gastropods, echinoderms, serpulids and crustaceans. The Cenomanian part of the succession was also described by Kennedy (1970). Many of the phosphatized ammonites from the basement bed were figured

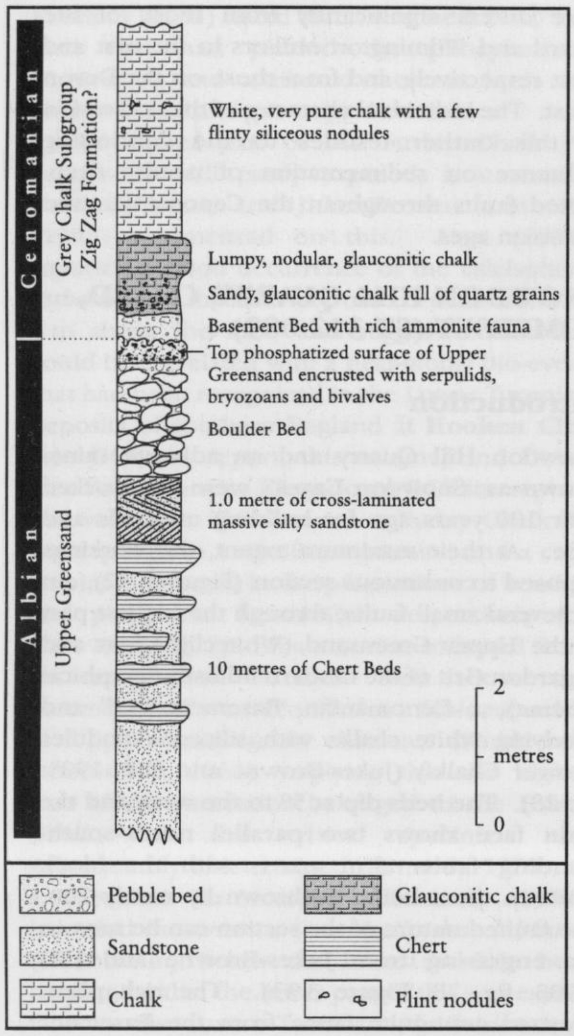


Figure 3.32 Snowdon Hill Quarry, Chard, Somerset. The most important Chalk Basement Bed assemblage of fossils in south-west England.

by Kennedy (1971) and by Wright and Kennedy (1984).

Despite the 100 years since excavation ceased the tough Whitecliff Chert is still well exposed, but the overlying chert-free calcarenites and calcareous sandstones (Eggardon Grit facies of the Upper Greensand) and the Cenomanian deposits were largely overgrown at the time of writing.

Lithostratigraphy

The succession summarized in Figure 3.32 is based on the descriptions by Jukes-Browne and Hill (1903) and by Kennedy (1970). The oldest Cenomanian deposits consist of calcarenites and calcareous sandstones that infill crevices in an irregular mineralized complex hardground surface that formed on the top of the sandy Upper Greensand calcarenites. The highest part of the Upper Greensand is complexly fractured to produce a 'cobble conglomerate' similar to that described by Ali (1976) at the top of the Upper Greensand on the Devon coast at Beer. The Upper Greensand and Lower Cenomanian infillings within it appear to have been planed off by erosion and are overlain by the 'Basement Bed', an intensely reworked, highly bioturbated chalky sandstone crowded with phosphatized pebbles and the phosphatized moulds of fossils. Above the 'Basement Bed,' highly bioturbated glauconitic chalks pass up into gritty and nodular chalks with a sparse fauna, which are in turn overlain by white chalks containing sparse flinty siliceous nodules.

Biostratigraphy

The sandy limestone that separates the Upper Greensand from the 'Basement Bed' was reported by Smith and Drummond (1962) to be rich in rather poorly preserved crustacean remains and to contain the rhynchonellid brachiopods *Cyclothyris schloenbachi* (Davidson) and *Grasirhynchia grasiana* (d'Orbigny), and the echinoids *Catopygus columbarius* (Lamarck) and *Discoides subuculus* (Leske).

The pebbles of sandy limestone in the Basement Bed contain poorly preserved, glauconitized Lower Cenomanian ammonites (Kennedy, 1970): *Hyphoplites curvatus* (Mantell), *H. falcatus* (Mantell), *Mantelliceras* ex gr. *saxbii* (Sharpe) as well as (Wright and Kennedy, 1996, pl. 105, figs 4, 20) the rare species *Mesoturrilites boerssumensis* (Schlüter).

The phosphatic pebbles in the 'Basement Bed' contain a diverse ammonite assemblage that is indicative of the *Turrilites acutus* Subzone of the Middle Cenomanian *Acanthoceras rhotomagense* Zone, including *Acanthoceras rhotomagense* (Brongniart), *Anagaudryceras involvulum* (Stoliczka), *Anisoceras plicatile* (J. Sowerby), *Calycoceras* (*Gentoniceras*) *gentoni* (Brongniart), *C.* (*G.*) *subgentoni* (Spath), *C.* (*Calycoceras*) *bathyomphalum* (Kossmat), *C.* (*Newboldiceras*) *asiaticum asiaticum* (Jimbo), *C.* (*N.*) *a. spinosum* (Kossmat), *C.* (*N.*) *a. hunteri* (Kossmat),

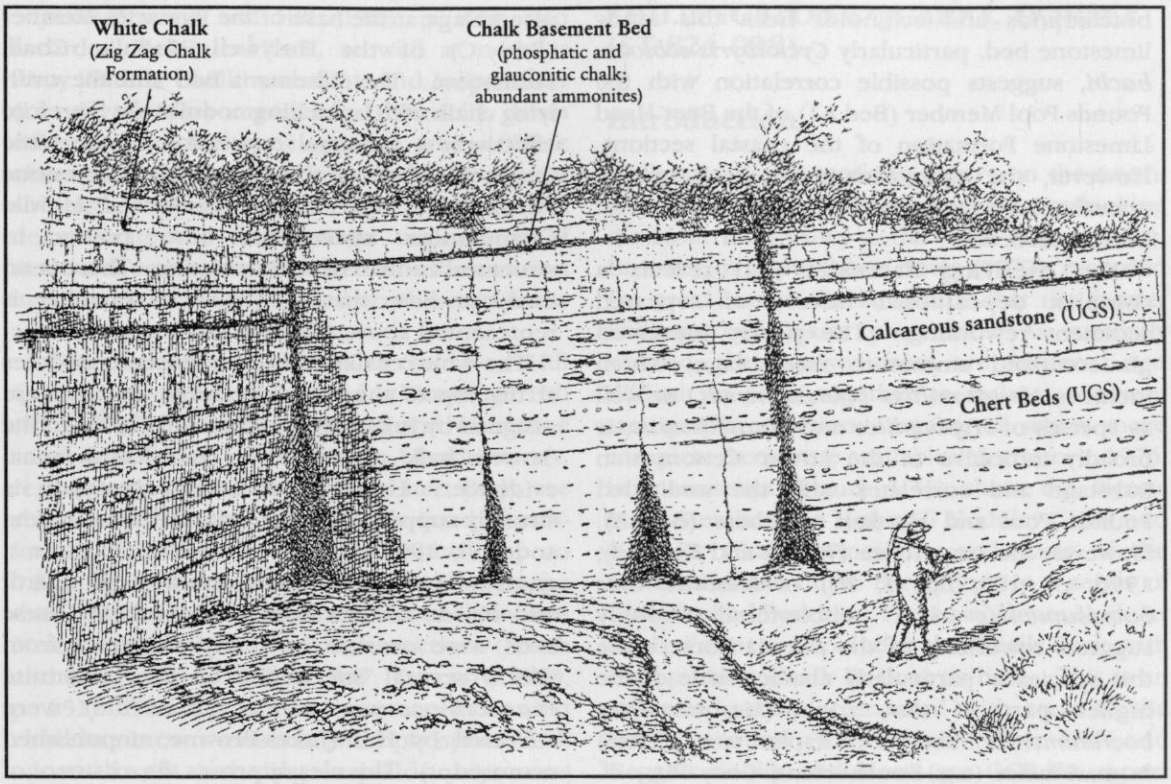


Figure 3.33 Snowdon Hill Quarry, Chard, Somerset, as seen in 1892 (UGS = Upper Greensand). (From Jukes-Browne and Hill, 1903, fig. 28, p. 118.)

C. (*N.*) *tunetanum* (Pervinquière), *C.* (*N.*) *vergonsense* (Collignon), *C.* (*Proeucalycoceras*) *picteti* Wright and Kennedy, *Desmoceras latidorsatum* (Michelin), *Eoscaphites chardensis* Wright and Kennedy, *Eucalycoceras gothicum* (Kossmat), *Forbesiceras obtectum* (Sharpe), *F. largilliertianum* (d'Orbigny), *Hamites subvirgulatus* Spath, *Parapuzosia* (*Austiniceras*) *austeni* (Sharpe), *Protacanthoceras arkelli verrucosum* Wright and Kennedy, *P. tuberculatum tuberculatum* Thomel, *Puzosia mayoriana* (d'Orbigny), *Scaphites equalis* J. Sowerby, *S. obliquus* J. Sowerby, *Schloenbachia coupei* (Brongniart), *Sciponoceras baculoides* (Mantell), *Turrilites acutus* Passy, *T. costatus* Lamarck and *Worthoceras* sp.. Snowdon Hill Quarry is the type locality for *Eoscaphites chardensis* and provided paratypes for *Calycoceras* (*Proeucalycoceras*) *picteti* and *Protacanthoceras arkelli verrucosum*.

The chalk with branching nodular concretions, immediately above the 'Basement Bed', contains a weakly or non-phosphatized *Acanthoceras jukesbrownei* Zone fauna which includes *A. jukesbrownei* (Spath), *Calycoceras* (*Proeucalycoceras*) *picteti*, *C.* (*Newboldiceras*) *asiaticum spinosum*, *Eucalycoceras gothicum* (Kossmat), *Lotzeites* sp., *Parapuzosia* (*Austiniceras*) sp. and *Puzosia* sp..

Interpretation

The relationship of the 'Basement Bed' to the Upper Greensand is complex, and this has led to varying descriptions of the section. It is clear, however, that the oldest Cenomanian deposit is the sandy limestone that infills crevices in the Upper Greensand and is intercalated between the Upper Greensand and the Basement Bed. The similarity of the lithologies of the infillings and the host rock led some early authors to assign a Cenomanian age to this highest part of the Upper Greensand. The top surface of the Upper Greensand is phosphatized and glauconitized and has phosphatized bivalves, serpulids and bryozoans adhering to it (Kennedy, 1970). The fauna of small brachiopods and echinoids from this sandy limestone bed, particularly *Cyclothyris schloenbachi*, suggests possible correlation with the Pounds Pool Member (Bed A1) of the Beer Head Limestone Formation of the coastal sections. However, the characteristic coralline sponge *Acanthochaetetes ramulosus* (Michelin) has not been recorded.

The overlying Basement Bed reveals a complex depositional history of repeated sediment reworking. The poorly preserved glauconitized ammonite assemblage, which includes *Mesoturrilites boerssumensis*, as well as species of *Hyphoplites* and *Mantelliceras*, is broadly indicative of the Lower Cenomanian Substage and correlates with the undivided Pounds Pool and Hooken members (Bed A). However, the occurrence (Wright and Kennedy, 1996, pl. 105, figs 4, 20) of *Mesoturrilites boerssumensis* as a pebble-fossil strongly suggests reworking of the *dixoni* Zone, since this species is particularly characteristic of the higher part of that zone (*Mesoturrilites boerssumensis* Subzone of Kaplan *et al.*, 1998) in marl facies (e.g. **Southerham Grey Pit** – cf. Gale, 1996; see GCR site report, this volume). The derived Lower Cenomanian ammonites in the Basement Bed are therefore not necessarily of the same age as the non-ammonite fossils recorded from the sandy limestone below the Basement Bed, but they could have been derived from an equivalent of the *dixoni* Zone 'Grizzle' at the top of the Wilmington Sand, i.e. the equivalent of the Hooken Member (Bed A2). Some of the other pebbles may have been reworked from the sandy limestone that underlies the 'Basement Bed'. Corresponding to the non-sequence elsewhere between the Hooken and Little Beach members of the Beer Head Limestone, there is no evidence in the phosphatized assemblage of the Basement Bed for the basal Middle Cenomanian *Cunningtoniceras inerme* Zone. The phosphatized *acutus* Subzone ammonite assemblage of the Basement Bed, together with the presence of abundant *Holaster subglobosus*, suggest correlation with the lower part of the Little Beach Member (Bed B), above the level with phosphatized *costatus* Subzone ammonites. The partially phosphatized *jukesbrownei* assemblage above the Basement Bed is represented as an indigenous fauna in the higher part of the Little Beach Member of the coastal sections and (sparingly) in the derived phosphatized assemblage at the base of the Pinnacles Member (Bed C) of the Holywell Nodular Chalk Formation. The Basement Bed and the overlying chalk with branching nodules are therefore effectively a proximal expression of the Little Beach Member of the Beer Head Limestone Formation. The highly condensed Middle Cenomanian succession here points to structural control of sedimentation. There is no evidence here that the Pinnacles Member is represented above this level.

The white chalks with flinty siliceous nodules at the top of the formerly visible section were assigned by Jukes-Browne and Hill (1903) to the 'Lower Chalk', although they recorded no faunal evidence. However, their interpretation is strongly supported by the record (Jukes-Browne and Hill, 1903, fig. 29) of similar chalks in a quarry, 2 miles (3.2 km) north-west of Chard, and well to the north of Snowdon Hill. These beds were overlain by marly sediments from which several specimens of the belemnite *Praeactinocamax plenus* (Blainville) were collected by Hill (Jukes-Browne, unpublished manuscript). This clearly proves the existence of Plenus Marls in the vicinity of Chard. If this interpretation of the highest part of the Snowdon Hill Quarry succession is correct, these white chalks with siliceous nodules would be partially time-equivalent to the derived phosphatized *Calycoceras guerangeri* Zone ammonites at the base of the Pinnacles Member (Bed C) of the Holywell Nodular Chalk Formation, and to the higher part of the Zig Zag Chalk Formation of the Grey Chalk Subgroup in sections to the east. The foraminiferal evidence (Carter and Hart, 1977a, fig. 34) provides some support for this interpretation, in that the highest sample, *c.* 1 m above the Basement Bed, is suggestive of a horizon in the *guerangeri* Zone. The Snowdon Hill Quarry succession would then differ significantly from that at **Furley Chalk Pit** (see GCR site report, this volume) in the Membury outlier, where the Pinnacles Member (i.e. Plenus Marls equivalent) is represented directly above the Chalk Basement Bed. On the other hand, in view of the intensely faulted nature of the Cretaceous outcrop in the vicinity of Chard, it may be that the highest part of the Snowdon Hill Quarry succession correlates with the Chalk above the Basement Bed at Furley Chalk Pit. This intriguing question remains unresolved.

Jukes-Browne and Hill (1903, p. 429) also recorded Melbourn Rock, as well as nodular flinty 'Middle Chalk' with flints and *Inoceramus* (i.e. *Mytiloides*) *mytiloides* (Mantell), from other pits in the same general area. These observations show that elements of the normal succession appear here for the first time and demonstrate the fundamental importance of structural control on Cretaceous sedimentation in this zone of closely-spaced north–south faults and associated half-grabens.

A similar section to that at Snowdon Hill Quarry was formerly exposed at Storridge Hill (ST 318 048), 4 km to the south and within the same fault block. Here, 1.3 m of sandstones, resting with erosive contact on Chert Beds, are sharply overlain by an intensely hard, fossiliferous conglomeratic sandy limestone, up to 0.3 m thick, that is lithologically similar to the thin, condensed developments of the Hooken Member (Bed A2) of the coastal sections (Smith and Drummond, 1962, p. 347; Kennedy, 1970, p. 651). The top of this limestone has a thin chocolate-brown veneer of shiny phosphate with adnate fossils including serpulids, bryozoans and bivalves. The overlying Basement Bed contains pebbles reworked from the underlying limestone, phosphatized *acutus* Subzone ammonites, abundant *Holaster subglobosus* (some phosphatized), and non-phosphatized ammonites from the *jukesbrownei* Zone. The Chalk above the Basement Bed contains a foraminiferal fauna (Carter and Hart, 1977a, fig. 35) suggestive of the *guerangeri* Zone, as at Snowdon Hill. This key succession is thus intermediate in character between the coast sections and the inland sections on the one hand, and the basinal successions to the east, on the other.

Conclusions

Snowdon Hill Quarry contains the most northerly exposure of Cenomanian deposits within the fault-bounded Upper Cretaceous outliers of south-west England. The highly condensed and richly fossiliferous nature of the Cenomanian deposits and their complex relationship to the underlying Albian Upper Greensand make it a key locality for understanding the Cenomanian history of the area. The Middle Cenomanian ammonites from the Basement Bed are critical for international correlation.

SHILLINGSTONE QUARRY, DORSET (ST 824 098)

Introduction

Shillingstone is a working quarry on the north-west face of the Chalk escarpment overlooking the Stour River valley to the north (Figure 3.34). Bromley, in unpublished notes (1977), recorded the great scar in the landscape that the former Shillingstone Quarry presented. As currently worked, the exposed faces are scattered and difficult to piece together to make a coherent stratigraphy. Sections measured when more complete faces were available (Mortimore, 1976, in manuscript; Figure 3.35) show the Plenus Marls Member, the Holywell Nodular Chalk and New Pit Chalk formations, and parts of the Lewes Nodular Chalk Formation, in a series of badly faulted benches. The basal Lewes Nodular Chalk Formation includes the Chalk Rock with the Spurious Chalk Rock at its base. This is an expanded section compared with areas to the north, around Warminster (Cley Hill and Beggars Knoll), and Mere (see GCR site report for **Charnage Down Chalk Pit**, this volume). Despite many attempts to measure and collect the sections, there is still great uncertainty about parts of the stratigraphy.

Description

Shillingstone is first mentioned by White (1923), and Drummond (1967) visited the quarry during the course of his research (1950s) on the Albian–Cenomanian successions. Carter and Hart (1977a) sampled Shillingstone and published a simplified Cenomanian section for micropalaeontological studies. Mortimore and Pomerol (1987) and the British Geological Survey (Bristow *et al.*, 1995) published graphic logs of the Turonian–Coniacian section. One kilometre to the west, on the far side of a possibly structurally controlled valley (Figure 3.34), there are important correlative exposures beside the so-called 'Shillingstone track sections' (ST 815 095) in the woodland.

It was not until the 1970s that systematic work was undertaken on the whole of the exposure (Mortimore, 1976, 1979, 1983, in manuscript; Mortimore and Pomerol, 1987). Bromley and Gale (1982) recorded the Chalk Rock sections as part of their study of the Chalk Rock through the region. Latterly, the British Geological

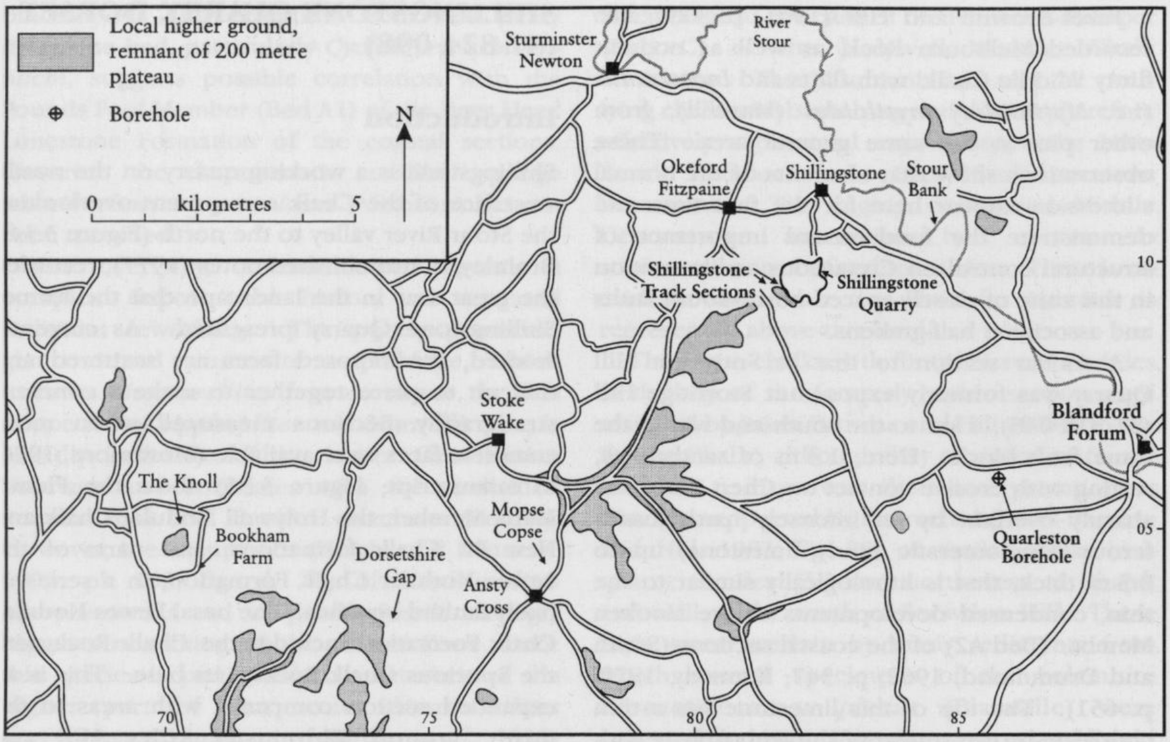


Figure 3.34 Location of Shillingstone Quarry and Track Sections, other sites mentioned in the text in the Blandford Forum area, Dorset.

Survey revisited the section and systematically collected the fossils (Bristow *et al.*, 1995). On each occasion, a different section had been seen, leading to differences in interpretation. Several controversies remain, including:

(i) the age of the beds underneath the Spurious Chalk Rock;
(ii) correlation of the marls within the Chalk Rock with those of the main basin;
(iii) thicknesses of sediment above the Chalk Rock to the other marker beds in the upper Lewes Nodular Chalk.

Lithostratigraphy

The currently exposed composite 80 m succession (Figure 3.35) extends from the Plenus Marls Member at the base of the Holywell Nodular Chalk Formation to the inferred basal beds of the Seaford Chalk Formation.

Drummond (1967, 1970) suggested a thickness of 140 ft (*c.* 45 m) for the Lower Chalk at Shillingstone, comprising some 60 ft (18 m) of Chalk Marl (West Melbury Marly Chalk Formation) with perhaps 10–20 ft (3–6 m) of Lower Cenomanian deposits (Figure 3.36). Currently, the Grey Chalk Subgroup is only very scrappily exposed along track sections 1 km west of the the quarry. There are no detailed logs and no prospect of obtaining any at the present time. However, the British Geological Survey Quarleston Borehole, to the east (Figure 3.34), provides a geophysical log showing the thickness of the Grey Chalk as 63 m (Bristow *et al.*, 1995, fig. 49). The borehole gamma-log illustrates a marly lower part and a more calcareous upper part with a well-defined Plenus Marls Member. A conspicuous spike on the borehole log marks the Tenuis Limestone at the boundary between the West Melbury Marly Chalk Formation below and the Zig Zag Chalk Formation above. The stratigraphy and thicknesses compare closely with the sparse records from Shillingstone Quarry.

During the 1970s the lowest exposures included the White Bed at the top of the Grey Chalk Subgroup and the overlying Plenus Marls Member. The Plenus Marls are about 4 m thick (compared with 5 m in the Quarleston

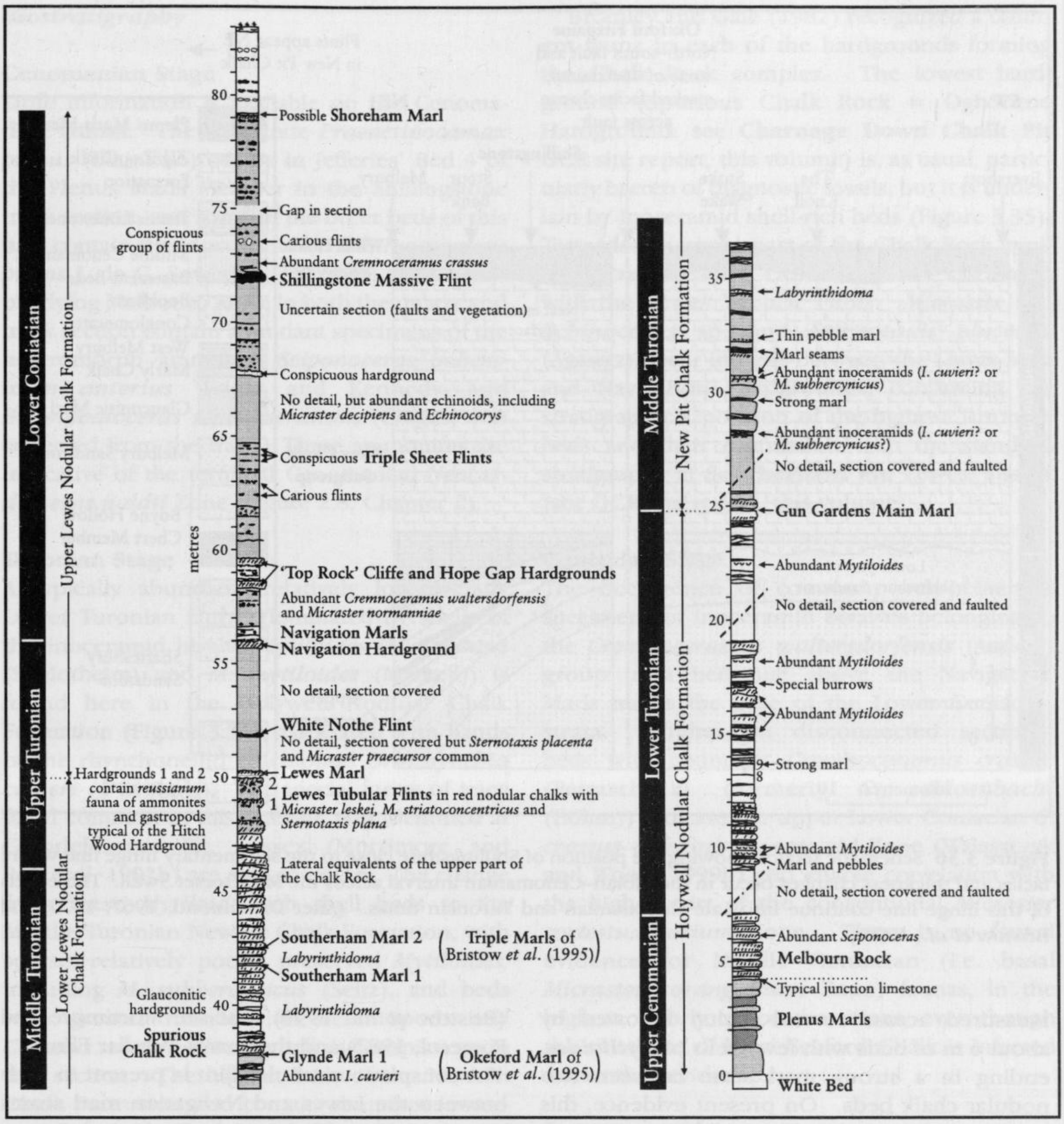


Figure 3.35 The succession of Upper Cretaceous Chalk at Shillingstone Quarry, Dorset. (After Mortimore and Pomerol, 1987; and Bristow *et al.*, 1995.)

Borehole), comprising three prominent marly units separating paler limestones. As is typical, the uppermost beds of the Plenus Marls form a complex of very thin marls and limestones. Jefferies' (1962, 1963) bed numbers for the standard Plenus Marls succession can be applied. The overlying Melbourn Rock begins with a hard, relatively smooth, limestone (Junction Limestone, Mortimore, 1986a), succeeded by much more nodular hard limestones with interbedded marl seams. These marl seams and intervening nodular chalks in the Melbourn Rock can be correlated with the standard stratigraphy at Beachy Head, Sussex (Mortimore, 1986a; Mortimore and Pomerol, 1987, 1996).

Typical gritty, shell-detrital, nodular chalks enter about 5 m above the top of the Plenus Marls in a faulted section. There are about 10–12 m of shell-detrital chalks (section

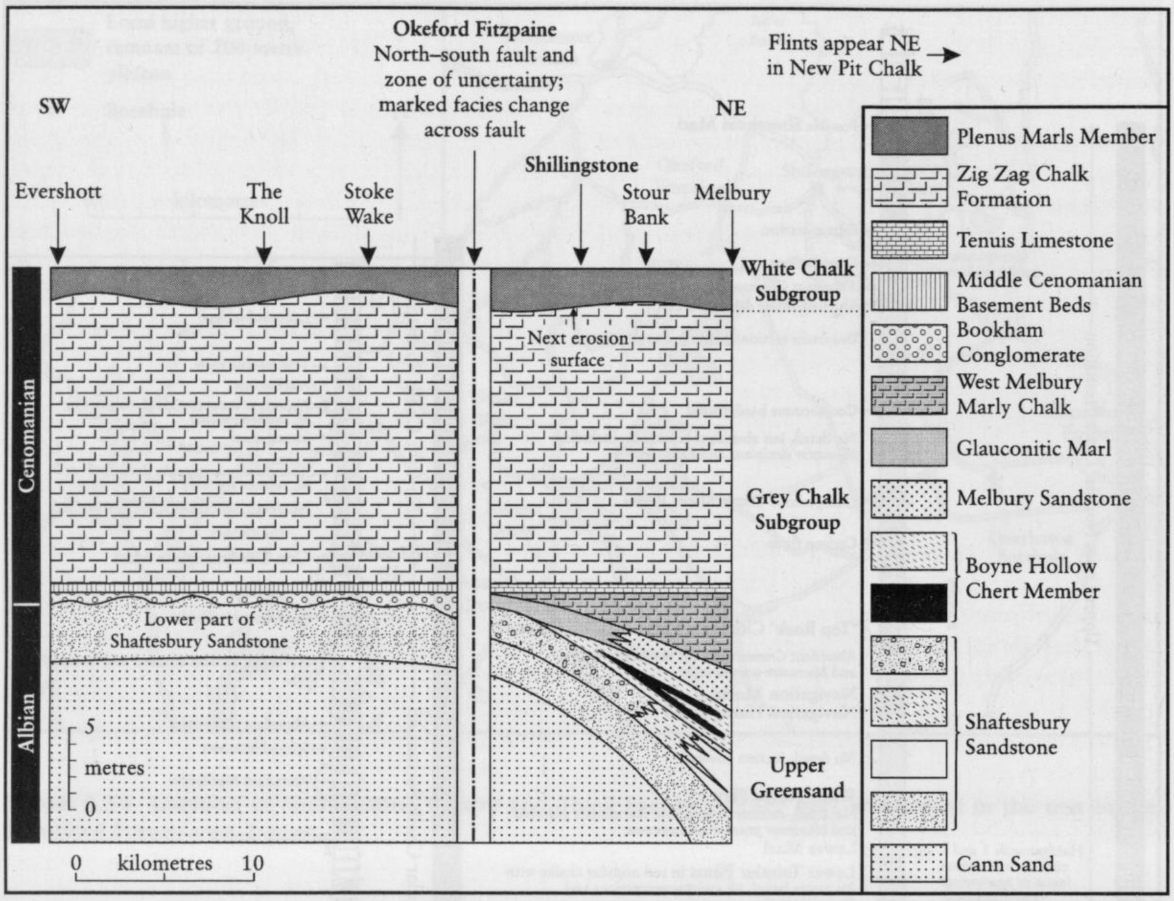


Figure 3.36 Schematic section showing the position of Shillingstone close to the sedimentary hinge line where facies and thickness changes occur in the Albian–Cenomanian interval across the Mid-Dorset Swell. The effects of this hinge line continue into Late Cenomanian and Turonian times. (After Drummond, 1967, 1970; and Bristow *et al*., 1995.)

measured across several faults) followed by about 6 m of beds with few shells of *Mytiloides*, ending in a strong marl seam between two nodular chalk beds. On present evidence, this marl seam is correlated with the Gun Gardens Main Marl of the standard succession at Beachy Head, Sussex. If this correlation is correct, the boundary between the Holywell Nodular Chalk and New Pit Chalk formations is present (but see information about track sections below).

Faulting between benches in the quarry makes detailed and accurate logging of sections in the New Pit Chalk and the overlying Chalk Rock exceedingly difficult. Bromley and Gale (1982) provide a detailed section of the Chalk Rock interval at the base of the Lewes Nodular Chalk. Particularly useful lithological markers include the Southerham Marls (named the 'Triple Marls' by the British Geological Survey (Bristow *et al*., 1995), but see Mortimore and Pomerol, 1987) and the Lewes Tubular Flints.

A conspicuous tabular flint is present in beds between the Lewes and Navigation marl seams (Figure 3.35). The British Geological Survey (Bristow *et al*., 1995) named this the 'Shillingstone Tabular Flint', but it clearly correlates with the White Nothe Flint (Mortimore and Pomerol, 1987) of the **White Nothe** GCR site. The beds comprising the Navigation Marls and the remaining upper Lewes Nodular Chalk Formation are exposed in a series of discontinuous sections behind the main quarry, and thicknesses are uncertain. A marl seam resting on a poorly developed hardground near the base of the highest section may correlate with one of the Shoreham Marls, in which case the highest beds would fall within the Seaford Chalk Formation.

Biostratigraphy

Cenomanian Stage

Little information is available on the Cenomanian faunas. The belemnite *Praeactinocamax plenus* (Blainville) occurs in Jefferies' Bed 4 of the Plenus Marls Member in the Shillingstone track section, and some of the other beds of this unit contain the inoceramid bivalve *Inoceramus pictus* J. de C. Sowerby. The basal beds of the overlying Melbourn Rock, in both the quarry and track section contain abundant specimens of the heteromorph ammonite *Sciponoceras bohemicum anterius* Wright and Kennedy, and *Euomphaloceras septemseriatum* (Cragin) was collected from the track. These ammonites are indicative of the terminal Cenomanian *Neocardioceras juddii* Zone (Figure 2.8, Chapter 2).

Turonian Stage

A typically abundant, relatively low-diversity Lower Turonian fauna, dominated by shells of the inoceramid bivalve *Mytiloides* (*M. labiatus* (Schlotheim) and *M. mytiloides* (Mantell)) is found here in the Holywell Nodular Chalk Formation (Figure 3.35), associated with bands of the rhynchonellid brachiopod *Orbirhynchia cuvieri* (d'Orbigny). The special forms of trace fossil common in this interval, and identified at Glyndebourne Pit, Sussex (Mortimore and Pomerol, 1991b) are also common. The change from these *Mytiloides*-rich shell beds to the Middle Turonian New Pit Chalk Formation, with sparse, relatively poorly preserved *Mytiloides*, including *M. subhercynicus* (Seitz), and beds with greater numbers of brachiopods and *Conulus subrotundus* Mantell, is conspicuous in this section. The highest beds of the New Pit Chalk Formation also contain abundant *Inoceramus cuvieri* J. Sowerby. The British Geological Survey recorded the Middle Turonian zonal index ammonite *Collignoniceras woollgari* (Mantell) 1 m beneath the Spurious Chalk Rock from the Shillingstone track section to the west of the quarry (Bristow *et al.*, 1995).

A feature of the higher beds of the Middle Turonian Substage is the presence of the giant deep-water foraminifer *Labyrinthidoma southerhamensis* Hart (*Coskinophragma* in the earlier literature – see Hart, 1993) (Figure 3.35), which provides a guide to the Glynde and Southerham marls across the Southern Province (Mortimore, 1986a; Mortimore and Pomerol, 1987).

Bromley and Gale (1982) recognized a different fauna in each of the hardgrounds forming the Chalk Rock complex. The lowest hardground (Spurious Chalk Rock = Ogbourne Hardground; see **Charnage Down Chalk Pit** GCR site report, this volume) is, as usual, particularly barren of diagnostic fossils, but it is underlain by inoceramid shell-rich beds (Figure 3.35). Towards the upper part of the Chalk Rock, typical *Micraster leskei* Desmoulins are associated with the Lewes Tubular Flints. *Micraster* sp., *Echinocorys* sp. and *Sternotaxis placenta* (Agassiz) occur in beds between the Lewes Marl and Navigation Hardgrounds, confirming the stratigraphical position of the highest Turonian beds and their correlation with the standard stratigraphy at **Southerham Pit**, Lewes, Sussex (see GCR site report, this volume).

Coniacian Stage

The occurrence of common, well-preserved specimens of inoceramid bivalves belonging to the *Cremnoceramus waltersdorfensis* (Andert) group in a bed just above the Navigation Marls marks the base of the Lower Coniacian strata. Higher, in disconnected sections, beds with abundant *Cremnoceramus crassus* (Petrascheck) (formerly *C. schloenbachi* (Böhm)) indicate the upper Lower Coniacian *C. crassus–deformis* inoceramid Zone (Walaszczyk and Wood, 1999b) and enable correlation with the higher part of the conventional *Micraster cortestudinarium* Zone. There is no faunal evidence for Middle Coniacian (i.e. basal *Micraster coranguinum* Zone) faunas, in the highest, poorly exposed sections, even though the existence of basal Seaford Chalk is inferred from other evidence.

Interpretation

Drummond (1967, 1970) illustrated the critical position of Shillingstone, in that it provides evidence for thickening and thinning of Albian–Cenomanian sediments in Wessex as a result of structural control related to a Mid-Dorset swell (Figure 3.36). North from Shillingstone towards Melbury, the Grey Chalk Subgroup thickens into a Wessex Trough; to the south and west thinning occurs towards Okeford Fitzpaine and Stoke Wake. Today no useful exposures exist of this part of the succession.

Shillingstone Quarry is, however, one of the few exposures of the lower part of the White

Chalk Subgroup on the western margin of the Chalk outcrop, and provides a vital link between the major south coast sections and sections in the Transitional Province. It is critical to an understanding of condensation in the Turonian Stage, notably the development of the 'Spurious Chalk Rock' and Chalk Rock, and the interpretation of the Turonian marl seam correlation framework. There is uncertainty regarding the total thicknesses of units, and recent work by the British Geological Survey (Bristow *et al.*, 1995) has cast doubt on the 'Middle Chalk' section of Mortimore and Pomerol (1987). This is because of the record of ***Mytiloides subhercynicus*** not far below the base of the Spurious Chalk Rock in the Shillingstone track section. This section is one kilometre to the west (Figure 3.34), across a valley which may be structurally controlled. In the same direction at Okeford Fitzpaine, Drummond (1967, 1970) recorded thinning of the Albian and Cenomanian deposits compared with Shillingstone. In contrast to the track section, the record of ***Inoceramus cuvieri*** and the giant foraminifer ***Labyrinthidoma southerhamensis*** below the Spurious Chalk Rock at Shillingstone Quarry (Mortimore and Pomerol, 1987), places the basal contact of the Spurious Chalk Rock higher in the Turonian succession there than in the track section. These apparent differences between the two localities may result from the exceptionally common faulting in the quarry, or there may be a genuine lateral change in the erosion base below the Spurious Chalk Rock.

Shillingstone is located close to a sedimentary hinge line, with sediments thickening north-eastwards and thinning dramatically south-westwards. To account for the thinning, Drummond (1967, 1970) introduced a structural element termed the Mid-Dorset Swell, this interpretation and terminology being later adopted by Kennedy (1970) and the British Geological Survey (Bristow *et al.*, 1995). For the Albian–Cenomanian strata, Drummond (1967, 1970), Kennedy (1970) and the British Geological Survey (Bristow *et al.*, 1995) have all produced schematic diagrams to illustrate the changes in sediments, linked to correlative sections nearby. Each differs in detail, particularly in the interpretation of erosion surfaces, which has a great bearing on correlation into more basinal sections and the recognition of sequence boundaries. An attempt to summarize the geology in the Albian–Cenomanian succession (Figure 3.36) shows the importance of sections related to Shillingstone at Melbury, Stour Bank, Okeford Fitzpaine, Bookham Farm and Evershott. The GCR sites at **Dead Maid Quarry** (Mere), and **White Nothe** (Dorset coast) are also critical to the interpretation. Although the locus of thinning has been identified as the Mid-Dorset Swell, recent seismic evidence has identified a Cranbourne–Fordingbridge High (e.g. Bristow *et al.*, 1995) and it is across the northern flank of this structure that Shillingstone is located.

Immediately west of Shillingstone, at Okeford Fitzpaine, the West Melbury Marly Chalk Formation thins to virtually nothing, in contrast to some 20 m of silty marly poorly differentiated chalk at Shillingstone and, to the south-east, in the Quarleston Borehole (Figure 3.34). Locally, thin patches of this unit are present at Mopse Copse. Okeford Fitzpaine is a key locality where all lithologies thin and change westwards and south-westwards. It is not clear how each of the units correlate in detail from north-east to south-west, the change taking place either side of a north–south fault that may have been active during sedimentation of Late Cretaceous deposits.

Localities around Shillingstone (Figure 3.34) such as Stour Bank, Dorsetshire Gap, Bookham Farm, the Knoll and Evershott have provided a diverse range of well-preserved ammonite and inoceramid bivalve faunas, which were described by Kennedy (1970), Wright and Kennedy (1984) and Bristow *et al.* (1995). Because of the complex nature of the condensed sections at, for example Bookham Farm, the stratigraphy has been evaluated in centimetres with some boulders in the conglomerates containing fossils not present in the enclosing sediment.

In the Turonian Stage, Shillingstone provides a contrasting section with Beggars Knoll, Wiltshire (Figure 3.37), illustrating lateral variation, particularly in the Chalk Rock.

Conclusions

Despite the uncertainties in the stratigraphy, Shillingstone Quarry and the surrounding track exposures provide rare and invaluable Albian–Cenomanian to Coniacian records. These records confirm the presence of regional marker

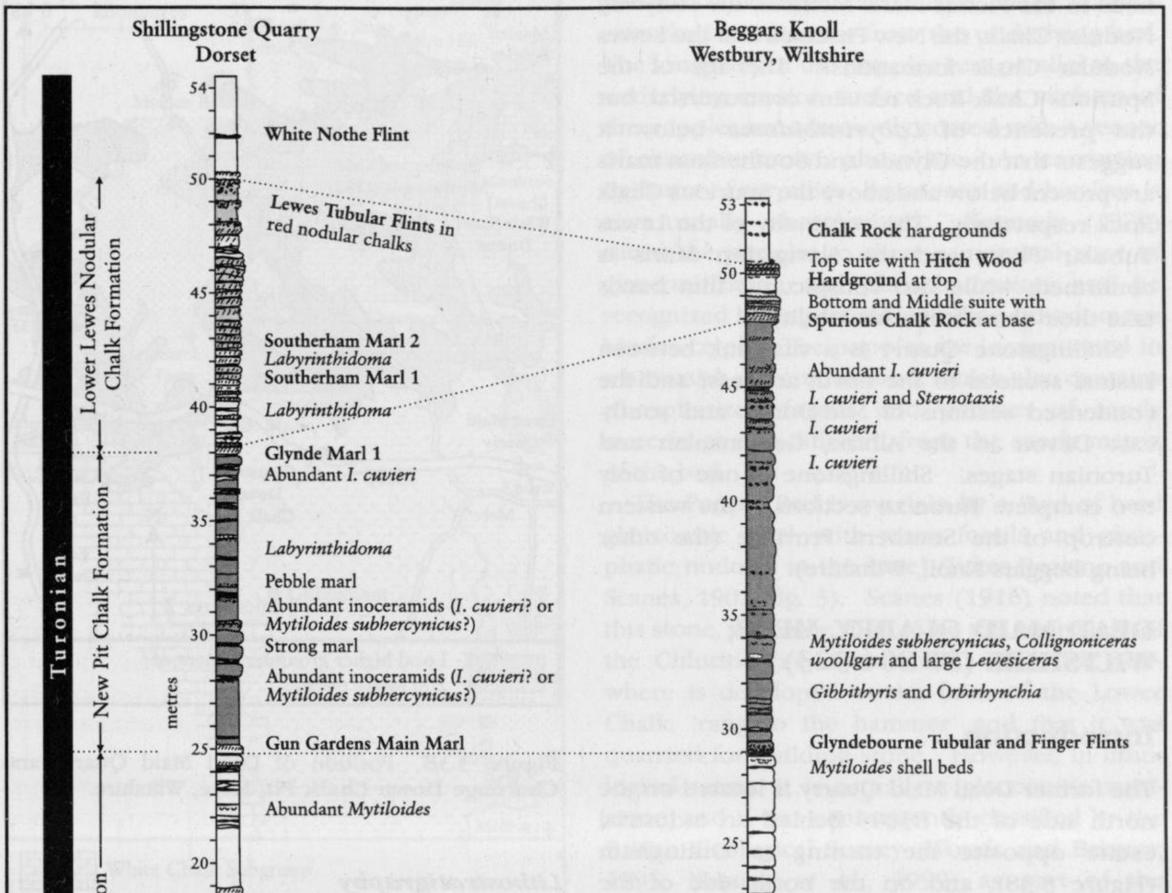


Figure 3.37 Highest Cenomanian and Turonian successions at Shillingstone Quarry (Dorset) compared with Beggars Knoll (Westbury, Wilts), 40 km to the north.

beds in the Plenus Marls Member, the Holywell Nodular Chalk, the New Pit Chalk and the Lewes Nodular Chalk formations. The age of the Spurious Chalk Rock remains controversial, but the presence of *Labyrinthidoma* below it suggests that the Glynde and Southerham marls are present below and above the Spurious Chalk Rock respectively. The continuity of the Lewes Tubular Flints and the Navigation Marls is confirmed, while two conspicuous flint bands take their name from this locality.

Shillingstone Quarry is a vital link between basinal sections to the north and east and the condensed sections of Mid-Dorset and south-east Devon in the Albian, Cenomanian and Turonian stages. Shillingstone is one of only two complete Turonian sections in the western outcrop of the Southern Province (the other being Beggars Knoll, Wiltshire).

DEAD MAID QUARRY, MERE, WILTSHIRE (ST 804 323)

Introduction

The former Dead Maid Quarry is located on the north side of the B3095 behind an industrial estate opposite the turning to Gillingham (Figure 3.38), and on the north side of the re-entrant into the Chalk escarpment that is controlled by the Mere Fault. The beds dip at *c.* 5° to the east and are on the north side of the Mere Fault (Figure 3.39). This former quarry is famous for its condensed highly fossiliferous basal Cenomanian succession, comprising the so-called 'Popple Bed' and overlying Glauconitic Marl, which is intercalated between the Upper Greensand Chert Beds and the Lower Chalk of the traditional stratigraphy.

Description

Dead Maid Quarry was first described by Jukes-Browne and Scanes (1901) and by Jukes-Browne and Hill (1903). Additional details were given by Scanes (1916), Edmunds (1938) and Smith and Drummond (1962). Jukes-Browne and Scanes (1901), Scanes (1916), and Kennedy (1970) gave graphic logs differing in points of detail, and the first two papers included annotated photographs of the section. The description given here is a based on a combination of these sources and the authors own observations.

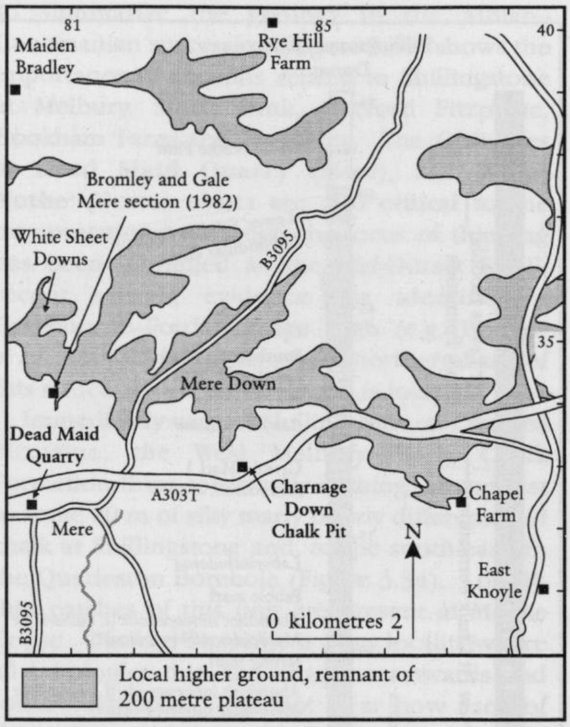


Figure 3.38 Position of Dead Maid Quarry and **Charnage Down Chalk Pit**, Mere, Wiltshire.

Lithostratigraphy

In modern British Geological Survey stratigraphical terminology (Woods and Bristow, 1995; Bristow *et al.*, 1999), the 6 m section (Figure 3.40) comprises a complex and highly condensed succession, belonging to the Melbury Sandstone Member of the Upper Greensand Formation, which rests with marked erosive contact on the Boyne Hollow Cherts Member of that formation, and is overlain by the West Melbury Marly Chalk Formation of the Grey Chalk Subgroup. However, following the rationale of the new classification (Rawson *et al.*, 2001), the Melbury Sandstone Member now becomes the basal member of the Grey Chalk Subgroup.

The Boyne Hollow Cherts Member consists of fine-grained, buff-green laminated silts with lenticular, black-brown cherts. A bed of fine-grained, grey calcareous glauconitic sandstone, containing very hard, grey concretions of calcite-cemented quartz-sand, which is also assigned by the British Geological Survey to the Boyne Hollow Cherts, rests with burrowed contact on the beds with cherts.

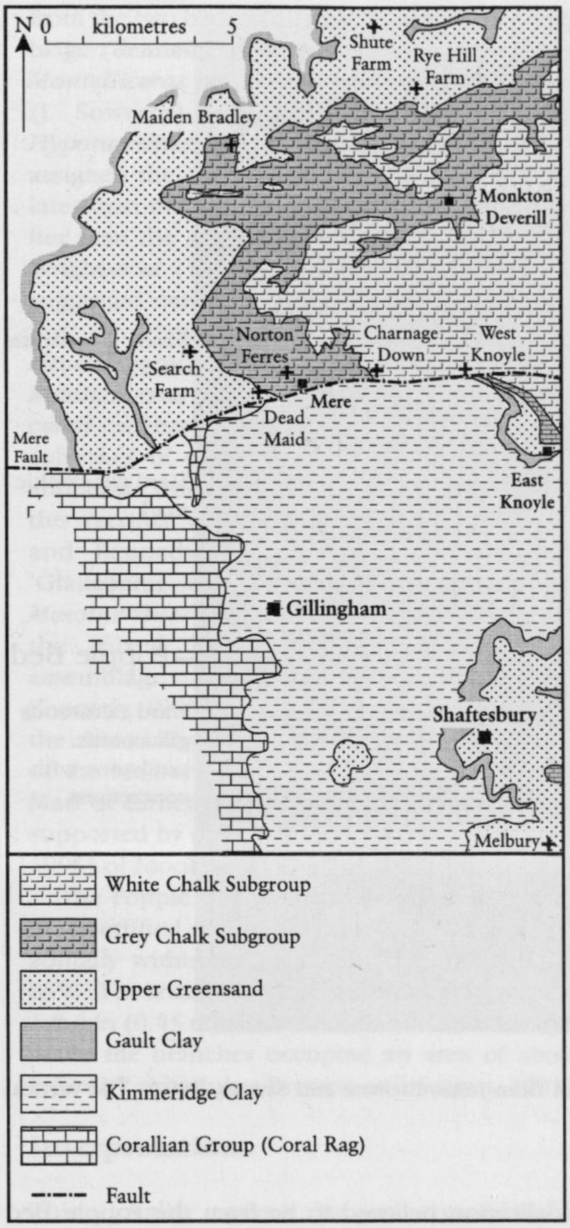


Figure 3.39 The position of Dead Maid Quarry and **Charnage Down Chalk Pit** in relation to the Mere Fault and other key localities in the area. (After Scanes, 1916.)

Of particular interest is the so-called 'Popple Bed', which rests on a highly irregular erosion surface with an amplitude of at least 0.3 m at the base of the Grey Chalk Subgroup, cut into the underlying sandstone with concretions (Jukes-Browne and Scanes, 1901, pl. 5). The 'popples' are pebbles, flat cobbles and boulders 0.2–0.25 m in length, which Kennedy (1970) and previous observers considered were actually reworked concretions from the underlying bed. The long-axes of the popples rest parallel to the underlying erosion surface and the surfaces of the popples are commonly coated with a veneer of chocolate-brown phosphate. An encrusting epifauna of serpulids, bryozoans and bivalves is also usually phosphatized. Kennedy (1970) sliced the popples to show a marginal zone of glauconitization and phosphatization, and he recognized boring traces including lithodomous bivalve crypts. The popples are incorporated in a brownish calcareous sand, which also contains phosphatized fossils and patches of sandy material that is different from the sandy matrix of the bed.

The Popple Bed is overlain by a 'bed of hard glauconitic marl, with many fossils and phosphatic nodules at the base' (Jukes-Browne and Scanes, 1901, fig. 3). Scanes (1916) noted that this stone, which he took to be the equivalent of the Chloritic (i.e. Glauconitic) Marl that elsewhere is developed at the base of the Lower Chalk, 'rang to the hammer' and that it was quarried for building stone. However, in lithological terms, it is actually a glauconitic sandstone, and it was consequently classified by the British Geological Survey (Woods and Bristow, 1995; Bristow *et al.*, 1999) as part of the Melbury Sandstone Member of the Upper Greensand, with the thin overlying sandy, glauconitic marl containing a few phosphatic nodules (their Glauconitic Marl *sensu stricto*) being assigned to the basal bed of the Chalk Group (West Melbury Marly Chalk Formation). In this account, we treat the Popple Bed as the basal member of the West Melbury Marly Chalk Formation (Figure 3.40).

Biostratigraphy

The Boyne Hollow Cherts here are undated, but by analogy with sections in the Shaftesbury district, can be inferred to belong to the Upper Albian *Stoliczkaia dispar* Zone. The bed of glauconitic sandstones with concretions that is developed here, and in the localities around Maiden Bradley, is reported to contain rare macrofossils at Dead Maid Quarry, but there are no fossil names in the literature and the bed is, therefore, of uncertain age. Arenaceous foraminifera cited by Carter and Hart (1977a, fig. 23) from this bed were assigned to the Lower Cenomanian Substage; however, most of the

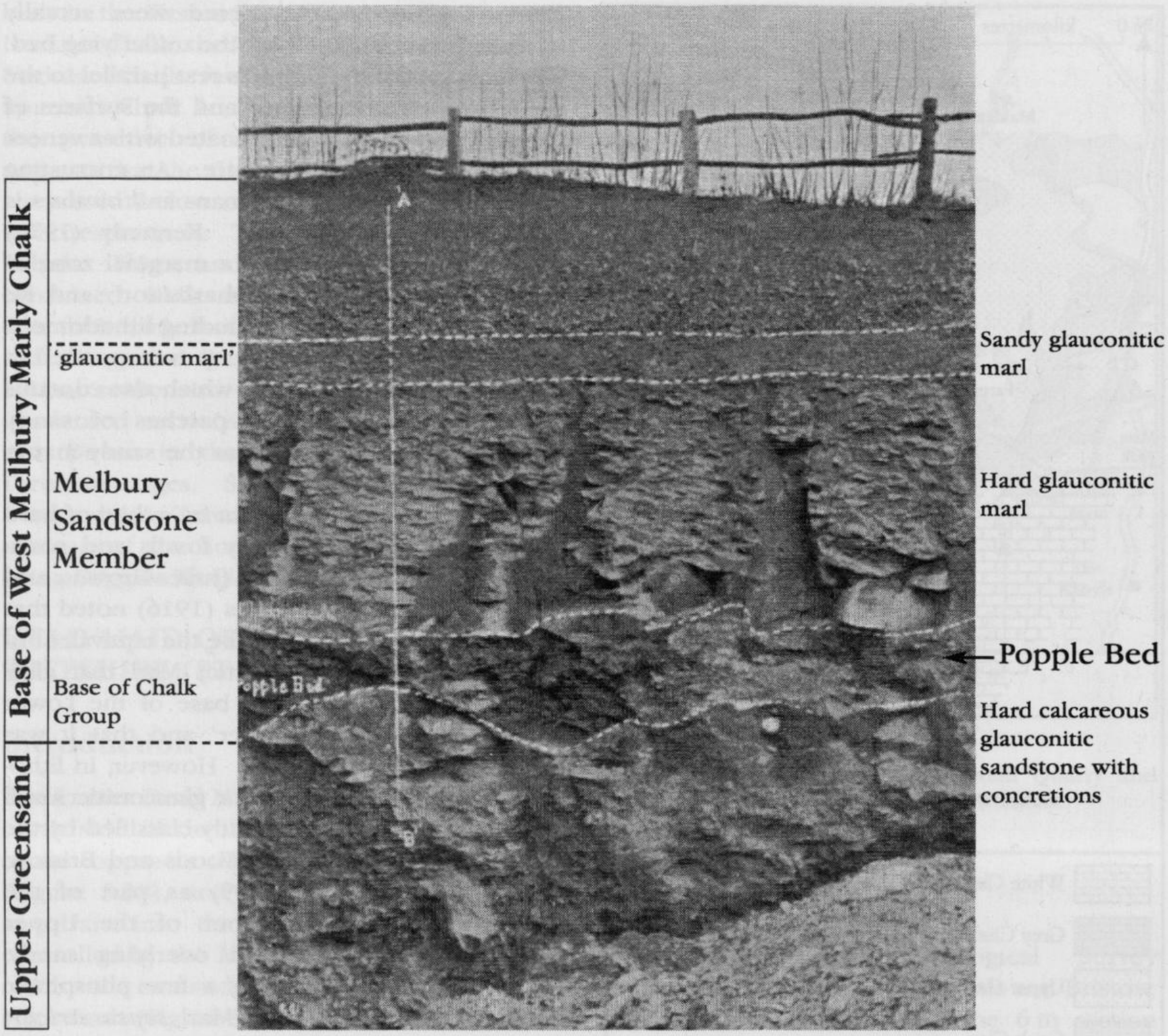


Figure 3.40 Dead Maid Quarry, Wiltshire. (Reproduced from Jukes-Browne and Scanes, 1901. The vertical line 'A–B' indicates where their section was taken.)

taxa indicate a latest Albian rather than an Early Cenomanian age (cf. their fig. 9).

The sediment in between the popples of the Popple Bed, the overlying top bed of the Melbury Sandstone Member, and the thin bed of sandy glauconitic marl all contain phosphatized fossils, including bivalves, gastropods and ammonites. Extensive fossil collections (now at the British Geological Survey, Keyworth), were made here at the beginning of the 20th century by the local amateur geologist, Dr Pope Bartlett. It must be emphasized that, although he assigned his fossils to the various beds, inspection of this material suggests that the stratigraphical information is not necessarily reliable. Phosphatized material from this collection believed to be from the Popple Bed contains 14 species of bivalves and 4 of echinoids (notably *Catopygus columbarius* (Lamarck)), as well as species of the ammonites *Mariella* and *Mantelliceras*, including *Mantelliceras dixoni* Spath (Woods and Bristow, 1995). Kennedy (1970) observed that there was locally a phosphatic crust at the top of the Popple Bed, while in other places the sediment of the 'Glauconitic Marl' infilled the interstices between the popples. He noted that the Popple Bed itself contained some fossils, stating that most of the ammonites that he collected came from the top of the bed, in the complex zone of contact between it and the 'Glauconitic Marl', and that it was therefore impossible to separate the faunas from the two beds. The mixed ammonite assemblage (Kennedy, 1970, p. 620) is dominated by *Mantelliceras* spp. and *Schloenbachia varians* (J. Sowerby) with subordinate *Hyphoplites*, *Hypoturrilites* and *Mariella*. Kennedy (1970) assigned the assemblage to the *mantelli* Zone, later than the *carcitanense* assemblage and earlier than the *saxbii* assemblage. Subsequently, Wright *et al.* (1984) stated that the *Mantelliceras* suggested derivation from the *couloni* Horizon (i.e. the upper part of the basal Cenomanian *Neostlingoceras carcitanense* Subzone) and the *Mantelliceras saxbii* Subzone (i.e. the *Sharpeiceras schlueteri* and *Mantelliceras saxbii* subzones of the current zonal scheme). The ammonite evidence from here is equivocal, but the records of *Mantelliceras dixoni* (Wright and Kennedy, 1984, pl. 37, fig. 5) from the 'Glauconitic Marl' above the Popple Bed and *Mesoturrilites boerssumensis* (Schlüter) from the mixed Popple Bed/'Glauconitic Marl' assemblage (Kennedy, 1970; Wright and Kennedy, 1996) clearly indicate the presence of the *dixoni* Zone. The assignment of the top bed of the Melbury Sandstone (i.e. the Glauconitic Marl of earlier literature) to the *dixoni* Zone is supported by a recent find (Woods and Bristow, 1995) of *Inoceramus virgatus* Schlüter.

The Popple Bed is noted for the find in 1899 of a petrified coniferous tree lying almost horizontally within the bed, and orientated NNE–SSW. The trunk was nearly 20 ft (6 m) long and 1 ft 6 in (0.45 m) in diameter at the thickest end, while the branches occupied an area of about 9 ft^2 (2.7 m^2) (Jukes-Browne and Scanes, 1901).

Interpretation

This locality gave rise to considerable controversy in the early years of the 20th century, because it appeared to show transition beds, which lithologically belonged to the highest beds of the Upper Greensand, but contained fossils of Lower Chalk (i.e. Cenomanian) age. It was difficult to know whether these transition beds should be placed in the Upper Greensand or in the Lower Chalk, and opinion on this question swung backwards and forwards between the two interpretations. Eventually Scanes, (1916, p. 115), following some preliminary hints given earlier (Jukes-Browne and Scanes, 1901), decided that the fossil evidence was paramount, and placed the beds in question in the Lower Chalk, despite the obvious difference in lithology. Jukes-Browne and Scanes (1901) introduced a new subzone (*Catopygus columbarius* Subzone) of the existing *Ammonites* (i.e. *Schloenbachia*) *varians* Zone for the transition beds, and assigned the overlying Chloritic (Glauconitic) Marl to the existing subzone of the sponge *Stauronema carteri* Sollas. In the Wincanton Memoir (Bristow *et al.*, 1999) the British Geological Survey has now placed all of the transition beds, including the 'Glauconitic Marl' of earlier workers, once again in the Upper Greensand Formation, while recognizing their Cenomanian age. Following the recent revision of the lithostratigraphical classification (Rawson *et al.*, 2001), all these transition beds once again revert to classification in the Grey Chalk Subgroup.

Dead Maid Quarry is a key locality in the interpretation of two other former sections near Mere, Norton Ferris (ST 810 331) and Search Farm (ST 790 334), as well as a group of sections around Maiden Bradley, some 6 km to the north (Figures 3.38 and 3.39), which exposed the so-called 'Warminster Greensand'. The most important of these latter sections were at Maiden Bradley Quarry (ST 797 310), Rye Hill Farm (ST 848 403) and Shute Farm (ST 843 410).

In all of these localities, the chert-bearing beds are overlain by a bed of conspicuously glauconitic sandstone containing concretions of calcite-cemented quartz sand, with inconspicuous sparse, very small glauconite grains. This bed at Maiden Bradley Quarry yielded a diverse fauna including ammonites, identified by Jukes-Browne, which are clearly Lower Cenomanian *Hyphoplites*, *Mantelliceras* and *Schloenbachia* (Jukes-Browne and Hill, 1900, p. 238). However, it must be emphasized that the ammonites actually came from the top of the bed, immediately beneath the Cornstones (see below), and that it is possible that their true provenance was in the overlying bed. None of these Cenomanian ammonites has been found in museum collections. The only ammonite (British Geological Survey Zb 1213) known to have come from this bed is an indigenous, poorly preserved Upper Albian *Callihoplites vraconensis* (Pictet and Campiche).

At Rye Hill Farm and Shute Farm, the sandstone with concretions at the top of the Boyne Hollow Cherts is overlain by a boulder bed made of similar concretions, which are known as 'Cornstones'. The Cornstones are succeeded by friable glauconitic calcareous quartz sands with very few phosphates, the Rye Hill Sands. Note that Kennedy (1970, fig. 4) incorrectly identified the bed *below* the Cornstones as the Rye Hill Sands. These sands are richly fossiliferous and are the source of the non-phosphatized, calcitic (and hence, inferred indigenous or quasi-indigeneous) fossils attributed to the so-called 'Warminster Greensand' (Jukes-Browne, 1896). Small fossil brachiopods and echinoids occur in profusion, together with well-preserved shells of the inoceramid bivalve *Inoceramus* ex gr. *crippsi* Mantell and poorly preserved calcareous internal moulds of ammonites. The association of the thin-shelled bivalve *Aucellina gryphaeoides* (J. de C. Sowerby *non* Sedgwick), the belemnite *Neohibolites ultimus* (d'Orbigny) and the heteromorph ammonite *Neostlingoceras carcitanense* (Matheron) enables the Rye Hill Sands to be assigned, at least in part, to the basal Cenomanian *carcitanense* Subzone. The two latter taxa identify the presence of the *ultimus/Aucellina* Event (Ernst *et al.*, 1983) of European event stratigraphy. The Rye Hill Sands are succeeded by glauconitic sandstone with phosphates, the Glauconitic Marl of the literature, which provided the superbly preserved, irridescent, phosphatized components (mainly ammonites) of the 'Warminster Greensand' faunas in museum collections.

The relationship between this succession and that developed at Dead Maid Quarry is tantalizingly unclear. Although the popples of the Popple Bed can perhaps be equated with the Cornstones of Rye Hill Farm, there is no sign of the unequivocal, albeit non-phosphatized *carcitanense* subzonal fauna of the Rye Hill Sands, the phosphatized ammonites of the Popple Bed/'Glauconitic Marl' assemblage indicating, if anything, a *dixoni* Zone provenance, this being supported by the occurrence of *Inoceramus virgatus* in the terminal 'Glauconitic Marl' (i.e. terminal Melbury Sandstone). A possible explanation is that the high-amplitude erosion surface at the base of the Popple Bed, below the popples/Cornstones themselves, marks a significant hiatus and that no basal Cenomanian sediments are preserved. On the other hand, there appears to be evidence of westward thinning from Rye Hill to Maiden Bradley Quarry, and thence south to Norton Ferris, involving a coalescing of the phosphates above the Rye Hill Sands with the Cornstones at the base (cf. Kennedy, 1970, fig. 4; Bristow *et al.*, 1999, fig. 27). In this case, the Rye Hill sands are perhaps represented at Maiden Bradley by the poorly fossiliferous sands surrounding the Cornstones (cf. Jukes-Browne and Scanes, 1901) and, at Dead Maid Quarry, by the sandy patches reported within the Popple Bed. At present, there is no clear understanding why the basal Cenomanian Rye Hill Sands are only locally developed, and the possible influence of local structures controlling the deposition and preservation of sediments must be seriously considered.

The biostratigraphical evidence from Dead Maid Quarry leads to the unexpected conclusion that the Melbury Sandstone and basal West Melbury Marly Chalk belong to the *dixoni* Zone, whereas the top of the Melbury Sandstone in its type area, near Shaftesbury, clearly falls in the basal Cenomanian *carcitanense* Subzone (Woods and Bristow, 1995; Bristow *et al.*, 1999).

Conclusions

The sequence of superbly preserved phosphatized Lower Cenomanian ammonite faunas from Dead Maid Quarry, is critical to the interpretation of sections around Maiden Bradley that were formerly attributed to the loosely defined 'Warminster Greensand', including those in which the highly fossiliferous basal Cenomanian 'Rye Hill Sands' are developed. The section provides an important link with the new Albian–Cenomanian stratigraphy recently established in the Shaftesbury district, on the southern side of the Mere Fault, by the British Geological Survey.

This historically important section through the Albian–Cenomanian junction beds with its rich ammonite faunas is vital, on the one hand, for the resolution of the stratigraphical problem of the 'Warminster Greensand' and, on the other, for the interpretation of structural control of sedimentation across the Mere Fault, and in the area to the north.

CHARNAGE DOWN CHALK PIT, MERE, WILTSHIRE (ST 837 329)

Introduction

Charnage Down Chalk Pit is a working lime quarry located 2 km east of Mere, Wiltshire (Figure 3.38), on the north side of the A303(T). It is cut into the south-facing Chalk scarp controlled by the east–west Mere Fault (Figure 3.10), overlooking the Vale of Wardour. The pit is famous as an example of extreme condensation of the Turonian Chalk Rock. However, some 30 m of Chalk are exposed in this pit, from a few metres beneath the Upper Turonian Chalk Rock to the base of the Middle Coniacian Seaford Chalk Formation. This large section provides a link to **Shillingstone Quarry** to the south (see GCR site report, this volume). It was in this area that William Smith (in Townsend, 1813), recognized the 'green-tinctured chalk' (Chalk Rock) separating 'useful white chalk' above from 'useless malmy chalk' below. This is probably the first reference to a division of the Chalk that subsequently became the traditional Middle–Upper Chalk boundary and it is now the boundary between the New Pit Chalk and Lewes Nodular Chalk formations.

Description

Although there are many references to exposures of Chalk Rock in the area of Mere Down (e.g. Jukes-Browne and Hill, 1904, p. 75) it was not until 1916 (Scanes, 1916, p. 133, pl. 24B) that the Charnage Down Chalk Pit was illustrated and the thickness of the Chalk Rock identified. Jukes-Browne and Hill (1904) noted the changing aspect of the Chalk Rock when traced from Mere Down to West Knoyle and Chapel Farm, Upton (Figures 3.38 and 3.39) to the east of Charnage Down. They also recorded that the dip increased rapidly towards the Great (Mere) Fault. The stratigraphy of the pit was briefly outlined by Smith and Drummond (1962), together with some fossil records. Charnage Down was also incorporated in two long-range skeletal correlation diagrams for the lower and upper Lewes Nodular Chalk respectively (Mortimore, 1983, figs 4a,b) and another section was given by Mortimore (1987, fig. 5). The most recent published section is in the British Geological Survey Wincanton Memoir (Bristow *et al.*, 1999, fig. 29) but this does not extend up to the Seaford Chalk Formation and is difficult to interpret.

A photographic illustration of the section was given by Bathurst (1976), which showed how much the section with the Chalk Rock had degraded since the time of both the earlier photograph and a later photograph (Edmunds, 1938, pl. 12). Bromley (1967) investigated the Chalk Rock section and discussed burrow-fills associated with one of the hardgrounds, which were so closely spaced that they made up over 50% of the rock. He also produced an elegant block diagram (Bromley, 1975a, fig. 18.7) to show the detailed architecture of two of the hardgrounds, the higher one with a hummocky surface and the lower with a planar surface. This figure also demonstrates the effect of 'imposed horizontality' on the *Thalassinoides* burrow systems, i.e. the burrows extending down from the higher surface are unable to penetrate the hardened lower surface and divert to run along the top of it. Subsequently, Bromley and Gale (1982, fig. 12) published a detailed section of the Chalk Rock interval from a trench (ST 808 342; see Figure 3.38) at or near the original Jukes-Browne and Hill (1903) Mere Down locality, and illustrated that this was one of the most condensed Chalk Rock sections, but they did not actually publish a section of Charnage Down Chalk Pit.

Lithostratigraphy

The exposed succession (Figure 3.41) extends from a few metres below the Chalk Rock to some 5 m above the Shoreham Marls at the boundary between the Lewes Nodular Chalk and Seaford Chalk formations of the White Chalk Subgroup (Mortimore and Pomerol, 1987). Formerly 40 ft (12 m) were exposed beneath the Chalk Rock (Scanes, 1916).

The most conspicuous feature of the Chalk succession is the Chalk Rock, here about 1 m thick, comprising a number of glauconitized hardgrounds and associated chalkstones. Bromley and Gale (1982, fig. 3) divided the Chalk Rock into three suites of hardgrounds based on their type section at Ogbourne Maizey, near Marlborough, Wiltshire, some 58 km to the north-east (Figure 3.1). Each of these suites can be recognized in highly condensed form at Charnage Down (Figures 3.41 and 3.42), and a correlation established with exposures in the area, based almost entirely on lithological features. The basal Ogbourne Hardground has a flat top surface here, in contrast to its convolute morphology elsewhere. The middle suite of hardgrounds is the most difficult to distinguish, but the uppermost 'Hitch Wood' Hardground, of the top suite, with many *Micraster leskei* Desmoulins on its top surface and in the soft chalk burrow-fills, is the most easily identified hardground.

Beneath the Chalk Rock, some 4 to 5 m of New Pit Chalk Formation are exposed. These

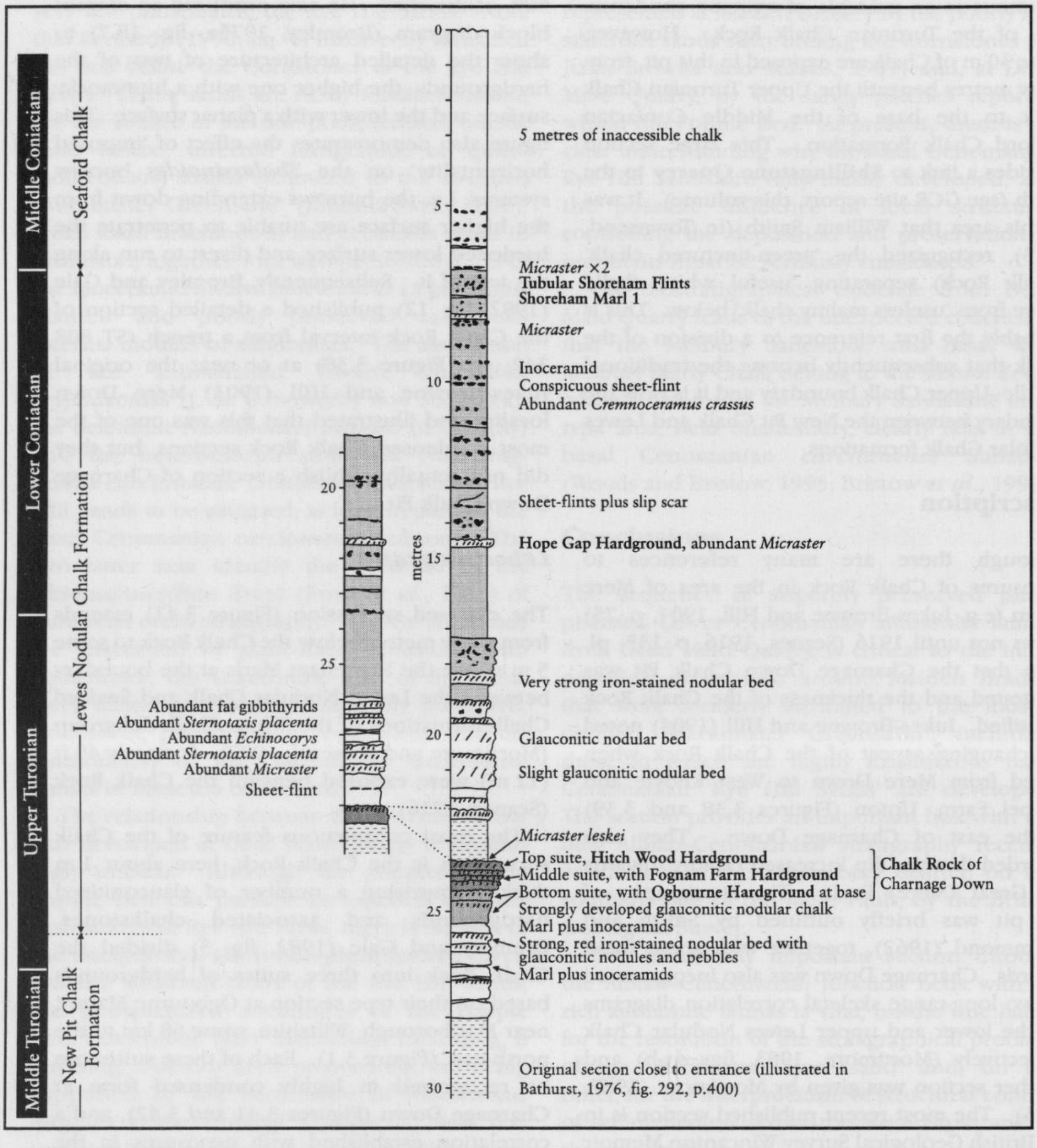


Figure 3.41 The succession of Chalk at Charnage Down Chalk Pit, Mere, Wiltshire, showing lateral variation along section.

contain weakly developed marl seams and one better-developed marl seam (Figure 3.41). None of these marl seams is comparable to the group of marker marl seams used for correlation in the Middle Turonian New Pit Chalk and Middle–Upper Turonian lower Lewes Nodular Chalk formations.

In the first 6 m above the Chalk Rock there is a group of nodular chalk beds containing sporadic flints. More continuous flint bands enter above a hardground that can be correlated with the Hope Gap Hardground of Sussex. Sheet-flints are also present above this hardground, some on curving shear planes. In the highest accessible exposures a conspicuous marl seam overlain by a bed of tubular flints is

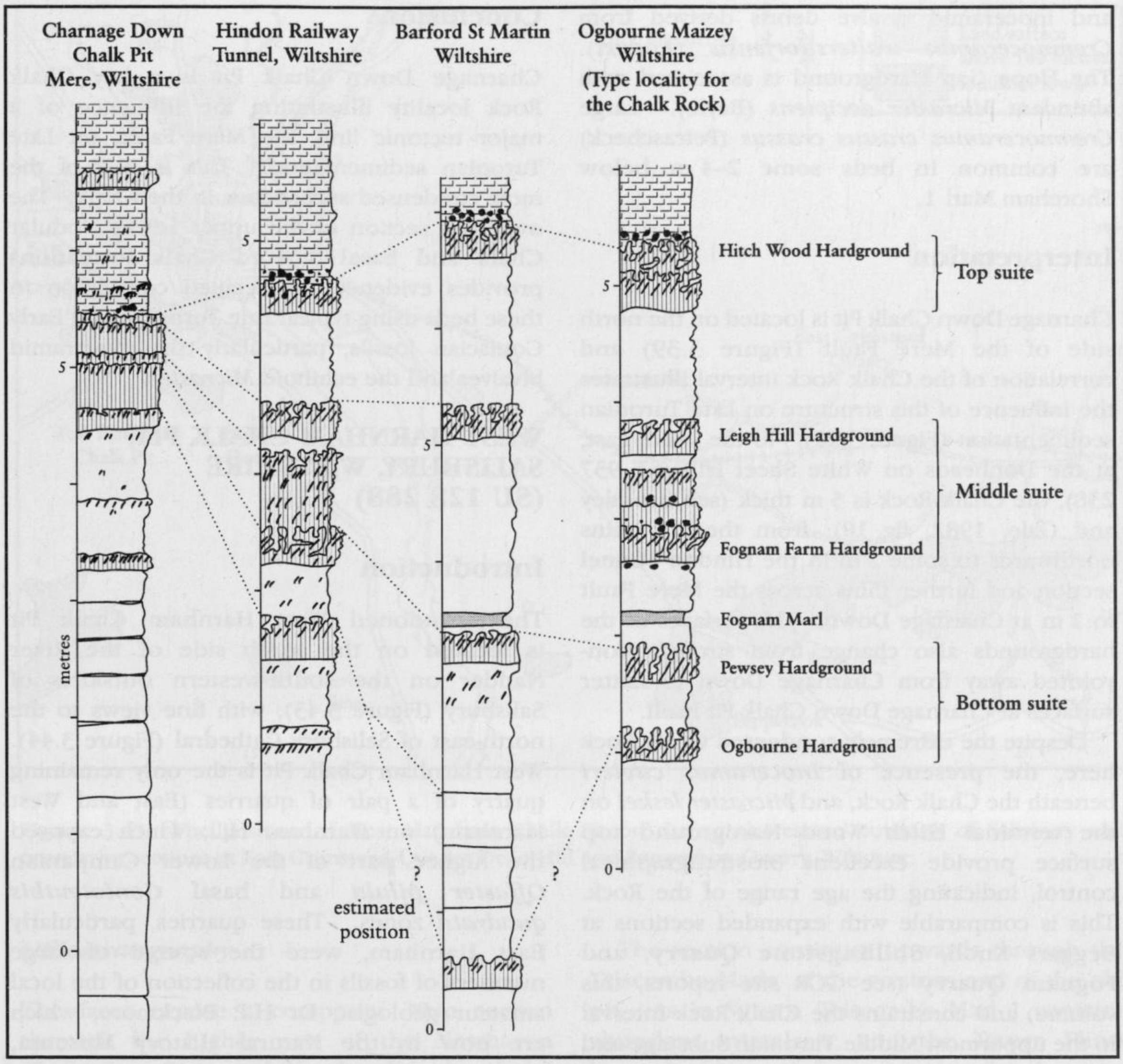


Figure 3.42 Correlation of the Chalk Rock stratigraphy from its type locality to Charnage Down Chalk Pit and nearby localities, illustrating the condensation present at Charnage Down. (After Bromley and Gale, 1982.)

correlated with the Shoreham Marl 1 and the Shoreham Tubular Flints. The chalk up to this point is very pure white, but noticeably gritty with fossil debris, as is typical of the highest part of the Lewes Nodular Chalk Formation.

Biostratigraphy

Fossils beneath the Chalk Rock are scarce. Only fragments of inoceramid bivalves having affinities with *I. cuvieri* J. Sowerby have been obtained. Smith and Drummond (1962) assigned these beds to the top of the *Terebratulina lata* Zone. Within the Chalk Rock no diagnostic fossils have been recorded, with the exception of *Micraster leskei* in the uppermost (Hitch Wood) Hardground.

In the nodular beds above the Chalk Rock, a typical suite of Upper Turonian fossils is present, including *Sternotaxis placenta* (Agassiz), *Echinocorys*, *Micraster praecursor sensu* Drummond and *Micraster normannie* Bucaille. Well-preserved inoceramid bivalves from this level include *Inoceramus websteri sensu* Woods *non* Mantell. Beds presumed to equate with the the interval between the Navigation and Cliffe hardgrounds (i.e. Lower Coniacian Substage) contain late forms of *Micraster normanniae* and inoceramid bivalve debris derived from *Cremnoceramus waltersdorfensis* (Andert). The Hope Gap Hardground is associated with abundant *Micraster decipiens* (Bayle). Large *Cremnoceramus crassus crassus* (Petrascheck) are common in beds some 2–4 m below Shoreham Marl 1.

Interpretation

Charnage Down Chalk Pit is located on the north side of the Mere Fault (Figure 3.39) and correlation of the Chalk Rock interval illustrates the influence of this structure on Late Turonian sedimentation (Figure 3.42). To the south-east, at the Donheads on White Sheet Hill (ST 937 238), the Chalk Rock is 5 m thick (see Bromley and Gale, 1982, fig. 10); from there it thins northwards to some 2 m in the Hindon Tunnel section and further thins across the Mere Fault to 1 m at Charnage Down. The surfaces of the hardgrounds also change from strongly convoluted away from Charnage Down to flatter surfaces at Charnage Down Chalk Pit itself.

Despite the extremely condensed Chalk Rock here, the presence of *Inoceramus cuvieri* beneath the Chalk Rock, and *Micraster leskei* on the terminal Hitch Wood Hardground top surface provide excellent biostratigraphical control, indicating the age range of the Rock. This is comparable with expanded sections at Beggars Knoll, **Shillingstone Quarry**, and **Fognam Quarry** (see GCR site reports, this volume) and constrains the Chalk Rock interval to the uppermost Middle Turonian Substage and the lower part of the Upper Turonian Substage, an interval corresponding to the lower Lewes Nodular Chalk.

Figure 3.42 shows that there is considerable lateral variation in the succession overlying the Chalk Rock. The fossil records, notably abundant specimens of the echinoid *Sternotaxis placenta* (Agassiz) from the left-hand section indicate a level above the Chalk Rock, and the conspicuous flint (also seen in Bartlett and Scanes, 1916, pl. 24B) could possibly be the same White Nothe Flint that is seen at **Shillingstone Quarry** and in other sections nearer Shaftesbury (see Bristow *et al.*, 1995, fig. 52). However, the interpretation of the succession in the right-hand section between the Chalk Rock and the Hope Gap Hardground is highly problematic, and requires further investigation.

Conclusions

Charnage Down Chalk Pit is a key Chalk Rock locality illustrating the influence of a major tectonic line, the Mere Fault, on Late Turonian sedimentation. This is one of the most condensed successions in the Chalk. The overlying section in the upper Lewes Nodular Chalk and basal Seaford Chalk formations provides evidence for detailed correlation in these beds using typical Late Turonian and Early Coniacian fossils, particularly the inoceramid bivalves and the echinoid *Micraster*.

WEST HARNHAM CHALK PIT, SALISBURY, WILTSHIRE (SU 128 288)

Introduction

The abandoned West Harnham Chalk Pit is located on the south side of the River Nadder on the south-western outskirts of Salisbury (Figure 3.43), with fine views to the north-east of Salisbury Cathedral (Figure 3.44). West Harnham Chalk Pit is the only remaining quarry of a pair of quarries (East and West Harnham) on Harnham Hill, which exposed the higher part of the Lower Campanian *Offaster pilula* and basal *Gonioteuthis quadrata* zones. These quarries, particularly East Harnham, were the source of large numbers of fossils in the collection of the local amateur geologist, Dr H.P. Blackmore, which are now in the Natural History Museum, London. West Harnham Chalk Pit is also one of the few in the western part of the region to expose the Lower Campanian Newhaven Chalk Formation and the basal beds of the overlying Culver Chalk Formation. It serves to confirm the stratigraphical continuity of many of the lithological marker beds recognized in the type sections of these two formations.

Description

The exposures in the pit are divided into several old benches and faces. The pit was briefly described by Jukes-Browne and Hill (1904, p. 81), but no complete section was published until 1986 (Mortimore, 1986a, fig. 19, repeated in part in Mortimore, 1986b, fig. 3.19).

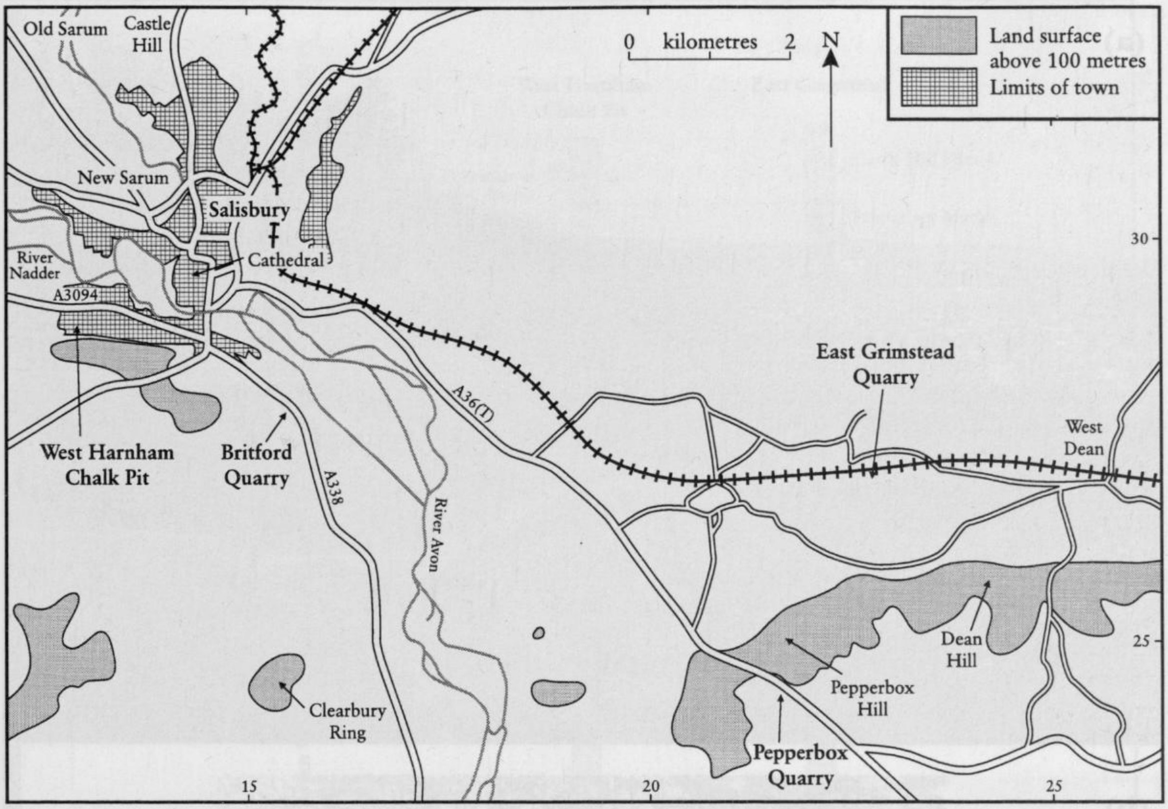


Figure 3.43 The position of West Harnham Chalk Pit on the south-western outskirts of Salisbury and correlative sections at East Grimstead Quarry, Dean Hill and Pepperbox Quarry, Wiltshire.

Lithostratigraphy

The faces expose a composite 30 m section through the higher part of the Newhaven Chalk Formation and the basal beds of the Culver Chalk Formation (Figure 3.45). The south face of the lowest bench contains beds between the Peacehaven and Meeching marls (Meeching Beds of Mortimore, 1986a) and in places extends up to the lower Telscombe Marls. As indicated by Jukes-Browne and Hill (1904), the bedding is indistinct and the chalk rather massive at this level. There are several flint bands, and bedding joints occur along weakly developed marl seams. In contrast, the Meeching Pair of Marls are strongly developed, forming a conspicuous marker in the upper part of this face. Telscombe Marls 1 and 2 are present at the top. The steeply inclined, clay-smeared conjugate joints, some filled by sheet-flints, that typify the Newhaven Chalk Formation, are present in this part of the section.

The section continues upwards through the Telscombe Marls, at the western end of the old pit. As in Sussex, Telscombe Marl 1 contains abundant intraclasts, and the Tavern Flints beneath this marl form fingers related to the abundant occurrence of the trace fossil *Zoophycos*. The Arundel Sponge Bed is a well-developed iron-stained sponge bed 3 m above the Telscombe Marls. This sponge bed is a key marker throughout the Southern Province.

Chalk faces in the uppermost bench expose the well-developed Castle Hill Marls and the Pepperbox Marls. Castle Hill Flints 1 and 4 are also strongly developed (Figures 3.44 and 3.45).

Biostratigraphy

West Harnham, combined with East Harnham, provided many of the specimens of inoceramid bivalves figured in the Palaeontographical Society Monograph on Cretaceous Lamellibranchia. From East Harnham these included the

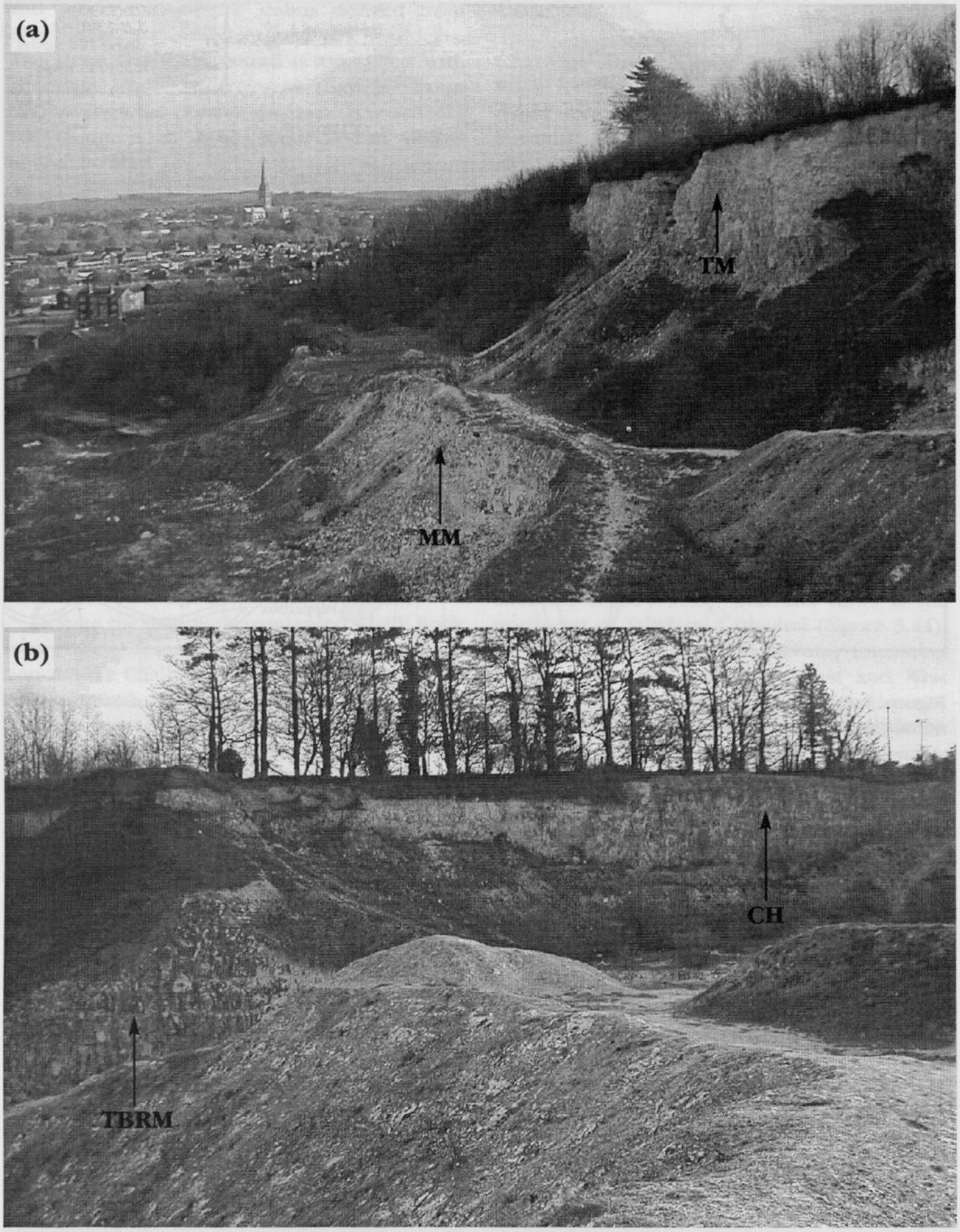


Figure 3.44 West Harnham Chalk Pit, Salisbury. (a) Looking north-east over Salisbury Cathedral. (b) Looking south-east on to the highest beds. (CH = upper face exposes Castle Hill and Pepperbox Marls and Castle Hill Flints, with the change from large to small forms of *Echinocorys* (Gaster, 1924); MM = Meeching Marls and *Echinocorys scutata cincta* beds in lowest exposures; TBRM = Access track to upper quarry exposing Telscombe and Black Rabbit marls; TM = Telscombe Marls and abundant *Offaster pilula planatus* beds.) (Photos: R.N. Mortimore.)

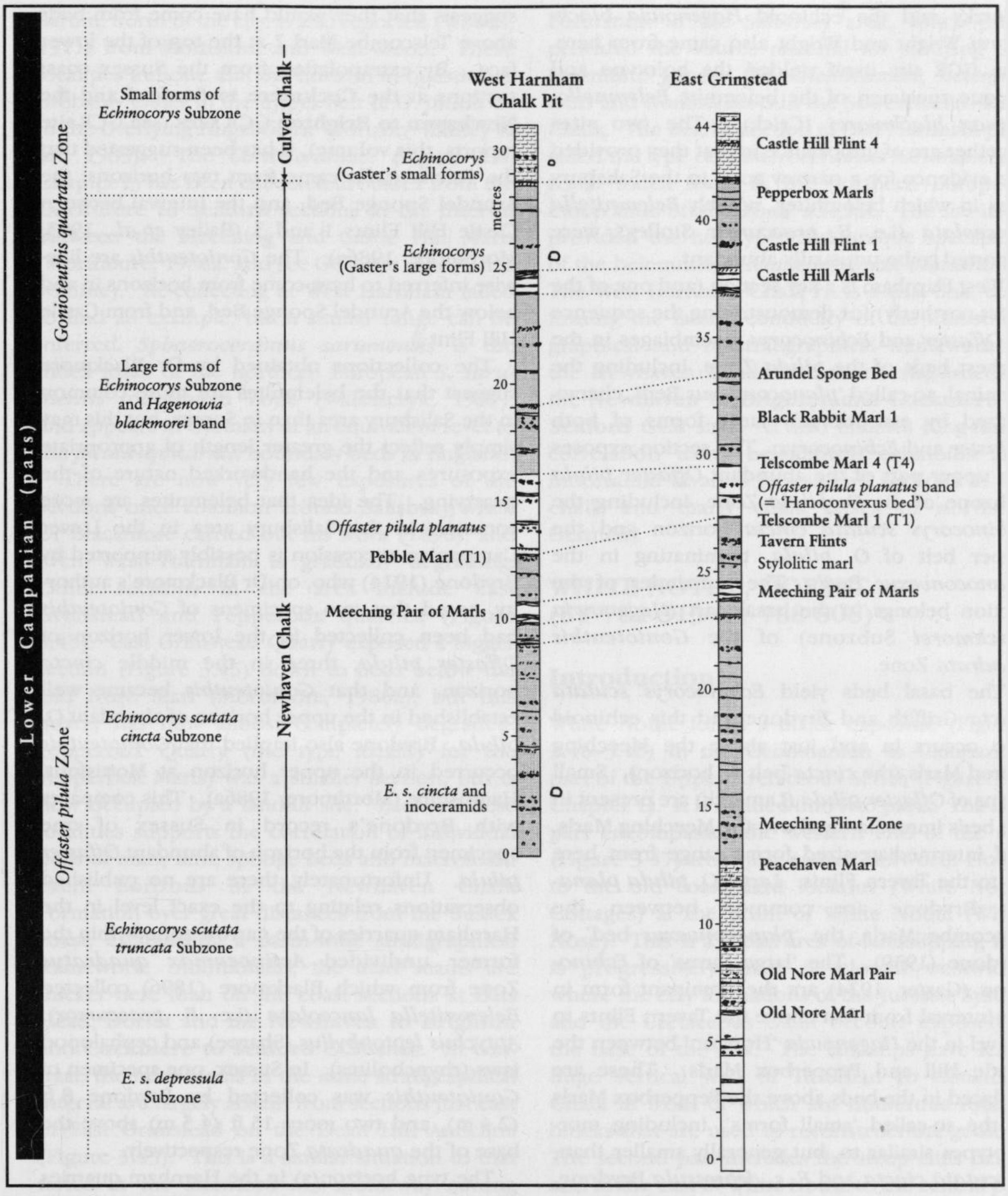


Figure 3.45 Chalk at West Harnham Chalk Pit compared with East Grimstead Quarry.

(recently designated) lectotype of *Sphaeroceramus sarumensis* (Woods) (Figures 2.26 and 2.27, Chapter 2), which is now a zonal index species in the standard European inoceramid zonal scheme for the Campanian Stage; and also one of the two specimens that were later assigned to *Inoceramus subsarumensis* Renngarten (see discussion by Walaszczyk, 1997). The holotypes of the brachiopods *Kingena blackmorei* Owen, *Orbirhynchia bella* Pettitt and *O. granum* Pettitt, the belemnite subspecies *Belemnitella praecursor mucronatiformis*

Jeletzky and the echinoid *Hagenowia blackmorei* Wright and Wright also came from here. The GCR site itself yielded the holotype and unique specimen of the belemnite *Belemnellocamax blackmorei* (Crick). The two sites together are of importance in that they provided the evidence for a narrow zone in the Salisbury area in which belemnites, notably *Belemnitella lanceolata* (i.e. *B. praecursor* Stolley) were reported to be unusually abundant.

West Harnham is a key section (and one of the most northerly) for demonstrating the sequence of *Offaster* and *Echinocorys* assemblages in the highest beds of the *pilula* Zone, including the terminal, so-called '*planoconvexus* Bed', characterized by exceptionally large forms of both *Offaster* and *Echinocorys*. The section exposes the upper part of the abundant *Offaster pilula* Subzone of the *O. pilula* Zone, including the *Echinocorys scutata cincta* horizon and the upper belt of *O. pilula,* terminating in the '*planoconvexus* Bed'. The remainder of the section belongs to the basal part (*Hagenowia blackmorei* Subzone) of the *Gonioteuthis quadrata* Zone.

The basal beds yield *Echinocorys scutata cincta* Griffith and Brydone and this echinoid also occurs in and just above the Meeching paired Marls (the *cincta* belt or horizon). Small forms of *Offaster pilula* (Lamarck) are present in the beds immediately above the Meeching Marls, and intermediate-sized forms range from here up to the Tavern Flints. Large *O. pilula planatus* Brydone are common between the Telscombe Marls, the '*planoconvexus* bed' of Brydone (1939). The 'large forms' of *Echinocorys* (Gaster, 1924) are the dominant form in the interval from just above the Tavern Flints to a level in the *Hagenowia* 'Horizon' between the Castle Hill and Pepperbox Marls. These are replaced in the beds above the Pepperbox Marls by the so-called 'small forms', including morphotypes similar to, but generally smaller than, *E. scutata cincta* and *E. s. depressula* Brydone, from lower in the *pilula* Zone.

Interpretation

It is uncertain which bed or beds yielded the many belemnites that Dr Blackmore obtained primarily from the quarrymen. Jukes-Browne and Hill (1904, p. 81), indicated that belemnites were relatively common in the upper part of the pit and absent from the lower part. This suggests that they would have come from beds above Telscombe Marl 2 at the top of the lower face. By extrapolation from the Sussex coast sections at the **Cuckmere to Seaford** and the **Newhaven to Brighton** GCR sites (see GCR site reports, this volume), it has been suggested that the *Belemnitella* came from two horizons: the Arundel Sponge Bed; and the interval between Castle Hill Flints 1 and 3 (Bailey *et al.*, 1983; Mortimore, 1986a). The *Gonioteuthis* are likewise inferred to have come from horizons in and below the Arundel Sponge Bed, and from Castle Hill Flint 3.

The collections obtained by Dr Blackmore suggest that the belemnites are more common in the Salisbury area than in Sussex, but this may simply reflect the greater length of appropriate exposures and the handworked nature of the quarrying. The idea that belemnites are more common in the Salisbury area in the Lower Campanian succession is possibly supported by Brydone (1914) who, on Dr Blackmore's authority, noted that two specimens of *Gonioteuthis* had been collected in the lower horizon of *Offaster pilula*, three in the middle *cincta* horizon, and that *Gonioteuthis* became well established in the upper horizon of abundant *O. pilula*. Brydone also implied that *Gonioteuthis* occurred in the upper horizon at Mottisfont, Hampshire (Mortimore, 1986a). This compares with Brydone's record in Sussex of one specimen from the horizon of abundant *Offaster pilula*. Unfortunately, there are no published observations relating to the exact level in the Harnham quarries of the narrow zone within the former undivided *Actinocamax quadratus* Zone from which Blackmore (1896) collected *Belemnitella lanceolata* (i.e. *B. praecursor*), *Aptychus leptophyllus* (Sharpe) and cephalopod jaws (rhyncholites). In Sussex, one specimen of *Gonioteuthis* was collected by Brydone 8 ft (2.4 m), and two more 15 ft (4.5 m) above the base of the *quadrata* Zone respectively.

The type horizon(s) in the Harnham quarries of *Sphaeroceramus sarumensis* (Woods, 1912, pl. 52, figs 2, 3) and the coarsely ornamented, unrelated forms (Woods, 1912, text-fig. 49, pl. 51, figs 3, 4), variously called *Inoceramus subsarumensis* Renngarten and *Haenleinia inordinata* Heinz (probably a *Cordiceramus*), is not known. To judge from the Blackmore collection in the Natural History Museum, London, both species must be relatively common here. The former species, which takes its name from Old

Sarum, north of the city, is also reported (Woods, 1911) from Mottisfont and West Meon. These localities indicate that the horizon in question is probably either in the upper belt of *O. pilula* or in the overlying *Hagenowia* 'Horizon' (Bailey *et al.*, 1983). The *Cordiceramus*? (Figure 2.6, Chapter 2) has been collected in Sussex from the **Cuckmere to Seaford** sections in the interval between the Meeching and Castle Hill Marls (Mortimore, 1986a; and see GCR site report, this volume). Re-collecting at West Harnham failed to find an example, but a similar range can be inferred. *Sphaeroceramus sarumensis* is the index fossil of the northern European *S. sarumensis* inoceramid Zone (Walaszczyk, 1997), and appears in Germany at an equivalent level to the *pilula–quadrata* boundary beds in England.

There are now very few exposures of the sections once common around Salisbury when Dr Blackmore carried out his work (1896), and even West Harnham is gradually degrading. Other sections in the area include East Grimstead and Pepperbox quarries (Figure 3.43). East Grimstead Quarry exposed a bigger section (Figure 3.45) down to beds below the Old Nore Marl (Mortimore, 1986a), but this quarry has now almost completely degraded. Pepperbox Quarry (the type locality for the Pepperbox Marls) was a smaller section, but is now occupied by a landfill site. Each of these localities supports the correlation of individual beds of marl, flint, sponge beds and macrofossil event horizons in the Newhaven Chalk Formation over great distances from the Sussex coast, establishing a basin-wide stratigraphical framework. Additionally, the marl seams are thicker here than on the coast sections at Bats Head, Dorset and the **Newhaven to Brighton** and **Cuckmere to Seaford** GCR sites. In contrast, the marl seams in the same stratigraphical interval are largely absent from sections just east of East Grimstead on the Dean Hill Anticline (Figure 3.43). This is a similar situation to that noted at the Shawford M3 motorway cutting near Winchester and at Hollingbury, Brighton (Mortimore and Pomerol, 1991a, 1997), where the Newhaven Chalk Formation locally loses its marl seams over tectonically controlled highs.

Conclusions

West Harnham Chalk Pit is the last remaining exposure of the Lower Campanian Newhaven Chalk Formation and basal Culver Chalk Formation in the Salisbury area, which once provided the source material for studying the belemnite genera *Belemnellocamax*, *Belemnitella* and *Gonioteuthis* in the Southern Province Chalk. The nearby section at East Harnham provided the type of *Sphaeroceramus sarumensis*, a zonal index fossil in the northern European inoceramid bivalve zonal scheme. The site itself provided the holotype (and unique specimen) of the belemnite *Belemnellocamax blackmorei*. The West Harnham Chalk Pit is a vital link, confirming the lateral continuity of the lithostratigraphical and biostratigraphical framework in the Newhaven Chalk Formation established in the **Newhaven to Brighton** and **Cuckmere to Seaford** GCR sites. It also enables long-range correlation using belemnites, echinoids and inoceramid bivalves to standard sections in the chalk and marly chalk facies of northern Germany.

WHITE NOTHE, DORSET (SY 764 813–SY 788 806)

Introduction

White Nothe forms a major exposure (Figures 3.46–3.48) in the Cenomanian to Campanian part of the Upper Cretaceous Series (Figure 1.2, Chapter 1). It is divided into two parts. The first part encompasses the western end of the site (Figure 3.47) from just east of Holworth House to the old coastguard lookout (White Nothe Cottages) at the point of White Nothe (White Nose). This is a broad area of landslipping that is progressively more developed westwards where the clay formations of the Jurassic System and the Cretaceous Gault become exposed at the base of the cliff. The landslips have left a huge vertical wall of Turonian to Coniacian Chalk in front of which are numerous rotated blocks that are used to reconstruct the geology. The second part includes the steep cliffs below and to the east of White Nothe to the central part of Middle Bottom at the eastern extremity of the site. Tectonic disturbance is pronounced in West Bottom and Middle Bottom (Figures 3.47, 3.49 and 3.50). This huge, landslipped coastal section contains a spectacular unconformity between the Jurassic succession and the overlying Cretaceous (Gault, Greensand and Chalk). It is the most westerly coastal exposure of the higher Middle and Upper Cenomanian Zig Zag Chalk Formation of the Grey Chalk Subgroup,

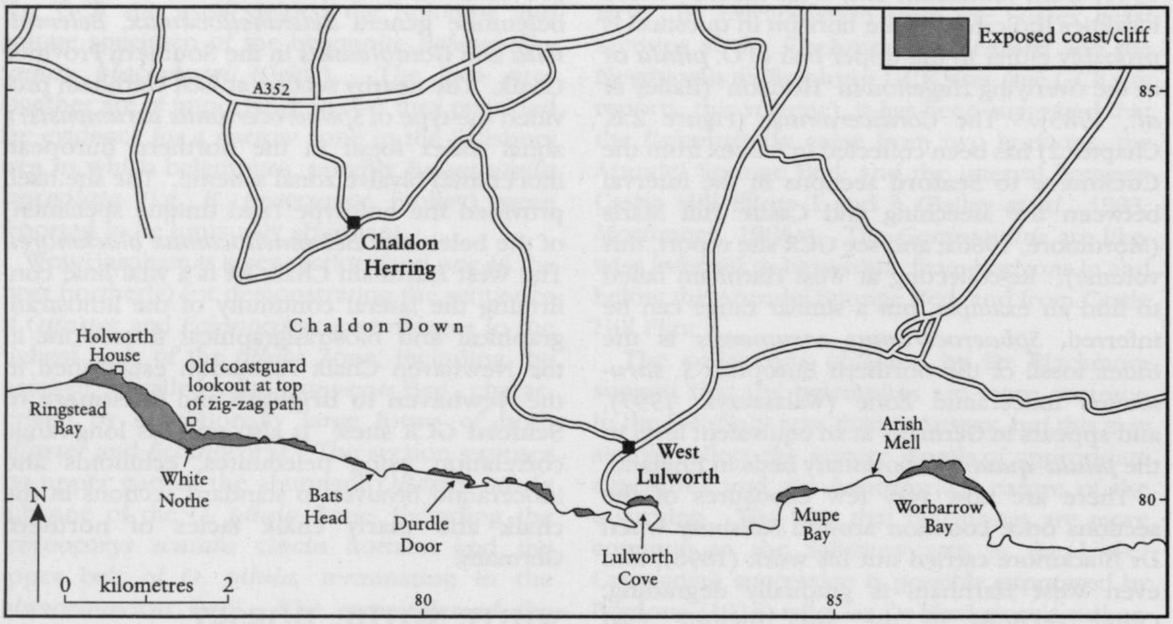


Figure 3.46 The White Nothe GCR site in relation to other key Late Cretaceous sections on the adjacent Dorset Coast.

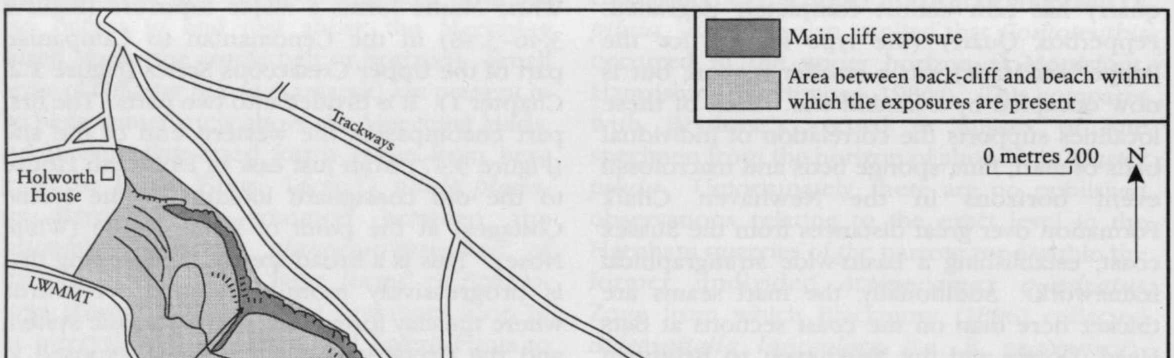


Figure 3.47 Map of the White Nothe GCR site, see also Figure 3.48.

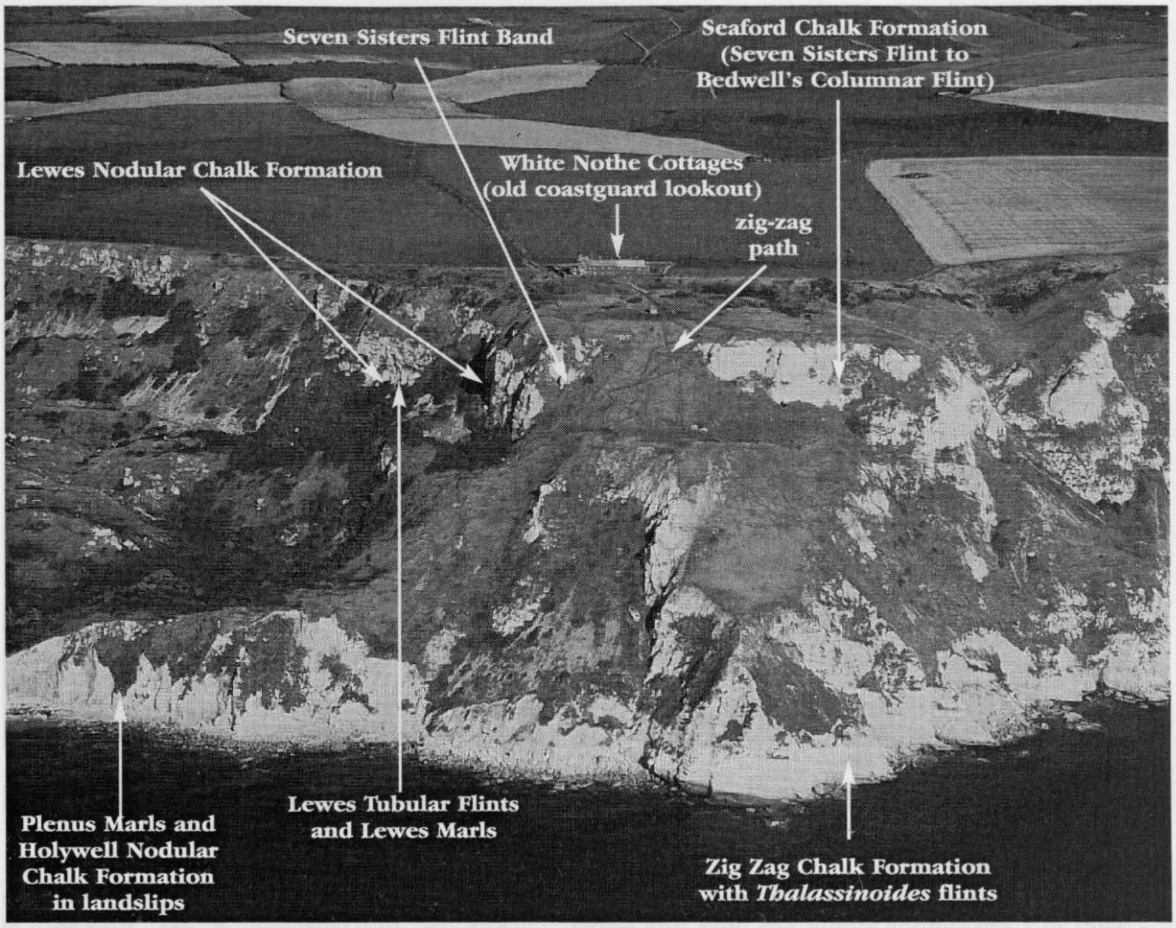


Figure 3.48 White Nothe, Dorset, landslipped masses of Chalk and the zig-zag path from the old coastguard lookout (White Nothe Cottages) through the landslipped masses. (Photo: Cambridge University Collection of Aerial Photography: copyright reserved).

before it condenses into the higher Basement Beds of south-east Devon. The Zig Zag Chalk Formation has a glauconitic, sandy base which rests, not on marly chalk typical of the main basin to the east, but on highly condensed Cenomanian Basement Beds. In turn, these thin Cenomanian deposits rest on a complex succession of Albian Greensand and Chert Beds. The succession at White Nothe has been described as the best demonstration of Cenomanian onlap in southern England.

Higher in the succession, hardgrounds and nodular chalks have formed on spectacular erosional surfaces in the Lower Coniacian upper Lewes Nodular Chalk Formation. In combination, the Cenomanian onlap and the Coniacian erosional events illustrate key aspects of Late Cretaceous stratigraphy and sedimentary processes.

Description

Access to the White Nothe sections is exceedingly difficult and involves trekking through small paths and thick undergrowth or scaling the steep cliffs. The main access is via a zig-zag path from the old coastguard lookout (White Nothe Cottages – Figures 3.47 and 3.48) through the landslipped blocks that eventually leads to beach level. The Cenomanian sections are not always well exposed, depending on the amount of slipped debris. Turonian sections are rarely exposed in their entirety and have to be pieced together from intermittent exposures and boulder falls. Steep, near vertical walls of gritty, red, iron-stained nodular chalk characterize the Upper Turonian–Lower Coniacian Lewes Nodular Chalk Formation, which can be studied in bluffs below and west of the old coastguard

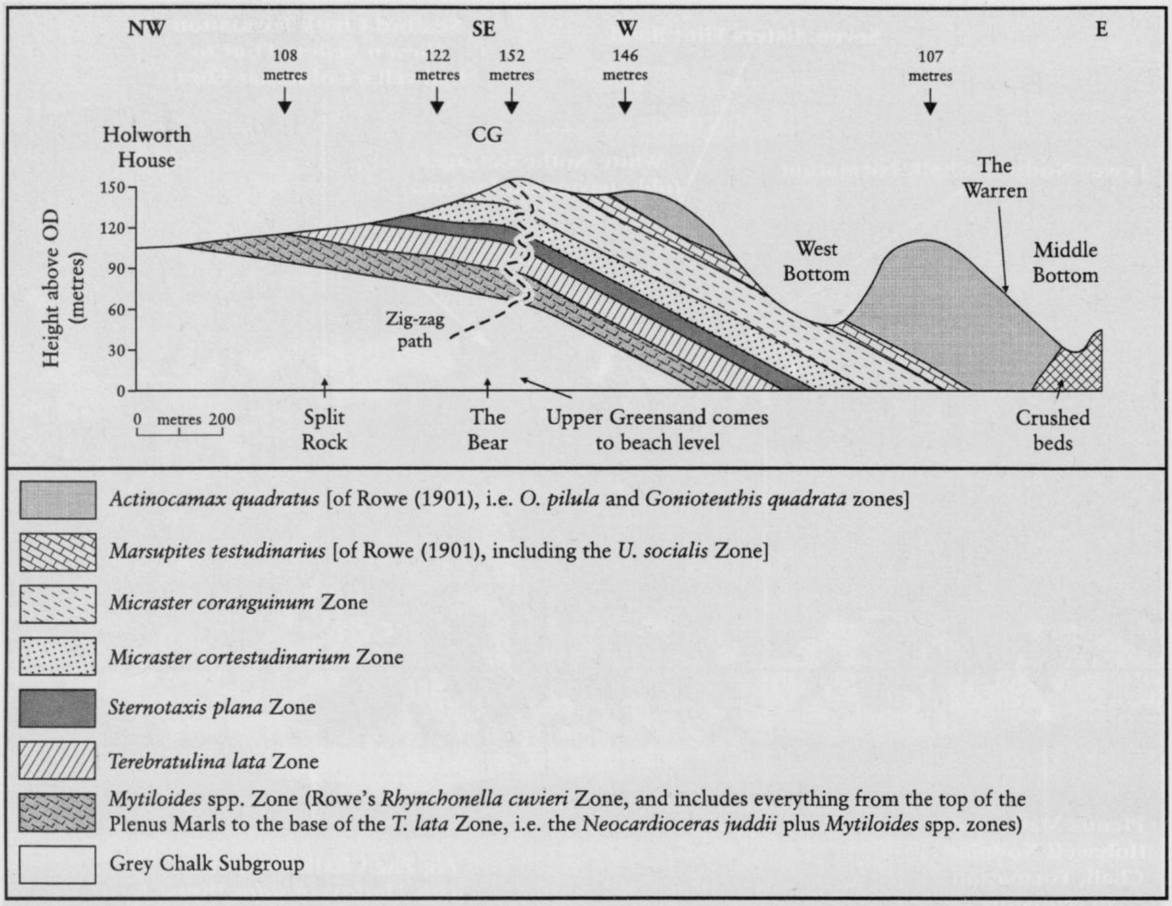


Figure 3.49 White Nothe showing the zones of the Chalk in relation to the old coastguard lookout (CG = White Nothe Cottages on Figure 3.48) and the zig-zag path. (After Rowe, 1901, fig. 1.)

lookout. The highest Chalk exposed in the bluffs near the top of these cliffs adjacent to the old coastguard lookout are in the Upper Coniacian and Lower Santonian Seaford Chalk Formation (Figures 3.51 and 3.52).

To the east, the steep northerly dip brings the higher beds of the Seaford Chalk, Newhaven Chalk, and Culver Chalk formations to beach level. The Newhaven Chalk Formation at Bats Head just east of the site boundary (Figure 3.50) is discernable by the weathering out of marl seams to form conspicuous grooves in the high cliff face.

Despite its spectacular nature and importance to Cretaceous stratigraphy there are no complete, published measured sections of White Nothe. A first attempt at zoning these cliffs was made by Barrois (1876), who also provided a measured section in the uppermost bluffs containing parts of the Lewes Nodular Chalk and Seaford Chalk formations. The most complete and historically most important account is by Rowe (1901), who divided the section into two parts; the undercliff along the shoreline, and the top of the cliff in the landslipped bluffs. The [British] Geological Survey (Jukes-Browne and Hill, 1904) largely followed Rowe's account of this section. Brydone (1914) provided some lithological and paleontological details in the Newhaven Chalk. Later researchers have looked at parts of the succession only. Drummond (1967, 1970) investigated the Albian–Cenomanian strata, but the field section is described only in his unpublished PhD Thesis (1967). Mortimore and Pomerol (1987, fig. 9) investigated the Turonian–Santonian sections but published only part of their measured section. Gale (1996, fig. 7) provided a graphic log of part of the Lewes Nodular Chalk Formation, from Southerham Marl 1 to

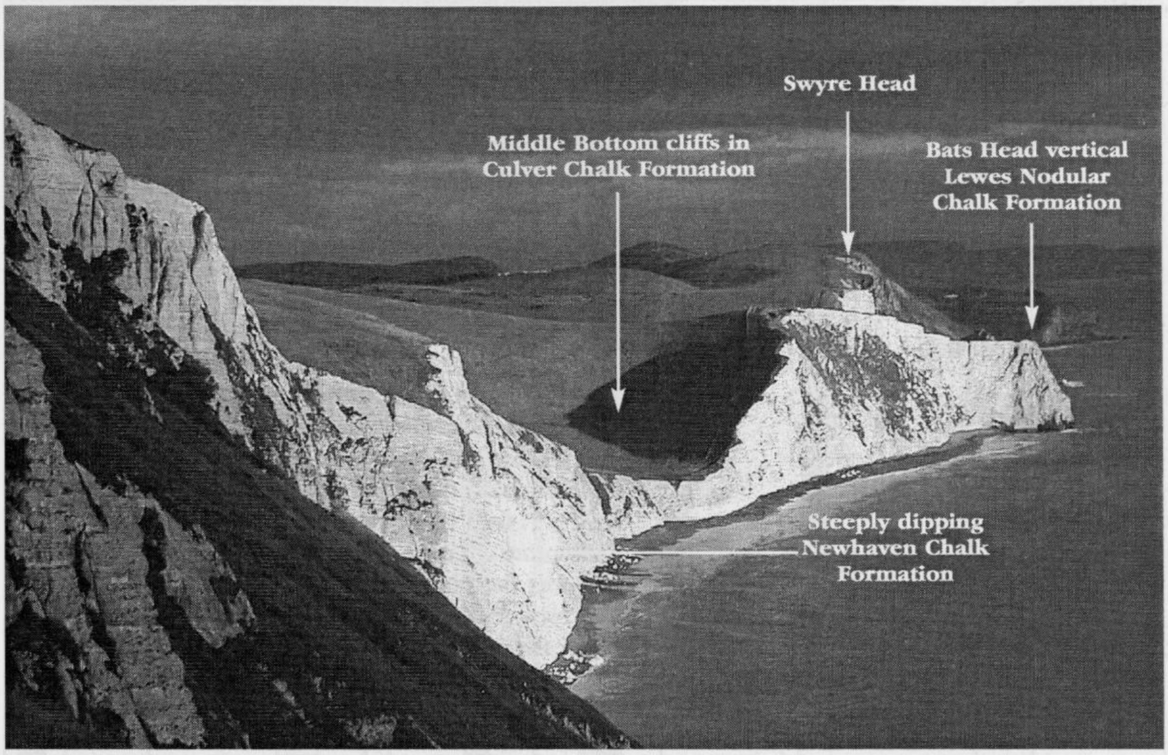


Figure 3.50 Looking east from White Nothe across Middle Bottom to Bats Head. (Photo: R.N. Mortimore.)

the Cliffe Hardground. The details given in this account are a combination of these sources.

Lithostratigraphy

Grey Chalk Subgroup

The typical basin succession in the Grey Chalk Subgroup, seen in Sussex and Kent, where it is divided into the West Melbury Marly Chalk and Zig Zag Chalk formations, is not present at White Nothe. Instead there are two units; the first is broadly termed 'Cenomanian deposits' and represents a highly condensed West Melbury Marly Chalk and lower part of the Zig Zag Chalk formations, and the second is a lithological variant of the Zig Zag Chalk Formation.

The Cenomanian deposits at White Nothe are recorded as 24 m thick by Drummond (1967, p. 44) and about 15 m by House (1993). This difference in thickness relates not only to the difficulty of measuring a complete section but to the possible tectonic thinning considered by Drummond (1967). Within this succession, Drummond recorded about 1.5 m of Chert Beds (pars) followed upwards by 1.5 m of nodular sandstone, a similar thickness of nodular limestone and then the highly condensed 1 m thick Cenomanian Basement Beds representing the entire Lower Cenomanian and part of the Middle Cenomanian successions. The remaining part of the Middle and Upper Cenomanian succession is represented by the pale coloured Zig Zag Chalk Formation (the 'Grey Chalk' of Drummond, 1970) with a basal sandy layer. Bands of pale, porcellaneous flints are present. These flint bands are concentrated in the lower part of the Zig Zag Chalk Formation and are wonderfully spiky, having replaced the fill of thalassinid crustacean burrows. Eastwards, towards and in the main basin, flints are entirely absent from the Grey Chalk Subgroup, but flint is common in the Cenomanian strata of the south-west margin of the basin in France at Antifer-Tilleul (Pays de Caux) as well as in Wessex (Mortimore and Pomerol, 1987).

Rowe (1901) worked the coast sections beneath and east of White Nothe by boat. He noted that the Zig Zag Chalk comprised alternating hard and soft layers which weathered out at the foot of the headland giving the place a (p. 8) '...strikingly sculptured appearance'.

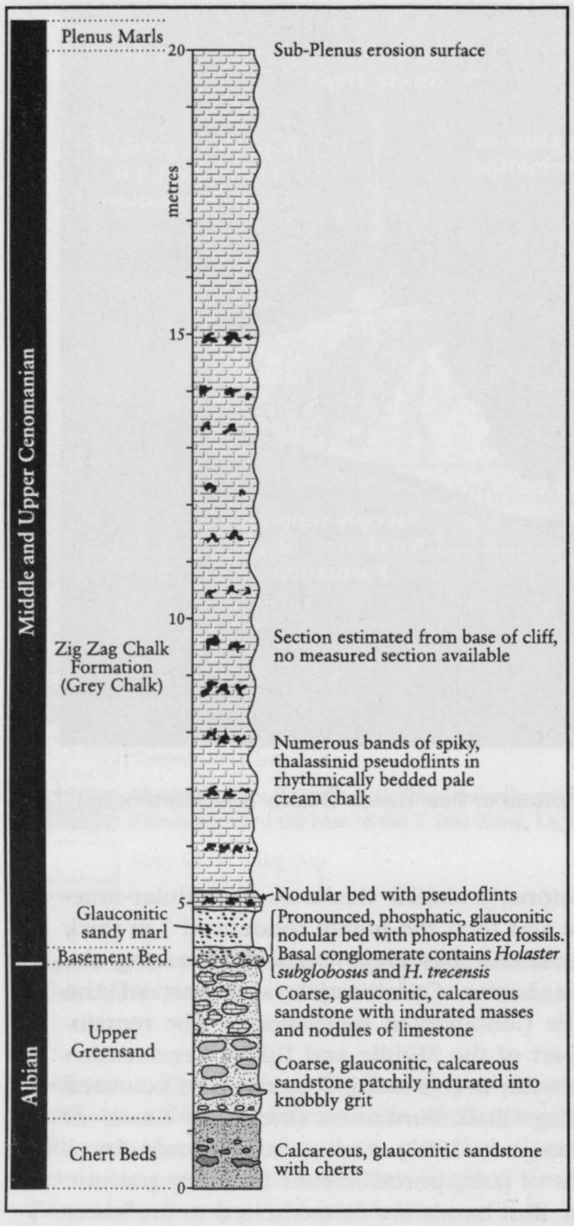


Figure 3.51 Upper Greensand/Chalk contact and the Zig Zag Chalk succession exposed at the base of White Nothe cliffs, Dorset, in the landslipped masses.

White Chalk Subgroup

The basal units of the White Chalk Subgroup comprising the Upper Cenomanian Plenus Marls Member–Melbourn Rock–Meads Marls interval (as defined in Sussex, Mortimore, 1986a), is well exposed here but has not been logged in detail. Rowe described the Holywell Nodular Chalk Formation (his *Rhynchonella cuvieri* Zone) as very hard and nodular with pyrite nodules and occasional marl seams and about 76 ft (23 m) thick. He noted a flint band at the junction between his *R. cuvieri* Zone and the overlying 58 ft (18 m) thick *Terebratulina gracilis* (i.e. *lata*) Zone. On the basis of correlation with the Worbarrow Bay and the **Handfast Point to Ballard Point** sections (see GCR site report, this volume), this flint band probably equates with the Glyndebourne Flints at the base of the New Pit Chalk Formation. Rowe noted a 5 ft (1.5 m) thick band of yellow-green nodules not far above the base of the *T. lata* Zone, which earlier observers had correlated with the Chalk Rock. In his later study of the Isle of Wight, Rowe (1908) termed these nodules the 'Spurious Chalk Rock' on the basis that they were located in the *T. lata* Zone rather than in the overlying *Sternotaxis plana* Zone. Rowe's observations support the suggestion that most, if not all, of the New Pit Chalk Formation may be missing here: the Lewes Nodular Chalk Formation, with the Spurious Chalk Rock at the base, appears to rest almost directly on Holywell Nodular Chalk Formation (Freshney, pers. comm., 1998).

The intermittent exposures in the Holywell Nodular Chalk and New Pit Chalk formations in the landslip masses to the west, and above the beach, do not allow a complete section to be logged, but typical Holywell Nodular Chalk Formation lithologies with abundant *Mytiloides* shell-debris beds and griotte or flaser marls are present.

The Lewes Nodular Chalk Formation is spectacularly air-weathered in the vertical faces of the high chalk cliffs beneath and west of the coastguard lookout. This enhances the nodular character of the formation. In addition, all of the major marker beds including the marker tephro-event marl seams have been identified (Figures 3.9, 3.48 and 3.52; Figure 2.9 Chapter 2; Mortimore and Pomerol, 1987, fig. 9). The Lower Lewes Tubular Flints with the overlying Lewes Marl are conspicuous. As at the **Compton Bay** GCR site, the marl here contains abundant crinoid (*Isocrinus dixoni*) and other shelly fragments as well as *Micraster leskei*. A very conspicuous thick, tabular flint, the White Nothe Flint, for which this is the type locality, is present between the Lewes Marl and the Navigation Marls. This is a marker flint traceable north to the **Shillingstone Quarry** GCR site and east to the **Handfast Point to Ballard Point** GCR site. Towards the top of the Lewes Nodular Chalk, at about the level of the Light Point Hardgrounds,

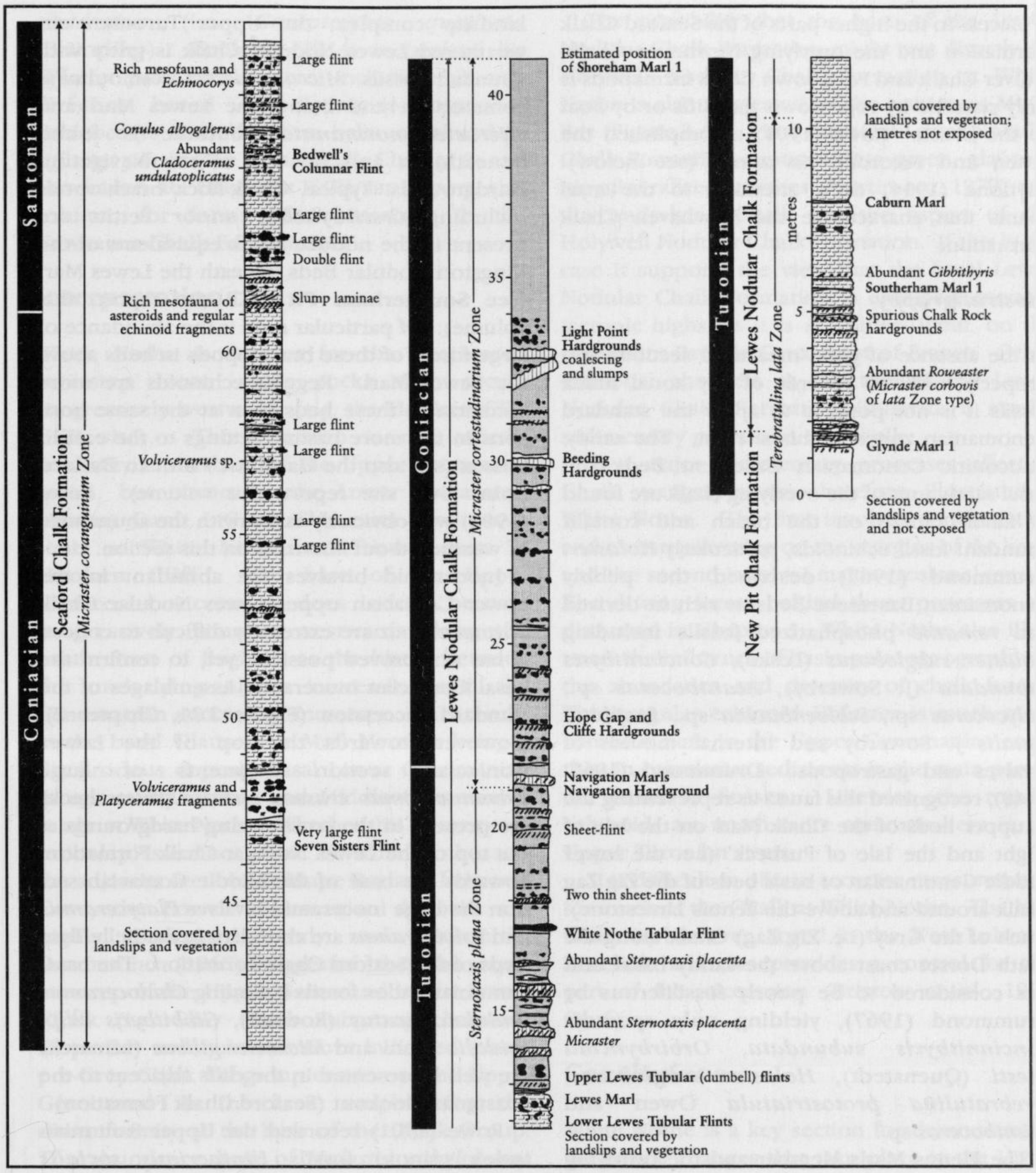


Figure 3.52 Part of the Chalk succession exposed at White Nothe, Dorset, in the slipped masses and in the cliff.

there are two red, iron-stained and mineralized hardground surfaces which form along obvious erosional channels (Figure 3.52).

Key basin-wide marker bands in the Seaford Chalk Formation also recognized here include the Belle Tout Marls, Seven Sisters Flint Band and the group of large flints at the Coniacian–Santonian boundary, including Bedwell's Columnar Flint Band (Figures 2.21 and 2.22, Chapter 2). As noted in the **Whitecliff** and **Handfast Point to Ballard Point** GCR site reports, many of these latter flints are larger than their equivalents in Sussex and Kent. The abundance of inoceramid bivalve fragments in the Belle Tout Beds of the Seaford Chalk Formation is almost rock-forming at some levels.

Access to the higher parts of the Seaford Chalk Formation and the overlying Newhaven Chalk, Culver Chalk and Portsdown Chalk formations is only possible by rope down the cliffs or by boat to the beach. Rowe (1901) accomplished the latter, and recorded his zones (see below). Brydone (1914) drew attention to the marl seams that characterize the Newhaven Chalk Formation.

Biostratigraphy

In the absence of good measured sections and properly localized records of key zonal index fossils it is not possible to apply the standard Cenomanian zones to this site yet. The sandy, glauconitic Cenomanian Basement Beds and basal sandy unit of the overlying chalk are found in fallen blocks on the beach and contain abundant fossil echinoids, particularly *Holaster*. Drummond (1967) described the pebbly Cenomanian Basement Beds as rich in derived and *remanié* phosphatized fossils including *Holaster subglobosus* (Leske), *Concinnithyris subundata* (J. Sowerby), *Acanthoceras* sp., *Calycoceras* sp., *Schloenbachia* sp., *Scaphites equalis* J. Sowerby and internal moulds of bivalves and gastropods. Drummond (1967, p. 48), recognized this fauna as representing the '...upper beds of the Chalk Marl on the Isle of Wight and the Isle of Purbeck' (i.e. the lower Middle Cenomanian or basal beds of the Zig Zag Chalk around and above the Tenuis Limestone). Much of the Grey (i.e. Zig Zag) Chalk along the south Dorset coast above the sandy basal unit was considered to be poorly fossiliferous by Drummond (1967), yielding only sporadic *Concinnithyris subundata*, *Orbirhynchia wiesti* (Quenstedt), *Holaster subglobosus*, *Terebratulina protostriatula* Owen and *Acanthoceras* sp..

The Plenus Marls Member and the overlying Melbourn Rock and the Meads Marls (as defined in Sussex, see **Southerham Grey Pit** GCR site report, this volume) have yielded the characteristic Upper Cenomanian fossils including the eponymous belemnite and the inoceramid bivalve *Inoceramus pictus* J. de C. Sowerby. Fallen blocks of Lower Turonian Holywell Nodular Chalk yield abundant *Mytiloides*, hence the boundary between the Cenomanian and Turonian stages can be broadly drawn at the change from *I. pictus* to *Mytiloides* in this section. In the big, vertical chalk cliffs within the landslip complex, the Upper Turonian air-weathered Lewes Nodular Chalk is gritty with abundant fossils. *Micraster leskei* Desmoulins is common in and below the Lewes Marl and *Micraster normanniae* Bucaille is found beneath, in and on top of the Navigation Hardgrounds. Typical 'Chalk Rock' brachiopods including *Cretirhynchia minor* Pettitt are present in the nodular chalk equivalents of the Kingston Nodular Beds beneath the Lewes Marl (see **Southerham Pit** GCR site report, this volume). Of particular note is the abundance of large forms of these brachiopods in beds above the Lewes Marl. Regular echinoids are more common in these beds than at the same horizons in the more basinal settings to the east in Sussex (see also the **Handfast Point to Ballard Point** GCR site report, this volume). Rowe (1901) was obviously taken with the abundance of weathered-out *Micraster* in this section.

Inoceramid bivalves are abundant in the Lower Coniacian upper Lewes Nodular Chalk Formation but are extremely difficult to collect. It has not proved possible, yet, to confirm the basal Coniacian inoceramid assemblages of the standard succession (Figure 2.21, Chapter 2). However, towards the top of the Lower Coniacian section fragments of large *Cremnoceramus crassus crassus* (Petrascheck) are present in the cross-cutting hardgrounds at the top of the Lewes Nodular Chalk Formation. Towards the base of the Middle Coniacian section the large inoceramid bivalves *Platyceramus* and *Volviceramus* are abundant in the Belle Tout Beds of the Seaford Chalk Formation. The basal Santonian index fossils including *Cladoceramus undulatoplicatus* (Roemer), *Gibbithyris ellipsoidalis* Sahni and *Micraster gibbus* (Lamarck) are well represented in the cliffs adjacent to the coastguard lookout (Seaford Chalk Formation).

Rowe (1901) recorded the Upper Santonian index crinoid fossils *Uintacrinus socialis* Grinnell and *Marsupites testudinarius* (Schlotheim) in the undercliff sections *c.* 100 m east of White Nothe. He also noted the special forms of *Echinocorys*, the nipple-shaped calyx of the crinoid *Bourgueticrinus papilliformis* Griffith and Brydone and the small brachiopod *Terebratulina rowei* Kitchin that are typical of these beds. Beneath Middle Bottom (Figure 3.50), Rowe identified the Lower Campanian *Offaster pilula* horizons and, farther eastwards in this section, he described a 15 ft (5 m) thick bed that yielded 15 specimens of *Actinocamax* *quadratus* (i.e. *Gonioteuthis quadrata* (Blainville)). Brydone (1914) recognized his *Offaster pilula* Zone here, including his subdivisions based on distinctive forms of *Echinocorys* and the two belts of abundant *Offaster pilula* (see Figure 2.27, Chapter 2; and **Newhaven to Brighton** GCR site report, this volume, for forms of *Echinocorys* in the Newhaven Chalk Formation).

Interpretation

White Nothe is famous for the Cretaceous 'overstep' onto older rocks that occurs progressively westwards (e.g. the **Hooken Cliff** GCR site). This overstep is not strictly, however, at the base of the Upper Cretaceous Series, but occurs in the Lower Cretaceous (Albian) Gault. Gault Clay rests on Jurassic strata at White Nothe and Triassic strata at **Hooken Cliff**. The base of the Upper Cretaceous succession does indeed become progressively younger westwards along the south coast of England as the hiatus between the underlying Albian succession and the Cenomanian succession increases. This results in the basal Glauconitic Marl Member being a diachronous deposit, basal Lower Cenomanian in age at Folkestone and Middle Cenomanian in age at White Nothe. Whether this is 'overstep' or 'onlap' is a moot point. At White Nothe, and the adjacent sections at Mupe Bay and Lulworth Cove, the Lower Cenomanian deposits are highly condensed, sandy, and glauconitic. Drummond (1967) suggested that the rapid overstep of the Upper Greensand by the Lower Chalk (i.e. Grey Chalk Subgroup) between Mupe Bay and Lulworth Cove indicated severe pre-Grey Chalk Subgroup erosion of the Upper Greensand in the area, emphasizing the disconformity at the base of the Chalk Group. The abundance here of *Holaster subglobosus* in the basal Zig Zag Chalk Formation is a feature of the south-west margin of the basin seen also at **Compton Bay** (see GCR site report, this volume). Similarly, the occurrence of flint in the Zig Zag Chalk on the western margin probably relates to water mass upwelling related to relative 'highs' along the south-west margin and consequent high organic productivity. Flints are also unusually present in the lower part of the Holywell Nodular Chalk Formation in the Melbourn Rock at Worbarrow Bay and Mupe Bay (Mortimore and Pomerol, 1987).

The possibility that the base of the Lewes Nodular Chalk Formation might rest directly on Holywell Nodular Chalk Formation at White Nothe is also suggested by the section at Mupe Bay (Figure 3.46). Here the basal Lewes Nodular Chalk Formation contains nine green, glauconitic mineralized surfaces (Mortimore, 1979) and the underlying Chalk has the aspect of the Holywell Nodular Chalk Formation. If this is the case it supports the view that the basal Lewes Nodular Chalk Formation is erosional towards tectonic highs, as it is at Antifer-Tilleul, on the equivalent Pays de Caux coast of France. Other erosional channels at the top of the Lewes Nodular Chalk Formation illustrate a similar sedimentary process in the Chalk.

Two major sedimentary processes affecting Chalk stratigraphy are, therefore, illustrated at White Nothe. The first involves condensation and overstep/overlap on the margins of the basin and the second involves major erosional events. The driving forces behind these processes are discussed in Chapter 1. White Nothe also illustrates the influence of basin palaeogeography on the abundance and diversity of chalk faunas. The irregular echinoid *Holaster* is much more common here in the Upper Cenomanian rocks than in correlative sediments in the main part of the basin in Sussex. Likewise, the regular echinoids are much more common here in the Upper Turonian strata.

It is difficult to obtain accurate measurements for much of the Chalk at White Nothe. The high Chalk is, however, cored in the West Lulworth Borehole and this provides a control for that part of the succession (Bristow *et al.*, 1997, fig. 6).

Conclusions

White Nothe is a key section for demonstrating the lateral changes that take place in the Upper Cretaceous sediments and fossil assemblages as they are traced from the main basin in Sussex to the margins in south Dorset and south-east Devon. It is a classic area for investigating the sub-Chalk erosion surface and overstep. This is further emphasized by intra-Cenomanian faulting in Mupe Bay. As a transitional area, White Nothe also provides evidence for both continuity and changes in the correlation framework of lithologies, marl seams, flint bands and fossil event horizons in the Chalk of the Southern Province.

HANDFAST POINT TO BALLARD POINT, DORSET (SZ 043 824–SZ 048 813)

Introduction

The Handfast Point to Ballard Point GCR site, near Studland, Dorset (Figures 3.53 and 3.54), is perhaps the most inaccessible and inhospitable Upper Cretaceous section of all the Upper Cretaceous GCR sites. As Rowe (1901, p. 37) indicated, however, it is also the most important section in the Upper Campanian *Belemnitella mucronata* Zone, but this can only be worked by boat.

There are three parts to this coastal cliff section (Figure 3.53), which has been formed by the sea breaking through a narrow Chalk ridge that once continued eastwards to the Needles, Isle of Wight. The first part extends from Swanage Bay (Punfield Cove) to Ballard Point. It exposes a section from the contact of the Chalk Group on the Lower Cretaceous (Upper Greensand) up to the top of the lower Lewes Nodular Chalk Formation. The Grey Chalk Subgroup (Zig Zag Chalk Formation) rests here on a glauconitic Basement Bed containing phosphatized Middle Cenomanian ammonites. The upper Lewes Nodular Chalk forms the Headland and was estimated by Rowe to be about 42 ft (13 m) thick. The second part, from this point northwards to Handfast Point and Old Harry Rocks, constitutes the GCR site *sensu stricto*, and contains the Ballard Fault (Figure 3.55) and the long Upper Campanian section. The third part is the Studland Bay section from Handfast Point to Studland, which exposes the Studland Chalk and the overlying Palaeogene deposits.

Description

The most conspicuous feature of this site is the great Ballard Fault, south of which the Chalk dips are nearly vertical. North of the fault, the beds dip more gently to the north, with the dip becoming 10° north at Handfast Point (Figures 3.55 and 3.56). Each layer is brought to sea level in turn by the dip. This dip creates a 2500 m long section in the *B. mucronata* Zone, which Rowe estimated to be here about 76 m thick.

The curving plane of the thrust fault (Rowe, 1901, p. 35, pl. VIII) is located low in the Portsdown Chalk Formation, along a marl seam that, on photographic evidence, can be inferred to be the Shide Marl (see the **Whitecliff** GCR site report, this volume), not far above the base of the *mucronata* Zone. On the north side of the Handfast Point to Ballard Point headland is Studland Bay, where well-developed dissolution pipes into the Chalk are found below the Chalk–Palaeogene contact. Studland Bay is also the type locality for the Studland Chalk Member (Gale *et al.*, 1988).

Barrois (1876) was once again the first to provide an account of these cliff sections. He identified the great Ballard Fault and the *B. mucronata* Zone beneath the fault.

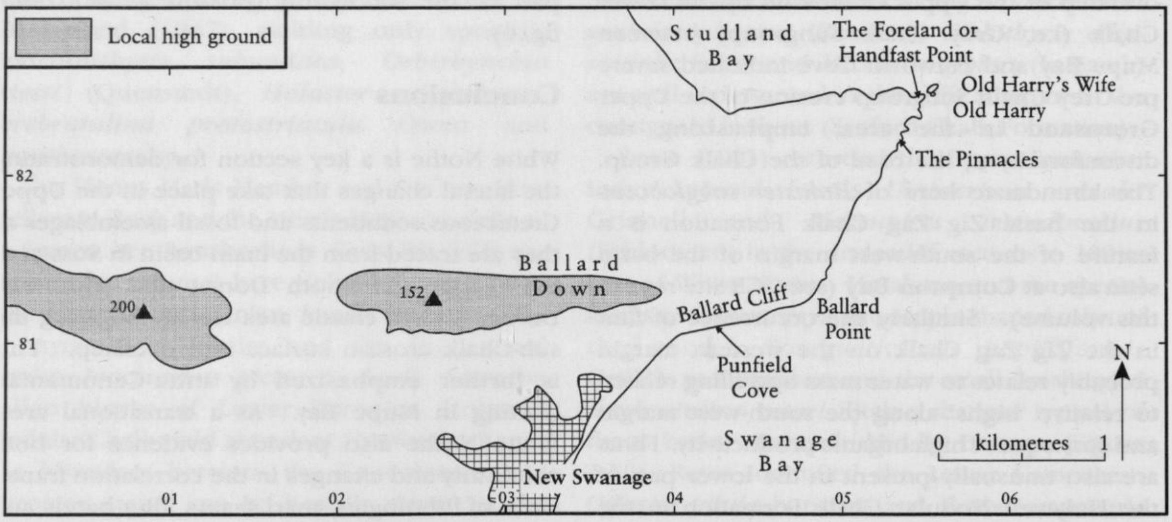


Figure 3.53 The Handfast Point to Ballard Point Upper Cretaceous GCR site, Swanage, Dorset.

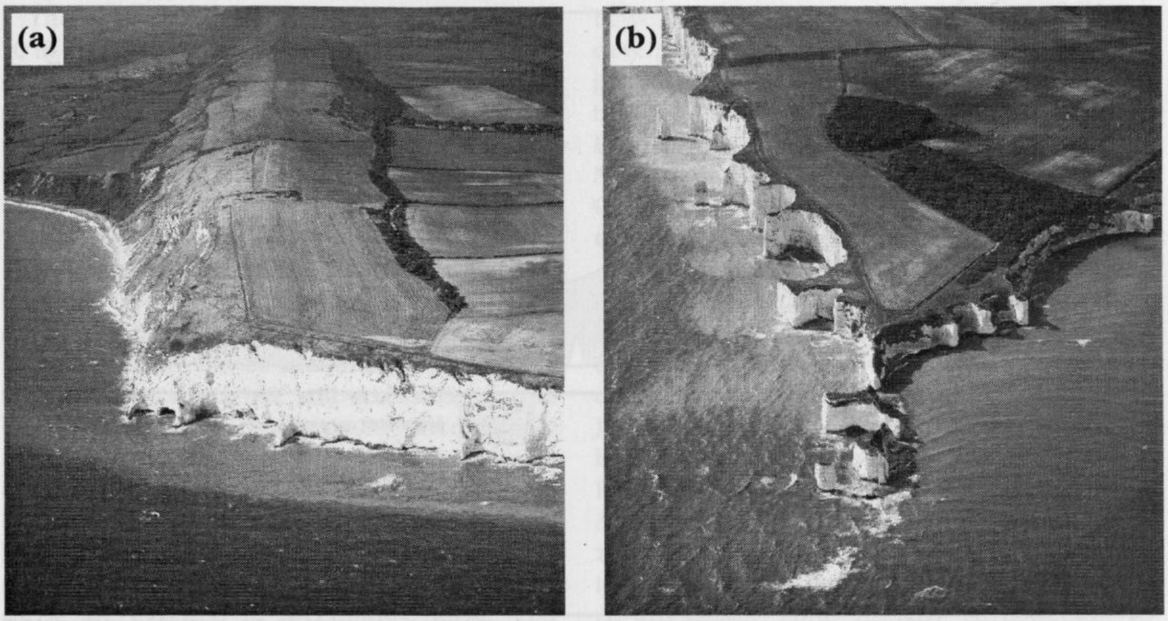


Figure 3.54 The two ends of the Handfast Point to Ballard Point GCR site. (a) The southern end at Ballard Head, looking south-west. (b) The northern end at Handfast Point – Handfast Point and Old Harry sea stack looking south-west. (Photos: Cambridge University Collection of Aerial Photography; copyright reserved.)

Strahan's memoir for the Isle of Purbeck (1898) included a description of the Ballard Fault, but it was Rowe (1901) who provided the first fully detailed and comprehensive account of the 'zonal' stratigraphy. The [British] Geological Survey (Jukes-Browne and Hill, 1904) largely followed the observations of Barrois, Strahan and Rowe. Others have reviewed these sections (Wright, 1947) but in less detail. Later research concentrated on particular parts of the stratigraphy or structure. Drummond (1967, 1970) investigated the Albian–Cenomanian deposits in Punfield Cove. Gale (1995, fig. 12) illustrated the cyclostratigraphy of part of the Zig Zag Chalk Formation. Although the Plenus Marls Member, at the base of the White Chalk Subgroup, is well exposed, this was not a site visited by Jefferies (1962, 1963). A log of the member was given by Gale (1995, fig. 14).

Gale (1996, p. 178) introduced the term 'Ballard Cliff Member' (named after this site) for the basal beds of the Holywell Nodular Chalk Formation overlying the Plenus Marls Member. His member extends up to the top of the Meads Marls and hence includes the Melbourn Rock–Meads Marls as defined by Mortimore (1986a) in Sussex. He also provided (Gale, 1996, fig. 5) a log of the New Pit Chalk Formation and the basal Lewes Nodular Chalk Formation (including the Spurious Chalk Rock) up to Southerham Marl 1. The Holywell Nodular Chalk to Seaford Chalk sections were investigated by Mortimore and Pomerol (1987, figs 8, 9) and the highest Studland Chalk by Gale *et al.* (1988).

Strahan (1898) discussed the slickensided structure of much of the chalk adjacent to the Ballard Fault. The Ballard Fault was illustrated photographically by Ameen (1990, fig. 3). Conflicting models for the generation of the fault were reviewed by Carter (1992) and by Ameen and Cosgrove (1992). Ameen and Cosgrove (1990) investigated the detailed fracture pattern in the Chalk at Studland Bay to determine the post-Mesozoic stress history of the Chalk (see also Carter, 1992). Barrois (1876) thought that the *Marsupites* Zone occupied all the section stratigraphically above the fault. This was corrected by Rowe (1901), who realized that the fault occurred within, but close to the base of, the *B. mucronata* Zone.

Lithostratigraphy

Upper Greensand–Grey Chalk Subgroup

Drummond (1967) described the Albian–Cenomanian Upper Greensand–Lower Chalk section in Punfield Cove just west of Ballard Point. He separated the Upper Greensand into

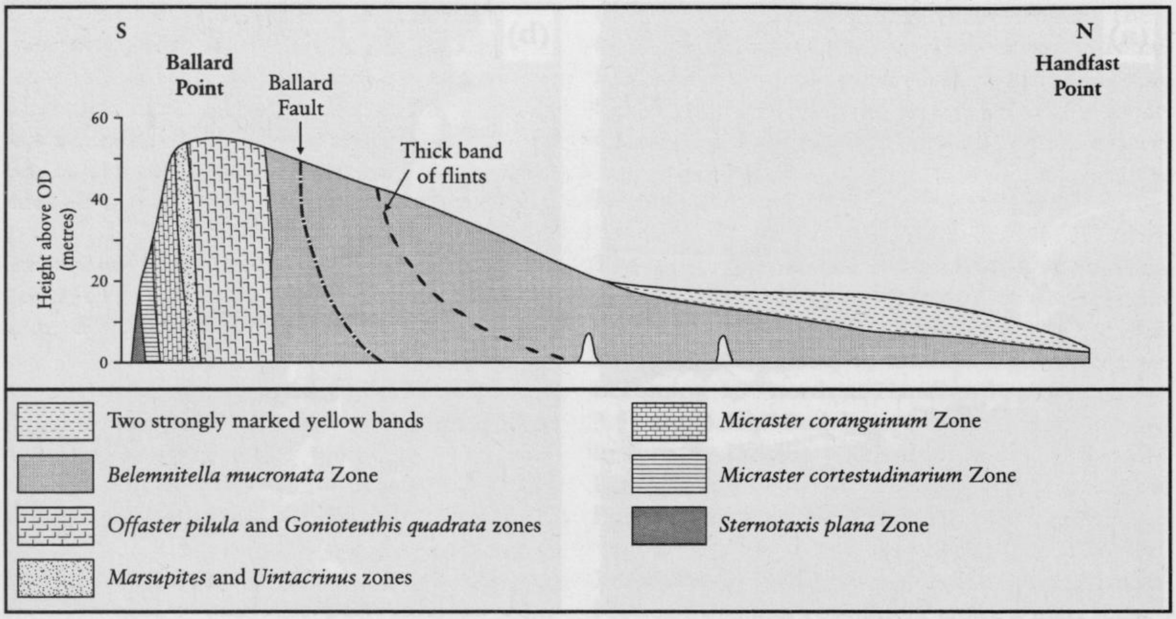


Figure 3.55 Cliff section from Ballard Point to Handfast Point, Isle of Purbeck, Dorset. (After Rowe, 1901, fig. 2.)

two beds. The lower bed, nearly 1 m thick, consists of nodular, coarse greensand passing down into soft, coarse greensand. This is overlain by the second bed, a 0.2–0.3 m thick layer of bored limestone doggers. These two beds lie beneath an erosion surface on which is the 0.3–0.4 m thick Basement Bed, a condensed, nodular glauconitic sandstone of greensand pebbles in a Glauconitic Marl matrix forming the basal unit of the Glauconitic Marl. This is overlain by 0.6 m of calcareous sandstone with both phosphatized and unphosphatized fossils. There is a further 0.6 m of Glauconitic Marl with unphosphatized fossils.

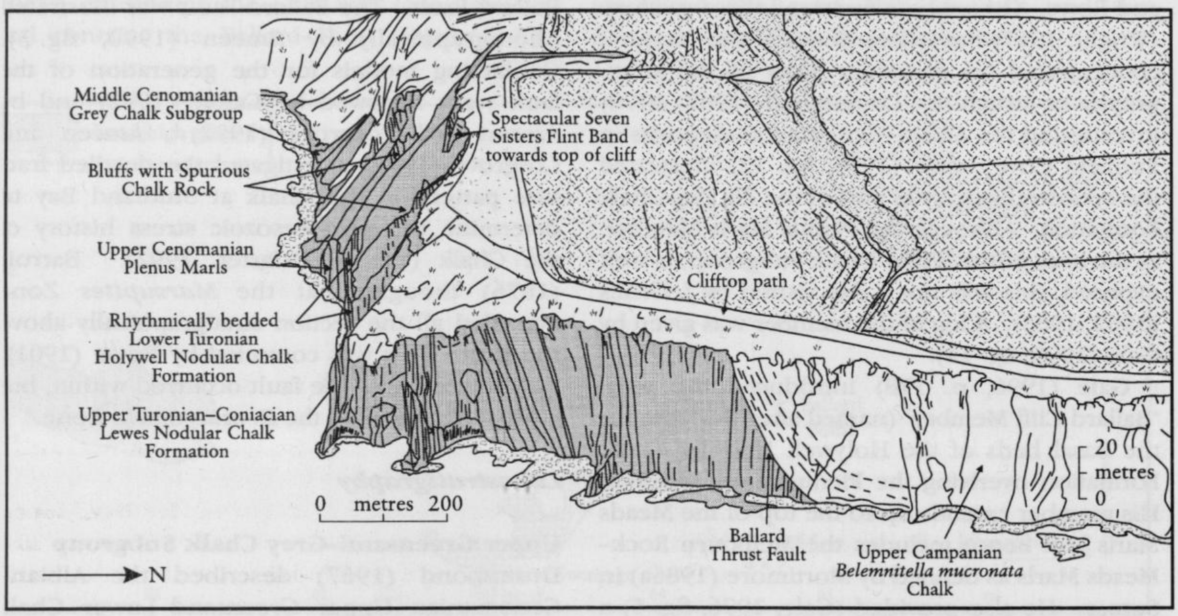


Figure 3.56 Chalk stratigraphy and the major thrust fault in the Chalk at Ballard Point, Dorset (see Figure 3.54a).

The Glauconitic Marl grades up into about 10 m of marly chalk separated by an erosion surface from a further 3 m of glauconitic, marly chalk. The overlying 27 m of Zig Zag Chalk Formation is massively bedded and contains thin marl seams.

White Chalk Subgroup

The Plenus Marls Member at the base of the Holywell Nodular Chalk Formation is well developed and all of Jefferies' (1962, 1963) numbered beds can be identified. Beyond the Plenus Marls, which are still accessible on the beach, the section becomes increasingly hazardous. The lower part of the Holywell Nodular Chalk, with a weakly developed Melbourn Rock (in the sense of Sussex, Mortimore, 1986a) at the base, is washed clean on the last part of the beach area, but the beds above are exposed in precipitous, loose, cliff faces. Fallen blocks of Holywell Nodular Chalk yield abundant shell-debris layers, as well as the typical flaser marl seams and intraclast beds. Rowe (1901, p. 40) noted a flint band at the boundary between the *Rhynchonella* (i.e. *Orbirhynchia*) *cuvieri* and *Terebratulina gracilis* (i.e. *lata*) zones, which corresponds to a level around the Glyndebourne Flints and the Gun Gardens Main Marl (Mortimore and Pomerol, 1996). This flint is shown at the base of the section in Gale (1996, fig. 5).

Rowe (1901), by landing from a boat, found a magnificent, clean, air-weathered section in the *Terebratulina gracilis* (*lata*) Zone just south of Ballard Point. He noted the absence of flint, and also observed marl seams that did not weather back into grooves (probably the brittle marls such as New Pit Marls 1 and 2). Rowe also noted the yellow-green nodule beds of the Spurious Chalk Rock well within the *Terebratulina gracilis* (*lata*) Zone. The same Spurious Chalk Rock horizons are to be found in the high bluffs on the cliff face (Mortimore and Pomerol, 1987, fig. 9). Many of the fallen blocks at beach level also contain the glauconitic surfaces of the Spurious Chalk Rock hardgrounds.

Mortimore and Pomerol (1987, fig. 9) published a section logged in the chalk bluffs high in the dangerous cliff, showing the position of the Spurious Chalk Rock in relation to the marker marl seams in the lower Lewes Nodular Chalk Formation. The Southerham, Caburn and Bridgewick marl seams are well developed. The Lewes Tubular Flints are also spectacularly developed in tough, red, iron-stained and very grey, nodular chalks. There are many fallen blocks of chalk from this horizon at beach level. Each of the marker beds in the upper Lewes Nodular Chalk has been identified, including the Cuilfail Zoophycos Beds, Navigation Marls and the Cliffe Hardground.

Exposures in the Seaford Chalk Formation are limited. However, the Seven Sisters Flint Band, associated with conspicuous large potstones can be examined high in the cliff close to the cliff-top path. Strahan (1898), Rowe (1901) and Jukes-Browne and Hill (1904) all provided a longitudinal section of the cliff from Ballard Point northwards to Handfast Point (Figure 3.55). Their sections showed the traditional zones of the Chalk, but these can be used to identify the lithostratigraphy. The *Micraster coranguinum* Zone broadly corresponds to the Seaford Chalk Formation, while the *Uintacrinus socialis*, *Marsupites testudinarius* and *Offaster pilula* zones broadly conform to the Newhaven Chalk Formation. It is inferred that the crinoid and *O. pilula* zones contain marl seams here, as these are present at Scratchell's Bay, Isle of Wight, to the east, and at Arish Mell, Bats Head and Middle Bottom near **White Nothe** to the west (see GCR site report, this volume). This is supported by the fact that Rowe (1901) indicated that these beds were conspicuous because of the reduced amount of flint; and that his broadly conceived *Actinocamax quadratus* Zone (which included the *Offaster pilula* Zone) was marly with discrete veins.

The very large columnar flints noted by Rowe (1901, p. 35) south of the Ballard Fault are probably in the upper part of the *Gonioteuthis quadrata* Zone. It is possible that these correlate with the Warren Farm Paramoudra Flints in the Culver Chalk Formation of Portsdown and Culver Cliff, Isle of Wight (see Figure 3.15; and the **Whitecliff** and **Downend Chalk Pit** GCR site reports, this volume). The overlying beds belong to the basal Portsdown Chalk Formation.

Rowe noted some bands of very large flints in the beds north of the fault. One of his strong flint bands, *c.* 30 m above the fault plane, was used by him as a marker, noting that it came to the shoreline 30 m north of the first pinnacle. At the top of the cliff, above this point, Rowe identified two well-developed yellow, nodular chalk bands, *c.* 30 m above the flint. These he traced to Handfast Point and Old Harry where they were about two-fifths of the way up the cliff, coming to beach level in Studland Bay west of Handfast Point. The upper of these bands is the weaker and dies out northwards. Gale *et al.* (1988) took the upper band as the basal marker of their Studland Chalk (Member).

Biostratigraphy

Cenomanian Stage

The calcareous sandstone in the lower part of the Glauconitic Marl resting on the Basement Bed, contains phosphatized internal moulds of ammonites (*Turrilites costatus* Lamarck and *Schloenbachia*) derived from the *T. costatus* Subzone of the *Acanthoceras rhotomagense* Zone, and sporadic unphosphatized specimens of the brachiopod *Dereta pectita* (J. Sowerby). From the overlying sandy Glauconitic Marl unphosphatized brachiopods (*Orbirhynchia mantelliana* (J. de C. Sowerby), *Grasirhynchia grasiana* (d'Orbigny) and *Concinnithyris subundata* (J. Sowerby)) have been collected. The *Orbirhynchia* point to a correlation with the *Orbirhynchia mantelliana* Band near the top of the *costatus* Subzone in basinal sections. This Middle Cenomanian assemblage, both reworked and indigenous, correlates with that of the expanded sections at **Southerham Grey Pit** (see GCR site report, this volume), which are developed in rhythmically bedded marly chalk facies.

Holaster subglobosus (Leske), *Camerogalerus cylindricus* (Lamarck) and *Concinnithyris subundata* occur in the marly chalk above the Glauconitic Marl, indicating the *Turrilites acutus* Subzone of the *Acanthoceras rhotomagense* Zone. Within the Zig Zag Chalk Formation, *Acanthoceras jukesbrownei* (Spath) is common in Jukes-Browne Bed 7, and Wright (1947) recorded *Calycoceras* from Punfield Cove. Bands of *Holaster* are a feature of the Zig Zag Chalk Formation here.

The belemnite *Praeactinocamax plenus* (Blainville) is present in the Plenus Marls Member (Wright, 1947, p. 199). Bands full of *Inoceramus pictus* J. de C. Sowerby were found in both the Plenus Marls and basal Holywell Nodular Chalk in a section on Ballard Down. One specimen of the zonal index ammonite *Metoicoceras geslinianum* (d'Orbigny) was also found in the basal beds of the Plenus Marls at the same locality.

Turonian Stage

A standard succession of *Mytiloides* shell-beds in the Lower Turonian Holywell Nodular Chalk Formation can be pieced together from the fallen blocks towards Ballard Point. The band of flints identified by Rowe is presumed to correlate with the Glyndebourne Flints because one block contained both these flints and the overlying beds with *M. subhercynicus* (Seitz). Rowe (1901, p. 33) found an air-weathered section in the Middle Turonian New Pit Chalk Formation, which yielded a diverse collection of fossil echinoids and brachiopods.

Fallen blocks of Upper Turonian chalk belonging to the Lewes Nodular Chalk Formation at the horizon of the Lewes Tubular Flints contain abundant regular echinoids (*Gautheria radiata* (Sorignet)), a feature not seen in more basinal successions in Sussex and Kent.

Coniacian to Campanian stages

As Rowe (1901) noted, collecting from the chalk between Ballard Point and Handfast Point is both hazardous and almost impossible because of the very hard chalks and the seaweed cover at the base of the cliffs. He established the position of the Upper Santonian *Uintacrinus socialis* and *Marsupites testudinarius* zones but could not find the Lower Campanian *Offaster* (his *Cardiaster*) *pilula* beds. Unfortunately, Brydone never managed to include this section in his review of the *Offaster pilula* Zone. Worn and battered belemnites provided Rowe with the evidence for the *Gonioteuthis quadrata* and *Belemnitella mucronata* zones. Rowe (1901) devoted several pages to a discussion of the fossils in the *B. mucronata* Zone of Dorset, including those of this site. In particular, he recorded conical forms of *Echinocorys* (i.e. presumably *Echinocorys conica* (Agassiz) and related forms) in a band north and south of the southernmost pinnacle. In addition, Rowe noted the entry of the small brachiopod *Magas pumilus* J. Sowerby (i.e. *M. chitoniformis* (Schlotheim)) in the *mucronata* Zone towards Old Harry and in Studland Bay, at about the level of the two yellow-nodular beds marking the base of the Studland Chalk Member of Gale *et al.* (1988).

Interpretation

Access to much of the section between Ballard Point and Handfast Point is very limited and consequently a detailed stratigraphy has not been established. Vital evidence for the Late Cretaceous overstep, however, is provided by the Albian–Cenomanian section exposed in Punfield Cove just west of Ballard Point. In conjunction with the **Compton Bay** and **White Nothe** GCR sites, the Punfield section is critical to a study of the great Late Cretaceous transgression in the region, as illustrated by Drummond (1967, 1970).

Rowe (1901) used the occurrence of a small *Echinocorys* (presumably *Echinocorys subconicula* Brydone) in the cave at the base of the thrust plane to identify a position close to the base of the *mucronata* Zone. Photographs of the section enabled Professor A.S. Gale (pers. comm., 1999) to recognize the same marl seams as are seen in the sections at the **Whitecliff** GCR site, and Scratchell's Bay on the Isle of Wight. These photographs show that the Ballard Fault slices through these beds along the Shide Marl, which is situated only a short distance above the Farlington Marls at the base of the zone, thus confirming Rowe's interpretation.

The entry of the brachiopod *M. chitoniformis* is an important bio-event in the lower part of the *mucronata* Zone of the Southern Province and Norfolk sections, a fact that was recognized by both Rowe and Brydone. For example, the absence of this species from the highest *mucronata* Zone sections on Portsdown shows that only the basal part of the zone (pre-Weybourne Chalk of Wood (1988)) is represented there, whereas the sections in the present site, in inland Dorset and on the Isle of Wight, extend up into the equivalent of the Weybourne Chalk of Norfolk (see Figure 4.5, Chapter 4).

Gale (1996, fig. 5) showed that eight more marl–chalk couplets of the New Pit Chalk Formation were preserved here beneath the base of the Spurious Chalk Rock (Ogbourne Hardground of the standard Chalk Rock stratigraphy) than at the **Compton Bay** GCR site.

Conclusions

There are four key aspects to the Handfast Point to Ballard Point section. The first is seen at Punfield Cove where the West Melbury Marly Chalk Formation of Central Dorset and elsewhere in the Southern Province is absent, being represented only by ***remanié*** phosphatized internal moulds of Middle Cenomanian fossils in the glauconitic Basement Bed at the base of the Zig Zag Chalk Formation. This relates to the regional Cretaceous overstep that progressively develops westwards and to the local tectonic control of sedimentation with uplift along the Purbeck–Wight Fault. The second is the remarkable abundance of regular echinoids in the interval containing the Lewes Tubular Flints, which again is related to the palaeogeographical position of the site in the Upper Turonian along the line of a fault-controlled shelf. The third relates to the spectacular Ballard Fault that brings the folded basal *Belemnitella mucronata* Zone (Portsdown Chalk Formation) into juxtaposition with vertical beds low in the same formation. The tectonic complexity of this remarkable structure and its initiation remain points of continuing controversy. The fourth aspect is the exposure of the longest continuous sections in the *mucronata* Zone in the Southern Province. In addition there are invaluable data from the near-horizontal Upper Campanian strata in Studland Bay, making this complete coastal section critical to Upper Cretaceous studies.

COMPTON BAY, ISLE OF WIGHT (SZ 350 855)

Introduction

Compton Bay has formed by the erosion of Cretaceous strata over the Brixton Anticline (pericline) (Figure 3.57) leaving the Late Cretaceous chalks exposed on its northern flanks, dipping steeply northwards. In the core of the exposure is Freshwater Bay, the truncated and drowned headwaters of the River Western Yar, whose tributary streams must have drained the region to the south now occupied by Compton Bay. There are three parts to this site. The first, at beach level, approached via Compton Chine, exposes the Cenomanian Grey Chalk Subgroup, including the Glauconitic Marl, West Melbury Marly Chalk and Zig Zag Chalk formations, overlain by the Plenus Marls Member at the base of the White Chalk Subgroup. The second is a cliff section in Turonian Chalk that ends towards the top of the New Pit Chalk Formation. The third part comprises the Military Road section on Compton Down (Afton Down, Figure

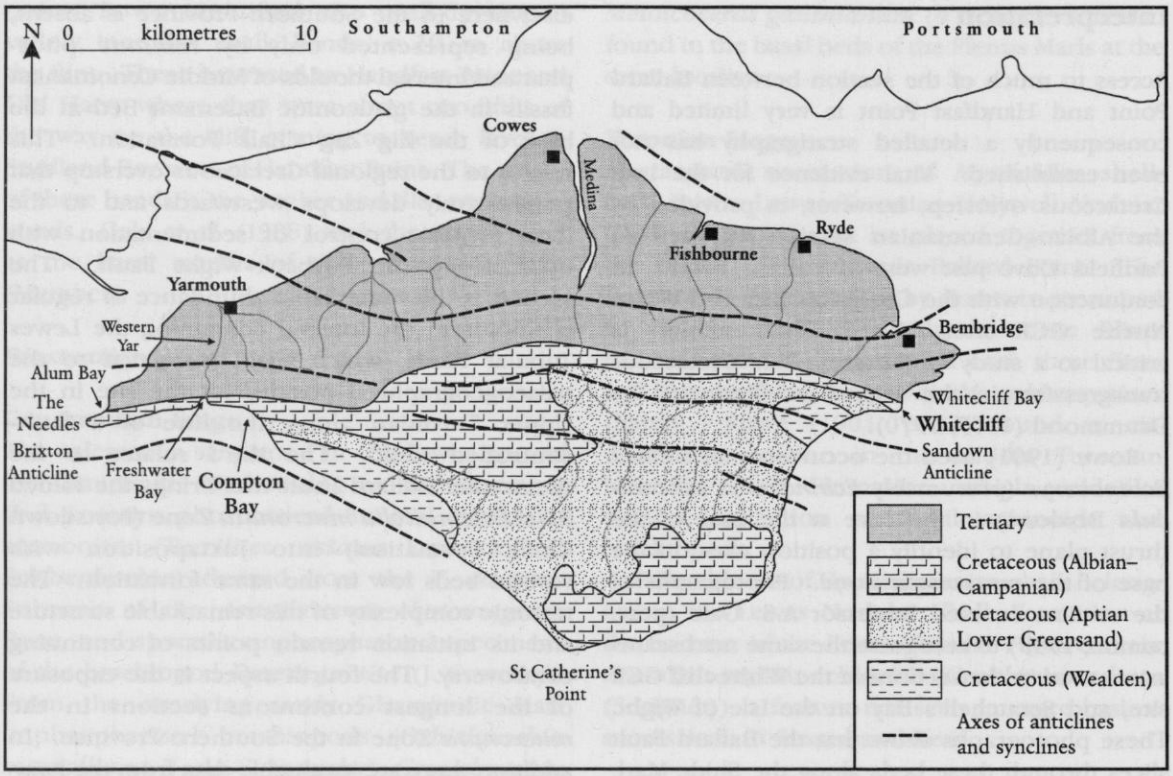


Figure 3.57 Simplified geology of the Isle of Wight, showing the position of the two GCR sites, at Compton Bay and Whitecliff and related sections.

3.58), which expose the Spurious Chalk Rock, the entire Lewes Nodular Chalk Formation and the basal part of the Seaford Chalk Formation. A supplementary fourth section is Freshwater Bay, which has excellent exposures of the lower Lewes Nodular Chalk on the sea stacks on the south-east side of the bay, and Seaford Chalk in the cliffs of the inner bay. There is a sharp angular discordance here between near-vertical Cretaceous strata and near-horizontal Quaternary sediments (cf. Figure 3.62, p. 181).

Description

The first systematic account of the Upper Cretaceous Chalk of the Isle of Wight was given by Barrois (1875). He identified a lower unit comprising Chalk Marl and Grey Chalk with Glauconitic Marl at the base and Plenus Marls at the top. His 'Craie Marneuse' (including the zones of *Inoceramus* (i.e. *Mytiloides*) *labiatus* and *Terebratulina gracilis* (i.e. *lata*) corresponds to the Holywell Nodular Chalk and New Pit Chalk formations. Barrois (1875) recognized the very hard yellowish nodules embedded in a greenish-grey marl at the base of his *I. labiatus* Zone and he later (1876) correlated this level with the Melbourn Rock. Barrois also recognized the green-coated nodules forming Whitaker's (1865c) Chalk Rock (the Spurious Chalk Rock of Rowe (1908)), towards the top of his *T. gracilis* Zone. These nodules were later taken by the [British] Geological Survey (Reid and Strahan, 1889) as the base of the Upper Chalk. Barrois placed all of the Chalk above the *T. lata* Zone in his 'Craie Blanche' (White Chalk). Barrois (1876) made several corrections to his zonal account of the Chalk of the Isle of Wight, including a revision of the boundary between the *M. cortestudinarium* and *M. coranguinum* zones, and the identification of the *Marsupites* Zone.

The [British] Geological Survey later (Jukes-Browne and Hill, 1904, p. 88, p. 90; White, 1921, pp. 62–63) took the base of the Upper Chalk in the Compton Down Military Road section (Afton Down), on palaeontological evidence (i.e. at the boundary between the *T. lata* and *S. plana*

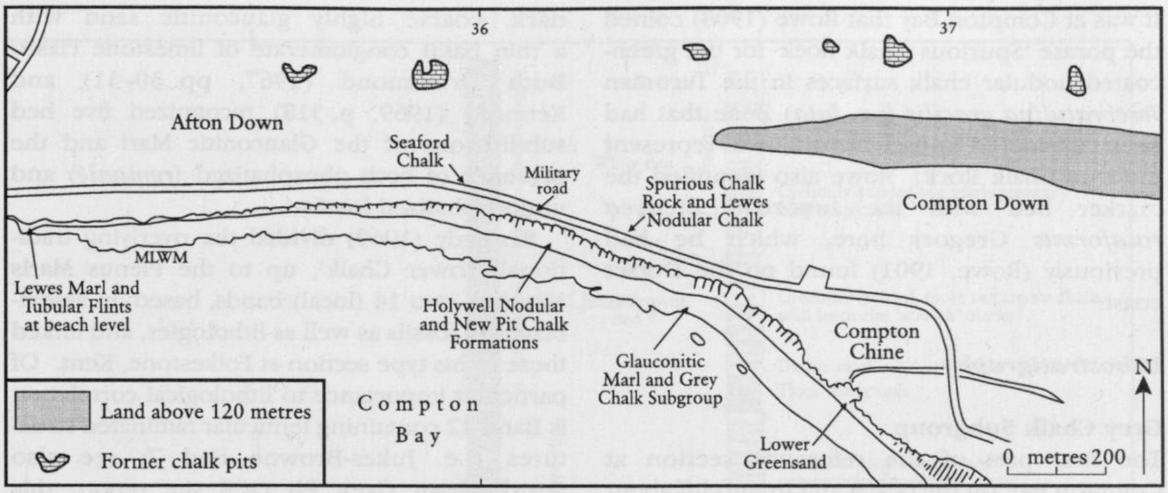


Figure 3.58 Map showing the details of the Compton Bay site. (MLWM = mean low water mark.)

zones). This boundary coincided with a grey marl interpreted to be the Caburn Marl (Figure 3.63, p. 183), found at a level considerably higher than the level of the Spurious Chalk Rock used by Reid and Strahan (1889). Rowe (1908, p. 220) took his boundary at the the second 'grey marl' above the Spurious Chalk Rock (i.e. the presumed Caburn Marl). White (1921) noted, but dismissed, Brydone's (1917) suggestion that the Chalk Rock should be included as the basal beds of the Upper Chalk.

A particular point emphasized by White (1921, p. 61) is the thinning of the Lower Chalk (Glauconitic Marl and West Melbury Marly Chalk) and 'Middle Chalk' westwards across the island to Compton Bay.

By far the most comprehensive account of the Chalk of the Isle of Wight, including the present site, was given by Rowe (1908). This includes section measurements, descriptions of lithologies, superb annotated photographic plates and comprehensive lists of fossils. Early researchers (e.g. Reid and Strahan, 1889, p. 77) had noted strange bands of siliceous nodules in marl seams in the *T. lata* Zone (New Pit Chalk). Rowe (1908, p. 218) describes these as '... grey or fawn coloured on the surface, and very white inside, contrasting strongly when broken with the greyer tint of the surrounding matrix'. Rowe traced these nodules, which he regarded as unique, through the Compton Bay cliff section and the Military Road section as well as in several inland pits. The nodules were shown by Gale (1996, fig. 5) as flints *c.* 1 m below the Round Down Marl.

Later work concentrated on particular aspects of the Chalk of Compton Bay. Drummond (1967, 1970) investigated the Albian–Cenomanian section. Kennedy (1969) published a detailed log of the Lower Chalk, correlating his marker bands initially recognized in the Folkestone section (see **Folkestone to Kingsdown** GCR site report, this volume), through Sussex (**Southerham Grey Pit**; see GCR site report, this volume), to the Isle of Wight. Gale (1995, figs 8, 11, 12) illustrated the marl–chalk couplet cyclostratigraphy of parts of the Cenomanian succession and (1996, figs 3, 5) published sections for the Holywell Nodular Chalk and New Pit Chalk formations. The Plenus Marls were investigated by Jefferies (1962, 1963), who allocated his bed numbers to the succession. Graphic logs of parts of the White Chalk Subgroup sections were published by Mortimore (1986b, fig. 3.6), Mortimore and Wood (1986, figs 2.3, 2.4) and Mortimore and Pomerol (1987, figs 8, 9). All of these studies have added increasing precision to correlations and to understanding the lateral variations in the Chalk and their causes.

A steep northerly dip results in an excellent Chalk reference section at Compton Bay, especially in the Cenomanian and Turonian successions. The section forms part of a key network of sections used to establish a cyclostratigraphy and timescale for the Middle Cenomanian strata by Gale (1989, 1990a, 1995).

It was at Compton Bay that Rowe (1908) coined the phrase 'Spurious Chalk Rock' for the green-coated nodular chalk surfaces in the Turonian *Terebratulina gracilis* (i.e. *lata*) Zone that had been considered by earlier workers to represent the true Chalk Rock. Rowe also identified the marker bed with the bryozoan *Bicavea rotaformis* Gregory here, which he had previously (Rowe, 1901) found on the Dorset coast.

Lithostratigraphy

Grey Chalk Subgroup

The first part of the reference section at Compton Bay, on the beach and in the cliff about 600 m west of Compton Chine, provides an excellent exposure in the Grey Chalk Subgroup (Figures 3.59–3.62), which here is about 47 m thick (Kennedy, 1969). Kennedy (1969) took the base of the Glauconitic Marl and hence the base of the Chalk at the change from fine buff sand at the top of the Upper Greensand to dark, coarse highly glauconitic sand with a thin basal conglomerate of limestone clasts. Both Drummond (1967, pp. 30–31) and Kennedy (1969, p. 518) recognized five bed subdivisions of the Glauconitic Marl and the presence of both phosphatized (*remanié*) and unphosphatized fossils.

Kennedy (1969) divided the overlying traditional 'Lower Chalk', up to the Plenus Marls Member, into 14 (local) bands, based on assemblages of fossils as well as lithologies, and linked these to his type section at Folkestone, Kent. Of particular importance to lithological correlation is Band 12 containing lenticular laminated structures (i.e. Jukes-Browne Bed 7; see also **Southerham Grey Pit** GCR site report, this volume). Gale (1995), using a cyclostratigraphy based on (inferred precession-driven) marl–chalk couplets, recognized five groups of couplets lettered A to E in the Cenomanian strata. His A division couplets incorporate the Glauconitic Marl and the condensed Lower Cenomanian succession. Gale (1995, p. 183)

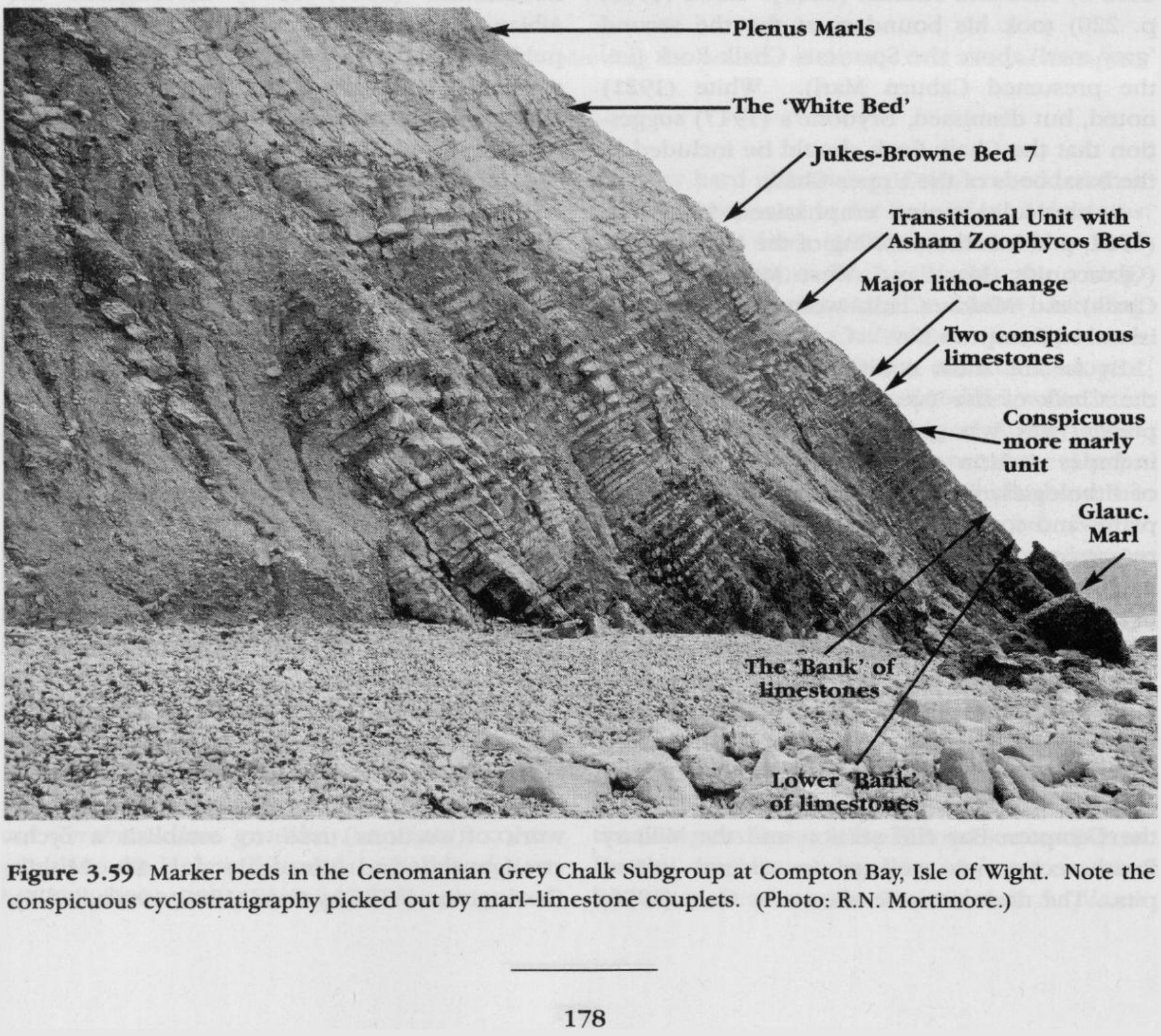


Figure 3.59 Marker beds in the Cenomanian Grey Chalk Subgroup at Compton Bay, Isle of Wight. Note the conspicuous cyclostratigraphy picked out by marl–limestone couplets. (Photo: R.N. Mortimore.)

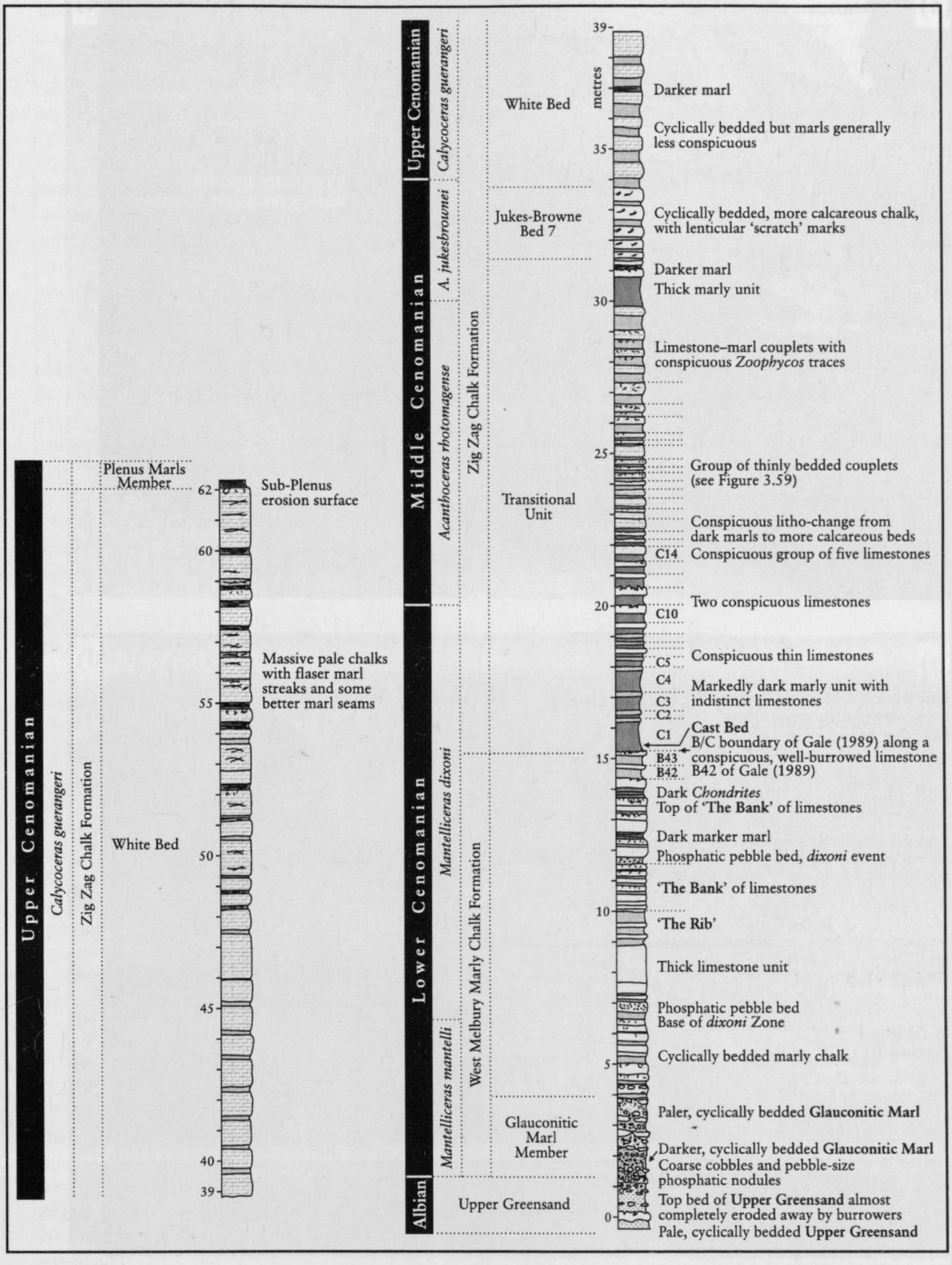
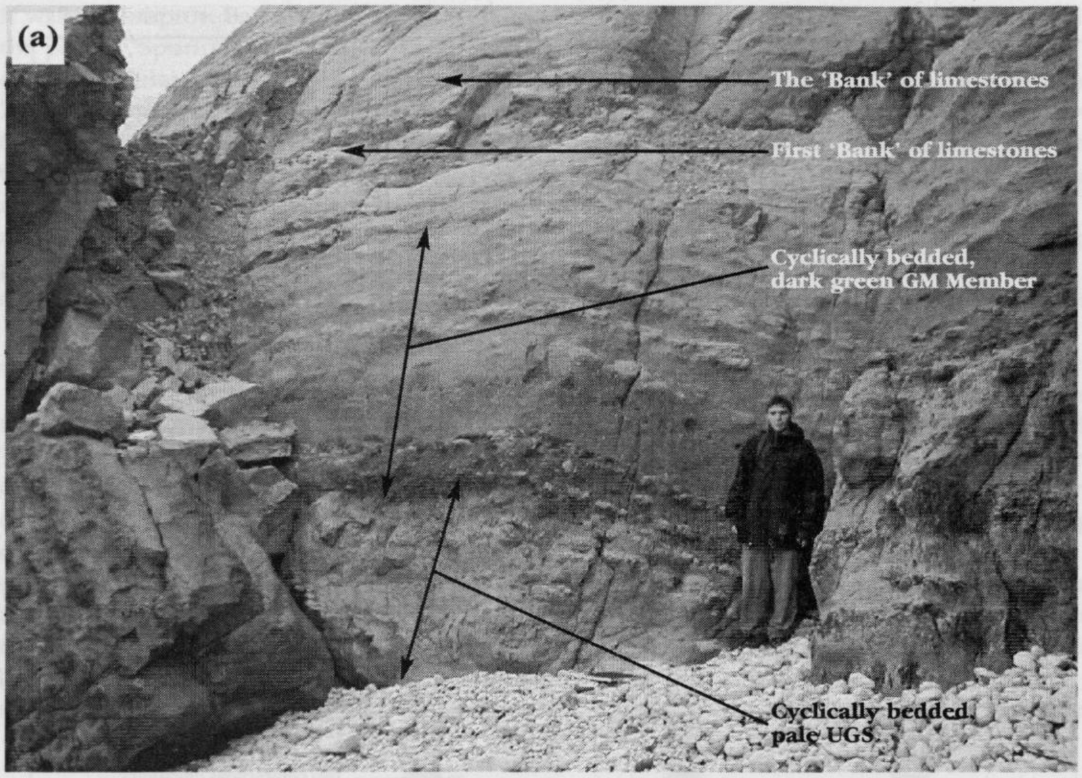


Figure 3.60 The Grey Chalk Subgroup succession, exposed at Compton Bay, Isle of Wight.



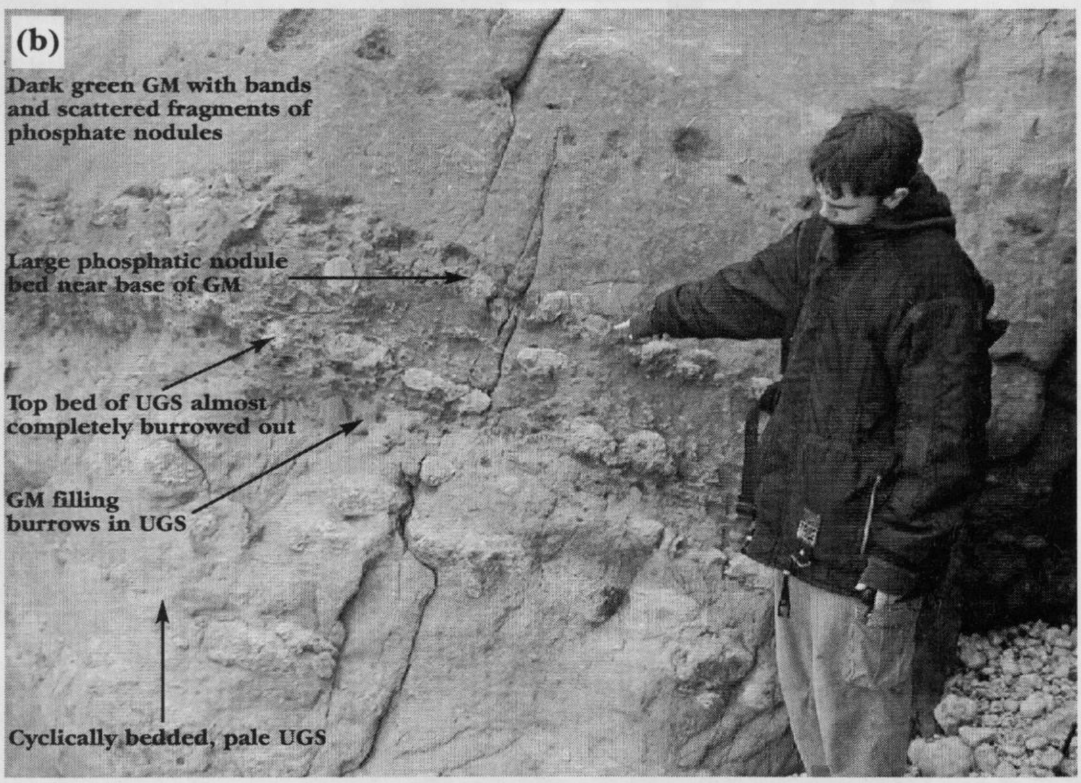


Figure 3.61 (a, b) The base of the Upper Cretaceous in Compton Bay, Isle of Wight, at the contact between the Albian Upper Greensand and the Cenomanian Glauconitic Marl. (Scale: Tom Mortimore = 1.8 m tall). (GM = Glauconitic Marl; UGS = Upper Greensand). (Photos: R.N. Mortimore.)

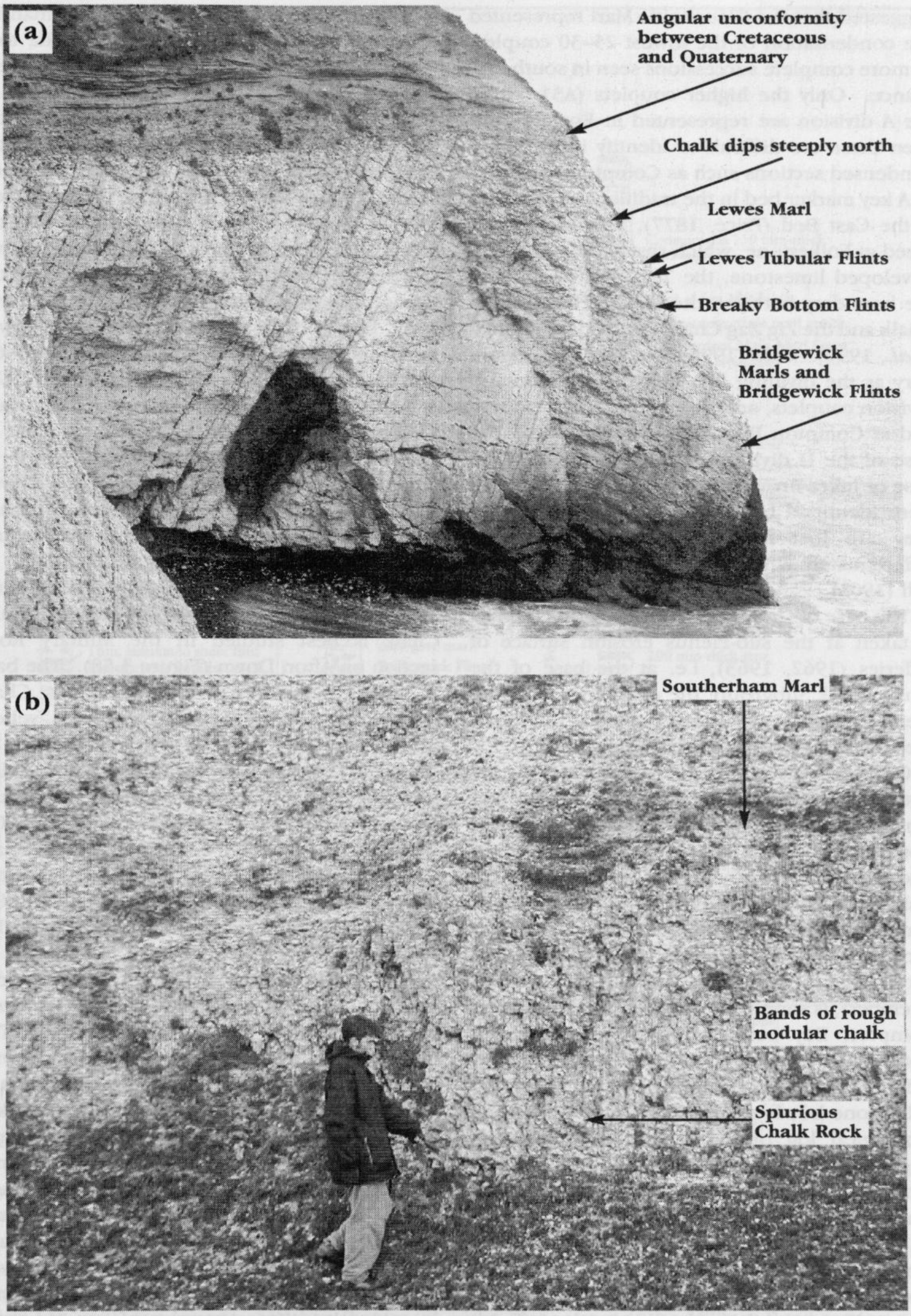


Figure 3.62 (a) Turonian–Coniacian Lewes Nodular Chalk Formation at the western end of the Compton Bay GCR site, adjacent to Freshwater Bay, Isle of Wight. (b) Base of the Lewes Nodular Chalk Formation in the Compton Down Military Road section in the Compton Bay GCR site, Isle of Wight. (Photos: R.N. Mortimore.)

suggested that the Glauconitic Marl represented the condensation of the lowest 25–30 couplets of more complete successions seen in south-east France. Only the higher couplets (A31–51) of the A division are represented in England, but even these are difficult to identify in the more condensed sections such as Compton Bay.

A key marker bed in the traditional Chalk Marl is the Cast Bed (Price, 1877), originally recognized at Folkestone, which rests here on a well-developed limestone, the Tenuis Limestone, at the boundary between the West Melbury Marly Chalk and the Zig Zag Chalk formations (Bristow *et al.*, 1997). Gale (1995) took this same boundary as the dividing line between his B and C division couplets, and this can be readily identified at Compton Bay (Gale, 1995, fig. 8). The base of the D division couplets is taken at the base of Jukes-Browne Bed 7. Up to 20 couplets were identified by Gale (1995, fig. 12) before they are lost in the lithologically poorly-differentiated White Bed of Jukes-Browne and Hill (1903).

The base of Gale's (1995) E Division couplets is taken at the sub-Plenus erosion surface of Jefferies (1962, 1963), i.e. at the base of the White Chalk Subgroup; the couplets of division E end in the Lower Turonian strata at the top of the Holywell Nodular Chalk Formation.

Gale's work is admirable in demonstrating the potential time frame for the Cenomanian and illustrating the gaps in successions, such as at Compton Bay. The broader division, however, into the West Melbury Marly Chalk and Zig Zag Chalk formations, divided at the Tenuis Limestone, and their subdivisions into units such as the Glauconitic Marl (Member), Jukes-Browne Bed 7, the White Bed and Plenus Marls (Member), is simpler to apply. The White Bed at Compton Bay contains numerous bands of wispy marls (Kennedy, 1969) and in this respect differs markedly from the correlative interval at Folkestone but is similar to Beachy Head. The lithological log of the Grey Chalk Subgroup (Figure 3.60), is a synthesis of previous observations, our own measurements and details kindly provided by Professor A.S. Gale.

White Chalk Subgroup

The basal unit of the White Chalk Subgroup, the Plenus Marls Member, was divided by Jefferies (1963, pp.14–15; and Figure 3.63) into his eight beds at Compton Bay. Above the Plenus Marls it is possible to scramble over most of the Holywell Nodular Chalk and New Pit Chalk formations on the steeply dipping cliff section. The total section is only *c.* 36–37 m thick, with the greatest loss of section apparently in the New Pit Chalk. Barrois (1875, 1876) recognized the hard, nodular Melbourn Rock lithology at the base of the Middle Chalk and the presence, some distance above, of layers of rich, shell-detrital chalks. This is comparable with the Sussex definition of the Melbourn Rock (Mortimore, 1986a), which was applied to the Compton Bay section (Mortimore and Pomerol, 1987, fig. 8). The Meads Marls are well developed above the Melbourn Rock (Figure 3.63; Mortimore and Pomerol, 1987; Gale, 1996) and the overlying part of the Holywell Nodular Chalk Formation contains many beds of abundant inoceramid bivalves (*Mytiloides*). In contrast, the New Pit Chalk Formation above, about 14 m thick, is more massive and smoother, and contains several conspicuous marl seams weathering out as grooves (Figure 3.63).

Lewes Nodular Chalk Formation and Seaford Chalk Formation: The Lewes Nodular Chalk is best studied in the Military Road section on Afton Down (Figure 3.58). The base is taken at the base of the Spurious Chalk Rock, the lower of the two green-coated, yellow nodular beds (Figure 3.63) recognized by Whitaker (1865c), Barrois (1875), Rowe (1908) and the [British] Geological Survey (Reid and Strahan, 1889; Jukes-Browne and Hill, 1904; White, 1921). This bed is presumed to correlate with the Ogbourne Hardground (at Ogbourne Maizey, Wiltshire; Bromley and Gale, 1982; Gale, 1996; see **Charnage Down Chalk Pit** GCR site report, and Figure 3.42). It is underlain by beds containing inoceramid bivalves, which are questionably *Inoceramus cuvieri* J. Sowerby, rather than *Mytiloides*. The overlying 'Black Marl' has been correlated with the Southerham Marl 1 (Mortimore, 1986a,b; Mortimore and Wood, 1986). The other key marker marl seams of the Upper Turonian framework (Figure 2.9, Chapter 2) have been identified here, including the Caburn, Bridgewick and Lewes marls (Figure 3.63). Features of the remainder of the Lewes Nodular Chalk include the conspicuous Lewes Tubular Flints and overlying Lewes Marl, which here is packed with crinoid debris (*Isocrinus granulosus* (Valette)), as well as *Micraster leskei* (Desmoulins); and the rough, nodular intraclast beds in the succession above. In the upper Lewes Nodular Chalk

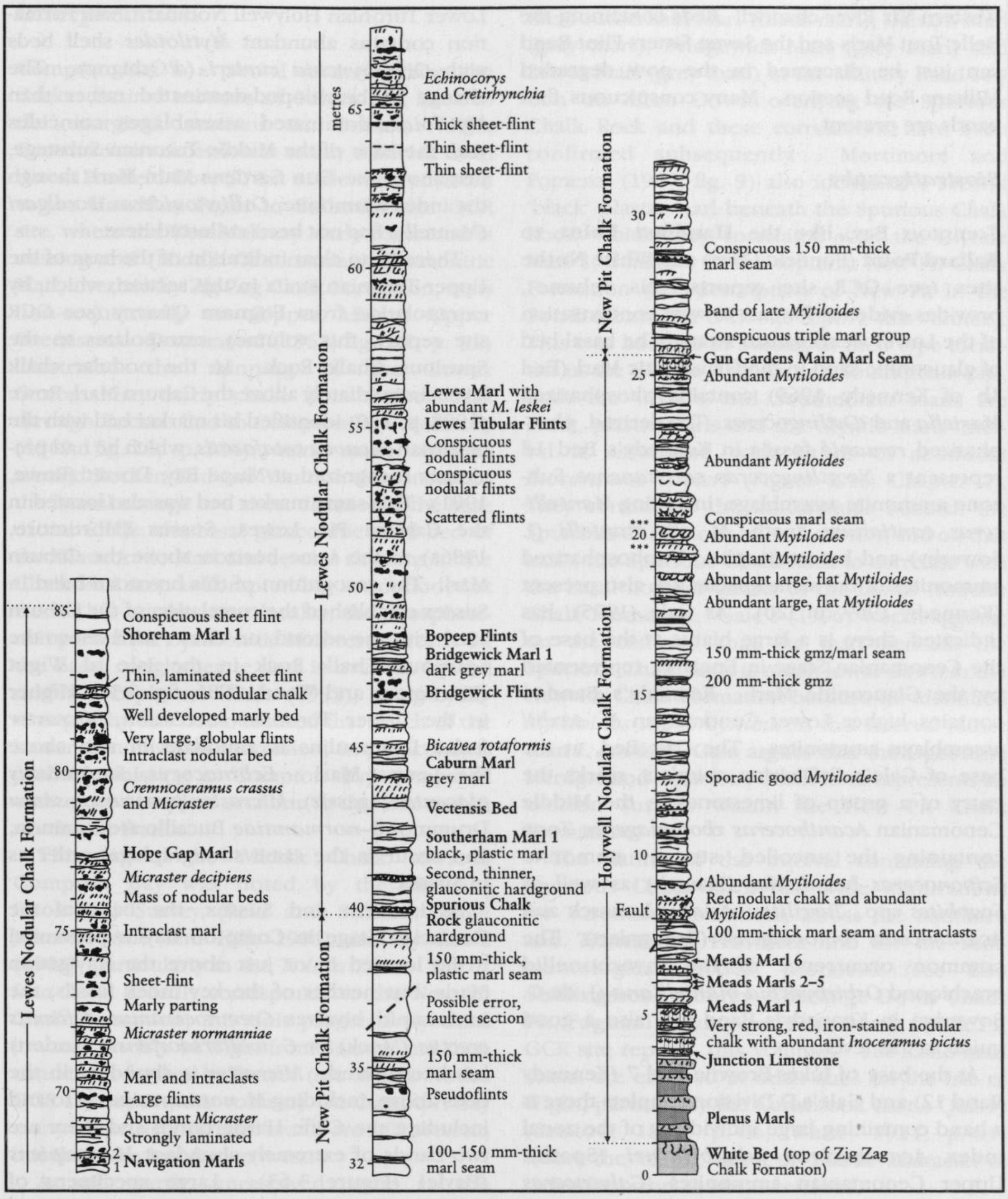


Figure 3.63 The lower part of the White Chalk Subgroup, exposed in Compton Bay and on the north side of Compton Down Military Road section, Isle of Wight. (gmz = griotte (or flaser) marl zone.)

(Figure 3.63), the Navigation and Shoreham marls are well developed. Another feature of these beds is the presence of numerous, well-developed sheet-flints closely following the bedding.

The Seaford Chalk Formation is exposed in the higher part of the Military Road section and is repeated on either side of Freshwater Bay, where it is highly disturbed by Quaternary weathering on the margins of the former

Western Yar River channel. Beds containing the Belle Tout Marls and the Seven Sisters Flint Band can just be discerned in the now degraded Military Road section. Many conspicuous flint bands are present.

Biostratigraphy

Compton Bay, like the **Handfast Point to Ballard Point** (Punfield Cove) and **White Nothe** sites (see GCR site reports, this volume), provides evidence for east to west condensation of the Lower Cenomanian strata. The basal bed of glauconitic sand in the Glauconitic Marl (Bed 1b of Kennedy, 1969) contains phosphatized *Mariella* and ?*Ostlingoceras*. The derived, phosphatized *remanié* fossils in Kennedy's Bed 1d represent a *Neostlingoceras carcitanense* Subzone ammonite assemblage, including *Mantelliceras cantianum* Spath, *M.* aff. *mantelli* (J. Sowerby) and heteromorphs. Unphosphatized ammonites of the same species are also present (Kennedy, 1969, p. 520). As Gale (1995), has indicated, there is a large hiatus at the base of the Cenomanian Stage in England, represented by the Glauconitic Marl. Kennedy's Band 4 contains higher Lower Cenomanian *M. saxbii* assemblage ammonites. The Cast Bed, at the base of Gale's C Division couplets, marks the entry of a group of limestones in the Middle Cenomanian *Acanthoceras rhotomagense* Zone containing the uncoiled, straight ammonite *Sciponoceras baculoides* (Mantell) as well as *Scaphites* spp., *Turrilites costatus* Lamarck and *Acanthoceras rhotomagense* (Brongniart). The common occurrence of the rhynchonellid brachiopod *Orbirhynchia mantelliana* (J. de C. Sowerby) in Kennedy's Band 3 is also a good guide to this level.

At the base of Jukes-Browne Bed 7 (Kennedy Band 12) and Gale's D Division couplets there is a band containing large individuals of the zonal index *Acanthoceras jukesbrownei* (Spath). Upper Cenomanian ammonites (*Calycoceras guerangeri* Zone) enter in couplet D14, low in the interval between the top of Jukes-Browne Bed 7 and the Plenus Marls Member.

In the Cenomanian–Turonian boundary transition the change in inoceramid bivalve assemblages from *Inoceramus pictus* J. de C. Sowerby and related forms, below Meads Marl 4, to *Mytiloides* spp. above the same marl, is conspicuous. Above this level, a standard Turonian biostratigraphical succession is present. The Lower Turonian Holywell Nodular Chalk Formation contains abundant *Mytiloides* shell beds with *Orbirhynchia cuvieri* (d'Orbigny). The change to brachiopod-dominated rather than *Mytiloides*-dominated assemblages coincides with the base of the Middle Turonian Substage, just above the Gun Gardens Main Marl, though the index ammonite, *Collignoniceras woollgari* (Mantell), has not been collected here.

There is no clear indication of the base of the Upper Turonian strata in this section, which, by extrapolation from **Fognam Quarry** (see GCR site report, this volume), extrapolates to the Spurious Chalk Rock. In the nodular chalk layers immediately above the Caburn Marl, Rowe (1908, p. 220) identified his marker bed with the bryozoan *Bicavea rotaformis,* which he had previously recognized at Mupe Bay, Dorset (Rowe, 1901). This same marker bed was also located in the Caburn Pit, Lewes, Sussex (Mortimore, 1986a) at the same horizon above the Caburn Marl. The recognition of this bryozoan band in Sussex established the correlation of the Caburn Marl with the second, or 'Grey', marl above the Spurious Chalk Rock in the Isle of Wight (Mortimore and Wood, 1986, fig. 2.3). Higher in the Upper Turonian succession, *Micraster leskei* Desmoulins is abundant in and above the Lewes Marl. *Echinocorys*, *Sternotaxis placenta* (Agassiz), *Micraster praecursor sensu* Drummond–*normanniae* Bucaille are common, and occur in the same stratigraphical order as in Sussex.

As in Kent and Sussex, the base of the Coniacian Stage in Compton Bay is presumed to be located in or just above the Navigation Marls, but neither of the key index fossils, the inoceramid bivalves *Cremnoceramus deformis erectus* (Meek) or *C. waltersdorfensis* (Andert) has been found. *Micraster* is abundant in the beds above, including *M. normanniae* up to and including the Cliffe Hardground, and there are two bands of extremely abundant *M. decipiens* (Bayle) (Figure 3.63). Large specimens of *Cremnoceramus crassus crassus* (Petrascheck) are common in the higher beds of the Lewes Nodular Chalk Formation (Figure 3.63).

The basal (Belle Tout) beds of the Seaford Chalk Formation (*Micraster coranguinum* Zone), in the highest sections in the Military Road section and in Freshwater Bay, contain abundant specimens of the inoceramid bivalve genera *Platyceramus* and *Volviceramus,* indicative of the Middle Coniacian Substage.

Interpretation

Compton Bay is a pivotal section linking the thicker basinal sections of Sussex and Kent to the marginal sections in Dorset. The Cenomanian succession is totally different from that at Punfield Cove 30 km to the west, adjacent to the **Handfast Point to Ballard Point** GCR site, where the West Melbury Marly Formation is missing and (Middle Cenomanian) Glauconitic Marl, overlain by Zig Zag Chalk Formation, rests non-sequentially on (Upper Albian) Upper Greensand. Drummond (1967, fig. 2-2, p. 32) illustrated the thinning of the Lower Cenomanian marly chalk from Culver Cliff through Rocken End to Compton Bay. Kennedy (1969, fig. 15, p. 524), using more sections around Rocken End and Ventnor, demonstrated the lateral change in a short distance at the base of the Chalk: the basal glauconitic sand bed of the Glauconitic Marl and several rhythms in the Chalk Marl seen at Compton Bay are occluded at Gore Cliff. At the latter locality, the phosphate-rich part of the Glauconitic Marl rests directly on the basal conglomerate and is overlain by the *saxbii* phosphates. Gale (1995), using cyclostratigraphy, has demonstrated that much of the Lower Cenomanian succession, in particular, is probably missing at Compton Bay, compared with more complete sections to the east and in south-east France.

Thinning of the 'Middle Chalk' towards Compton Bay was noted by the [British] Geological Survey (Reid and Strahan, 1889; Jukes-Browne and Hill, 1904) and by Rowe (1908), particularly in the *T. lata* Zone. The *T. lata* Zone broadly corresponds to the New Pit Chalk Formation; this unit progressively thins towards the Isle of Wight from Sussex, and then condenses further in Dorset (see **White Nothe** GCR site report, this volume). At Compton Bay many of the New Pit marl seams are still present, but these are lost farther west.

A still partly unresolved issue is the identification and correlation of the Middle and Upper Turonian marker marl seams in the New Pit and lower Lewes Nodular Chalk Formations at Compton Bay. This issue is crucial to dating the 'Spurious Chalk Rock' at its type locality, Compton Bay, which Gale (1996) correlated with the Ogbourne Hardground at the base of the Chalk Rock of the Wiltshire–Berkshire Downs (see above). Mortimore (1979, 1983, 1986a; Mortimore and Pomerol, 1987) identified the Southerham Marl (black marl), Caburn Marl (grey marl), Bridgewick Marl (grey marl) and Lewes Marl (grey marl) in the Military Road section on Afton Down overlying the Spurious Chalk Rock and these correlations have been confirmed subsequently. Mortimore and Pomerol (1987, fig. 9) also identified a second 'black' plastic marl beneath the Spurious Chalk Rock, which they correlated with the Glynde Marl 1, a marker in the topmost New Pit Chalk Formation (see description of New Pit in the **Southerham Pit** GCR site report, this volume). This was because in Sussex, at their type localities in the Glynde, Caburn and Southerham pits, both the Glynde and Southerham marls are black, plastic marls and the Glynde Marls interval is associated with bands of abundant *Inoceramus cuvieri* (Figure 2.16, Chapter 2). They considered the inoceramids beneath the Spurious Chalk Rock to be *I. cuvieri*, and on that basis, the Spurious Chalk Rock to correlate with the basal nodular chalks of the Lewes Nodular Chalk Formation. Gale's (1996) work suggests, on the contrary, that the marl beneath the Spurious Chalk Rock is much lower down in the New Pit Chalk Formation because he identified *Mytiloides subhercynicus* in this interval rather than *I. cuvieri*. Gale argues that the Ogbourne Hardground–Spurious Chalk Rock represents an erosion surface within the New Pit Chalk Formation.

The dating of the interval containing the Spurious Chalk Rock has wide implications for Turonian correlations across the Southern and Transitional Provinces and for the sedimentological models proposed (see also **Shillingstone Quarry**, **Charnage Down Chalk Pit**, **Fognam Quarry** and **Kensworth Chalk Pit** GCR site reports, this volume). The same marl seams are exposed at other sites on the Isle of Wight, particularly the Carisbrook Castle Quarry (Bristow, 1889, p. 86; White, 1921, p. 64) where the 'black', 'grey' or 'plastic' character of individual marl seams is retained.

Conclusions

Compton Bay provides an excellent section in the Grey Chalk Subgroup and in the lower part of the White Chalk Subgroup at a key point in the palaeogeography of the Chalk sea, between the main basin in Sussex and Kent, and the south-western margin in Dorset and Devon. Most of the major marker beds used in the correlation framework can still be identified here. Compton Bay forms part of a key network of sections used to establish a cyclostratigraphy and timescale for the Middle Cenomanian strata. It is also at Compton Bay where the phrase 'Spurious Chalk Rock' was first used and the Upper Turonian section here is vital for the interpretation of the stratigraphy and for correlating the basal hardgrounds of the Chalk Rock.

WHITECLIFF, ISLE OF WIGHT (SZ 638 854–SZ 639 858)

Introduction

Whitecliff, Isle of Wight, is an extraordinary site, forming a continuous north–south dip section exposing some 300 m of Chalk from the Upper Turonian Substage at 'The Nostrils' at the southern end, to the Upper Campanian Substage beneath the Palaeogene unconformity at the northern end (Figures 3.12 and 3.64). It is one of the few dip sections in the Chalk of England. The GCR site is complemented by the excellent Cenomanian and Lower Turonian sections on Culver Cliff in Sandown Bay, to the west. The Chalk dips steeply north at 70° and each bed is exposed in turn over a relatively short distance. The only access to the section is from Whitecliff Bay or by boat.

Description

The Whitecliff section falls completely within Barrois' 'Craie Blanche' (White Chalk), which he subdivided into four macrofossil assemblage zones (Barrois, 1875). In Reid and Strahan's (1889) account of the geology of the Isle of Wight, the Whitecliff section is, surprisingly, not mentioned. This omission contrasts with the measured section given for the Lower and Middle Chalk in the adjacent Culver Cliff. Jukes-Browne and Hill (1904, p. 93) made only one reference to the Whitecliff section (calling it 'Culver Cliff'). They recorded an observation made by Whitaker (1865c) on the so-called 'flintless belt' with its single tabular (sheet-) flint band and four green-coated nodular beds, from which Whitaker obtained the echinoid *Offaster pilula* (Lamarck).

It was left to Rowe (1908) to provide the first full account of this wonderful section. He divided the exposures into three; the 'Southern cliff', 'Eastern cliff' and, on the northern side, his 'White Cliff proper'. However, due to the numerous cliff falls and the seaweed and algal slime-coated faces, he found measuring the section and the collection of fossils particularly difficult. Nevertheless, he recognized the zonal divisions and was the first to record the *Uintacrinus socialis* and *Marsupites testudinarius* zones here.

Later researchers have concentrated on particular parts of the stratigraphy. Mortimore (1979, 1986a,b) used the section above Whitaker's 'Flintless Belt' as the standard for his Culver Chalk Formation (originally the 'Culver Chalk Member'). This formation is now divided into the Tarrant and Spetisbury Chalk members (Bristow *et al.*, 1997; Rawson *et al.*, 2001). Mortimore also used this section as a standard for the boundary between his Culver and Portsdown Chalk members. The Flintless Belt, named the 'Whitecliff Member' by Gale *et al.* (1988), was illustrated in detail by Mortimore and Pomerol (1997, fig. 9) as part of their study of tectonic influences on Chalk sedimentation. A detailed log of the section from the Flintless Belt up to the top of the Chalk was provided by Gale (in Jenkyns *et al.*, 1994, fig. 15).

Key features in the lower part of this huge section (Figures 3.12 and 3.64) include the Lewes Tubular Flints and Lewes Marl at the base, a condensed upper Lewes Nodular Chalk Formation with well-developed Cliffe and Hope Gap hardgrounds, and spectacular potstone flints at the level of the Seven Sisters Flint Band.

In the centre of the section there is a bluff of harder, almost flintless chalk in the Lower Campanian Newhaven Chalk Formation, the so-called 'Flintless Belt' (Figures 3.12 and 3.65, Figures 3.69 and 3.70, pp. 192–3), which includes several major hardgrounds and palaeoseismic horizons (Figures 3.69 and 3.71, pp. 192, 194). Towards the top of the Lower Campanian Culver Chalk Formation there are conspicuous bands of giant paramoudra flints and a range of sedimentary structures, including splitting and anastomosing flint bands.

A second bluff at the northern end of the section is created by the Portsdown Chalk Formation with numerous marl seams, the marls forming grooves in the cliff. Within the Portsdown Chalk there are special marker beds, including the Isle of Wight Tubular Flints (Figure 3.74, p. 197), bands of abundant inoceramid bivalves and distinctive forms of the echinoid *Echinocorys*.

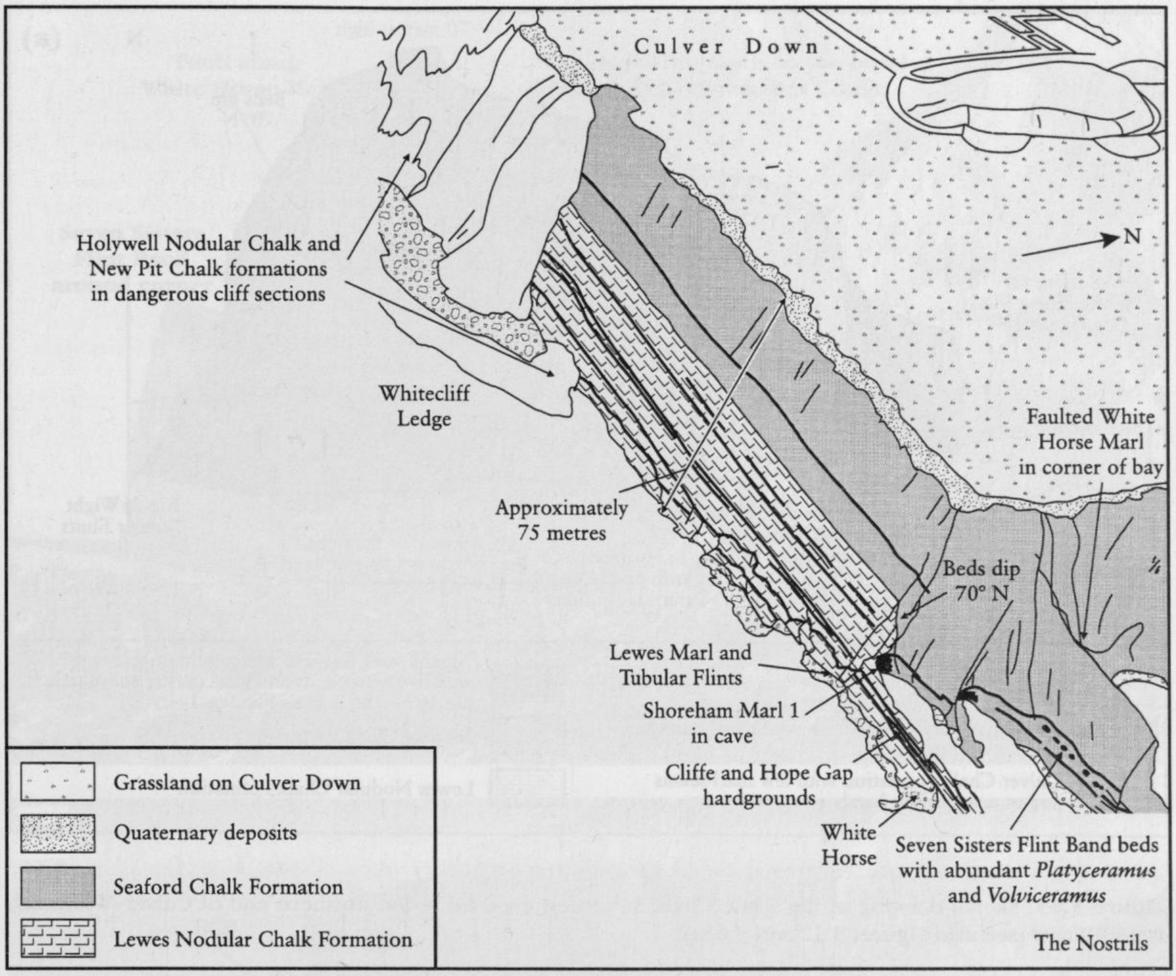


Figure 3.64 The southern end of the Whitecliff GCR site at Culver, Isle of Wight.

Lithostratigraphy

The base of the Lewes Nodular Chalk Formation is found on the cliffs between Whitecliff Ledge and The Nostrils (Figure 3.64). Rowe (1908) found the Spurious Chalk Rock *in situ* and in fallen blocks along this section, overlain by the first grey marl (Southerham Marl 1). Rowe also found his *Bicavea rotaformis* band above the second grey marl (Caburn Marl). The section on the southern side of The Nostrils begins with beds beneath the Lewes Marl and the Lewes Tubular Flints. Above the Lewes Marl, the upper Lewes Nodular Chalk Formation contains the conspicuous Cuilfail Zoophycos Bed and the Navigation Hardgrounds and Navigation Marls. In the succeeding exposure there are two conspicuous hardgrounds, the strongly phosphatic Cliffe Hardground and the green, glauconitic Hope Gap Hardground. In comparison with **Compton Bay** (see GCR site report, this volume) and most mainland sections, the upper part of the Lewes Nodular Chalk is extremely attenuated (6–7 m from the Hope Gap Hardground to the Shoreham Marl), with many laminated chalk horizons and intraclast beds. The overlying basal Seaford Chalk Formation is expanded, with the first Belle Tout Marl being some 13 m above the Shoreham Marl. The typical inoceramid bivalve shell-bands (*Platyceramus* and *Volviceramus*) are strongly developed, continuing up to the Seven Sisters Flint Band (25 m above the Shoreham Marl), which has huge round potstones associated with it. These beds are on the north side of the cave controlled by the fault that runs along the Shoreham Marl.

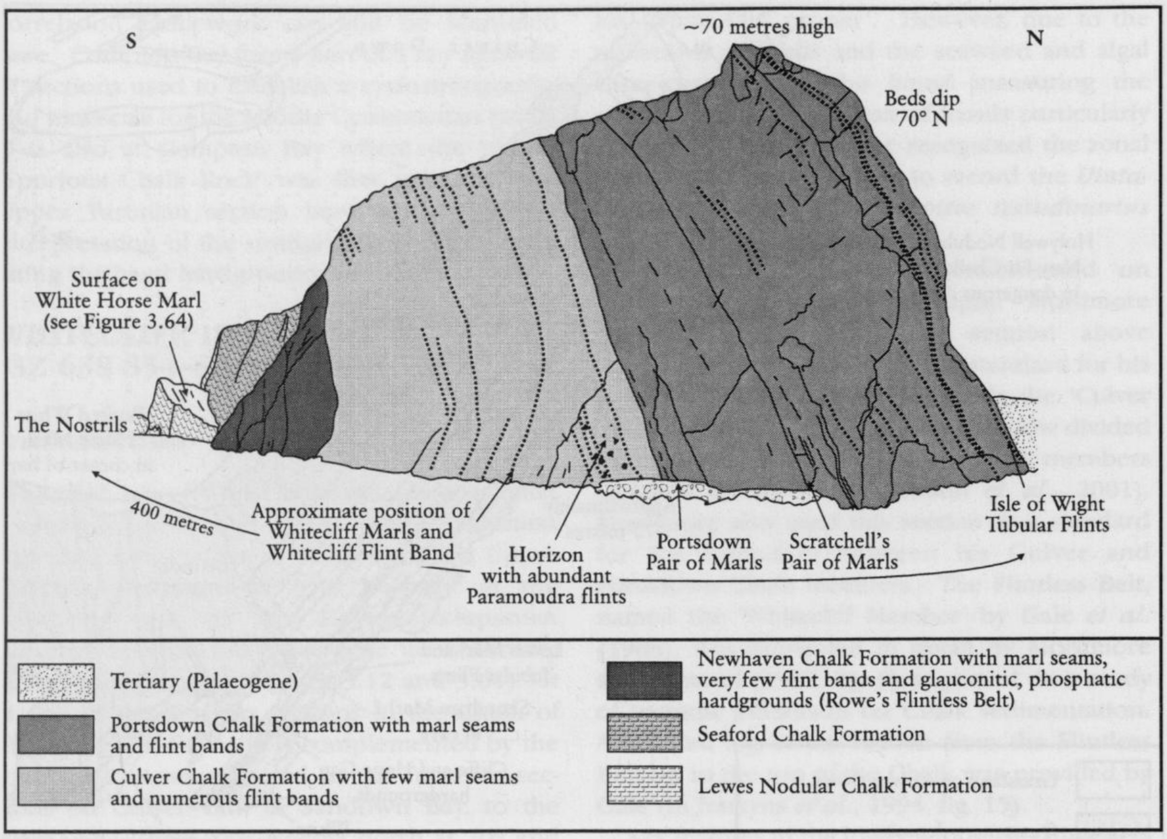


Figure 3.65 Sketch drawing of the White Chalk Subgroup exposed at the northern end of Culver–Whitecliff, Isle of Wight (see also Figures 3.12 and 3.66a).

On the far side of this headland there is a small bay that extends up to the bluffs formed by the Flintless Belt. In the southern corner of this bay there is a second fault on a marl seam, the White Horse Marl (new name herein), which is in the 'Barren Beds' of the Seaford Chalk Formation (Figures 3.66 and 3.67). Midway along this bay are seen the flint bands associated with occurrences of the inoceramid bivalve zonal index fossil, *Cladoceramus undulatoplicatus* (Roemer), at the base of the Santonian Stage. The next obvious lithological features are two well-developed nodular chalk beds, 1.8 m apart, the upper one with a glauconitized surface containing, and overlain by, glauconite-coated intraclasts (Figure 3.68). Marl seams enter above the top hardground but first become common 11 m higher, at about the entry of the zonal index crinoid, *Uintacrinus socialis* Grinnell. The marls are strongly stylolitic throughout the interval leading up to the Flintless Belt, in what is presumed to be the lower part of the Newhaven Chalk Formation (Figure 3.68).

The Flintless Belt is not entirely flintless since it contains several bands of small finger-flints as well as sheet-flints (Figures 3.69 and 3.70). The interval is also full of marl seams and there are six conspicuous green, glauconitized hardgrounds. There is an extensive burrow network beneath hardground 3. Within this flintless unit there are several examples of slump beds and seismically disrupted beds (Figure 3.71). Telscombe Marl 1 also contains rounded gravel-sized clasts of chalk. The beds above the last conspicuous slump bed contain abundant *Zoophycos*, both as grey streaks and replaced by flint (Portobello Zoophycos Beds), as well as well-developed marl seams. The change from the Newhaven Chalk Formation to the Culver Chalk Formation lithology is conspicuous (Figures 3.69 and 3.72), and is marked by the change in the cliff-line, which weathers back faster in the Culver Chalk (Figure 3.13).

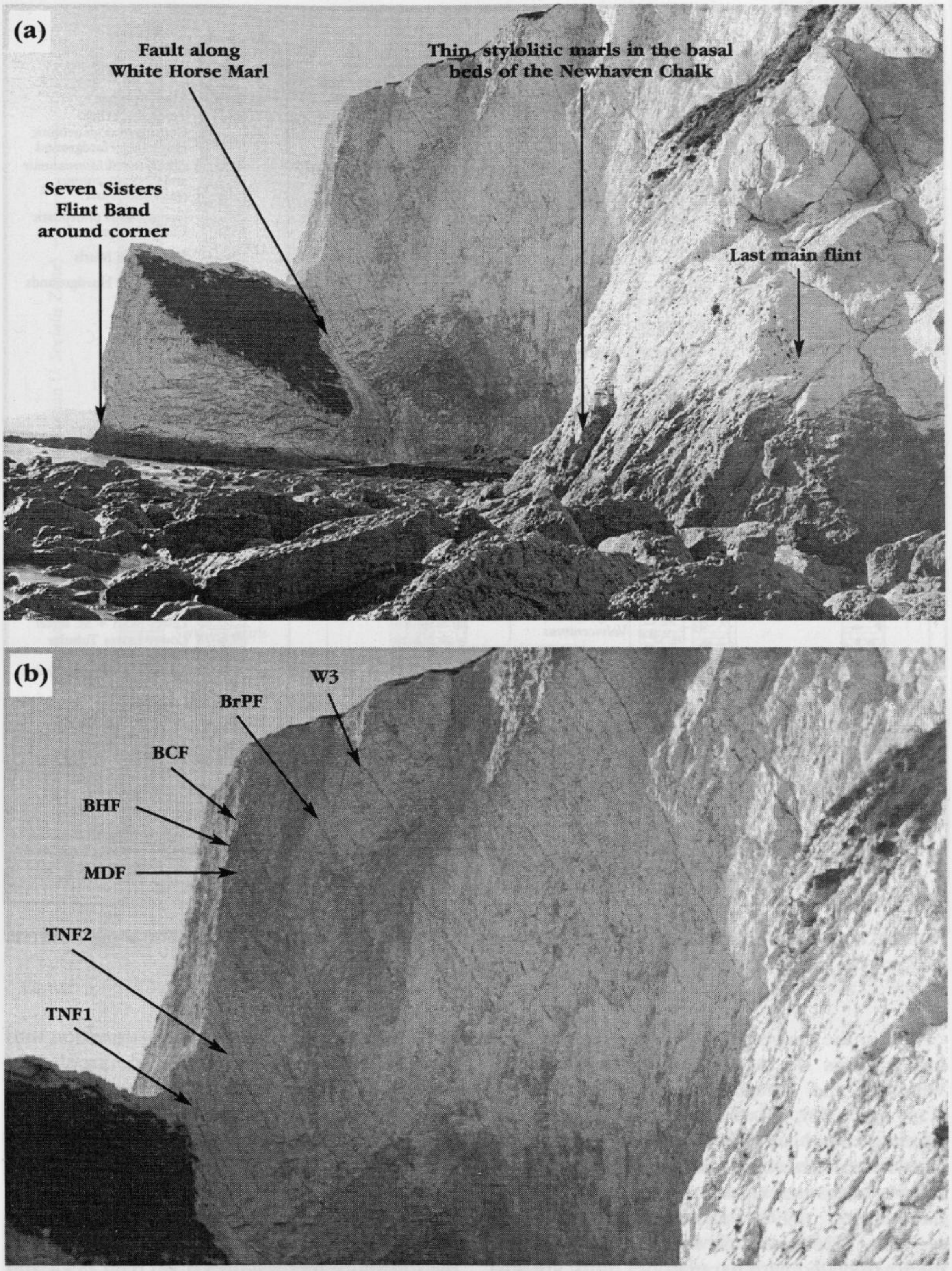


Figure 3.66 The Seaford Chalk Formation at Whitecliff, Isle of Wight. (a) Seaford Chalk Formation and Basal Newhaven Chalk Formation. (b) Close-up of the Seaford Chalk Formation seen in centre of (a). (BCF=Bedwell's Columnar Flint; BHF=Baily's Hill Flint; BrPF=Brasspoint Flint; MDF=Michel Dean Flint; TNF1, TNF2=Tarring Neville Flints 1 and 2; W3=Whitakers's 3-inch Flint Band). (Photos: R.N. Mortimore.)

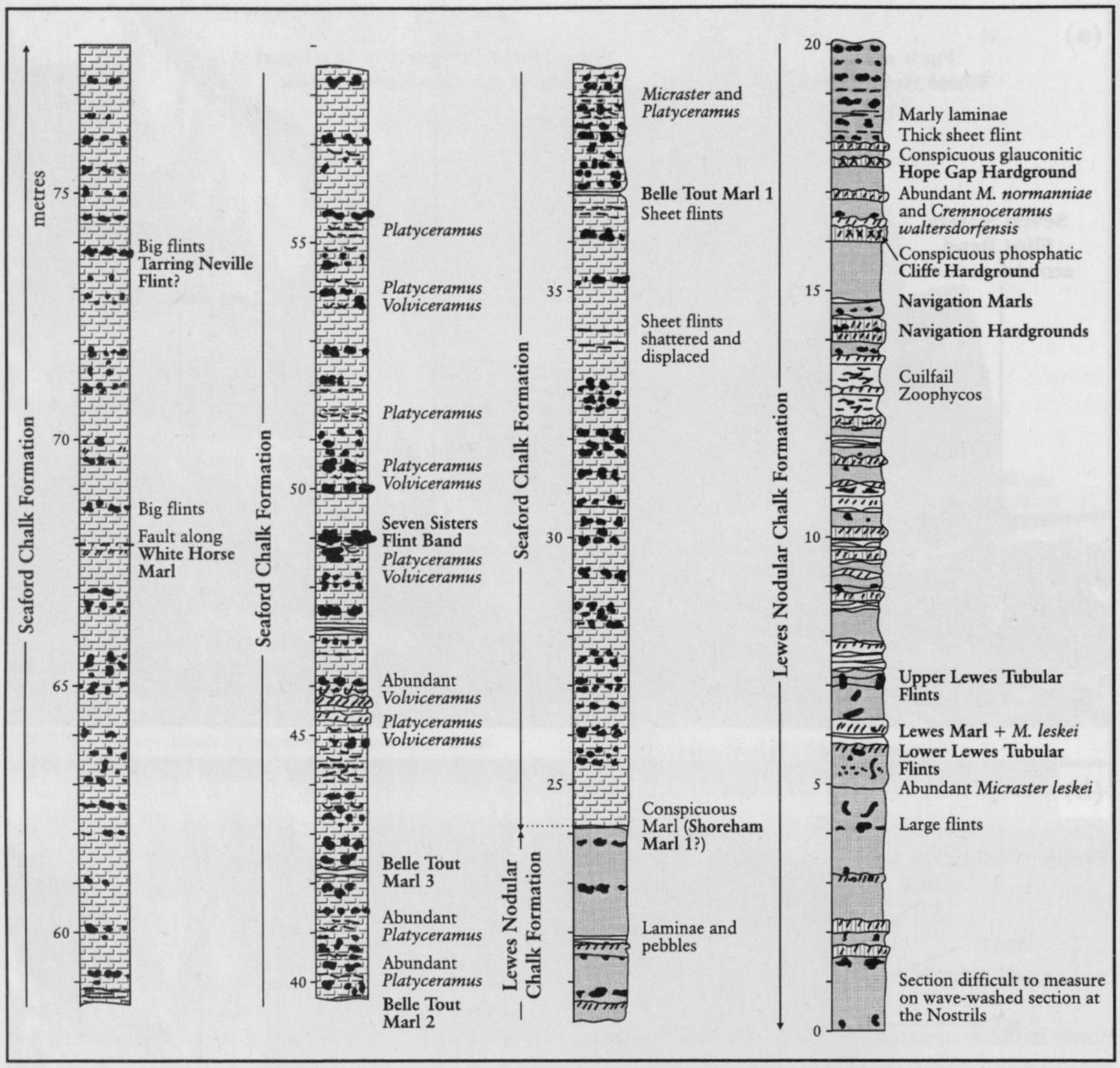


Figure 3.67 The lowest sections exposed at The Nostrils and 'White Horse' at the southern end of the Whitecliff GCR section.

Within the Culver Chalk Formation there are four groups of marls, the Lancing, Solent, Whitecliff and Yaverland marls (Figures 3.13, 3.14 and 3.72), of which the Solent Marl and Yaverland Marl are new names, not published elsewhere. These have been traced to boreholes across Langston Harbour on the mainland (Mortimore, 1998, unpublished industrial reports). Conspicuous flint bands, many of them associated with paramoudra flints, are also a feature here. Some flints show a range of unusual characters, such as a seam splitting into two or more bands, as well as highly disturbed horizons associated with low-angle sheet-flints. The division of the Culver Chalk Formation into a lower Tarrant Member and an upper Spetisbury Member is presumed to occur at the wispy Whitecliff Marls. Above these marls, paramoudra flints are more persistent and include the spectacular Warren Farm Paramoudra Flints (Figure 3.15).

The Portsdown Chalk Formation, with many marl seams, forms the next bluff in the cliff and the foreshore reef (Figures 3.12, 3.65, 3.72 and 3.73). The marl seams weather out as grooves in the cliff. The first marls do not contain abundant inoceramid bivalve shell debris, but the Bedhampton and Farlington marls are packed

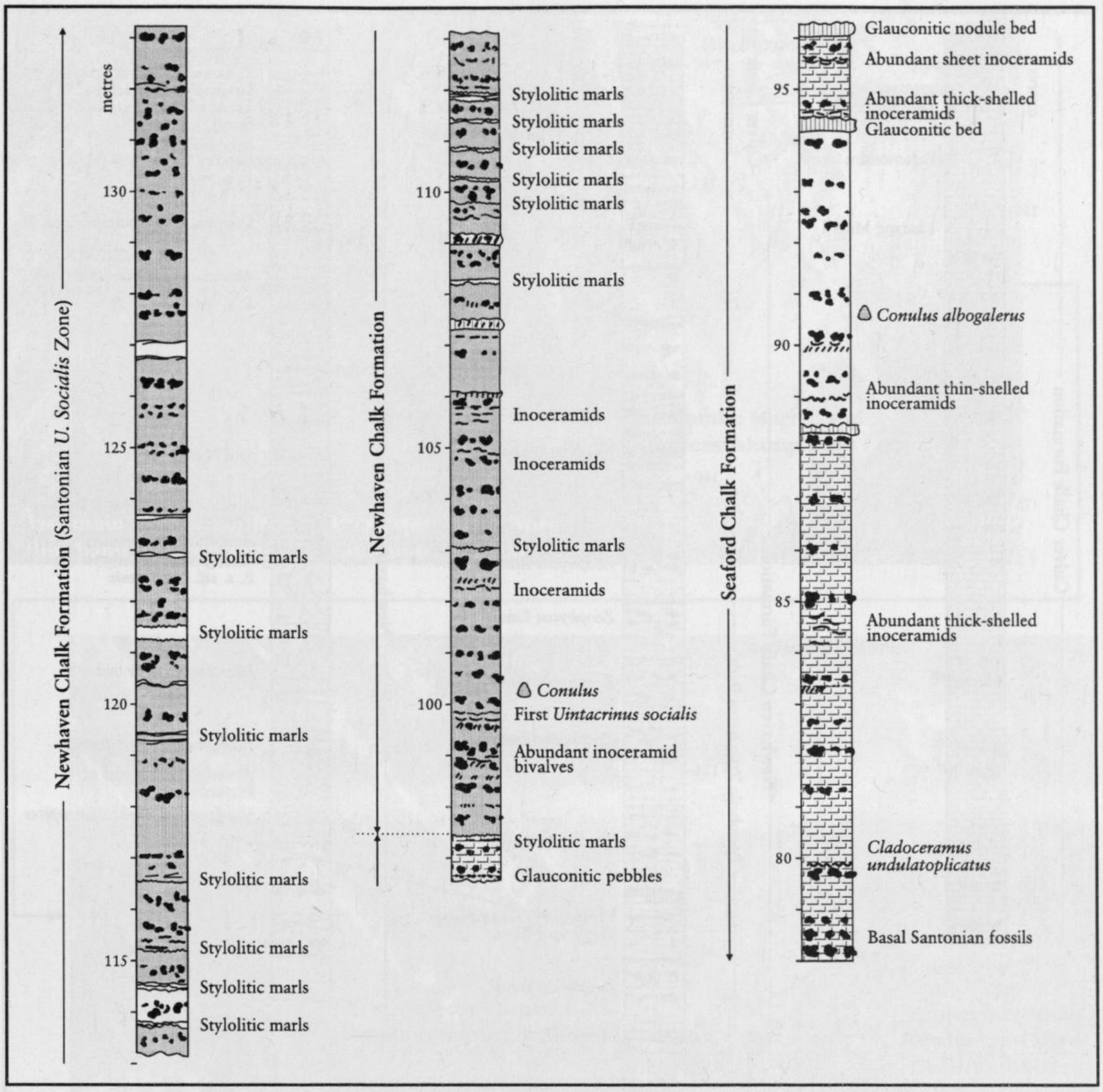


Figure 3.68 The top Seaford and basal Newhaven Chalk (Santonian) formations at Whitecliff, Isle of Wight.

with inoceramid bivalves, which are commonly well preserved. A highly disturbed (slumped?) group of flints is present between the Farlington and Shide marls. A key marker bed at the point where the cliff-line changes direction from north–south to east–west is a band of tubular flints, the Isle of Wight Tubular Flints (Figure 3.74). Ten metres below the Palaeogene erosion surface is seen the last conspicuous marker flint, the Yarbridge Flint. The marl seams above this flint are faint, wispy and stylolitic (Figure 3.73). Both of these two flint marker horizons are new names, not published elsewhere.

Biostratigraphy

As Rowe (1908) realized, collecting well-preserved fossils is difficult in this section. Despite this, all of the key marker inoceramid bivalves and shape changes in *Echinocorys* have either been collected or observed in place. Combined with the details given in Rowe (1908), a fairly complete picture of the biostratigraphy can be constructed.

The terminal Turonian–basal Coniacian inoceramid bivalve *Cremnoceramus waltersdorfensis* (Andert), associated with *Micraster*

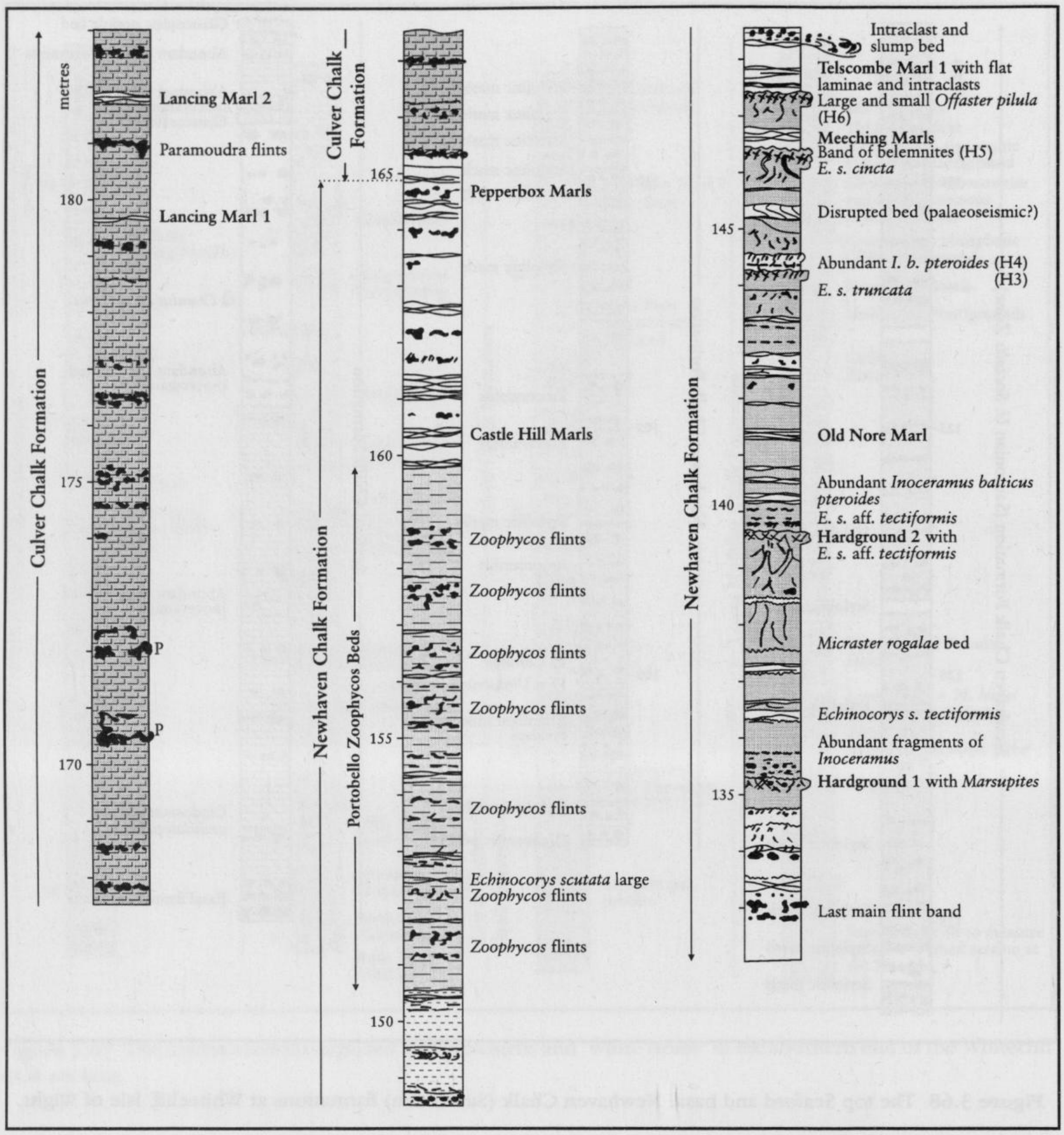


Figure 3.69 The succession including the so-called 'Flintless Belt' of Rowe (1908) in the middle of the Whitecliff GCR section, Isle of Wight. (P = paramoudra flints.) (From Mortimore and Pomerol, 1997.)

normanniae Bucaille are abundant in the beds below and in the Cliffe Hardground. The highly reduced section between the Hope Gap Hardground and the Shoreham Marl has not provided definite evidence of *C. crassus crassus* (Petrascheck), which occurs elsewhere in this interval. The beds immediately above the Shoreham Marl have also not yielded any diagnostic fossils. The presumed correlatives of the Belle Tout Marls and Seven Sisters Flint Band contain layers with abundant *Platyceramus* and *Volviceramus*. The overlying 'Barren Beds', up to the basal Santonian *Cladoceramus undulatoplicatus* beds, are, as their name implies, devoid of obvious macrofossils.

The higher Santonian fauna is more abundant, comprising many inoceramid shell debris beds and bands of the conical echinoid *Conulus*

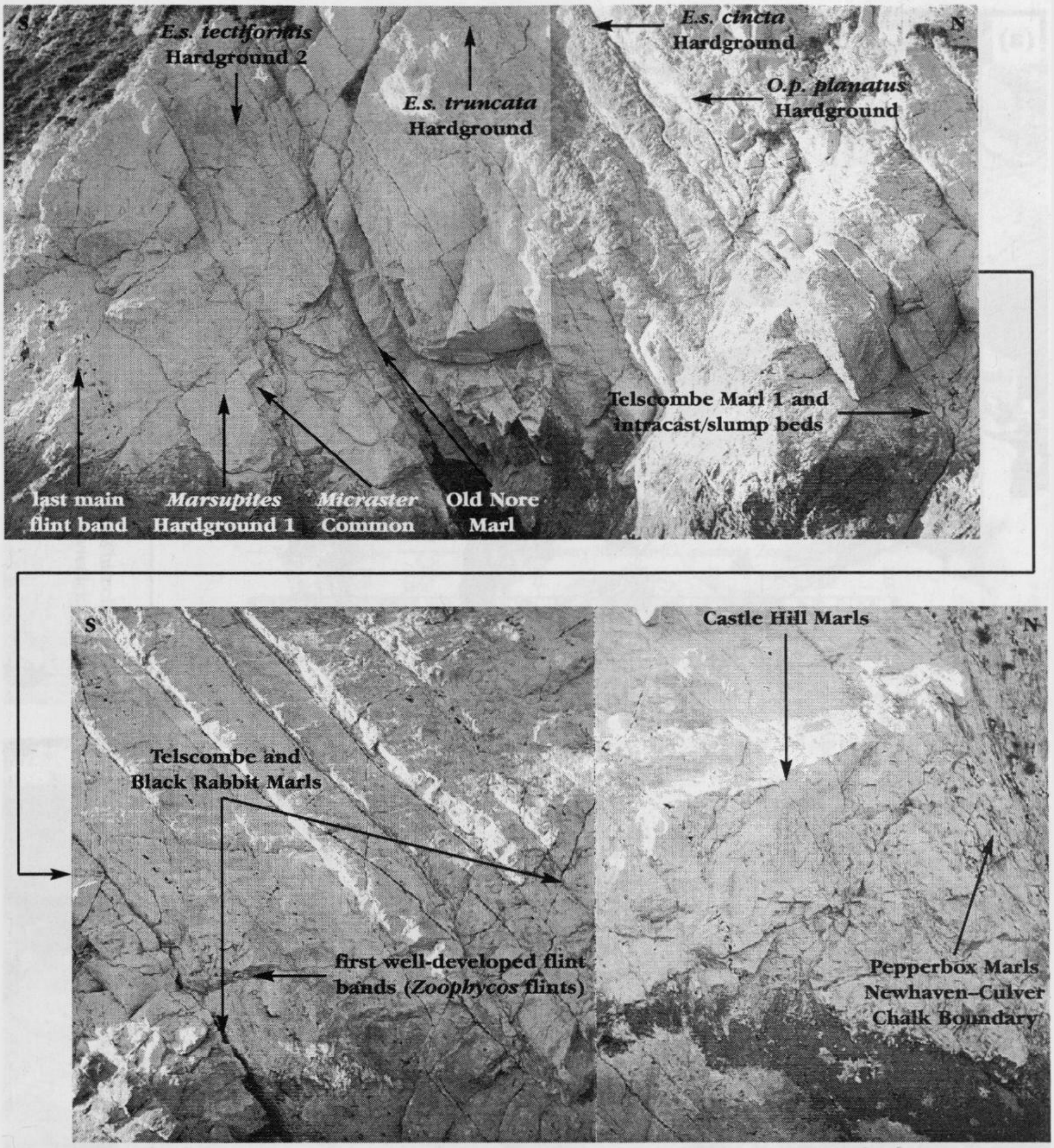


Figure 3.70 The 'Flintless-Chalk' unit with hardgrounds within the Newhaven Chalk Formation at Whitecliff. (Photomosaic: R.N. Mortimore.)

albogalerus Leske, as well as a rich mesofauna of crinoid (*Bourgueticrinus*) and asteroid ossicles. The lowest *Uintacrinus socialis* specimen so far located is associated with the beds with many stylolitic marl seams, but the exact base of its zone remains to be determined. Similarly, the base of the *Marsupites* Zone is only provisionally located, but the upper limit of the zonal index fossil at the top of the first hardground within the base of the Flintless Belt is supported by Rowe's (1908, p. 244) observations.

Within the Flintless Belt, fossils are fairly common, and the typical forms of *Echinocorys* in the Lower Campanian *Offaster pilula* and *Gonioteuthis quadrata* zones (see **Newhaven to Brighton** GCR site report, this volume)

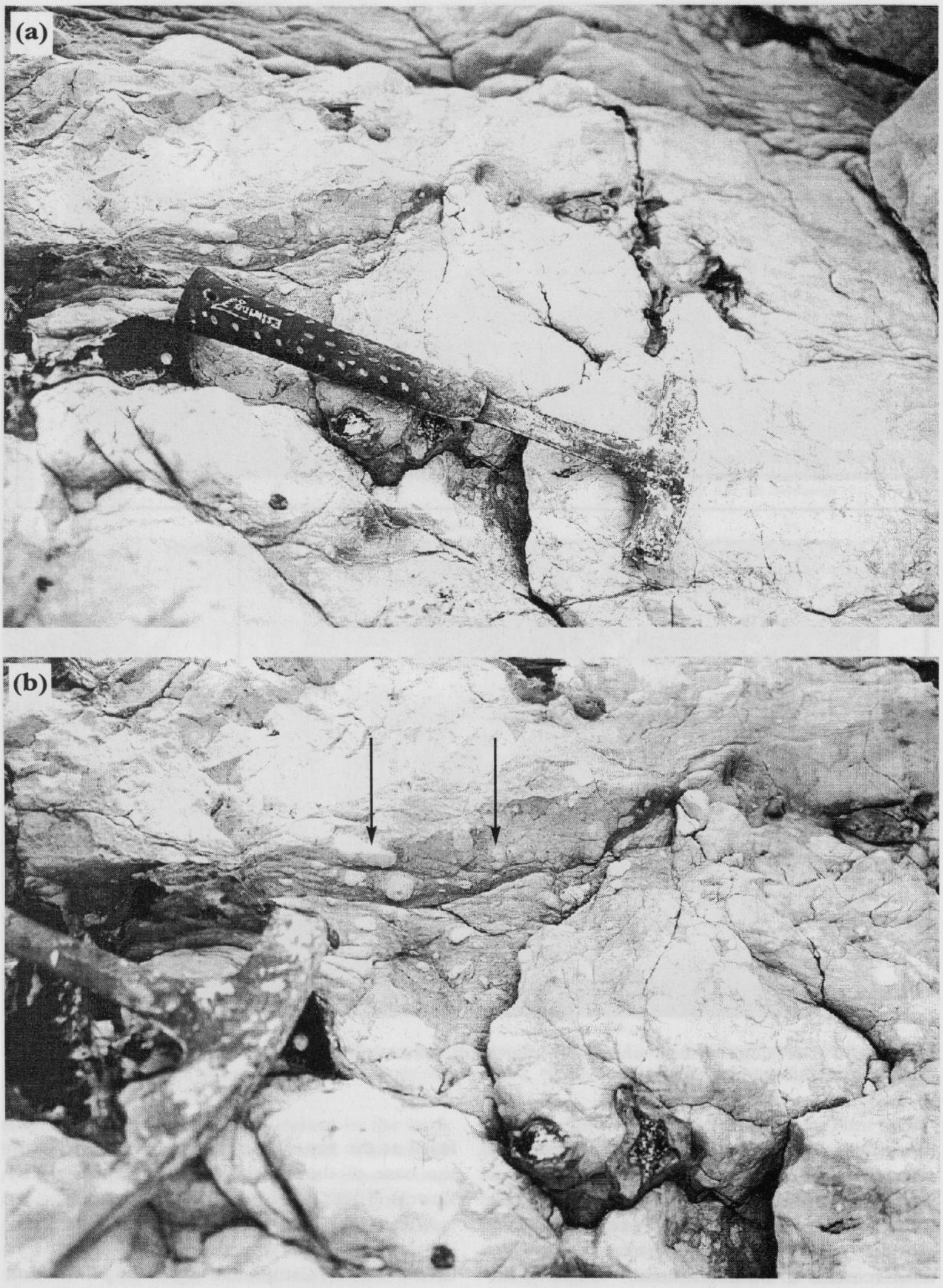


Figure 3.71 (a, b) Intraclasts, mobilized flints and block sliding incorporating the Telscombe Marl 1, the Culver section. Intraclasts in the Telscombe Marl in (b) are arrowed. (Photos: R.N. Mortimore).

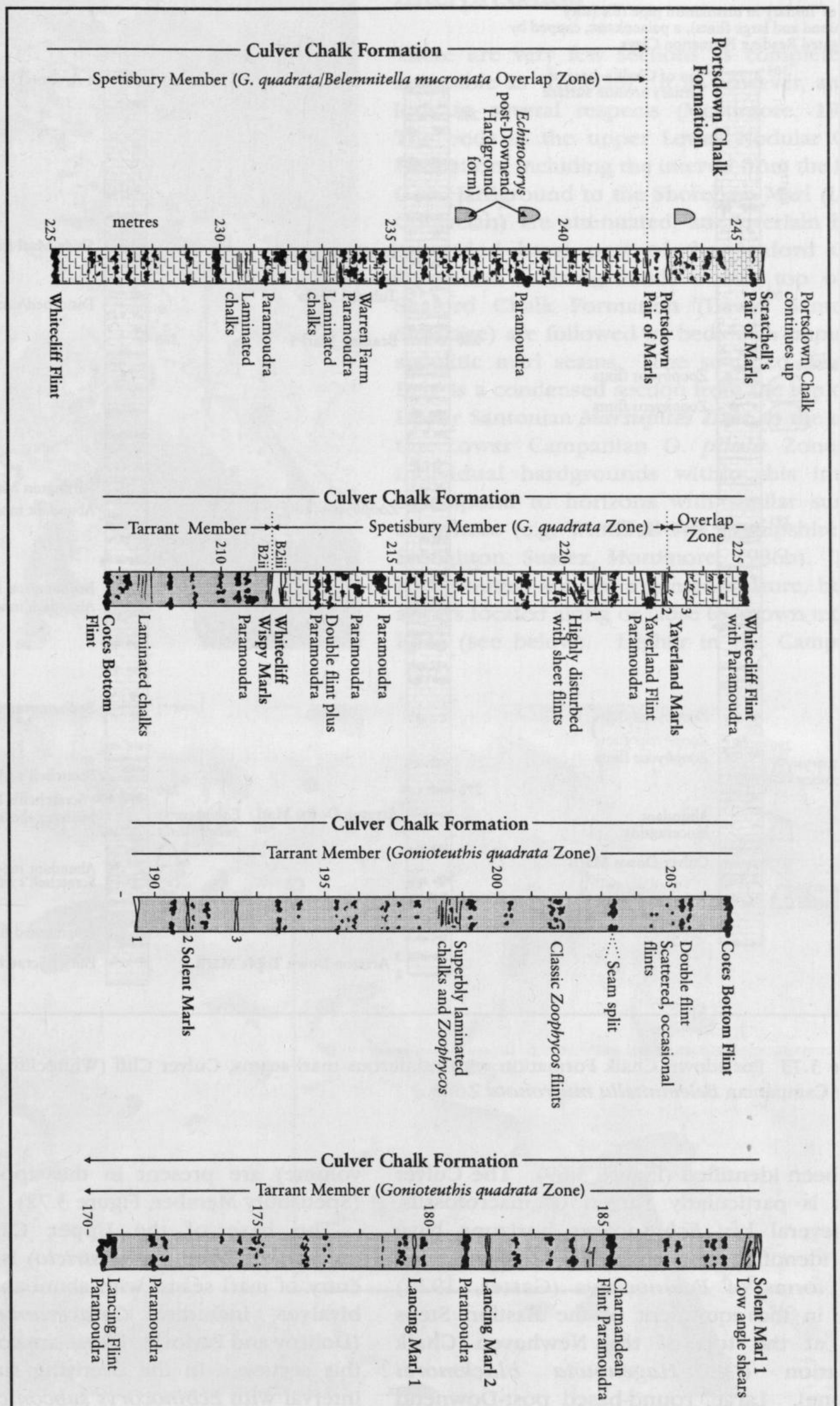


Figure 3.72 The Culver Chalk Formation, Culver Cliff (Whitecliff GCR site), Isle of Wight. Lower Campanian *Gonioteuthis quadrata* Zone. (B2ii and B2iii refer to the benthic foraminiferal zonal/subzonal scheme of Swiecicki (1980).)

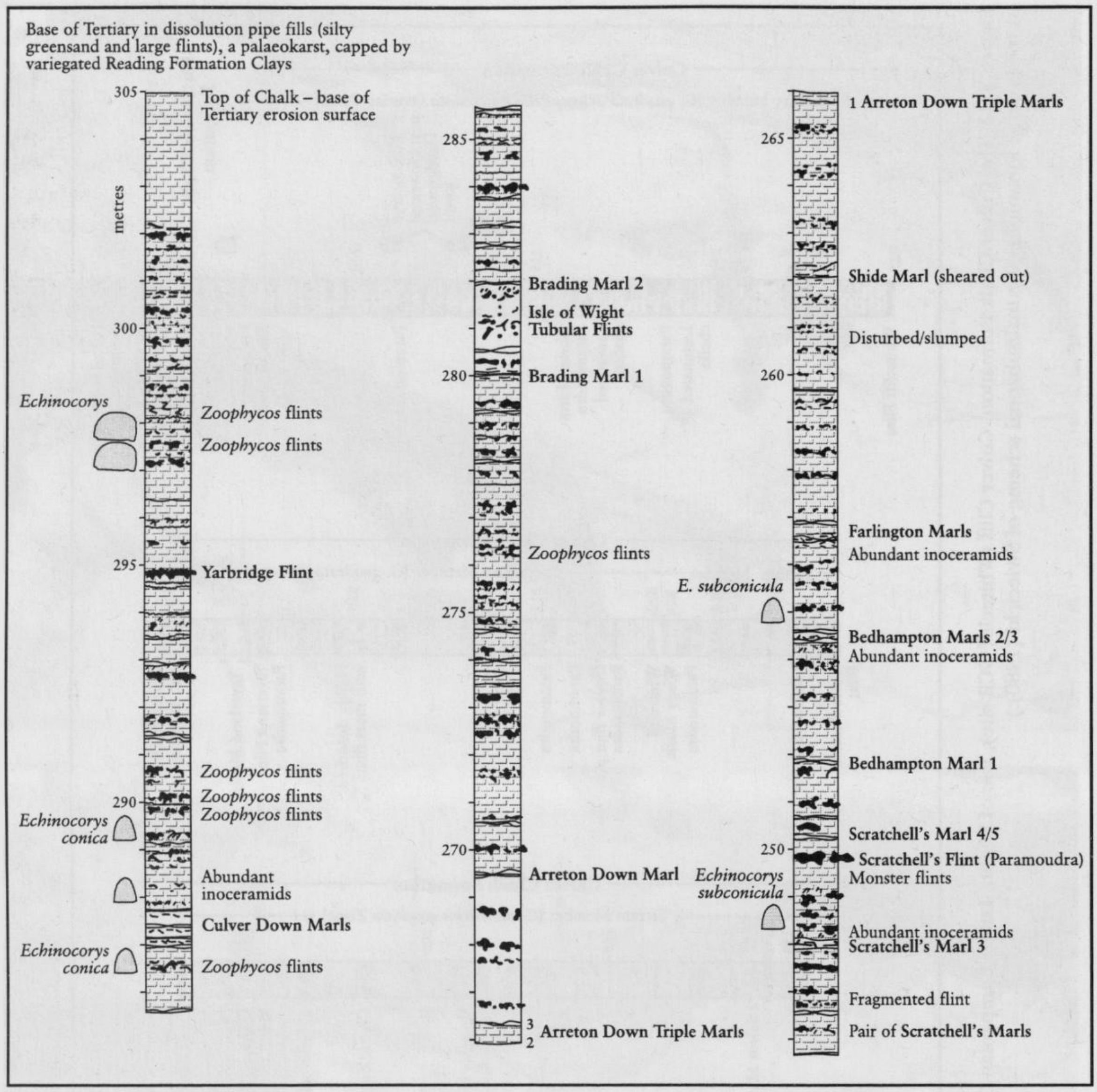
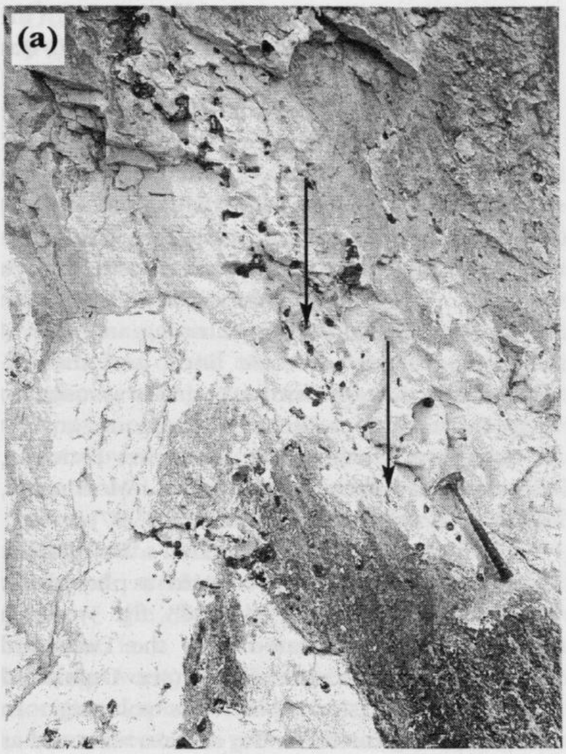


Figure 3.73 Portsdown Chalk Formation with numerous marl seams, Culver Cliff (Whitecliff), Isle of Wight, Upper Campanian *Belemnitella mucronata* Zone.

have been identified (Figure 3.69). The Culver Chalk is particularly barren of macrofossils, but several key *Echinocorys* horizons have been identified (Figure 3.72). In particular, large forms of *Echinocorys* (Gaster, 1924) occur in the equivalent of the Bastion Steps Beds at the top of the Newhaven Chalk Formation (i.e. *Hagenowia blackmorei* Subzone). Large, round-based post-Downend Hardground forms of *Echinocorys* (see **Downend Chalk Pit** GCR site report, this volume) are present in the uppermost beds (Spetisbury Member, Figure 3.72).

The base of the Upper Campanian *B. mucronata* Zone (*sensu stricto*) is taken at the entry of marl seams with abundant inoceramid bivalves, including *Cataceramus dariensis* (Dobrov and Pavlova). These are conspicuous in this section. In the overlying succession, an interval with *Echinocorys subconicula* Brydone is followed by an interval with *E. conica* (Agassiz) (Figure 3.73).



Interpretation

There are very few sections as complete and accessible as Whitecliff. It is, however, anomalous in several respects (Mortimore, 1986a). The beds in the upper Lewes Nodular Chalk Formation, including the interval from the Hope Gap Hardground to the Shoreham Marl (Lower Coniacian) are attenuated, and overlain by an expanded basal part of the Seaford Chalk Formation. Hardgrounds at the top of the Seaford Chalk Formation (Lower Santonian Substage) are followed by beds with numerous stylolitic marl seams. The so-called 'Flintless Belt' is a condensed section from the top of the Upper Santonian *Marsupites* Zone to the top of the Lower Campanian *O. pilula* Zone; the individual hardgrounds within this interval correspond to horizons with similar surfaces elsewhere (e.g. Windmill Hill, Hampshire, and Stoughton, Sussex, Mortimore, 1986b). These hardgrounds are not a general feature, but are always located along or close to known tectonic lines (see below). Higher in the Campanian

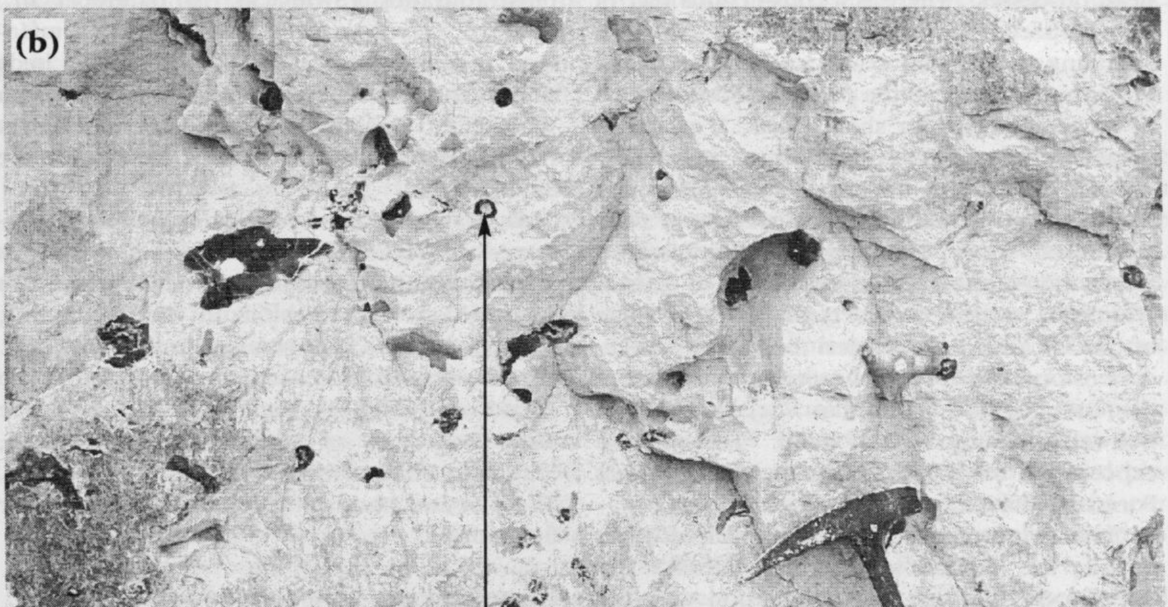


Figure 3.74 (a, b) The Isle of Wight Tubular Flints (arrowed) in the Portsdown Chalk Formation, Whitecliff, Isle of Wight. (Photos: R.N. Mortimore.)

succession, many of the flints in the Culver Chalk Formation, and some in the Portsdown Chalk Formation, show evidence of synsedimentary movements, but only at particular horizons.

Other research on the geochemistry and the Cretaceous palaeomagnetic reversal timescale for the Whitecliff section (Barchi, 1995) has identified the reversal from magnetochron 34N to 34R beneath the Old Nore Marl within the Flintless Belt. Geochemical spikes, linked to lithological and fossil event beds, provide evidence for palaeoceanographic and climatic changes in the Late Cretaceous Epoch in this section.

Whitecliff provides the standard stable isotope curves ($\delta^{13}C$, $\delta^{18}O$) for the Culver Chalk, Portsdown Chalk and basal Studland Chalk formations (Jenkyns *et al.*, 1994, fig. 7). As in the case of the curves for the underlying succession (higher Seaford Chalk, Newhaven Chalk and basal Culver Chalk formations) at **Cuckmere to Seaford**, the curves show a remarkable degree of covariance, suggesting that the isotope values have been affected by diagenetic processes. There is a conspicuous pair of closely-spaced 'spikes' of negative values corresponding to the marl seams at the base of the Portsdown Chalk and the paired marl seams rich in inoceramid bivalve shell debris, 5 m above, respectively.

Small pits along the Chalk Downs forming the spine of the Isle of Wight, because of their weathered state, often yield better-preserved fossils that support the identification of beds at Whitecliff. Arreton Down Pit (SZ 536 873) is one of these and has yielded beautiful, three-dimensional *Cladoceramus undulatoplicatus* at the base of the Santonian succession from Bedwell's Columnar Flint Band. This pit also exposes the basal beds of the Newhaven Chalk Formation with excellent marl seams.

Other important sections on the Isle of Wight include the difficult to access Scratchell's Bay (SZ 295 847), which, in combination with the Needles (SZ 290 849) and Alum Bay (SZ 301 851), provides a contrasting section in the Lower and Upper Campanian strata. The Newhaven Chalk Formation at the southern end of Scratchell's Bay contains numerous well-developed marl seams that correlate in detail with the standard successions at Newhaven and Seaford. In many cases the marl seams such as the Old Nore Marl are thicker than at Newhaven, comparable to those west of Brighton in the Shoreham Harbour Boreholes. Scratchell's Bay exposes, therefore, a very different, expanded Newhaven Chalk Formation in contrast to the highly condensed 'Flintless Belt' at Whitecliff. The Flintless Belt with associated hardgrounds has been traced only as far west as the Brading Pit (SZ 602 868) on Brading Down. This limits the lithology to the area of the Sandown Pericline. It was this evidence, in combination with other data indicating thinning and loss of marker beds over tectonic lines, and the evidence from seismic sections, that was used to suggest intra-Upper Cretaceous tectonic growth of structures, such as the Sandown Pericline, controlled by deeper level faults (Mortimore, 1986a,b; Mortimore and Pomerol, 1997).

The higher beds at Scratchell's Bay in the Culver Chalk Formation contain a phosphatic chalk horizon (Bailey *et al.*, 1983, fig. 3) which was tentatively correlated with the Downend Main Hardground phosphates (see **Downend Chalk Pit** GCR site report, this volume). In addition, the Scratchell's Bay section was used as a standard for the Campanian microfossil biostratigraphy (Swiecicki, in Bailey *et al.*, 1983). Extrapolation of this scheme to the mainland required correlation of key marker beds such as the Whitecliff and Portsdown marls from Whitecliff to Scratchell's Bay and to the Shide Pit (SZ 505 880), which is the type locality for the Shide Marl.

Alum Bay exposes beds higher than those preserved at Whitecliff. Tectonically, Alum Bay is down the plunge east to west which continues westward to Handfast Point–Studland Bay, Dorset, and the Chalk 'youngs' in that direction. The higher beds at Alum Bay are above the Portsdown Chalk Formation in the marl-free Alum Bay Beds of Mortimore (1979, 1983; Studland Chalk Member, Gale *et al.*, 1988). These beds contain several conspicuous, marker flint bands.

Conclusions

Whitecliff is unique in the extent and accessibility of the stratigraphy (including stable isotope stratigraphy and magnetostratigraphy) exposed in one continuous Chalk section and it additionally provides vital evidence for sedimentary processes and tectonic control of sedimentation in the Coniacian to Campanian Chalk of the Southern Province.

DOWNEND CHALK PIT, PORTSDOWN, HAMPSHIRE (SU 601 065)

Introduction

Downend Chalk Pit is a largely backfilled former large Chalk quarry on the south side of the western end of Portsdown Hill (Figures 3.75–3.79), adjacent to the M27. The site comprises two sections. The first, on the north side of the site, consists of a 3–4 m high cliff-cut along an old access road, which exposes a section near the base of the Portsdown Chalk Formation containing marl seams and abundant inoceramid bivalve shell-debris in the lower part of the *Belemnitella mucronata* Zone (Upper Campanian). The second section, which is stratigraphically below the first section, and 50 m to the south, is a north–south, 20 m high, west-facing, vertical face containing some of the original special features of the pit. This second section is part of the original excavation, but landfill, with a steep 70°– 80° face, has left only a narrow gully along the base of the chalk cliff. There is no easy access to the old chalk face and a track has to be beaten down the steep landfill slope through the undergrowth.

Downend Chalk Pit is unique in two particular aspects of Chalk stratigraphy and sedimentology. First, there is the spectacular evidence for the intra-Chalk movements represented by growth of sedimentary mounds and box-folded flints in the lower part of the exposure. These slump beds are overlain by parallel-bedded, undisturbed layers of flint and chalk, indicating a stratigraphically distinct period of movement in late Early Campanian times. The second key feature is the exposure of beds of the *Gonioteuthis quadrata* Zone and the overlying mixed assemblage of *G. quadrata* and *Belemnitella mucronata* of the belemnite 'Overlap Zone' at the top of the Lower Campanian strata (Figure 2.27, Chapter 2). Nowhere else in the UK has this level been so well exposed to study and the palaeontological evidence from this site has been vital in establishing the biostratigraphy of the 'Overlap Zone' and its correlation with successions in northern Germany.

Description

The earliest descriptions of Downend Chalk Pit (Brydone, 1912; White, 1913, p. 29) reported anomalous bedding dips in the *Gonioteuthis quadrata* Zone and *Belemnitella mucronata* Zone Chalk. Brydone (1912) referred to this locality as 'Rogers Whitening Pit' and gave it the Hampshire locality number 1153. White (1913) suggested that the anomalous dips could not be explained by the normal tectonic folding that produced the Portsdown Anticline. Subsequent work (Gale, 1980; Mortimore, 1979, 1983, 1986a,b; Mortimore and Pomerol, 1991a, 1997) has illustrated the sedimentological character of the Downend chalk, which contains intraformational slumping, very rare in onshore exposures of Chalk in England (see also the **Boxford Chalk Pit** GCR site report, this volume). These sedimentary structures are exposed on the eastern wall of the pit. Also, unique to England, are the ammonites found in, on and above the Downend Main Hardground (Gale, 1980). These fossils are a critical link in the correlation of the Campanian successions between North America and Europe.

Lithostratigraphy

The first published detailed descriptions of Downend Chalk Pit were by Gale (1980) when the pit was still being worked for lime. He identified three lithological groups of beds lettered A to C. Gale placed the boundary between his A and B Beds along the top surface of the most conspicuous of many hardgrounds, a composite surface, which he designated A12–13. The A Beds were generally free of flint and comprised a series of glauconitized green-coated hardground surfaces. Both the thickness and biostratigraphy of these beds were poorly constrained because they were caught up in the intraformational slump folding.

In contrast to the A Beds, the B Beds contained numerous bands of flint and less well-developed ferruginous hardgrounds and glauconitized erosion surfaces. A marl seam, the Lower Downend Marl, occurred just above one of the glauconitized surfaces. The basal marker to the C Beds at the top of the pit was the Upper Downend Marl, overlain by soft chalk with marly wisps and a few flints.

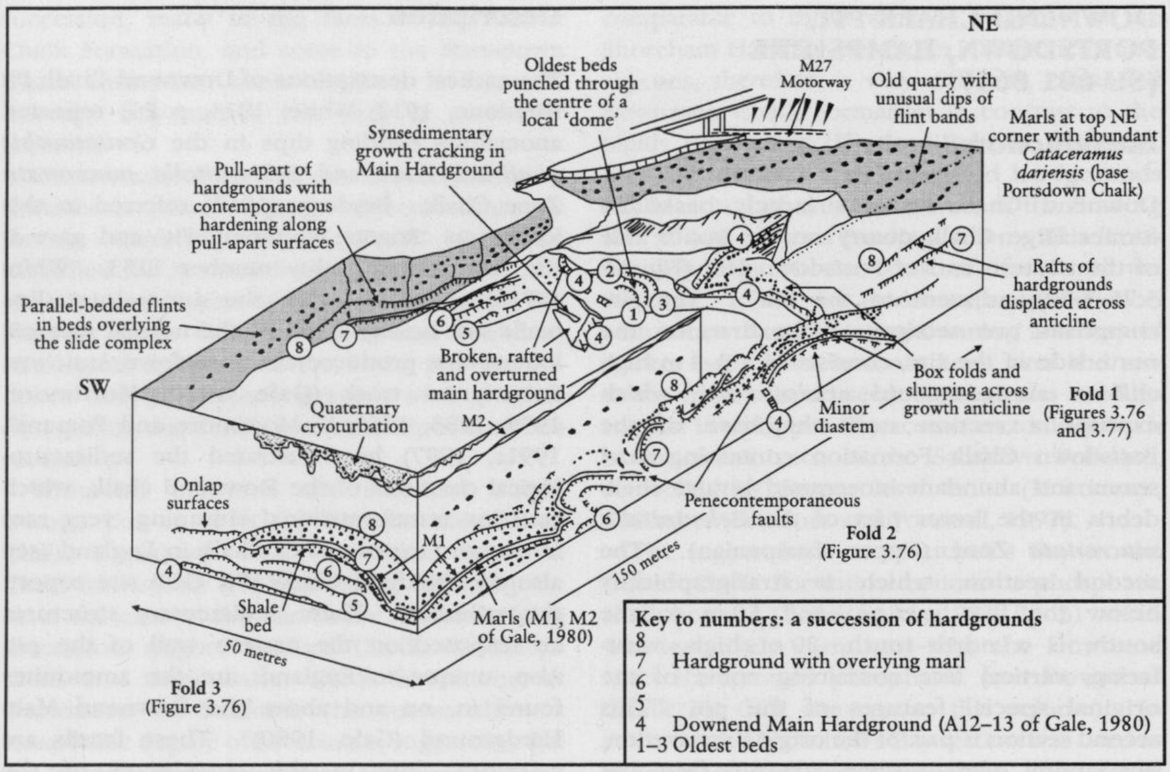


Figure 3.75 Sketch of the geology of the Culver Chalk Formation formerly exposed in Downend Chalk Pit, Portsdown. Hardgrounds, growth structures and slumps are interpreted as resulting from latest Early Campanian Peine Phase tectonic uplift. (From Mortimore, 1979, 1983; and Gale, 1980).

Gale (1980) identified two phases of intra-Chalk folding, the first after the A Beds had formed but before the B Beds were deposited, leading to dislocation and rafting of the A12–13 hardground. A second phase of folding, following deposition of the Bed B4, led to further brittle fracturing of A12–13 and disruption of the B Beds up to B4.

In an unpublished thesis (Mortimore, 1979, pp. 70–3, 166), the Downend succession was divided into Lower Beds and Upper Beds (Figure 3.78). The Lower Beds consisted of 16 mineralized hardgrounds or surfaces with few flints, comprising Gale's (1980) A Beds and the B Beds up to B4. The Upper Beds, with few mineralized surfaces and abundant flint bands, included all the chalk above the slump-folded and disturbed part of the sequence (i.e. above Gale's B4 hardground). In this description (Mortimore, 1979), Gale's strongly lithified composite surface (A12–13) was named the 'Downend Main Hardground', and the surface B4 the 'Upper Downend Hardground'. The Lower Downend Beds comprised six cycles divided by the most obvious hardground surfaces or groups of hardgrounds. The 'Downend Marl' of Mortimore (1979) is the same as the 'Lower Downend Marl' of Gale (1980). In addition, Mortimore identified a shaly-chalk bed beneath the hardground labelled 7 (see Figures 3.75 and 3.76), and provided a block diagram of the Downend Chalk Pit exposures as they were seen in 1977. Further section details were published by Mortimore (1983, 1986a,b), in which the Downend succession was divided into the Culver Chalk (Member) below, and Portsdown Chalk (Member) with marl seams above. Some correlations of the marl seams at Downend with those at Farlington, Portsdown and **Whitecliff**, Isle of Wight, were suggested.

The Downend Main Hardground (Mortimore, 1979, 1986a; bed A12–13 of Gale, 1980) formed a spectacular, undulating surface, strongly mineralized by glauconite and phosphate, and encrusted by large oysters. Hard, cemented

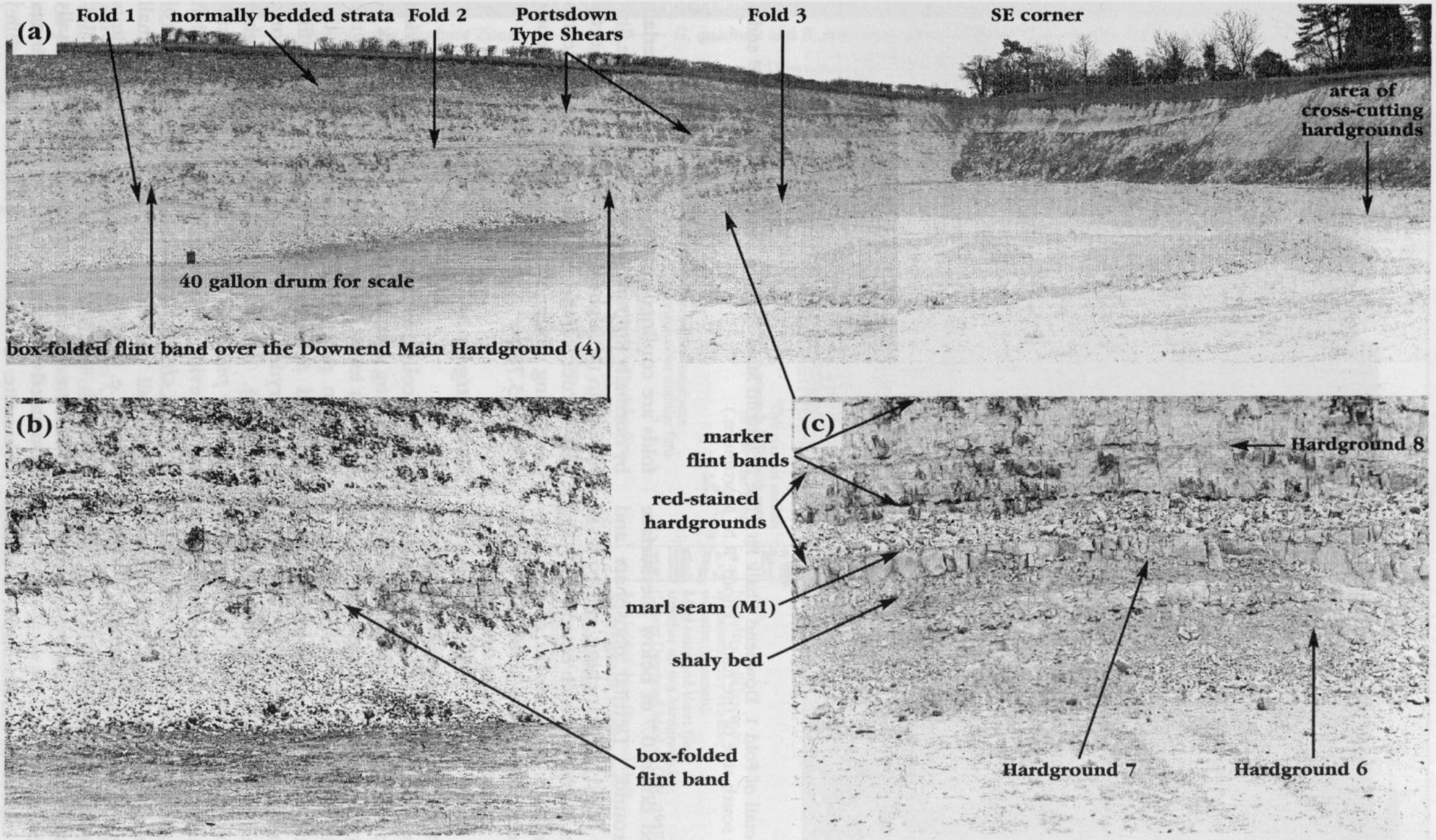


Figure 3.76 Downend Chalk Pit, Portsdown, Hampshire, looking east onto the eastern and southern faces. Growth tectonics, synsedimentary slumping and penecontemporaneous slump folding in the intra-Early Campanian Culver Chalk Formation. (a) Box-folded flint band over the Downend Main Hardground (4). (b) Detail within Fold 2; slump folding. (c) Detail within Fold 3; a hardground succession. (Photomosaic: R.N. Mortimore.)

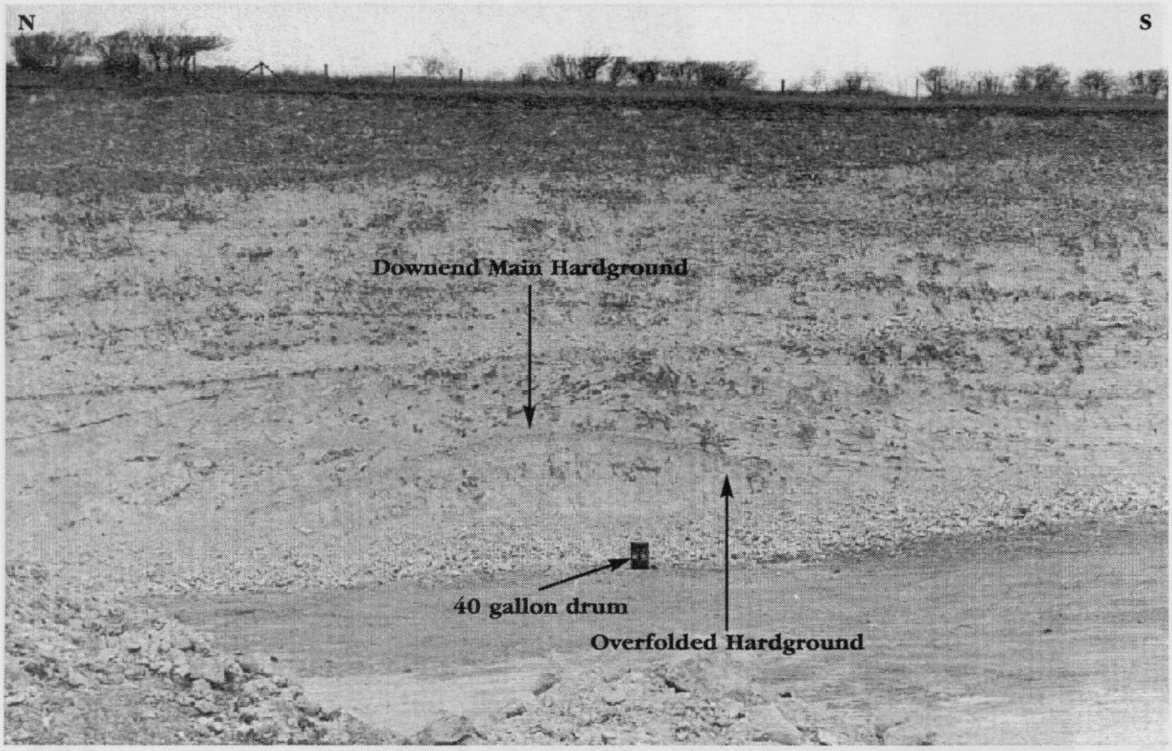


Figure 3.77 Detail of Fold 1, Downend Chalk Pit. The Downend Main Hardground picks-out the fold and is inverted on the south side of the fold. (Photo: R.N. Mortimore.)

chalk extended down 0.7 m below the surface of the hardground. Detrital phosphate and coarse chalk filled a branching network of *Thalassinoides* burrows, which extended to 2 m below the surface. Huge blocks of this hardground formed scattered rafts across the floor of the pit, lying at various angles and even overturned in soft white chalk. Critical observations included the evidence of cracking and pull-apart of the hardground while it was forming. The broken and split edges of the hardground were mineralized and bored like the top surface.

The Downend Main Hardground acted as a marker bed for tracing the complex system of intraformational folds through the pit. Generally, the hardground either buckled into open folds or cracked apart, and disrupted elements separated and rafted away. In contrast, the more plastic overlying beds, containing a conspicuous nodular flint band, formed much tighter and more complex box-folds. Within these beds was a well-developed marl seam named by Gale (1980) the 'Lower Downend Marl' (Figure 3.78).

Within the exposure, intraformational slump folds are confined stratigraphically and overlain by normally dipping beds, picked out by the flint bands. In the highest beds exposed in the north-east corner of the pit are several marl seams containing abundant inoceramid shell debris (Figure 3.78).

Biostratigraphy

Fossils collected from this pit have provided conflicting evidence for the age of the chalk at different levels. In the lowest exposures, in the southern part of the pit, a large form of the echinoid *Echinocorys scutata cincta* Griffith and Brydone was collected (Mortimore, 1986a,b). This usually indicates the higher *Offaster pilula* Zone but there is no other supporting evidence for this Zone. It is possible that the *E. s. cincta* represents the upper horizon of this fossil in Gaster's (1924) horizon of small forms (i.e. in beds equivalent to Castle Hill Flints 4 to 11 at Seaford and Newhaven), but the specimen was larger than the forms normally associated with this level. The zonal index belemnite *Gonioteuthis quadrata* (Blainville)

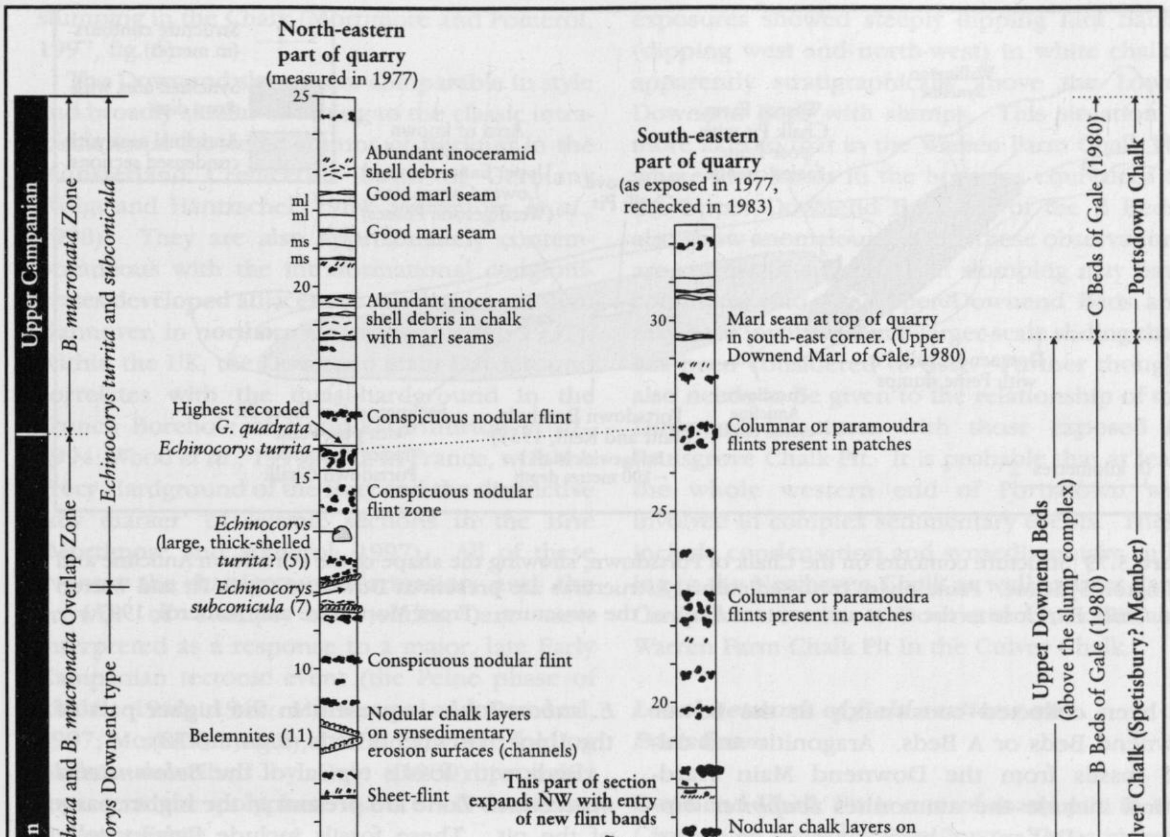


Figure 3.78 Stratigraphy of the Campanian Chalk originally exposed at Downend Chalk Pit, Portsdown. Any two sections are different as synsedimentary channels and growth of penecontemporaneous slump folds create local pockets of expanded or condensed sediments. The sections shown are an attempt to illustrate the total range of the stratigraphy and the main subdivisions unravelled from the slump complex. (ms = marl seam; ml = marly laminae.)

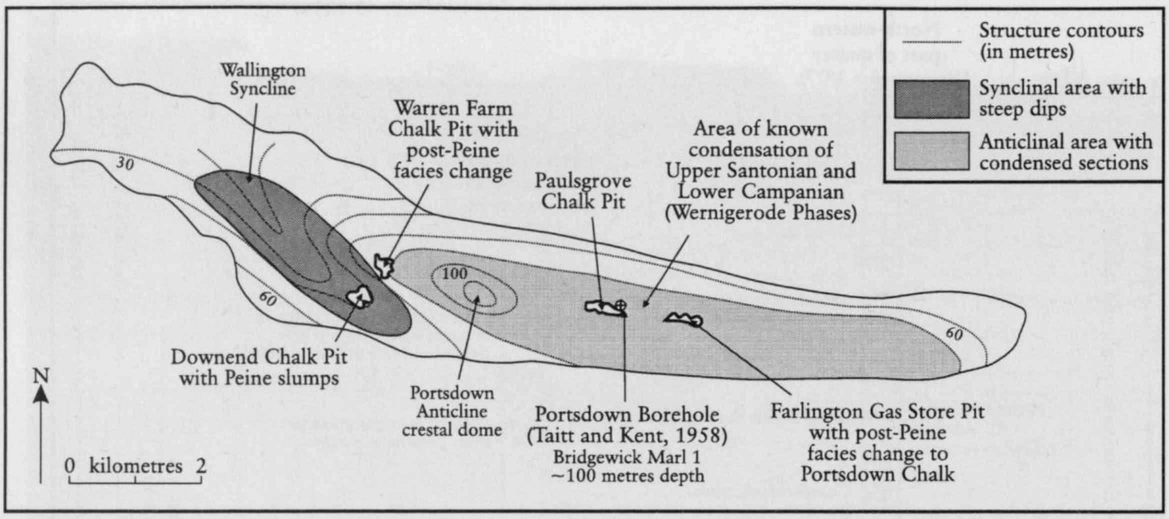


Figure 3.79 Structure contours on the Chalk of Portsdown, showing the shape of the Portsdown Anticline and Wallington Syncline. Peine phase tecto-sedimentary structures are present at Downend Chalk Pit and Warren Farm Chalk Pit, close to the crest and western flank of the structure. (From Mortimore and Pomerol, 1997.)

has been collected consistently in the Lower Downend Beds or A Beds. Aragonitic and calcitic fossils from the Downend Main Hardground include the ammonites *Scaphites hippocrepis* (DeKay), *Glyptoxoceras* sp., and *Baculites* (Gale, 1980). Belemnites, brachiopods, cephalopod jaws, elasmobranch teeth, teleost bone fragments and mosasaur teeth and bones have also been collected from this horizon. The belemnite genera *Gonioteuthis* and *Belemnitella* are found together in beds above the Downend Main Hardground (Bed A12–13). This belemnite Overlap Zone (Figure 2.27, Chapter 2) is widely recognized in Europe (Schmid, 1953, 1959) but it is only at Downend Chalk Pit that the zone has been studied in detail in England. Brydone's (1912) record of *G. quadrata*, based on a specimen of *G. quadrata gracilis* (Stolley), is the stratigraphically highest yet known in England (see discussion below).

Forms of *Echinocorys* provide index horizons in the Campanian Stage, and Downend has provided a unique collection from various levels. These fossils are still being researched and the different shapes have been given informal names and used for correlation across the Anglo-Paris Basin (Mortimore, 1983, 1986a,b; Mortimore and Pomerol, 1987, 1991a,b). In particular, a tall domed, round-based form is associated with the Downend Main Hardground. Very thick-shelled, globose forms of *E. turrita* are present in the Upper Downend Beds (B Beds above B4) and *E. subconicula* is present in the higher part of the Upper Downend Beds (Figure 3.78).

Beds with fossils typical of the *Belemnitella mucronata* Zone are present in the higher parts of the pit. These fossils include *Belemnitella* (without *Gonioteuthis*), *Echinocorys subconicula* Brydone and abundant inoceramid bivalves including *Cataceramus dariensis* (Dobrov and Pavlova), the last concentrated in marl seams.

Interpretation

Downend Chalk Pit is located on the Portsdown Pericline (Figure 3.79), which is one of a series of en-echelon periclines in this part of the Southern Province and the Paris Basin (Mortimore and Pomerol, 1991a, 1997). Although White (1913) considered that the unusual dips in the Chalk were not related to the tectonic folding, his only alternative explanation was to suggest that some form of cross-bedding related to currents was the cause. Gale (1980) invoked local (salt?) diapirism as a cause of folding, but there is no evidence of subsurface salt. Mortimore (1979, 1983; 1986a,b) and Mortimore and Pomerol (1987, 1991a, 1997) considered that the unusual dips were caused by intraformational slump folding and sliding, which was in turn caused by syntectonic, fault-controlled growth of the Portsdown Pericline. This interpretation was supported by seismic evidence from the Solent that illustrated similar slumping in the Chalk (Mortimore and Pomerol, 1997, fig. 6).

The Downend slumps are comparable in style and broadly similar in timing to the classic intraformational Bärsteine slumps of Beckum in the Münsterland Cretaceous Basin of Germany (Voigt and Häntzschel, 1964; Mortimore *et al.*, 1998). They are also approximately contemporaneous with the intraformational conglomerates developed adjacent to salt diapirs north of Hannover, in northern Germany (Riedel, 1937). Within the UK, the Downend Main Hardground correlates with the quasi-hardground in the Trunch Borehole of Norfolk (Arthurton *et al.*, 1994; Wood *et al.*, 1994) and, in France, with the Précy Hardground of the Bray and the distinctive 'key marker' of seismic sections in the Brie (Mortimore and Pomerol, 1997). All of these events, the hardground formation and the growth of slumps and slides, are now interpreted as a response to a major, late Early Campanian tectonic event (the Peine phase of Riedel, 1940, 1942; Mortimore and Pomerol, 1997; Mortimore *et al.*, 1998). The two folding phases described by Gale (1980) probably represent the polyphase nature of the Peine Tectonic Event.

None of the present descriptions and explanations fully deals with the anomalously dipping flint-bearing chalk in the now completely buried face to the north of the former entrance (Figure 3.75). These former northern exposures showed steeply dipping flint bands (dipping west and north-west) in white chalks, apparently stratigraphically above the Lower Downend Beds with slumps. This situation is more akin to that in the Warren Farm Chalk Pit, where flint bands in the horizons equivalent to the Upper Downend Beds (all of the B Beds) also show anomalous dips. If these observations are correct, it suggests that slumping may have continued into the Upper Downend Beds and may have involved much larger-scale sliding than has been considered to date. Further thought also needs to be given to the relationship of the Downend structures with those exposed in Paulsgrove Chalk Pit. It is probable that at least the whole western end of Portsdown was involved in complex sedimentary events. These include condensation and synsedimentary faulting in the Newhaven Chalk as well as later Early Campanian events at Downend Chalk Pit and Warren Farm Chalk Pit in the Culver Chalk.

Local network of field sections on Portsdown

Downend Chalk Pit is one of many pits in the Campanian strata on Portsdown. These include sections in the adjacent but now backfilled Warren Farm Chalk Pit (Figures 3.80 and 3.81), and other main sections on Portsdown at Paulsgrove and Farlington (Figures 3.82 and 3.83). Each of these pits, in combination with

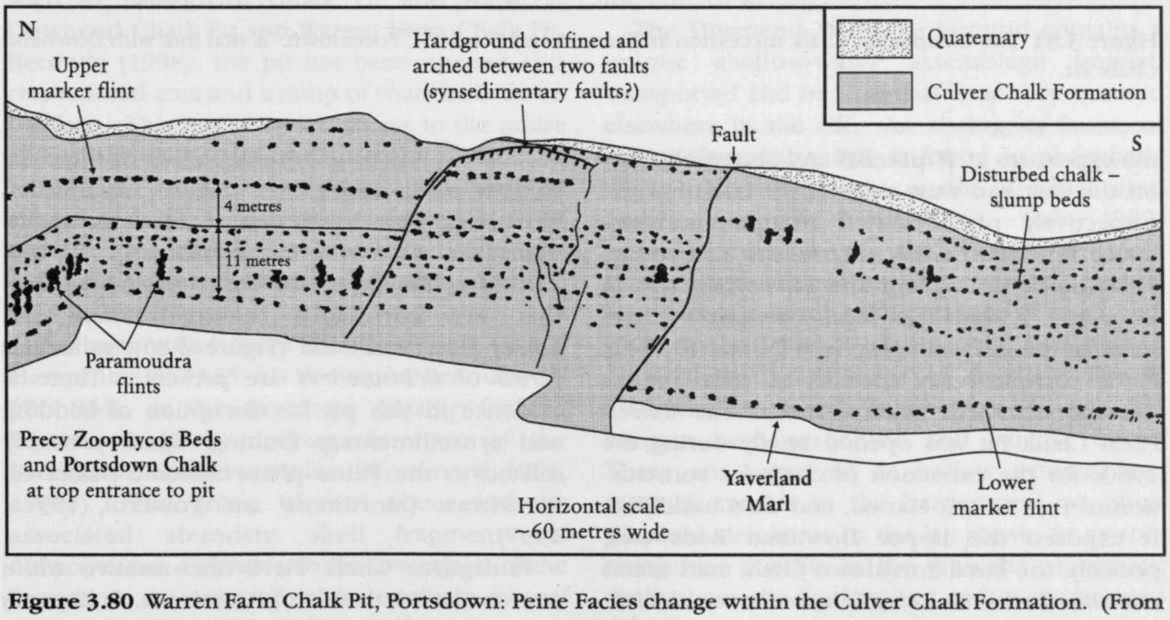


Figure 3.80 Warren Farm Chalk Pit, Portsdown: Peine Facies change within the Culver Chalk Formation. (From Mortimore and Pomerol, 1997.)

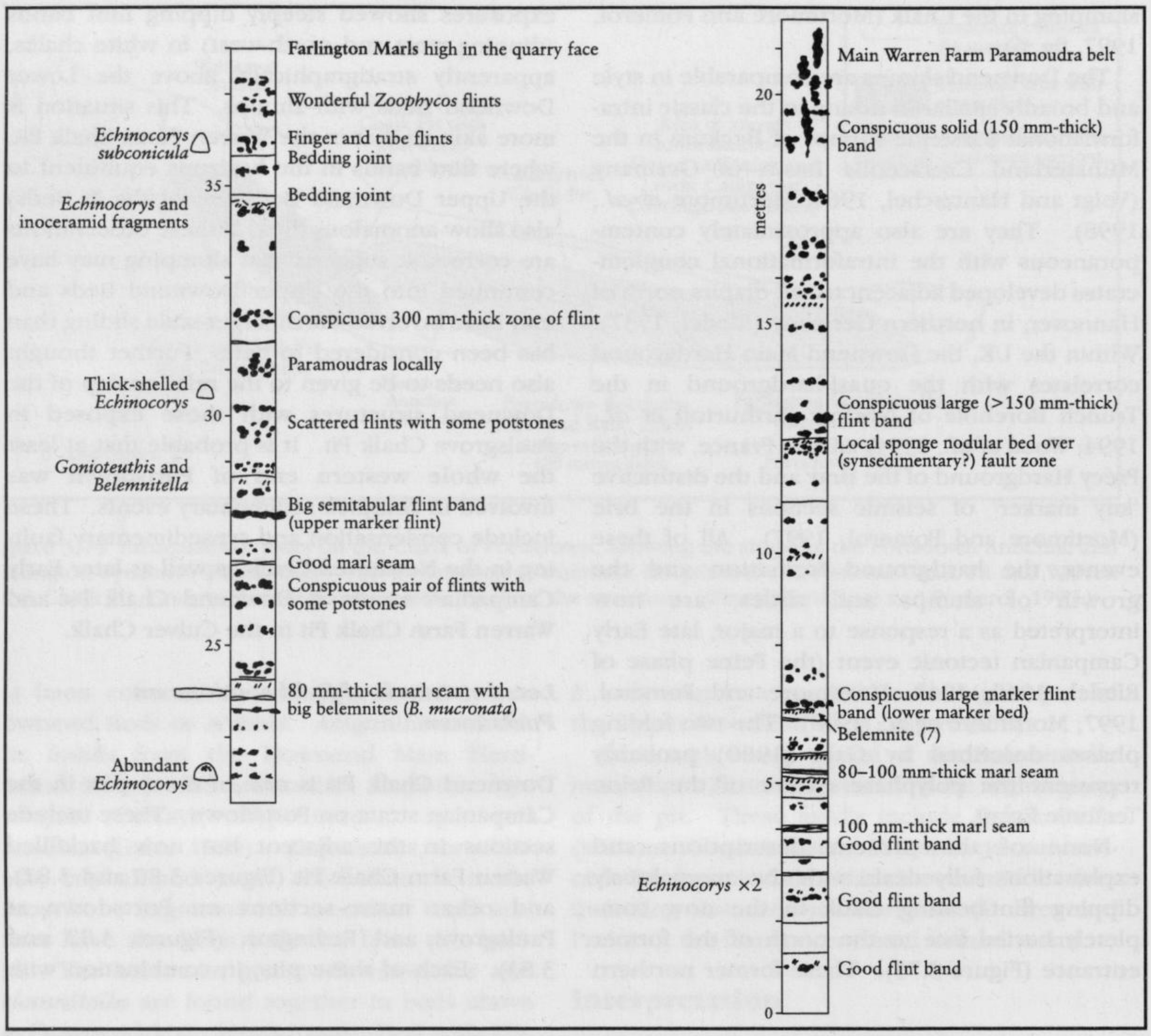


Figure 3.81 The Campanian Chalk succession at Warren Farm Chalk Pit, Portsdown. A vital link with Downend Chalk Pit.

the exposures at **Whitecliff** and Scratchell's Bay on the east and west sides of the Isle of Wight respectively, provides vital stratigraphical evidence for constructing an onshore Campanian stratigraphy in England and for correlations in Europe. Within this local network of field sections the lithostratigraphy at Downend Chalk Pit is conspicuously anomalous, reflecting its unusual tecto-sedimentary history. The Warren Farm Chalk Pit was opened briefly during the 1980s for the extraction of chalk for construction of Port Solent Marina, and then backfilled. It exposed the Upper Downend Beds and, possibly, the basal Portsdown Chalk marl seams associated with abundant *Cataceramus dariensis* at the topmost entrance to the pit. The succession passed down through a spectacular band of paramoudra flints (Figure 3.81), which have been correlated with those at Précy-sur-Oise, France (Mortimore and Pomerol, 1991b). Farther below there are beds with marl seams that are correlated tenuously with the Lower Downend Marl (Figure 3.83), as similar forms of *Echinocorys* are present. There is evidence in this pit for disruption of bedding and synsedimentary faulting, again probably related to the Peine phase tectonic pulses on Portsdown (Mortimore and Pomerol, 1991a, 1997).

Paulsgrove Chalk Pit is the massive white scar on the south side of Portsdown. It exposes beds through the Newhaven Chalk Formation,

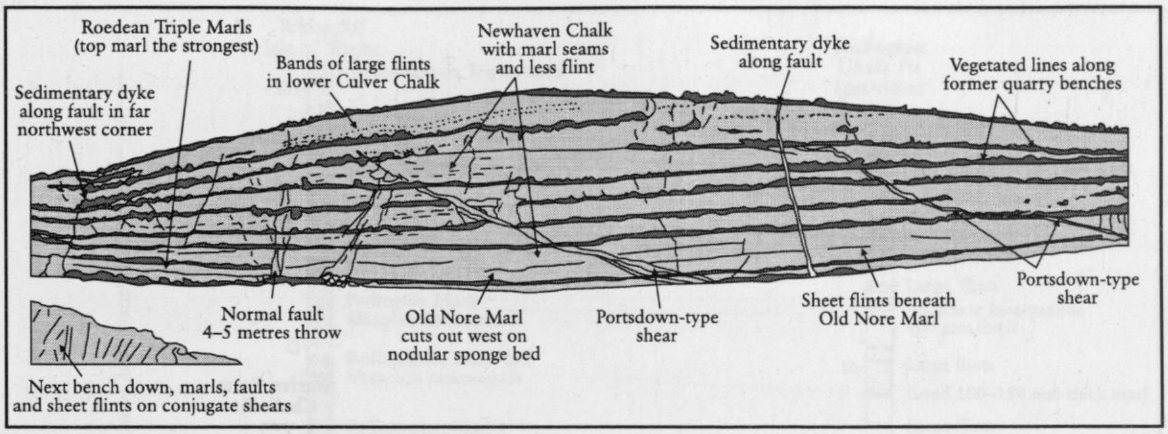


Figure 3.82 Paulsgrove Chalk Pit, Portsdown, Portsmouth, Hampshire.

from just above the *Marsupites* Zone, to beds in the lower part of the Culver Chalk Formation. The section details were first published by Mortimore (1986a,b), and indicated the thinning of the Newhaven Chalk onto the Portsdown Pericline. Marl seams, from the Rottingdean Pair in the Old Nore Beds, to the Castle Hill Marls, at the boundary with the overlying Culver Chalk, were identified. Out of reach in the high cliff face were the conspicuous Castle Hill Flints. The presence of sedimentary (chalk) dykes (Figure 3.82) here, as well as a special form of shear plane seen only on Portsdown, suggests there is a sedimento-tectonic link between features seen in Paulsgrove Chalk Pit and those at Downend Chalk Pit and Warren Farm Chalk Pit. Recently (1998), the pit has been opened as a recreational area and a ramp of chalk built down the face. This has provided access to the entire cliff, allowing a measured section to be made. This recent landscaping has, however, covered all of the lowest exposures including most of the Old Nore Beds as well as the best of the sedimentary dykes, which were in the far northwest corner.

Farlington Gas Store Pit (Brydone's (1912) Hampshire Pit 1145, his Farlington Redoubt; SU 686 064), is the stratotype locality for the Portsdown Marl, marking the base of the Portsdown Chalk Formation (Mortimore, 1983, 1986a). The group of marl seams and the associated abundant shell fragments of *Cataceramus dariensis*, in the lower part of the formation, are exposed in the northern face of the pit (Figure 3.83). *Belemnitella* is abundant above the Farlington Marls and *Echinocorys subconicula* is also common. It is probable that Griffith and Brydone (1911) and White (1913) took these marls as the base of their *Belemnitella mucronata* Zone. Large, globose, thick-shelled echinoids (*Echinocorys turrita*) and small forms related to *E. s.* 'pre-*conica*' occur in the currently grassed-over lowest beds. This distribution of inoceramid bivalves, *Echinocorys* and the belemnites suggests that the lowest, poorly exposed, beds equate with the Upper Downend Beds, and the marls with those at the top of Downend Chalk Pit and Warren Farm Chalk Pit (N.B. the basal boundary marker, the Portsdown Marl, was not exposed at the time of writing).

The Downend Main Hardground contains a unique shallow-water assemblage (mixed, transported and *in situ*) that is not represented elsewhere in the UK. An analogous fauna, of earlier Campanian age, is found in phosphatic chalks (Lavant Stone), north of Chichester, Sussex (Bone and Bone, 2000). Gale (1980) provided details of the Downend Main Hardground surface and the overlying pebble-lag deposit indicating the presence of reworked, phosphatized and encrusted hardground material and steinkerns of fossils. Fossils associated with this surface are diverse and contain both aragonitic and calcitic forms. These are preserved as hollow external and internal moulds in the hardground, as phosphatized steinkerns in the lag above, or as soft, composite moulds in the granular phosphatic chalk above the hardground and in the burrow-fills.

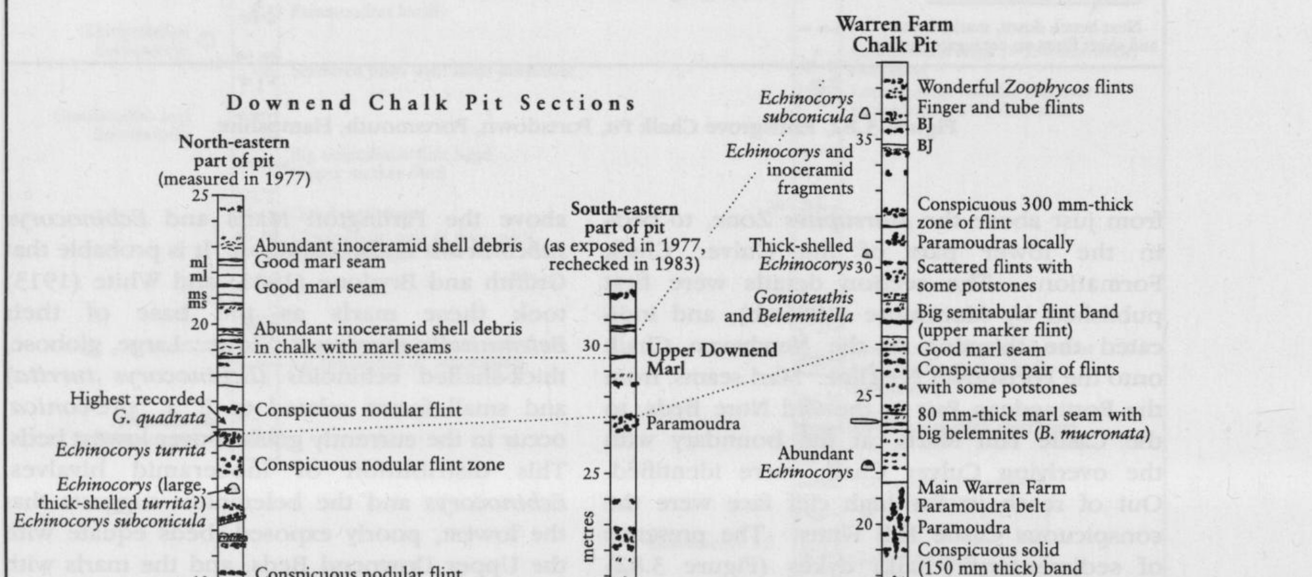


Figure 3.83 A possible correlation between Downend Chalk Pit, Warren Farm Chalk Pit and Farlington Chalk Pit (Gas Store Pit), Portsdown, and Whitecliff, Isle of Wight (*continued on p. 209*).

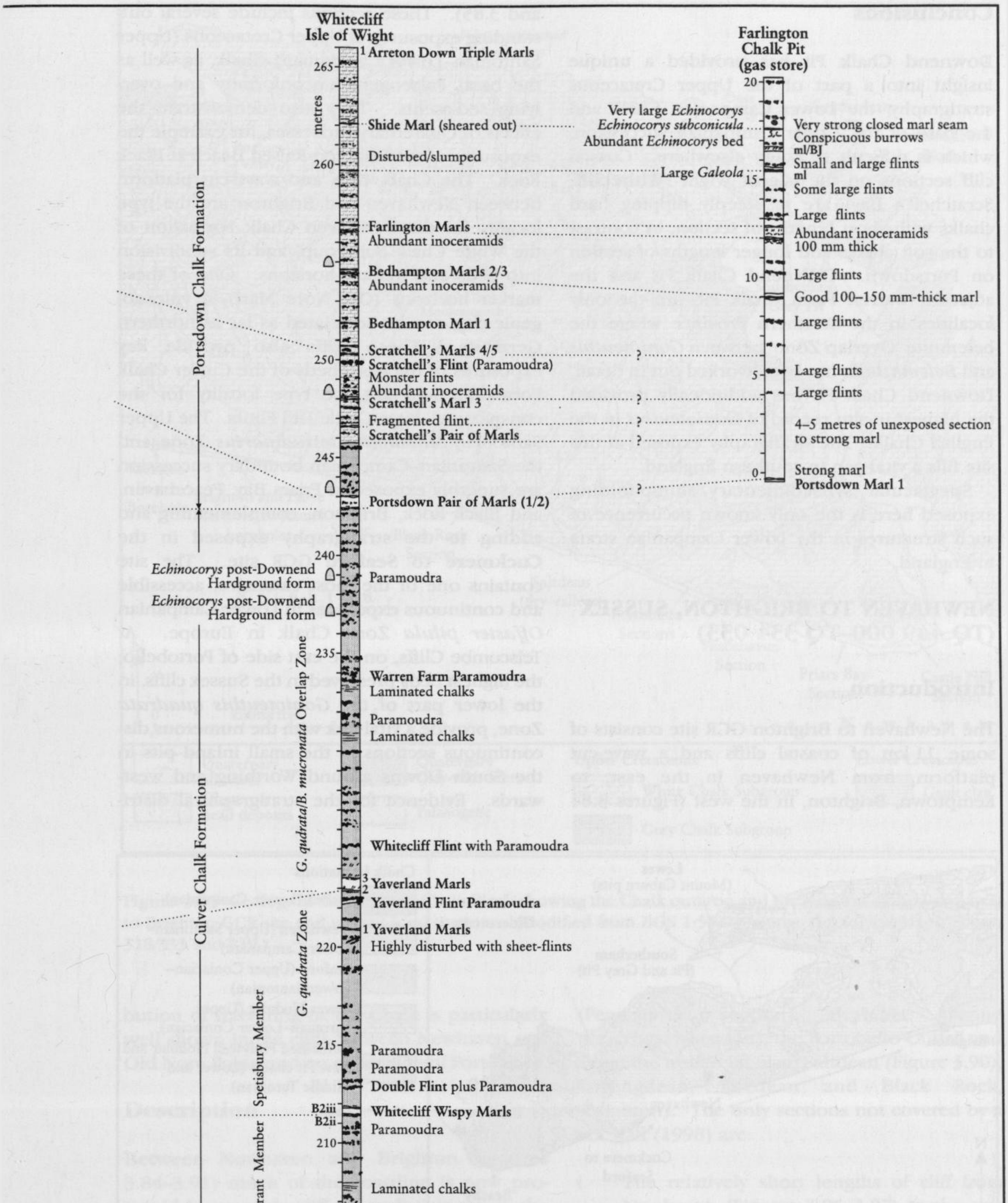


Figure 3.83 (*cont.*) B2ii and B2iii refer to the benthic foraminiferal zonal/subzonal scheme of Swiecicki (1980). (BJ = bedding joint; ms = marl seam; ml = marly laminae.)

Conclusions

Downend Chalk Pit has provided a unique insight into a part of the Upper Cretaceous stratigraphy, the Lower Campanian Chalk and the base of the Upper Campanian succession, which is difficult to study elsewhere. Coastal cliff sections on the Isle of Wight (**Whitecliff**, Scratchell's Bay) are in steeply dipping hard chalks with short lengths of section, in contrast to the soft chalks and longer lengths of section on Portsdown. Downend Chalk Pit and the adjacent Warren Farm Chalk Pit, are the only localities in the Southern Province where the belemnite 'Overlap Zone' between *Gonioteuthis* and *Belemnitella* has been worked out in detail. Downend Chalk Pit has additionally provided the highest in-situ record of *Gonioteuthis* in the English Chalk. The stratigraphy exposed at this site fills a vital gap in southern England.

Spectacular synsedimentary slump-folding exposed here is the only known occurrence of such structures in the Lower Campanian strata in England.

NEWHAVEN TO BRIGHTON, SUSSEX (TQ 449 000–TQ 334 033)

Introduction

The Newhaven to Brighton GCR site consists of some 11 km of coastal cliffs and a wave-cut platform, from Newhaven in the east, to Kemptown, Brighton, in the west (Figures 3.84 and 3.85). These sections include several outstanding exposures of Upper Cretaceous (Upper Santonian–Lower Campanian) Chalk, as well as the basal Palaeogene unconformity and overlying sediments. They also demonstrate the effects of Quaternary processes, for example the exposures of the Brighton Raised Beach at Black Rock. The Chalk cliffs and wave-cut platform between Newhaven and Brighton are the type locality for the Newhaven Chalk Formation of the White Chalk Subgroup, and its subdivision into beds and marker horizons. One of these marker horizons (Old Nore Marl), a vulcanogenic clay, can be correlated as far as northern Germany. These cliffs also provide key exposures of the basal beds of the Culver Chalk Formation and are the type locality for the conspicuous, large Castle Hill Flints. The Upper Santonian ***Marsupites testudinarius*** Zone and the Santonian–Campanian boundary succession are superbly exposed at Friars Bay, Peacehaven, and Black Rock, Brighton, complementing and adding to the stratigraphy exposed in the **Cuckmere to Seaford** GCR site. The site contains one of the most extensive, accessible and continuous exposures in Lower Campanian *Offaster pilula* Zone Chalk in Europe. At Telscombe Cliffs, on the east side of Portobello, the highest beds preserved in the Sussex cliffs, in the lower part of the *Gonioteuthis quadrata* Zone, provide a vital link with the numerous,discontinuous sections in the small inland pits in the South Downs around Worthing and westwards. Evidence for the stratigraphical distri-

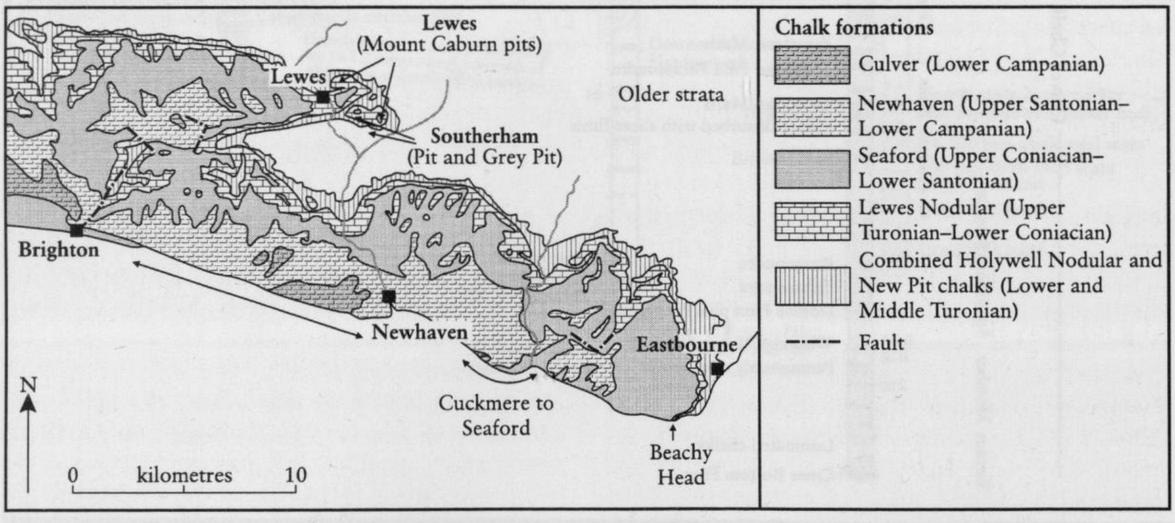


Figure 3.84 Location of GCR and other sites described in the text in the East Sussex Chalk Downs.

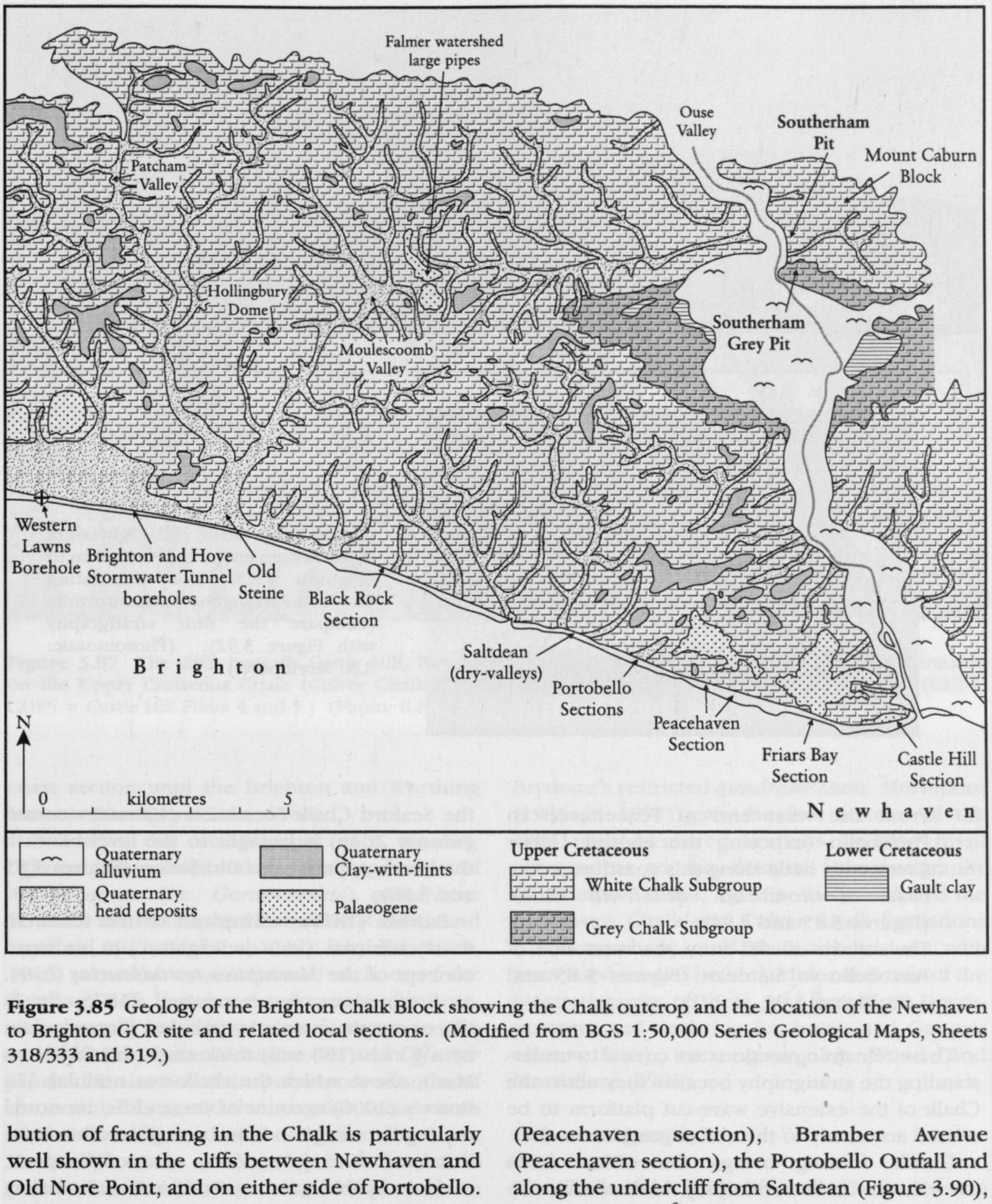


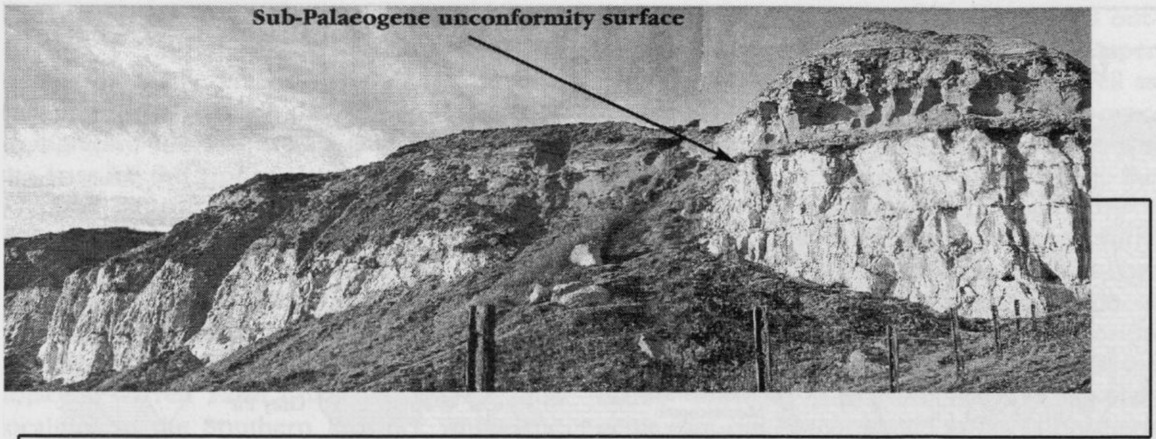
Figure 3.85 Geology of the Brighton Chalk Block showing the Chalk outcrop and the location of the Newhaven to Brighton GCR site and related local sections. (Modified from BGS 1:50,000 Series Geological Maps, Sheets 318/333 and 319.)

bution of fracturing in the Chalk is particularly well shown in the cliffs between Newhaven and Old Nore Point, and on either side of Portobello.

Description

Between Newhaven and Brighton (Figures 3.84–3.91) much of the coastline is now protected by an undercliff sea wall that covers the coastal geology (Figure 3.88), but the stratigraphy can be examined in steep stairways at Peacehaven (Peacehaven Steps), Bastion Steps (Peacehaven section), Bramber Avenue (Peacehaven section), the Portobello Outfall and along the undercliff from Saltdean (Figure 3.90), Rottingdean, Roedean and Black Rock, (Brighton). The only sections not covered by a sea wall (1998) are:

i The relatively short lengths of cliff from Newhaven (Figures 3.85–3.87) to the east end of Peacehaven (exposing the lowest beds on the coast in the Upper Santonian *Marsupites testudinarius* Zone).



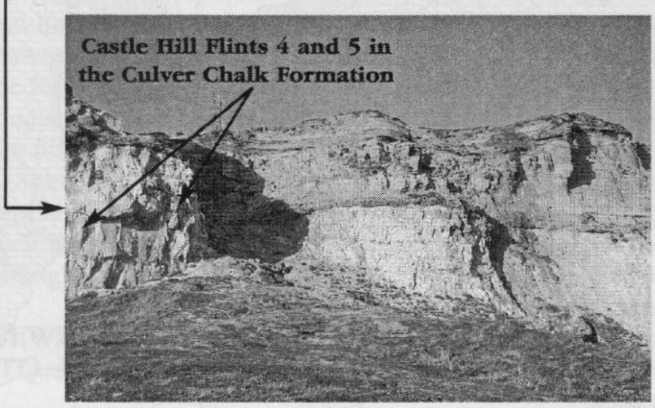


Figure 3.86 Castle Hill, Newhaven, at the eastern end of the Newhaven to Brighton GCR Site illustrating the sub-Palaeogene unconformity (compare the flint stratigraphy with Figure 3.92). (Photomosaic: R.N. Mortimore.)

ii From the west end of Peacehaven to Portobello (exposing the highest Upper Cretaceous beds along this coastline in the basal *Gonioteuthis quadrata* Zone (Figures 3.85 and 3.91).

iii The stretch of cliff from the west side of Portobello to Saltdean (Figures 3.85 and 3.88, Figure 3.95, p. 221).

These remaining sections are critical to understanding the stratigraphy because they allow the Chalk of the extensive wave-cut platform to be related accurately to the cliff exposures.

Gentle folding brings the oldest beds (Newhaven Chalk Formation) to the surface in Friars Bay, on the Friars Bay Anticline, and the youngest beds (Culver Chalk Formation) to the cliff top at Telscombe Cliffs (Portobello), in the core of the Newhaven Syncline (Figure 3.88). The beds then rise again westwards towards Brighton onto the more strongly folded Old Steine Anticline, with the oldest beds (*Marsupites testudinarius* Zone) being present between Roedean and Black Rock. To the west, the Seaford Chalk Formation (*Micraster coranguinum* Zone) is brought to the level beneath the beach opposite the Old Steine (Figures 3.85 and 3.88).

Barrois (1876) referred all of the Chalk in these cliffs (the 'Craie de Brighton') to his broad concept of the *Marsupites testudinarius* Zone. At Rottingdean, he recognized (1876, fig. 2) three conspicuous sheet- (tabular) flints overlain by a 4 inch (100 mm) thick marl (the Old Nore Marl), above which the chalk was nodular. In Rowe's (1900) account of these cliffs, he noted the regular marl bands and recognized his more restricted *Marsupites* Zone west of Roedean, overlain by the *Actinocamax* (i.e. *Gonioteuthis*) *quadratus* Zone with the band of abundant *Cardiaster* (i.e. *Offaster*) *pilula*. Rowe (1900) noted the common very large ammonites between Newhaven and Rottingdean, which stand proud on the wave-cut platform, and can reach 3 m in diameter. Jukes-Browne and Hill (1904, pp. 36–40) followed Barrois' and Rowe's descriptions. [British] Geological Survey memoirs (White, 1924) did not include details of this

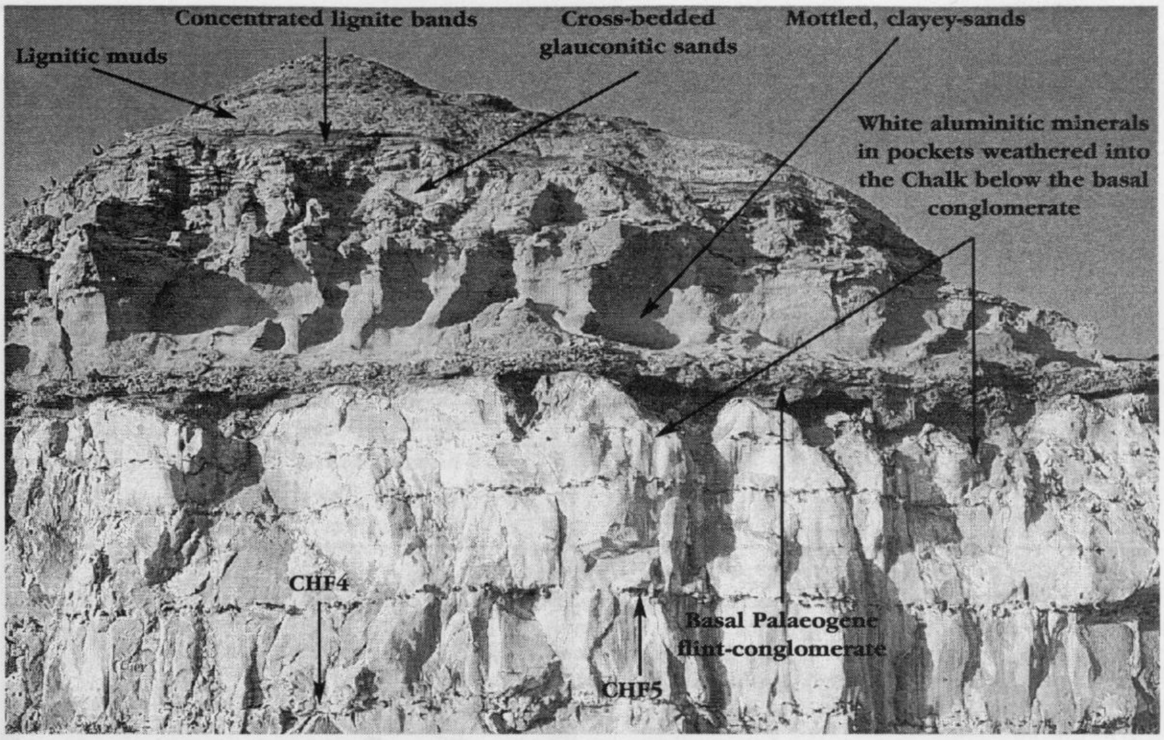


Figure 3.87 The cliffs beneath Castle Hill, Newhaven, with Palaeogene sediments resting unconformably on the Upper Cretacous Chalk (Culver Chalk Formation; Lower Campanian *G. quadrata* Zone). (CHF4, CHF5 = Castle Hill Flints 4 and 5.) (Photo: R.N. Mortimore.)

coast section until the Brighton and Worthing Memoir (Young and Lake, 1988).

Following the establishment of a separate *Offaster pilula* Zone and an overlying restricted *Actinocamax* (i.e. *Gonioteuthis*) *quadratus* Zone for the sections in Hampshire (Griffith and Brydone, 1911; Brydone, 1912), Brydone (1914, 1915) provided some measured sections of the Brighton cliffs showing the presence of numerous, laterally correlatable marl seams in the zones of *Marsupites testudinarius* and *Offaster pilula*. He also noted the persistence of some of the nodular flints and the irregular occurrences of the sheet-flints, commenting that the latter 'formed in cracks after the chalk had consolidated'. Like Barrois, Brydone (1914) was able to follow the Old Nore Marl (his '2 inch marl') through much of this stretch of cliffs. Brydone also indicated the fossils associated with these zones in Sussex and Hampshire; many of his fossil collections are in the Booth Museum, Brighton. Subsequently, Gaster (1924, 1928, 1941) gave further details for the recognition of these zones and revised the upper limit of the *pilula* Zone to include the basal part of Brydone's restricted *quadrata* Zone. Mortimore (1986a,b, 1997) gave the first account of the cliffs with measured sections, relating fossil occurrences to the detailed lithostratigraphy (Mortimore, 1986a, fig. 20). He introduced the Newhaven Chalk and Culver Chalk formations (then members), and their subdivisions with associated marker beds. Additional details of the biostratigraphy of these two formations, incorporating and updating Brydone's and Gaster's observations, were given by Wood and Mortimore (1988).

Lithostratigraphy

The Chalk of this long cliff section is divided into two main lithological units, the Newhaven Chalk and Culver Chalk formations of the White Chalk Subgroup, in ascending order. The Newhaven Chalk is characterized by numerous marl seams (Mortimore 1983, 1986a,b), and comprises the Chalk zones of *Uintacrinus socialis*, *Marsupites testudinarius*, *Uintacrinus anglicus* and *Offaster pilula*. The overlying Culver Chalk Formation (Mortimore, 1983, 1986a,b) is now

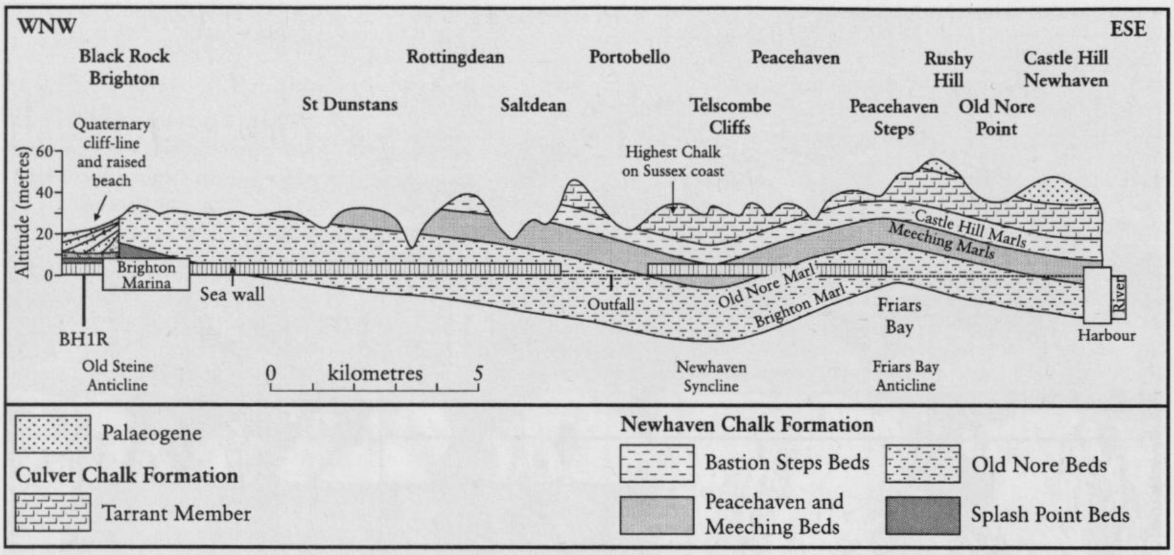


Figure 3.88 Schematic geological section of the Newhaven to Brighton cliffs GCR site showing the length of exposure in each of the main divisions of the Newhaven Chalk Formation and the length of section already covered by sea walls. Note the change from thinner beds at Friars Bay to thicker beds at Black Rock. The last vestiges of Palaeogene sediments capping Chalk die out at Portobello.

locally divided into a lower Tarrant Chalk Member and an upper Spetisbury Chalk Member (Bristow *et al.*, 1997); only the basal part of the Tarrant Chalk, comprising the lowest part of the *Gonioteuthis quadrata* Zone, is represented in these cliffs. The Newhaven Chalk Formation is divided into units (beds) at the Brighton Marl, Old Nore Marl, Peacehaven Marls and Meeching Marls; the Old Nore Beds, Peacehaven Beds, Meeching Beds and Bastion Steps Beds respectively (see Figure 3.88, Figures 3.101 and 3.102, pp. 231–2) (Mortimore, 1986a).

A small tectonic fold, the Friars Bay Anticline, brings low Newhaven Chalk Formation to the surface on the rock platform in Friars Bay, just west of Newhaven (Figure 3.88). The complementary Newhaven Syncline, to the north, with its axis running through Meeching, preserves the basal Culver Chalk and the overlying Palaeogene sediments. At Newhaven, the Castle Hill exposures are on the south-east limb of the Friars Bay Anticline and are approached from the east via Newhaven Harbour (Figures 3.86, 3.87 and 3.92). The relatively undisturbed outcrop of Palaeogene sediments that rests here unconformably on Culver Chalk provides an invaluable insight into these otherwise very poorly exposed Palaeogene deposits in the Sussex Downs. The 'angular' nature of the unconformity is not obvious at this site and can only be appreciated in a more regional context.

At the far western end of the Newhaven cliff is Old Nore Point, where the most conspicuous marl seam in the succession, the Old Nore Marl, forms a ledge in the cliff (Figure 3.92) and comes down to beach level eastwards. This marl is the thickest and most clay-rich of the marls in this part of the succession and it has recently been shown to be of volcanic origin (Wray, pers. comm.) and to correlate on biostratigraphical evidence with the vulcanogenic M1 marl in the Lägerdorf standard section in northern Germany (Wray, 1996). It is underlain by a band of small finger- and tube-flints, and marks a significant break in sedimentation and biostratigraphy.

Above the Old Nore Marl there is a distinctive group of marls and bands of large thalassinoid burrow-form flints, the Peacehaven Beds. Up-section, the marl seams form grooves or pale bands free of algal growth. The Peacehaven Marl, at the top of the Peacehaven Beds, again marks a break in the stratigraphy, with different forms of *Echinocorys* appearing in the overlying Meeching Beds. Similarly, the conspicuous Meeching Pair of Marls with associated red, iron-stained sponge beds mark an additional break in both the macrofossil and microfossil biostratigraphy, as well as the base of the Bastion Steps Beds. Below the Telscombe Marl 1 is the seam of scattered, mixed-sized and partly tubular

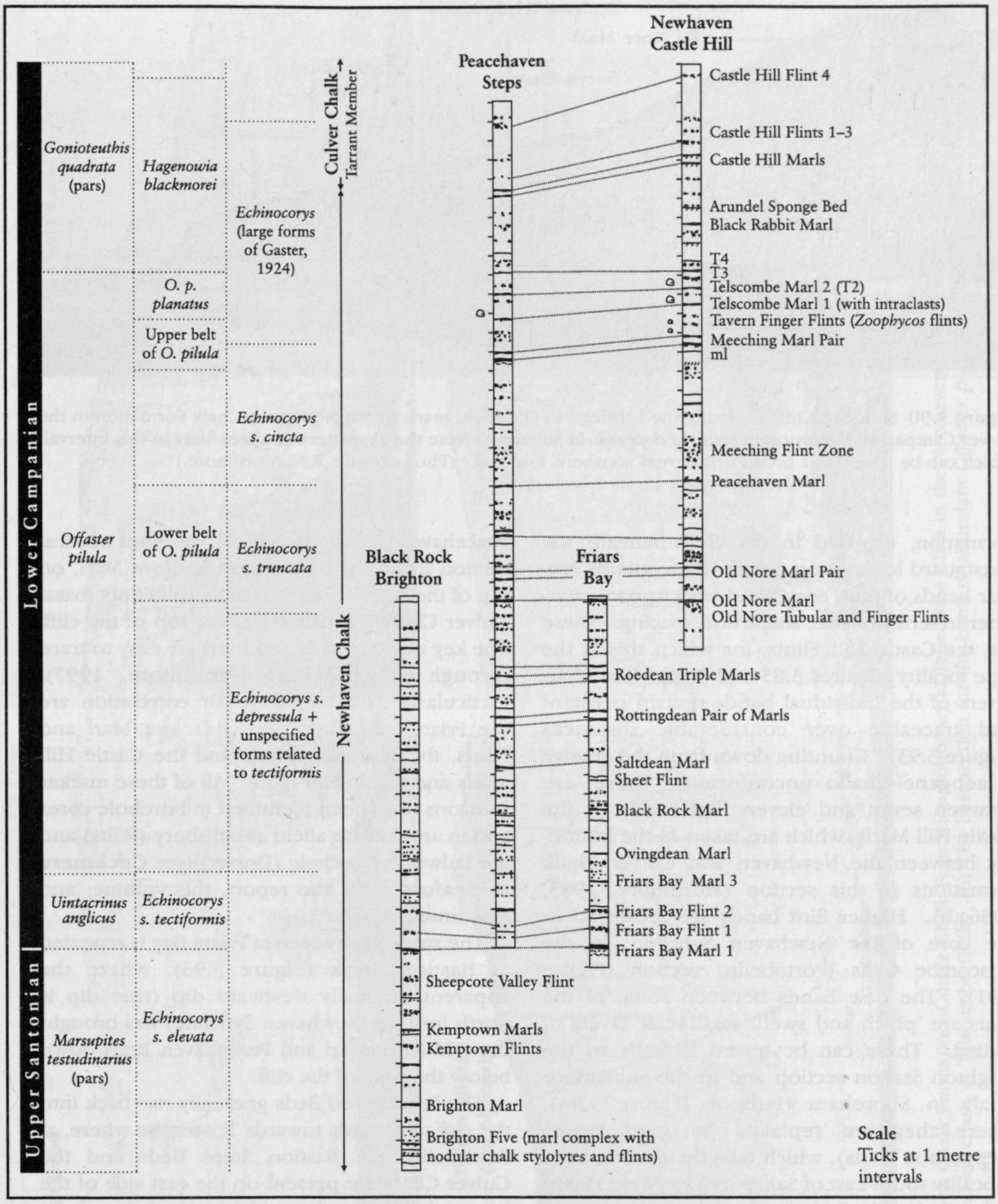


Figure 3.89 The Newhaven to Brighton coast sections showing the main Upper Cretaceous Chalk sections.

Tavern Flints. Telscombe Marl 1 contains abundant intraclasts of chalk, and marks the break between the occurrence of *Offaster pilula* below and the larger *Offaster pilula planatus* above. A red, iron-stained, intermittent sponge bed (Arundel Sponge Bed), occurs above the group of four Telscombe Marls.

Marl seams continue up to the Castle Hill Marls in this section, but these marls are only weakly developed here. The basal Culver Chalk

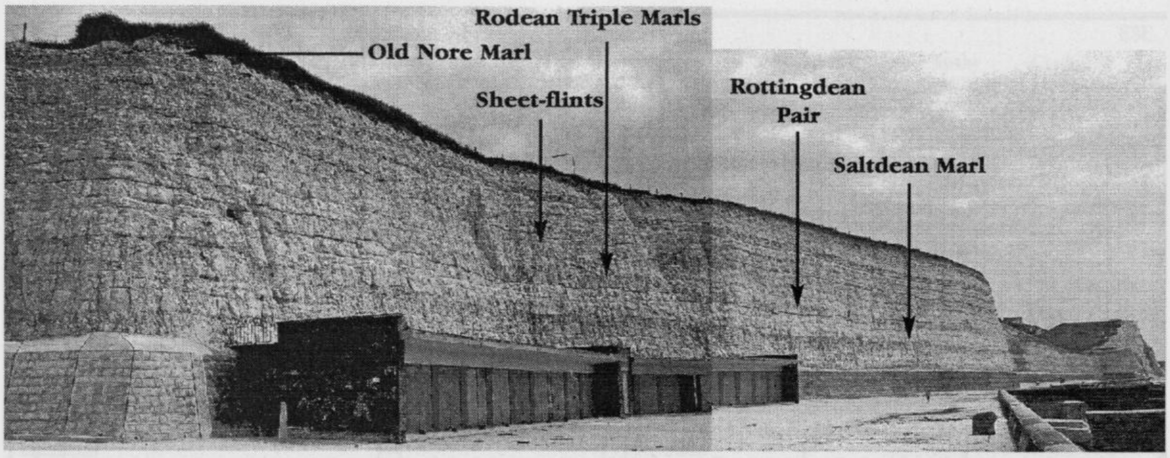


Figure 3.90 Saltdean Cliffs exposing the Saltdean to Old Nore marls in the Newhaven Chalk Formation in the Lower Campanian *Echinocorys scutata depressula* Subzone. Note the characteristic sheet-flints in this interval, which can be traced as a broad unit across southern England. (Photomosaic: R.N. Mortimore.)

Formation, exposed in the cliffs beneath the coastguard lookout on Castle Hill, contains regular bands of flint, each band with its own character in terms of size, shape and spacing. These are the Castle Hill Flints, for which this is the type locality (Figures 3.85 and 3.86). The characters of the individual bands remain constant and traceable over considerable distances (Figure 3.93). Counting down from the erosive Palaeogene–Chalk unconformity, there are between seven and eleven flint bands to the Castle Hill Marls, which are taken as the boundary between the Newhaven and Culver Chalk formations in this section (Mortimore, 1983, 1986a,b). Higher flint bands are preserved in the core of the Newhaven Syncline, in the Telscombe Cliffs (Portobello) section (Figure 3.91). The pale bands between some of the flints are 'pinch and swell' small-scale layers of sliding. These can be traced laterally to the Brighton Station section and to the subsurface Chalk in Shoreham Harbour (Figure 3.94), where they are replaced by marl seams (Pepperbox Marls), which take their name from a locality south-east of Salisbury (see **West Harnham Chalk Pit** GCR site report, this volume), where the base of the Culver Chalk Formation is taken at the highest Pepperbox Marl.

The cliffs and wave-cut platform east of the Peacehaven sea wall in Friars Bay expose the lower part of the Newhaven Chalk Formation (Splash Point and Old Nore Beds), including the Brighton Marl and marker marl seams and flint bands up to the Roedean Triple Marls. Peacehaven Steps provide an excellent vertical section from just below the Old Nore Marl, on top of the sea wall, to the Castle Hill Flints (basal Culver Chalk Formation), at the top of the cliff. The key marker marls and flints are easy to trace through the cliff face (Mortimore, 1997). Particularly useful markers for correlation are the Friars Bay Flints, the Old Nore Marl and Flints, the Meeching Marls and the Castle Hill Marls and Castle Hill Flints. All of these marker horizons have been identified in borehole cores and in areas as far afield as Salisbury (Wilts) and the Lulworth Borehole (Dorset) (see **Cuckmere to Seaford** GCR site report, this volume; and Mortimore, 1987).

The stratigraphy seen at Friars Bay is repeated at Bastion Steps (Figure 3.93), where the apparent gradually westward dip (true dip is north into the Newhaven Syncline) has brought the Old Nore Marl and Peacehaven Beds down below the base of the cliff.

The Peacehaven Beds gradually rise back into the cliff westwards towards Telscombe where, at Portobello, the Bastion Steps Beds and the Culver Chalk are present on the east side of the bay, and the Peacehaven Beds are seen on the west side (Figure 3.95). Immediately east of Portobello, the unprotected Telscombe Cliffs provide the finest exposure of the Meeching Marls and the interval containing the Tavern Flints (named after the Telscombe Tavern on the cliffs above), the Telscombe Marls and the Castle Hill Marls and Castle Hill Flints. Telscombe Marl 1 shows again its characteristic intraclasts. The

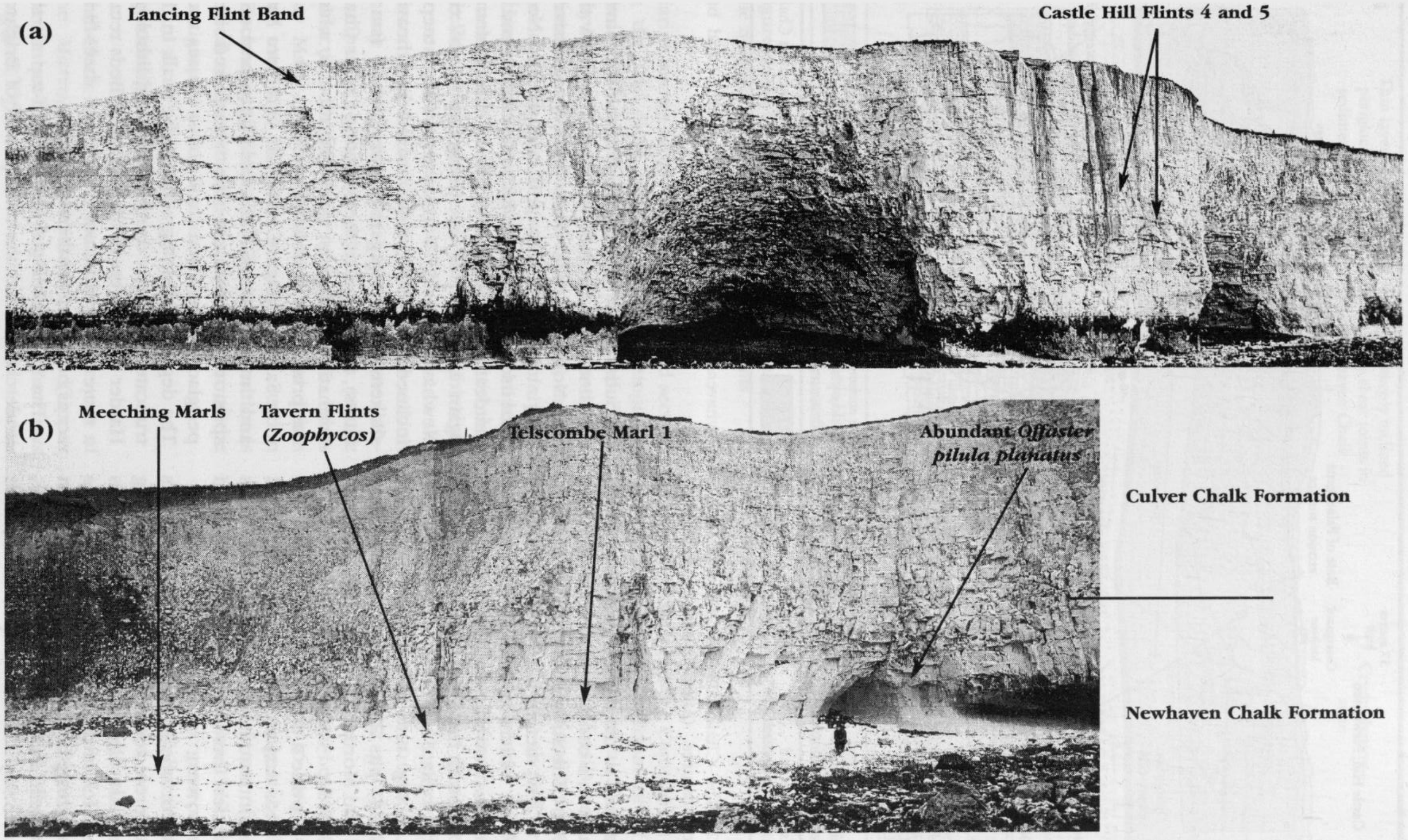


Figure 3.91 The Newhaven Chalk Formation–Culver Chalk Formation boundary at Telscombe Cliffs in the Newhaven to Brighton GCR site. (a) The youngest Chalk preserved on the Sussex coast, at Telscombe Cliffs. (b) The best section for the band of abundant *Offaster pilula* and large *O.p. planatus* in England. (Photomosaic: R.N. Mortimore.)

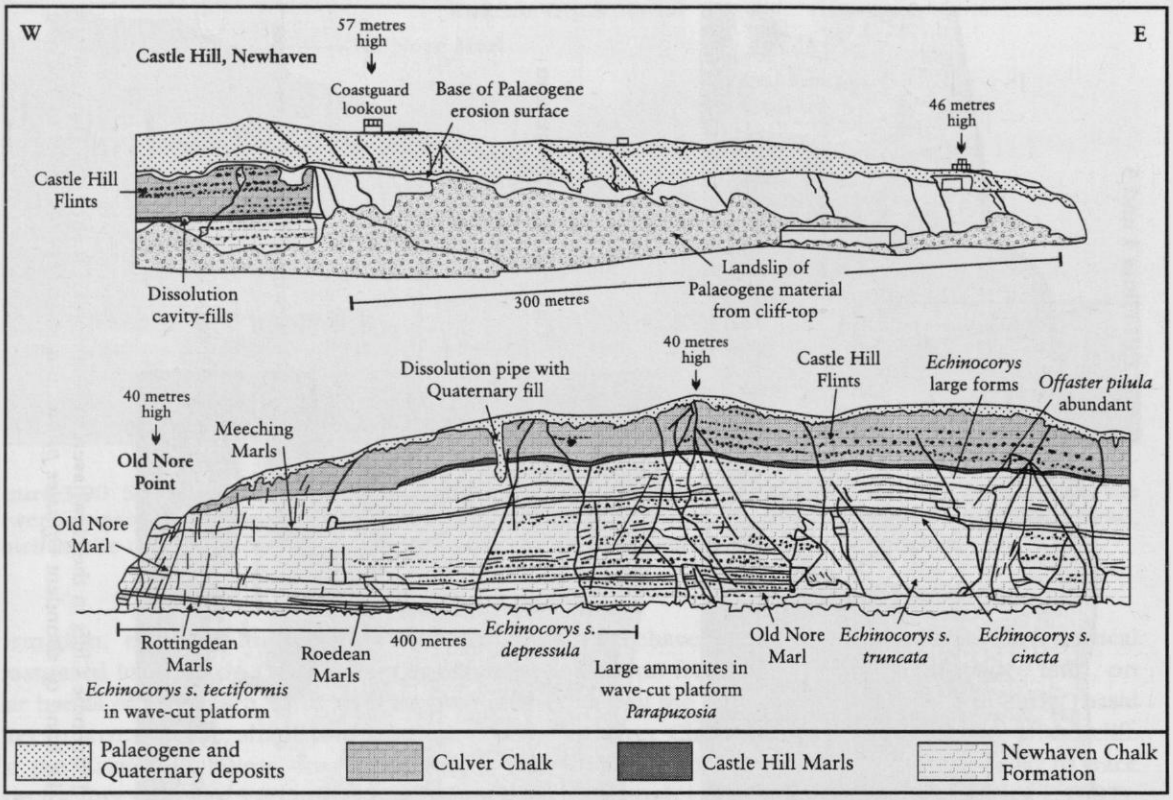


Figure 3.92 The Chalk cliffs on the west side of Newhaven Harbour showing the key litho- and biostratigraphical features. (After Mortimore, 1997.)

cliffs above, and to the east, expose the highest beds available in a continuous section in Sussex (Figure 3.91). The succession here extends up to a level a few metres above the prominent Lancing Flint, which is heavily iron-stained where water has flowed along it. These highest beds are still low in the Culver Chalk Formation, but probably equate with sections in chalk pits around Lancing and Worthing, especially Gaster's (1924) pits 2 and 3 at North Lancing (see Wood and Mortimore, 1988, fig. 20; Mortimore, 1986b fig. 3.19). Telscombe Cliffs at Portobello provide a critical section for the correlation of beds that are otherwise either buried or only discontinuously exposed in numerous small quarries on the West Sussex and Hampshire Downs.

Between Portobello and Saltdean, the cliffs are again unprotected by a sea wall, providing one of the last clean, wave-washed sections along this stretch of coast. The Old Nore Marl is exposed just above beach level immediately west of the Portobello Pumping Station (Mortimore, 1997; Figure 3.95). The true dip direction here is south on the northern limb of the Newhaven Syncline. As a result of this dip, beds below the Old Nore Marl (Old Nore Beds) progressively rise into the cliff westwards, and the Old Nore Marl itself is high in the cliff at the eastern end of Saltdean sea wall. This section of cliff illustrates again the style of fracturing typical of the Newhaven Chalk Formation, with steeply inclined (60°– 70°), clay-smeared and heavily slickensided conjugate shear planes (small faults), in contrast to the overlying Culver Chalk Formation on the east side of Portobello, which has primarily vertical joint sets.

At Saltdean (Figure 3.90), the Old Nore Marl and the Peacehaven Marls and Flints form conspicuous features in the weathered and periglacially disturbed chalk above the sea wall. The degree of disintegration of the chalk in the truncated valleys is controlled by bed lithology. Harder chalk layers in the Old Nore Beds retain a more blocky structure. Marls and sheet-flints act as breaks in weathering grade.

The path leading from the cliff-top to the undercliff walk at the eastern end of Brighton

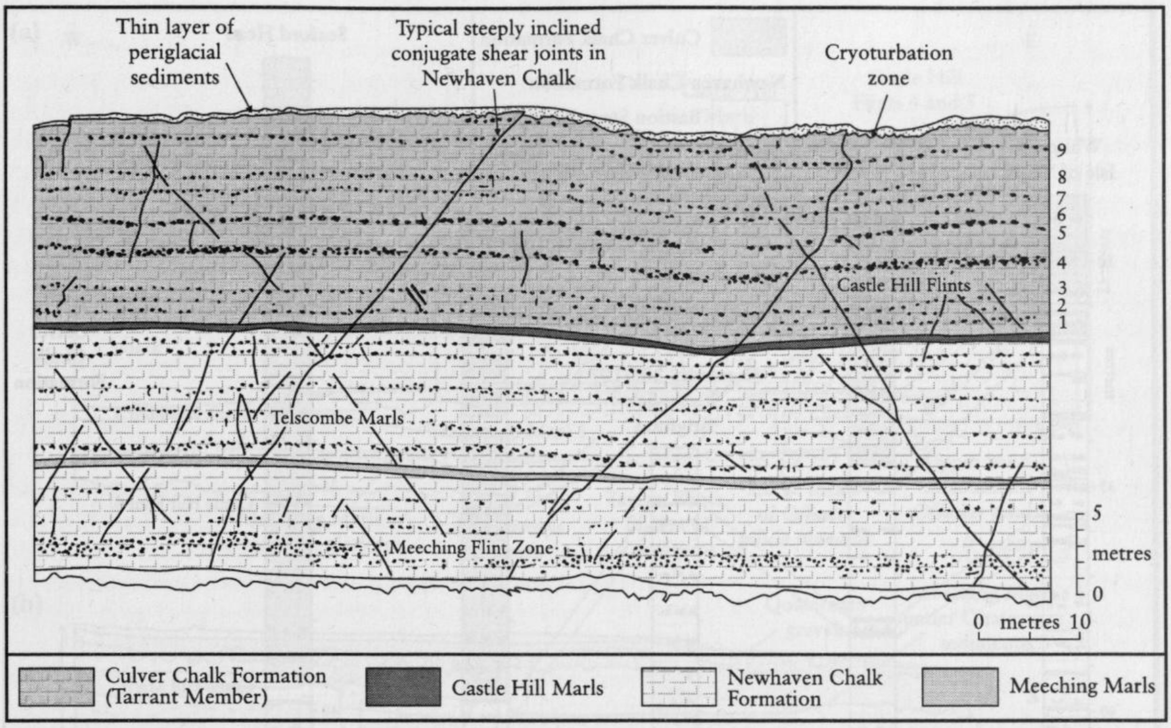


Figure 3.93 The Newhaven and Culver Chalk succession exposed in the cliffs at Bastion Steps, Peacehaven. The numbers 1–9 refer to the Castle Hill Flints.

Marina allows access to an air-weathered section in the Old Nore Beds from the Rottingdean Marls down to the Friars Bay Flints and Friars Bay Marls. *Uintacrinus anglicus* Rasmussen and *Marsupites testudinarius* (Schlotheim) can be found in the basal exposures along this path. Abundant worn specimens of the rhynchonellid brachiopod *Cretirhynchia exsculpta* Pettitt, and beekitized fragments of inoceramid bivalves occur on the wave-cut platform adjacent to the eastern harbour wall of the Marina. This section is one of the most accessible at the Santonian–Campanian boundary, which is taken at the extinction of *Marsupites testudinarius* in Friars Bay Marl 1. In conjunction with the Friars Bay exposure and the Seaford Head section (**Cuckmere to Seaford** GCR site), this section is critical to the international investigation of the stratigraphy at this boundary.

Biostratigraphy

The Chalk of the site spans the higher part of the *Marsupites testudinarius* Zone (Upper Santonian Substage), and the *Uintacrinus anglicus*, *Offaster pilula* and basal *Gonioteuthis quadrata* zones (Lower Campanian Substage). For details of the development of the zonal scheme and the stratigraphical ranges of key macrofossils and microfossils see Mortimore (1986a, fig. 20) and Wood and Mortimore (1988, pp. 58–64, figs 18, 19). It should be noted that in the last of these references the base of the Campanian Stage was drawn at the top of the *Uintacrinus anglicus* Zone and not, as recommended by the Brussels Symposium on Cretaceous stage boundaries (Hancock and Gale, 1996), at the extinction level of *Marsupites*.

The Upper Santonian–Lower Campanian Chalk in the Newhaven to Brighton cliffs is characterized by a wide range of echinoids. The succession of distinctive forms of *Echinocorys*, first identified by Brydone (1912, 1914, 1915) and Gaster (1924), is of great stratigraphical value. These stratigraphically restricted forms are conventionally treated as subspecies of *Echinocorys scutata*, a species that occurs in the *Micraster coranguinum* Zone. The abundance of *Echinocorys* in the cliff exposures of this site has enabled the *Echinocorys* biostratigraphy to be established in detail.

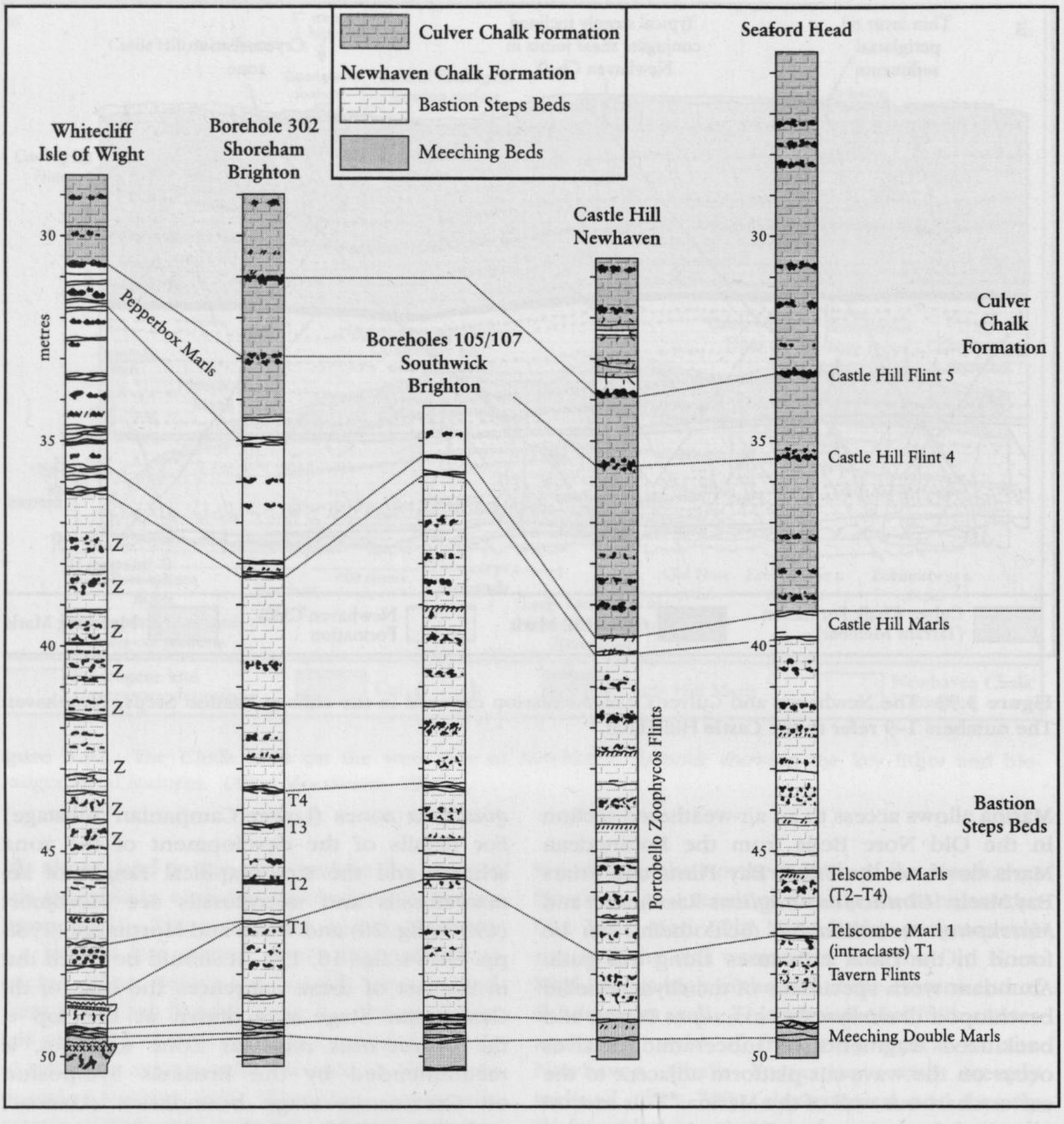


Figure 3.94 Correlation of the upper beds of the Newhaven Chalk Formation from Newhaven to adjacent areas and to the Isle of Wight. This shows the diachronous nature of the Culver Chalk Formation. (z = *Zoophycos* flints.) (After Mortimore and Pomerol 1997, fig.10.)

i *E. scutata elevata* Griffith and Brydone occurs in two bands between the Brighton Marl and Friars Bay Marl 1.

ii *E. s. tectiformis* Griffith and Brydone is found in and above the Friars Bay Marls, which are on either side of the horizon with *Uintacrinus anglicus* (Rasmussen).

iii *E. s. depressula* Brydone occurs sporadically as low as the Sheepcote Valley Flints in the *M. testudinarius* Zone, where it is associated with *Conulus* and *Micraster*, but it is not abundant until levels around the Rottingdean Pair of Marls.

iv *E. s. truncata* Brydone is concentrated mainly in the lower belt of *Offaster pilula* (Lamarck) between the Old Nore Marl and the Peacehaven Marl (Peacehaven Beds).

v *E. s. cincta* Griffith and Brydone is concentrated mainly in a belt below and in the Meeching Pair of Marls, but

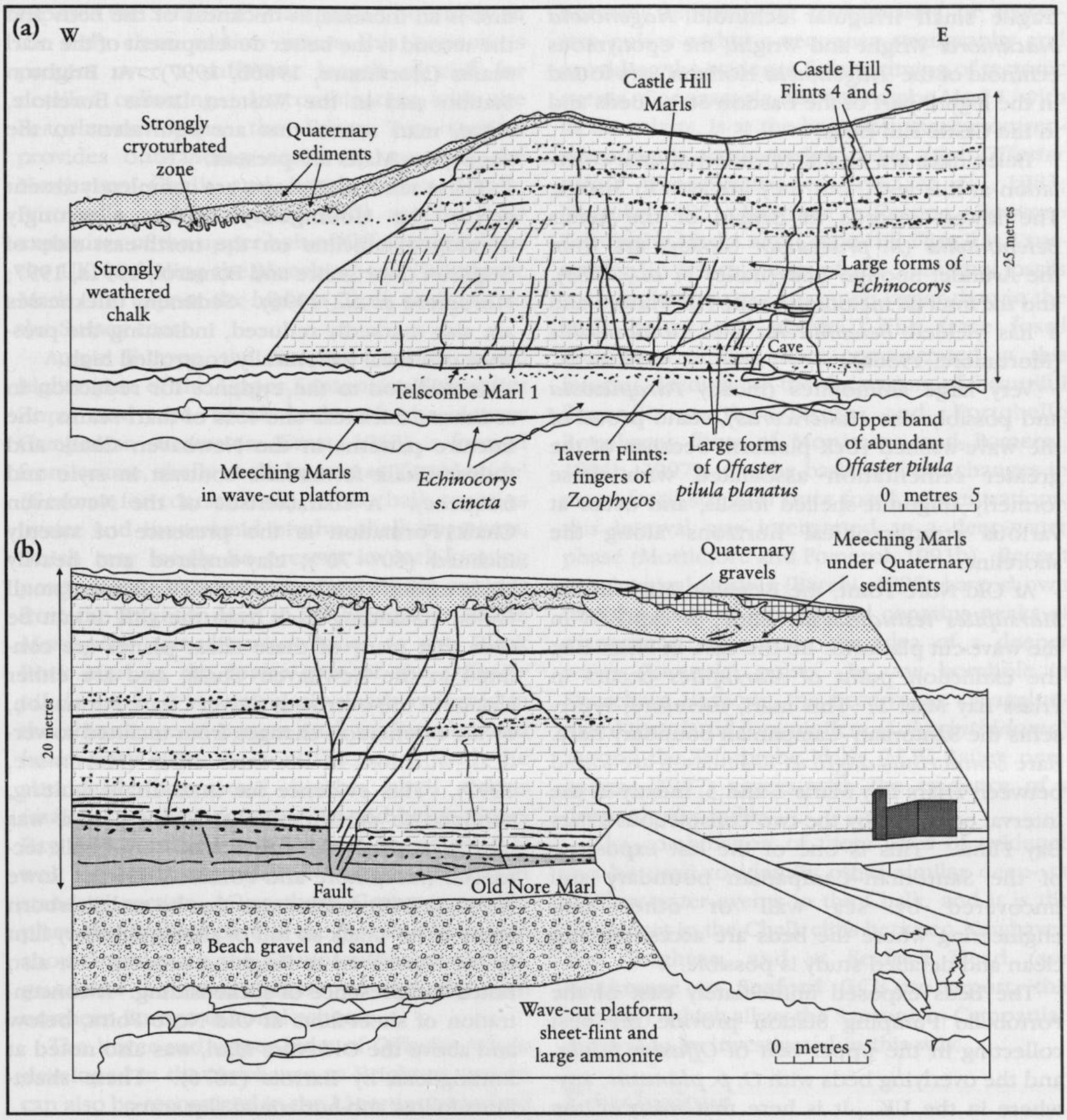


Figure 3.95 The Portobello locality in the Brighton and Newhaven Cliffs GCR site. (a) The Bastion Steps Beds and basal Culver Chalk Formation exposed at the southeastern end of the Portobello locality. (b) The chalk exposed at the north-western end of the Portobello locality.

is also found throughout the Meeching Beds.

vi The upper belt of *Offaster pilula* and the overlying three bands with the larger *O. pilula planatus* (Brydone, in manuscript; Ernst) are found by identifying the interval from the Tavern Flints up to the top of the Telscombe Marls; this is also the level of the 'large forms of *Echinocorys*' (Gaster, 1924).

Other echinoids are also present in these cliffs. *Micraster* is more common in the crinoid and lower *O. pilula* zones than in the underlying *M. coranguinum* Zone. Very small and rare *O. pilula* are found in beds below the Old Nore Marl. The three bands of large *O. pilula planatus* occur between the Telscombe Marls (Brydone's 'Planoconvexus Bed') and the upper belt of normal sized *O. pilula* is below these marls and associated flints. Bands with the fragile small irregular echinoid *Hagenowia blackmorei* Wright and Wright, the eponymous echinoid of the '*Hagenowia* Horizon', are found in the higher part of the Bastion Steps Beds and in the Castle Hill Beds.

Belemnites are crucial for international correlation at this level, but they are rare in Sussex. The lowest records in Britain of the genus *Belemnitella* (*B. praecursor* Stolley) are from the Arundel Sponge Bed (Bailey *et al.*, 1983), and the interval including Castle Hill Flints 3 and 4 has yielded *Belemnitella* and *Gonioteuthis* (Mortimore, 1986a).

Very large ammonites (mostly *Parapuzosia* and possibly also *Hauericeras*), stand proud of the wave-washed rock platform because of the greater cementation associated with these formerly aragonite-shelled fossils, and occur at various stratigraphical horizons along the shoreline.

At Old Nore Point, the Brighton Marl, in the *Marsupites testudinarius* Zone, is exposed in the wave-cut platform. To the east, in Friars Bay, the extinction point of *Marsupites* occurs in Friars Bay Marl 1. This marl, therefore, represents the Santonian–Campanian boundary here. Rare *Uintacrinus anglicus* Rasmussen are found between Friars Bay Marls 1 and 3, mostly in the interval occupied by the two conspicuous Friars Bay Flints. This is one of the last exposures of the Santonian–Campanian boundary still uncovered by sea wall or other civil engineering where the beds are accessible and clean and detailed study is possible.

The beds exposed immediately east of the Portobello Pumping Station provide the best collecting in the upper belt of *Offaster pilula*, and the overlying beds with *O. p. planatus*, anywhere in the UK. It is here that many of the fragile *Offaster* and *Hagenowia* can be seen weathered out in the cliff.

In addition to the more conspicuous macrofossils, there are abundant mesofossil marker beds, including the changes of shape in the calyx and columnals of the crinoid *Bourgueticrinus*. Ranges and abundance levels of foraminifera and the nannofossils are also used (see **Cuckmere to Seaford** GCR site report, this volume).

Interpretation

As the various beds of the Newhaven Chalk are traced westwards from Newhaven to Brighton there are two changes to the sediments. The first is an increase in thickness of the beds and the second is the better development of the marl seams (Mortimore, 1986b, 1997). At Brighton Station and in the Western Lawns Borehole, Hove, marl seams that are equivalent to the Pepperbox Marls are present.

These same marl seams are completely absent across the Hollingbury Dome, a strongly developed anticline on the north-east side of Brighton (Mortimore and Pomerol, 1991a, 1997; Mortimore *et al.*, 1996). Sediment thicknesses are also markedly reduced, indicating the presence of a local tectonically controlled high.

In addition to the evidence for reduction in sediment thickness and loss of marl seams, the fracture patterns in the Newhaven Chalk and Culver Chalk formations contrast in style and frequency. A characteristic of the Newhaven Chalk Formation is the presence of steeply inclined (60°– 70°), clay-smeared and heavily slickensided conjugate shear planes (small faults). Standing back from the cliff, it can be seen that many of these shear planes are confined to the Newhaven Chalk, and are either absent in the overlying Culver Chalk Formation, or the orientation changes from inclined to vertical, with loss of the fault offset (Mortimore, 1997). This evidence for intra-Chalk faulting, confined to particular units of the Chalk, was used to support the concept of intra-Chalk tectonism (Mortimore and Pomerol, 1987). Rowe (1900, p. 340) commented that he and Sherborn knew of no Chalk so full of sheet- (tabular) flint as the Newhaven to Brighton section. He also noted the presence of slickensiding. A concentration of sheet-flints at Old Nore Point, below and above the Old Nore Marl, was also noted at Rottingdean by Barrois (1876). These sheet-flints follow sub-horizontal slip scars.

Between Newhaven and Brighton there are some of the finest sections in Upper Santonian to Lower Campanian chalks in Europe. The cliff at Castle Hill, Newhaven, in addition to exposing the contact between the Newhaven Chalk and overlying Culver Chalk formations, is the only locality in Sussex where the sub-Palaeogene unconformity and the early Palaeogene sediments can be studied *in situ* (i.e. undisturbed by dissolution pipe collapse). On the wave-cut platform beneath these cliffs there is an outstanding exposure in the Meeching Beds containing forms of *Echinocorys* that do not conform to the main types described by Brydone (1912, 1914) and Gaster (1924). Friars Bay exposes the Santonian–Campanian boundary in the only clean section where this horizon is present over a sufficient length of cliff for detailed collecting. In combination with the Peacehaven Steps, the Friars Bay section provides outstanding access to most of the Newhaven Chalk and basal Culver Chalk. Portobello and Telscombe Cliffs are the best exposures of the upper belt of *Offaster pilula* in the UK, including the Meeching and Telscombe Marls, and expose the highest Chalk available on the Sussex coast.

Across Europe, the interval comprising the higher part of the Upper Santonian *Marsupites* Zone and the basal beds of the Lower Campanian succession (Ernst, 1963) is formed from coarse, shelly chalk known as 'Grobkreide' (German for coarse chalk). This chalk contains oyster and inoceramid bivalve shell fragments, which may locally be present in rock-forming proportions. In Sussex, the Grobkreide extends from the Brighton Marl in the higher part of the *Marsupites testudinarius* Zone, to the Black Rock Marl in the lower part of the *Offaster pilula* Zone. It is particularly clearly reflected in the abundance of oysters such as *Pseudoperna boucheroni* (Woods *non* Coquand) and the abundant inoceramid bivalve shell debris (mainly of *Sphenoceramus*) in and below Friars Bay Marl 1 in the Friars Bay section, where it is well exposed. Correlation with the Lägerdorf standard section, in northern Germany, would place this highest part of the Sussex succession about halfway up the *Gonioteuthis granulata-quadrata* belemnite Zone of the standard northern European zonal scheme.

The lower and upper belts of *Offaster pilula* developed in the Newhaven to Brighton section can also be recognized in the Lägerdorf standard section in northern Germany (Schönfeld and Schulz, 1996, fig. 2). The base of the lower belt in both sections is marked by a conspicuous, thick vulcanogenic marl seam, the Old Nore Marl and M1 respectively. The correlative in Sussex of the vulcanogenic M2 marl of the German succession has not yet been identified.

The ranges of the common fossils from the Newhaven to Brighton cliff sections have been plotted against the lithological column (Mortimore, 1986a,b; Wood and Mortimore, 1988). These provide one means of detailed international correlation and research continues on the sections. Of increasing importance to international correlation is the identification of horizons representing transgressive or regressive pulses within a sequence stratigraphy and providing the evidence for the timing of tectonic events. For example, the Telscombe Marl 1, with its intraclasts, is at the base of a succession representing a transgressive pulse (the *Offaster pilula* transgression of Ernst *et al.*, 1983; Niebuhr, 1995) elsewhere in Europe. Between Telscombe Marl 1 and Castle Hill Flint 4 is a succession in which many of the common fossils such as *Echinocorys* are much larger than in the beds below and above. The trace fossil *Zoophycos* is also more concentrated in this interval, leading to the formation of beautiful finger-flints (the Tavern and Portobello Zoophycos flints of Mortimore and Pomerol, 1991b, 1997). On the basis of these changes in macrofossil size and trace fossil concentrations, this interval was interpreted as a deep-water phase (Mortimore and Pomerol, 1991b). Recent geochemical studies (Barchi, 1995) have shown that the chalk of this interval contains peaks of manganese, supporting the idea of a deeper water (?oceanic) pulse. In one borehole in Shoreham Harbour, the occurrence of agglutinated textulariid foraminifera (*Labyrinthidoma*) around the Telscombe Marls (H.W. Bailey, pers. comm., 1997) agrees with the evidence of a deeper water pulse.

The combination of these lines of evidence can be used to identify other similar deep- or shallow-water events in the Chalk, and it is the exposures in the Chalk cliffs between Newhaven and Brighton, and at Seaford Head (see **Cuckmere to Seaford** GCR site report, this volume), which allow the Santonian–Campanian interval to be investigated in this way.

Conclusions

The Newhaven to Brighton coast section is unique in Europe for the length of exposure and stratigraphical completeness of the Lower Campanian Chalk, with the entire cliffs from Newhaven to Brighton forming a geological SSSI, but with special features at Newhaven, Portobello and Black Rock. Only at the Lägerdorf–Kronsmoor quarries in Schleswig-Holstein, northern Germany, is there another almost continuous section in this stratigraphical interval. This is used as a European chalk facies standard section (Schönfeld and Schulz, 1996), but these key sections are rapidly degrading.

The Newhaven to Brighton sections provide critical supporting evidence for the Newhaven Chalk Formation stratotype section (see **Cuckmere to Seaford** GCR site report, this volume), and extend the stratigraphy to higher levels in the Culver Chalk Formation than at Seaford Head. Without these coastal cliff sections it would be difficult to interpret the many small, discontinuous sections exposed in inland chalk pits and quarries around Worthing and Chichester, West Sussex and south Hampshire, as well as those in Wessex, East Anglia and Northern Ireland. These coast sections, in combination with the **Downend Chalk Pit** and Portsdown sections described previously, also provide evidence for intra-Late Cretaceous sea-level fluctuations and tectonic pulses. The Newhaven to Brighton site links to **West Harnham Chalk Pit**, Salisbury and **Whitecliff**, Isle of Wight (see GCR site reports, this volume).

It is only on the wave-cut platform that ammonites can be readily seen and identified, so this platform also forms an essential part of the site. Belemnites, critical for international correlation, are relatively rare and long lengths of exposure are required if they are to be found. Any reduction in exposure will, therefore, limit the value of the site.

CUCKMERE TO SEAFORD, SUSSEX (TV 515 976–TV 488 982)

Introduction

Cuckmere to Seaford forms a 3 km sea-cliff section between Cuckmere Haven in the east and the Seaford Sewer Outfall groyne in the west, at the eastern end of the Seaford Town coast road (Figure 3.96). It is one of the most complete, continuous and accessible sections in the White Chalk Subgroup in the Southern Province, with excellent wave-washed exposures. This highly fossiliferous section spans the higher part of the Lewes Nodular Chalk Formation, the stratotype Seaford Chalk Formation, the Newhaven Chalk Formation and the basal part of the Culver Chalk Formation. The major lithological changes from the relatively gritty chalks of the Lewes Nodular Chalk Formation to the less gritty, pure white chalks of the Seaford Chalk Formation, followed by the entry of regular marl seams in the Newhaven Chalk Formation, are all well displayed. The site additionally constitutes the type section for the bases of the Seaford Chalk and the Newhaven Chalk

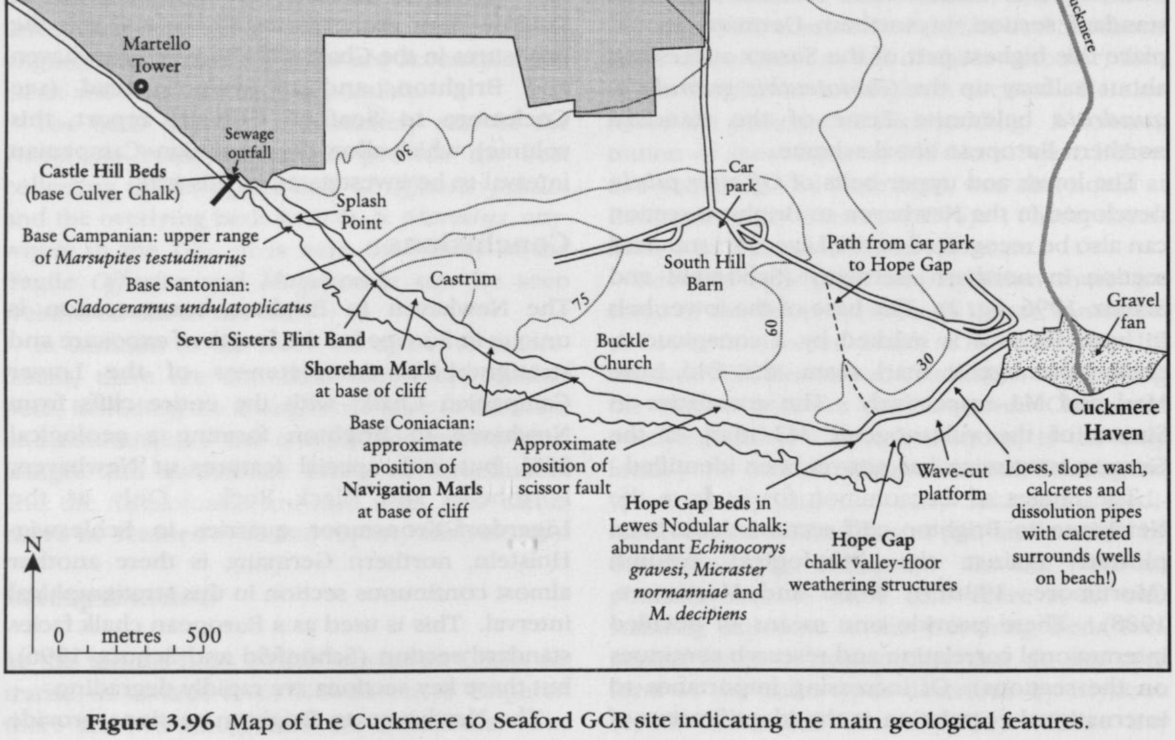


Figure 3.96 Map of the Cuckmere to Seaford GCR site indicating the main geological features.

formations. The entire Coniacian and Santonian stages, as well as the lower part of the Lower Campanian Substage are exposed and the section is currently being investigated as a candidate Global boundary Stratotype Section and Point (GSSP) for both the Santonian and Campanian stages.

The coastal geomorphology is also outstanding. The east side of Seaford Head provides the finest view across the Cuckmere Valley to the classic truncated-valley Chalk cliff-line of the Seven Sisters, within which the conspicuous dark line of the Seven Sisters Flint Band, dipping south-east towards Birling Gap, is clearly visible. At the eastern end, at Hope Gap, the cliffs are capped by Quaternary loess. West of Hope Gap, dissolution pipes are present, filled with a mixture of Clay-with-flints and/or loess. Towards the Castrum these pipes extend deeply into the Chalk giving a castellated skyline (Mortimore, 1997). At the western end of the cliff, the Chalk section is terminated by the sub-Palaeogene unconformity, above which are the sands, lignites and clays of the Early Palaeogene that are also seen at Castle Cliff, Newhaven.

Description

There are two major parts to the GCR Site. The first encompasses what Rowe (1900) described as 'the finest section for collecting fossils in the *Micraster cortestudinarium* Zone (upper Lewes Nodular Chalk Formation) in England'. This stretches for about 1.5 km from the Old Coast Guard cottages at Cuckmere Haven, eastwards through Hope Gap, to the point in the high cliff known as the Castrum, and includes the Turonian–Coniacian boundary. The second part of the site, from the Castrum westwards to the Sewer Outfall Groyne (Figure 3.96), exposes perhaps the most accessible, continuous section in the Upper Coniacian, Santonian and Lower Campanian substages in Europe. It includes the Coniacian–Santonian and Santonian–Campanian boundaries in beds that dip gently north at 10°, giving access to each bed in turn in clean, wave-washed sections. The site includes the cliff and its associated wave-cut platform. Both are essential for the measurement of sections, and for the collection of fossils and rock samples from this internationally important section.

Barrois (1876) commented briefly on the Chalk from Cuckmere to Seaford, but erroneously correlated the Seven Sisters Flint Band at Birling Gap with Whitaker's 3-inch Flint Band of the **Thanet Coast**. He also correlated the Cuckmere Sponge Bed, 6 m above the flint band, with a similar sponge bed on Thanet (Barrois' Sponge Bed). Consequently, Barrois placed much of the cliff in the *Marsupites* Zone. Rowe (1900) was aware of this error, and coined the name 'Barrois' Spurious Sponge Bed' for the Sussex sponge bed. He was the first worker to give details of the site. Rowe recognized the *Micraster cortestudinarium* Zone in the eastern part of the site, overlain in turn by the *Micraster coranguinum* Zone, the '*Uintacrinus* band' and '*Marsupites* band' of the *Marsupites testudinarius* Zone and the lower part of the *Actinocamax* (i.e. *Gonioteuthis*) *quadratus* Zone in the western part. The *Offaster pilula* Zone had not been introduced at that time, although Rowe realized the usefulness of *Cardiaster* (i.e. *Offaster*) *pilula* as a guide fossil to the lower part of the then current concept of an *Actinocamax quadratus* Zone.

Rowe (1900) thought that lithological marker beds could not be used for correlation, citing Barrois' mistake as supporting evidence, but he nevertheless chose lithological beds as boundaries to his zones. Beneath the Castrum at Seaford Head (Figure 3.96) he took the upper of two marls (the 'closed marl') (i.e. Shoreham Marl 2), as the boundary between the *M. cortestudinarium* and *M. coranguinum* zones. This marl contrasted with his 'open marl' (Shoreham Marl 1) below, and additionally formed a conspicuous failure plane in the cliff above and eastwards, making a '...hanging ledge'. Rowe drew the base of the *Uintacrinus* band of the *Marsupites* Zone (i.e. the base of the *Uintacrinus socialis* Zone) at the upper of two strong flint bands, 9 ft (3.7 m) apart, located 760 ft (230 m) measured horizontally along the beach from the old groynes at the western end of the site. These flint bands are the Exceat and Buckle flint bands respectively (Mortimore, 1986a; Figure 3.101, p. 231) and the accuracy of Rowe's measurement was confirmed during reinvestigation of this stretch of beach in the 1970s. Rowe also recorded a horizontal measurement of 242 ft (73 m) from the Buckle Flint to the Upper Shoreham Marl (i.e. the *Micraster coranguinum*

Zone) and he recognized that the cliffs at the western end of the site (Newhaven Chalk Formation) were '...seamed with marl'.

Subsequent researchers followed Rowe's biostratigraphical approach, but Brydone (1914) included measurements between some of the marl seams in the Newhaven Chalk. E.R. Martin's unpublished field notes (1923–1955) through this section also provide some detailed measurements and photographs of the state of the cliffs at that time. Martin also made an extensive collection of *Micraster* from the site. The first detailed account, making use of a correlatable, formalized lithostratigraphy as a framework for the ranges of common fossils, was introduced by Mortimore (1983, 1986a, 1997). The base of the Culver Chalk Formation in this section is taken at Castle Hill Marl 2.

Cuckmere to Seaford is on the crest of the Seaford Head Anticline, which dips north at 10°, bringing the Lewes Nodular Chalk Formation to the wave-cut platform east of the Castrum (Figures 3.96 and 3.97). Palaeogene sediments are preserved northwards beneath Seaford Town in the complementary syncline. There is no direct correlation from the eastern end of Seaford Head across Cuckmere Haven to the exposures visible in the first of the Seven Sisters. These coast sections are oblique to the southerly dip, and the dip across the gap in exposure formed by Cuckmere Haven could account for the different levels in the Chalk on the two sides of the Haven. However, Elsden (1909) and Gaster (1939) both required a fault along the Cuckmere Valley offset to Jevington, in order to account for the stratigraphical discrepancy between the two sides of the valley. The possibility of a north-east-trending fault is supported by seismic evidence (Smith and Curry, 1975). Small-scale slump beds in the Lewes Nodular Chalk Formation at Hope Gap provide evidence for intra-Chalk (Coniacian) tectonic movements that can be related to the Ilsede Phase of Subhercynian tectonism (Mortimore and Pomerol, 1997; Mortimore *et al.*, 1998). A sequence stratigraphical interpretation for the Coniacian and Santonian part of this section has been given by Grant *et al.* (1999). The cliffs between Hope Gap and the Castrum expose highly fossiliferous beds in the topmost Turonian and basal Coniacian strata. To the west, the northerly dip caused by the Seaford Head Anticline brings each bed to shore-level in turn.

Lithostratigraphy

Seaford Head cliffs are cut entirely in the White Chalk Subgroup, exposing the upper part of the Lewes Nodular Chalk Formation, the Seaford Chalk and Newhaven Chalk formations, and the basal part of the Culver Chalk Formation. It is the stratotype section for both the Seaford Chalk and Newhaven Chalk formations.

Lewes Nodular Chalk Formation

The eastern part of the cliff from the Castrum towards Cuckmere Haven and Hope Gap Steps is entirely in Lewes Nodular Chalk Formation (Figures 3.96 and 3.97). Because of the dips on the Seaford Head Anticline, the oldest Lewes Nodular Chalk is brought to the surface just east of the Castrum. From this point, both east and west, there is a complete, continuous section through most of the upper Lewes Nodular Chalk, from the Navigation Hardgrounds up to the Shoreham Marls at the boundary between the Lewes Nodular Chalk and Seaford Chalk formations. Mortimore (1986a) divided the upper Lewes Nodular Chalk Formation into a number of sedimentary packages or beds defined by the most conspicuous marker beds, which are generally mineralized hardgrounds or marl seams (Figure 3.97).

At the base of the cliffs, just east of the Castrum, the two well-developed, 0.05–0.07 m thick Navigation Marls, are 0.5 m apart and are associated with layers of intraclasts. The top surface of the upper Navigation Marl is taken as the boundary between the Navigation and Cliffe beds. Beneath the marls are two indurated and mineralized, 'knobbly' hardgrounds of the Navigation Beds. To the east, the beds above the Navigation Marls are progressively exposed, including excellent sections of the Cliffe and Hope Gap hardgrounds.

The Hope Gap Steps cliff section (Figure 3.97) shows good examples of the commonly occurring alternation between a lower very grey, soft chalk, and the overlying red, iron-stained nodular layers in which the grey sediment forms the burrow-fill. These are the A (grey) and B (nodular) units, which together form a single bed of chalk or couplet. The Hope Gap Hardground, 20 m west of the 'Steps', is the uppermost of a series of red, iron-stained nodular and hardground surfaces. It is overlain by a conspicuous sheet-flint, which crudely follows the 'streaky' Beeding Marl seam. The sheet-flint is

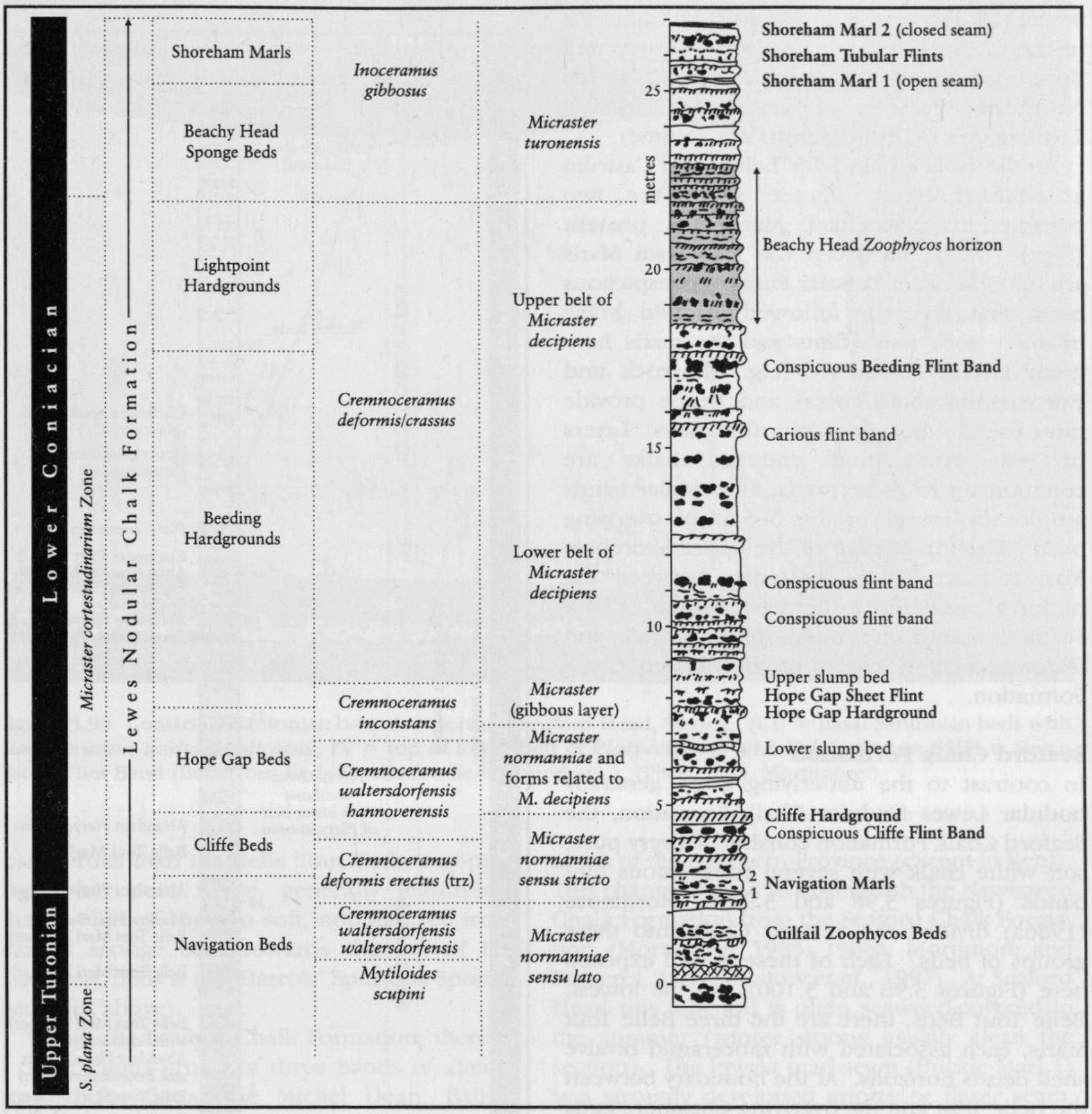


Figure 3.97 Lower Coniacian upper Lewes Nodular Chalk Formation at Seaford Head west beneath the Castrum. (trz = total range zone.)

overlain by 1.6 m of very soft, calcarenitic chalks with layers containing slump overfolds and 'laminae with shattered flints' (Mortimore and Pomerol, 1997). In the beds above there are several conspicuous, carious flint bands that are traceable through these cliffs and farther afield.

In large fallen slabs of chalk from the Light Point Hardgrounds and Beachy Head Sponge Beds, the trace fossil *Zoophycos* is abundant and occurs as a conspicuous, colour-contrasting post-omission suite of traces within the fills of earlier *Thalassinoides* burrows. The concentration of certain types of trace fossil at specific levels may indicate large-scale changes in oceanography, such as depth, causing changes in the burial or oxidation of organic matter (Mortimore and Pomerol, 1991b). This horizon of *Zoophycos* has provided a conspicuous correlation marker band in cored boreholes from the Thurrock area, Essex (Mortimore *et al.*, 1990), beneath London, as far as the the Chiltern Hills, where it is exposed in the **Kensworth Chalk Pit** in the Chiltern Hills. It is also extremely well developed across the Paris Basin and in the Northern Province at **Enthorpe Railway Cutting** (see GCR site report, this volume).

At the base of the cliff below the Castrum at Seaford Head (Figure 3.96), the two conspicuous Shoreham Marls are present (Figure 3.97). Between the Shoreham Marls are the Shoreham Tubular Flints, a conspicuous band that is easily followed in field brash inland. Both these flints and the marls have great lateral continuity (e.g. Thurrock and Faircross borehole cores) and hence provide most useful lithostratigraphical markers. Layers of red, iron-stained nodular chalks are common up to these marls, and similar bands are locally found in the 3–5 m of overlying beds. The top surface of the upper Shoreham Marl is taken as the boundary between the nodular and flinty Lewes Nodular Chalk Formation and the much purer, softer and featureless, flinty chalks of the Seaford Chalk Formation.

Seaford Chalk Formation

In contrast to the underlying gritty, generally nodular Lewes Nodular Chalk Formation, the Seaford Chalk Formation consists of a very pure, soft white chalk with several conspicuous flint bands (Figures 3.98 and 3.99). Mortimore (1986a) divided the Seaford Chalk into three groups of beds. Each of these is well exposed here (Figures 3.98 and 3.100). In the lowest, Belle Tout Beds, there are the three Belle Tout Marls, each associated with inoceramid bivalve shell debris horizons. At the boundary between the Belle Tout and the overlying Cuckmere beds is the most conspicuous lithological marker in the Seaford Chalk, the Seven Sisters Flint Band. The northerly dip brings this flint band to the base of the cliff just west of the Castrum (TV 493 978), where the over-silicified *Thalassinoides* burrow network gives the flint a vermiform structure. It varies between 0.2 and 0.3 m in thickness and it contains patches of red iron staining and sponges.

In practice, especially in core-logging, because flints are destroyed by coring, the boundary between the Belle Tout and Cuckmere beds is taken at the last level of abundant *Platyceramus* fragments, which occurs slightly higher, between the Cuckmere Flints. The Cuckmere Beds are conspicuously less

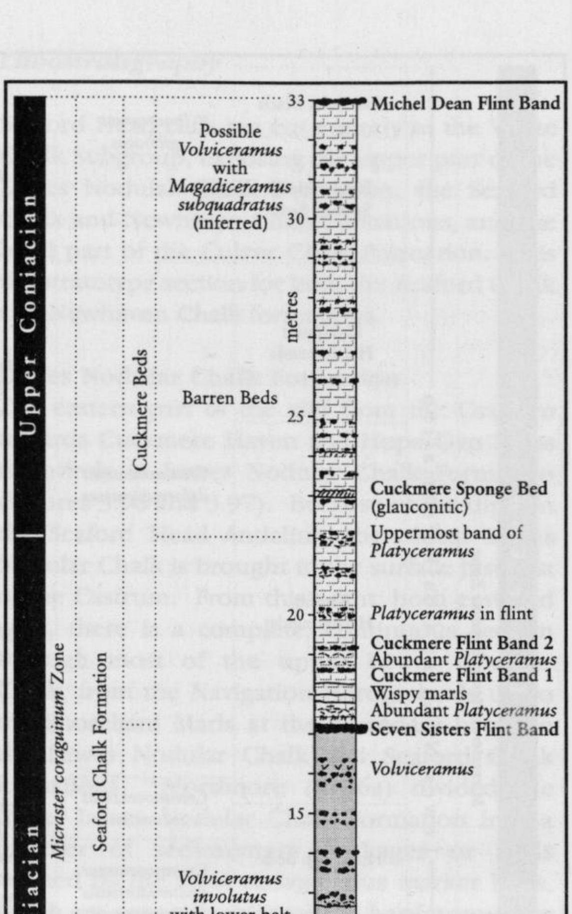


Figure 3.98 Topmost Lewes Nodular Chalk and lower part of the Seaford Chalk Formation, Cuckmere to Seaford GCR site.

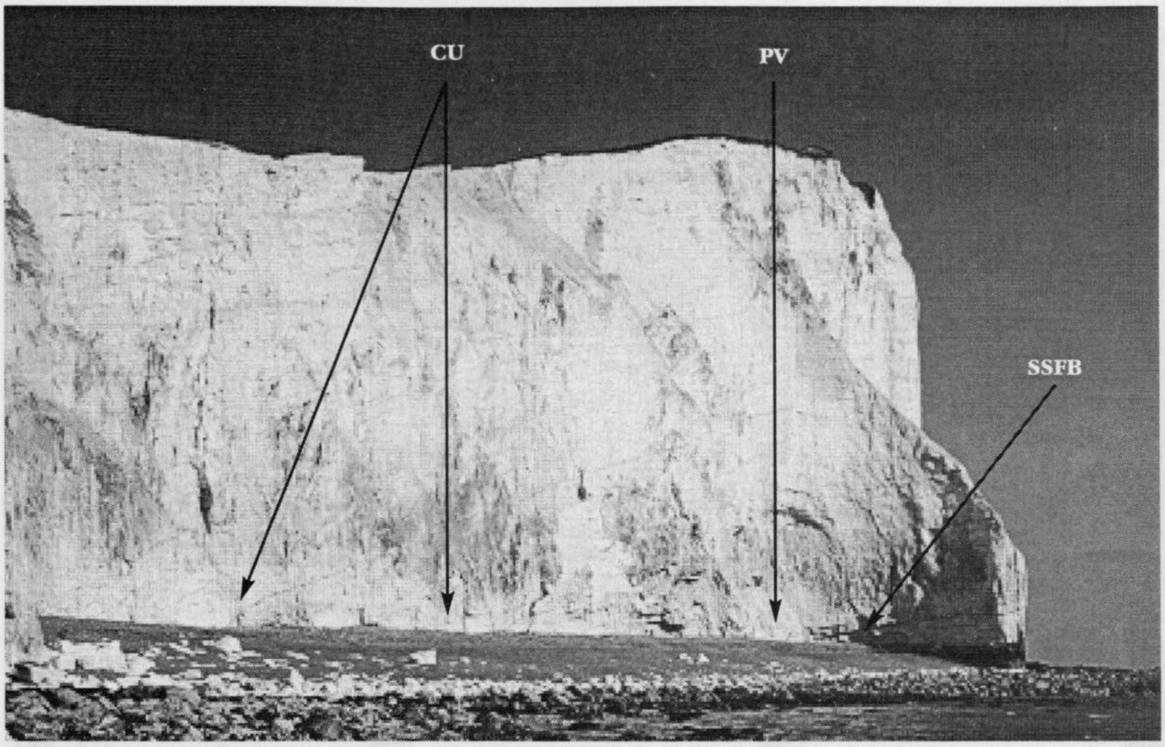


Figure 3.99 Coniacian–Santonian boundary section, Seaford Head, Sussex. (CU = Basal Santonian beds with *Cladoceramus undulatoplicatus*; PV = top of lower belt of *Platyceramus* with *Volviceramus*; SSFB = Seven Sisters Flint Band (Belle Tout Beds–Cuckmere Beds boundary).) (Photo: R.N. Mortimore.)

fossiliferous than the Belle Tout Beds, comprising rather pure white, generally featureless chalks. One of the two soft, nodular, red iron-stained sponge beds towards the top of the Cuckmere Beds is the 'Barrois' Spurious Sponge Bed' (see above).

Within the Seaford Chalk Formation, there is a conspicuous group of three bands of almost semi-tabular flints (the Michel Dean, Baily's Hill and Flat Hill flints), which is at beach level some 50 m west of the Seven Sisters Flint Band (Figure 3.99). The top surface of the lowest of this trio (Michel Dean) is taken as the boundary between the Cuckmere and Haven Brow beds (Figure 3.100). The Haven Brow Beds contain four additional conspicuous semi-tabular flint bands: the Brasspoint Flint, the Rough Brow Flint, the Short Brow Flint and the Exceat Flint, in ascending order.

Newhaven Chalk Formation (TV 491 981)

The return of marl seams in the Upper Santonian crinoid zones (*Uintacrinus socialis* and *Marsupites testudinarius* zones) is a lithological change that is maintained throughout much of the Southern Province (except in Kent). This change is used to distinguish the Newhaven Chalk Formation from the Seaford Chalk Formation (Mortimore, 1983, 1986a; Mortimore and Pomerol, 1987; Bristow *et al.*, 1997). At Seaford Head this junction is often seaweed-covered in the summer (winter storms usually clean the section). The lowest marl seam (Buckle Marl 1) is a strongly developed griotte or flaser seam, the base of which is taken as the boundary between the Newhaven Chalk and Seaford Chalk formations and the base of the Splash Point Beds, (Figure 3.101). The remaining Buckle Marls are accessible in the various caves that lead round to Splash Point (TV 490 981).

There are numerous distinctive grey marl seams and flint bands in the Newhaven Chalk Formation. The most important of these, in ascending order, are as follows (Figures 3.101–3.103):

- an abundance of *Zoophycos*-like flints in the Splash Point Beds;
- the Hawks Brow Flint at Splash Point, which comprises some very large nodules;

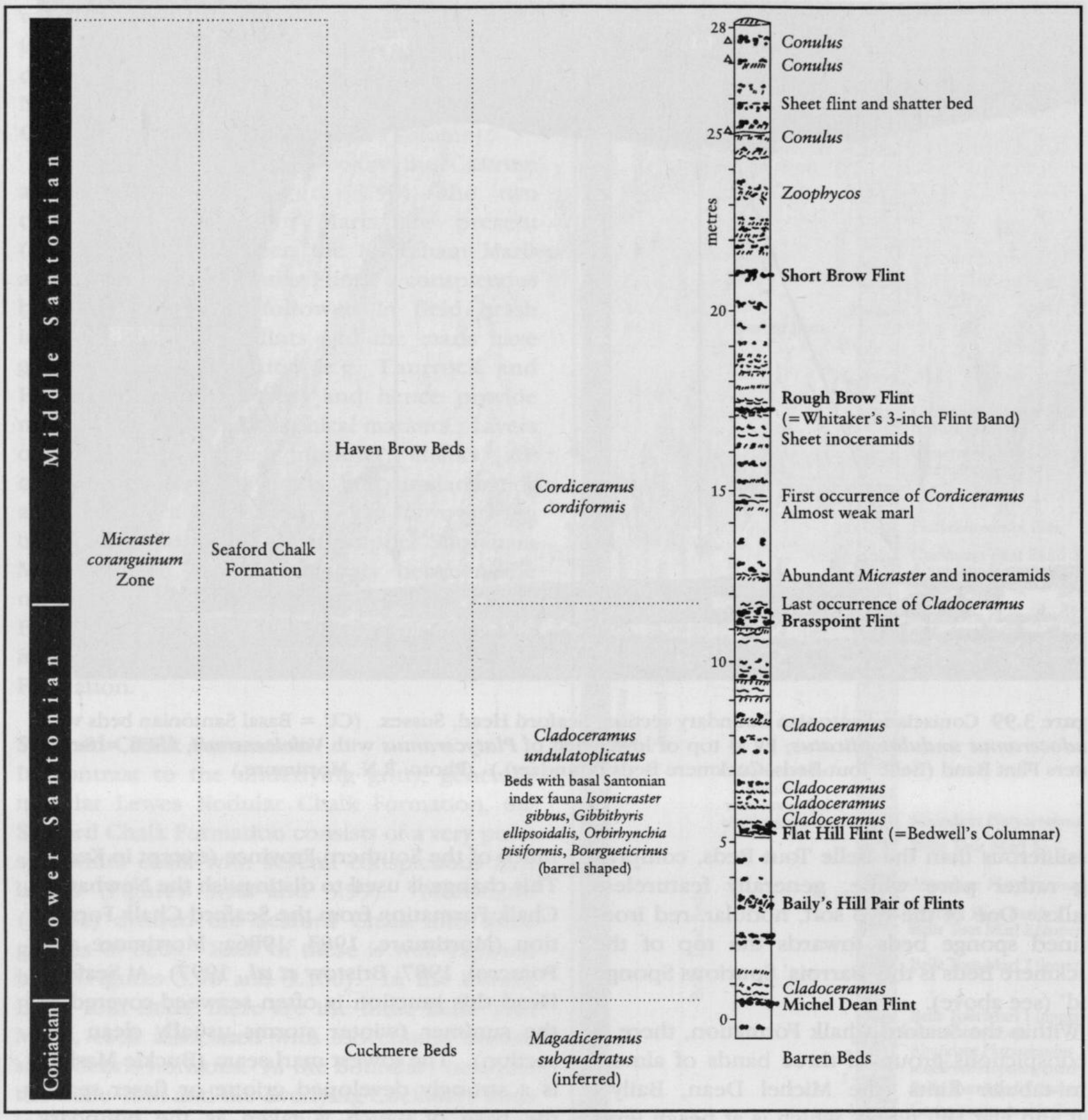


Figure 3.100 Seaford Head: the Coniacian–Santonian boundary and the higher part of the Seaford Chalk Formation.

- the Brighton Marl, a closed marl seam forming a conspicuous groove, underlain by a unit with five interlacing marls (Brighton Five) in hard, nodular (*Micula*) chalks with some flints; the Brighton Marl is taken as the boundary between the Splash Point and Old Nore beds;
- the Kemptown and Sheepcote Valley flints, which are broad scattered seams of horny nodules, in contrast to the more rounded and confined seams of the Friars Bay Flints;
- the Friars Bay Marl 1 (Figure 3.101), a conspicuous, laminated marl in which inoceramid bivalve shell fragments are common, overlying a unit of chalk with abundant inoceramid fragments;
- the group of marls comprising the Rottingdean, Roedean and Old Nore marls are the most conspicuous (Figures 3.101 and 3.102), and they maintain that aspect as they are traced westwards all the way to East Grimstead Quarry, Salisbury;

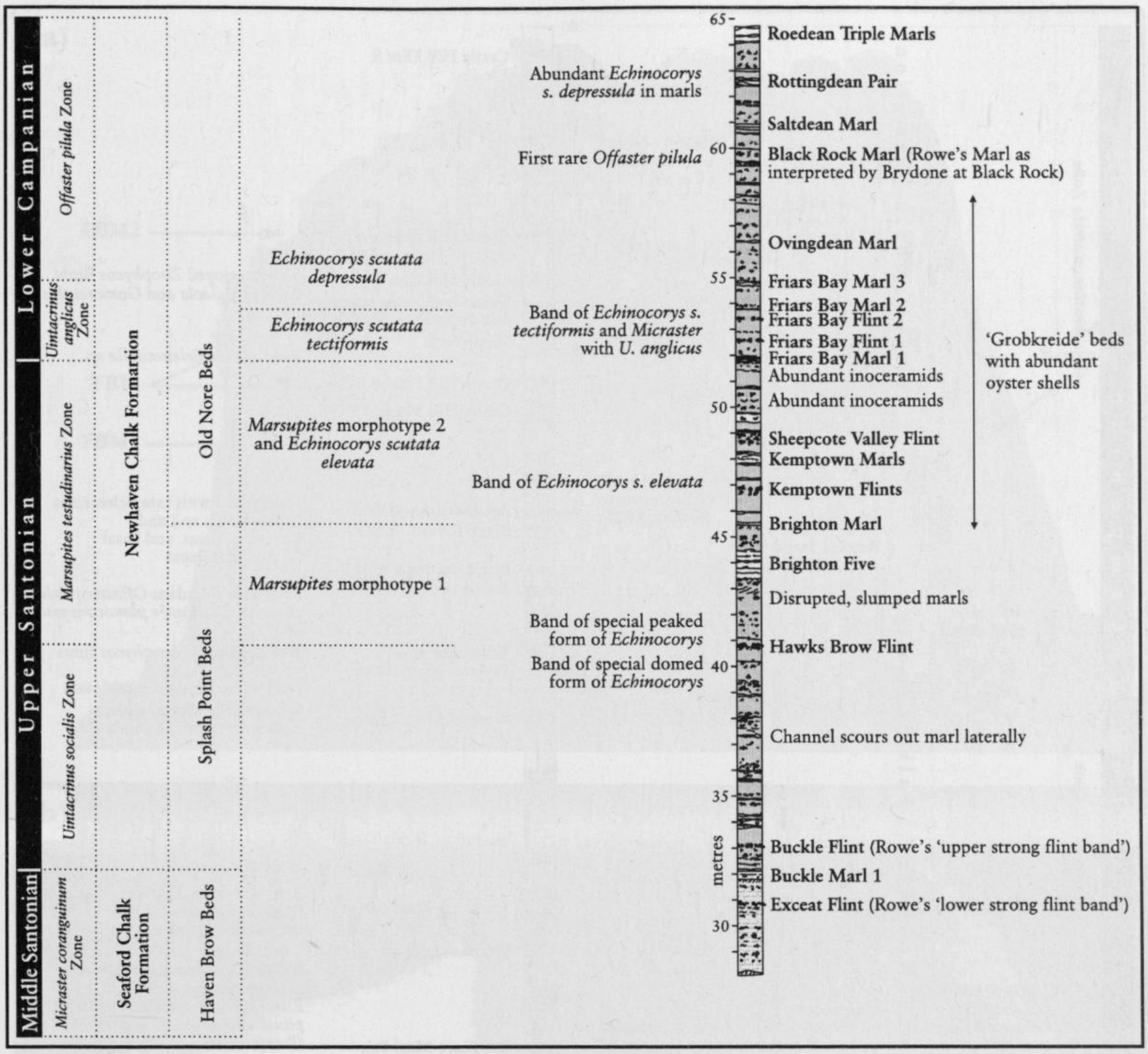


Figure 3.101 Seaford Head: the lower half of the Newhaven Chalk Formation, including the Santonian–Campanian boundary.

- a band of very hard, pure white chalk containing an abundance of the nanno-fossil *Micula* (see Mortimore and Fielding, 1990), and traversed by numerous small cracks, present beneath the Rottingdean Marls;
- the Peacehaven Beds (Figures 3.102 and 3.104) have at their base the best developed marl in the Newhaven Chalk (Old Nore Marl = Barrois' Four Inch Marl or Brydone's 2-Inch Marl). A large ammonite, associated with intraclast conglomerates, from the upper part of these beds, had encrusters attached to the 'chalk' infill rather than the shell. The fact that the encrusters were on the underside suggests that the heavy, chalk-filled ammonite had been ripped-up, transported and re-buried, an indication of powerful currents or slumping on the chalk seabed. The Peacehaven Beds are characteristically rich in red, iron-stained sponges, sponge nodular beds and the bivalve *Spondylus spinosus* (J. Sowerby);
- The boundaries between the Peacehaven Beds and the overlying Meeching Beds, and between the Meeching Beds and the Bastion Steps Beds, are the upper surfaces of the Peacehaven Marl and the upper Meeching Double Marl respectively (Figures 3.102 and 3.104). Telscombe Marl 1 with

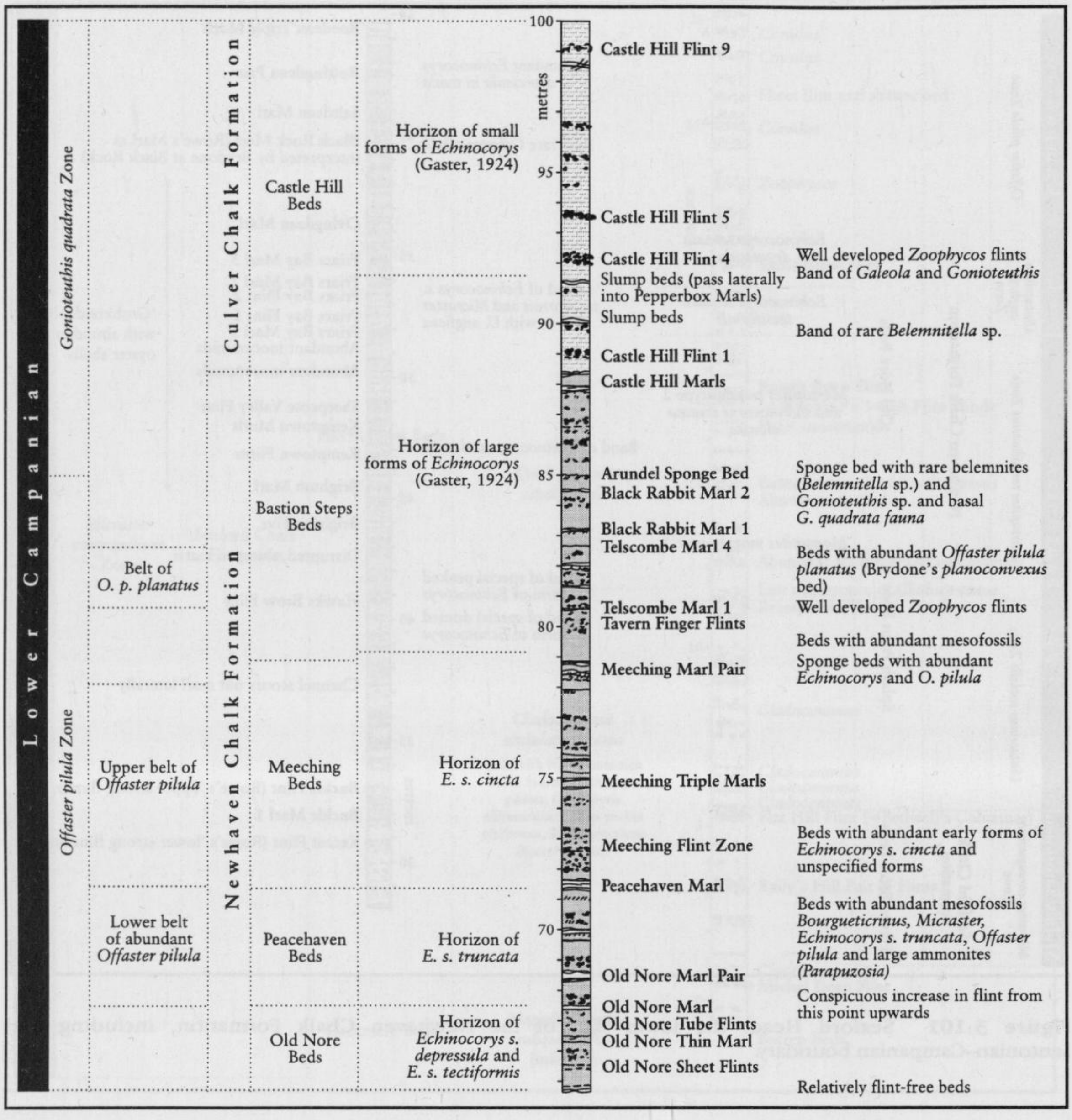


Figure 3.102 Seaford Head: the youngest Chalk from the Old Nore Beds, Newhaven Chalk Formation, to the Castle Hill Beds, Culver Chalk Formation (Lower Campanian).

its intraclast pebble conglomerate is also a key marker;

- The exposures adjacent to the groynes and the sewage outfall (TV 488 982) are in the uppermost Bastion Steps Beds and the Castle Hill Beds. The base of the Castle Hill Beds (also the base of the Culver Chalk Formation and the Tarrant Chalk Member in this section) is taken along the top surface of the last marl seam in the section, the upper Castle Hill Marl. The Culver Chalk, like the Seaford Chalk, is largely free of marl seams and layers of nodular chalk, but contains evident flint seams. Eleven Castle Hill Flints and associated *Echinocorys* bands are present in the section adjoining the undercliff walk (Figure 3.105);
- Pale-weathering bands of convolute, slump laminae are found in the broad, flint-free chalk intervals between Castle Hill Flints

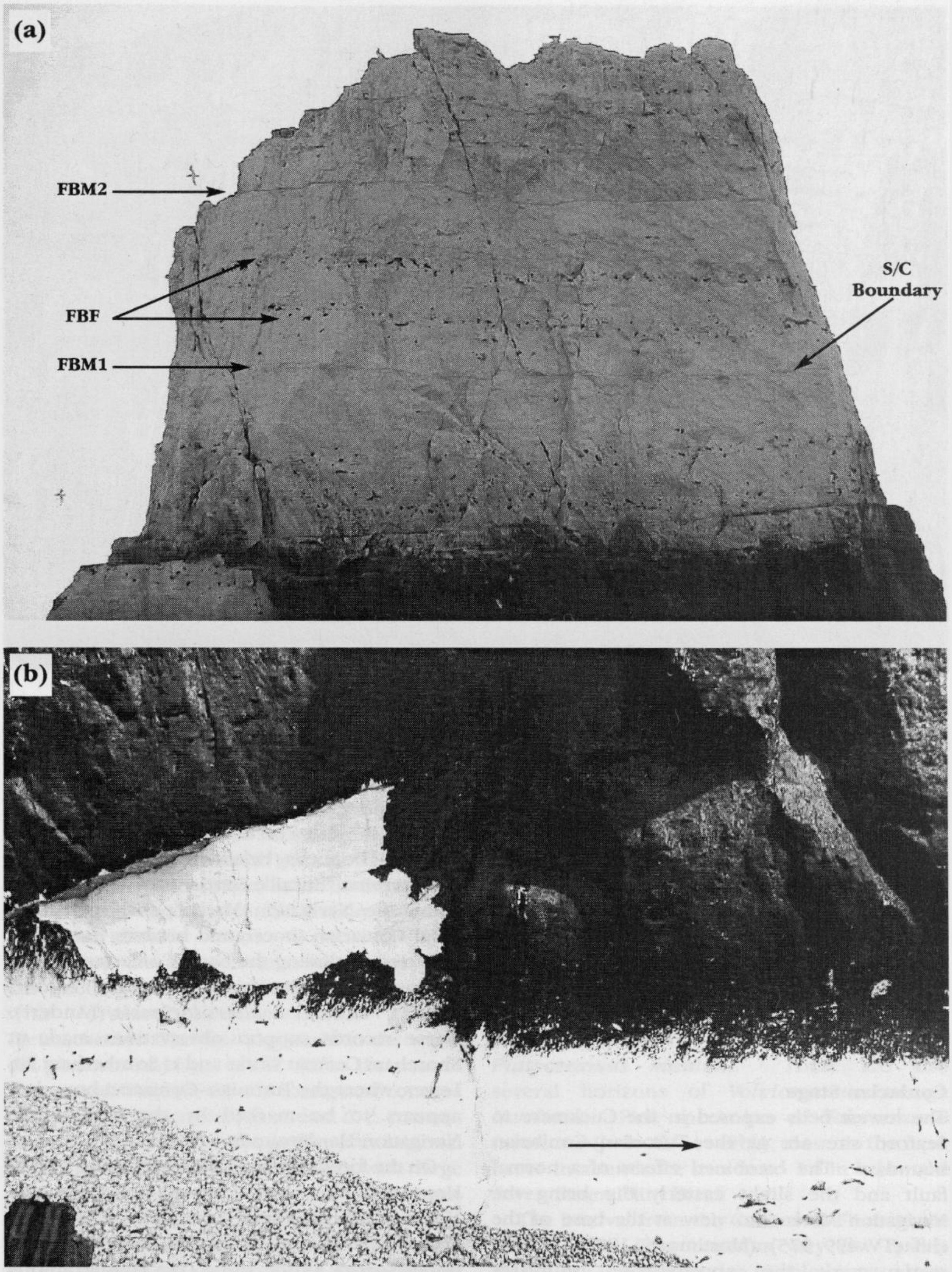


Figure 3.103 Seaford Head: The Santonian–Campanian (S/C) boundary. (a) The Pinnacle with the Brighton Marl at the base and Friars Bay Marls above. (b) Seaweed-covered Santonian–Campanian boundary: rough nodular beds below (arrowed). (FBF = Friars Bay Flints; FBM1, FBM2 = Friars Bay Marls 1 and 2.) (Photos: R.N. Mortimore.)

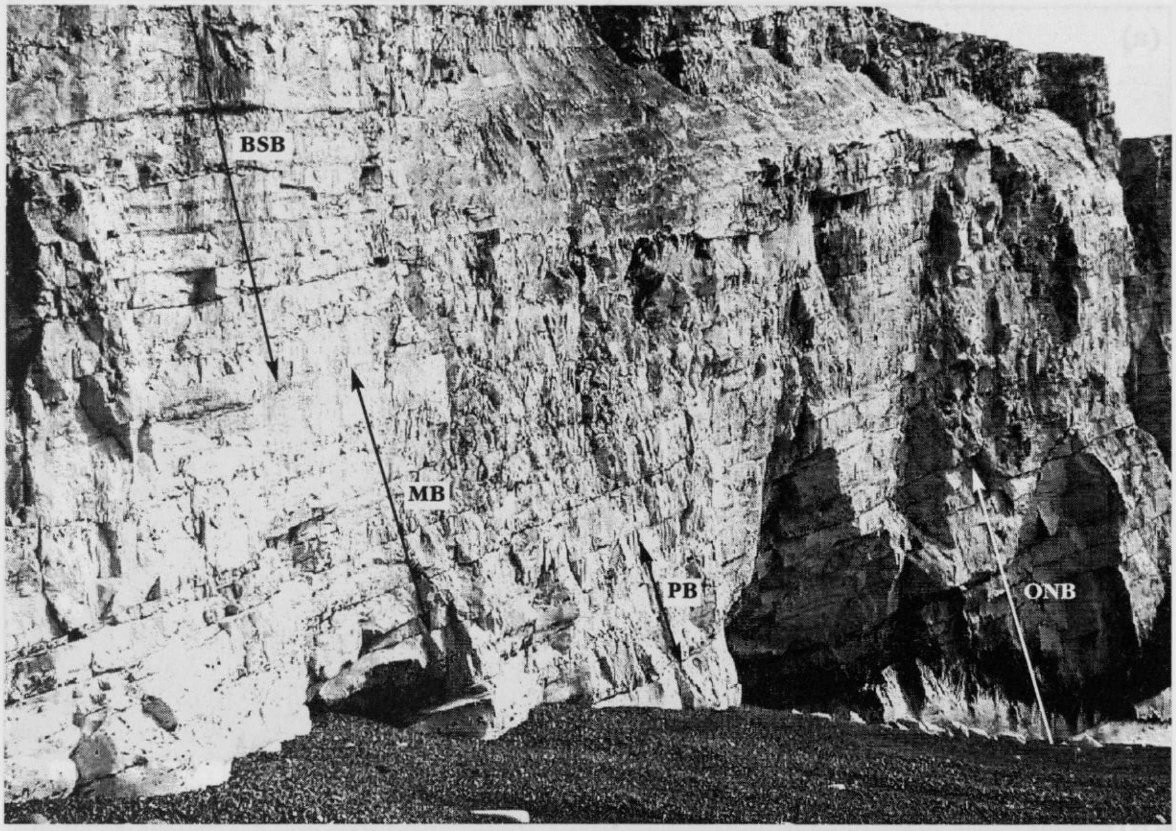


Figure 3.104 Seaford Head, Newhaven Chalk Formation, Lower Campanian *Offaster pilula* Zone. (BSB = Bastion Steps Beds; MB = Meeching Beds; ONB = Old Nore Beds; PB = Peacehaven Beds.) (Photo: R. N. Mortimore.)

3 and 4, and 5 and 6. To the west, in the Brighton Station exposures (Mortimore, 1988), and in the Western Lawns (Hove) and Shoreham Harbour cored boreholes, the horizons of small-scale slump laminae between Castle Hill Flints 3 and 4 are replaced by the Pepperbox Marls.

Biostratigraphy

Coniacian Stage

The lowest beds exposed in the Cuckmere to Seaford site are at the Turonian–Coniacian boundary. The combined effects of a normal fault and the slight easterly dip bring the Navigation Marls into view at the base of the cliff (TV 499 975) (Mortimore, 1997). These marls mark the approximate boundary between the traditional *Sternotaxis plana* Zone and the *Micraster cortestudinarium* Zone. In this section, the more refined division into *Micraster normanniae* and *M. decipiens* zones is used in place of the *M. cortestudinarium* Zone. The beds below the marls yield *M. normanniae* Bucaille *sensu stricto*. In and above the Navigation Marls, poorly preserved basal Coniacian inoceramid bivalves have been collected, including the basal Coniacian marker taxon, *Cremnoceramus deformis erectus* (Meek), and *C. waltersdorfensis* (Andert). These records support observations made at Shoreham Cement Works and at Southerham Pit, Lewes, where the Turonian–Coniacian boundary appears to be marked by the top of the Navigation Hardgrounds.

On the foreshore and in the cliffs 20 m west of Hope Gap Steps are exposed the Cliffe and Hope Gap beds, which here contain abundant *Echinocorys gravesi* Desor and *Micraster*. The upper surface of the Hope Gap Hardground is the boundary between the Hope Gap and Beeding beds, and it is also taken as the boundary between the *Micraster normanniae* and *M. decipiens* zones in this section.

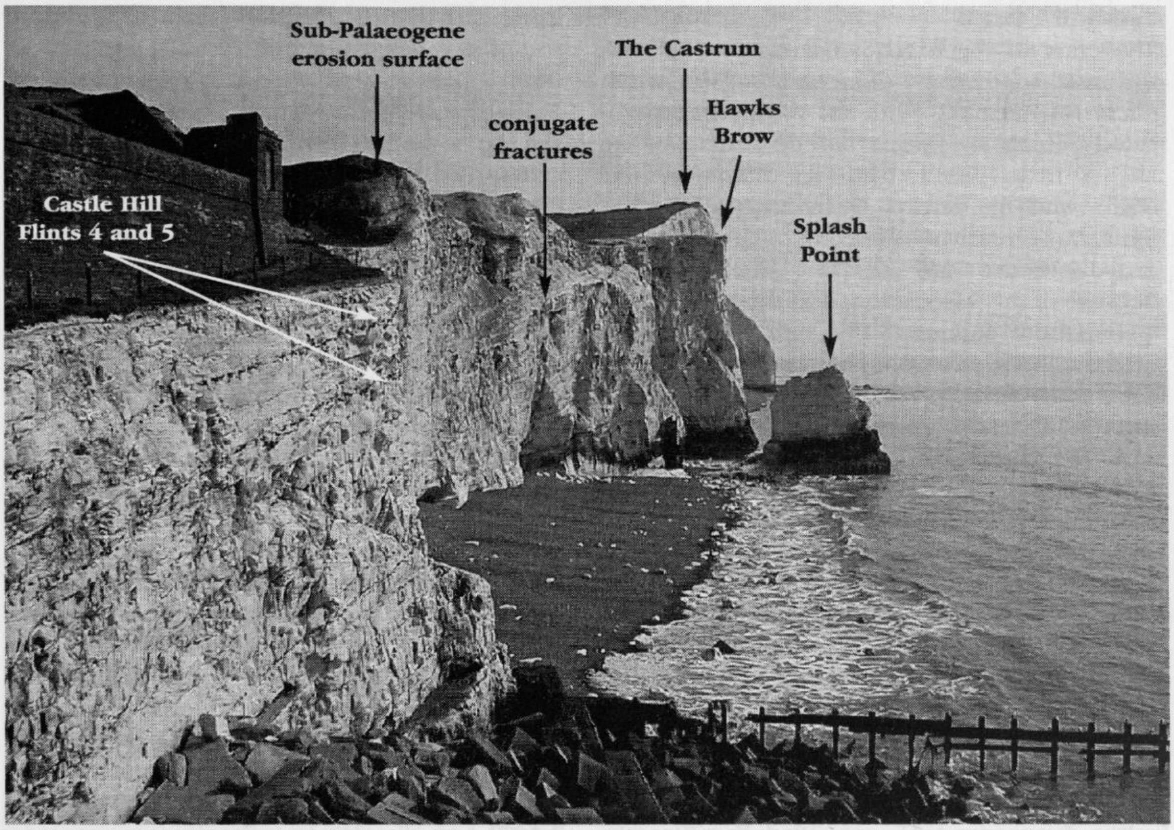


Figure 3.105 Seaford Head, western end, Newhaven and Culver Chalk formations; beds dip 10° north on the Seaford Anticline. (Photo: R.N. Mortimore.)

Large inoceramid bivalves (*Cremnoceramus*) have been collected from within the Hope Gap Hardground, while inflated 'gibbous' varieties of *Micraster decipiens* (Bayle) occur on the surface of the hardground and in the 'streaky' Beeding Marl seam above.

Micraster decipiens is relatively common in the Beeding and Light Point beds, associated with *Cremnoceramus crassus crassus* (Petrascheck). The first exposures in the wave-cut platform and base of the cliff to the west of the sea wall beneath the old coastguard cottages at Cuckmere Haven yield abundant *C. c. crassus*, *Micraster decipiens* and large forms transitional to *M. turonensis* (Bayle), together with large forms of *Echinocorys*. In Rowe's (1900) terms, this interval would be placed in the topmost *Micraster cortestudinarium* Zone. Numerous large *C. c. crassus* are also found in the Beachy Head Sponge Beds.

Rowe took the 'closed marl' (Shoreham Marl 2) as his boundary between the traditional *M. cortestudinarium* and *M. coranguinum* zones. The basal index fossil of the Middle Coniacian Substage, *Volviceramus koeneni* (Müller) has not been collected here. On the basis of correlation with the section at Shoreham Cement Works, it should occur in the 3 m belt above Shoreham Marl 3. In the overlying Seaford Chalk Formation, fossils are not common until the Belle Tout Marls, which contain abundant shell fragments of the inoceramid bivalve *Platyceramus mantelli*. There are also several horizons of *Volviceramus* ex gr. *involutus*. Fine specimens of *Volviceramus involutus* (J. de C. Sowerby), close to the type, occur in abundance in a band 1.6 m below the Seven Sisters Flint Band.

The interval from the Cuckmere Flints to the Michel Dean Flint contains very few macrofossils, but is relatively rich in colour-contrasting trace-fossils. This unit was informally designated the 'barren beds' (Mortimore, 1990) on the basis of core-logging experience, notably in the London area.

Santonian Stage

The entry of the basal Santonian index fossil, the inoceramid bivalve *Cladoceramus undulatoplicatus* (Roemer), with its distinctive corrugated ribbing, is seen on the top surface of the Michel Dean Flint. Sporadic *Cladoceramus* occur with the Michel Dean and Baily's Hill flints, but it reaches its maximum abundance in and above the Flat Hill Flint (Figure 3.100). Because of this association, and the presence of 'paramoudra columns', this flint is correlated with the 'Bedwell's Columnar Flint Band' of the Kent coast sections (see **Thanet Coast** GCR site report, this volume). However, since paramoudra columns also occur with the lower two flint bands, such flint bands with associated paramoudras cannot be used in isolation for correlative purposes. The interval above the Michel Dean Flint contains the characteristic basal Santonian assemblage, including the brachiopods *Orbirhynchia pisiformis* Pettitt and *Gibbithyris ellipsoidalis* Sahni, the barrel-shaped columnals of the crinoid *Bourgueticrinus*, and the echinoids *Cardiotaxis aequituberculatus* (Cotteau) and *Micraster gibbus* (Lamarck).

The four conspicuous semi-tabular flints in the Haven Brow Beds (Figures 3.100 and 3.101) can be safely used for correlation because of their association with particular fossils:

i the Brasspoint Flint is associated with abundant *Conulus albogalerus* (Leske);
ii the Rough Brow Flint is associated with abundant *Platyceramus* and sporadic *Cordiceramus* and is hence equated with the Whitaker's 3-inch Flint Band of Kent;
iii the Short Brow Flint is generally barren of fossils;
iv the Exceat Flint, the lower of Rowe's (1900) 'two flints 9 ft apart' is at the base of the *Uintacrinus socialis* Zone.

Micraster coranguinum sensu stricto (Leske) is characteristic in this interval, as well as *Micraster gibbus*, particularly towards the base of these beds. By comparison with the Kent coast sections, belemnites and ammonites in the Seaford Chalk in Sussex are exceedingly rare.

The zonal index crinoid for the base of the Upper Santonian succession, *Uintacrinus socialis* Grinnell, enters in and above Buckle Marl 1. It is relatively common at the base of its range, becomes rare in the middle part of the Zone and then is abundant again towards the top of its range, commonly forming a grit in the flints. One band of abundant pyramid-shaped *Echinocorys* ('pre-*elevata*') is a feature towards the top of the *U. socialis* Zone.

The *U. socialis* and *M. testudinarius* zones can be distinguished by the distribution of species of the rhynchonellid brachiopod genus *Cretirhynchia*. *C. plicatilis* (J. Sowerby) characterizes the *U. socialis* beds, and *C. exsculpta* Pettitt the *Marsupites* Zone, respectively. Both species are common at Seaford Head (Mortimore, 1986a). The change from *Marsupites* calyx plates with a simple central fold on each edge to plates with numerous small folds occurs at the level of the Brighton Marl (A.S. Gale, pers. comm., 2000). The chalk of the higher part of the *Marsupites* Zone is commonly gritty with shell debris, particularly comminuted shells of the oyster *Pseudoperna boucheri* (Woods *non* Coquand). This is the equivalent to the Grobkreide of northern Germany (see discussion under the **Newhaven to Brighton** GCR site report, this volume).

Santonian–Campanian Boundary (Figure 3.103)

The currently recommended base of the Campanian Stage (Hancock and Gale, 1996) is the extinction-level of *Marsupites*, which here, and in the correlative **Newhaven to Brighton** sections, is in Friars Bay Marl 1. In the corner cave at Splash Point, the two conspicuous nodular, horn-flint seams (Friars Bay Flints), immediately above Friars Bay Marl 1, mark the interval containing *Uintacrinus anglicus* Rasmussen, the eponymous index crinoid of the basal Campanian zone. The calyx plates and brachial ossicles of this crinoid are relatively small and are consequently difficult to find in this wave-washed section. In this interval *Echinocorys scutata tectiformis* Griffith and Brydone and *Micraster rogalae* Nowak are abundant.

Campanian Stage

The remaining beds above the Friars Bay interval in the higher Newhaven Chalk Formation contain:

- The entry of very small forms of *Offaster pilula* (*O. p. nana*; Brydone, in manuscript) above the Black Rock Marl.
- The presence of mixed forms of *Echinocorys*, some related to *E. scutata depressula*

Brydone, and others to forms that show affinities with *E. s. tectiformis*, but with a different aspect, occurs in the interval from the Rottingdean Marls to above the Roedean Marls.

- The Peacehaven Beds coincide with the lower belt of abundant *Offaster pilula* (Lamarck) associated with *E. s. truncata* Brydone.
- *Offaster pilula* (upper belt) occur in the beds above the Meeching Pair up to the Tavern Flints.
- The larger *Offaster pilula planatus* (Brydone, in manuscript; Ernst) occur between the Telscombe Marls.
- The base of the *Gonioteuthis quadrata* Zone (*sensu* Brydone) is taken at the Telscombe Marl 4 (Figure 3.102), above which the Arundel Sponge Bed is identified as a key bio-event (Bailey *et al.*, 1983, 1984).
- The boundary between the 'large and small forms' of *Echinocorys* (Gaster, 1924) occurs at Castle Hill Flint 4.

Bailey *et al.* (1983, 1984), Mortimore (1986a), and Wood and Mortimore (1988) published the first and last occurrences and ranges of the key common macrofossils, microfossils and nannofossils in relation to this lithostratigraphical framework. A much more detailed study is currently being undertaken (Mortimore *et al.*, in prep.). Barchi (1995) investigated the micropalaeontology, geochemistry and palaeomagnetism of the Chalk from the base of the *Uintacrinus* Zone to the top of the exposure.

Interpretation

Compared with the Kent succession, the Cuckmere to Seaford section extends stratigraphically much higher and is overall much more accessible. It also appears to be more expanded, particularly in the higher part of the *M. coranguinum* Zone and in the crinoid zones. Moreover, unpublished work on the ranges of foraminifera in relation to the Whitaker's 3-inch Flint Band and its Sussex equivalent indicate that there may well be up to 6 m more section preserved at Seaford at this level than in the **Thanet Coast** GCR site (H.W. Bailey, pers. comm., 1998). The Isle of Wight sections at **Whitecliff** and Scratchell's Bay are also excellent, but the chalk is intensely hard whereas the Seaford Head section is in soft chalk that is ideal for processing microfossils and nannofossils and for collecting macrofossils. The soft chalks have actually yielded a much greater diversity and abundance of microfossils compared to the Isle of Wight sections at the same levels (H.W. Bailey, pers. comm., 1998). In addition, the relatively gentle dip of 10°, compared with 70° on the Isle of Wight, allows greater lengths of beds to be exposed for collecting macrofossils on the wave-cut platform and in the cliff.

For the above reasons, the International Subcommission on Cretaceous Stratigraphy is investigating the Cuckmere to Seaford GCR site (Seaford Head section), as a candidate Global boundary Stratotype Section and Point (GSSP) for both the Santonian and Campanian stages. The inoceramid bivalve marker for the base of the Santonian Stage, *Cladoceramus undulatoplicatus*, has its entry point on top of the Michel Dean Flint. The currently accepted base of the Campanian Stage is taken at the extinction point of the crinoid *Marsupites testudinarius*, (Schlotheim), which here is located in Friars Bay Marl 1. Another commonly cited proxy for the base of the Campanian Stage is the first occurrence of the nannofossil *Broinsonia parca parca* (Stradner) Bukry. This subspecies, as well as its precursors, are well represented in the Seaford Head section. However, *B. parca parca* enters here well above the extinction point of *Marsupites*, demonstrating the difficulty of using this nannofossil as the international basal boundary index fossil. An additional proxy for the base of the Campanian Stage is the palaeomagnetic reversal from magneto Chron 34 Normal to Chron 33 Reverse, which has been identified beneath the Old Nore Marl at Seaford Head by Barchi (1995), but in the *Uintacrinus socialis* Zone by Montgomery *et al.* (1998) (see p. 26, Chapter 1 and Figure 2.3, Chapter 2). The same palaeomagnetic reversal was identified at Précy-sur-Oise, Paris Basin, northern France (Barchi, 1995), as well as at a correlative horizon beneath the M1 marl in the northern German Chalk standard section at Lägerdorf, Schleswig-Holstein Schönfeld and Schulz, 1996). The Seaford Head section clearly demonstrates that this reversal is well above the currently accepted base of the Campanian Stage and is actually approximately coincident with the first occurrence of *B. parca parca*.

The ease with which fossils from this section can be collected and related to a well-defined lithostratigraphical framework is assisting in the construction of an integrated biostratigraphical zonal and subzonal scheme that can be applied throughout the Southern Province and Anglo-Paris Basin. In addition, an international scheme for substage divisions of the Coniacian, Santonian and Campanian stages is currently under discussion and the Seaford Head section is critically important in this respect.

Widespread trace-fossil events, such as the Beachy Head Zoophycos Beds and the Shoreham Tubular Flints at the boundary between the Lewes Nodular Chalk and Seaford Chalk formations, contrast with more local (tectonically induced?) events, such as the flint shatter-beds and slump-folds at Hope Gap. The widespread events need a more global cause, such as sea-level change, which may change the rate of burial of organic matter and the preservation potential of burrow systems as flint. A similar widespread event is the appearance of chalks with marl seams at the base of the Newhaven Chalk Formation. In North Sea Basin petroleum geology this would be inferred to represent a sea-level fall, with increased clastic input to the Chalk sea.

The Hope Gap complex of shattered flint tectonite layers, passes laterally onto the axis of the Seaford Head Anticline, where the Cliffe and Hope Gap beds are progressively attenuated and the mineralization of the Hope Gap Hardground intensifies (Mortimore, 1977, 1997). Concomitant cracking of lithified hardground nodules is a brittle response to the plastic flow deformation seen in the small-scale slump beds below and above the hardground. These structures at Seaford Head have preserved the early stages of the movement that lead eventually to major slumps such as those seen at **Downend Chalk Pit**, Portsdown. The plastic flow micro-faults and vein fabrics associated with the Hope Gap slides are also typical of chalks that have moved (Mortimore, 1977, 1979, 1997). The greater the movement, the more extensive the pore-pressure release fabric that develops, ultimately leading to the sedimentary dykes seen in the Paulsgrove Chalk Pit on Portsdown. These movements at Seaford Head correspond to the Late Turonian–Early Coniacian Ilsede Phase of the Subhercynian Tectonism (Mortimore and Pomerol, 1997; Mortimore *et al.*, 1998). The effects of coeval tectonic events are seen at Shoreham Cement Works, Upper Beeding, on the flanks of the Pyecombe Anticline.

Other horizons indicative of intra-Cretaceous tectonism include the numerous small laminated slide-planes with chalk intraclasts that occur throughout the Seaford Chalk Formation. For this reason, Mortimore (1979) originally referred to the Seaford Chalk as the 'Seaford Sponge Bed and Laminate Chalk Member'. A characteristic feature of the Splash Point Beds, at the base of the Newhaven Chalk Formation, is the disturbed nature of many of the beds, especially the marly wisps in the group of marls named the 'Brighton Five'. Higher in the section, the main sheet-flint horizons around the Rottingdean, Roedean and Old Nore marls are probably related to low-angle sliding. Each of these events coincides with pulses of movement related to the Wernigerode Phase (Late Santonian–Early Campanian age) of Subhercynian tectonism (Stille, 1924; Mortimore *et al.*, 1998). In this context, the characteristic concentration of intraclasts in Telscombe Marl 1, at the top of the upper belt of abundant *Offaster pilula*, and below the beds with *O. pilula planatus*, is of particular interest. The intraclasts are relatively small, millimetre size, at Seaford Head and Newhaven, but they increase to centimetre-sized clasts westwards (e.g. on the A27 Slonk Hill road cuttings on the west side of Brighton), where all the marl seams are also thicker. This intraclast marl probably relates to the final pulse of the Wernigerode movements of Subhercynian tectonism and to the onset of the *Offaster pilula* transgression (Niebuhr, 1995; Mortimore and Pomerol, 1997).

At Beachy Head, from 300 m west of the lighthouse, there is a comparable stratigraphy to that of the Cuckmere to Seaford section for the interval from the Navigation Marls to the Shoreham Marls. The lower three Light Point Hardgrounds coalesce here (TV 565 954) to form a synsedimentary mound (cf. the **White Nothe** GCR site). The very gentle dip of the chalk towards Birling Gap, in the axis of the Birling Gap Syncline, provides long sections through the upper part of the Lewes Nodular Chalk and the lower Seaford Chalk formations. In the Belle Tout Beds of the Seaford Chalk Formation, horizons with *Volviceramus involutus* and associated *Micraster* cf. *turonensis* are well exposed. The Seven Sisters Flint Band forms a spectacular solid mat of flint on the wave-cut platform at Birling Gap (TV 552 960). Just out of reach in the cliff here is the pale green, glauconite-coated Cuckmere Sponge Bed (Barrois' 'Spurious Sponge Bed'), containing opalized wood.

The Cuckmere to Seaford Head GCR site provides the standard reference section (Jenkyns *et al.*, 1994, fig. 6) for the stable isotope stratigraphy ($\delta^{13}C$, $\delta^{18}O$) of the interval from the Middle Santonian (*Micraster coranguinum* Zone, Whitaker's 3-inch Flint Band) to the middle of the Lower Campanian (basal *Gonioteuthis quadrata* Zone, Castle Hill Flints). These stable isotope curves link on to the top of the curves for the East Kent composite section (Jenkyns *et al.*, 1994, figs 3, 4). There is a significant shift to more positive values in both the $\delta^{13}C$ and $\delta^{18}O$ curves at about the Peacehaven Marl. The two curves show covariance, suggesting that the isotope values have been modified by diagenetic effects.

The Cuckmere to Seaford GCR site links to five other GCR sites described in this chapter; **Newhaven to Brighton**, the **Thanet Coast**, **Whitecliff**, **Compton Bay**, and **White Nothe**.

Conclusions

The Cuckmere to Seaford GCR site is one of the most important sections in Europe for the Coniacian, Santonian and Campanian stages in terms of basal boundary points, subdivisions of the stages and completeness of the sections. It is a proposed boundary stratotype section for the base of the Santonian and Campanian stages. The various types of evidence informing discussions on nannofossil and microfossil entry points and ranges, the extinction of the index crinoid *Marsupites* and magnetostratigraphy at the base of the Campanian Stage are all well represented here. Cuckmere to Seaford is also a standard reference section for stable isotope stratigraphy. The importance of the section is enhanced by the abundance of internationally useful inoceramid bivalves, and by the soft chalks that yield excellent microfossil and nannofossil data. The biostratigraphy is easily related to lithological marker beds that have long-range correlation potential in the Southern Province and beyond. Unpublished studies of the foraminifera have shown that at certain lithological marker horizons, such as Whitaker's 3-inch Flint Band, more sediment is preserved here than in the **Thanet Coast** sections.

Because of the completeness and continuous exposure through a large part of the White Chalk Subgroup, the Seaford Head section is used as the standard against which variation in other sections is measured.

SOUTHERHAM GREY PIT, LEWES, SUSSEX (TQ 427 090)

Introduction

Southerham Grey Pit (Figures 3.84, 3.85, 3.106 and 3.107) is the southern of two abandoned quarries, both of which have been called 'Grey Pit' in the past. These are the Southerham Grey Pit, on the south side of the A27 Lewes–Eastbourne road; and the Machine Bottom Pit, on the north side of the road, to the east of Southerham Farm (Figure 3.107). Both pits were excavated for cement manufacture and form part of a historically important group of pits in the Cenomanian Chalk of Lewes. Although the Ordnance Survey 1:10 000 topographical map now clearly labels the two pits Machine Bottom Pit and Southerham Grey Pit, it is the two pits together that form the historically important Cenomanian 'Grey Pit' sections. The two pits provide a composite exposure of the entire Cenomanian succession, with the exception of the basal beds; the latter, and the contact with the underlying Gault, were proved in cored boreholes.

Southerham Grey Pit ceased working in 1978 when the Rugby Lewes Cement Works finally closed. This saw the end of nearly two centuries of quarrying for construction materials, lime and subsequently Portland cement in the Southerham group of quarries. The mixture of clay and lime present in the pit provided an ideal source of material for cement.

Together with the Folkestone–Dover section (**Folkestone to Kingsdown** GCR site), the Southerham Grey Pit section has enabled the establishment of a standard biostratigraphy for the Cenomanian Stage of the Southern Province, including many of the macrofossil marker horizons. It is of international importance as a candidate Global boundary Stratotype Section and Point (GSSP) for the Middle Cenomanian Substage. Southerham Grey Pit is the type locality for the Tenuis Limestone (named after the occurrence of the inoceramid bivalve *Actinoceramus tenuis*), which forms the boundary between the West Melbury Marly Chalk Formation and the overlying Zig Zag Chalk Formation of the Grey Chalk Subgroup (Figure 3.3). This site also provides one of the standard sections for the cyclostratigraphy (marl–chalk couplets) of the Cenomanian strata. The integrated cyclostratigraphy, stable isotope

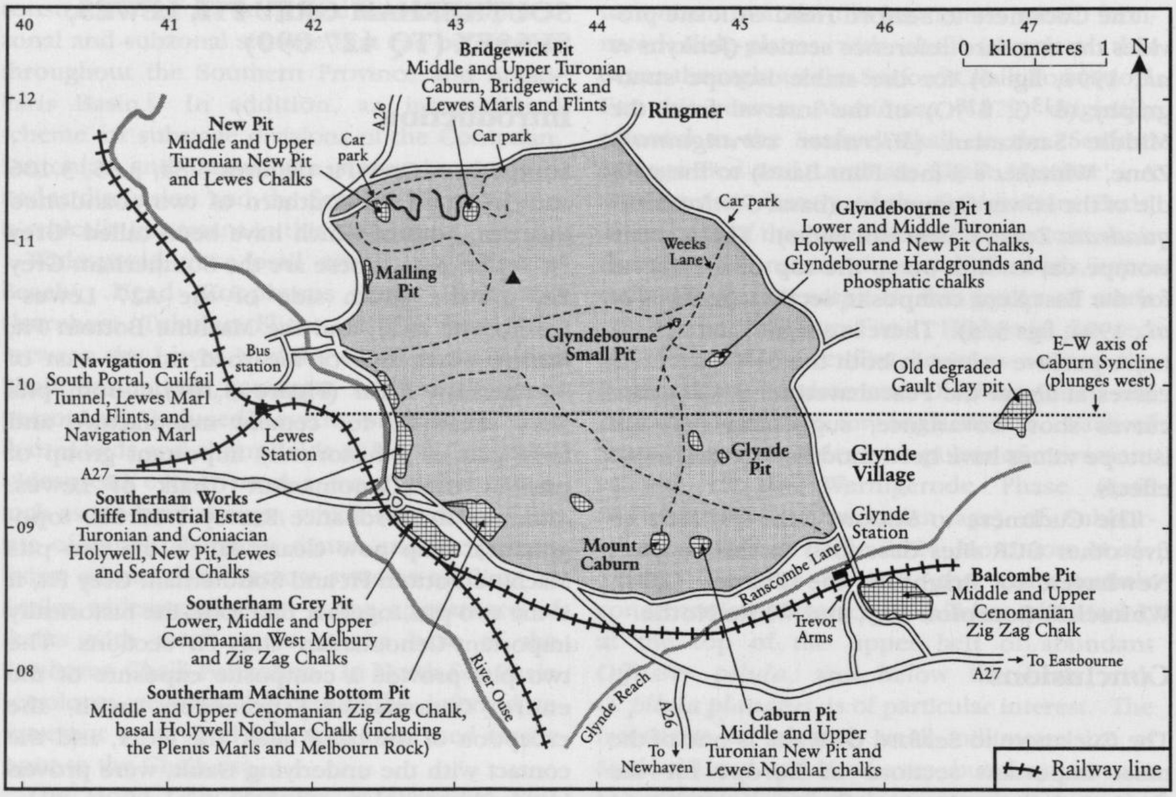


Figure 3.106 Map of the Caburn group of chalk pits at Lewes, Sussex showing the position of the GCR sites (boldface type) in relation to correlative sections. (After Mortimore, 1997.)

geochemistry and biostratigraphy of the Middle Cenomanian succession have been investigated in detail and provide a standard against which other sections in the UK and Europe are compared. Southerham Grey Pit is, therefore, one of the stratigraphically most important Cenomanian localities in north-west Europe.

Description

The Southerham Grey Pit is a narrow quarry, *c.* 0.5 km long and 100 m wide, elongated NW–SE and situated between the railway and the A27 road. Access is obtained via a roadway leading from the Cliffe Industrial Estate beneath the A27 Lewes Bypass. The beds dip 10° north on the northern limb of the Kingston Anticline, so that the oldest beds (West Melbury Marly Chalk Formation) and the highest beds (Zig Zag Chalk Formation) are exposed in the south-east and north-west ends of the pit respectively. The main section is on the eastern side of the pit. It provides an exposure through the greater part of the Lower Cenomanian, the entire Middle Cenomanian, and the lower part of the Upper Cenomanian successions (see Figure 3.108). The abundance and diversity of well-preserved ammonites has led to refinements of the international zonal scheme. Other fossil groups are also very well represented, and bed-by-bed collections are currently under study. The site is unusually rich in fossil lobsters and fish.

The first description of the 'Grey Pit' was given by Jukes-Browne and Hill (1903, p. 60), based on fossil collecting by Rhodes, but it is uncertain whether their locality was the Machine Bottom Pit or the Southerham Grey Pit. White (1926, p. 46) threw some light on the position of the two pits. He recognized a 'comparatively new and narrow quarry' with bedding dips around 20° north-west, decreasing to 5° in a southward direction. In this southward direction he noted that the Chalk became more marly and regular marl–chalk alternations more pronounced. This suggests that the upper beds of the traditional Chalk Marl were present. In particular, White described a rather lumpy, iron-stained marl containing casts of cephalopods;

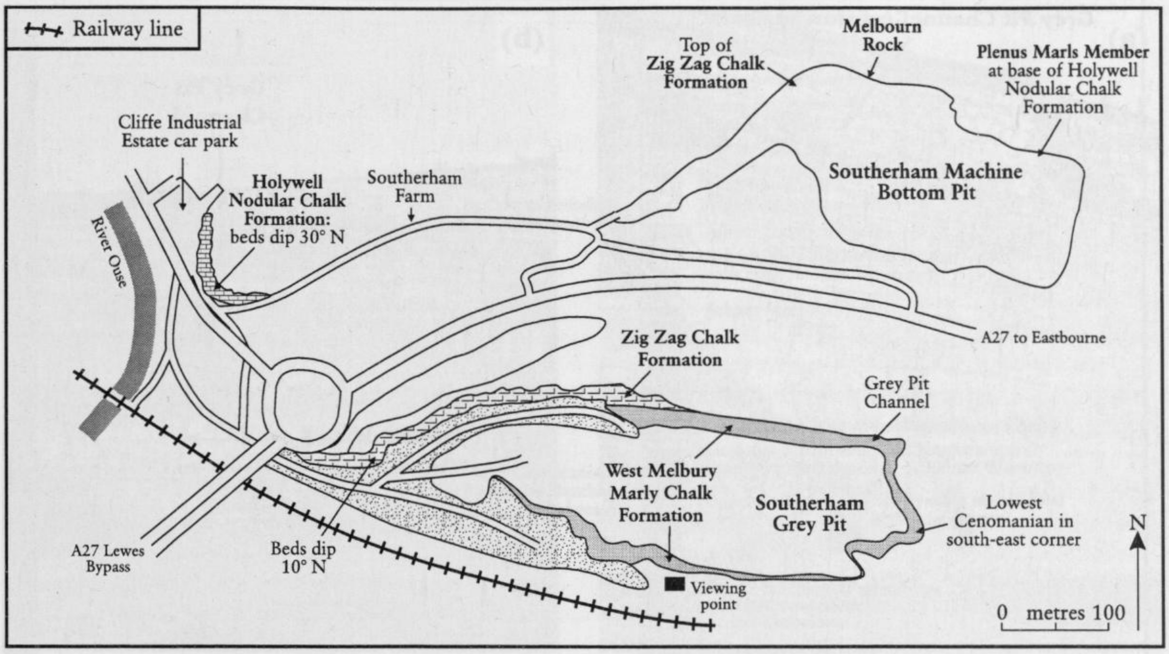


Figure 3.107 Map of the former cement works quarries, Southerham Grey Pit and Machine Bottom Pit, Lewes, Sussex. (After Mortimore, 1997.)

the assemblage of fossils in this bed suggests a level around and above the Tenuis Limestone–Cast Bed interval at the boundary between the West Melbury Marly Chalk and Zig Zag Chalk formations (Bristow *et al.*, 1997). White also noted a strongly developed fault in this pit.

White (1926) next described the 'well-known Southerham Grey Pit'. His record here of the complete *Holaster subglobosus* Zone (i.e. broadly Upper Cenomanian) and the Plenus Marls at the top, suggests that this must have been the Machine Bottom Pit. It is probable that the new excavations described by White were on the old roadway now leading into the current 'Southerham Grey Pit'. Dips do not exceed 10° north in the pit but increase northwards into the Southerham Works Pit (Cliffe Industrial Estate) exposures (Figures 3.106 and 3.107).

Kennedy (1969, p. 497) described the present day Southerham Grey Pit as 'Eastwoods Cement Company Southerham'. Eastwoods had worked all of the Southerham pits (including those constituting the Southerham Grey Pit and the **Southerham Pit** GCR sites), from the beginning of the 20th century, but subsequently sold them to Rugby Portland Cement (Crown Concrete). It is essential to realize that fossils in old collections labelled 'Southerham Grey Pit' may have come from the Machine Bottom Pit, White's section (now no longer extant), and the present-day Southerham Grey Pit. Fossils labelled 'Southerham' could have come from any of these localities and therefore may not necessarily be Cenomanian in age.

Kennedy (1969, fig. 10, p. 499) provided the first decription and measured section. Unpublished studies by Anderson and Drummond during the 1970s (in Mortimore and Young, 1980), based on bed-by-bed collection of all the 'Lower Chalk' sections and cored boreholes in the area, added to the knowledge of the distribution of fossils in relation to the detailed lithostratigraphy. Much of this work was incorporated in the British Geological Survey Lewes Memoir (Lake *et al.*, 1987).

Subsequent work by Gale (1989, 1995) identified the bed in which the basal Middle Cenomanian index ammonite *Cunningtoniceras inerme* (Pervinquière) enters, thereby establishing Southerham Grey Pit as a key Middle Cenomanian section for international biostratigraphy. Gale (1995) also counted the number of marl–chalk couplets in the higher part of the Lower Cenomanian and Middle Cenomanian successions here and established a standard cyclostratigraphy, which he applied to the

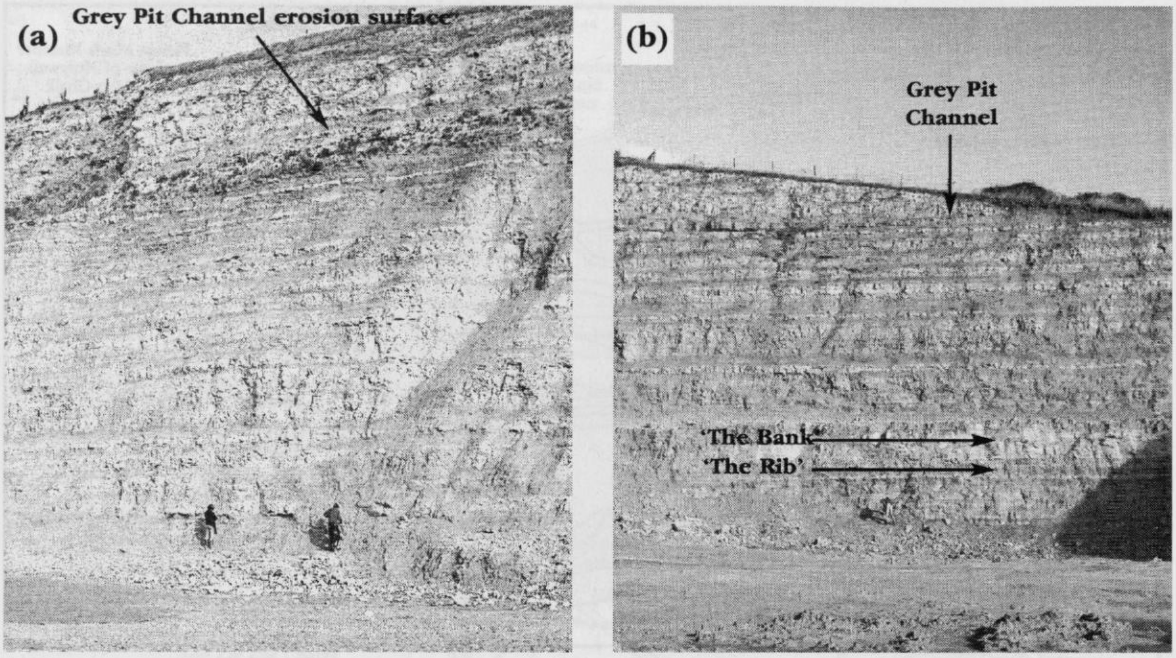


Figure 3.108 (a, b) Southerham Grey Pit, Lewes, Sussex, in 1976 prior to closure in 1978. Marker beds and the rhythmic sedimentation used to establish the cyclostratigraphy in the lower part of the Grey Chalk Subgroup are indicated (see also Figure 3.5). (Photos: R.N. Mortimore.)

Folkestone and Isle of Wight sections, as well as to sections on the French Channel coast and in northern Germany. The integrated cyclostratigraphy, stable isotope geochemistry and biostratigraphy of the Middle Cenomanian succession were investigated in detail by Paul *et al.* (1994).

Lithostratigraphy

The exposed section extends from the lower part of the West Melbury Marly Chalk Formation to just above Jukes-Browne Bed 7 in the Zig Zag Chalk Formation. Cored boreholes have shown that the base of the Chalk lies 8.5 m beneath the present floor of the pit, giving a composite total of 80 m of Grey Chalk Subgroup for Southerham Grey Pit and Machine Bottom Pit. Southerham Grey Pit is the type section for the Tenuis Limestone, which is used as the boundary marker between the West Melbury Marly Chalk and Zig Zag Chalk formations (Bristow *et al.*, 1997; Rawson *et al.*, 2001).

Kennedy (1969, fig. 10, p. 499) lettered the beds in the lower part of the 'Chalk Marl' from a to z, in ascending order, and then from 1 to 41 in the upper part, up to the unusually sharp contact marked between the traditional 'Chalk Marl'and the 'Grey Chalk' (see below). Another log, based on unpublished work by Mortimore, was given by Lake *et al.* (1987, fig. 16). The log in this account (Figure 3.109) is a modified version of the British Geological Survey Lewes Memoir figure. Detailed logs of the higher Lower Cenomanian and the greater part of the Middle Cenomanian strata were published by Gale (in Paul *et al.*, 1994; Gale, 1995, 1998).

The higher part of the Middle Cenomanian succession has been locally cut out by a deep channel with an anomalous fill, providing evidence of local structural control that may also have initiated the later (Turonian) channel in the **Southerham Pit** GCR site, immediately to the north.

West Melbury Marly Chalk Formation

The lowest beds exposed consist of rhythmically bedded layers of thick marls and thinner sponge-bearing marly limestones (Figures 3.5, 3.108 and 3.109). Conspicuous markers at the eastern end of the pit include a thin (0.2 m) prominent bed of hard, nodular, sponge-rich limestone (known informally as 'The Rib' or the 'Rib'), overlain, some metres higher, by a distinctive 'Bank' (also known as 'The Bank') of pale limestones with thin beds of marly chalk (Mortimore, 1997, fig.

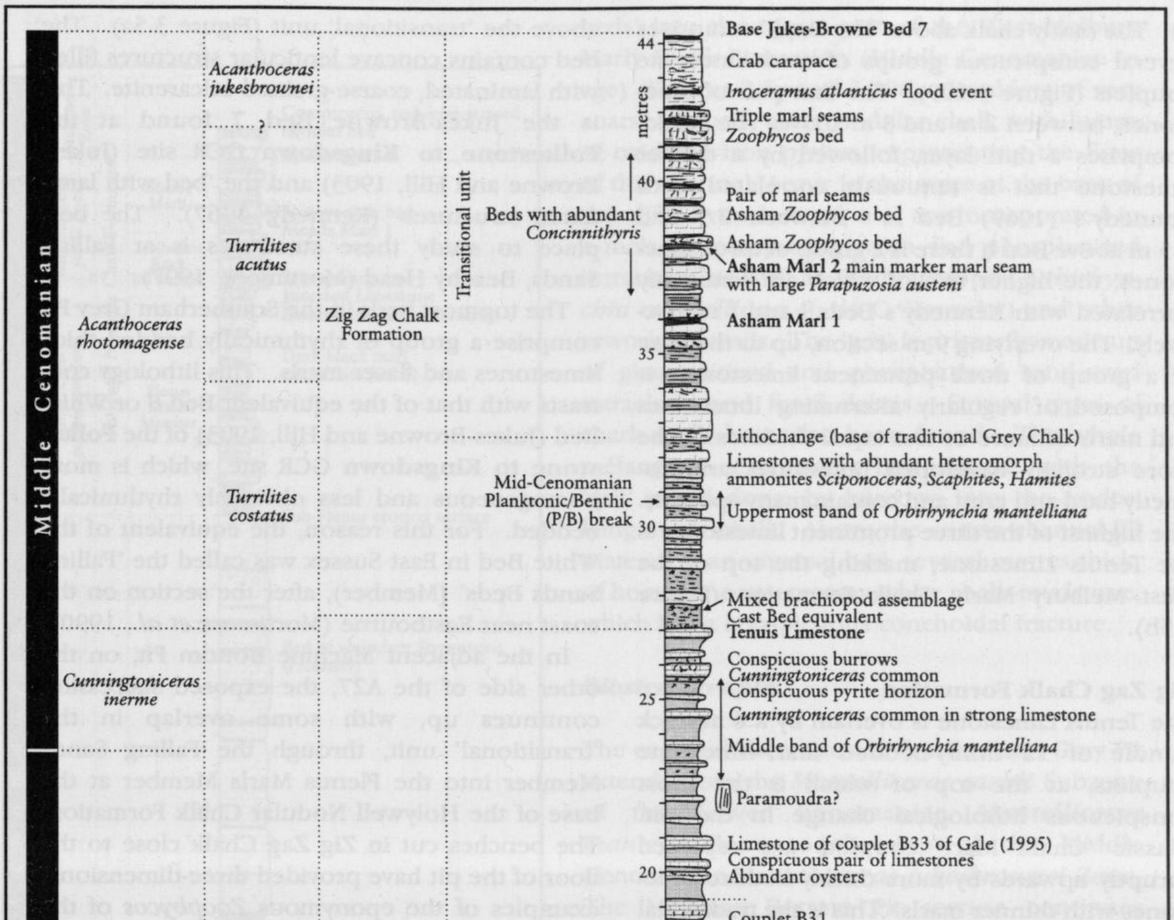


Figure 3.109 Geological section for Southerham Grey Pit, Lewes, Sussex. Compare with Figures 3.5 and 3.108; and Figure 2.8, Chapter 2.

7). The marly chalk above 'The Bank' comprises several conspicuous groups of marl–limestone couplets (Figure 3.109). The first pair of limestones, between 2 m and 3 m above 'The Bank', comprises a thin layer, followed by a thicker limestone that is tenuously correlated with Kennedy's (1969) Bed h. Between 2.5 and 3.5 m above Bed h there is a group of three limestones, the higher two of which are tenuously correlated with Kennedy's Beds j and l respectively. The overlying 9 m section, up to the base of a group of three prominent limestones, is composed of regularly alternating limestones and marls of more or less equal thickness. The more strongly developed limestones are distinctly hard and grey, and contain many sponges. The highest of the three prominent limestones is the Tenuis Limestone, marking the top of the West Melbury Marly Chalk Formation (Figure 3.5b).

Zig Zag Chalk Formation

The Tenuis Limestone is overlain by a 6 m thick bundle of 12 thinly-bedded marl–limestone couplets, at the top of which is the most conspicuous lithological change in the pit. Classic 'Chalk Marl' couplets are replaced abruptly upwards by more thickly bedded limestones with thinner marls. This is the traditional 'Chalk Marl'–'Grey Chalk' boundary in this pit. The basal Zig Zag Chalk Formation hence incorporates the highest 12 couplets of the traditional 'Chalk Marl' (Figures 3.5 and 3.109).

Between the major lithological break and the massively bedded Jukes-Browne Bed 7, there is a 10 m thick rhythmic succession of thick limestones interbedded with thinner but conspicuous marl seams. These beds are lithologically distinct in this area and hence were designated the 'transitional' unit (sic) (Mortimore *et al.*, 1990). The 'transitional' unit includes several conspicuous marl seams, three of which form a distinctive triplet ('Triple Marls') just beneath Jukes-Browne Bed 7 (Figure 3.5a). Towards the top of this unit, the trace fossil *Zoophycos* is abundant, preserved as vertical, millimetre thick tubes from which horizontal feeding traces emanate. These are the Asham Zoophycos Beds, named after the Asham Pits on the east side of the Ouse valley where they are also a conspicuous feature.

Just below the top of the face, beneath the electricity pylon, a very thickly bedded unit of relatively coarse-grained chalk weathers proud above the 'transitional' unit (Figure 3.5a). The bed contains concave lenticular structures filled with laminated, coarse-grained calcarenite. This is the Jukes-Browne Bed 7 found at the **Folkestone to Kingsdown** GCR site (Jukes-Browne and Hill, 1903) and the 'bed with laminated structures' (Kennedy, 1967). The best place to study these structures is at Falling Sands, Beachy Head (Mortimore, 1997).

The topmost beds in the Southerham Grey Pit comprise a group of rhythmically bedded thick limestones and flaser marls. This lithology contrasts with that of the equivalent Bed 8 or White Bed (Jukes-Browne and Hill, 1903) of the **Folkestone to Kingsdown** GCR site, which is more homogeneous and less obviously rhythmically bedded. For this reason, the equivalent of the White Bed in East Sussex was called the 'Falling Sands Beds' (Member), after the section on the coast near Eastbourne (Mortimore *et al.*, 1990).

In the adjacent Machine Bottom Pit, on the other side of the A27, the exposed succession continues up, with some overlap in the 'transitional' unit, through the Falling Sands Member into the Plenus Marls Member at the base of the Holywell Nodular Chalk Formation. The benches cut in Zig Zag Chalk close to the floor of the pit have provided three-dimensional examples of the eponymous *Zoophycos* of the Asham Zoophycos Beds, showing both the central and marginal tubes, which here are commonly lightly iron-stained.

The Plenus Marls Member in Machine Bottom Pit, about 6 m thick (Figure 3.110), rests with marked disconformity of about 15° on the Falling Sands Member. All of the eight standard beds (Jefferies 1962, 1963) can be recognized. The marked lithological break between the basal Plenus Marls Member and the remainder of the Holywell Nodular Chalk Formation is well exposed, and each of the beds of the standard Holywell (Eastbourne) succession up to Meads Marls 3 and 4 is present. There is an unexposed interval between the top of this section and the Holywell Nodular Chalk Formation exposure at the southern end of the Cliffe Industrial Estate (see **Southerham Pit** GCR site report, this volume).

A notable feature at the far eastern end of the main face of the Southerham Grey Pit is provided by a channel (the 'Grey Pit Channel', Mortimore and Pomerol, 1991a; Mortimore, 1997), with a lateral extent of some 100 m. This channel has eroded down from the 'transitional

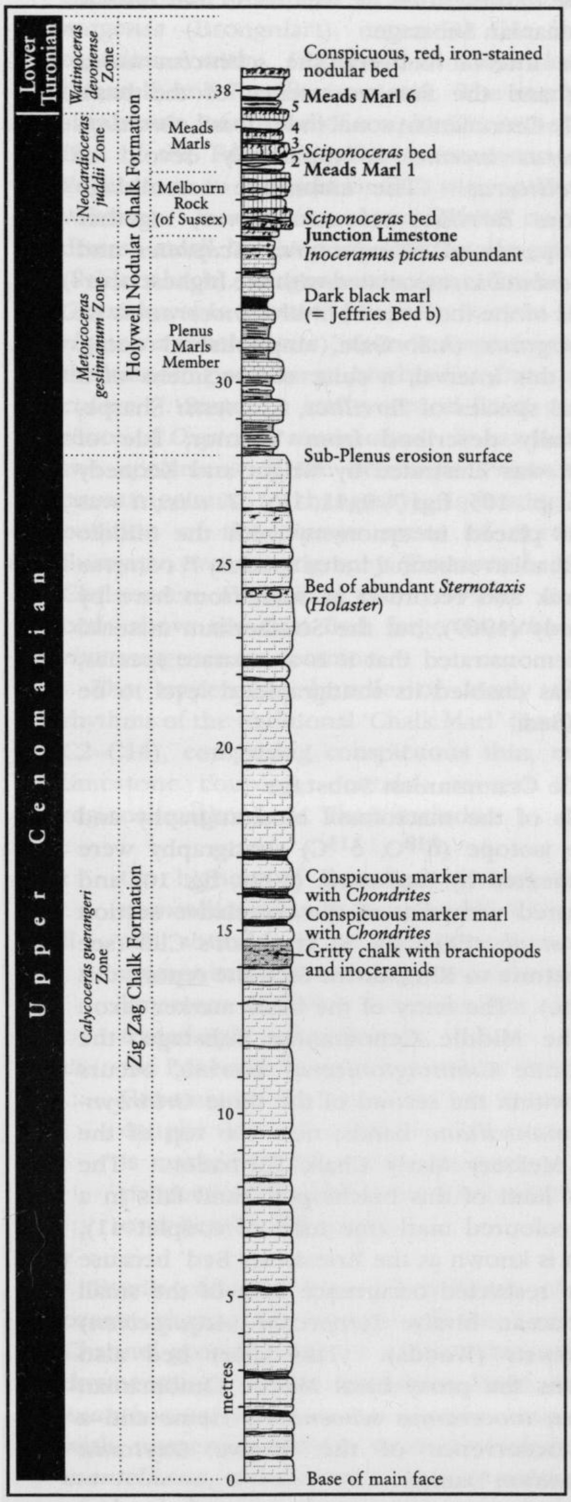


Figure 3.110 Section for the Machine Bottom Pit (Southerham Grey Pit GCR site), Lewes, Sussex.

beds' into the upper part of the West Melbury Marly Chalk Formation (Middle Cenomanian in age) (Figures 3.5c and 3.108). Boulders of very coarse-grained, gritty nodular chalk with lumps of oxidized iron pyrites, representing the floor of this channel, occur in the scree at the base of the cliff. Intraclasts of marl are incorporated in a mélange comprising worn and phosphatized intraclasts, as well as the brachiopod *Orbirhynchia mantelliana* (J. de C. Sowerby) and other reworked fossils. The 'grit' is primarily made up of glauconitized and phosphatized sand-sized intraclasts and fossil debris. Several types of shark teeth have also been found. The whole mélange is extensively bioturbated, with the 'grit' piped down by burrows into the underlying marly chalk. Above the coarse channel-fill material is an unusual bed, several metres thick, of homogeneous, creamy-white chalk-mudstone, which has a conspicuous conchoidal fracture.

Biostratigraphy

The exposed succession in Southerham Grey Pit extends from the *Mantelliceras saxbii* Subzone of the Lower Cenomanian *Mantelliceras mantelli* Zone to the top of the Middle Cenomanian *Acanthoceras jukesbrownei* Zone. The Machine Bottom Pit section continues the biostratigraphical record up to the Cenomanian–Turonian boundary and the basal beds of the Turonian. In the Lower and Middle Cenomanian strata, specific marker horizons are related to the cyclostratigraphy (couplet numbers) of Gale (1990a, 1995, 1998).

Lower Cenomanian Substage

In the lowest beds irregular echinoids (*Epiaster*?) have occasionally been found. Throughout this eastern face ammonites are common, particularly *Schloenbachia varians* (J. Sowerby) and, less commonly, the Lower Cenomanian index fossils *Mantelliceras saxbii* (Sharpe) and *Mantelliceras mantelli* (J. Sowerby), as well as *Mariella*, all in specific bands. In one bed near the base of the section, the *M. saxbii* event, the eponymous ammonite is common and, uniquely, *Mantelliceras* dominates over *Schloenbachia*, in contrast to the ratio in the beds above. This same event was formerly exposed at **Chinnor Chalk Pit**, virtually the only other place in the UK where this event can be recognized. It is a key correlation horizon in the *M. saxbii* Subzone.

The thin 'Rib' (limestone of couplet B11) contains well-preserved specimens of the zonal index ammonite, *Mantelliceras dixoni* Spath, associated with the inoceramid bivalve *Inoceramus virgatus* Schlüter. This lithological marker and its associated fossils can be traced throughout the Southern Province and as far as northern Germany (Gale, 1995, fig. 4).

Inoceramus ex gr. *virgatus*, commonly with the valves associated, is abundant in the conspicuous 'Bank' of limestones (couplets B13–18). This occurrence corresponds to the *virgatus* (acme) event of the northern German event stratigraphy (Ernst *et al.*, 1983; Ernst and Rehfeld, 1997). The lowest of the three *Orbirhynchia mantelliana* bands used for correlation throughout the English Cenomanian succession, follows 'The Bank' of limestones, but is less well developed here than in the Folkestone–Dover section (see **Folkestone to Kingsdown** GCR site report, this volume).

The prominent limestone of couplet B24 (Gale, 1995, fig. 4) (?= Kennedy's Bed h), is unusually well cemented here (at Dover this bed is uncemented and does not have the same abundance of ammonites) and forms a conspicuous marker horizon in the face. It contains common ammonites (*Acompsoceras*, *Forbesiceras*, *Hyphoplites*, *Mantelliceras*, *Schloenbachia*) and large inoceramid bivalves, all superbly preserved in three dimensions and easy to extract from the hard limestone. The occurrence of the small heteromorph ammonite *Mesoturrilites boerssumensis* (Schlüter) in this bed, and in the underlying *Orbirhynchia mantelliana* Band, indicates the presence of the second of the three successive ammonite assemblages recognized by Gale (1995) in the *dixoni* Zone. It also enables correlation with the *boerssumensis* Subzone, which has recently been distinguished (Kaplan *et al.*, 1998) in Westphalia, northern Germany.

A conspicuous bed of limestone in the middle of the face (Figure 3.5), contains well-preserved *Turrilites scheuchzerianus* Bosc. This occurrence, the *scheuchzerianus* event, can be traced elsewhere, notably to the **Chinnor Chalk Pit** GCR site (see site report, this volume). *T. scheuchzerianus* was originally thought to be restricted to the Middle Cenomanian Substage and its occurrence in this bed was taken by Kennedy (1969) to mark the entry of Middle Cenomanian ammonite assemblages in this section. However, it is now known that this species is relatively common in the higher part of the *dixoni* Zone as well as in the Middle Cenomanian Substage.

The interval between the *scheuchzerianus* event and the first occurrence of the basal Middle Cenomanian zonal index fossil, *Cunningtoniceras inerme*, is apparently devoid of *Mantelliceras*. The ammonite assemblage includes *Turrilites scheuchzerianus*, together with species of *Acompsoceras*, *Scaphites* and *Schloenbachia*, associated with the highest occurrences of the inoceramid bivalve *Inoceramus* ex gr. *virgatus* (A.S. Gale, unpublished data). From this interval, a suite of specimens of a second species of *Turrilites*, *T. wiestii* Sharpe, originally described from Ventnor, Isle of Wight, was illustrated by Wright and Kennedy (1996, pl. 105, figs 7, 8, 11, 15). *T. wiestii* was earlier placed in synonymy with the Middle Cenomanian subzonal index species, *T. costatus* Lamarck and recorded as such from here by Kennedy (1969), but the Southerham material has demonstrated that it is a separate species, and has enabled its stratigraphical level to be identified.

Middle Cenomanian Substage

Details of the macrofossil biostratigraphy and stable isotope ($\delta^{18}O$, $\delta^{13}C$) stratigraphy were documented by Paul *et al.* (1994, fig. 10) and compared with that of the correlative section (Paul *et al.*, 1994, fig. 5) at Abbot's Cliff (see **Folkestone to Kingsdown** GCR site report, this volume). The entry of the basal marker taxon for the Middle Cenomanian Substage, the ammonite *Cunningtoniceras inerme*, occurs here within the second of the three *Orbirhynchia mantelliana* bands, near the top of the West Melbury Marly Chalk Formation. The upper limit of this brachiopod band falls in a dark coloured marl (the marl of couplet 41), which is known as the 'Arlesiensis Bed' because of the restricted occurrence in it of the small pectinacean bivalve *Lyropecten* (*Aequipecten*) *arlesiensis* (Woods). This latter bed also contains the proxy basal Middle Cenomanian marker, *Inoceramus schoendorfi* Heinz and a flood-occurrence of the bivalve *Oxytoma seminudum* Dames.

The Tenuis limestone, just above the West Melbury Marly Chalk, contains common, well-preserved specimens of the eponymous inoceramid bivalve, *Actinoceramus tenuis* (Mantell) (see Crampton, 1996). The traditional ammonite marker for the base of the Middle Cenomanian Substage, *Acanthoceras rhotomagense* (Brongniart), enters at this level, together with *Sciponoceras baculoides* (Mantell) and *Turrilites costatus*. The overlying silty brown marl (marl of couplet C1) is the Cast Bed of the Folkestone–Dover succession (see **Folkestone to Kingsdown** GCR site report, this volume) It contains many fossils, notably diverse small brachiopods (*Modestella geinitzi* (Schloenbach), *Kingena concinna* Owen and *Grasirhynchia martini* (Mantell), but not *Orbirhynchia mantelliana*), abundant specimens of the smooth pectinacean bivalve *Entolium orbiculare* (J. Sowerby) and a second flood occurrence of *Oxytoma seminudum*. It has yielded two specimens of the belemnite *Praeactinocamax primus* (Arkhangesky), indicating the position of the *primus* event of northern European event stratigraphy (Ernst *et al.*, 1983; Christensen, 1990; Paul *et al.*, 1994). In the beds above the Cast Bed, large *Acanthoceras rhotomagense* are common.

The uppermost bundle of marly chalk rhythms of the traditional 'Chalk Marl' (couplets C2–C14), comprising conspicuous thin, marl–limestone couplets, contains several inter-regional marker beds. These include:

i the highest of the three *Orbirhynchia mantelliana* bands (couplets C5–C10);
ii an abundance of the heteromorph ammonite *Sciponoceras baculoides* in the limestone of C10, a bio-event that can be traced right across Europe;
iii the P/B break (formerly known as the 'Mid-Cenomanian non-sequence') at the top of couplet C10, a hemisphere-wide event that is marked by the sudden increase in the proportion of planktonic (P) foraminifera over benthic (B) species.

Fossils collected from fallen blocks of the coarse channel-fill material of the Grey Pit Channel provide evidence of the extent of the downcutting. These include a large, worn *Acanthoceras jukesbrownei* (Spath) associated with numerous rolled, worn *Orbirhynchia mantelliana*, and also extremely rare specimens of the belemnite *Praeactinocamax primus*, presumably derived from the Cast Bed (Mortimore, 1997).

Above the major lithological break there is a dramatic drop in macrofossil diversity. The diverse brachiopod faunas of the underlying beds are replaced by a low diversity assemblage dominated by the terebratulid brachiopod *Concininnthyris subundata* (J. Sowerby). Although smaller ammonites are generally rare, specimens of the very large species, *Parapuzosia* (*Austiniceras*) *austeni* (Sharpe) occur commonly for some metres below Jukes-Browne Bed 7 and are regularly found in rock-falls from this level. There are occurrences of the inoceramid bivalve zonal index fossil, *Inoceramus atlanticus* (Heinz) at several horizons (commonly in the large fallen blocks), notably at the level of the 'Triple marls'. The entry of *I. atlanticus* is more-or-less coincident with that of the zonal index ammonite, *Acanthoceras jukesbrownei* and is a better marker for the base of the *jukesbrownei* Zone than the eponymous ammonite, thus making the Southerham Grey Pit critical for biostratigraphical interpretation at this level.

36 large specimens of *Acanthoceras jukesbrownei* (Spath) were lifted by excavators from one layer at the base of the massive Jukes-Browne Bed 7 during construction of the adjacent section of the A27. *Inoceramus* ex gr. *pictus* J. de C. Sowerby and the ammonite genus *Calycoceras* occur in the fallen blocks from the Falling Sands Member overlying Jukes-Browne Bed 7.

In the Machine Bottom Pit, White (1926) recorded *Belemnitella plenus* (i.e. *Praeactinocamax plenus*), which is particularly common in Bed 4 of the Plenus Marls Member. *Inoceramus pictus* is common at the base of the Melbourn Rock. A band of the bivalve *Mytiloides* between Meads Marls 4 and 5 marks the beginning of the Turonian Stage.

Interpretation

Several cored boreholes were drilled in the 1970s to prove the reserves when Southerham Grey Pit was still a working quarry. These demonstrated that the Upper Greensand was absent, and that the basal unit of the Grey Chalk Subgroup, the Glauconitic Marl Member, rested directly on Gault, 8.5 m beneath the present floor at the south-eastern end of the pit. The unexposed Grey Chalk Subgroup succession proved in the boreholes is relatively condensed compared to the equivalent beds in the East Wear Bay and Abbot's Cliff sections in the Folkestone–Dover section (**Folkestone to Kingsdown** GCR site), in Kent.

Combining the borehole successions with measurements of the exposed composite Southerham Grey Pit/Machine Bottom Pit succession, indicates that the Grey Chalk Subgroup here is *c.* 80 m thick, compared with a measurement of *c.* 50 m, some 16 km away at Beachy Head, the next nearest exposure. The succession was even thicker in the Asham Pits to the south, which hindered the correlation of cored boreholes drilled to investigate the site for landfill purposes. The boreholes also indicated further marked thickening southwards (Mortimore and Pomerol, 1991a). An expanded basal Cenomanian succession was proved to the north-east of Southerham in the cored British Geological Survey Glyndebourne Borehole (Lake *et al.*, 1987, fig. 15). Mortimore and Pomerol (1991a, 1997) related these variations in thickness to underlying fault movements in the region. The position of the Grey Pit Channel on the northern limb of the Kingston Anticline and its underlying main inversion axis is closely aligned with that of the channel associated with Strahan's Hardground in the nearby **Southerham Pit**.

One of the features of Southerham Grey Pit is the striking rhythmicity of the traditional 'Chalk Marl' (Figures 3.5 and 3.108). Ditchfield and Marshall (1989) established, using calculations from oxygen stable isotope ($\delta^{18}O$) values, that individual correlative marl–limestone couplets at Folkestone were climatically controlled, with a *c.* 4°C difference in temperature between the (colder) marl and the (warmer) limestone component. These conclusions were questioned by Mitchell *et al.* (1997), who considered that the $\delta^{18}O$ values were diagenetically controlled, and did not relate to sea-water temperature. Gale (1995) inferred that the individual marl–limestone couplets reflected orbitally controlled Milankovitch climatic cycles of 19 000–23 000 years' duration, corresponding to the precession cycle. He established a standard cyclostratigraphy for a large part of the Cenomanian succession based on the couplets here and at other localities, notably Folkestone, which he used to produce an absolute timescale for the Cenomanian Age and to identify gaps in the succession at any one locality.

The sequence stratigraphy of the exposed part of the Southerham Grey Pit/Machine Bottom Pit succession can be extrapolated from the Folkestone standard section (cf. Gale, 1995; Robaszynski *et al.*, 1998, fig. 6). The transgressive (onlap) surfaces of Cenomanian depositional sequences 3, 4 and 5 respectively are identified at:

- a coarse-grained bed, *c.* 3 m below 'The Rib';
- the base of the 'Cast Bed' (i.e. at the base of the Zig Zag Chalk Formation);
- the base of Jukes-Browne Bed 7;
- the base of Jefferies' Bed 4 of the Plenus Marls Member.

In basinal successions such as those found at Southerham Grey Pit and Folkestone, the sequence boundaries themselves are not expressed as erosion surfaces and their positions must be inferred from increases in the proportion of clay and acid insoluble residue. The sub-Plenus erosion surface, at the base of the White Chalk Formation, on the other hand, is a major sequence boundary, and is marked at the Southerham Machine Bottom Pit by the 15° angular discordance between the Plenus Marls Member and the underlying beds (Mortimore and Pomerol, 1991a).

It is not possible to determine the geometry of the Grey Pit Channel, but it is known from photographs taken at an earlier stage of quarrying that the channel originally cut more deeply into the West Melbury Marly Chalk Formation than in the present exposure. Although its upper limit is truncated by the land surface, the channel may well be connected with the sequence boundary that is inferred to lie below the beds with *Inoceramus atlanticus* in the north-west part of the pit. This is the sequence boundary at the base of Cenomanian Sequence 5 of Robaszynski *et al.* (1998) and the *Pycnodonte* Sequence of Ernst and Rehfeld (1997). The presence of *I. atlanticus* indicates less erosion at this sequence boundary here than at other localities. The sequence boundary lies just above the position of the most abundant *Zoophycos* in the Asham Zoophycos Beds. The occurrence of abundant *Zoophycos* in chalks with low-diversity faunas is paralleled by the beds beneath the sub-Plenus erosion surface, where abundant *Zoophycos* characterize the highstand sediments below the new sequence boundary. This latter event is recognizable everywhere in Europe and is especially well developed in the Northern Province at the top of the Ferriby Chalk Formation at South Ferriby (Mortimore and Pomerol, 1991b).

Other nearby correlative sections in Sussex include the former Asham Pits, described by Kennedy (1969) as 'Beddingham Limeworks', but now a major landfill site named after Asham House, made famous by Virginia Woolf and the Bloomsbury Group. Three separate pits here exposed different parts of the succession from the Gault Clay and Grey Chalk Subgroup to the Holywell Nodular Chalk Formation.

Asham Pit 1 exposed the contact between the Glauconitic Marl Member and the underlying Gault Clay, which here exhibited a marked angular discordance (Mortimore and Young, 1980; Mortimore, 1986b). The fact that a similar discordance has been noted elsewhere (e.g. in the North Downs of Surrey) at this level suggests the possibility of tectonic movements between Albian and Cenomanian times. A thin limestone at the top of the Glauconitic Marl yielded a basal Cenomanian *Neostlingoceras carcitanense* Subzone ammonite fauna (Kennedy, 1969). This can be compared with the occurrence of a single specimen of the subzonal index fossil in an apparently equivalent limestone in the 'rotated slab' section in East Wear Bay (see **Folkestone to Kingsdown** GCR site report, this volume). There was no overlap between Asham Pits 1 and 3. Asham Pit 2 exposed the West Melbury Marly Chalk Formation and the basal Zig Zag Chalk Formation, from about the *Turrilites scheuchzerianus* band up to the highest *Orbirhynchia mantelliana* Band. This section just overlapped with the base of the largest quarry, Asham Pit 3, which exposed the remainder of the succession up into the Holywell Nodular Chalk Formation. The section showing the contact between the Plenus Marls Member and the Melbourn Rock in Asham Pit 3 was published by Mortimore (1986b) and Lake *et al.* (1987).

Compared with that in Southerham Grey Pit, the West Melbury Marly Chalk succession at Beachy Head, near Eastbourne, is markedly thinner and less complete, with clear signs of erosion in the Lower and Middle Cenomanian strata (Kennedy, 1969, fig. 12; Figures 3.111 and 3.112). The Glauconitic Marl contains a rich and diverse *Neostlingoceras carcitanense* Subzone ammonite assemblage preserved as phosphatized moulds. The combined sequence boundary and transgressive surface at the base of the *dixoni* Zone is represented here by a concentration of phosphatized and glauconitized ammonites derived from the underlying *saxbii* Subzone (the '*saxbii* phosphates'); an equivalent concentration is found in the Isle of Wight at Gore Cliff and Compton Bay. Correlation with the successions proved in the Rodmill, Eastbourne, and the Glyndebourne cored boreholes (Lake *et al.*, 1987, fig.15) illustrates the extent of section loss at Beachy Head, which is probably related to another deep-seated tectonic structure.

The only GCR site in this region to include the Plenus Marls Member is the Machine Bottom Pit at the Southerham Grey Pit GCR site, where the unit is *c.* 5 m thick. Jefferies (1963) used Merstham in Surrey as his type section for the Plenus Marls (3.2 m), and established a standard succession of eight numbered beds. He recognized that the succession on the Sussex coast at Eastbourne was much thicker than elsewhere. There is considerable lateral variation in thickness in these sections, ranging from 6 m at Holywell, to 8 m at Beachy Head and to a maximum 11 m at Gun Gardens (Figures 3.112 and 3.113). This variation reflects structural control (Mortimore, 1986b, figs 3.3, 3.4).

The Cenomanian–Turonian (C/T) boundary interval, beginning with the Plenus Marls and extending to the top of the Meads Marls, is of particular interest in the context of the present-day climatic changes and consequent reduction in biodiversity. For this reason it is one of the most intensively studied parts of the Cretaceous succession. It corresponds to an inferred period of global sea-water anoxia resulting from a major sea-level highstand. This so-called 'Oceanic Anoxic Event [OAE II]' (Jenkyns, 1980) is considered to have initiated the stepwise extinction, or diminution in numbers, of many groups of micro-organisms, including nannofossils, ostracods, foraminifera and dinoflagellates (but see a different interpretation in Gale *et al.*, 2000). The interval is recorded by a complex major positive excursion in $\delta^{13}C$ values of the carbonates, reflecting high burial rates of organic carbon (Gale *et al.*, 1993, fig. 2). It is also marked by the deposition of organic-rich black shales and similar dark coloured sediments, for example the Plenus Marls–Meads Marls of the Southern Province, Black Band of the Northern Province and the North Sea Basin (Wood and Mortimore, 1995). The interval is additionally characterized by sharp, discrete manganese and iridium spikes (see Pomerol and Mortimore, 1993, and references therein). The ocurrence of iridium spikes has led some workers to infer that the climatic perturbations resulted from an impact from an extra-terrestrial body, as in the case of the Cretaceous–Palaeogene (K/P) boundary.

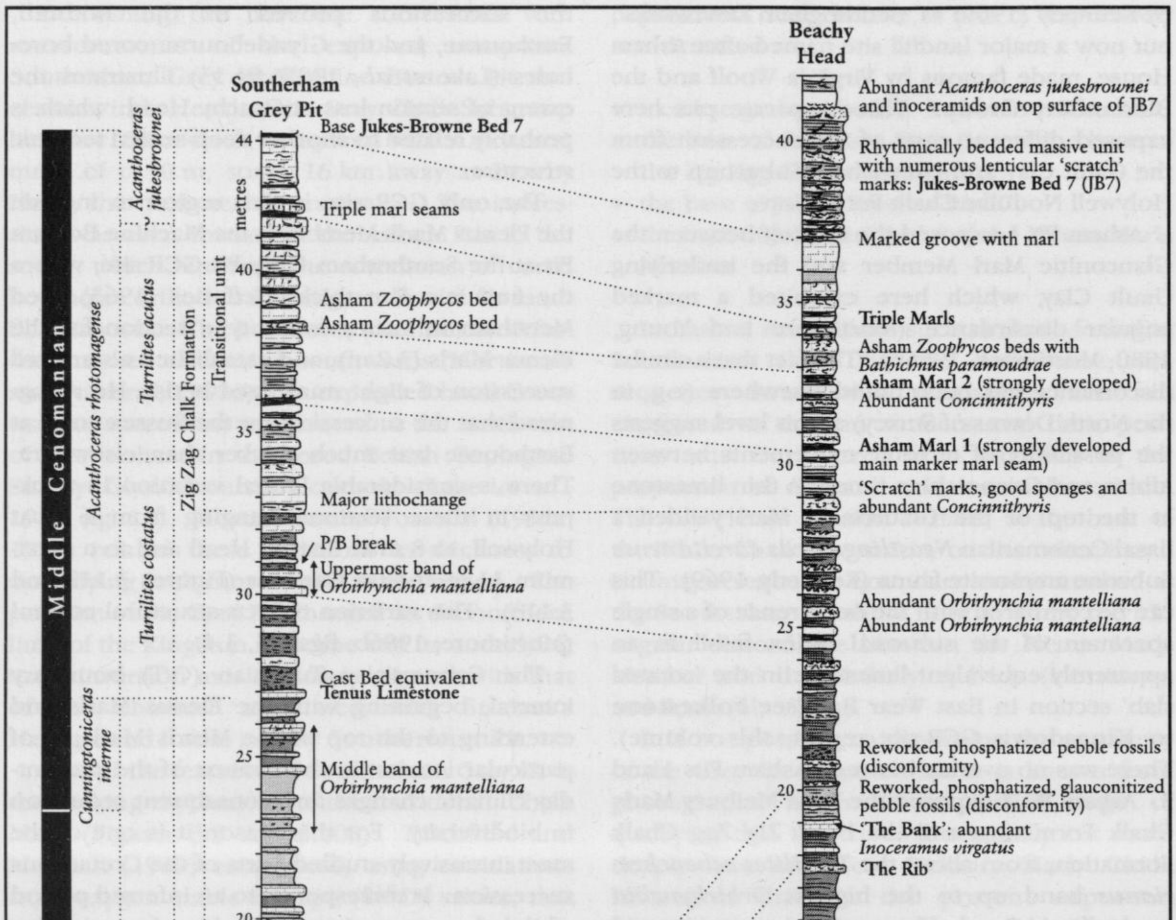


Figure 3.111 Southerham Grey Pit correlated with Beachy Head illustrating the marked condensation in the Early Cenomanian West Melbury Marly Chalk at Eastbourne.

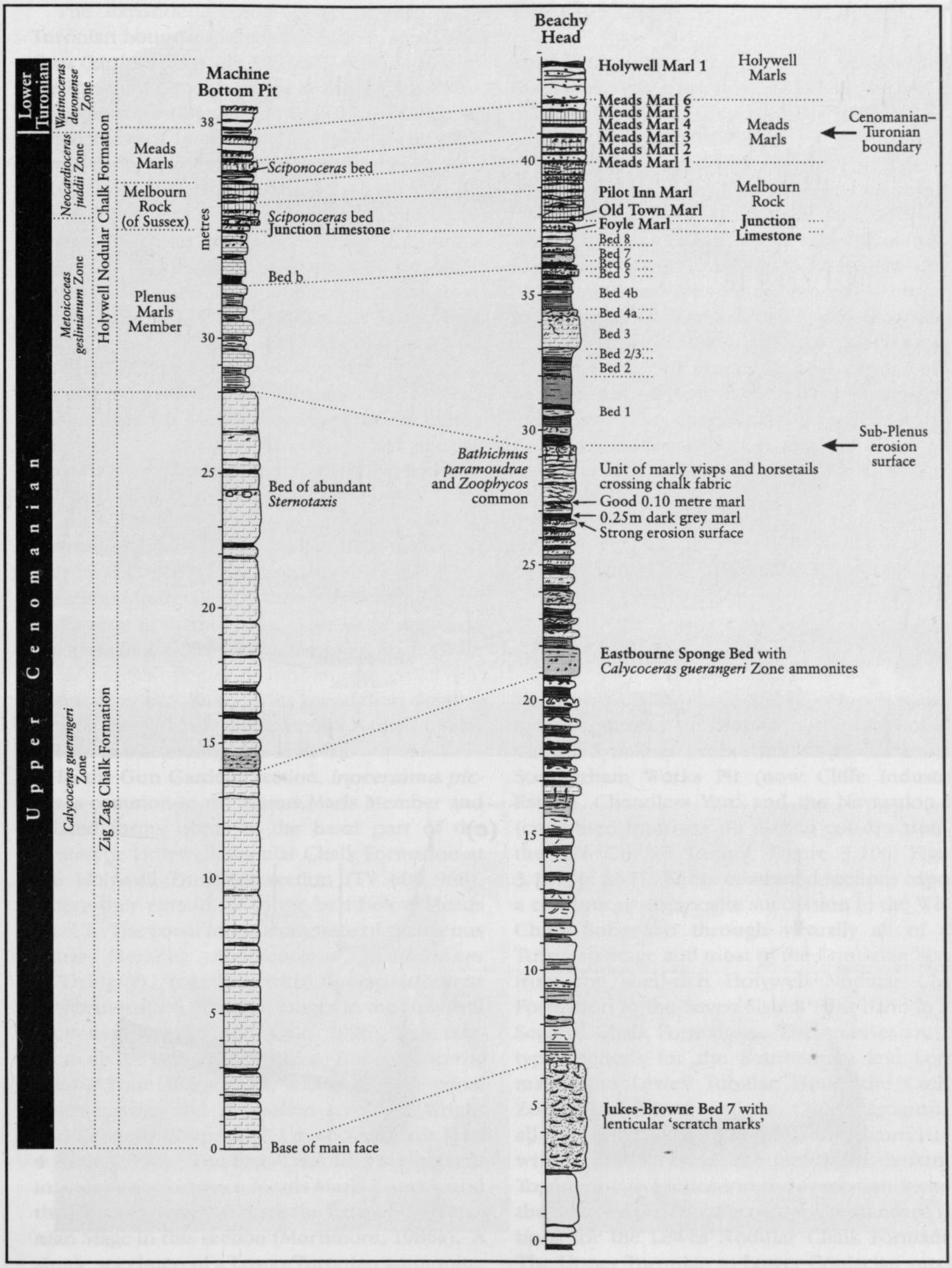


Figure 3.112 The Machine Bottom Pit (part of the Southerham Grey Pit GCR site) correlated with Beachy Head, near Eastbourne, showing the very different lithologies of the two sites.

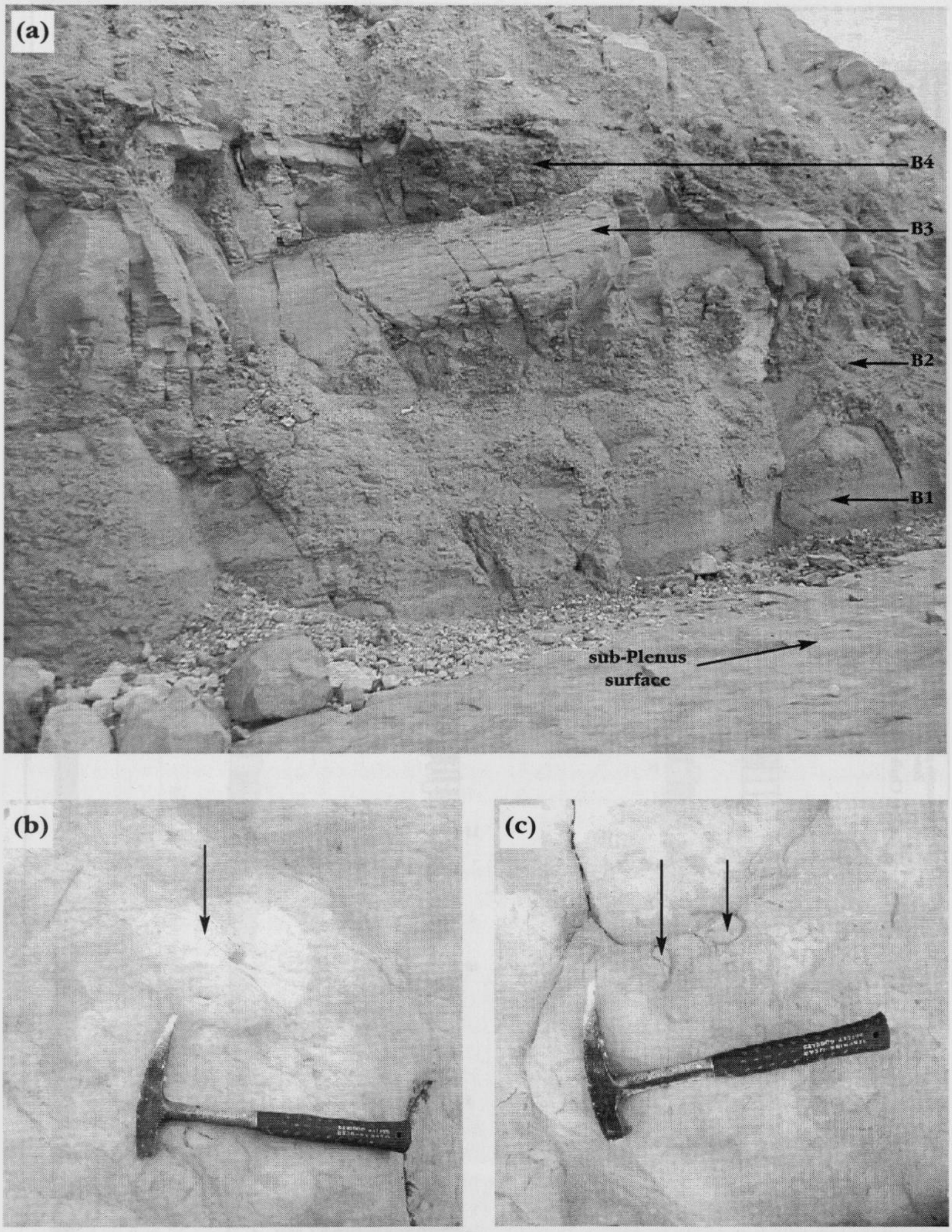


Figure 3.113 Basal beds of the Plenus Marls Member in the type section at Beachy Head, Sussex. (a) Basal beds showing a cyclostratigraphy of paler and darker bands. (b, c) Sub-Plenus erosion surface mottled with (b) pale haloes of *Bathichnus paramoudrae* (arrowed) and (c) dark spirals of *Zoophycos* (arrowed). (B1 = Bed 1 with pyrite-filled burrows; B2 = Bed 2 with pyrite-filled burrows and an oyster band; B3 = Bed 3, a pale calcareous band; B4 = Bed 4, a dark marl with belemnites.) (Photos: R.N. Mortimore.)

The expanded, continuous, Cenomanian–Turonian boundary interval at Beachy Head and Gun Gardens (Figures 3.6 and 3.113) is one of the most important sections spanning this interval in Europe (Figure 3.112) and worldwide in the context of biostratigraphy and geochemical stratigraphy (Paul *et al.*, 1999). For this reason, this section has been proposed as an international reference section for the boundary and for future GCR site status specifically for stratigraphy (it is already a GCR site/SSSI for other geological features). Unpublished work by Professor Gale (pers. comm., 2000) has shown that the Beachy Head and equivalent Holywell sections are rich in inoceramid bivalves and contain an unexpectedly diverse terminal Cenomanian *Neocardioceras juddii* Zone ammonite fauna, including the zonal index species and species known from North America. The microfossils have recently been completely reassessed (Ferre *et al.*, 1996). The integrated (nannofossil, microfossil, macrofossil, dinoflagellate) biostratigraphy and geochemical stratigraphy has been correlated in detail with those of the condensed succession in Pueblo, USA. This latter section is the candidate GSSP for the Turonian Stage (Gale *et al.*, 1993; Pomerol and Mortimore, 1993; Kennedy *et al.*, 2000). This correlation demonstrates the virtually isochronous nature of the events characterizing this interval.

In the Gun Gardens section, *Inoceramus pictus* is common in the Plenus Marls Member and related forms occur in the basal part of the stratotype Holywell Nodular Chalk Formation at the Holywell Pinnacles section (TV 600 968), where they extend up to the bed below Meads Marl 1. The zonal index ammonite of the Plenus Marls Member, *Metoicoceras geslinianum* (d'Orbigny), together with *Euomphaloceras septemseriatum* (Cragin), ranges in the Holywell section to couplet E13 (Gale, 1996), four couplets above the Plenus Marls. *Neocardioceras juddii* Zone ammonites, including the zonal index species and *Thomelites serotinus* Wright and Kennedy disappear 0.1 m above Meads Marl 4 (Gale, 1996). The first *Mytiloides* are present in abundance between Meads Marls 4 and 5, and their entry is taken to mark the base of the Turonian Stage in this section (Mortimore, 1986a). A single specimen of a Lower Turonian ammonite, *Watinoceras* cf. *amaduriense* (Arkhangesky), was also found at this level and the basal Lower Turonian ammonite zonal index species, *W. devonense* Wright and Kennedy, is also present.

Conclusions

The accessibility of the beds, the abundance of fossils and the completeness of the succession make Southerham Grey Pit a key section in the Cenomanian strata of Europe. It is a candidate GSSP for the Middle Cenomanian Substage and a standard reference section for the couplet cyclostratigraphy, stable isotope stratigraphy, as well as for the integrated macrofossil and microfossil biostratigraphy of the Cenomanian Stage. The occurrences here of the inoceramid bivalve *Inoceramus atlanticus* and the ammonite *Acanthoceras jukesbrownei* are of critical importance in current international investigations to establish the base of the Upper Cenomanian Substage. The spectacular Grey Pit Channel provides evidence for structural control of sedimentation related to intra-Late Cretaceous periclinal structures located over or adjacent to basement shears.

SOUTHERHAM PIT, LEWES, SUSSEX (TQ 426 096)

Introduction

The Southerham Pit GCR site comprises three former quarries at Lewes, in the core of the Caburn Syncline. From south to north these are Southerham Works Pit (now Cliffe Industrial Estate), Chandlers Yard and the Navigation Pit (combined into one pit during construction of the A26 Cuilfail Tunnel, Figure 3.106; Figure 3.115, p. 257). These combined sections expose a continuous composite succession in the White Chalk Subgroup through virtually all of the Turonian Stage and most of the Coniacian Stage, from the shell-rich Holywell Nodular Chalk Formation to the Seven Sisters Flint Band in the Seaford Chalk Formation. The quarries are the type sections for the Southerham and Lewes marls, the Lewes Tubular Flints, the Cuilfail Zoophycos (Flints) and the Cliffe Hardground, all of which are used for long-range correlation within and outside the Southern Province. Together with sections in the immediate vicinity, the quarries provide the composite standard sections for the Lewes Nodular Chalk Formation. The Upper Turonian to Lower Coniacian succession is thicker and more complete than anywhere else in England, and contains fossils that are apparently not present elsewhere. Many of the fossils described and illustrated by Mantell

(1822, 1827), and now housed in the Natural History Museum, London, came from these quarries. This is one of only two sites in England in which granular phosphatic chalk is known to occur in the Turonian strata, the other being the nearby Glyndebourne Pit.

These 'Southerham' quarries are cut into the steep, west-facing slope of the Mount Caburn Chalk Block with the hill of Cuilfail overlooking the site from the north. This steep slope, one of the steepest natural slopes in England, was the site of a fatal avalanche in 1856. The avalanche swept off Cuilfail Hill onto a public house, which subsequently became known as 'The Snowdrop'. Mantell (1822, Tablet II, fig. 3) and Jukes-Browne and Hill (1903, pp. 399–402, fig. 72) described the line of hills from Malling to Southerham informally as the 'Cliff Hills'.

Description

The three former quarries comprising the Southerham Pit GCR site expose Chalk with bedding dips of 30° north at the southern end in Southerham Works Pit, nearly horizontal below the Lewes Golf Club House in the former Chandlers Yard, and 5°–8° south at the northern end in the Navigation Pit. These angles of dip, and the plunge westwards of the strata, were first recorded and illustrated by Mantell (1822, p. 140 and Tablet VII). The quarries have been variously named depending on the occupancy. Southerham Works Pit is the most southerly and largest and was simply known as 'the quarry at Southerham' by Mantell (1822, p. 140) and later the 'Southerham Limekiln Quarry' (Jukes-Browne and Hill, 1904, p. 46), where lime kilns and, subsequently, the cement works, were located. It is now occupied by Cliffe Industrial Estate and exposes most of the Turonian and the Coniacian succession up to the Seven Sisters Flint Band. It includes the famous Lewes Phosphatic Chalk (Strahan, 1896; Jukes-Browne and Hill, 1904, p. 46), floored by Strahan's Hardground (Mortimore, 1986a,b). The phosphatic chalk overlies a mineralized hardground (Strahan's Hardground) which represents the lithification of a local channel. The overlying 15 m of flinty chalk are anomalous and are assumed to represent a channel-fill.

The next quarry to the north, Chandlers Yard, is named after Chandlers, a local Builders Merchants. Chandlers occupied the quarry until the Cuilfail Tunnel was constructed in 1978–1979 (Figure 3.115, p. 257). The quarry was last worked in the 19th and early 20th centuries, when a railway was used to transport chalk to the kilns in Southerham Works Quarry. Relict pieces of this railway were finally removed when the A26 was constructed south of the Cuilfail Tunnel, but its position is occupied by the slope bench in the spur of chalk dividing Southerham Works from Chandlers Yard. The most northerly of the quarries is the 'Navigation' or 'Snowdrop' Pit, which is named after the Navigation of the River Ouse construction project, completed in 1796, under the guidance of canal building civil engineer, William Smith. Mantell (1822, Tablet II, fig. 3 and p. 140) illustrates the position of a quarry that appears to be the Navigation Pit that he calls the 'South Street Pit' where the strata were horizontal. Chalk was excavated from the Navigation Pit and other quarries (e.g. the Chalk Pit at Offham) for the original construction and subsequent maintenance of the revetments along the banks of the Ouse between Lewes and Newhaven. White (1926, pl. IV) illustrated these quarries and the railway line between them.

Southerham Works Quarry (now Cliffe Industrial Estate) (TQ 425 095)

The Southerham Works Quarry (formerly known as 'Eastwoods Pit' or 'Southerham Cement Works') has provided exposures for studying the stratigraphy of the Chalk since the end of the 18th century. Mantell's *The Fossils of the South Downs* (1822, Tablet VII) illustrates the extent of his 'Lower Chalk' then exposed at Southerham near the Old Lime Kilns. Parts of this old section still remained when Strahan (1896) and Dibley (1906) described the Lewes Phosphatic Chalk, but until recently it was degraded and overgrown. Since 1980, construction of the Cliffe Industrial Estate has resulted in a complete re-excavation of the whole succession from near the base of the Holywell Nodular Chalk Formation to the Beeding Beds in the upper part of the Lewes Nodular Chalk Formation, providing an outstanding section through the Turonian succession and the phosphatic chalk (Mortimore, 1986a,b; 1997). Parts of the succession were included in the descriptions by Jukes-Browne and Hill (1903, 1904) with lists of fossils and some lithological details. The first detailed logs of the stratigraphy were provided by Mortimore (1979, 1983, 1986a,b) and sketches of the exposures showing the stratigraphy are illustrated in Mortimore (1997).

Lithostratigraphy

At the southern end of the quarry, the beds of the Holywell Nodular Chalk Formation dip relatively steeply north at 25°–30°. The lowest horizons that can be identified are the Holywell Marls and the griotte or flaser bedded chalks containing bands of abundant *Mytiloides* (Figure 3.114). Higher up-section are found the Gun Gardens Marls and, at the top of the formation, the Gun Gardens Main Marl, which here is associated with numerous nodules of red-weathering iron pyrites. The basal metre of the overlying New Pit Chalk Formation contains inconspicuous, small white flints, the Glyndebourne Tubular and Finger Flints, which take their name from a nearby locality, Glyndebourne Pit 1. Two normal faults filled with a weathered gouge complicate the section.

A strongly developed, red-orange, iron-stained nodular chalk bed in the now poorly exposed upper part of the section, where it turns eastwards towards the Malling Street Marls exposures, is the lateral equivalent of Glyndebourne Hardground 1 in the anomalous succession at Glyndebourne Pit 1. The section up to the Malling Street Marls is poor, but the two dark, plastic marls are well exposed at the south corner behind the first building (Mortimore, 1997, fig. 8). Iron-stained nodular beds, equivalent to Glyndebourne Hardgrounds 2 and 3 (Figure 3.114), are present in the succeeding face behind the first building.

The section between the Malling Street Marls and Strahan's Hardground is largely covered by scree, but the section above, up to the Cliffe Hardground, is well exposed. The lowest beds below the hardground contain a well-developed bed of nodular chalk overlain by a thick, plastic marl. Some 2 m above is the hardground originally described by Strahan (1896), and later named 'Strahan's Hardground' (Mortimore, 1986a,b). It is an intensely indurated chalkstone penetrated by an extensive *Thalassinoides* burrow system, which pipes the overlying phosphatic chalk up to 0.15 m below the heavily phosphatized surface. The walls of the burrows are glauconitized and phosphatized and the phosphatic chalk fills may include bored and mineralized pebbles of hardened chalk.

The hardground is overlain by the Lewes Phosphatic Chalk (Strahan, 1896; Figure 3.114), a complex unit *c.* 2 m thick of pelletal phosphatic chalk containing sharks teeth, with a basal lag of worn glauconitized and phosphatized pebbles. The pelletal phosphate is concentrated in the first 0.5 m. The phosphatic chalk is followed by a sparsely flinty unit comprising two flaser marls and a weakly developed marl seam, above which there is a thick interval (*c.* 10 m) of very flinty chalk, terminating in a pair of wispy marls. The beds above contain two conspicuous bands of nodular flint, separated and overlain by thin marl seams. Some metres higher, above two closely spaced beds of indurated nodular chalk, are seen the paired Southerham Marls, for which this is the type section. The interpretation of the succession between Strahan's Hardground and the Southerham Marls presents difficulties and is discussed below.

In the succeeding section, the Caburn and Bridgewick marls are readily identifiable. Farther north in the old quarry, the Lewes Marl and Lewes Tubular Flints and the Navigation Marls can be seen on the steeply dipping south flank of the Caburn Syncline. At the northern limit of the quarry (TQ 425 098), the stratotype section of the overlying Cliffe Hardground is exposed (Figure 3.115) on the upper bench of the road cutting, where a spur formerly separated the Southerham Works Pit from Chandlers Yard. The Shoreham Marls and the Belle Tout Marls form grooves towards the top of the high, inaccessible part of the cliff, and the conspicuous Seven Sisters Flint Band can be seen just below the top.

Navigation Pit and Chandlers Yard (TQ 425 100) (South Portal, Cuilfail Tunnel)

Construction of the Cuilfail Tunnel (1976–1978) has partly obscured the section formerly exposed in the Navigation Pit. As a result of the southerly dip, the entire lower Lewes Nodular Chalk succession up to the Lewes Marl was exposed during construction of the tunnel. The Navigation Pit is the stratotype section for the Lewes Marl and the Lewes Tubular Flints, as well as for the succession between the Lewes Marl and the Cliffe Hardground. The latter comprises, in ascending order, the South Street Beds, Navigation Beds and Cliffe Beds (Mortimore, 1986a) and includes several key

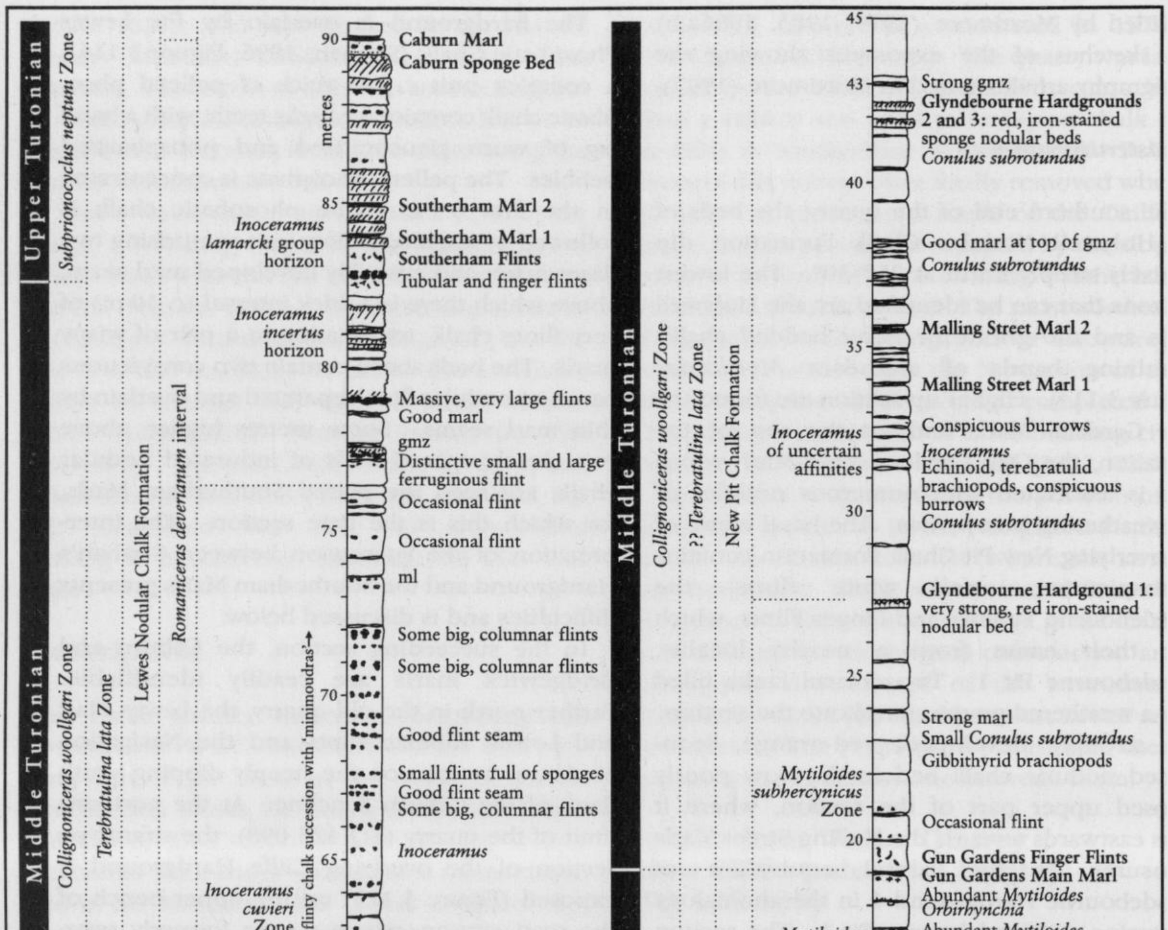


Figure 3.114 Stratigraphy of the Turonian Holywell Nodular Chalk, New Pit Chalk and Lewes Nodular Chalk formations at Southerham Pit, Cliffe Industrial Estate (formerly known as 'Eastwoods Pit' or 'Southerham Cement Works'). (gmz = griotte (or flaser) marl zone; ml = marly laminae.)

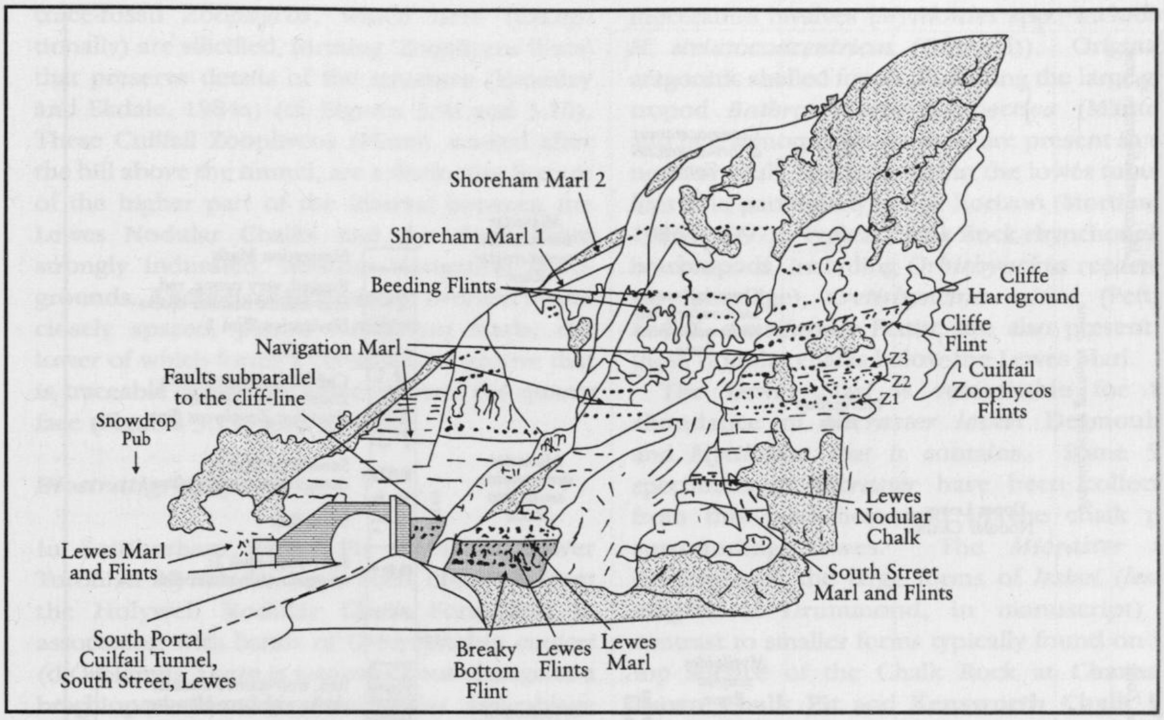


Figure 3.115 The northern end of the Southerham Pit GCR site showing the Cuilfail Tunnel, South Portal cut in the former Navigation Pit. (After Mortimore, 1997.)

marker horizons, notably the South Street Marl, the Lewes Nodular Chalks, the Cuilfail Zoophycos (Flints) and the Navigation Hardgrounds and Navigation Marls. The University of Brighton's South Street Research Borehole was drilled in the floor of Chandlers Yard, immediately to the south, to provide control geophysical logs. The non-standard resistivity and gamma logs obtained (Mortimore, 1986b) helped in the interpretation of the stratigraphical position of Strahan's Hardground and the overlying Lewes Phosphatic Chalk (see below) and provided information on thicknesses of the Turonian Chalk in the area. These stratigraphical studies were complemented by the logs from three rotary cored boreholes and the logging of an old well sunk through the hillside.

Lithostratigraphy

The highest beds of the lower Lewes Nodular Chalk Formation (upper part of the Kingston Beds, Figure 3.116) are well exposed in the faulted section immediately south of the tunnel portal, dipping south on the northern limb of the Caburn Syncline. At the base of the section is seen a continuous layer of large flints, the Breaky Bottom Flint, which takes its name from a small section near Breaky Bottom Vineyard (TQ 405 055). The overlying succession, comprising two beds of nodular chalk, separated by non-nodular chalk, is penetrated by an inter-connecting network of spectacular branching *c.* 0.03 m diameter vertical 'tubular' flints up to 3 m long, the Lower Lewes Tubular Flints (Figures 3.9b and 3.116). These flints are annular in cross-section, with the original burrow wall preserved as a thin layer of white chalk between an inner core and an outer layer of flint. The inner flint is frequently missing and/or weathered-out, leaving a tubular flint.

The top of the lower Lewes Nodular Chalk Formation is marked by a bed of hard, iron-stained nodular chalk, which is overlain by the Lewes Marl, 0.05–0.1 m thick (cf. Figure 3.86). Although this marl is vulcanogenic (Wray, 1999), it has the 'brittle' (i.e. non-plastic texture) that is typically associated with a detrital marl and is full of mesofossil debris, mainly crinoid ossicles. It also contains many macrofossils, including inoceramid bivalves, regular echinoids and abundant *Micraster* (see below). Between

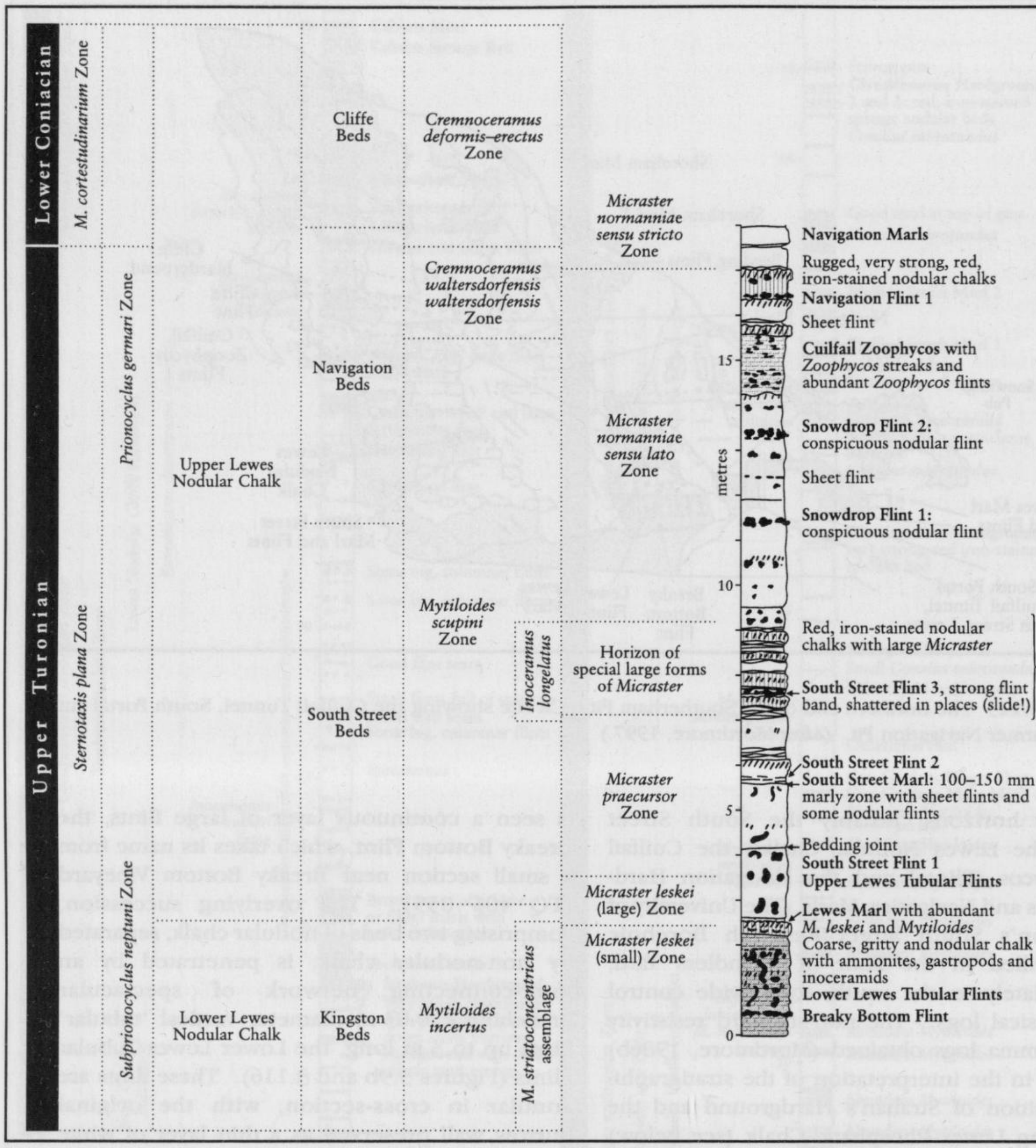


Figure 3.116 The Southerham Navigation Pit, Lewes, Sussex, Late Turonian and the base of the Coniacian stages (inoceramid bivalve zones inferred by extrapolation from expanded successions in Germany, see Walaszczyk and Wood, (1999b)). (LNC = Lewes Nodular Chalk.)

0.5 and 1 m above the Lewes Marl there are the Upper Lewes Tubular Flints, which are fatter and more dumbell-shaped than the elongate tubular flints below the marl. The South Street Marl, 2 m above the Lewes Marl, marks the base of the South Street Beds and also has a few thin elongate tubular flints below it. It is followed by beds of increasingly nodular chalk and flaser marls containing chalk pebbles (intraclasts). The nodularity culminates in the conspicuous group of iron-stained Lewes Nodular Chalks and flaser marls.

Above this level, following two bands of conspicuous nodular flints (Snowdrop Flints, Figure 3.116), there is a significant change to soft chalks containing three horizons of the trace-fossil *Zoophycos*, which here (exceptionally) are silicified, forming '*Zoophycos* flints' that preserve details of the structure (Bromley and Ekdale, 1984a) (cf. Figures 3.9a and 3.10). These Cuilfail Zoophycos (Flints), named after the hill above the tunnel, are a distinctive feature of the higher part of the interval between the Lewes Nodular Chalks and the three more strongly indurated, nodular Navigation Hardgrounds. These hardgrounds are overlain by the closely spaced, paired Navigation Marls, the lower of which forms a conspicuous groove that is traceable across the lower part of the quarry face (Figures 3.115 and 3.116).

Biostratigraphy

In Southerham Works Pit abundant Lower Turonian *Mytiloides* have been obtained from the Holywell Nodular Chalk Formation in association with bands of *Orbirhynchia cuvieri* (d'Orbigny). There is a conspicuous change to a brachiopod–*Conulus subrotundus* assemblage above the Gun Gardens Main Marl, which marks the base of the Middle Turonian Substage (Figure 3.114). Few fossils other than *Conulus subrotundus* Mantell, large terebratulid brachiopods and nautiloids have been recorded from the interval between the Malling Street Marls and the Strahan's Hardground. Strahan's Hardground and the overlying Lewes Phosphatic Chalk is remarkably barren of fossils in contrast to many other phosphatic chalk deposits (e.g. **Boxford Chalk Pit** and **South Lodge Pit** GCR sites). Strahan (1896) recorded *Holaster planus* (i.e. *Sternotaxis plana* (Mantell)) from above the hardground. Fragments of inoceramid bivalves indicative of *I. cuvieri* were found below the main hardground and *Terebratulina lata* R. Etheridge occurs both below and above Strahan's Hardground.

The ammonite *Lewesiceras peramplum* has been collected from between the two Southerham Marls in association with a remarkable specimen of *Holaster* cf. *subglobosus* (Leske).

In the Navigation Pit, the beds from the base of the section around the Breaky Bottom Flint up to the Navigation Marl 1 (Figure 3.116) belong to the Upper Turonian Substage. The abundance and variety of the heart-shaped urchin *Micraster* is a special feature here and in nearby chalk pits. The beds with the Lower Lewes Tubular Flints contain abundant inoceramid bivalves (*Mytiloides* spp., including *M. striatoconcentricus* (Gümbel)). Originally aragonitic shelled fossils, including the large gastropod *Bathrotomaria perspectiva* (Mantell) and heteromorph ammonites, are present in the nodular chalk horizons within the lower tubular flint belt, particularly at one horizon (Mortimore 1986a, 1997). Typical Chalk Rock rhynchonellid brachiopods, including *Orbirhynchia reedensis* (R. Etheridge), *Cretirhynchia minor* (Pettitt) and *C. cuneiformis* Pettitt, are also present in these nodular chalks below the Lewes Marl.

The Lewes Marl is remarkable for the abundance of *Micraster leskei* Desmoulins and *Mytiloides* that it contains. Some 500 specimens of *Micraster* have been collected from this marl here and in the chalk pits surrounding Lewes. The *Micraster* are predominatly the large forms of *leskei* (*leskei magna* of Drummond, in manuscript) in contrast to smaller forms typically found on the top surface of the Chalk Rock at **Charnage Down Chalk Pit** and **Kensworth Chalk Pit**. The interval above the marl containing the Upper Lewes Tubular Flints is characterized by *Micraster praecursor* (Rowe, in manuscript; Drummond, 1983).

Very large specimens of *Micraster* are found in the higher part of the South Street Beds (Figure 3.116) which is possibly the horizon of the holotype of *Micraster corbovis* (Forbes). Large, inflated specimens of *Sternotaxis placenta* (Agassiz) and *Echinocorys* occur immediately above and in the soft Cuilfail Zoophycos Chalks of the Navigation Beds.

Late Turonian *Mytiloides* are found in the South Street Beds and, with the evidence from Shoreham Cement Works, probably range up to the Navigation Hardgrounds. The topmost Turonian–Lower Coniacian inoceramid bivalve *Cremnoceramus waltersdorfensis* (Andert) has been found in the Navigation Marls and *Micraster normanniae* Bucaille enters above the Lewes Nodular Chalks. *M. normanniae* was taken in France to mark the traditional base of the stratotype Senonian, and by inference, therefore, the base of the Coniacian Stage. The presence of this fossil at Southerham led to earlier suggestions that the base of the Coniacian Stage might coincide with the base of the Navigation Beds rather than with the top of these beds (Bailey *et al.*, 1983, 1984; Mortimore and Pomerol, 1987; Pomerol *et al.*, 1987).

Interpretation

The sections comprising the composite Southerham Pit GCR site cannot be studied in isolation, but need to be seen in the context of the other exposures around Mount Caburn and the sections at Beachy Head, Eastbourne and Upper Beeding, Shoreham (Mortimore, 1986a).

In the Lower and Middle Turonian strata, a key section in relation to Southerham Pit is Glyndebourne Pit 1 (TQ 448 102), on the northern flank of the Caburn Syncline. In the lowest part of the pit, there are exposures of Holywell Nodular Chalk Formation shell-beds containing abundant *Mytiloides* and large ammonites (*Metasigaloceras rusticum* (J. Sowerby), *Mammites nodosoides* (Schlotheim) and *Morrowites wingi* (Morrow) (Mortimore and Pomerol, 1991b, 1996). In the overlying sections, the *Filograna avita* horizon of abundant *Mytiloides* encrusted with the serpulid *Filograna avita* (J. Sowerby) provides a marker that can be traced throughout the Southern Province and the Anglo-Paris Basin (Gale, 1996), and as far north as the southern Chiltern Hills (see also Aker's Steps in the **Folkestone to Kingsdown** GCR site report, this volume, where the succession is condensed).

In the upper section at Glyndebourne Pit 1, the Gun Gardens Main Marl, at the top of the Holywell Nodular Chalk, is well developed. This marl is overlain by a 1 m thick bed with slender finger-flints, the Glyndebourne Tubular and Finger Flints, for which this is the type locality (Mortimore, 1990, 1997; Mortimore and Pomerol, 1996). These flints are white externally and hence are relatively inconspicuous. The marl and the associated flints occur very widely throughout the Southern Province and Anglo-Paris Basin but have not so far been recognized in the extremely condensed sections in the Folkestone–Dover section (**Folkestone to Kingsdown** GCR site) although they are present in the North Downs Medway Pits at Halling. They mark a break from the *Mytiloides*-dominated, shelly Holywell Nodular Chalk Formation to the brachiopod-rich, smooth chalks with the echinoid *Conulus subrotundus* (Leske), that characterize the basal part of the New Pit Chalk Formation. The entry of the international marker for the base of the Middle Turonian Substage, the ammonite *Collignoniceras woollgari* (Mantell), has been located *in situ* in this section and a succession of *Mytiloides* from *M. mytiloides* (Mantell) to *M. subhercynicus* (Seitz) has been identified (Mortimore and Pomerol, 1991b, 1996). In conjunction with data from the expanded Beachy Head (Gun Gardens) section, these fossil records enable the basal Middle Turonian Chalk successions of the Southern Province to be linked to the ammonite and inoceramid bivalve standard international zonal schemes.

Of particular interest in this pit is a group of six glauconitized and phosphatized hargrounds, the Glyndebourne Hardgrounds (Mortimore, 1986a,b, 1997; Mortimore and Pomerol, 1987, 1991a,b, 1996) in the Middle Turonian Substage. Glyndebourne is the only place in England where hardgrounds associated with phosphatic chalks are known from the Middle Turonian Substage. Hardground 1 is located below the Malling Street Marls, while the remaining hardgrounds lie above these marls. The interval between Hardground 1 and the Malling Street Marls contains beds of chalk intraclast conglomerates, indicating synsedimentary erosion and channelling. In the Southerham Works Quarry (Cliffe Industrial Estate) section of the Southerham Pit GCR site, Glyndebourne Hardgrounds 1, 2 and 3 are represented by iron-stained nodular beds. Whether or not any of the higher Glyndebourne Hardgrounds (4, 5 or 6) relate to Strahan's Hardground at that locality is uncertain. Hardgrounds of a similar age, the Tilleul Hardgrounds, are present on the French Normandy coast at Tilleul (Mortimore and Pomerol, 1997, fig. 14).

At the nearby Glyndebourne Pit 2 (TQ 446 105), *Collignoniceras woollgari*, associated with *Inoceramus cuvieri* J. Sowerby, is not uncommon beneath New Pit Marl 1 (Mortimore, 1986a; Mortimore and Pomerol, 1996). This section extends the range of *C. woollgari* in the Southern Province up to a relatively high level in the New Pit Chalk Formation and additionally suggests the existence here of a standard succession in proximity to the anomalous successions in the Glyndebourne Pit containing numerous hardgrounds formed on erosional channel floors.

Glynde Pit (TQ 449 096) exposes a section from Glynde Marl 1 (for which this is the type locality) to above Southerham Marl 2. The well-developed Southerham Marl 1 here yielded the holotype and six paratypes of the unusually large lituolacean foraminifer *Labyrinthidoma southerhamensis* Hart. This species was formerly (e.g. Hart, 1982; Mortimore and Wood,

1986) referred to as *Coskinophragma* (see Hart, 1993 for discussion) and is generally inferred to indicate a deeper water environment.

Three additional chalk pits around Mount Caburn expose sections that are critical to long-range correlations within the Southern Province (and deserve to be considered for GCR status). The very large Caburn Pit (TQ 447 089) (Ranscombe Pit of Barrois (1876)) must formerly have extended from the Zig Zag Chalk Formation of the Grey Chalk Subgroup to the Lewes Marl, in the Lewes Nodular Chalk Formation of the White Chalk Subgroup. This is the type locality for the base of the Lewes Nodular Chalk Formation (Mortimore, 1986a, 1997; Bristow *et al.*, 1997). It is also the type locality for the Caburn Sponge Bed and carious flints, and for the overlying Caburn Marl. The strong development of flint in the Glynde Beds here, and in correlative localities around Mount Caburn, including the Southerham Pit, emphasizes the difference between sections in the South Downs and those in the North Downs, such as at Dover, where flints are much less well developed at this level.

The occurrence of *Micraster michelini* (Agassiz) immediately below the Caburn Marl in the Caburn pit (Mortimore, 1986a) compares with records (Stokes, 1975) of similar forms from below this marl at Langdon Stairs, Dover (**Folkestone to Kingsdown** GCR site). The Turonian zonal index ammonite, *Romaniceras deverianum* (d'Orbigny) has been collected here just above the Glynde Marls. The occurrence of the diminutive, wheel-like bryozoan, *Bicavea rotaformis* Gregory, in the nodular beds immediately above the Caburn Marl (Mortimore, 1986a), establishes a key correlation with the abundance level of this species above the so-called 'Grey Marl' in the **Compton Down**, Isle of Wight GCR site (Rowe, 1908, White, 1921). This event-occurrence has not been traced farther east, since it is not represented at Dover, or in any of the correlative sections in the North Downs (Mortimore and Wood, 1986, fig. 3.3).

New Pit Depot (TQ 424 113) on Malling Hill (Figure 3.106), on the north side of the Caburn Chalk Block, is the type locality of the New Pit Marls, and exposes an excellent section in the lower Lewes Nodular Chalk Formation (Figure 3.117). In this pit *Micraster corbovis* of *lata* Zone type has been obtained from the basal nodular beds of the formation and through the overlying beds to above Bridgewick Marl 2. This range can be compared with the records for *Micraster* in south-east Devon (see **Hooken Cliff** GCR site report, this volume). On track sections adjacent to New Pit Depot, the Middle Turonian ammonite *Romaniceras* (*Yubariceras*) *ornatissimum* (Stoliczka) was collected just below New Pit Marl 2. *Romaniceras deverianum* has been collected in the interval from below the Glynde Marls (Offham Track adjacent to 'The Chalk Pit', Offham), to 0.3 m below the Caburn Marl (Firle Pit) (Mortimore, 1986a). These in-situ records of the international indices for the Middle and Upper Turonian Substages help with correlation in chalk facies in Europe.

Bridgewick Pit (TQ 431 113), to the east of New Pit, is an outstanding section in the lower Lewes Nodular Chalk extending up to just above the Lewes Marl. Horizons of nodular chalks in the Glynde, Caburn, Ringmer and Kingston beds preserve moulds of originally aragonitic-shelled molluscs, including ammonites, i.e. elements of the so-called *reussianum* fauna that typically characterizes the Kingston Nodular Beds and the Chalk Rock (Mortimore, 1986a). This is a greater range of occurrences than elsewhere in the Southern Province. Bridgewick is also the type locality of the Bridgewick Marls and Bridgewick Flints.

Despite the wealth of stratigraphical information from the Lewes chalk pits, one outstanding stratigraphical anomaly remains. Dating Strahan's Hardground and the overlying Lewes Phosphatic Chalk in the Southerham Works Pit has proved very difficult. It clearly lies above a New Pit Marl seam, and below Southerham Marl 1 and the associated Southerham Flints. The only fossil data are Strahan's (1896) records of *Holaster planus* (i.e. *Sternotaxis plana* (Mantell)) and *Terebratulina lata* R. Etheridge from less than a metre above the hardground. These fossils suggest a horizon in the basal Lewes Nodular Chalk Formation, i.e. at the level where *S. plana* first becomes common.

The hardground is, however, identifiable as a positive resistivity 'spike' in the non-standard resistivity log of the South Street Borehole in Chandlers Yard, close to the axis of the Caburn Syncline (Mortimore, 1986b, fig. 3.10). The resistivity log suggests that New Pit Marl 2 is missing, and that the marl below the hardground is probably New Pit Marl 1. Furthermore, the succession between the top of the

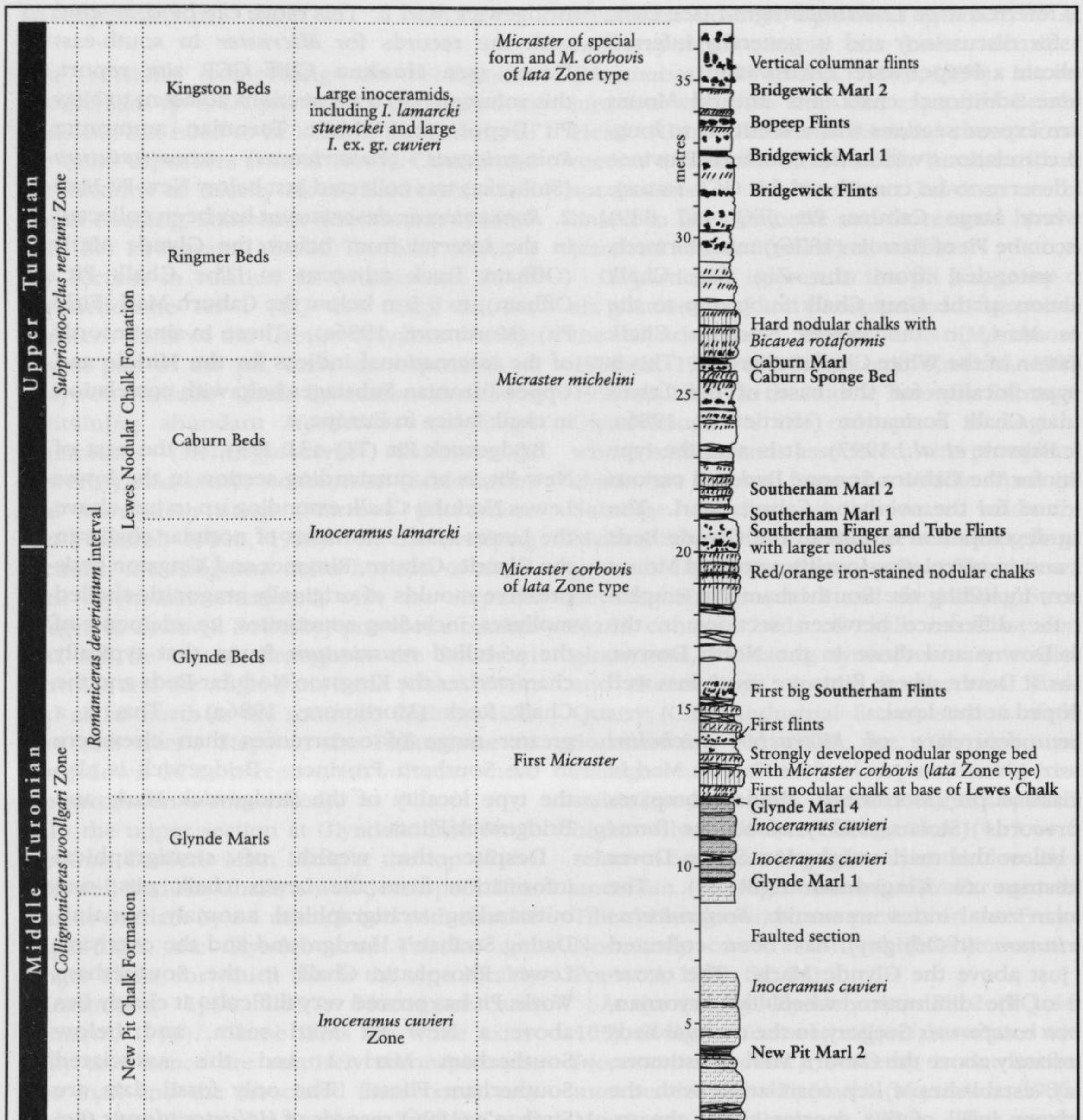


Figure 3.117 New Pit on Malling Hill, Lewes: the type section for the New Pit Chalk Formation–Lewes Nodular Chalk Formation junction and the New Pit Marls. A link to the Southerham Pit sections and the Sussex Downs.

anomalous interval of flinty chalk above the phosphatic chalk, and below the Southerham Flints, is broadly similar to the standard Glynde Beds succession in the New Pit Depot section, on the north side of the Caburn Syncline (Mortimore, 1986b, fig. 3.11). Both of these sections contain two conspicuous bands of nodular flint that, at New Pit Depot, overlie well-developed marl seams (Glynde Marls) and, at Southerham, succeed wispy marls that may represent Glynde Marls. The typically thick, dark, plastic Glynde Marl 1 appears to be absent at the latter locality.

A possible interpretation of the succession is that Strahan's Hardground represents the lithification of the floor of a channel that has cut down from the Glynde Beds, at the base of the Lewes Nodular Chalk, into the New Pit Chalk Formation (e.g. Mortimore and Pomerol, 1987, 1991a). This channel appears to have cut out both Glynde Marl 1 and New Pit Marl 2, to terminate just above New Pit Marl 1. The anomalous flinty chalk above the phosphatic chalk can be inferred to represent the channel fill. The exposure of the hardground is laterally extremely limited and consequently the original extent and geometry of the channel remain unclear. There is no evidence for Strahan's Hardground at New Pit Depot, only 3 km from the Cliffe Industrial Estate, but on the northern, less steeply inclined flank of the Caburn Syncline. The New Pit Chalk Formation–Lewes Nodular Chalk Formation boundary is represented in New Pit by a standard succession. These facts indicate that the anomalous succession is restricted to the axis of the syncline and to the steeply dipping northern flank of the Kingston Anticline.

The succession comprising Strahan's Hardground, the overlying Lewes Phosphatic Chalk and the anomalous interval of flinty chalk below the Southerham Marls has a major bearing on the interpretation of the base of the Lewes Nodular Chalk Formation and its probable correlative, the Chalk Rock of the Marlborough–Berkshire Downs (see **Fognam Quarry** GCR site report, this volume). The localization of the hardground and phosphatic chalks on the northern, steeply dipping limb of the Kingston Anticline, underlain by a major inversion fault-line, suggests tectonic control of sedimentation (Mortimore, 1986b; Mortimore and Pomerol, 1987, 1991a, 1997).

Conclusions

The Southerham Pit GCR site provides a unique composite inland section through an almost complete Turonian succession. This includes the thickest, most complete and most fossiliferous, Turonian–Coniacian boundary succession in the Southern Province, which is consequently of great potential international importance. This importance is enhanced by the abundance and variety of the echinoid genus *Micraster* and the inoceramid bivalves in the Turonian and Coniacian stages. Many type and figured species are also considered to have come from the Chalk pits in the vicinity including *Micraster corbovis* and *Collignoniceras woollgari*.

The site includes the type sections for the Southerham and Lewes marls, the Lewes Tubular Flints, the Cuilfail Zoophycos, the Navigation Hardgrounds and Navigation Marls and the Cliffe Hardground, all of which are used as marker horizons for correlation within and outside the Southern Province. Other marker horizons (New Pit Marls, Glynde Marls, Caburn Marls and Bridgewick Marls) have their type sections in nearby related pits. The GCR site and these related sites collectively provide the standard section for the Lewes Nodular Chalk Formation and for the framework of Turonian detrital marls and vulcanogenic marls. These relatively expanded sections help in the interpretation of the condensed successions in the adjoining regions.

The site is unique in the occurrence of Strahan's Hardground and the Lewes Phosphatic Chalk in the Middle Turonian succession. Solving the stratigraphy of these deposits and establishing their relationship with the Chalk Rock is a key to understanding sedimentary processes in the Chalk.

FOLKESTONE TO KINGSDOWN: FOLKESTONE–DOVER (TR 242 365–TR 316 402) AND DOVER–KINGSDOWN (TR 339 422–TR 381 478), KENT

Introduction

The Folkestone to Kingsdown site forms the classic White Chalk cliffs of England and has two distinct parts. **Part 1: Folkestone–Dover**, incorporates 'The Warren' and Shakespeare Cliff in the Grey Chalk Subgroup and the lower part of the White Chalk Subgroup (Plenus Marls Member and the Holywell Nodular Chalk, New Pit Chalk and lower Lewes Nodular Chalk formations) at Aker's Steps and Shakespeare Cliff. **Part 2: Dover–Kingsdown**, includes East Cliff, Dover, St Margaret's Bay and the sections north of the South Foreland. This second part is entirely in the White Chalk Subgroup (Lewes Nodular Chalk Formation, Seaford Chalk Formation and basal Margate Chalk Member).

The exposures in these cliffs are some of the most studied Upper Cretaceous rocks in the British Isles and essential to the historical development of the stratigraphy of the Chalk. Phillips' (1818, 1819) remarkably detailed description of the strata can be fairly regarded as the first attempt to produce a lithostratigraphical classification of part of the English Chalk. The chalks are generally softer than those farther south and west in the Southern Province because the site is located on the southern edge of the Anglo-Brabant Massif (Figure 1.8, Chapter 1). As a result, the Dover sections are famous for their fossils, primarily because of their excellent preservation in soft chalk. The standard French macrofossil zones of the Chalk of the Paris Basin were first applied to the English Chalk by Hébert (1874) and Barrois (1876) at Dover. In addition, these sections have provided many type and figured specimens, notably the holotype of the international inoceramid bivalve index fossil *Inoceramus lamarcki* Parkinson. It was here that the medical doctor, Arthur Rowe of Margate, carried out the work that led to his still classic evolutionary study (Rowe, 1899) of the Chalk echinoid *Micraster*, and laid the foundations, together with Charles Sherborn, for his series of equally important papers (1900–1908) on '*The Zones of the White Chalk of the English coast*'.

Part 1: Folkestone–Dover, includes one of the most important Cenomanian successions in the UK, which, because it is the most complete, is generally regarded as the standard British succession for the stage (Kennedy, 1969; Gale, 1989, 1995; Robaszynski *et al.*, 1998). It also exposes a highly condensed Holywell Nodular Chalk Formation at Shakespeare Cliff, which has yielded Lower Turonian ammonites of biostratigraphical importance, including the zonal index fossils *Fagesia catinus* (Mantell) and *Mammites nodosoides* (Schlotheim). It is also a key component in establishing the link from the expanded successions on the south coast to the condensed successions in the Transitional Province.

The 7 km of sea cliffs from **Dover–Kingsdown (Part 2)**, are the classic 'White Cliffs of Dover'. Much of the White Chalk Subgroup stratigraphy here, can be correlated in detail with the standard succession in the Southern Province. One of the most conspicuous features of these cliffs is the so-called 'Basal Complex', the succession of exceptionally large flints and marl seams that was formerly taken by the British Geological Survey to mark the base of the *Sternotaxis plana* Zone and hence of the traditional Upper Chalk. The 'Basal Complex' is overlain by beds of highly fossiliferous nodular chalks which are known as the 'Dover Chalk Rock' and represent a condensed and, in some aspects, a more fossiliferous development of the Kingston Nodular Beds of Sussex. These beds contain Upper Turonian ammonites and inoceramid bivalves that are critical for international correlation. Dover is one of the few localities in the Southern Province where the succession of these ammonites established in expanded successions in Germany can be recognized. Condensation at this level also results in loss of some biostratigraphy, particularly the species of *Micraster* found elsewhere.

The stratigraphy of the Folkestone to Kingsdown sections has been important since Napoleonic times when attempts to construct a link to mainland Europe began seriously, and the geology was paramount to route selection and method of construction. Both onshore and offshore exploration identified the continuity of the strata across the English Channel and, from the very earliest proposals, the Lower Chalk (i.e. Grey Chalk Subgroup) was considered the best medium for tunnelling. The knowledge of the stratigraphy of the Folkestone sections was critical to correlation of boreholes, geological interpretation and understanding the construction problems encountered during building of the Channel Tunnel (1988–1992; see papers in Harris *et al.*, 1996a).

Description

The **Folkestone–Dover** cliffs (Figure 3.118) expose continuous sections from the West Melbury Marly Chalk Formation of the Grey Chalk Subgroup up to and including the lower beds of the Lewes Nodular Chalk Formation of the White Chalk Subgroup. Near Folkestone, the highest beds exposed in the cliff belong to the Holywell Nodular Chalk Formation. Farther east, the gentle easterly dip brings the Plenus Marls Member at the base of the Holywell Nodular Chalk Formation to the foot of Shakespeare Cliff, on the west side of Dover.

At the western end of the **Folkestone–Dover** cliffs in East Wear Bay (Figure 3.118), between Copt Point, on the east side of Folkestone, and the western end of Abbot's Cliff, the Gault mudstones beneath the Chalk Group are exposed at and above sea level. Landslip failure in the Gault mudstones has led to the development of a vast, and now extensively overgrown, area of rotated

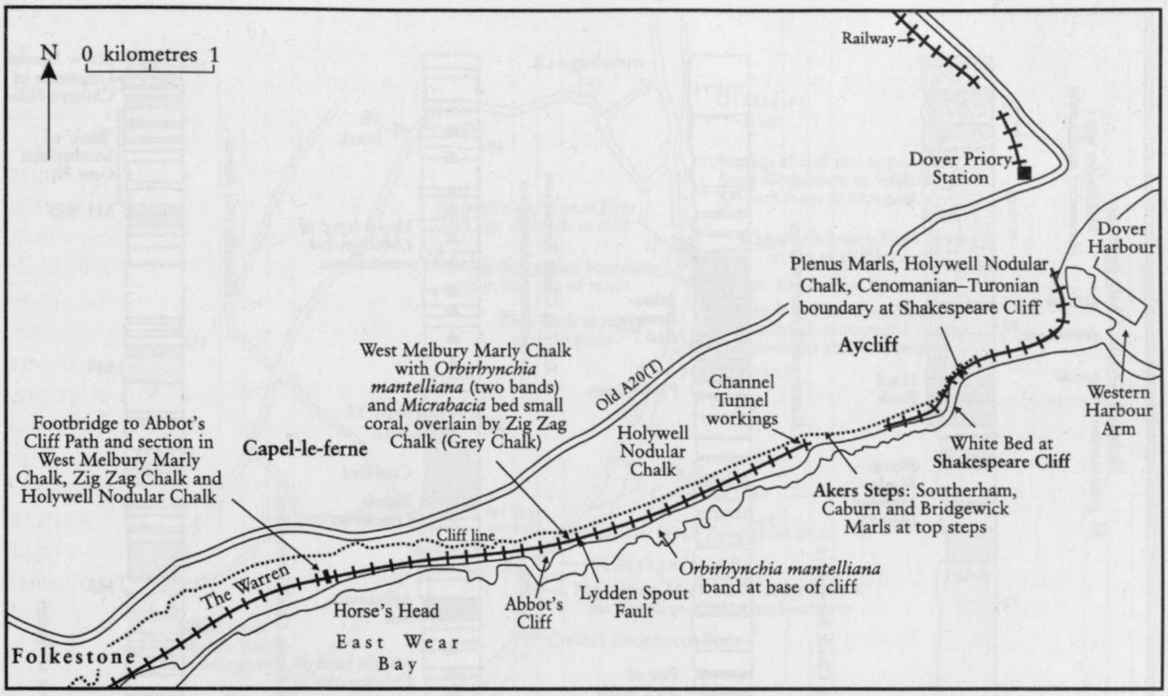


Figure 3.118 The Folkestone to Kingsdown GCR site; **Folkestone–Dover** cliffs including 'The Warren', Abbot's Cliff, Shakespeare Cliff and Aycliff.

slipped blocks of Grey and White Subgroup chalks, which is known as 'The Warren'. From Abbot's Cliff eastwards, the dip takes the Gault below sea level, and consequently the same beds are exposed in near-vertical cliffs, up to 50 m high. Apart from exposures at beach level, these sections are accessible only at the back of areas of stabilized rock falls, or in those places where zig-zag paths down the face of the cliff provide air-weathered exposures.

The Folkestone to Shakespeare Cliff sections collectively constitute the type succession for the division by Jukes-Browne and Hill (1903) of the traditional Lower Chalk into nine component beds, of which Jukes-Browne Bed 7, the White Bed (Bed 8) and the Plenus Marls (Bed 9) still form part of the modern lithostratigraphical scheme (Figure 3.119). The section at the base of Abbot's Cliff (Gale and Friedrich, 1989) provides the only uncondensed succession through the basal part of the Cenomanian Stage in the Southern Province. Folkestone, in conjunction with **Southerham Grey Pit**, provides one of the standard sections for the orbitally controlled cyclostratigraphy of the Cenomanian succession of northern Europe (Gale, 1995). The macrofossil and microfossil biostratigraphy, stable isotope stratigraphy and cylostratigraphy of the Middle Cenomanian strata at Folkestone have been studied in minute detail (Paul *et al.*, 1994; Mitchell and Carr, 1998). Despite being greatly condensed compared with Eastbourne, the Plenus Marls Member at Shakespeare Cliff has been subject to more intense study than elsewhere (Jarvis *et al.*, 1988b; Jeans *et al.*, 1991; Lamolda *et al.*, 1994).

From **Dover–Kingsdown** (Figure 3.120) there are four key sections. East Cliff (1) and Langdon Stairs (2), Dover, expose beds from near the base of the Lewes Nodular Chalk Formation to beds up to Whitaker's 3-inch Flint Band in the Seaford Chalk Formation. The accessible sections at the base of the cliffs from Langdon Stairs to the South Foreland (3), are primarily cut in the lower beds of the Lewes Nodular Chalk Formation. The inaccessible parts of the cliff expose the upper beds of the Lewes Nodular Chalk Formation and the Seaford Chalk Formation with its conspicuous marker flint bands. The highest points in these cliffs are capped by a small thickness of Margate Chalk Member. The cliff line is broken at St Margaret's Bay, which forms a natural divide; just to the

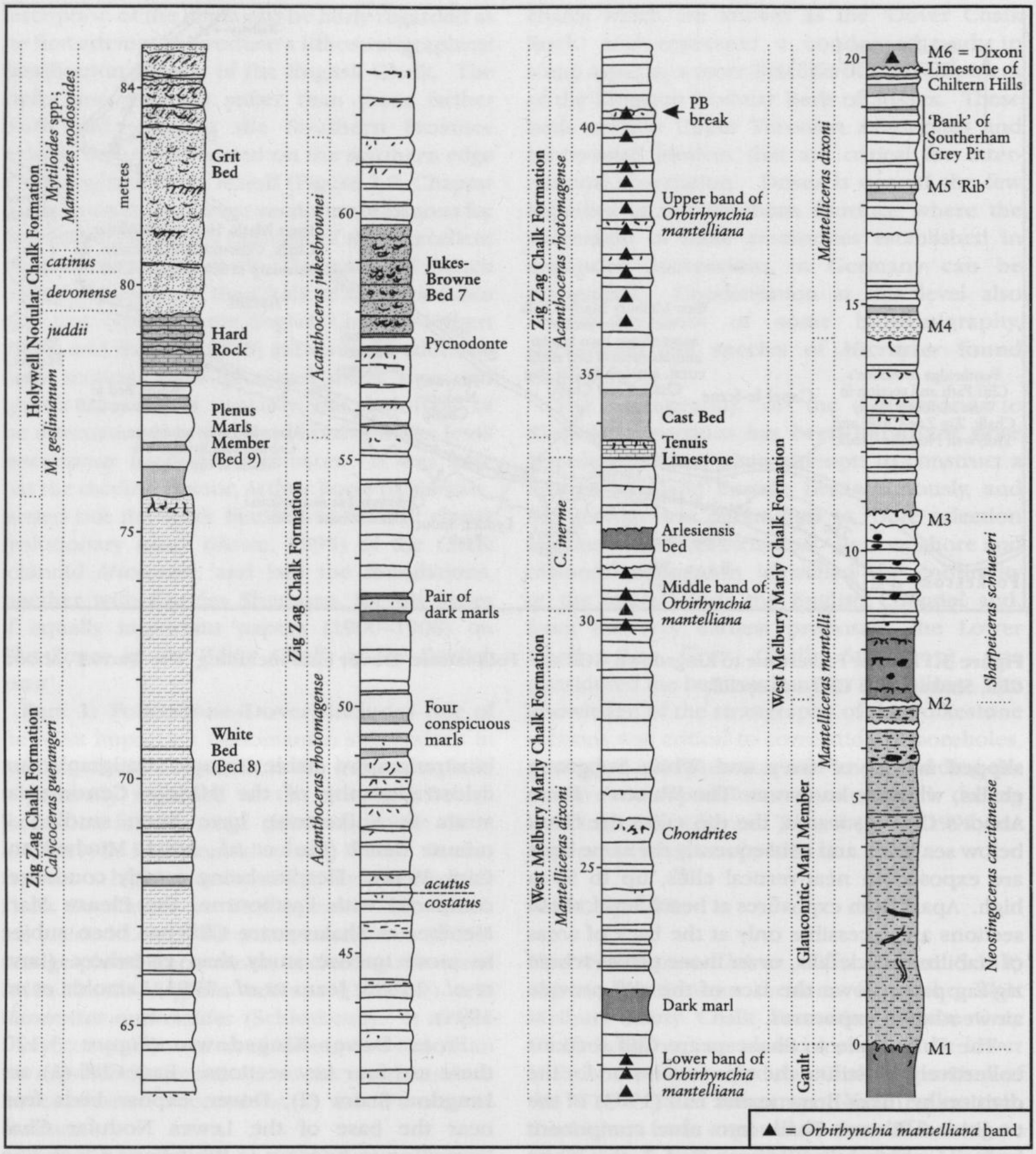


Figure 3.119 The Grey Chalk Subgroup type section at Folkestone, Abbot's Cliff, showing key litho- and bio-stratigraphy. (Modified from Gale in Jenkyns *et al.*, 1994: and Mortimore, 1997.) The black symbols in the *schlueteri* Subzone represent spongiferous nodules.

south, the cliff direction changes at the South Foreland, and trends northwards to Kingsdown (4). This is the down-dip direction, and higher beds in the Lewes Nodular Chalk and Seaford Chalk formations, up to the Bedwell's Columnar Flint Band, are progressively brought down to accessible levels in a northerly direction.

Lithostratigraphy

As in Sussex, the first records of the geology of these cliffs were published early in the 19th century. Phillips (1818, 1819) was the first to describe the sections. He divided the Chalk (republished in Conybeare and Phillips, 1822)

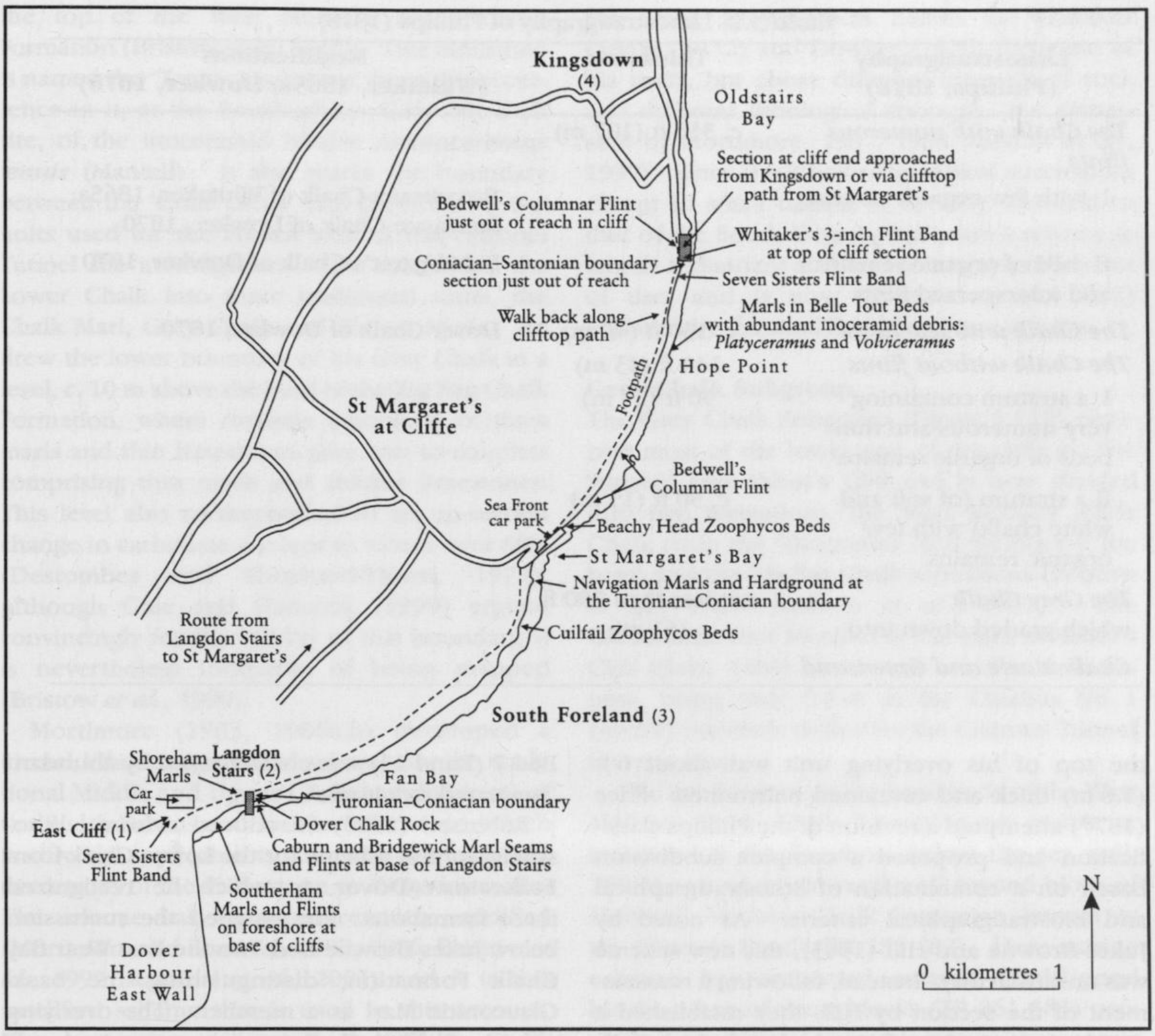


Figure 3.120 The Folkestone to Kingsdown GCR site from Langdon Cliffs to Kingsdown. For a description of localities (1)–(4) see text.

on the basis of the presence, absence or relative abundance of flints and of 'organic remains'. As noted by Whitaker (1872), the 'organic remains' probably included nodularity of the chalk as well as fossils. Whitaker (1865a, 1872) and Dowker (1870) followed Phillips' divisions, but gave some of them local geographical names taken from the **Thanet Coast** and Dover coast. Whitaker (1872) also provided some supplementary descriptive notes. In descending order, Phillip's divisions (and their subsequent modifications) are provided in Table 3.2.

The highest (flintless) Chalk in the Isle of Thanet was separated by Whitaker (1865a), followed by Dowker (1870), and subsequent workers (Whitaker, 1872; Mortimore 1983, 1986a; Robinson, 1986; Bristow *et al.*, 1997), as the Margate Chalk.

Jukes-Browne and Hill (1904, p. 2) did not regard the divisions of Phillips, Whitaker and Dowker as correlatable or mappable horizons and concentrated instead on identifying macrofossil zones within their threefold framework of Lower, Middle and Upper Chalk.

Whitaker (1872) considered that Phillips' 'Grey Chalk' included beds that should properly be included in the Chalk Marl. He noted that 'near the top there was a massive bed, about 8 ft (3.4 m) thick, which at Hay Cliff has small hard projections, some being pyrites, some fossils and others stony lumps'. He also commented that the bed of 'soft marl' recorded by Phillips at

Table 3.2 Lithostratigraphy of Phillips (1818).

Lithostratigraphy (Phillips, 1818)	Thickness	Modifications (Whitaker, 1865a, Dowker, 1870)
The Chalk with numerous flints	*c.* 350 ft (107 m)	
I with few organic remains		Broadstairs Chalk of Whitaker, 1865a; Ramsgate Chalk of Dowker, 1870
II bed of organic remains and interspersed flints		St Margaret's Chalk of Dowker, 1870
The Chalk with few flints	*c.* 130 ft (40 m)	Dover Chalk of Dowker, 1870
The Chalk without flints	140 ft (43 m)	
I a stratum containing very numerous and thin beds of organic remains	90 ft (27 m)	
II a stratum (of soft and white chalk) with few organic remains	*c.* 50 ft (15 m)	
The Grey Chalk which graded down into *Chalk Marle and Greensand*	not less than 200 ft (61 m)	

the top of his overlying unit was about 6 ft (1.8 m) thick and contained belemnites. Price (1877) attempted a revision of the Phillips classification and proposed a complex subdivision based on a combination of lithostratigraphical and biostratigraphical criteria. As noted by Jukes-Browne and Hill (1903), this new scheme was unsatisfactory. Instead, following a reassessment of the section by Hill, they established a standard succession of nine beds, of which Beds 1–5 were assigned to the Chalk Marl, Bed 6 and Bed 7 (the bed with stony lumps) to the Grey Chalk, Bed 8 (which they termed the 'White Bed') corresponded to Phillips' 'Chalk without flints and few organic remains', and Bed 9 (their 'Belemnite marl') equated with the 'soft marl with belemnites', the Plenus Marls Member of the modern classification.

Kennedy (1969) divided the Lower Chalk of Folkestone (excluding the Plenus Marls) into 14 'bands' and described the lithostratigraphy in detail, providing a graphic log (his fig. 2) and grid references for localities at which the various bands could be examined. He drew particular attention to two prominent limestones at the top of his Band 6, a unit (Band 9) with abundant specimens of the rhynchonellid brachiopod *Orbirhynchia mantelliana* (J. de C. Sowerby), which he named the '*Orbirhynchia mantelliana* Band', and additionally noted that Jukes-Browne Bed 7 (Band 13) was characterized by abundant 'laminated structures'.

Robinson (1986) introduced a formal lithostratigraphical scheme for the Lower Chalk from **Folkestone–Dover**, in which he recognized three formations. He assigned the succession below Jukes-Browne Bed 7 to the East Wear Bay Chalk Formation, distinguishing the basal Glauconitic Marl as a member. The overlying Abbot's Cliff Chalk Formation comprised two members, the Hay Cliff Member (Jukes-Browne Bed 7) and the Capel-le-Ferne Member (the White Bed). These were followed by the Plenus Marls Formation. This scheme has not met with general acceptance and is not used today.

Gale (1989, 1995, and in Jenkyns *et al.*, 1994, fig. 13a) revised Kennedy's stratigraphy and, from better exposures, documented (Gale, 1989, figs 3, 4) additional strata at the base of the succession, above the Glauconitic Marl. Gale (1989) showed that the lower of Kennedy's (1969) two prominent limestones was underlain by a bed of dark fossiliferous marl, and that the higher limestone was overlain by the bed of silty marl that Price (1877) had named the 'Cast Bed' in view of the abundance in it of composite moulds ('casts') of gastropods. He also demonstrated that Kennedy's *Orbirhynchia mantelliana* Band was the highest of three similar bands. The higher of the two limestones marks the top of the West Melbury Marly Chalk Formation (Bristow *et al.*, 1997). This limestone is named the 'Tenuis Limestone' from the occurrence in it, at the **Southerham Grey Pit** GCR site, of the inoceramid bivalve *Actinoceramus tenuis* (Mantell). It also marks the boundary between the 'Craie Bleue' and the 'Craie Grise' units used for the French side of the Channel Tunnel site investigation. Gale subdivided the Lower Chalk into three traditional units, the Chalk Marl, Grey Chalk and Plenus Marls. He drew the lower boundary of his Grey Chalk at a level, *c.* 10 m above the base of the Zig Zag Chalk Formation, where rhythms (couplets) of thick marls and thin limestones gave way to couplets comprising thin marls and thicker limestones. This level also corresponded to an up-section change in carbonate content to values over 80% (Destombes and Shephard-Thorn, 1971). Although Gale and Hancock (1999) argued convincingly for the validity of this boundary, it is nevertheless incapable of being mapped (Bristow *et al.*, 1999).

Mortimore (1983, 1986a,b) developed a formal lithostratigraphical scheme for the traditional Middle and Upper Chalk (subdivisions) of the South Downs and Southern Province, which is directly applicable to the post-Plenus Marls succession of the Folkestone to Kingsdown site. The scheme has been progressively modified (Mortimore and Pomerol, 1987, 1996; Bristow *et al.*, 1997; Rawson *et al.*, 2001) and it is this modified scheme that is used in this account. The succession comprises the White Chalk Subgroup divided into the Holywell Nodular Chalk, New Pit Chalk, Lewes Nodular Chalk and Seaford Chalk formations, with a thin capping of Margate Chalk Member. The (flintless) Margate Chalk Member, previously recognized by Whitaker (1865a) and subsequent workers, equates with the flinty and marl-rich Newhaven Chalk Formation of the standard Southern Province succession.

Robinson (1986) introduced a formal lithostratigraphy for the traditional Middle and Upper Chalk of the North Downs, which, with the exception of the highest beds, was based on the coast sections between Folkestone and Kingsdown. He replaced the existing informal subdivisions by two formations, each divided into three members, and gave new names to all of the marker horizons (particularly marl seams) that had already been established in the South Downs by Mortimore (1983, 1986a,b). He used the same geographical names as Whitaker (1865a, 1872) and Dowker (1870) for some of his units, but chose different intervals of rock and different lithological concepts (see discussion by Mortimore, 1987, 1988; Bristow *et al.*, 1999). Since the lithostratigraphical succession, except in small details, is virtually identical to that of the South Downs, Robinson's scheme is largely redundant and has increasingly fallen out of use, and is now (Rawson *et al.*, 2001) replaced by the modified Mortimore scheme.

Grey Chalk Subgroup

The Grey Chalk Subgroup (Figure 3.119) occupies most of the lower part of the cliffs at 'The Warren' and Abbot's Cliff and is now divided into two formations, the West Melbury Marly Chalk (with the Glauconitic Marl Member at the base) and the Zig Zag Chalk formations (Bristow *et al.*, 1997; Rawson *et al.*, 2001). The Glauconitic Marl Member is 7 m thick at Abbot's Cliff (Gale, 1989) but is very variable in thickness, being only 0.4 m in the Craelius No. 1 (Aycliff) Borehole drilled for the Channel Tunnel investigation.

The key sections in the basal beds of the West Melbury Marly Chalk Formation are visible at low tide on the foreshore below the sea wall, 200 m east of an air-weathered rotated block of Holywell Nodular Chalk Formation known as the 'Horse's Head' (TR 256 382). Here marine erosion has truncated rotated landslipped blocks. One of these blocks (TR 261 383) provides a continuous succession from the contact between the Chalk Group and the underlying Gault mudstones, through the basal Glauconitic Marl Member (here 7 m thick), into the basal part of the West Melbury Marly Chalk Formation (Gale, 1989, fig. 2). This exposure, known as the 'rotated slab', includes several conspicuous or otherwise distinctive limestones and/or erosion surfaces that have been designated as marker horizons (M1–M6 of Gale, 1989) and used for correlation with sections elsewhere in the UK and in northern Europe (Gale, 1995). M1 and M2 correspond to the basal contact of the Glauconitic Marl Member and to a thin limestone at the top of the member respectively. M3 is a massive, burrowed limestone containing three-dimensional ammonites and inoceramid bivalves. M4 is a dark, silty marl containing small phosphate intraclasts. It rests on pale marly chalk with conspicuous colour-contrasting *Thalassinoides* burrows. M5 is a thin limestone equating with 'The Rib' of **Southerham Grey Pit** GCR site, and M6 comprises a closely spaced pair of thin spongiferous limestones at the top of the equivalent of 'The Bank' of the same locality, and the Dixoni Limestone of the Chiltern Hills (see p. 301, Chapter 4). The rotated slab is faulted to the east against the highly fossiliferous basal beds of the Zig Zag Chalk Formation.

An even better section of the basal beds of the West Melbury Marly Chalk Formation, beginning immediately above the Glauconitic Marl Member, and terminating in the massive burrowed limestone, M3, is intermittently exposed at low tide on the foreshore at the foot of the eastern end of the sea wall below Abbot's Cliff (TR 269 384). This section, which is part of the *in-situ* succession on the far side of the back-wall fault of 'The Warren' landslip, is highly fossiliferous and exposes the best section in the UK through the *Sharpeiceras schlueteri* ammonite Subzone (Gale and Friedrich, 1989, fig. 4; and below).

The upward continuation of this section, beginning with the spongiferous limestones (M6), was formerly exposed at the foot of Abbot's Cliff, immediately to the east, but this section (1999) is currently largely buried beneath an extensive cliff-fall that took place in 1989. The brachiopod-rich marly chalks above M6 (*Orbirhynchia mantelliana* Band 1), and the overlying dark recessing marl from which water flows (Gale, 1995, fig. 3), are exposed beside the top of the sea wall to the east of the adit leading to the Beaumont Tunnel.

Between Abbot's Cliff (TR 271 385) and Lydden Spout (TR 279 386), the easterly dip brings the beds of the West Melbury Marly Chalk Formation progressively down to the base of the cliff. There are accessible exposures of the highest beds and the lower part of the Zig Zag Chalk Formation above the western end of a plateau-like area of long-stabilized cliff-fall. Here there is an air-weathered section (Gale, 1995, fig. 7B) of the remainder of the Grey Chalk Subgroup and the overlying Plenus Marls Member, which clearly shows the sedimentary rhythmicity. The coarse-grained Jukes-Browne Bed 7 weathers slightly proud, and the overall green coloration of the Plenus Marls Member contrasts with the underlying chalks of the White Bed (Jukes-Browne Bed 8) and with the pale coloured, indurated Holywell Nodular Chalk Formation limestones. Wave-washed exposures showing the sedimentary details of the highest beds of the West Melbury Marly Chalk are found near Lydden Spout, on the far side of the same fall (see Gale, 1995, fig. 8).

There was never a clear division between the traditional Chalk Marl and Grey Chalk at Folkestone, because the marl–limestone rhythms continue up to the base of Jukes-Browne Bed 7. Nevertheless, there is a change from 'Chalk Marl' to 'Grey Chalk' type rhythms *c.* 10 m above the Tenuis Limestone. The Tenuis Limestone and overlying 'Cast Bed' of Price (1874) are, however, easy to identify. Within the Zig Zag Chalk Formation, the numbered beds recognized by Jukes-Browne and Hill (1903), particularly Jukes-Browne Bed 7, the 'Bed of laminated structures' of Kennedy, (1969), and the White Bed (Bed 8), are widely employed. Their Bed 9 is always now referred to as the Plenus Marls Member. These higher beds are exposed at Abbot's Cliff and farther to the east, on Aker's Steps and at Shakespeare Cliff.

White Chalk Subgroup

The Plenus Marls Member, and the air-weathered 'Grit Beds' constituting the condensed Holywell Nodular Chalk Formation, are exposed above the sea wall at the eastern end of Shakespeare Cliff (TR 307 398). The Plenus Marls are not as thick (about 2 m compared to 11 m at Eastbourne) nor conspicuously rhythmic as they are in Sussex. Nevertheless, Jefferies (1962, 1963) recognized all of his eight numbered beds here. A slipped block at the back of the sea wall (TR 263 384), provides an air-weathered section through the Plenus Marls Member in which the individual beds can be clearly seen. This is a better section than the one exposed above the sea wall at the foot of Shakespeare Cliff.

The Holywell Nodular Chalk Formation: Phillips' (1818, 1819) 'Chalk without flints but with many thin beds of organic remains' corresponds to the Holywell Nodular Chalk Formation, but may include the lower part of the overlying New Pit Chalk Formation, which here is slightly nodular. The Holywell Nodular Chalk Formation was referred to as the 'Melbourn Rock' by the British Geological Survey (Shephard-Thorn, 1988) and as the 'Melbourn Rock Beds' by Robinson (1986). Strictly, the Melbourn Rock in its type area of Cambridgeshire does not include the shell-debris beds typical of the higher part of the Holywell Nodular Chalk Formation. At Dover, the lowest part of the formation is nodular and very hard, but without shell-debris, as is typical elsewhere. (This corresponds to the Melbourn Rock as defined in Sussex by Mortimore (1986a); Gale (1996) named this unit the 'Ballard Head Member').

The condensed nature of the Holywell Nodular Chalk Formation at Shakespeare Cliff has resulted in the loss of the many marker beds recognized in this unit in Sussex. Because of this, there are spectacular concentrations of *Mytiloides* shell-debris bands in the air-weathered sections on the Lydden Spout track, at Aker's Steps and Shakespeare Cliff. These concentrations gave rise to the descriptive term 'Grit Bed' in the earlier literature. The condensation also results in a sharp break with the smoother, softer New Pit Chalk Formation above. This lithological change is well exposed and accessible only on the Aker's Steps and Lydden Spout cliff paths.

The Gun Gardens Main Marl (Mortimore, 1983, 1986a; Mortimore and Pomerol, 1987, 1996) (the 'Lulworth Marl' of Gale, 1996) is taken as the boundary between the Holywell Nodular Chalk and New Pit Chalk formations. Marker marl seams characterize the New Pit Chalk, including New Pit Marls 1 and 2 and the Glynde Marls (the 'Maxton Marls' of Robinson, 1986). These marker beds have been correlated through field sections and on geophysical borehole logs throughout the North Downs (Mortimore and Pomerol, 1987).

Air-weathered sections in the Holywell Nodular Chalk and New Pit Chalk formations are found on steep, and now rather dangerous, paths from the cliff top down to beach level at Abbot's Cliff (TR 268 385), Lydden Spout (TR 283 387), and Aker's Steps (TR 297 393). The most easterly of these paths (Aker's Steps) additionally exposes the basal beds of the Lewes Nodular Chalk Formation, providing the link with the Athol Terrace and Langdon Bay sections to the east of Dover. This is also the standard section for the foraminiferal zonation of the Turonian strata of southern England and for the stable isotope stratigraphy (Jenkyns *et al.*, 1994, figs 3, 4).

Lewes Nodular Chalk Formation: The base of the Lewes Nodular Chalk Formation is taken at the entry of nodular chalk, which occurs above the Glynde Marls,and is best exposed in the Aker's Steps section. Regular flint bands also enter the rock column in this interval. The white Chalk cliffs beneath Dover Castle (Figure 3.11) expose a magnificent, air-weathered section from the Glynde Marls, through the Lewes Nodular Chalk Formation, up to the Belle Tout Beds at the base of the Seaford Chalk Formation. In these cliffs the Lewes Nodular Chalk forms conspicuous layers of red-stained rough nodular chalk and the basal nodular beds are exposed along Athol Terrace at the eastern end of this cliff. The Athol Terrace exposures are stratigraphically below those in the cliffs at the base of Langdon Stairs and in Langdon Bay and, with the Aker's Steps section, illustrate the entry of nodular chalk and flint well below the 'Basal Complex'.

At beach level in Langdon Bay, between Langdon Stairs and the Eastern Arm of Dover Harbour (Figures 3.121 and 3.122), the two Southerham Marls and underlying Southerham Tubular Flints are exposed. Southerham Marl 1 is a conspicuous, plastic marl, and the underlying flints retain their Sussex features of mixed small tubular and large nodular flint character. Beneath these flints, iron-stained nodular sponge beds indicate the presence of nodular chalks in the Glynde Beds in the Lewes Nodular Chalk.

Langdon Stairs (TR 345 425) is a narrow zig-zag cliff path leading down to Langdon Bay that exposes an air-weathered 50 m section, from the Caburn Marl, in the lower Lewes Nodular Chalk Formation, up to just above the Seven Sisters Flint Band in the Belle Tout Beds of the Seaford Chalk Formation (Figure 3.123). The Caburn Marl, with the underlying Caburn Sponge Bed and flints, is present on the lowest bench on Langdon Stairs (Figure 3.7; Mortimore, 1997). The flints between the marl and the tough, nodular Caburn Sponge Bed are small, pink and characteristically carious, retaining the detail also present in Sussex.

In the lower part of the cliff in Langdon Bay (Figure 3.7) and at the foot of the cliffs in the adjacent Fan Bay (Figure 3.122), the most conspicuous feature is the 'Dover Chalk Rock' and its underlying 'Basål Complex' of Bridgewick Marls and the associated Bridgewick and Bopeep flints (Jukes-Browne and Hill, 1903, fig. 18; 1904, fig. 45; Mortimore and Wood, 1986, fig. 2.2). The Bridgewick Marls and Bridgewick Flints were taken by the British Geological Survey to map the base of the former Upper Chalk in the North Downs (Holmes, pers. comm., in Mortimore, 1987; Mortimore and

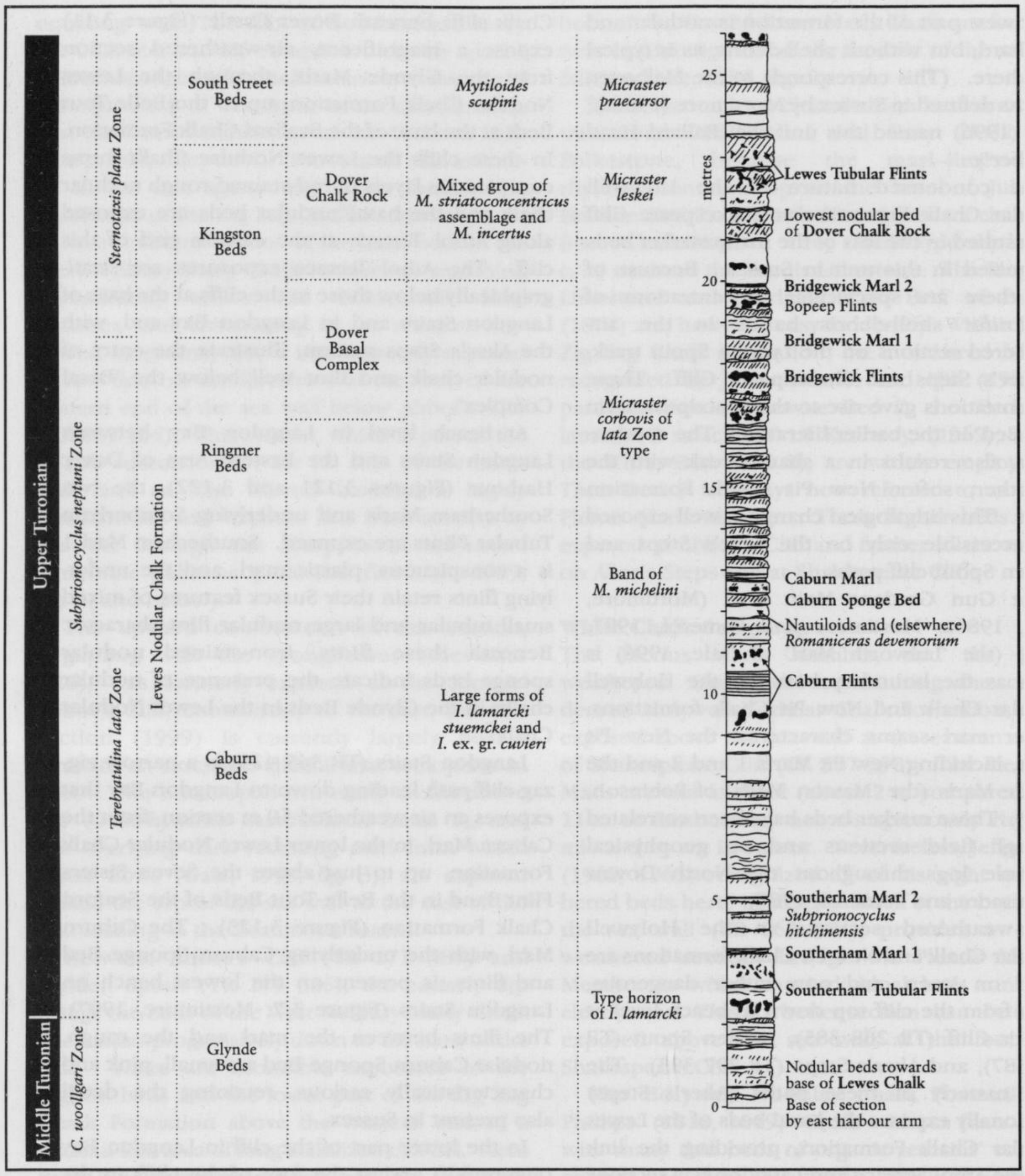
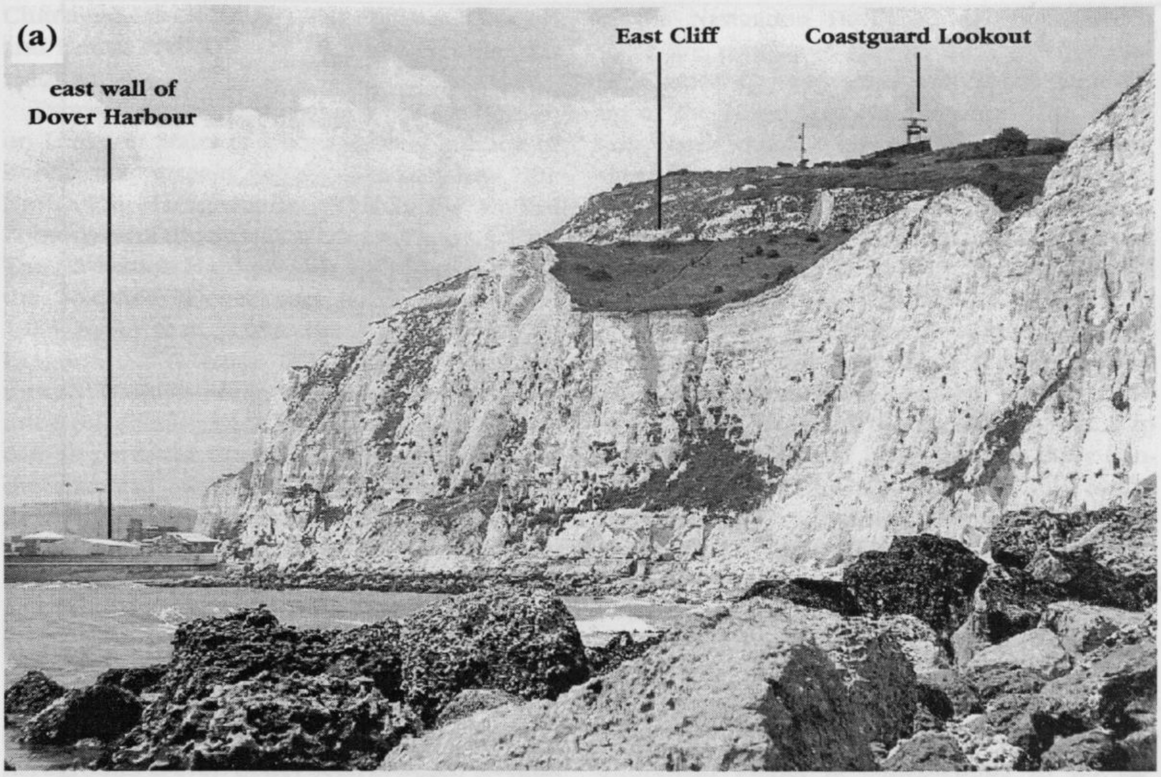


Figure 3.121 The lowest sections on Langdon Stairs including the Dover Chalk Rock and Basal Complex. (Based on Mortimore, 1997.)

Wood, 1986). Jukes-Browne and Hill (1903, fig. 68; 1904, fig. 45) used the section in Fan Bay to illustrate this succession. Their 'two marls 4 feet apart' (their Bed 12) are the Southerham Marls, the 'seam of grey marl forming an open crevice' (Bed 10) is the Caburn Marl, and the 'seam of grey marl' (Bed 6) is Bridgewick Marl 1. Bridgewick Marl 2 is in their Bed 3, 'a band of smooth chalk with a marl in the middle'.

The 'Dover Chalk Rock' comprises a series of nodular chalks separated by softer layers above the Bridgewick Marls, with the lower nodular



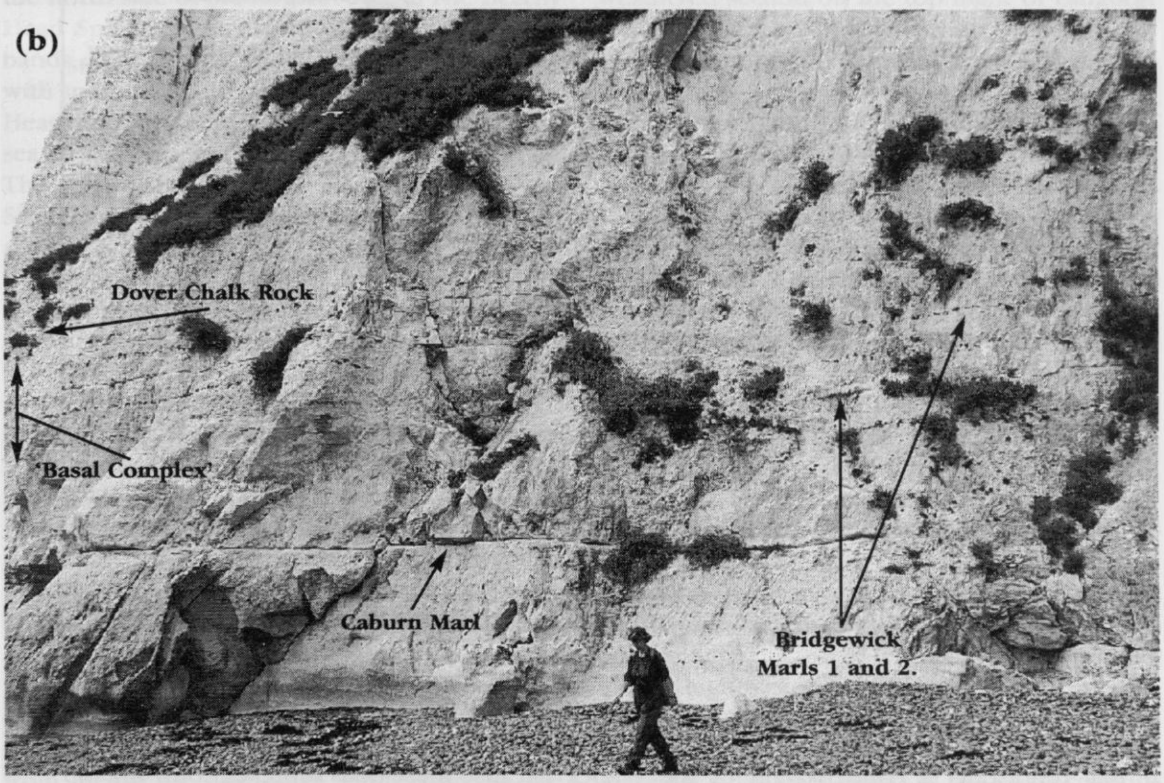


Figure 3.122 East Cliff, Dover. (a) Looking west from Fan Bay across Langdon Bay to the east wall of Dover Harbour. (b) Lower part of the Lewes Nodular Chalk Formation in Fan Bay (scale given by Dr Silke Voigt). (Photos: R.N. Mortimore.)

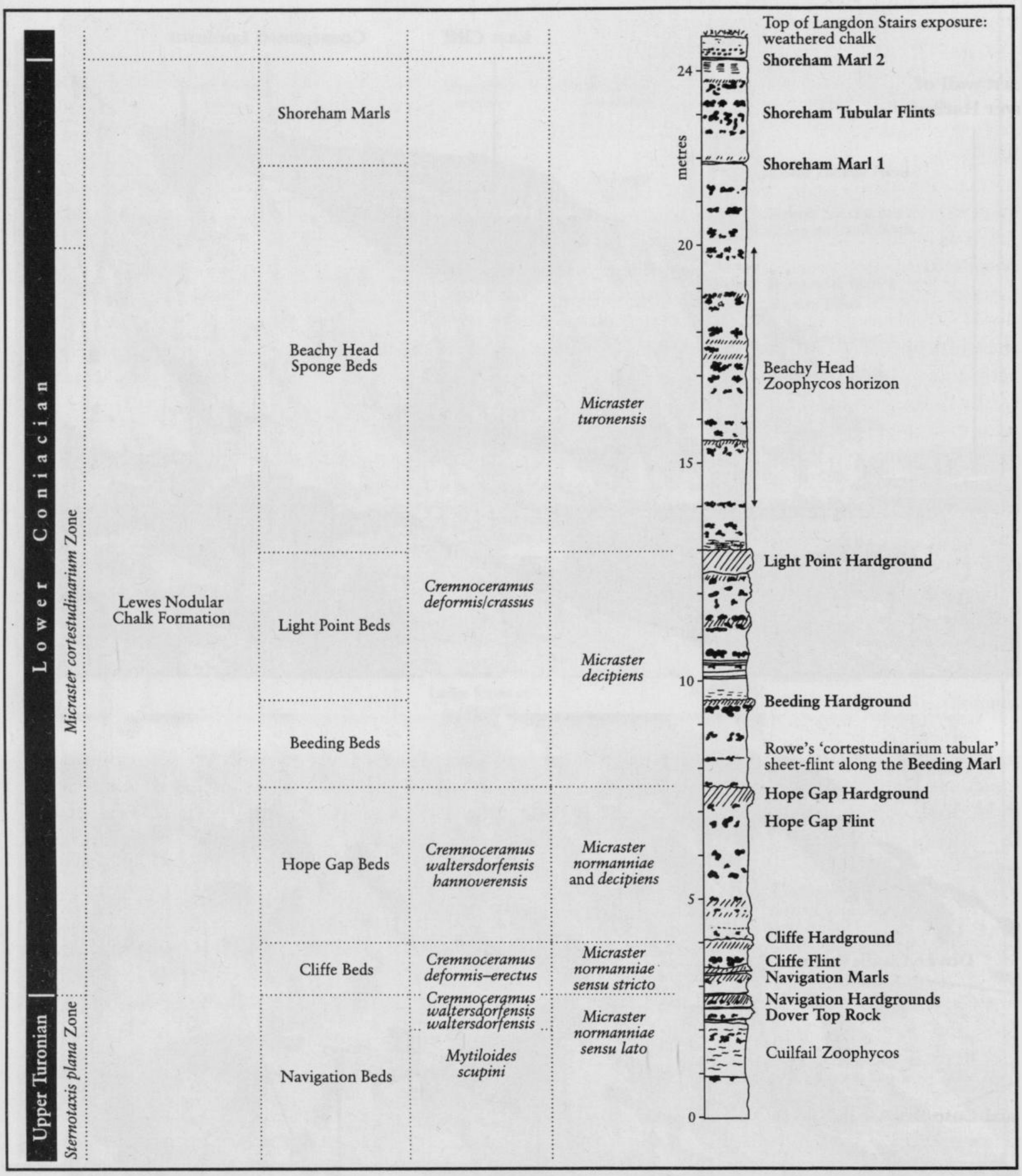


Figure 3.123 The upper sections on the Langdon Stairs exposure, Dover showing the Dover Top Rock and upper Lewes Nodular Chalk Formation. Inoceramid bivalve zones are inferred from expanded sections in Germany and are subject to review.

beds, in particular, containing ammonites. At Dover, this represents a condensation of the Kingston Beds and the beds immediately above the Lewes Marl. The Lewes Marl is occluded but the characteristic Lewes Tubular Flints are still present. It is informally called the 'Dover Chalk Rock' because these beds represent only the top hardground suite of the complete Chalk Rock succession of the type area in Berkshire–Wiltshire (Bromley and Gale, 1982; see

Charnage Down Chalk Pit, **Fognam Quarry**, and **Kensworth Quarry** GCR site reports, this volume).

Exposed on the first corner from the bottom on Langdon Stairs is a conspicuous horizon of *Zoophycos* streaky chalk seen below the Navigation Hardgrounds. This is the Cuilfail Zoophycos of the Sussex sections (Figure 3.10a). The Navigation Hardgrounds are represented by the so-called 'Dover Top Rock' (Mortimore, 1983; Bailey *et al.*, 1983, 1984). The section on Langdon Stairs from the Cuilfail Zoophycos upward is outstanding, particularly for sedimentological detail. Each one of the hardground complexes of the upper Lewes Nodular Chalk of the standard succession in the **Cuckmere to Seaford** and **Southerham Pit** GCR sites, and their associated flints, can be readily identified. The Cliffe, Hope Gap and Beeding hardgrounds and the large Cliffe and Hope Gap flints are conspicuous features (Figure 3.123). The Light Point Hardground is particularly well developed here, with a glauconitized surface overlain by a lag of glauconitized pebbles. This aspect of the hardground is even better seen at beach level on the north side of St Margaret's Bay. The Beachy Head Sponge Beds also develop nodular chalk bands, and the soft chalks between are packed with spectacular *Zoophycos*. These same Beachy Head Zoophycos Beds are accessible above the sea wall on the north side of St Margaret's Bay. The Shoreham Tubular Flints between the Shoreham Marls are very strongly developed (Figure 3.10b).

Between Langdon Bay and Frenchman's Fall, there are excellent, partly sea-washed and partly air-weathered sections through the Basal Complex and 'Dover Chalk Rock'. The Bridgewick Marl cuts out locally on a hardground between Fan Bay and Frenchman's Fall. Near Frenchman's Fall, the individual beds of nodular Chalk Rock, and the associated Lewes Tubular Flints (Phillips, 1819, p. 46), can be clearly seen. Eastwards, towards the South Foreland, the sedimentological details of the Cuilfail Zoophycos chalks and the overlying Navigation Hardgrounds can be examined in long wave-washed sections. These are probably the best exposures of this interval in the Southern Province. Fallen flints on the beach include giant paramoudras from Bedwell's Columnar Flint Band in the Seaford Chalk Formation.

The wave-cut platform on the south side of St Margaret's Bay is formed along the surface of the Navigation Hardgrounds above which there are exposures rich in the rhynchonellid brachiopod *Cretirhynchia subplicata* (Mantell) up to the Hope Gap Hardground. The Hope Gap Hardground, with its distinctive overlying sheet-flint is also clearly seen.

Seaford Chalk Formation: As in Sussex, there is a marked upward change in lithology from coarse, rough chalk with regular beds of nodular chalk (Lewes Nodular Chalk Formation) to the smooth, pure white Seaford Chalk with conspicuous large flint bands (Figure 3.124). This is the classic 'White Chalk' of authors. The Belle Tout Beds, from the Shoreham Marl 2 to the Seven Sisters Flint Band, contain three conspicuous groups of marls, the Belle Tout Marls, associated with abundant inoceramid bivalve shell debris. Shell debris horizons are present from 3.5 m above the Shoreham Marl 2, to the two Cuckmere Flint Bands, 2 m above the Seven Sisters Flint band. The semi-continuous Seven Sisters Flint Band (the 'East Cliff Semi-Tabular Flint' of Gale and Smith, 1982; and the 'Oldstairs Bay Flint' of Robinson, 1986), 17 m above the Shoreham Marls, is conspicuous in an air-weathered section on the top flight of Langdon Stairs and in the East Cliff section.

To the north of St Margaret's Bay (Figure 3.9b), there are long, wave-washed exposures through the Belle Tout Beds at the base of the Seaford Chalk Formation around Hope Point (Figure 3.124) and up to the Seven Sisters Flint Band. The Cuckmere Beds, with the Seven Sisters Flint Band and Cuckmere Flints at their base, and the Michel Dean Flint at the top, can also be examined in the East Cliff section, but are inaccessible in the cliffs between Langdon and St Margaret's Bay. At Kingsdown, higher beds in the Seaford Chalk (e.g. the Cuckmere Beds) are exposed in the cliffs behind the old Army range where they can be reached using a ladder. These beds are largely barren of macrofossils (hence the designation 'Barren Beds' by Mortimore, 1997) but they contain horizons rich in trace fossils, some possibly related to unsilicified *Bathichnus* sp., and two iron-stained sponge beds.

The highest accessible sections are just into the Haven Brow Beds (cf. Figure 3.100). Many cliff-falls between Langdon Stairs and St Margaret's Bay yield blocks of this chalk containing the basal *Cladoceramus* shell debris beds. Numerous fallen paramoudra flints from the interval that includes the Michel Dean, Baily's

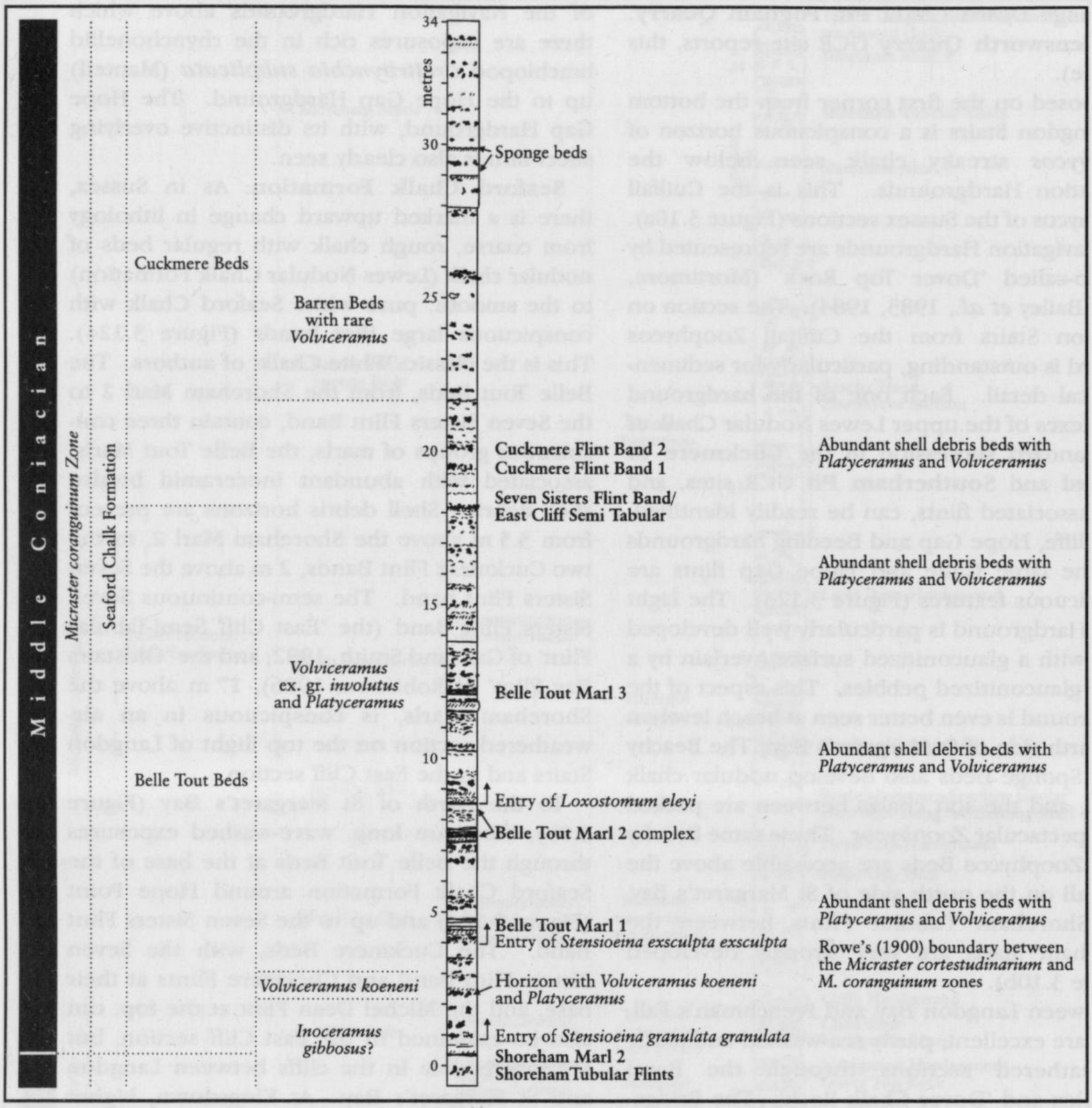


Figure 3.124 Seaford Chalk Formation on Langdon Stairs, Langdon Cliff and East Cliff, Dover, showing key marker beds.

Hill and Bedwell's Columnar flints can also be found on the beach. Whitaker's 3-inch Flint Band is conspicuous near the top of the cliffs.

Margate Chalk Member: The (flintless) Margate Chalk Member is present only in the highest parts of the cliff between **Dover–Kingsdown**. The base is marked by a yellow sponge bed (the Barrois' Sponge Bed of the **Thanet Coast**), a short distance above the conspicuous Whitaker's 3-inch Flint Band. Apart from poor exposures in the shallow cutting for the old construction railway near Langdon Hole, the Margate Chalk is inaccessible, and details of the stratigraphy are given in the **Thanet Coast** GCR site report, this volume.

Biostratigraphy

The biostratigraphy of the site is essentially that of the standard Southern Province successions. There are huge collections of fossils from these cliffs held by the British Geological Survey (Keyworth) and the Natural History Museum, London. The British Geological Survey also holds comprehensive bed-by-bed collections of brachiopods, echinoids (notably *Micraster*), inoceramid bivalves and belemnites from the White Chalk Subgroup. The old collections contain numerous rare fossils, including rudists and reptile bones. Rowe (1899, 1900), investigated the detailed palaeontology of the 'White Chalk' zones

Cenomanian Stage

The burrowed contact between the Upper Albian Gault mudstones and the lowest beds of the West Melbury Marly Chalk Formation is exposed on the faulted wave-cut platform at the eastern end of the groynes in East Wear Bay (TR 261 383). These exposures, described by Gale (1989, Locality 3), take the Cenomanian stratigraphy below levels exposed at the **Southerham Grey Pit**. Here the locally thick Glauconitic Marl Member contains common sponges, including the former zonal index sponge, *Stauronema carteri* Sollas, and indeterminate inoceramid bivalve hinges. The terminal thin limestone, M2, has yielded a single specimen of *Neostlingoceras carcitanense* (Matheron), the basal Cenomanian subzonal index species (Gale, 1989). Where the Glauconitic Marl is thin, for example in the Channel Tunnel Craelius No. 1 (Aycliff) Borehole it contains well-preserved specimens of the thin-shelled bivalve *Aucellina* (illustrated in Morter and Wood, 1983), indicative of the *Neohibolites ultimus/Aucellina gryphaeoides* event of European event stratigraphy (Ernst *et al.*, 1983).

The section at the base of Abbot's Cliff (Gale and Friedrich, 1989) is the most important section of the Lower Cenomanian *Sharpeiceras schlueteri* Subzone of the *Mantelliceras mantelli* Zone in Europe. The 3 m section of marl–limestone rhythms above the Glauconitic Marl is extremely fossiliferous and has yielded a rich *S. schlueteri* subzonal ammonite assemblage. This comprises the large ammonites *Sharpeiceras schlueteri* Hyatt, *S. laticlavium* and *Utaturiceras vicinale* (Stoliczka) (illustrated by Wright and Kennedy, 1996), which are not found at other horizons in the Cenomanian succession, together with large, inflated *Mantelliceras* and heteromorphs such as *Hypoturrilites*. *Utaturiceras*, originally described from India, has not been found elsewhere in Britain. These ammonites are associated with large ornate oysters with a zig-zag commissure (*Rastellum colubrinum* (Lamarck)) and common large terebratulids (*Tropeothyris carteri* (Davidson) and related forms) which are likewise restricted to this level. This is also the inferred type horizon of *Inoceramus crippsi* Mantell, which is common at this level, but was originally described from the Hamsey pits near Lewes by Mantell (1822). The subzone terminates in the prominent massive M3 limestone, which contains abundant three-dimensionally preserved specimens of the former zonal index ammonite *Schloenbachia varians* (J. Sowerby). This is the inferred correlative of the Doolittle Limestone of the Chiltern Hills (see p. 300, Chapter 4).

The next section east (Abbot's Cliff to Lydden Spout) is one of the most important for the biostratigraphy of the Middle Cenomanian Substage in England, complementing that at **Southerham Grey Pit** (Kennedy, 1969; Gale, 1989, 1995; Gale, in Jenkyns *et al.*, 1994; Paul *et al.*, 1994; Mitchell and Carr, 1998).

The basal Middle Cenomanian index ammonite, *Cunningtoniceras inerme* (Pervinquière) enters slightly below the middle of the three *Orbirhynchia mantelliana* bands (Gale, 1995). The dark marl below the lower of the two prominent limestones in this section is extremely fossiliferous. It is named the Arlesiensis Bed after the restricted occurrence in it of the small pectinacean bivalve *Lyropecten (Aequipecten) arlesiensis* (Woods) together with a diverse fauna including serpulids, a flood occurrence of the small bivalve *Oxytoma seminudum* Dames and the inoceramid bivalve *Inoceramus schoendorfi* Heinz. The second of the Middle Cenomanian zonal index ammonites, *Acanthoceras rhotomagense* (Brongniart), enters in the higher of the two prominent limestones. This latter limestone is the correlative of the Tenuis Limestone of **Southerham Grey Pit**.

The Cast Bed of Price (1877) contains an abundant, diverse assemblage of small brachiopods, including *Grasirhynchia grasiana* (d'Orbigny), *G. martini* (Mantell), *Kingena concinna* Owen and *Modestella geinitzi* (Schloenbach), the latter being restricted to this bed. The associated fossils include sporadic small corals, (*Micrabacia coronula* (Goldfuss)), the smooth pectinacian bivalve *Entolium orbiculare* (J. Sowerby) and a second flood abundance of *Oxytoma seminudum*. A key element of the fauna is the belemnite *Praeactinocamax primus*; rare occurrences (three specimens) from here compare with two finds at **Southerham Grey Pit** (Paul *et al.*, 1994) and provide evidence for the *primus* event of European event stratigraphy (Ernst *et al.*, 1983; Christensen, 1990, Figure 2.8, Chapter 2).

The range of *Orbirhynchia mantelliana* (J. de C. Sowerby) in the upper of the three bands is greater here than elsewhere (Gale, 1990). Above this upper band of *O. mantelliana* there is a succession of nine, more or less equally developed, 0.12–0.2 m thick, conspicuous limestone bands. The lowermost two limestones are formed from discontinuous concentrations of sponges. On the upper surface of the eighth band the small coral *Micrabacia coronula* is again abundant: this is the *Micrabacia* Band (Band 11 of Kennedy, 1969). The terebratulid brachiopod *Concinnithyris subundata* (J. Sowerby) is also abundant throughout this interval and above the *Micrabacia* band. The occurrence of this brachiopod provides a useful marker throughout the Southern and Transitional provinces.

An integrated biostratigraphical study of the Cenomanian–Turonian boundary succession (with particular reference to the Plenus Marls Member) on the Abbot's Cliff path using nannofossils, foraminifera, ostracods, dinoflagellates within a stable isotope stratigraphical framework was undertaken by Jarvis *et al.* (1988b). A quantitative study of nannofossil changes across the Plenus Marls was carried out by Lamolda *et al.* (1994). These studies relate to mass extinctions and the recovery of faunas and floras across the OAE II.

Turonian Stage

The extremely condensed Lower Turonian Holywell Nodular Chalk succession is particularly important as a source of ammonites that can be used for international correlation. The Holywell Marl 2/3 interval contains *Fagesia catinus* (Mantell) and *Lewesiceras peramplum* (Mantell) indicating the presence of the *Fagesia catinus* Zone in Britain. The sediment of this interval is composed of comminuted debris from the microcrinoid genus *Roveacrinus*, constituting the lower of two microcrinoid events in the Turonian succession. A specimen of *Pseudaspidoceras* cf. *footeanum* (Stoliczka), the only one known from Britain, found loose on the beach here and illustrated by Wright and Kennedy (1981, pl. 21, fig. 3), came from this horizon.

The higher part of the Holywell Nodular Chalk Formation is a grit bed, characterized by abundant bivalve shell debris. *Mytiloides* shells encrusted by the serpulid *Filograna avita* (J. Sowerby), are found at the at the top of the maximum abundance of *Mytiloides* shell detritus, constituting the *Filograna avita* event.

An ammonite bed in the upper part of the Holywell Nodular Chalk Formation, a few couplets above the *Filograna avita* event, has yielded specimens of the large ammonites *Mammites nodosoides* (Schlotheim), *Morrowites wingi* (Morrow) and *Metasigaloceras rusticum* (J. Sowerby). Thus, even in this highly condensed succession it is possible to recognize some of the key biostratigraphical marker horizons in the Lower Turonian succession. The limestone immediately overlying the Gun Gardens Main Marl (the 'Lulworth Marl' of Gale, 1996) is composed of *Roveacrinus* debris and constitutes the higher of the two microcrinoid events.

The Aker's Steps section is used as the standard reference section for the foraminiferal biostratigraphy of the Turonian Stage in the UK. Unfortunately, the published logs (Hart, 1982, figs 1, 2; Hart *et al.*, 1989), which are based on an unpublished PhD thesis (M. Owen, 1970), are seriously incorrect and hence difficult to interpret. Because of failure to take account of a fault in the middle of the section, some 3 m of strata are repeated in the New Pit Marl 2–Glynde Marls interval. Nevertheless, some of the key planktonic foraminiferal events can be interpreted with a degree of confidence. *Marginotruncana sigali* (Reichel) enters at the Malling Street Marl 1 (Round Down Marl of Robinson (1986)) and ranges up to a level within the Glynde Marls. *M. pseudolinneiana* Pessagno (Figure 2.41, Chapter 2) enters 3 m above New Pit Marl 2, and *M. coronata* (Bolli) in the Glynde Marls–Southerham Marl 1 interval, *c.* 4 m above the Lydden Spout Flint. These entry levels define the bases of the *sigali* (UKP6), *pseudolinneiana* (UKP7) and *coronata* (UKP8) planktonic foraminiferal zones respectively.

Inoceramid bivalves of the *Inoceramus lamarcki* Parkinson group are common in the nodular sponge beds below Southerham Marl 1 in Langdon Bay. This is the type locality for the European inoceramid zonal index fossil *I. lamarcki sensu stricto*. The holotype (now in the Natural History Museum, London) was collected (Parkinson, 1819) from a flint below the Southerham Marls, probably from the big nodular Southerham Flints. The ammonite *Subprionocyclus hitchinensis* (Billinghurst) was found here in the Southerham Marl 1–Marl 2 interval (Gale, 1996). *Micraster corbovis* Forbes of *lata* Zone type (Stokes, 1975), thin-shelled *Sternotaxis plana* (Mantell) and terebratulid brachiopods are also present above and below the Southerham marls. The surface beneath the Caburn Marl has yielded *Micraster michelini* (Agassiz), the same level as the Caburn Pit examples in Sussex (Mortimore, 1986a). So far, unlike in Sussex, no specimens of the international zonal index ammonite, *Romaniceras deverianum* (d'Orbigny) have been collected at this level at Dover.

The boundary between the conventional *Terebratulina lata* Zone and the *Sternotaxis* (formerly *Holaster*) *plana* Zone was taken by Jukes-Browne and Hill (1903, 1904) at the base of the Basal Complex of nodular chalks, marl seams and large flints. This level corresponds to the lowest Bridgewick Flint Band in the Ringmer Beds of Sussex. In the Bridgewick Flints echinoids are common, including *Micraster michelini*, *M. corbovis* of *lata* Zone type and *S. plana*. Rowe (1900), on the other hand, took the base of his *Holaster planus* Zone at Bridgewick Marl 1, which is the horizon of the last occurrence of *Terebratulina lata* R. Etheridge (it is abundant in this marl seam). The Basal Complex above this level is characterized by common specimens of the rhynchonellid brachiopod *Orbirhynchia dispansa* Pettitt and the regular echinoid *Gauthieria radiata* (Sorignet). The rhynchonellid brachiopod genus *Cretirhynchia* enters above Bridgewick Marl 3.

Each of the nodular chalks of the Dover Chalk Rock contains a specific Upper Turonian ammonite and inoceramid bivalve assemblage. The bottom nodular layer contains a low diversity assemblage comprising the inoceramid bivalves *Inoceramus perplexus* Whitfield and *Mytiloides costellatus* (Woods), together with *Subprionocyclus hitchinensis* and *Yezoites bladenensis* (Schlüter), but without *Hyphantoceras reussianum* (d'Orbigny). This is the 'allocrioceratid and collignoniceratid ammonite fauna' of the *Hyphantoceras* Event complex of northern Germany (Kaplan and Kennedy, 1996). Nodular beds 2 and 3 contain the higher diversity, 'nostoceratid ammonite fauna' (Kaplan and Kennedy, 1996), including *Hyphantoceras reussianum*, *Eubostrychoceras saxonicum* (Schlüter) and *Scaphites geinitzii* d'Orbigny, but not *Subprionocyclus*. These beds also contain many small bivalves and gastropods and typical Chalk Rock brachiopods including *Orbirhynchia reedensis* (R. Etheridge), *Cretirhynchia cuneiformis* Pettitt, *C. minor* Pettitt and *Gibbithyris subrotunda* (J. Sowerby). The beds with the characteristic Lewes Tubular Flints contain the echinoid *Micraster leskei* Desmoulins as well as the inoceramid bivalves *Mytiloides striatoconcentricus* (Gümbel) and *M. incertus* (Jimbo), marking the position of the 'desmoceratid ammonite fauna' of the German succession, but without the characteristic ammonites. Each of these assemblages enables correlation to the expanded Sussex sections and to the more condensed Chalk Rock sections of the Chiltern Hills (see **Kensworth Quarry** GCR site report, this volume) and Marlborough Downs (see **Fognam Quarry** GCR site report, this volume). Dover is the one place in England where the succession of distinct ammonite faunas found in the German 'Scaphiten-Schichten' can be demonstrated.

Beds above the Chalk Rock contain *Micraster* that are already more advanced than the *M. praecursor sensu* Drummond assemblages of Sussex, indicating further condensation here. The soft chalks of the Cuilfail Zoophycos contain large, inflated specimens of the thin-tested echinoid *Sternotaxis placenta* (Agassiz) associated with *Micraster normanniae* Bucaille. Within these highest beds below the Navigation Hardground, Rowe (1900) took his boundary of the *S. plana* and *Micraster cortestudinarium* zones.

Coniacian Stage

The boundary between the Turonian and Coniacian stages is currently taken along the top surface of the Navigation Hardground. A juvenile ammonite, questionably identified as *Forresteria petrocoriensis*, was found inside a broken echinoid on this surface at Langdon Stairs (Gale and Woodroof, 1981). The only unequivocal record of the biostratigraphically significant (Turonian–Coniacian boundary transition) thin-shelled bivalve *Didymotis* from the Southern Province was from soft chalk within the Navigation Hardground complex at the South Foreland. The basal index taxon for the Coniacian Stage, the inoceramid bivalve

Cremnoceramus deformis erectus (Meek) occurs together with *C. waltersdorfensis* (Andert) in a shell-rich bed 0.7 m above the Navigation Marls at East Cliff, Dover. This compares with the occurrence of these species in the lower Navigation Marl at Upper Beeding Quarry, Shoreham Cement Works, Sussex. The small rhynchonellid brachiopod *Cretirhynchia subplicata* (Mantell) is particularly common between the Cliffe and Hope Gap hardgrounds. The Hope Gap Hardground is well cemented and contains moulds of small, originally aragonite-shelled, bivalves and gastropods. Large, poorly preserved, unidentified ammonites occur in this hardground at the South Foreland.

The beds above the Hope Gap Hardground contain larger inoceramid bivalves (*Cremnoceramus* spp.) and large specimens of the inoceramid zonal index fossil *C. crassus crassus* (Petrascheck) are a particular feature of the interval from the Light Point Hardground to the Beachy Head Sponge Beds. *Micraster decipiens* (Bayle) (i.e. *M. cortestudinarium* (Goldfuss)) occurs in several bands: on the Hope Gap Hardground, in the Beeding Hardgrounds and in the Light Point Hardground. Large specimens of *Micraster turonensis* (Bayle) characterize the Beachy Head Sponge Beds. The boundary between the traditional *Micraster cortestudinarium* and *M. coranguinum* zones was taken by Rowe (1900) at a sponge bed above Shoreham Marl 2 on Langdon Stairs (Figure 3.124), but lower down, at a sponge bed below Shoreham Marl 1 at St Margaret's Bay.

The basal Middle Coniacian zonal index inoceramid bivalve, *Volviceramus koeneni* (Müller), has been collected from the calcarenite 2.7 m above Shoreham Marl 2 at East Cliff (Figure 3.124). The lowest specimens of *Platyceramus mantelli* were also noted at this horizon. Abundant shell fragments of *Platyceramus* (Figure 2.20, Chapter 2) are characteristic throughout the Belle Tout Beds and up to the Cuckmere Flints. These shells are abundant in the Belle Tout Marls. There are also several bands of *Volviceramus* ex gr. *involutus* (J. de C. Sowerby) in these beds (Figure 3.124; Figure 2.20, Chapter 2). The Seven Sisters Flint Band has the same association of *Platyceramus* and *Volviceramus* below, in and above as in the **Cuckmere to Seaford** site, Birling Gap and Tarring Neville Quarry. The echinoid *Conulus raulini* (d'Orbigny) occurs in the Belle Tout Beds in the Kent sections, but has not been found in Sussex.

The successive, closely-spaced entry datums of the benthic foraminifera *Stensioeina granulata granulata* (Olbertz) (Figure 2.41, Chapter 2), *S. exsculpta exsculpta* (Reuss) (Figure 2.42, Chapter 2) and *Loxostomum eleyi* (Cushman) in the lower half of the Belle Tout Beds (Figure 3.124) mark, respectively, the bases of the UKB12 and UKB13 benthic foraminiferal zones and a bio-horizon within the UKB13 Zone (see Hart *et al.*, 1989; Bailey *et al.*, 1983).

Interpretation

The **Folkestone–Dover** section is usually considered to be the standard section for the Cenomanian Stage in the UK. The most complete Lower Cenomanian succession in England is present here, but the *Mantelliceras saxbii* flood-event seen at **Southerham Grey Pit**, Sussex, is missing either because of erosion or to non-preservation. The marker horizon M4, the erosion surface at the base of the *M. dixoni* Zone, passes laterally into phosphates in Sussex (Eastbourne) and the Isle of Wight (i.e. it becomes a much more developed erosion surface compared to the burrowed surface at Folkestone). The highly fossiliferous limestone of couplet B24 of Gale (1995) at **Southerham Grey Pit** (the possible equivalent of Bed h of Kennedy, 1969) is barely cemented and inconspicuous at Folkestone. Consequently the rich and well-preserved three-dimensional ammonite and inoceramid fauna is not represented in the Folkestone sections.

The White Bed at the top of the Grey Chalk Subgroup is more homogeneous, less obviously rhythmically bedded and thinner compared to its development at **Southerham Grey Pit** and at Beachy Head. This is probably due to its position on the margin of the Anglo-Brabant Massif (Figure 1.8, Chapter 1) compared to the more basinal Sussex sections.

In the Turonian strata, the highly condensed nature of the Holywell Nodular Chalk Formation has resulted in the loss of numerous marker beds. The marl seams of the expanded succession are represented here merely by thin, marl-coated wavy surfaces. This condensation continues across the Anglo-Brabant Massif into the southern Chiltern Hills. Despite this condensation, the presence of some regional markers such as the *Filograna avita* event

(Gale, 1996), has allowed a correlation to be established in the upper part of the shell-detrital layers. The *Filograna avita* event is found throughout the Southern Province and in the southern Chiltern Hills, where it has been traced as far north as Pitstone Quarry. There are fewer ammonite horizons in the Lower Turonian Holywell Nodular Chalk Formation at Dover compared with Sussex. Because of the extreme condensation of the basal beds of the Holywell Nodular Chalk Formation (equivalent of the Melbourn Rock of Sussex) the rich *Neocardioceras juddii* Zone ammonite assemblage of the expanded Eastbourne sections is represented only by occurrences of *Sciponoceras*.

The extreme condensation at Dover continues into the base of the New Pit Chalk Formation, which here is still nodular but does not contain the shell detritus of the Holywell Nodular Chalk Formation below. The Glyndebourne Flints are missing in the Aker's Steps section but are present elsewhere in the North Downs (e.g. Halling Pit, Mortimore, 1990). Some of the nodular beds may represent the Glyndebourne Hardgrounds of Sussex (see **Southerham Pit** GCR site report, this volume).

The **Dover–Kingsdown** section of the Folkestone to Kingsdown GCR site is a link in the New Pit Chalk and Lewes Nodular Chalk formations between the main basinal sections of Sussex and Hampshire and the Transitional Province sections such as **Fognam Quarry**, **Kensworth Quarry** and the sections in East Anglia, including Grimes Graves, near Brandon. It is critical to the development of a lithostratigraphy for the Transitional Province. This is particularly the case with the Chalk Rock because the nodular 'Dover Chalk Rock' succession is intermediate between the highly condensed Chalk Rock *sensu stricto* of **Fognam Quarry** and **Charnage Down Chalk Pit** and the expanded Kingston Beds of Sussex.

The interval between the top of the 'Dover Chalk Rock' and the Navigation Hardgrounds is also condensed compared with that in the **Southerham Pit**, Lewes. There are more species of *Micraster* at Lewes, and current evidence suggests that there are also more Late Turonian inoceramid bivalves in this expanded section. However, the only basal Coniacian ammonite to be found so far in the Chalk of the UK came from the Navigation Hardground at Langdon Stairs.

The Aker's Steps section has provided a detailed isotope stratigraphy for the Turonian Stage of the Southern Province, the upward continuation being taken from the Langdon Bay–Langdon Stairs composite section (see Jenkyns *et al.*, 1994, figs 3, 4 for the $\delta^{13}C$ and $\delta^{18}O$ curves respectively). The remainder of the stable isotope stratigraphy up to the top of the preserved Chalk on Thanet was based on the cliff sections south of Kingsdown and in the Isle of Thanet.

The Turonian $\delta^{13}C$ curve from the Dover sections has been extensively used for long-range correlation to reference sections in Lower Saxony and Saxony (Germany) and to the cliffs near Santander in northern Spain. In all of these sections, several $\delta^{13}C$ positive 'spikes' serve as correlative marker horizons (Voigt and Hilbrecht, 1997, figs 6, 7). These have been given numbers in relation to the point on the curve with the minimum $\delta^{13}C$ value (the datum or zero – see Wiese, 1999, figs 4, 5). The most prominent of the four 'spikes' below the datum (–4 or the Pewsey event) is inferred (Gale, 1996) to correlate with the Pewsey Hardground in the bottom hardground suite of the stratotypic Chalk Rock (see **Fognam Quarry** GCR site report, this volume). At Dover, this peak falls low in the Lewes Nodular Chalk Formation, *c.* 4 m above the Lydden Spout Flint and immediately below the entry of the planktonic foraminifer *Marginotruncana coronata* at the base of the UKP8 planktonic foraminiferal Zone. The inception of this species may relate to a transgressive episode. Peaks –3, –2 and –1 (in ascending order) correspond respectively to the Southerham Flints below Southerham Marl 1; to a level *c.* 1 m above the Southerham Marls; and to the Caburn Flints below the Caburn Marl. This latter level, which yields the Upper Turonian zonal index ammonite, *Romaniceras deverianum*, in both the Southern and Transitional provinces, can be equated, using stable isotope stratigraphy, with the *costellatus*/*plana* event of European event stratigraphy and the provisional marker for the base of the Upper Turonian Substage. However, the entry of *Subprionocyclus hitchinensis* at Dover between the Southerham Marls, and the lowest ocurrence of *S. neptuni* (Geinitz) a short distance beneath the inferred equivalent of Southerham Marl 1 at **Fognam Quarry**, suggests that the base of the Upper Turonian Substage in the UK should be shifted significantly downwards (see also Appendix, this volume).

Conclusions

The Folkestone to Kingsdown Upper Cretaceous Chalk cliffs are ideally situated on the northern flanks of the Southern Province, providing a link to the Transitional Province and on into the North Sea and German sections. Detailed correlations have also been made with northern France. These cliffs provide the standard reference section for the Cenomanian Stage of the Southern Province. The Albian–Cenomanian boundary is better developed here than elsewhere in the Southern Province, with an expanded, lithologically differentiated and fossiliferous Glauconitic Marl Member at the base of the Chalk Group. This is also the best section in Europe of the *Mantelliceras schlueteri* ammonite Subzone. It is one of the standard reference sections, with **Southerham Grey Pit** and **Compton Bay**, for the marl–limestone couplet cyclostratigraphy of the Cenomanian Stage. The sections illustrate the stratigraphical and sedimentological impacts of condensation in the 'Melbourn Rock' (Holywell Nodular Chalk Formation) and Chalk Rock. Many type specimens of Upper Cretaceous macrofossils come from these cliffs. It is only in the 'Dover Chalk Rock' that it is possible to demonstrate the succession of Upper Turonian ammonite faunas known from expanded sections in Germany. The rich inoceramid bivalve faunas enable correlation between the traditional macrofossil zones and the standard inoceramid zonal scheme. The site also includes several of the reference sections for the microfossil (foraminiferal) zonal scheme of the UK.

Together with the Sussex sections, the Folkestone to Kingsdown cliffs provide standard reference sections for the trace element and rare earth geochemistry of the Turonian marl seams. Closely spaced chalk samples collected from this and the **Thanet Coast** GCR site were used to establish the lowest part of the continuous stable isotope curve for the Cenomanian–Upper Santonian interval in the Southern Province.

THANET COAST, KENT (TR 296 696–TR 399 675)

Introduction

The Thanet Coast GCR site (Figure 3.125) comprises several separate cliff sections, covering 21 km between Cliffs End in Pegwell Bay on the south coast; along the east coast through Ramsgate, Broadstairs and Kingsgate; and along the north coast from Margate westward to Grenham Bay.

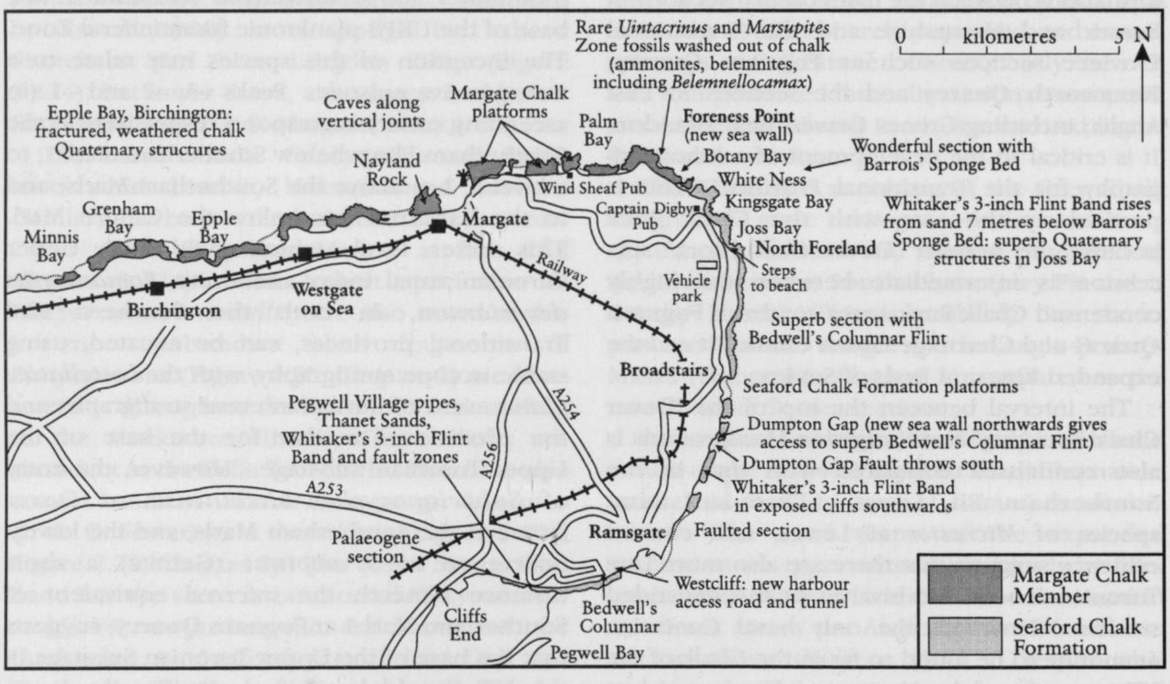


Figure 3.125 The Thanet Coast Upper Cretaceous Chalk GCR site showing key features.

The Isle of Thanet is the type locality for three of the most conspicuous marker beds in the White Chalk Subgroup of the Southern Province: Bedwell's Columnar Flint Band, Whitaker's 3-inch Flint Band and the Barrois' Sponge Bed. It is also the type area for the Margate Chalk Member. Thanet is famous for the excellent preservation in very soft chalks of fossil echinoderms and (towards the higher part of the succession) for the relative abundance of giant ammonites. Compared with other sites in the Southern Province, there is also an unusual abundance of belemnites in the Santonian succession, including several records of *Belemnellocamax grossouvrei* (Janet), which is extremely rare elsewhere in the UK.

Sea walls have been constructed around much of the coast, at Dumpton Gap, Broadstairs, Joss Bay and Foreness Point; and also along the greater part of the north coast, reducing in particular the exposure of Margate Chalk in the *Uintacrinus socialis*, *Marsupites testudinarius* and *Uintacrinus anglicus* zones. Extension of Ramsgate Harbour by land reclamation east into Pegwell Bay has also reduced the exposure of the Seaford Chalk Formation (*Micraster coranguinum* Zone), but the section on the undercliff road is still just workable. On the other hand, the building of the relatively new undersea walls has resulted in significantly less cliff erosion and has provided access to parts of the succession that were formerly difficult to study. For example, Bedwell's Columnar Flint Band is now within reach along the top of the sea wall northwards from Dumpton Gap.

Description

The Chalk of the Thanet Coast (Figures 3.125 and 3.126) is cut entirely in the Seaford Chalk Formation and overlying Margate Chalk Member (Newhaven Chalk Formation) of the White Chalk Subgroup (Bristow *et al.*, 1997; Rawson *et al.*, 2001). Whitaker (1865a, 1872) placed all the Chalk of Thanet in two lithological units. The Broadstairs Chalk, at the base, included the beds described by Phillips (1818, 1819) as 'Chalk with many flints and few organic remains' (i.e. the upper half of the Lewes Nodular Chalk Formation and all of the Seaford Chalk Formation). Above this were beds with few flints, which he called 'Margate Chalk'. Dowker (1870) also followed this division of the Chalk of Thanet, but termed Whitaker's 'Broadstairs Chalk' the 'Ramsgate Chalk'. The [British] Geological Survey (Jukes-Browne and Hill, 1904) did not accept this lithostratigraphical scheme, which to them was of local application only, and used instead Upper Chalk divided (biostratigraphically) into macrofossil assemblage zones. Robinson (1986) provided detailed graphic stratigraphical logs of the Thanet succession, and used the lithological concepts of Mortimore (1983, 1986a) to define a Broadstairs Chalk Member with exactly the same lower limit as that of the Seaford Chalk Formation. He also accepted the traditional concept of the Margate Chalk. In the new classification, the variously defined 'Broadstairs Chalk' is replaced by the Seaford Chalk Formation (Mortimore, 1983, 1986a; Bristow *et al.*, 1997) and the 'Margate Chalk' is retained (Bristow *et al.*, 1997) but now with member status as part of the Newhaven Chalk Formation.

Two conspicuous flint bands (in the Broadstairs or Ramsgate Chalk) were identified by Whitaker (1865a, 1872), Dowker (1870) and Bedwell (1874) as useful stratigraphical markers in the cliffs of the Thanet Coast. Bedwell (1874) also recognized a higher flint band, in the Margate Chalk. These flints were later named by Rowe (1900): the 'Bedwell Columnar Flint Band' (Figures 3.126 and 3.127), the 'Whitaker's 3-inch Flint Band' and the 'Bedwell Line', in ascending order. Barrois (1876) additionally identified a well-developed 'sponge bed' that he could trace from Joss Bay to White Ness, at the boundary between his *Micraster coranguinum* and *Marsupites* zones. Rowe (1900) named this the 'Barrois' Sponge Bed' after its discoverer.

Skeletal longitudinal sections of the cliffs showing the position of these key markers were published by Sherborn (in Rowe, 1900, Section 3, p. 368) and in the British Geological Survey Dover and Ramsgate Sheet Memoir (Shephard-Thorn, 1988, fig. 12). The memoir also includes descriptions of the geology of the area, a map (fig. 11) to show the distribution of the Chalk zones in Thanet, and an analysis of the geological structure, showing faults and folds. Further details are to be found in the Geologists' Association Guide to the Chalk of the region (Mortimore, 1997), and the stratigraphy of the Chalk (using the Robinson scheme) was also published by Gale (in Jenkyns *et al.*, 1994, fig. 13c) as part of a composite stratigraphy of the Chalk of the Kent coast sections.

A continuing dip northwards from the Dover–

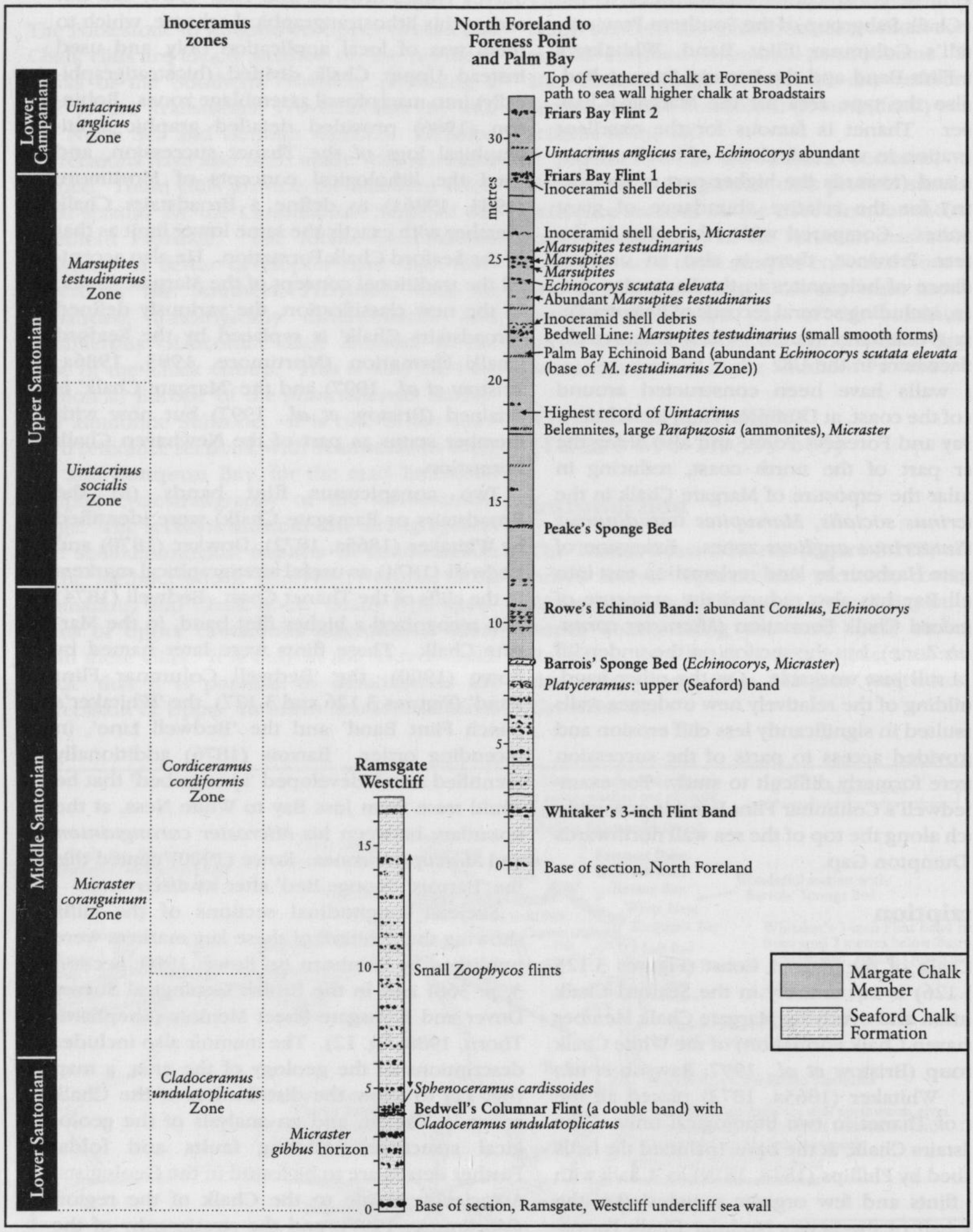


Figure 3.126 The Chalk succession around the Thanet Coast of north-east Kent. The upper limit of the *Cladoceramus undulatoplicatus* Zone is uncertain.

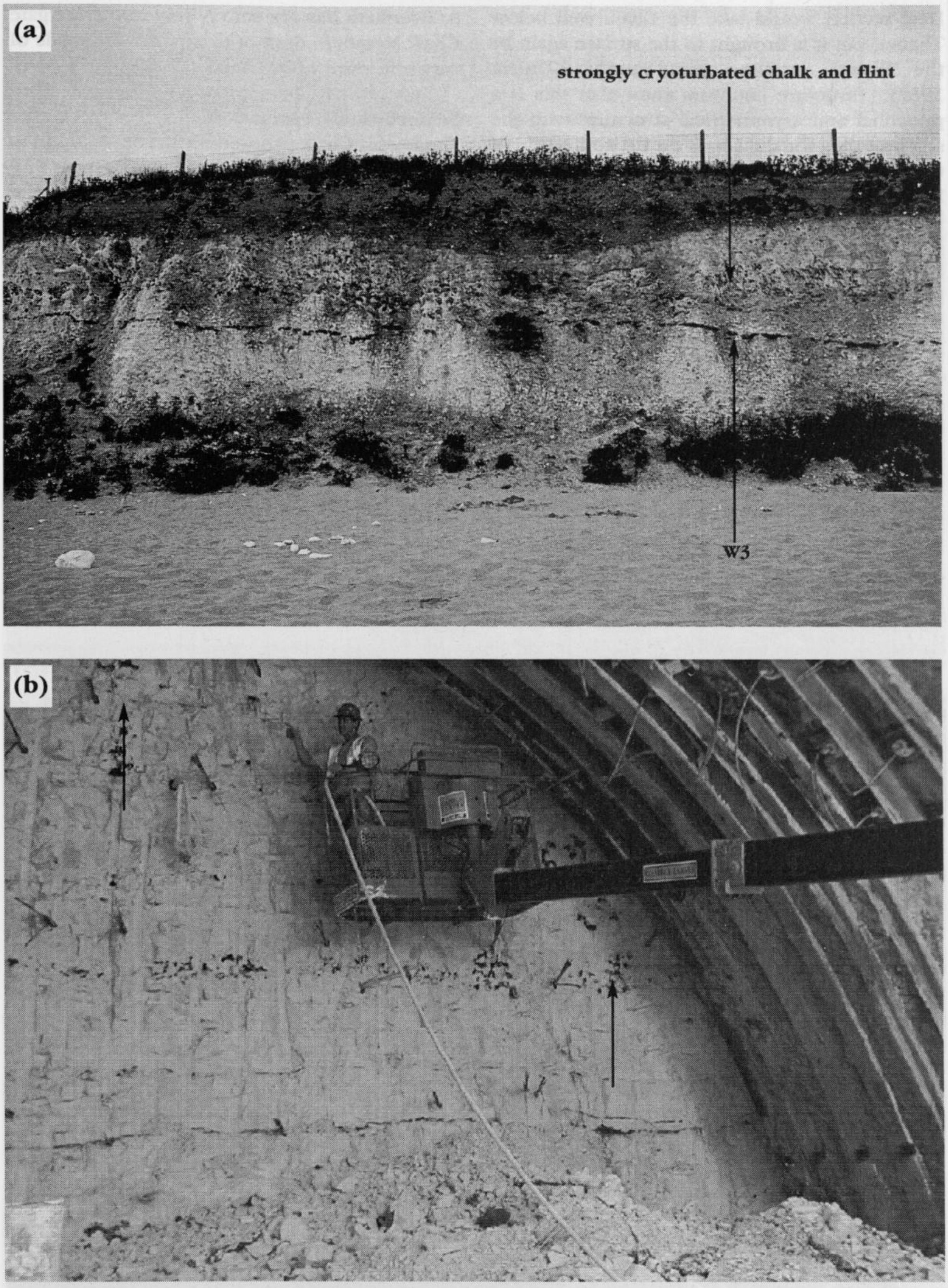


Figure 3.127 (a) The cliffs at Joss Bay, showing Whitakers 3-inch Flint Band (W3) and strongly cryoturbated chalk and flint. (b) Giant flint columns emanating from Bedwell's Columnar Flint Band, South Portal, Ramsgate Harbour Tunnel (arrowed). (Photos: R.N. Mortimore.)

Deal section would take the Chalk well below Thanet, but it is brought to the surface again by the Thanet Anticline (e.g. Shephard-Thorn, 1988). Structure contours show that this is a periclinal and asymmetrical structure, with the steepest dips for the Chalk on the south side of the anticline, along the north coast of Pegwell Bay. Here the Chalk dips south into the Richborough Syncline beneath the Palaeogene deposits. The Thanet Chalk is regularly faulted and the faults are frequently associated with intense jointing with a dominant trend between 310° and 330°.

Lithostratigraphy

Seaford Chalk Formation is present along the south coast in Pegwell Bay, at Ramsgate and Broadstairs, and extends as far north as White Ness, Kingsgate. The cliffs and foreshore in Botany Bay, at Foreness Point, in Palm Bay and along the north coast from Margate westwards to Grenham Bay are cut entirely in the Margate Chalk Member. Both of these units are made of very soft, pure white chalk.

Seaford Chalk Formation

The lowest Chalk exposed on Thanet is found at the western end of the Western Undercliff, Ramsgate (Figures 3.127–3.129). Flints on the wave-cut platform here probably correlate with the Michel Dean and Baily's Hill flints of Seaford Head, Sussex. The cliff section includes Bedwell's Columnar Flint Band (Figure 3.127), which in places consists of a double band of scattered nodular flints with several large paramoudra columns. Paramoudra flints are more common in this band in the coast section north of Dumpton Gap, and also occur in association with the underlying flint bands.

Between Bedwell's Columnar Flint Band and the next conspicuous marker above, Whitaker's 3-inch Flint Band (Figure 3.127), are some 12 m of chalk with 13 flint bands, most of which con-

Figure 3.128 Aerial view of the Chalk cliffs on the south coast of the Isle of Thanet, Kent, between Pegwell village and Ramsgate Harbour. (Photo: R.N. Mortimore.)

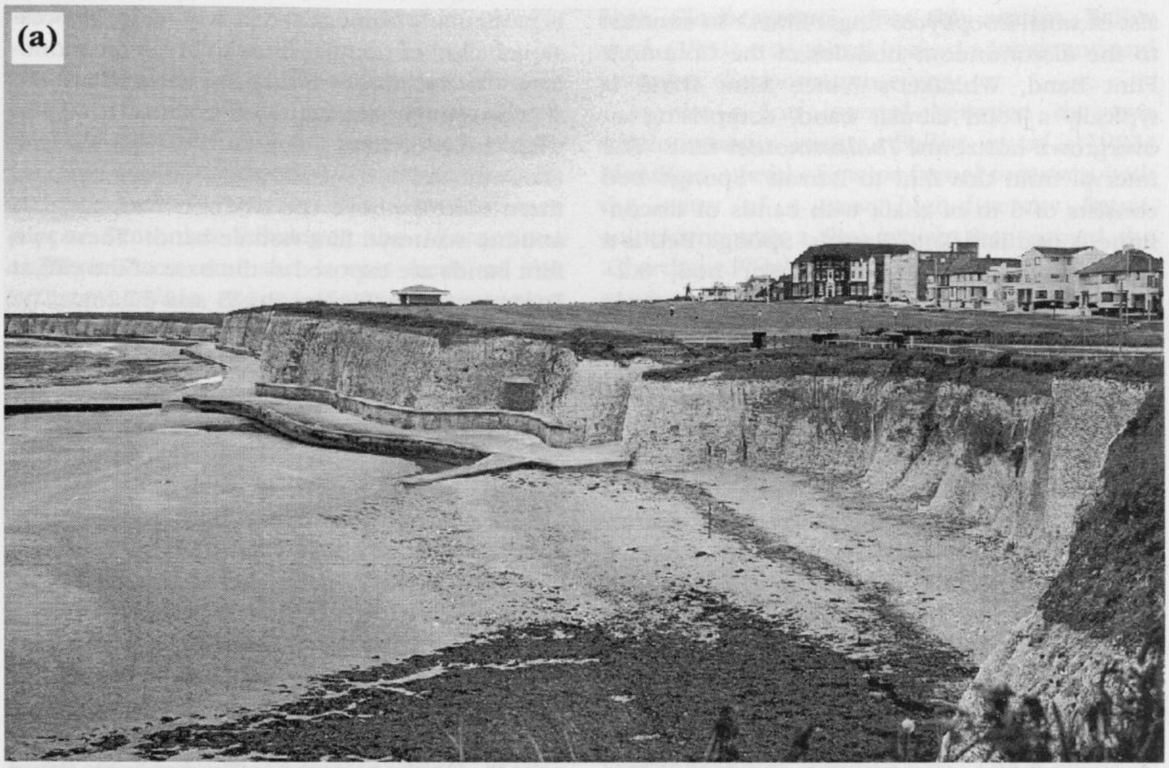


Figure 3.129 The Margate Chalk Member of the Thanet Coast. (a) North Thanet Coast, Birchington to Margate; caves are developed along vertical joint sets in Margate Chalk where the sea wall is absent. (b) South Thanet Coast, western end of Pegwell Bay, caves have developed along vertical joint sets in the Margate Chalk Member. (Photo: R.N. Mortimore).

sist of small *Zoophycos* finger-flints. In contrast to the discontinuous nodules of the Columnar Flint Band, Whitaker's 3-inch Flint Band is typically a solid tabular band, comprising an overgrown horizontal *Thalassinoides* flint. The interval from this flint to Barrois' Sponge Bed consists of 6 m of chalk with bands of discontinuous nodular flint. Barrois' Sponge Bed is a conspicuous iron-stained nodular bed, 0.2–0.3 m thick, with a weakly developed, pale green, glauconitized top surface. It forms a small reef on the wave-cut platform at White Ness.

Margate Chalk Member of the Newhaven Chalk Formation

Barrois' Sponge Bed marks a significant change in lithology: the underlying Chalk contains regular flint bands, while the Chalk above appears flintless. This was the criteria originally chosen by Whitaker (1865a) to distinguish the Margate Chalk from the Broadstairs Chalk below. In the cliffs around White Ness it is difficult to identify any marker beds, the chalk appearing homogeneous and pure white. Close inspection reveals a horizon 2 m above Barrois' Sponge Bed, comprising an inconspicuous group of four weakly developed, iron-stained sponge beds, above which there are sporadic occurrences of nodular flints. This horizon was named by Robinson (1986) 'Rowe's Echinoid Bed' (Figure 3.126). Three metres higher there is a weakly indurated, discontinuous and inconspicuous sponge bed that was originally described by Peake (1967), and is generally known as 'Peake's Sponge Bed' (Figure 3.126).

For 8 m above Peake's Sponge Bed the chalk is particularly homogeneous, with only the occasional 'clot' of nodular flints to break the monotony. A continuous flint band then enters the section, comprising scattered nodules in a 0.5 m wide zone of flint. This is the Bedwell Line (Bedwell, 1874; Rowe, 1900). Between two and three metres above the Bedwell Line there is another scattered flint nodule band. These two flint bands are exposed at the base of the cliff at Foreness Point (Figures 3.125 and 3.126). The section in the gully leading down to the beach past Margate Headworks (Figure 3.130) here includes two additional flint bands, which are the highest in the Margate coast sections.

North-east of St Peter's Church, Broadstairs, Shephard-Thorn (1988) recorded the highest Margate Chalk on Thanet in a small, partly backfilled pit (TR 384 686), but its lithology is poorly known. Here, the Chalk is overlain, as in Pegwell Bay, by the Palaeogene Thanet Formation

The Margate Chalk is truncated by the Palaeogene erosion surface in Pegwell Bay, but this surface is not exposed in the Thanet Coast section proper. On the eastern headland of Epple Bay, a few nodular flints, preserving strongly developed trace fossils typical of the basal Newhaven Chalk Formation, can be seen in the Chalk wave-cut platform at low tide. The Chalk in the cliffs is virtually flintless, but a single sheet-flint is present towards the top of the cliffs on the eastern headland of Epple Bay and continues east towards Westgate on Sea. The Chalk is regularly and closely jointed, with the dominant trend between 310° and 330°, as it is on the south Thanet Coast at Pegwell Bay. A similar frequency and style of faulting is also present.

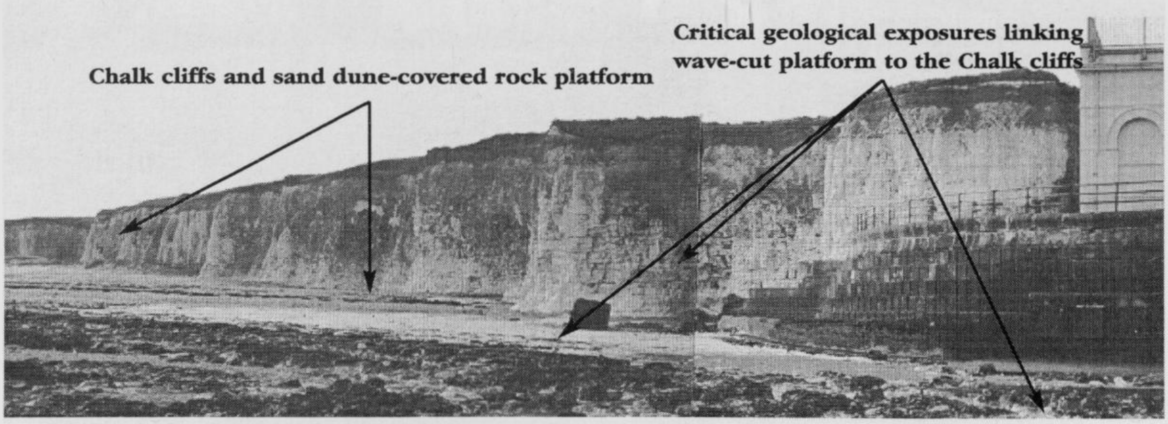


Figure 3.130 East side of Margate Headworks showing the cliffs of Botany Bay and the critical Chalk exposures in the *Uintacrinus socialis* and *Marsupites testudinarius* zones. (Photomosaic: R.N. Mortimore.)

Biostratigraphy

The Chalk of the Isle of Thanet spans the higher part of the *Micraster coranguinum* Zone (highest Upper Coniacian, Lower and Middle Santonian substages), the *Uintacrinus socialis* and *Marsupites testudinarius* crinoid zones (Upper Santonian Substage), the *Uintacrinus anglicus* Zone and the lowest beds of the *Offaster pilula* Zone (Lower Campanian Substage). The cliffs are primarily cut in Santonian chalks, with just a few metres of basal Campanian strata preserved in the core of a minor syncline at Foreness Point, and also inland at Broadstairs. Key papers on the macrofossils are those by Rowe (1900), Gale and Smith (1982) and Bailey *et al.* (1983, 1984). The foraminiferal biostratigraphy, including new benthic foraminiferal biozones developed here and based on the genera *Stensioeina* and *Bolivinoides* (Figure 1.5, Chapter 1), was documented by Bailey *et al.* (1983, 1984) and is also incorporated in skeletal sections in *The Stratigraphical Index of Fossil Foraminifera* (Hart *et al.*, 1989).

Santonian Stage

In Thanet, the lowest occurrences of the basal marker taxon for the Santonian Stage, the inoceramid bivalve *Cladoceramus undulato-plicatus* (Roemer), are found in two concentrations below, and immediately above, a conspicuous flint band that is the probable correlative of the Michel Dean Flint of Seaford Head. This composite occurrence constitutes the 'Pegwell Inoceramid Band' of Robinson (1986), for which the type locality is the West Cliff Promenade, Ramsgate (TR 376 642). Robinson (1986) actually recorded scattered occurrences of *Cladoceramus* for up to 0.3 m beneath the lower concentration. The distinctively corrugated, pinkish-purple shells of *Cladoceramus* at this level were earlier erroneously identified as *Inoceramus digitatus* J. de C. Sowerby, a species that characterizes a high level in the Upper Coniacian strata of the Northern Province, and the occurrence was accordingly named the 'Inoceramus digitatus Band' (Bailey *et al.*, 1983, fig. 2). Subsequent work showed that the inoceramid bivalves at this horizon and those that characterize the basal part of Bedwell's Columnar Flint Band cannot be distinguished, and that they are both *Cladoceramus*. For this reason, Bailey *et al.* (1984) recognized instead a lower and and an upper *Cladoceramus* event.

In the *c.* 5 m interval between the two *Cladoceramus* events, Bailey *et al.* (1983) identified a level of major faunal turnover, with the entry of a new, high-diversity fauna, coincident with a flint which they named the 'Chartham Flint', after a locality (TR 105 559), south-west of Canterbury. The development of flint in this interval in the North Downs sections is extremely variable (cf. Robinson, 1986, fig. 22) and it is not always possible to identify the Chartham Flint unequivocally. The new fauna, which enters the succession in Thanet only 2 m above the base of the Santonian Stage, is characterized by the first appearance of the benthic foraminifer *Stensioeina granulata polonica* Witwicka, marking the base of the UKB14 Zone, and by the entry of the terebratulid brachiopod *Gibbithyris ellipsoidalis* Sahni, the inoceramid bivalve *Cordiceramus cordiformis* (J. Sowerby), the echinoid *Conulus albogalerus* (Leske) and the ammonite aptychus *Spinaptychus* cf. *spinosus* Cox. Other elements of this fauna include the small rhynchonellid brachiopod *Orbirhynchia pisiformis* Pettitt and the echinoids *Cardiotaxis aequituberculatus* (Cotteau), *Micraster gibbus* (Lamarck) and thin-tested *Sternotaxis* sp., as well as barrel-shaped columnal ossicles of the crinoid *Bourgueticrinus*. The occurrence of *Spinaptychus* is of particular interest, since this aptychus has been found in Zululand in association with *Texanites* (Kennedy and Klinger, 1972). Although poorly preserved chalk moulds of texanitid ammonites are known from this level at Cliffe in north Kent (Spath, 1926), there are no records from Thanet. The inferred occurrence of *Texanites* here fits well with records of this genus in association with *Cladoceramus* in Germany.

This fauna can be collected from the wave-cut platform below the first sea-worn cliff exposures at the west end of the Western Undercliff Wall, Ramsgate, where Bedwell's Columnar Flint Band, with abundant *Cladoceramus undulato-plicatus* at the base, is present just above beach level. It is also to be found where the basal Santonian beds are brought into the foot of the cliff again by faulting, in the cliffs and foreshore of the long, northward dipping section to the north of Dumpton Gap. This is the type locality for the giant agglutinating foraminifer *Labyrinthidoma dumptonensis* Adams, Knight and Hodgkinson, a species that appears to range from the base of the Santonian to *c.* 3 m above Whitaker's 3-inch Flint Band (Adams *et al.*, 1973; Hart, 1993).

There is a minor concentration of *Cordiceramus cordiformis* below the remarkable flood occurrence of *Cladoceramus undulatoplicatus* at the base of Bedwell's Columnar Flint Band. The long-ranging Santonian inoceramid bivalve, *Sphenoceramus cardissoides* (Goldfuss), the thin-tested echinoid *Hagenowia rostrata* (Forbes) and extremely rare belemnites (*Gonioteuthis praewestfalica* Ernst and Schulz or early *G. westfalica* (Schlüter)) have been collected from just above the base of the Columnar Flint at the foot of the cliff at North Foreland.

There are several minor concentrations of *Cladoceramus* above the second *Cladoceramus* event at the base of the Columnar Flint. The last occurrence of *C. undulatoplicatus* is provisionally taken as the boundary between the Lower and Middle Santonian substages (Lamolda and Hancock, 1996): this is located in Thanet in a *Cladoceramus/Platyceramus* shell-bed situated several metres above the Columnar Flint.

The richly fossiliferous beds between the Columnar Flint and the Whitaker's 3-inch Flint Band contain distinctive forms of *Echinocorys*, relatively rounded *Conulus* (which tend to occur concentrated at particular horizons) and *Micraster coranguinum* (Leske). Other common elements of the fauna include several species of small simple corals ('*Parasmilia*'), numerous bivalves, including *Spondylus spinosus* (J. Sowerby) and the inoceramid bivalves *Platyceramus* sp. and *Cordiceramus cordiformis*, regular echinoids (predominantly isolated spines), for example *Phymosoma koenigi* (Mantell), *Temnocidaris sceptrifera* (Mantell), *Tylocidaris clavigera* (Mantell) and asteroids, including *Metopaster parkinsoni* (Forbes) and *M. uncatus* (Forbes). There is an acme-ocurrence of the thin-tested echinoid *Infulaster infulasteroides* (Wright and Wright) 2–4 m beneath the 3-inch flint (Gale and Smith, 1982, fig. 1).

Whitaker's 3-inch Flint Band is accessible on top of the short stretch of sea wall beneath the Pegwell Bay Hotel, and also at the head of Joss Bay. At the former locality, late forms of the inoceramid bivalve *Platyceramus*, as well as *Sphenoceramus* sp. and *Cordiceramus cordiformis*, are associated with an acme of the echinoid *Conulus*. The 3-inch Flint Band is a major biostratigraphical boundary. Specimens of *Micraster coranguinum* from above the flint show an anterior prolongation of the labrum that is not seen in specimens from lower beds. The benthic foraminifer *Cibicides beaumontianus* (d'Orbigny) first enters in strength just above the flint, together with *C. ribbingi* Brotzen, marking the base of the *C.* ex gr. *beaumontianus* Assemblage Biozone of Bailey *et al.* (1983). The last (sporadic) occurrence of the benthic species *Gavelinella arnagerensis* Solakius (*Lingulogavelinella* cf. *vombensis* (Brotzen) in the earlier literature, for example Bailey *et al.*, 1983, 1984) is located *c.* 2 m above the flint, close to the upper limit of the giant agglutinating form *Labyrinthidoma dumptonensis*. The upper limit of *G. arnagerensis* was used in the interpretation of boreholes for the site investigation for the Thames Barrage (Carter and Hart, 1977b).

A minor surface *c.* 2 m beneath Barrois' Sponge Bed marks the entry of the small, spindle-shaped belemnite *Actinocamax verus* Miller and the highest record of the terebratulid brachiopod genus *Gibbithyris* in Thanet. This horizon also yields rare specimens of the belemnite *Gonioteuthis westfalica* and a distinctive small form of *Echinocorys*, which is reminiscent of (but not so elevated as) the *E. scutata elevata* Griffith and Brydone that occurs at the base of the *Marsupites testudinarius* Zone. It is noteworthy that elsewhere in the Southern Province there is a virtual absence of terebratulid brachiopods from this level up to the highest beds of the *Gonioteuthis quadrata* Zone. Thick-shelled *Platyceramus* sp. are common in the interval between this surface and the Barrois' Sponge Bed.

Barrois' Sponge Bed was formerly taken (e.g. White, 1928) as the boundary between the *Micraster coranguinum* and *Uintacrinus socialis* zones, but this latter datum is now taken *c.* 3 m higher, at the entry of the zonal index crinoid (Figure 3.126). Barrois' Sponge Bed itself contains the large vertical-sided 'tea-cosy' form of *Echinocorys*, both in and resting on its surface, as well as unusual large forms of *Micraster*. The latter include *Micraster gibbus* and *M.* sp. close to the eastern European and German form *Micraster rogalae* Nowak. These echinoids can be readily collected from the wave-cut reef at the foot of White Ness.

The *c.* 2 m unit of coarse-grained, shell-detrital chalk with small scours and closely spaced minor iron-stained sponge beds ('Rowe's Echinoid Bed') that overlies Barrois Sponge Bed is very fossiliferous. It takes its name from the abundance of acutely pyramidal *Conulus albogalerus* and other echinoids such as *Echinocorys* and *Micraster*. The *Conulus* tend to occur in concentrations with the tests in juxtaposition, notably near the base of the cliff at White Ness. It is also a bed characterized by sporadic belemnites (*Actinocamax verus* and *Gonioteuthis* sp.: either *G. westfalica* or *G. westfalicagranulata* (Stolley)) and the large rhynchonellid brachiopod *Cretirhynchia plicatilis* (J. Sowerby), which appears to be restricted to this level.

There is a significant increase in benthic foraminiferal diversity a short distance below the base of the *Uintacrinus* Zone in the Thanet section, marked by the entry of *Reussella szajnochae praecursor* de Klasz and Knipscheer immediately followed by that of *Gavelinella stelligera* (Marie) and *G. cristata* (Goel). The last occurrence of *Stensioeina granulata polonica* is just below the entry of *Uintacrinus.* The first occurrence of *Stensioeina granulata perfecta* Koch, marking the base of the *perfecta* Biozone (Bailey *et al.*, 1983), is near the base of the *socialis* Zone. The inception of *Bolivinoides strigillatus* (Chapman), marking the base of the UKB15 zone, is at or close to the last occurrence of *Uintacrinus,* based on a revision downwards of this latter datum compared with that previously published by Bailey *et al.* (1983, fig. 2). All of these bio-events, which were first recognized in the Thanet cliffs, are critical to long-range correlation within the UK and with successions in northern Europe, as well as offshore, in the southern North Sea Basin (cf. Hart *et al.*, 1989, fig. 8.9).

The *Uintacrinus socialis* Zone contains sporadic accumulations of calyx plates and arm ossicles of the zonal index crinoid, but the commonest fossil is the belemnite *Actinocamax verus*. Inland sections, such as at Sayer's Woodyard, Ramsgate, have yielded the distinctive flat-topped form of *Echinocorys* that characterizes this zone but these, partly as a result of the activities of fossil collectors, are difficult to find in the coast sections. Gale and Smith (1982, fig. 1) recorded an acme-ocurrence of the thin-tested echinoid *Hagenowia anterior* Ernst and Schulz in the middle of the zone. The wave-cut platform in the beds below the Bedwell Line contains specimens of the giant ammonite *Parapuzosia* (*P.*) *leptophylla* (Sharpe) and belemnites (*Actinocamax verus* and sporadic *Gonioteuthis*; see Bailey *et al.*, 1983). Bedwell (1874) drew attention to the fact that the giant ammonites were concentrated in several levels of abundance below a datum flint (the Bedwell Line), notably near the top, and just above the base, of the interval now placed in the *socialis* Zone. Several specimens of the rare belemnite *Belemnellocamax grossouvrei* collected loose from the wave-cut platform are inferred to have come from the top beds of the *Uintacrinus socialis* Zone. The upper limit of *Uintacrinus* is 3.5 m beneath the Bedwell Line. There is a small (1.2 m) gap here between the last *Uintacrinus* and the first *Marsupites*. Unfortunately, construction of a sea wall around Foreness Point, and in Palm Bay, has partly obscured some of the best sections of the boundary between the two crinoid zones.

The Bedwell Line (Figure 3.126) is associated with another fossil turnover, the entry of the zonal index crinoid *Marsupites*, at a minor indurated surface, 2.3 m below the flint, followed by the occurrence of abundant specimens of the distinctively shaped echinoid *Echinocorys scutata elevata* (resembling an old-fashioned policeman's helmet in cross-section) in a sponge bed ('Palm Bay Echinoid Band' of Robinson (1986)), immediately below the flint. There is a second acme-occurrence of *Hagenowia anterior* just above the Bedwell Line. The *Marsupites* calyx plates exhibit the same successive changes in ornament from small smooth plates, through large strongly ornamented plates, to small ornamented plates, that are seen in the expanded successions of the zone elsewhere, for example in the air-weathered faces of the Black Rock path, east of Brighton (**Newhaven to Brighton** GCR site, this volume). The two distinct types of calyx plates, i.e. the lower form, with a simple fold in each edge of the plate; and the higher form with crinkled edges, can also be recognized here. The acme-ocurrence of strongly ornamented calyx plates in Thanet is associated with relatively common specimens of the belemnite *Gonioteuthis granulata* (Blainville). This association is seen particularly well in the air-weathered section above the sea wall at Foreness Point.

Campanian Stage

The youngest beds of chalk are exposed beside the access path to the sea wall at Foreness Point. The base of the stage is marked by the last occurrence of *Marsupites* and the first occurrence, within the *Gonioteuthis* evolutionary lineage, of the belemnite *G. granulataquadrata* (Stolley) (Hancock and Gale, 1996). The extinction level of *Marsupites* in the marl-free Margate Chalk Member of Thanet occurs in an inoceramid bivalve shell-debris bed beneath the lower of two conspicuous flints that are presumed to correlate with the two Friars Bay Flints of the marl-rich Newhaven Chalk in Sussex at Seaford Head, Seaford, and Friars Bay, Newhaven; at these latter localities the top of this debris band is coincident with Friars Bay Marl 1.

The arm ossicles and the distinctive fluted calyx plates of the basal Campanian zonal index crinoid, *Uintacrinus anglicus* Rasmussen, occur here rarely between Friars Bay Flints 1 and 2 (Figure 3.126; Mortimore, 1997, fig. 66), constituting the basal Lower Campanian *Uintacrinus anglicus* Zone. Better specimens (British Geological Survey collections) were found in Chalk excavated from graves at St Peters Church, Ramsgate. This crinoid has a short total range in the Southern Province and also (Mitchell, 1995b) in the Northern Province in the **Flamborough Head** GCR site. The correlation at this level between the Kent and Sussex successions is supported by the abundance of *Echinocorys scutata tectiformis* Griffith and Brydone above Friars Bay Flint 1 at Foreness Point, and at a similar level in Sussex. The successive entry of the benthic foraminifer *Bolivinoides culverensis* Barr, and the last occurrence of the planktonic foraminifer *Globigerinelloides rowei* (Barr), two events that are critical to long-range correlation (Bailey *et al.*, 1983, fig. 2; Hart *et al.*, 1989, fig. 8.9), are at or just above the upper limit of *Uintacrinus anglicus*, in the higher part of the interval between the Friars Bay Flints.

The highest Chalk in the Isle of Thanet and the North Downs is in the basal beds of the *Offaster pilula* Zone. Up to 6 m of *Offaster pilula* Zone chalk, overlain by the Thanet Beds Formation, was proved in the partially backfilled pit that formerly exposed the *Marsupites testudinarius* Zone, north of St Peter's Church, Broadstairs (TA 384 686). The discovery of the zonal index fossil here proved, as many had suspected, that *O. pilula* Zone chalk does actually occur on Thanet.

Interpretation

The north-east Kent coastal sections expose the highest chalk in the North Downs in the Santonian and the very base of the Campanian stages, divided into two lithological units, the Seaford Chalk Formation and the overlying Margate Chalk Member. By contrast with the same levels in the coeval Newhaven Chalk Formation at Seaford Head (**Cuckmere to Seaford** GCR site) and Black Rock (**Newhaven to Brighton** GCR site), there is a conspicuous absence of marl seams in the Margate Chalk, and no, or reduced numbers, of flint bands. Those flint bands that do occur are, therefore, more conspicuous. A similarity between the two areas lies in the fact that the equivalent in Thanet of the Friars Bay Flints of Sussex are likewise well-developed, rounded flints. These contrast with the flints below, which are peppered with the trace fossil *Chondrites*. Flint *form* is surprisingly consistent in the basin, an observation that contradicts the views expressed by Whitaker (1872) and Rowe (1900–1908), who considered flints to be only of extremely local use in correlation. In one respect, however, the loss of some flint bands on Thanet has had the advantage of emphasizing the remaining beds. This is true of three key marker flint beds: Bedwell's Columnar Flint Band, Whitaker's 3-inch Flint Band and the Bedwell Line, which stand out in Kent, but form two of several very conspicuous bands in Sussex and elsewhere.

Barrois' Sponge Bed (or its correlative) is a hardground that is a key marker bed throughout much of the Southern Province. However, it is developed only over structural highs, and is absent from the intervening, thicker successions. This implies the differentiation of the depositional area into a submarine 'swell and basin' topography at this time. It represents a lithified erosion surface located at various levels in the *Micraster coranguinum* Zone, depending on the extent of downcutting. It is relatively weakly indurated in Thanet, and not represented at all at Canterbury. Barrois' Sponge Bed forms the intensely indurated, glauconitized and phosphatized floor of the Chislehurst caves in south London, and is particularly well-developed at the West Clandon Quarry, east of

Guildford (TQ 038 508) (where it was called the 'Clandon Hardground' by Robinson, 1986). It is inferred to equate with the Taplow Lower Hardground at the **South Lodge Pit**, Taplow; with the Whitway Rock (Hawkins, 1918) of the Kingsclere area; with the Boxford Paired Hardgrounds of the **Boxford Chalk Pit**, where it rests on a level in the (Middle Coniacian) beds with *Volviceramus involutus* (J. de C. Sowerby); and with the hardground in the North Barn Pit near Dorchester, Dorset.

There are several biostratigraphical differences between Thanet and Sussex in the distribution and/or abundance of the belemnites, brachiopods and crinoids (Mortimore, 1979, 1986a, 1997). The Chalk of Thanet has long been famous for the rich diversity of fossils contained in soft, white chalk, enhancing the quality of preservation and ease of extraction. Echinoids, particularly *Micraster* (Rowe, 1899, 1900), *Echinocorys* and *Conulus*, as well as the fragile *Hagenowia* (Gale and Smith, 1982) and cidarids are common in the higher (Santonian) part of the *M. coranguinum* Zone. In the *Uintacrinus socialis* and *Marsupites testudinarius* zones belemnites are much commoner than in Sussex, where they are exceptionally rare. In contrast, the rhynchonellid brachiopod *Cretirhynchia exsculpta* Pettitt, which is common in the crinoid zones in Sussex, has not been found in Kent.

The relative abundance and diversity of belemnites, compared with their rarity in the more basinal Sussex successions, has been critical for correlation of this part of the Chalk with the standard belemnite zonal scheme for the European Boreal Cretaceous (e.g. Christensen, 1997). The soft chalks also contain more microbrachiopods (Johansen and Surlyk, 1990). Detailed study of the microfossil and nannofossil biostratigraphy (see **Cuckmere to Seaford** GCR site report, this volume) has shown how the ranges of many index species are condensed in Thanet compared to Sussex, implying significant loss of section. It is for this reason that the Seaford Head section, which is more complete in terms of both litho- and biostratigraphy than the Thanet section, has been selected as a candidate Global boundary Stratotype Section and Point (GSSP) for the Santonian Stage.

Despite the missing stratigraphy on Thanet compared to the more basinal Sussex sections, this coastline provides a standard for the successions developed over the Anglo-Brabant Massif in the Transitional Province. Margate Chalk with little flint is present in Essex and Suffolk, and has been proved in cored boreholes at Layer de la Hay and Ipswich. Flinty equivalents of the Margate Chalk Member come in westwards, so that the same levels west of the Medway at Pinden, Pepperbox Hill and in pits around Croydon, Surrey and on the Leatherhead–Dorking sections of the M25 are packed with numerous good flint seams. These lateral changes in lithology, which have not been fully appreciated before, aid in the interpretation of Santonian–Campanian palaeogeography.

Conclusions

The Isle of Thanet is the type locality for three of the most conspicuous marker beds in the White Chalk Subgroup of the Southern Province: Bedwell's Columnar Flint Band, Whitaker's 3-inch Flint Band and the Barrois' Sponge Bed. It is also the type area for the Margate Chalk Member of the Newhaven Chalk Formation. Thanet is famous for the excellent preservation in very soft chalks of fossil echinoderms and (towards the higher part of the succession) for the relative abundance of giant ammonites. Compared with other sites in the Southern Province, there is also an unusual abundance of belemnites in the Santonian succession, including several records of *Belemnellocamax grossouvrei*, which is extremely rare elsewhere in the UK. The belemnites and inoceramid bivalves from here enable correlation between the traditional macrofossil zones and the standard northern European zones. It is a key section for the microfossil (foraminiferal) zonal scheme of the Santonian Stage and it has provided one of the standard stable isotope curves.