SOUTHERHAM GREY PIT

OS Grid Reference: TQ427090

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.

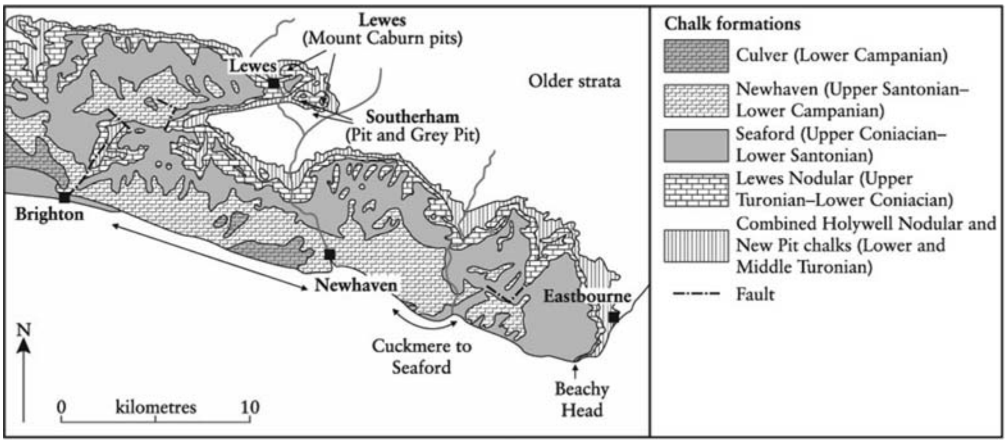

Figure 3.84: Location of GCR and other sites described in the text in the East Sussex Chalk Downs.

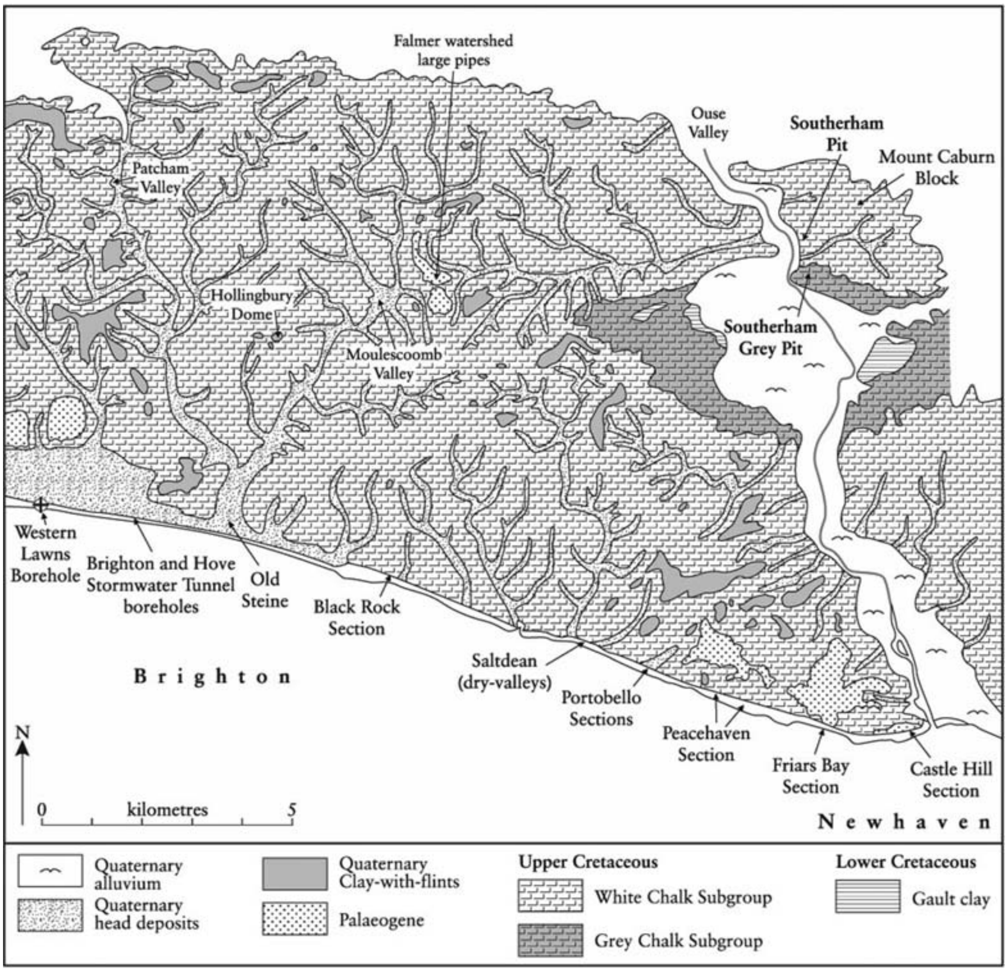

Figure 3.85: Geology of the Brighton Chalk Block showing the Chalk outcrop and the location of the Newhaven to Brighton GCR site and related local sections. (Modified from BGS 1:50,000 Series Geological Maps, Sheets 318/333 and 319.)

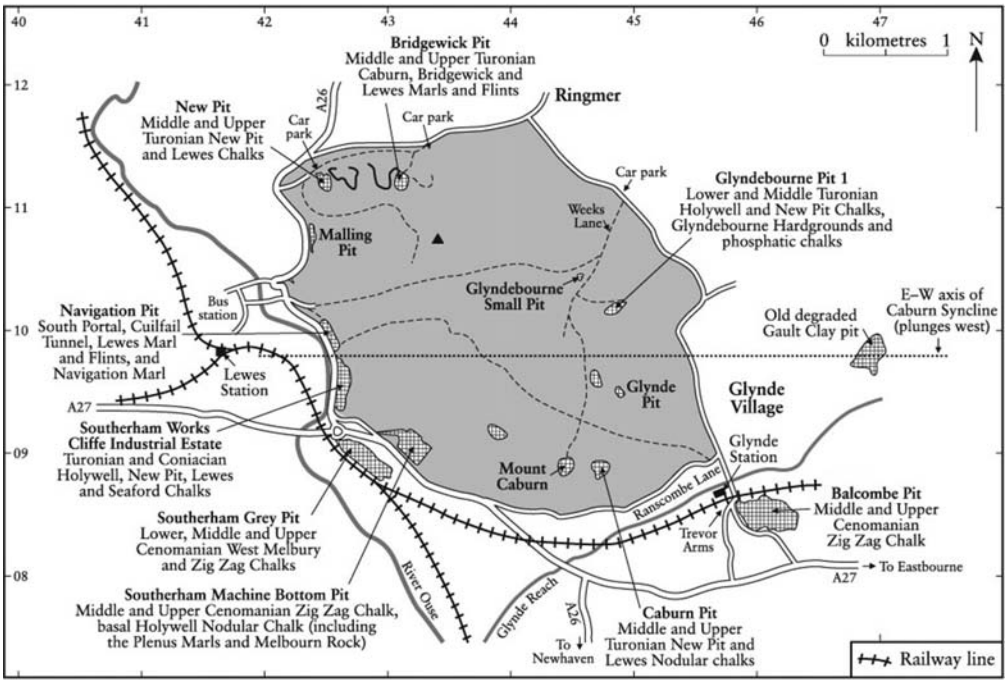

Figure 3.106: Map of the Caburn group of chalk pits at Lewes, Sussex showing the position of the GCR sites (boldface type) in relation to correlative sections. (After Mortimore, 1997.)

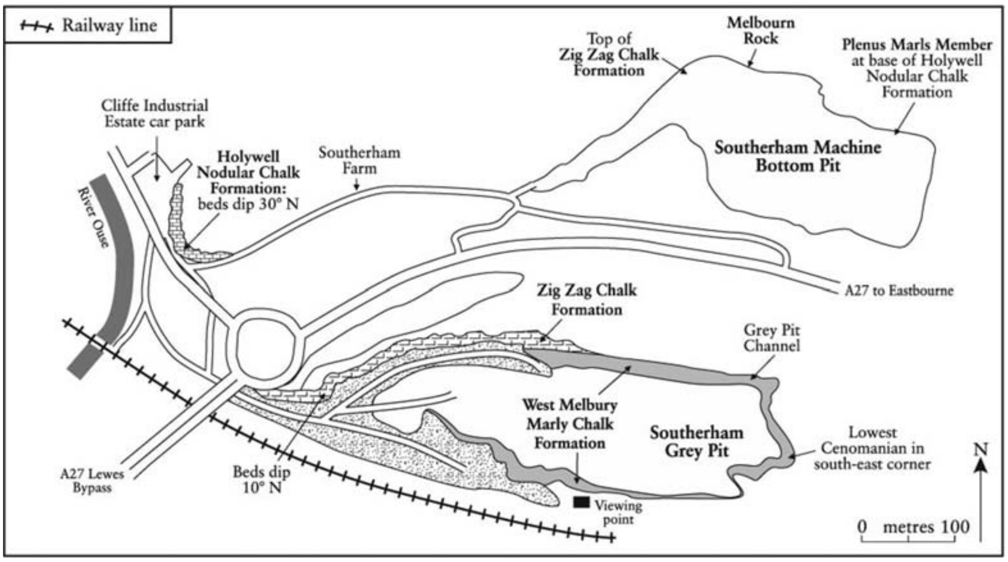

Figure 3.107: Map of the former cement works quarries, Southerham Grey Pit and Machine Bottom Pit, Lewes, Sussex. (After Mortimore, 1997.)

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 (Figure3.3). This site also provides one of the standard sections for the cyclostratigraphy (marl–chalk couplets) of the Cenomanian strata. The integrated cyclostratigraphy, stable isotope 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.

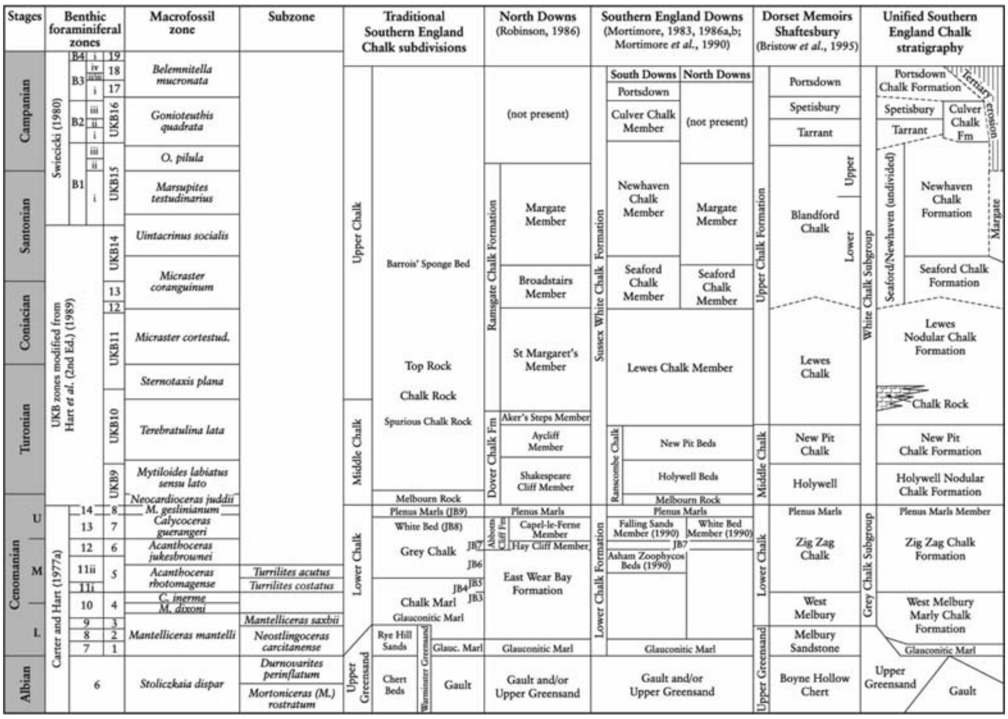

Figure 3.3: Unified stratigraphy for the Upper Cretaceous successions of the Southern Province. (JB = Jukes-Browne bed numbers.) (Based on Bristow et al., 1997.)

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.

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.)

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 20º north-west, decreasing to 5º 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; 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 10º 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 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 (inPaul *et al*., 1994; Gale, 1995, 1998).

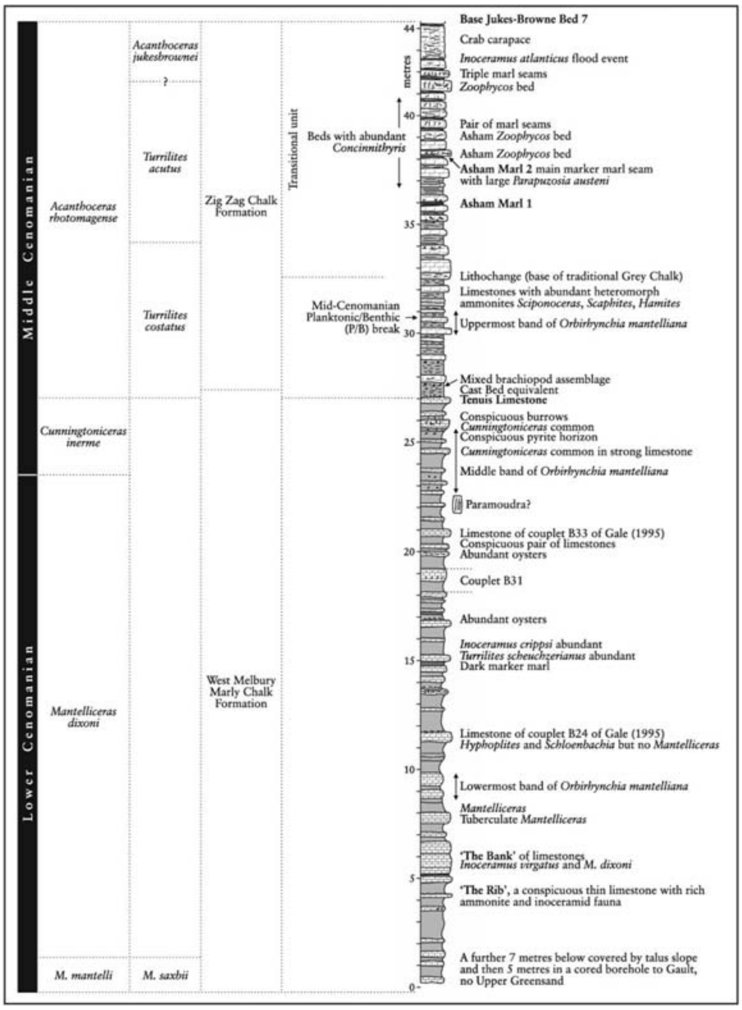

Figure 3.109: Geological section for Southerham Grey Pit, Lewes, Sussex. Compare with Figures 3.5 and 3.108; and Figure 2.8, Chapter 2.

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. 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 (Figure3.5b).

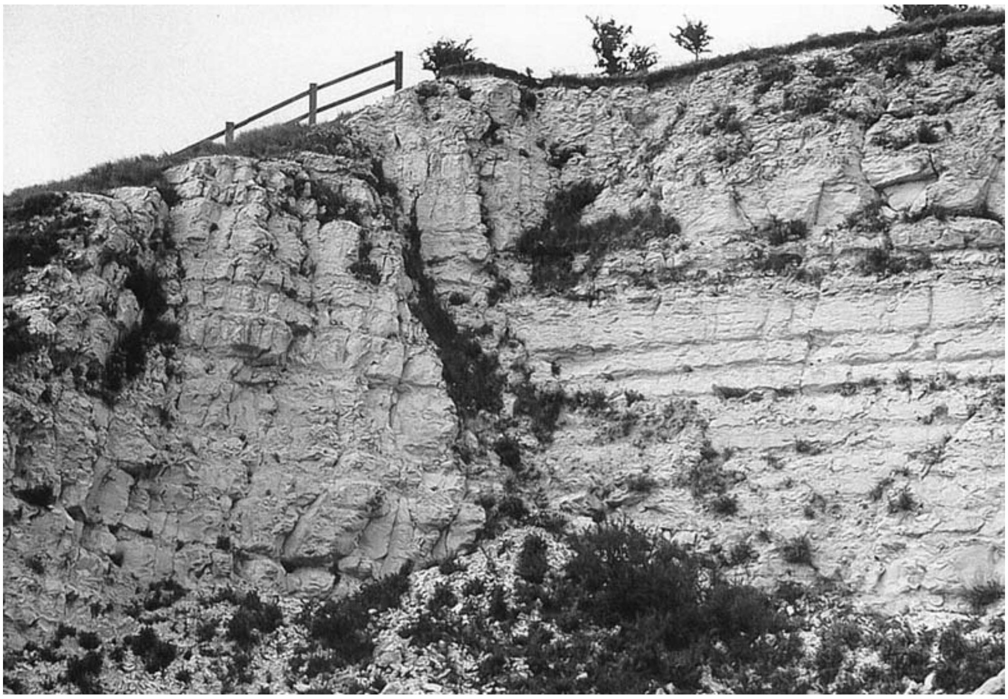

Figure 3.5: Southerham Grey Pit, Lewes, Sussex, showing the transition from West Melbury Marly Chalk rhythms below to Zig Zag Chalk above. AZB = Asham Zoophycos Beds; GPC = Grey Pit Channel; JB7 = Jukes-Browne Bed 7; TL = Tenuis Limestone forming the mapping base of the Zig Zag Chalk Formation; TM = Triple Marls and the Inoceramus atlanticus event; WMMCF = West Melbury Marly Chalk Formation. (Photos: R.N. Mortimore.)

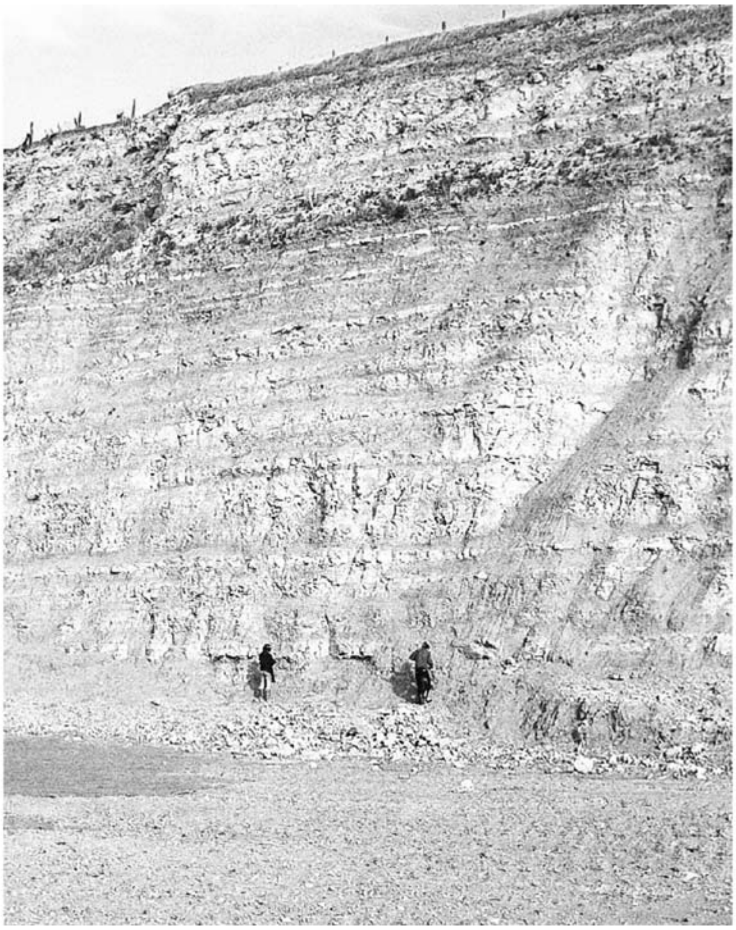

Figure 3.108: (a, b) Southerham Grey Pit, Lewes, Sussex, in 1976 prior to closure in 1978. Marker beds and the rhythmic sedimentation used to establish the cyclostratigraphy in the lower part of the Grey Chalk Subgroup are indicated (see also Figure 3.5). (Photos: R.N. Mortimore.)

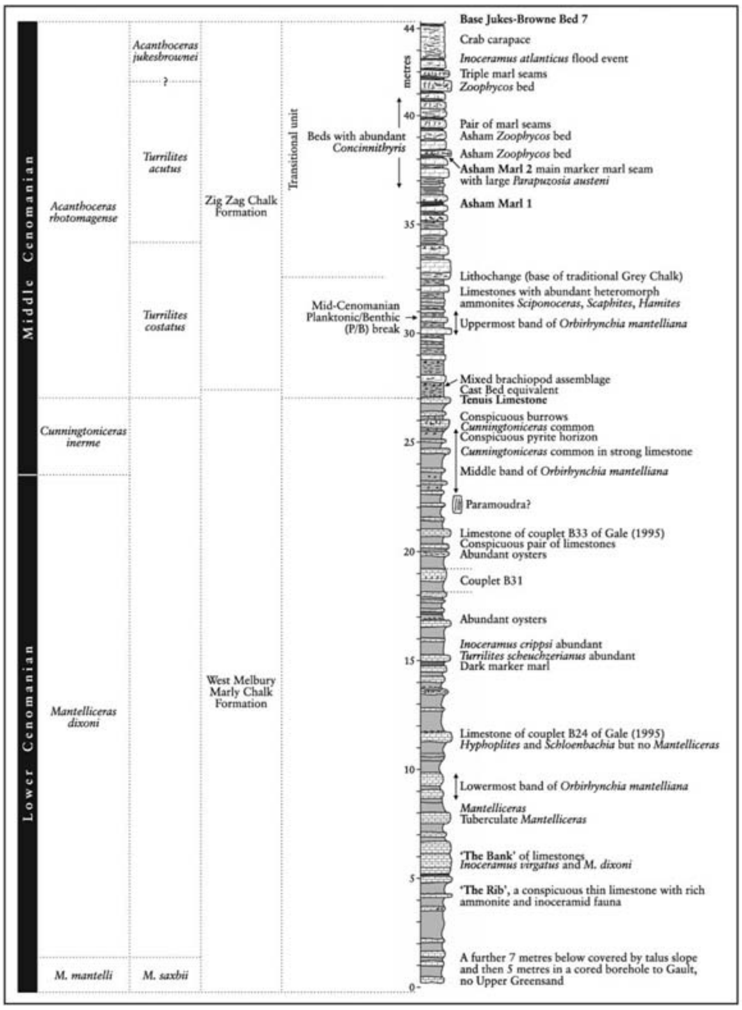

Figure 3.109: Geological section for Southerham Grey Pit, Lewes, Sussex. Compare with Figures 3.5 and 3.108; and Figure 2.8, Chapter 2.

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 (Figure3.5a). 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 (Figure3.110), rests with marked disconformity of about 15º 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).

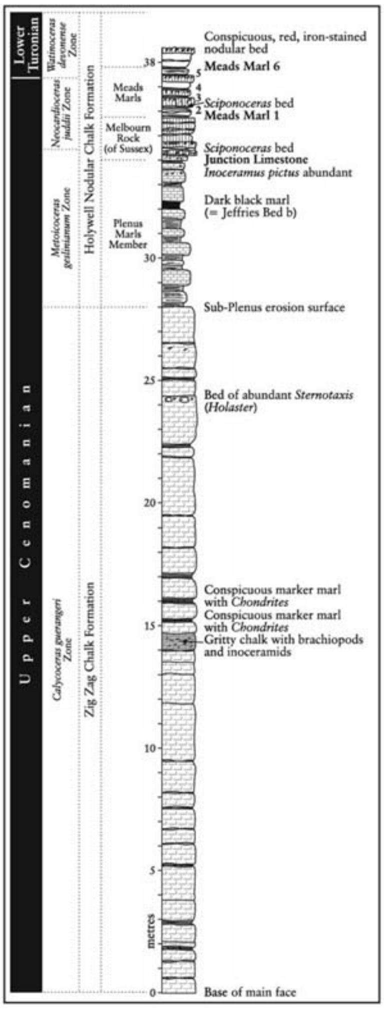

Figure 3.110: Section for the Machine Bottom Pit (Southerham Grey Pit GCR site), Lewes, Sussex.

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 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 ocurrences 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 (*^{18}O, *^{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 (*^{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 *^{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 15º 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 byMortimore (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.

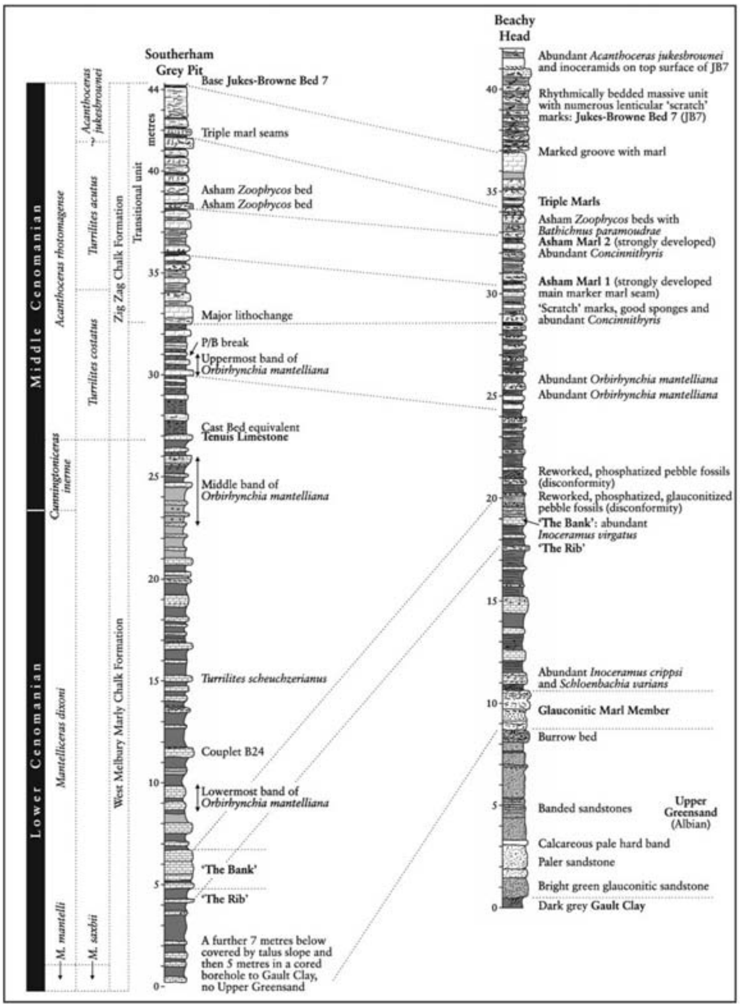

Figure 3.111: Southerham Grey Pit correlated with Beachy Head illustrating the marked condensation in the Early Cenomanian West Melbury Marly Chalk at Eastbourne.

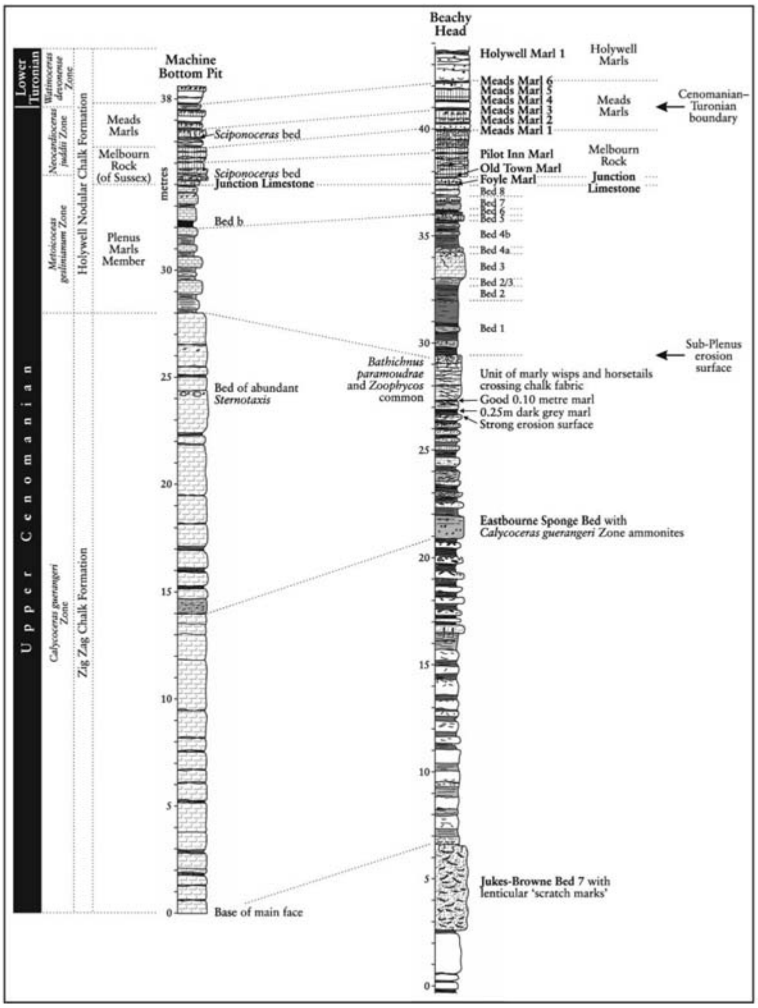

Figure 3.112: The Machine Bottom Pit (part of the Southerham Grey Pit GCR site) correlated with Beachy Head, near Eastbourne, showing the very different lithologies of the two sites.

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).

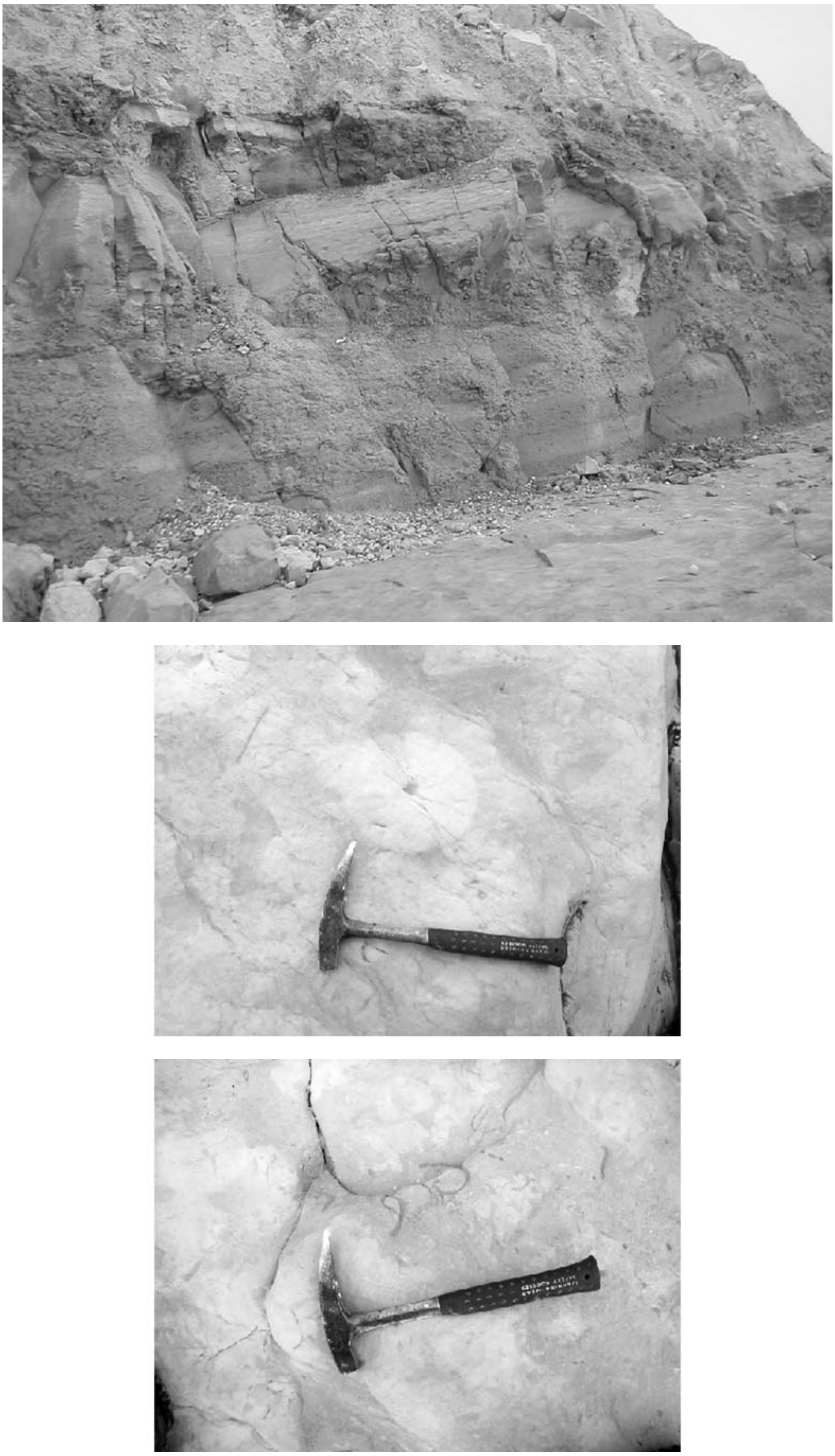

Figure 3.113: Basal beds of the Plenus Marls Member in the type section at Beachy Head, Sussex. (a) Basal beds showing a cyclostratigraphy of paler and darker bands. (b, c) Sub-Plenus erosion surface mottled with (b) pale haloes of Bathichnus paramoudrae (arrowed) and (c) dark spirals of Zoophycos (arrowed). (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 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.

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.

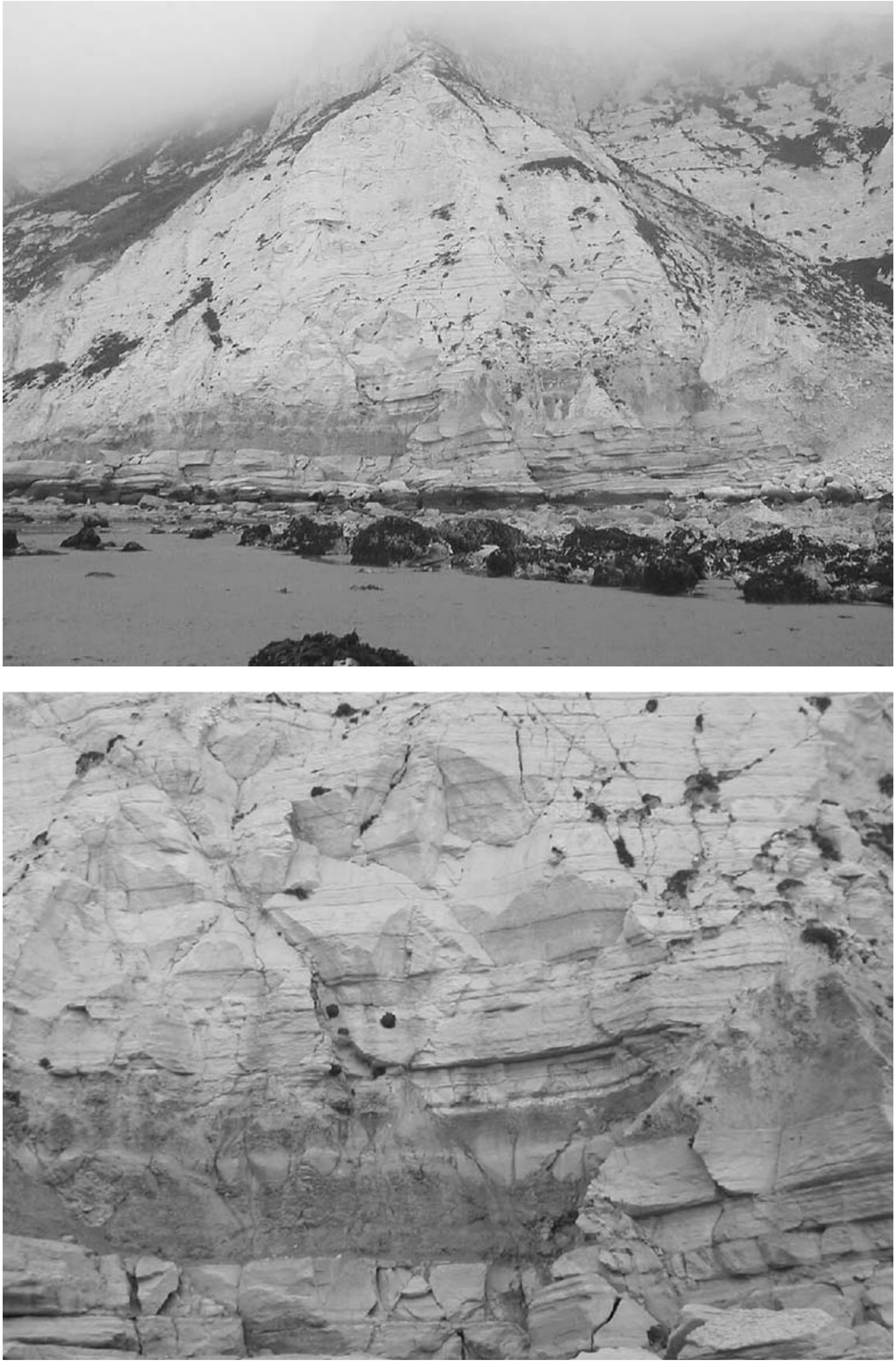

Figure 3.6: (a, b) Grey Chalk Subgroup and White Chalk Subgroup boundary at the base of the Plenus Marls at Beachy Head, Sussex. (Beds 1–8 are those of Jefferies, 1963.) (Photos: R.N. Mortimore.)

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.

Reference list

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.
Christensen, W.K. (1990) Actinocamax primus Arkhangelsky (Belemnitellidae; Upper Cretaceous). Biometry, comparison and biostratigraphy. Paläontologische Zeitschrift, **64**, 75–90.
Crampton, J.S. (1996) Biometric Analysis, Systematics and Evolution of Albian Actinoceramus (Cretaceous Bivalvia, Inceramidae), Institute of Geological and Nuclear Sciences monograph 15, Lower Hutt, New Zealand, 80 pp.
Ditchfield, P.W. and Marshall, J.D. (1989) Isotopic variation in rhythmically bedded chalks: Palaeotemperature variation in the Upper Cretaceous. Geology, **17**, 842–5.
Ernst, G. and Rehfeld, U. (1997) The transgressive development in the Lower and Middle Cenomanian of the Salzgitter area (N-Germany) recorded by sea level-controlled eco- and litho-events. Freiberger Forschungshefte, Reihe C, **468**, 79–107.
Ernst, G., Schmid, F. and Seibertz, E. (1983) Event-Stratigraphie im Cenoman und Turon von NW-Deutschland. Zitteliana, **10**, 531–54.
Gale, A.S. (1989) Field meeting at Folkestone Warren, 29th November, 1987. Proceedings of the Geologists' Association, **100**, 73–80.
Gale, A.S. (1990a) A Milankovitch scale for Cenomanian time. Terra Nova, **1**, 420–5.
Gale, A.S. (1995) Cyclostratigraphy and correlation of the Cenomanian Stage in Western Europe. In Orbital Forcing Timescales and Cyclostratigraphy, (eds M.R. House and A.S. Gale), Geological Society of London, Special Publication, No. 85, pp. 177–97.
Gale, A.S. (1996) Turonian correlation and sequence stratigraphy of the Chalk in southern England. In Sequence Stratigraphy in British Geology, (eds S.P. Hesselbo and D.N. Parkinson), Geological Society of London, Special Publication, No. 103, pp. 177–95.
Gale, A.S. (1998) Chapter 7: Cyclostratigraphy. In Unlocking the Stratigraphical Record: Advances in Modern Stratigraphy, (eds P. Doyle and M.R. Bennett), John Wiley and Sons Ltd, Chichester, pp. 195–220.
Gale, A.S., Jenkyns, H.C., Kennedy, W.J. and Corfield, R.M. (1993) Chemostratigraphy versus biostratigraphy: data from around the Cenomanian–Turonian boundary. Journal of the Geological Society, London, **150**, 29–32.
Gale, A.S., Smith, A.B., Monks, N.E.A., Young, J.R., Howard, A., Wray, D.S. and Huggett, J.M. (2000) Marine biodiversity through the Late Cenomanian–Early Turonian: palaeoceanographic controls and sequence stratigraphic biases. Journal of the Geological Society, London, **157**, 745–57.
Jefferies, R.P.S. (1963) The stratigraphy of the Actinocamax plenus Subzone (Turonian) in the Anglo-Paris Basin. Proceedings of the Geologists' Association, **74**, 1–33.
Jenkyns, H.C. (1980) Cretaceous anoxic events: from continents to oceans. Journal of the Geological Society, London, **137**, 171–88.

Jukes-Browne, A.J. and Hill, W. (1903) The Cretaceous Rocks of Britain, volume 2: The Lower and Middle Chalk of England, Memoir of the Geological Survey of the United Kingdom, HMSO, London, 568 pp.

Kaplan, U., Kennedy, W.J., Lehmann, J. and Marcinowski, R. (1998) Stratigraphie und Ammonitenfaunen des westfälischen Cenoman. Geologie und Paläontologie in Westfalen, **51**, 236 pp.

Kennedy, W.J. (1967) Burrows and surface traces from the Lower Chalk of southern England. Bulletin of the British Museum (Natural History). Geology Series, **15**, 125–67.

Kennedy, W.J. (1969) The correlation of the Lower Chalk of south-east England. Proceedings of the Geologists' Association, **80**, 459–551.

Kennedy, W.J., Walaszczyk, I., and Cobban, W.A. (2000) Pueblo, Colorado, USA, candidate Global Boundary Stratotype Section and Point for the base of the Turonian Stage of the Cretaceous, and for the base of the Middle Turonian Substage, with a revision of the Inoceramidae (Bivalvia). Acta Geologica Polonica, **50**, 295–334.

Lake, R.D., Young, B., Wood, C.J. and Mortimore, R.N. (1987) Geology of the Country around Lewes, Memoir of the British Geological Survey, Sheet 319 (England and Wales), HMSO, London, 117 pp.

Mitchell, S.F., Ball, J.D., Crowley, S.F., Marshall, J.D., Paul, C.R.C., Veltkamp, C.J. and Samir, A. (1997) Isotope data from Cretaceous chalks and foraminifera: Environmental or diagenetic signals? Geology, **25**, 691–4.

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

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. and Young, B. (1980) Field meeting for the Geologists' Association at Lewes, Shoreham and Eastbourne, August 1980. [Unpublished handout and report.]

Mortimore, R.N., Pomerol, B. and Foord, R.J. (1990) Engineering stratigraphy and palaeogeography for the Chalk of the Anglo-Paris Basin. In Chalk, (eds J.B. Burland, R.N. Mortimore, L.D. Roberts, D.L. Jones and B.O. Corbett), Thomas Telford, London, pp. 47–62.

Paul, C.R.C., Mitchell, S.F, Marshall, J.D., Leary, P.N., Gale, A.S., Duane, A.M. and Ditchfield, P.W. (1994) Palaeoceanographic events in the Middle Cenomanian of Northwest Europe. Cretaceous Research, **15**, 707–38.

Paul, C.R.C., Mitchell, S.F., Vaziri, M.R., Gorostidi, A. and Marshall, J.D. (1999) The Cenomanian–Turonian boundary at Eastbourne (Sussex, UK): a proposed European reference section. Palaeogeography, Palaeoclimatology, Palaeoecology, **150**, 83–121.

Pomerol, B. and Mortimore, R.N. (1993) Lithostratigraphy and correlation of the Cenomanian–Turonian boundary sequence. Newsletters on Stratigraphy, **28**, 59–78.

Rawson, P.F., Allen, P. and Gale, A.S. (2001) The Chalk Group – a revised lithostratigraphy. Geoscientist, **11**, 21.

Robaszynski, F., Gale, A.S., Juignet, P., Amédro, F. and Hardenbol, J. (1998) Sequence stratigraphy in the Upper Cretaceous Series of the Anglo-Paris Basin: exemplified by the Cenomanian Stage. In Mesozoic and Cenozoic Sequence Stratigraphy of European Basins, (eds J. Hardenbol, J. Thierry, M.B. Farley, Th. Jaquin, P.-C. de Graciansky and P.R. Vail), Society of Economic Paleontologists and Mineralogists Special Publication, No. 60, pp. 363–86.

White, H.J.O. (1926) The Geology of the Country near Lewes, Memoir of the Geological Survey of Great Britain (England and Wales) New Series, Sheet 319, HMSO, London, 97 pp.

Wood, C.J. and Mortimore, R.N. (1995) An anomalous Black Band succession (Cenomanian–Turonian boundary interval) at Melton Ross, Lincolnshire, eastern England and its international significance. Berliner geowissenschaftliche Abhandlungen, Reihe E, **16**, (1),

277–87.
Wright, C. W. and Kennedy, W. J. (1996) The Ammonoidea of the Lower Chalk: Part 5, Monograph of the Palaeontographical Society, London, pp. 320–403.