NEWHAVEN TO BRIGHTON

OS Grid Reference: TQ449000–TQ334033

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 (Figures3.84 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 distribution of fracturing in the Chalk is particularly well shown in the cliffs between Newhaven and Old Nore Point, and on either side of Portobello.

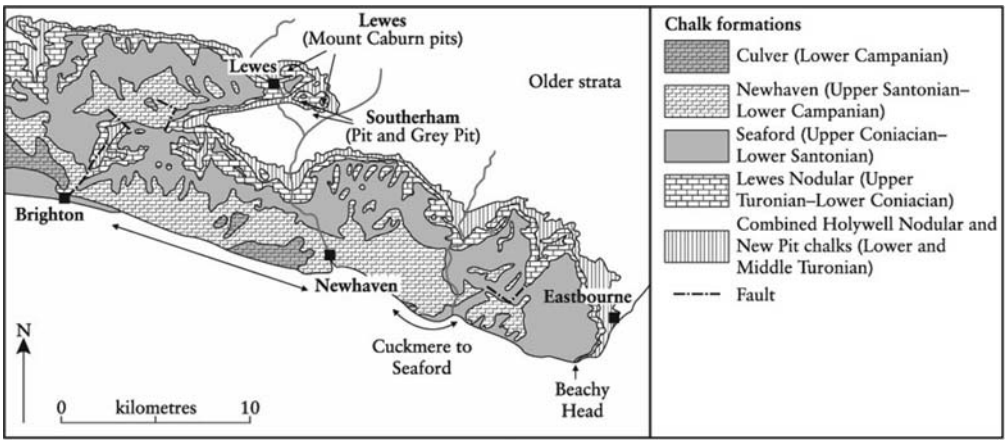

Figure 3.84: Location of GCR and other sites described in the text in the East Sussex Chalk Downs.

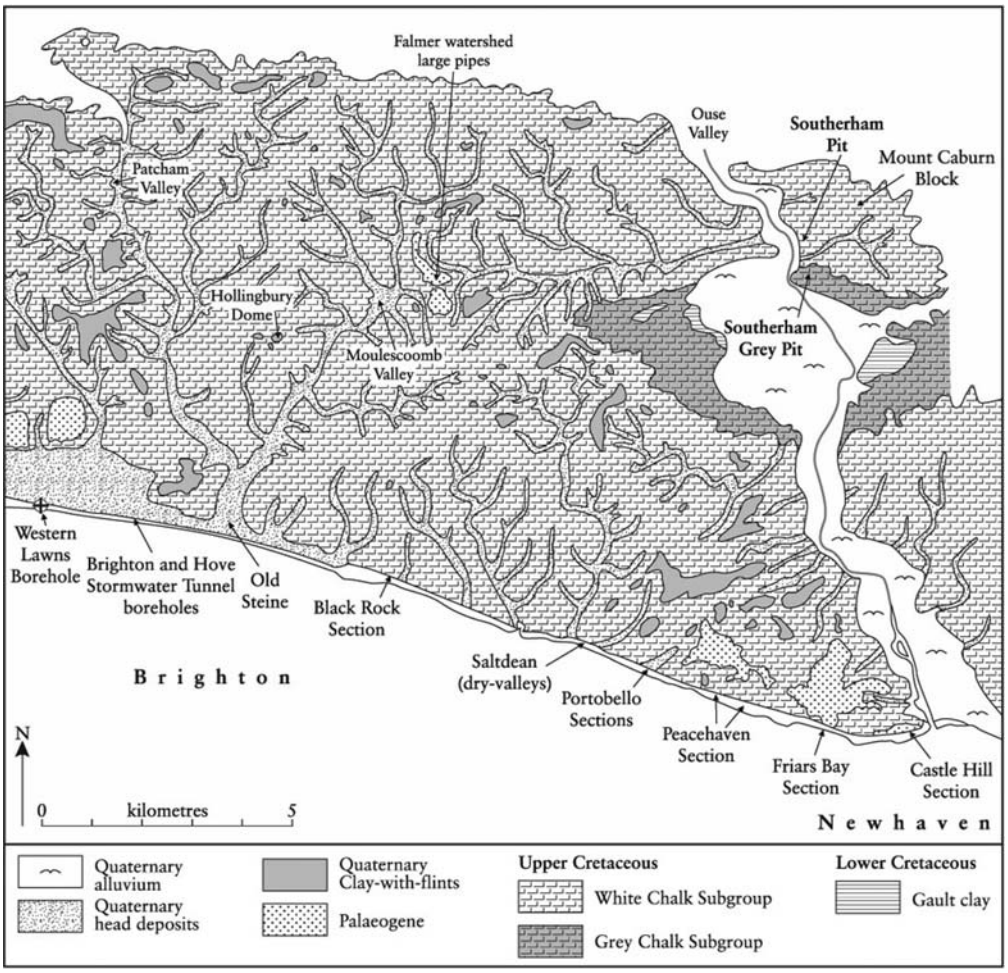

Figure 3.85: Geology of the Brighton Chalk Block showing the Chalk outcrop and the location of the Newhaven to Brighton GCR site and related local sections. (Modified from BGS 1:50,000 Series Geological Maps, Sheets 318/333 and 319.)

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 (Figure3.88), 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:

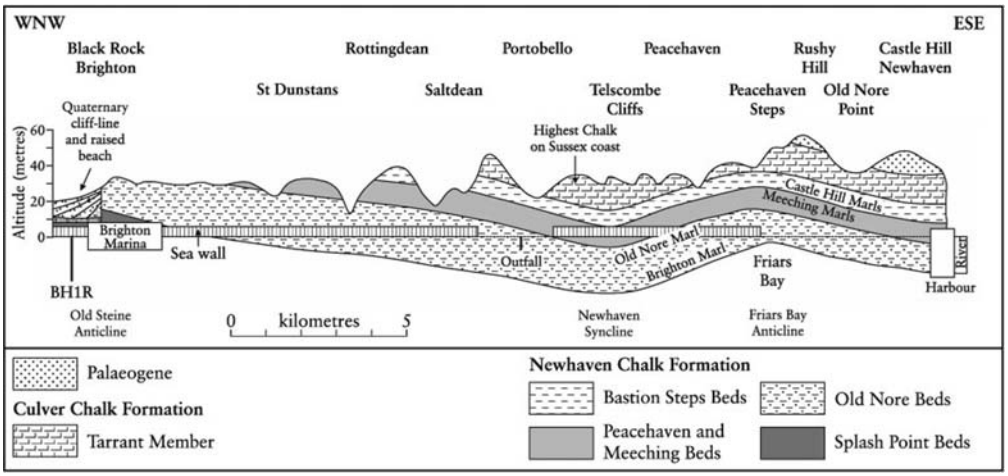

Figure 3.88: Schematic geological section of the Newhaven to Brighton cliffs GCR site showing the length of exposure in each of the main divisions of the Newhaven Chalk Formation and the length of section already covered by sea walls. Note the change from thinner beds at Friars Bay to thicker beds at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

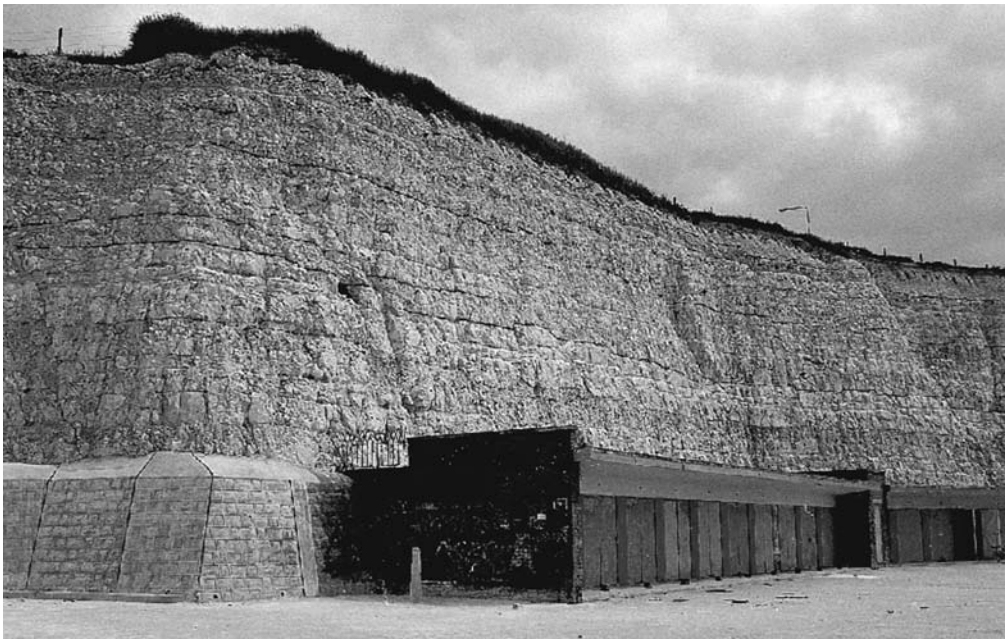

Figure 3.90: Saltdean Cliffs exposing the Saltdean to Old Nore marls in the Newhaven Chalk Formation in the Lower Campanian Echinocorys scutata depressula Subzone. Note the characteristic sheet-flints in this interval, which can be traced as a broad unit across southern England. (Photomosaic: R.N. Mortimore.)

i The relatively short lengths of cliff from Newhaven (Figures3.85–3.87) to the east end of Peacehaven (exposing the lowest beds on the coast in the Upper Santonian*Marsupites testudinarius* Zone).

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).

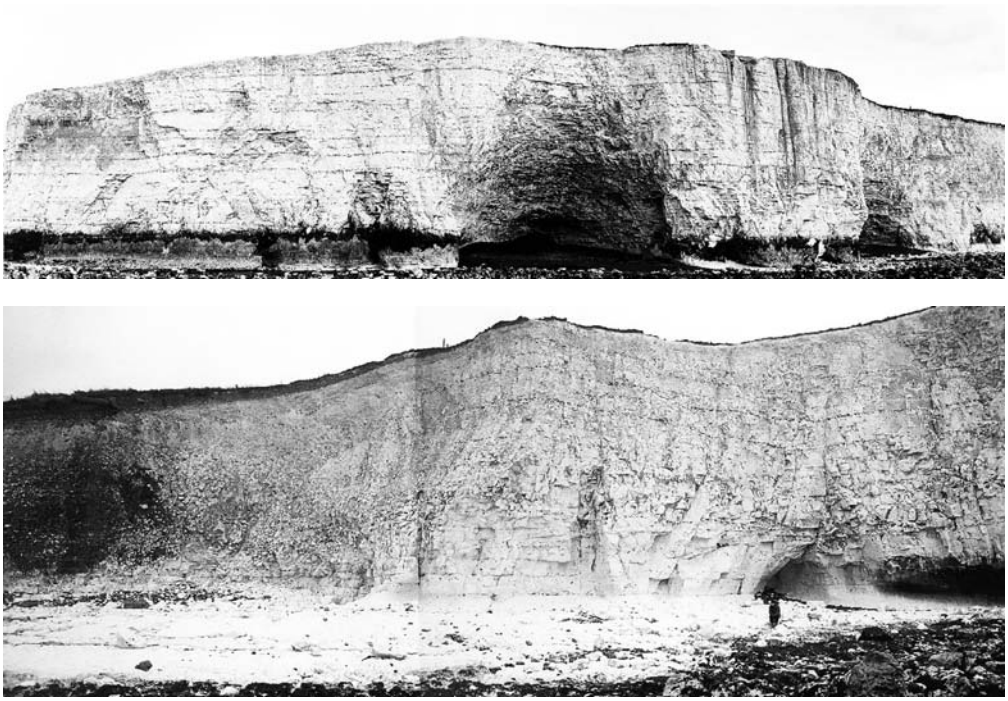

Figure 3.91: The Newhaven Chalk Formation–Culver Chalk Formation boundary at Telscombe Cliffs in the Newhaven to Brighton GCR site. (a) The youngest Chalk preserved on the Sussex coast, at Telscombe Cliffs. (b) The best section for the band of abundant Offaster pilula and large O.p. planatus in England.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

iii The stretch of cliff from the west side of Portobello to Saltdean (Figures3.85 and 3.88, Figure 3.95, p. 221).

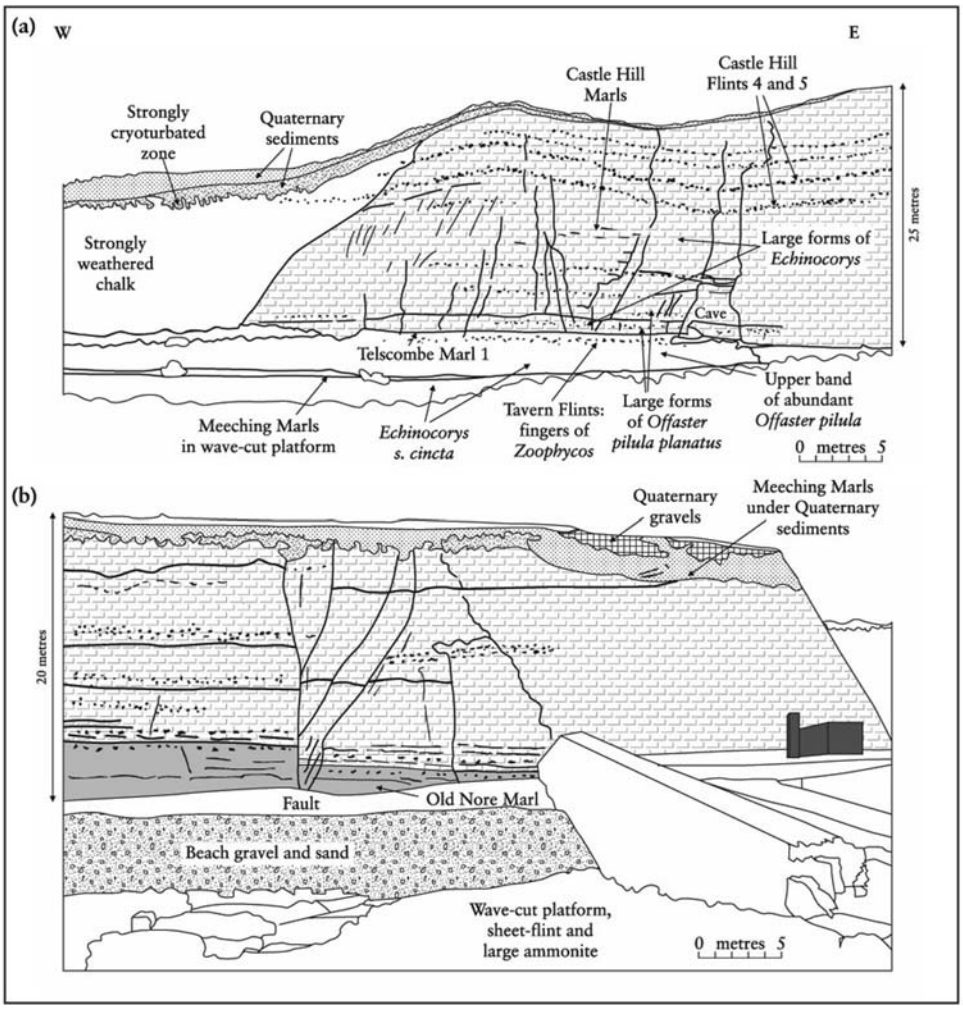

Figure 3.95: The Portobello locality in the Brighton and Newhaven Cliffs GCR site. (a) The Bastion Steps Beds and basal Culver Chalk Formation exposed at the southeastern end of the Portobello locality. (b) The chalk exposed at the north-western end of the Portobello locality.

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 (Figure3.88). 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 (Figures3.85 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 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 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).

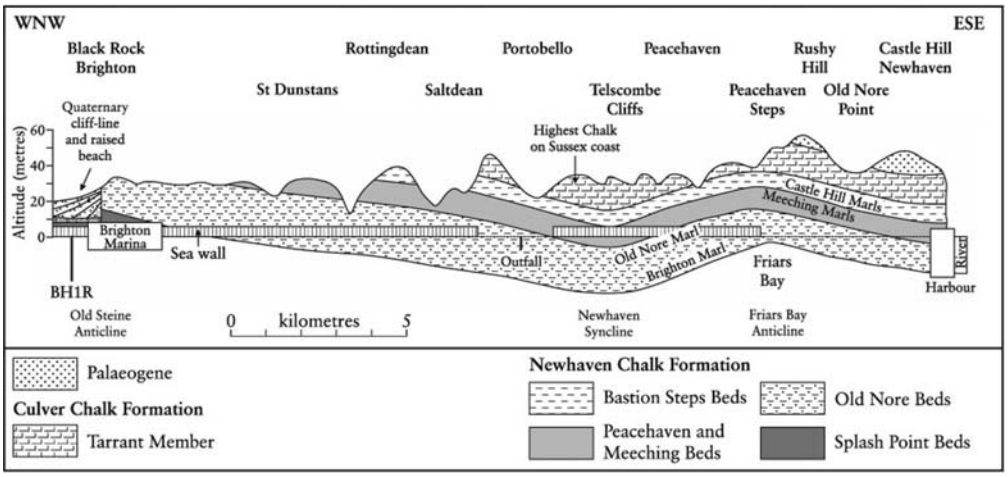

Figure 3.88: Schematic geological section of the Newhaven to Brighton cliffs GCR site showing the length of exposure in each of the main divisions of the Newhaven Chalk Formation and the length of section already covered by sea walls. Note the change from thinner beds at Friars Bay to thicker beds at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

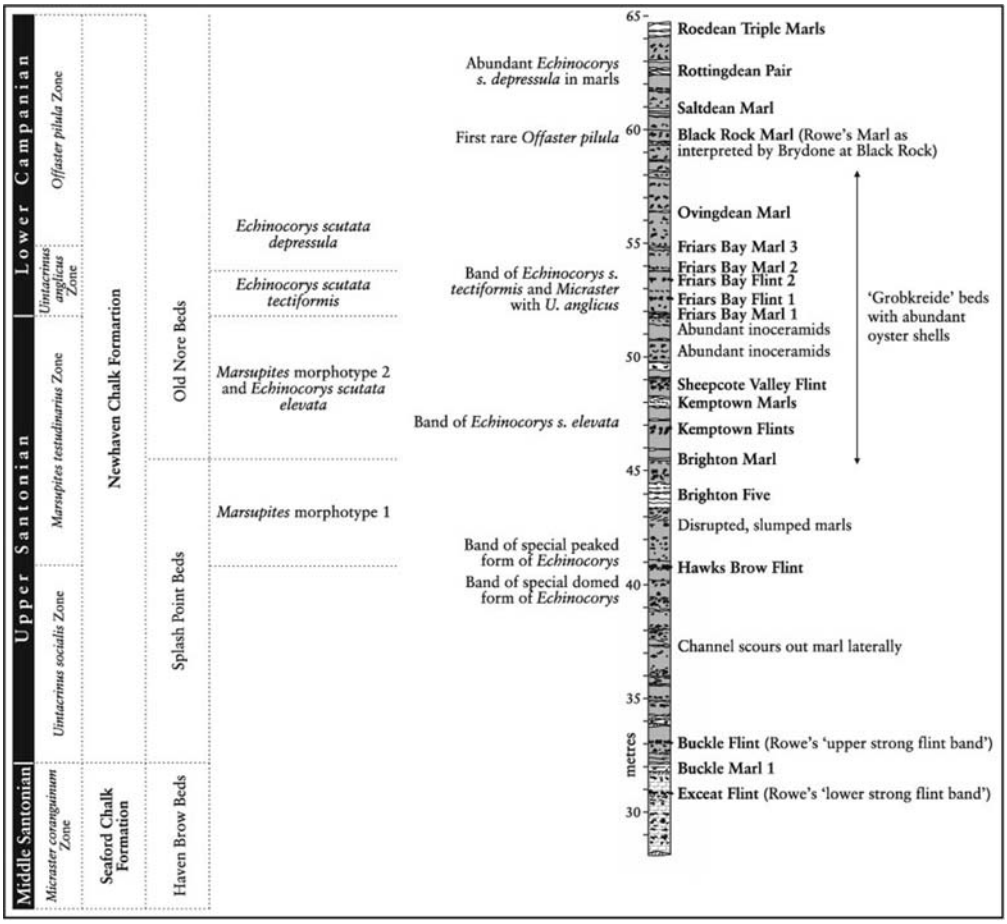

Figure 3.101: Seaford Head: the lower half of the Newhaven Chalk Formation, including the Santonian–Campanian boundary.

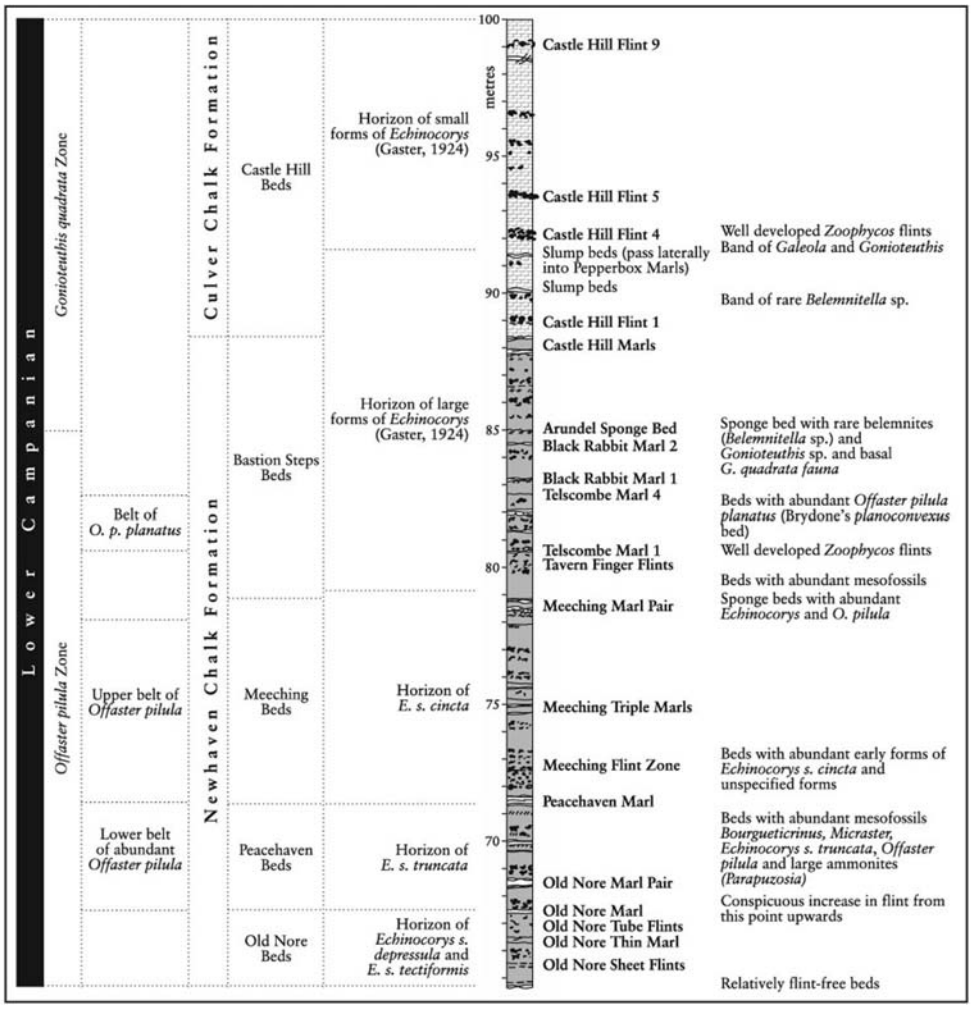

Figure 3.102: Seaford Head: the youngest Chalk from the Old Nore Beds, Newhaven Chalk Formation, to the Castle Hill Beds, Culver Chalk Formation (Lower Campanian).

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 (Figure3.88). 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.

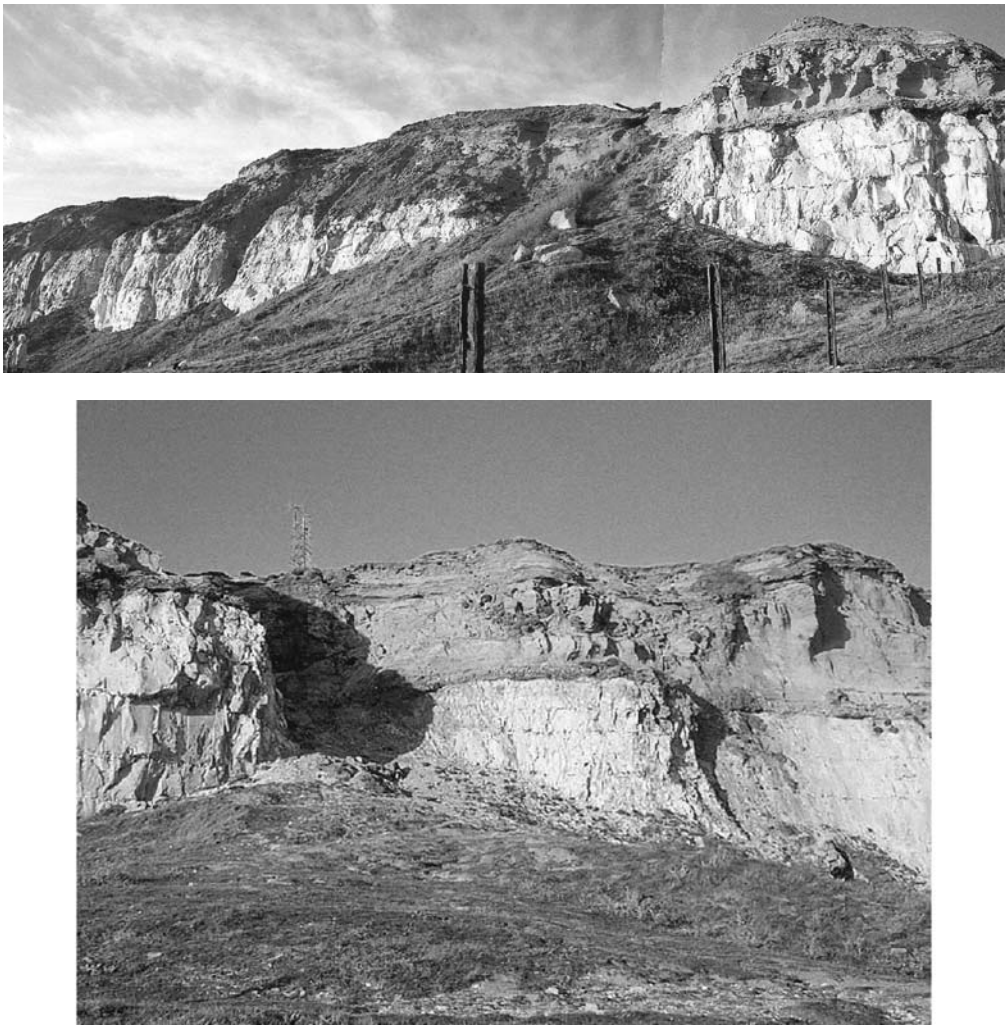

Figure 3.86: Castle Hill, Newhaen, at the eastern end of the Newhaven to Brighton GCR Site illustrating the sub-Palaeogene unconformity (compare the flint stratigraphy with Figure 3.92). (Photomosaic: R.N. Mortimore.)

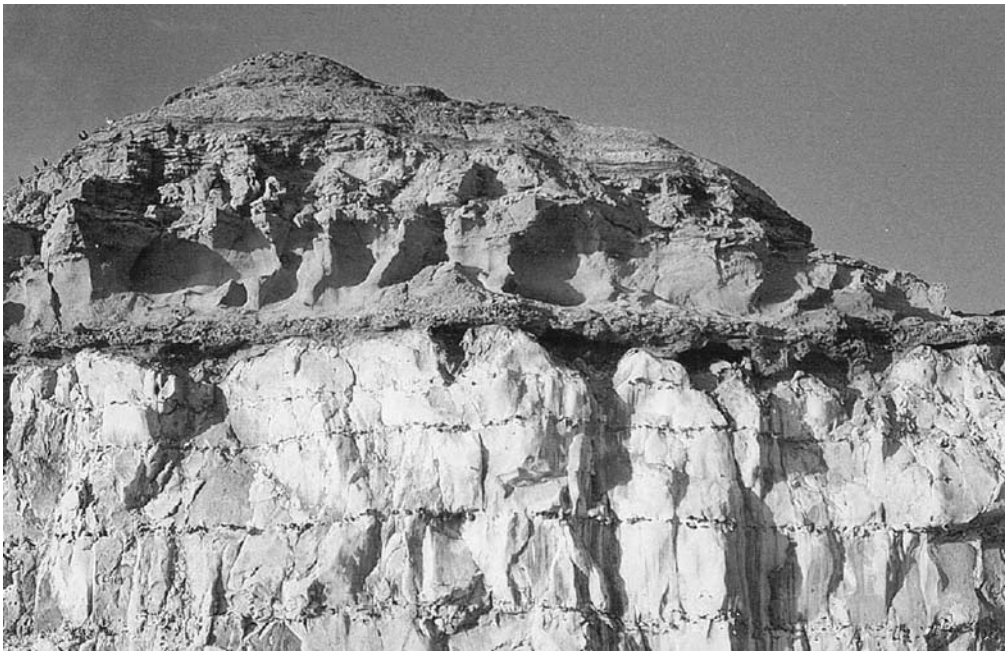

Figure 3.87: The cliffs beneath Castle Hill, Newhaven, with Palaeogene sediments resting unconformably on the Upper Cretacous Chalk (Culver Chalk Formation; Lower Campanian G. quadrata Zone). (CHF4, CHF5 = Castle Hill Flints 4 and 5.) (Photo: R.N. Mortimore.)

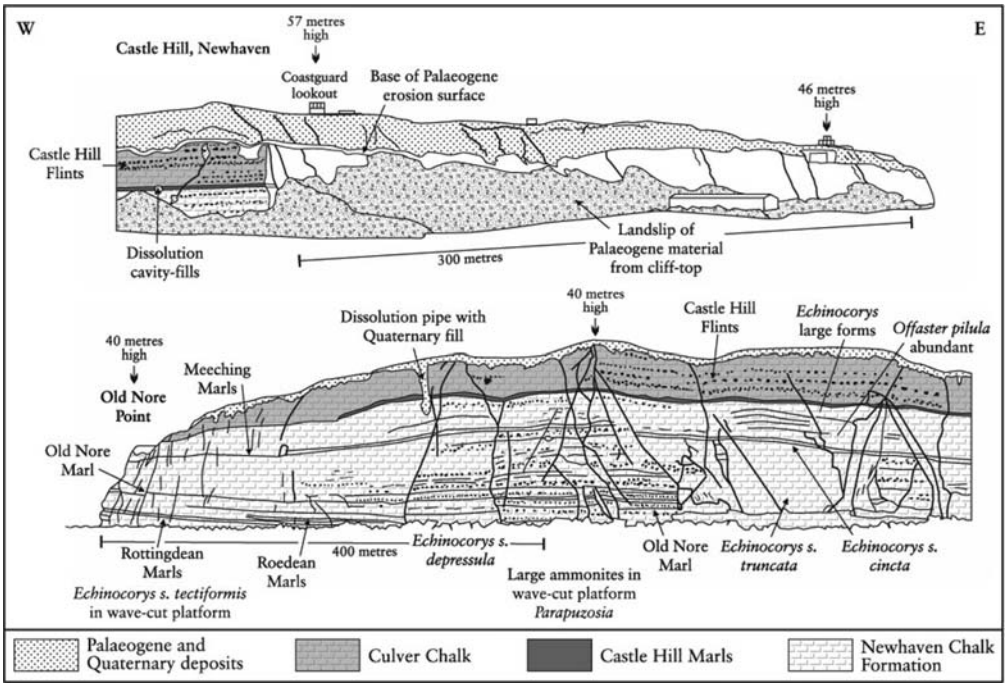

Figure 3.92: The Chalk cliffs on the west side of Newhaven Harbour showing the key litho- and biostratigraphical features. (After Mortimore, 1997.)

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 (Figure3.92) 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 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 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.

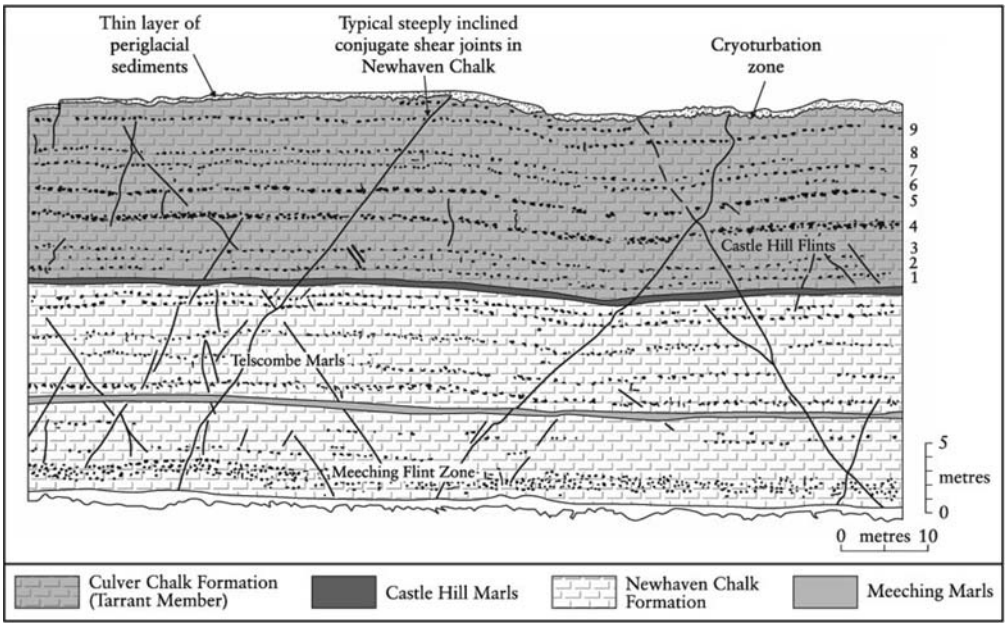

Figure 3.93: The Newhaven and Culver Chalk succession exposed in the cliffs at Bastion Steps, Peacehaven. The numbers 1–9 refer to the Castle Hill Flints.

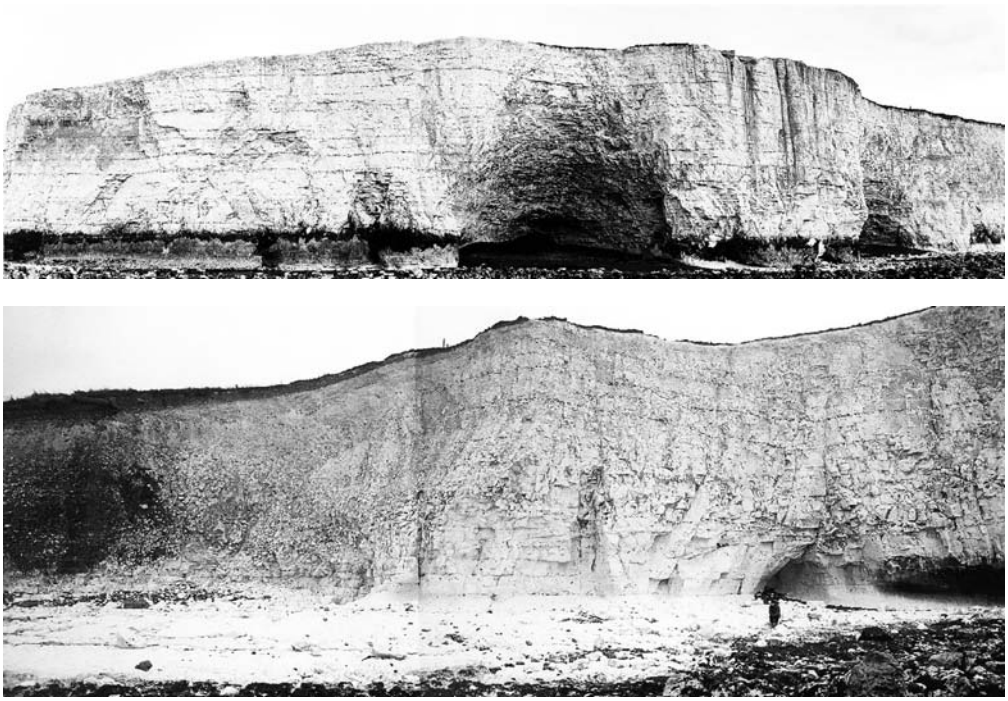

Figure 3.91: The Newhaven Chalk Formation–Culver Chalk Formation boundary at Telscombe Cliffs in the Newhaven to Brighton GCR site. (a) The youngest Chalk preserved on the Sussex coast, at Telscombe Cliffs. (b) The best section for the band of abundant Offaster pilula and large O.p. planatus in England.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

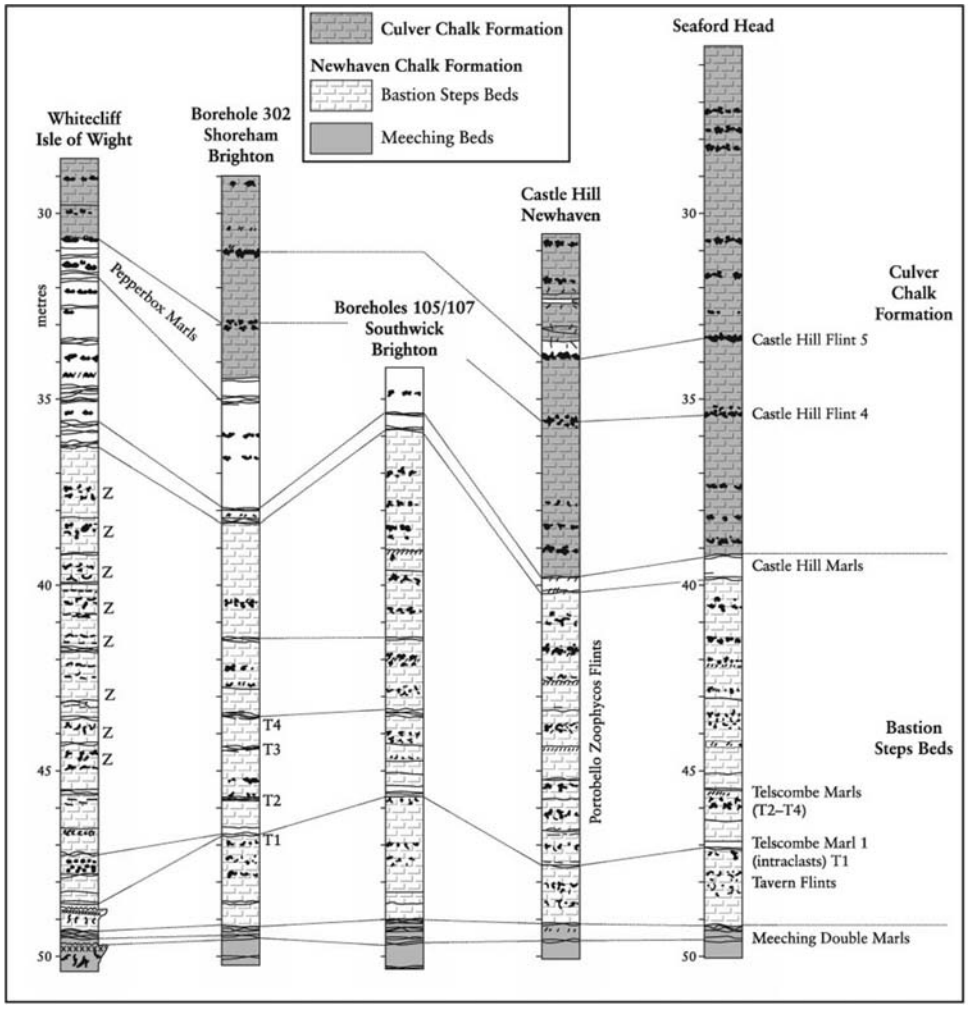

Figure 3.94: Correlation of the upper beds of the Newhaven Chalk Formation from Newhaven to adjacent areas and to the Isle of Wight. This shows the diachronous nature of the Culver Chalk Formation. (z = Zoophycos flints.) (After Mortimore and Pomerol 1997, fig.10.)

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 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.

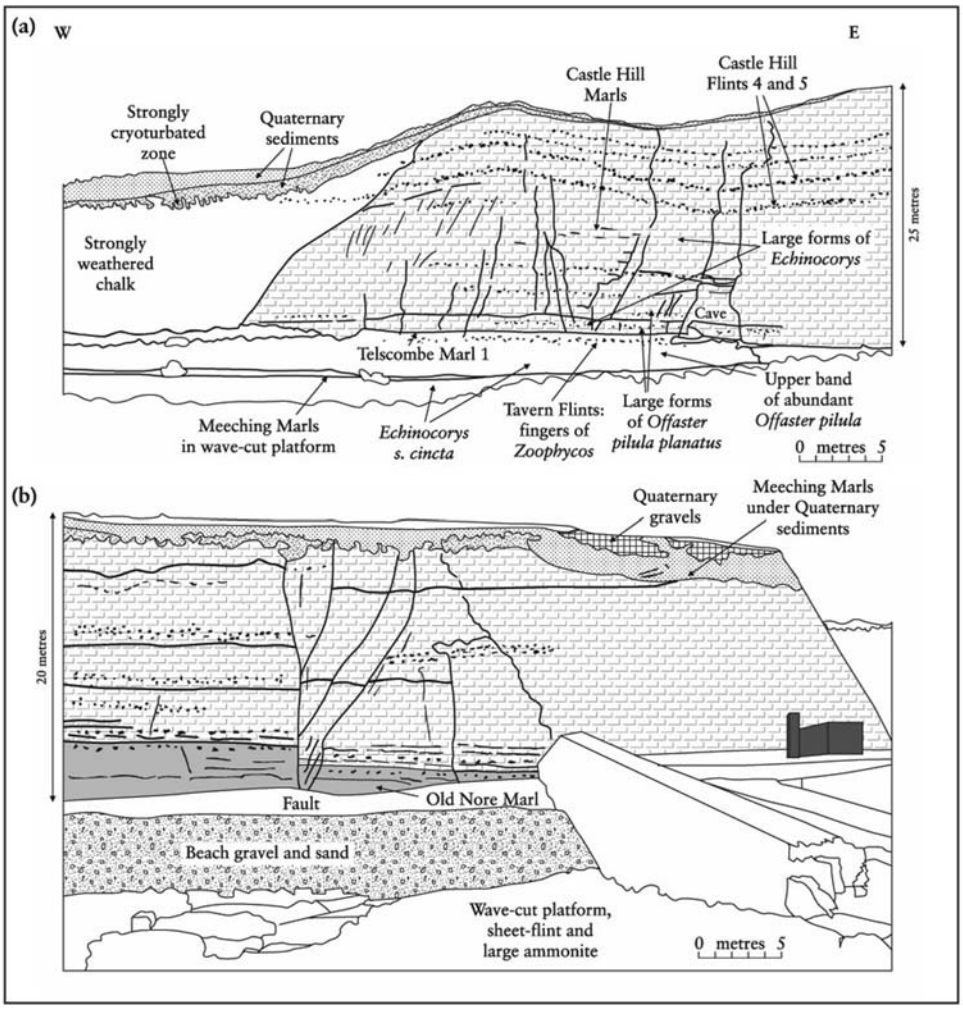

Figure 3.95: The Portobello locality in the Brighton and Newhaven Cliffs GCR site. (a) The Bastion Steps Beds and basal Culver Chalk Formation exposed at the southeastern end of the Portobello locality. (b) The chalk exposed at the north-western end of the Portobello locality.

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 (60º – 70º), 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.

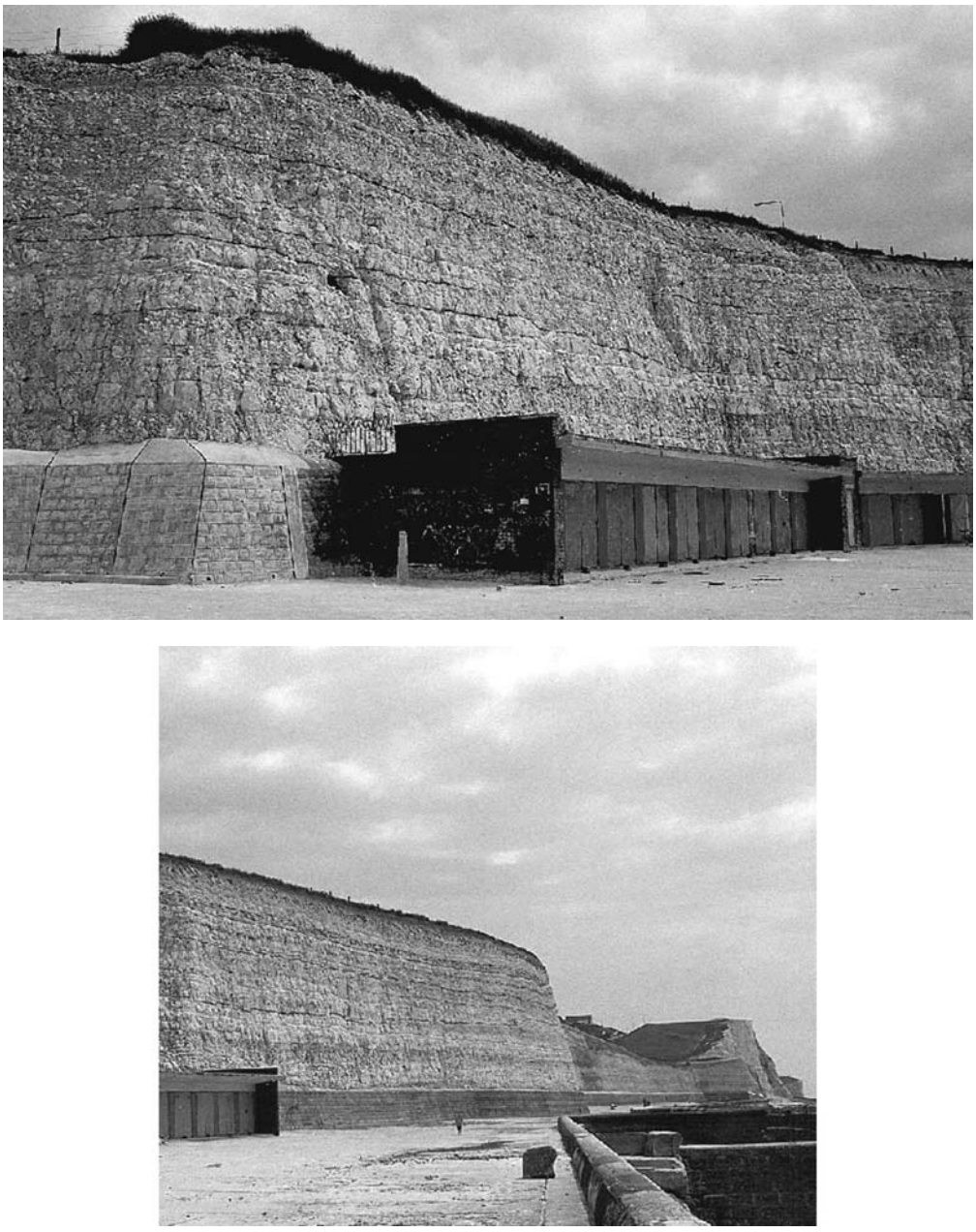

Figure 3.90: Saltdean Cliffs exposing the Saltdean to Old Nore marls in the Newhaven Chalk Formation in the Lower Campanian Echinocorys scutata depressula Subzone. Note the characteristic sheet-flints in this interval, which can be traced as a broad unit across southern England. (Photomosaic: R.N. Mortimore.)

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

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 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 (60º – 70º), 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 granulataquadrata* 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.

Reference list

Bailey, H.W., Gale, A.S., Mortimore, R.N., Swiecicki, A.and Wood, C.J. (1983) The Coniacian–Maastrichtian Stages in the United Kingdom, with particular reference to southern England. Newsletters on Stratigraphy, **12**, 19–42.

Barchi, P. (1995) Géochimie et magnetostratigraphie du campanien de l'Europe ?nord-ouest. Thèse de Doctorat de l'Université Pierre et Marie Curie (Paris IV).

Barrois, C. (1876) Recherches sur le terrain Crétacé Supérieur de l'Angleterre et de l'Irlande, Mémoire de la Société Géologique du Nord, 232 pp.

Bristow, C.R., Mortimore, R.N. and Wood, C.J. (1997) Lithostratigraphy for mapping the Chalk of southern England. Proceedings of the Geologists' Association,**108**, 293–315.

Brydone, R.M. (1912) The Stratigraphy of the Chalk of Hants, Dulau and Co. Ltd., London, 108 pp.

Brydone, R.M. (1914) The Zone of Offaster pilula in the south English Chalk. Parts I–IV. Geological Magazine, New Series, Decade VI, **1**, 359–69, 405–11, 449–57, 509–13.

Brydone, R.M. (1915) The Marsupites Chalk of Brighton. Geological Magazine, New Series, Decade VI, **2**, 12–5.

Ernst, G. (1963) Stratigraphische und gesteinschemische Untersuchungen im Santon und Campan von Lägerdorf (SW-Holstein). Mitteilungen aus dem Geologischen Staatsinstitut in Hamburg, **32**, 71–127.

Ernst, G., Schmid, F. and Seibertz, E. (1983) Event-Stratigraphie im Cenoman und Turon von NW-Deutschland. Zitteliana, **10**, 531–54.

Gaster, C.T.A. (1924) The Chalk of the Worthing District of Sussex. Proceedings of the Geologists' Association, **35**, 89–110.

Gaster, C.T.A. (1928) Excursion to Newhaven and Brighton. Proceedings of the Geologists' Association, **39**, 198–201.

Gaster, C.T.A. (1941) The Chalk Zones of Offaster pilula and Actinocamax quadratus. Proceedings of the Geologists' Association,**52**, 210–15.

Griffith, C. and Brydone, R.M. (1911) The Zones of the Chalk in Hants, Dulau and Co. Ltd, London, 31 pp.

Hancock, J.M. and Gale, A.S. (1996) The Campanian Stage. Bulletin de l´Institut Royal des Sciences Naturelles de Belgique, Sciences de la Terre,**66** (supp.), pp. 103–9.

Jukes-Browne, A.J. and Hill, W. (1904) The Cretaceous Rocks of Britain, volume 3: The Upper Chalk of England, Memoir of the Geological Survey of the United Kingdom, HMSO, London, 566 pp.

Mortimore, R.N. (1983). The stratigraphy and sedimentation of the Turonian–Campanian in the Southern Province of England. Zitteliana, **10**, 27–41.

Mortimore, R.N. (1986a) Stratigraphy of the Upper Cretaceous White Chalk of Sussex. Proceedings of the Geologists' Association, **97**, 97–139.

Mortimore, R.N. (1986b) Controls on Upper Cretaceous sedimentation in the South Downs with particular reference to flint distribution. In The Scientific Study of Flint and Chert, (eds G. de G. Sieveking and M.B. Hart), Cambridge University Press, Cambridge, pp. 21–42.

Mortimore, R.N. (1987) Upper Cretaceous White Chalk in the North and South Downs, England: a correlation. Proceedings of the Geologists' Association,**98**, 77–86.

Mortimore, R.N. (1997) The Chalk of Sussex and Kent, Geologists' Association Field Guide No. 57, Geologists' Association, London, 193 pp.

Mortimore, R.N. and Pomerol, B. (1987) Correlation of the Upper Cretaceous White Chalk (Turonian to Campanian) in the Anglo-Paris Basin. Proceedings of the Geologists' Association, **98**, 97–143.

Mortimore, R.N. and Pomerol, B. (1991a) Upper Cretaceous tectonic disruptions in a placid Chalk sequence in the Anglo-Paris Basin. Journal of the Geological Society, London,**148**, 391–404.

Mortimore, R.N. and Pomerol, B. (1991b) Stratigraphy and Eustatic Implications of Trace Fossil Events in the Upper Cretaceous Chalk of Northern Europe. Palaios, **6**, 216–31.

Mortimore, R.N. and Pomerol, B. (1997) Upper Cretaceous tectonic phases and end Cretaceous inversion in the Chalk of the Anglo-Paris Basin. Proceedings of the Geologists' Association, **108**, 231–55.

Mortimore, R.N., Pomerol, B. and J. Lamont-Black. (1996) Chapter 28. Examples of structural and sedimentological controls on chalk engineering behaviour. In. Engineering Geology of the

Channel Tunnel, (eds C.S. Harris, M.B. Hart, P.M. Varley and C.D. Warren), Thomas Telford, London, pp. 436–43.

Niebuhr, B. (1995) Fazies-Differenzierungen und ihre Steuerungsfaktoren in der höheren Oberkreide von S-Niedersachsen/Sachsen-Anhalt (N-Deutschland). Berliner geowissenschaftliche Abhandlungen, Reihe A, **174**, 1–131.

Rowe, A.W. (1900) The Zones of the White Chalk of the English Coast. I. Kent and Sussex. Proceedings of the Geologists' Association, **16**, 289–368.

White, H.J.O. (1924) The Geology of the Country near Brighton and Worthing, Memoir of the Geological Survey of Great Britain (England and Wales) New Series, Sheets 318 and 333, HMSO, London, 114 pp.

Wood, C.J. and Mortimore, R.N. (1988) Chalk biostratigraphy. In Geology of the Country around Brighton and Worthing, (eds B.Young and R.D. Lake), Memoir of the British Geological Survey (England and Wales) Sheets 318 and 333, HMSO, London, pp. 58–64.

Wray, D.S. (1996) 8. Rare-earth elements of Campanian marls and white chalks. In New results on biostratigraphy, palaeomagnetism, geochemistry and correlation from the standard section for the Upper Cretaceous white chalk of northern Germany (Lägerdorf–Kronsmoor–Hemmoor), (coord. J. Schönfeld and M.-G. Schulz). Mitteilungen aus dem Geologisch-Paläontologischen Institut der Universität Hamburg, **77**, pp. 563–8.