British Tertiary Stratigraphy

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Chapter 6

Hampshire Basin: mainland localities

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INTRODUCTION

Various mainland sites of the Hampshire Basin both complement and enhance an appreciation of Palaeogene stratigraphy and palaeoenvironments derived and established from those GCR sites on the Isle of Wight. Whilst not having the stratigraphical range found in the latter area, they demonstrate the lateral environmental changes that occurred across this region of southern Britain in Palaeogene times.

The Wittering to Selsey section represents the truly marine nature more typical of 'eastern facies', whilst the Bournemouth Cliffs site, for example, provides information on the passage to shallower marine and more continental conditions which lay further to the west. It is unfortunate that no permanent sites exist to demonstrate the full range of facies representing the latter, particularly within the upper part of the London Clay and the Poole Formation. Considerable borehole data are however now available, whilst good temporary sections are to be found in the ball clay pits operated by ECC Ball Clays.

The most 'classic' of the mainland Palaeogene sites of the Hampshire Basin is 'Barton Cliffs'. The subject of geological interest for over 200 years, with a molluscan fauna alone of some 500 species, and being the type section for the Bartonian stage, its international importance is indisputable.

STUDLAND BAY, DORSET (SZ 438230–SZ 037828)

Highlights

The relatively thin Reading Formation and London Clay of Studland represent proximity to the western margins of the Palaeogene sedimentary basin. The Studland Bay site may demonstrate the early regression of the London Clay sea in contrast with its far longer persistence to the east. Alternatively, it may have originally been thicker and later considerably eroded prior to the deposition of the fluvial Redend Member of the Poole Formation.

Introduction

The site extends from the unconformable contact with the Upper Cretaceous Chalk northwards to just beyond Redend Point. Apart from the few instances where sediments of possible Tertiary age infill solution pipes in the Chalk, such as is seen in St Oswald's Bay, to the east of Durdle Door (SY 812802), Studland Bay is the most westerly locality in southern England where the Palaeogene/Chalk unconformity is exposed. The Palaeogene strata present are the Reading Formation, the London Clay and the Poole Formation, represented by the Redend Member (Redend Sandstone) and the basal few metres of the Corfe Member.

Aspects of Studland were referred to by Lyell (1827) in his pioneer survey of the Tertiary succession in the Hampshire Basin but little was written about it until Monkton (1910) reported a visit by the Geologists' Association. Arkell (1947) gave a more detailed account in which the post-London Clay strata were referred to as the Bagshot Beds.

Little has been published since Arkell's description, with a few exceptions, such as a brief discussion of the plant fossils of the Corfe Member by Chandler (1962, p. 4) and that recording a short visit by the Tertiary Research Group (Cooper *et al.*, 1976). Microplankton have been obtained from the London Clay (Williams and Downie, 1966; Bujak *et al.*, 1980) which was also sampled by Costa and Downie (1976) in their work on the dinoflagellate zonation of the Palaeogene. A relatively brief reference to the London Clay and Redend Sandstone of this locality was made by King (1981) in his wider and comprehensive account of the London Clay of southern England. More recently, his unpublished PhD thesis includes a stratigraphical log of the London Clay (King, 1991, fig. A16).

Although referring to an area to the north and east of this site, the recent Bournemouth Memoir (Bristow *et al.*, 1991) provides considerable information that also assists interpretation here (see Figure 6.1 which summarizes the stratigraphy of the Palaeogene strata in the western part of the Hampshire Basin).

Recently (December, 1998), the author has learned that, following re-mapping by the British Geological Survey, doubts have been expressed as to whether the lithostratigraphical assignment of much of the succession to the Reading Formation and the London Clay is valid (see later discussion).

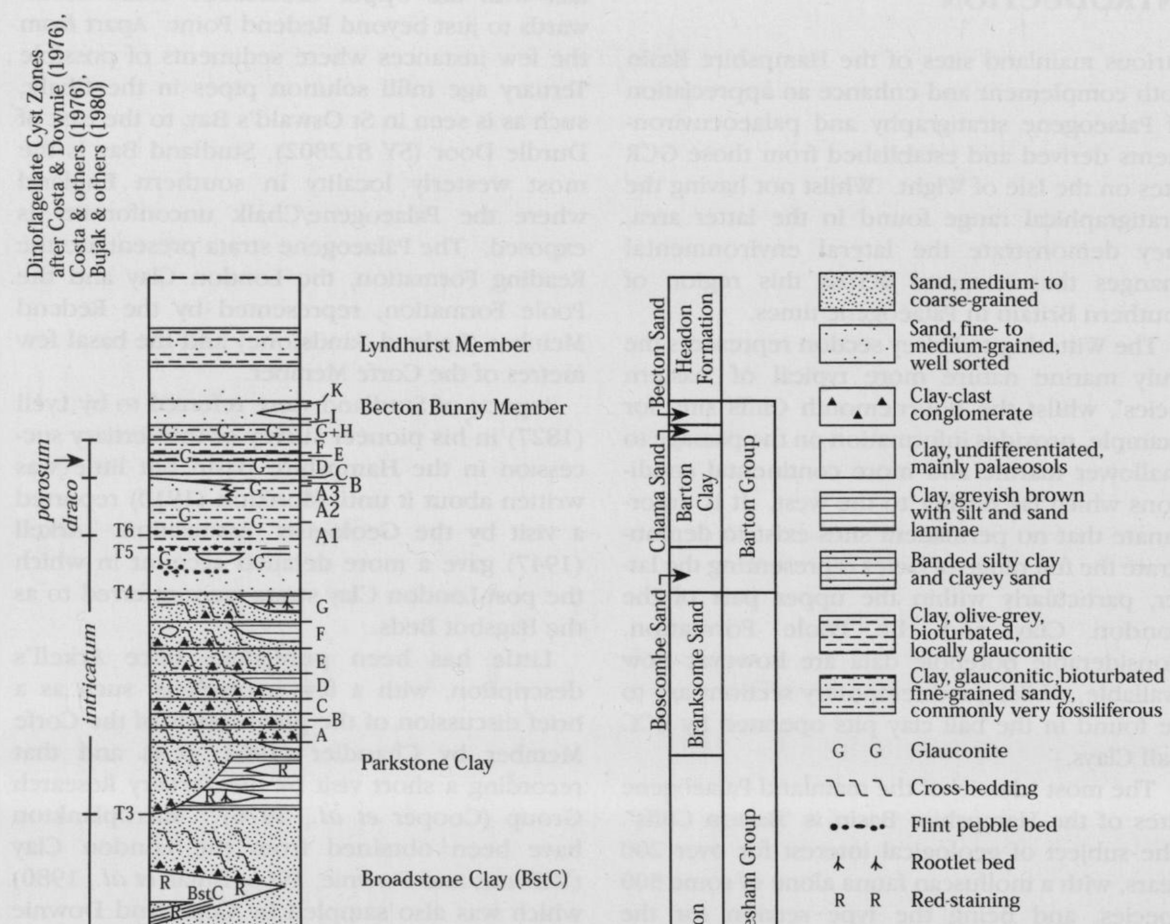

Figure 6.1 Generalized stratigraphical succession of Palaeogene strata in the Bournemouth area (from Bristow *et al.*, 1991, fig. 8). Units A1? to C (London Clay) after King (1981), A to G (Branksome Sand) after Plint (1983a) and A1 to K (Barton Group) after Burton (1933). 'T' numbers denote surfaces produced by marine transgressions.

Figure 6.2 Studland Bay, Dorset. Sands of the Reading Formation at the southern end. (Photograph: B. Daley.)

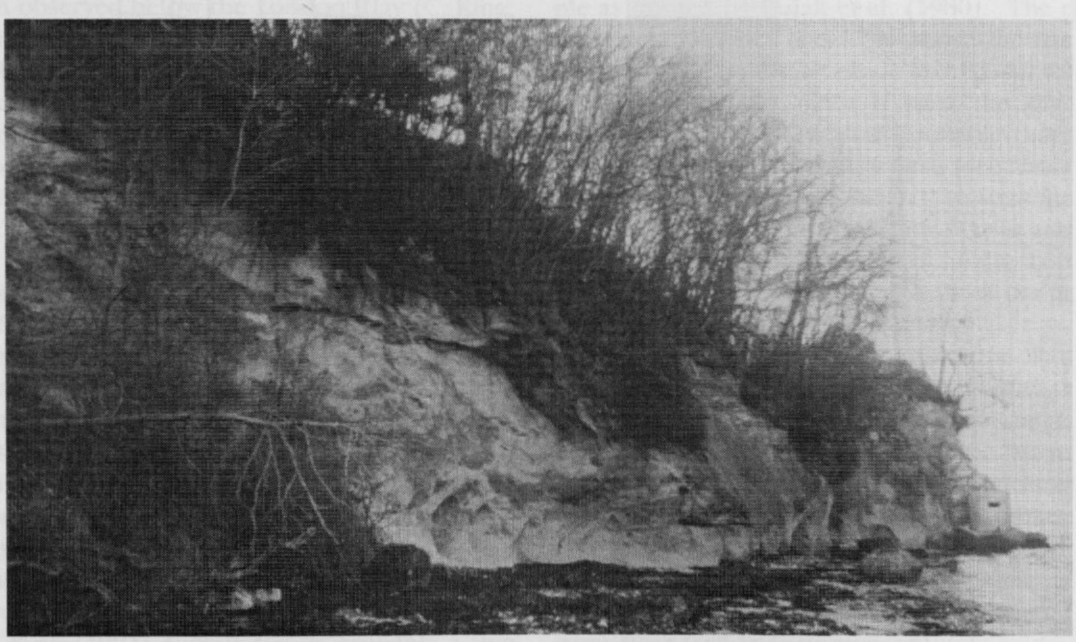

Figure 6.3 Studland Bay, Dorset. Redend Member exposed at Redend Point, from the south. (Photograph: B. Daley.)

Description

The Palaeogene succession at Studland Bay (Figures 6.2 and 6.3), in ascending order, comprises the Reading Formation, the London Clay and the Poole Formation, the last of these represented by the Redend Member and a few metres of the Corfe Member. It rests unconformably on the Upper Cretaceous Chalk.

The unconformity

The contact between the Reading Beds and the underlying Chalk is a particularly striking example of the irregular surface which is often associated with this unconformity. Erosional cavities up to 3 m wide and containing Palaeogene material extend down into the underlying Cretaceous strata. Those which are internally well-stratified indicate incremental, primary sediment accumulation. The junction of the Reading Formation and the Chalk is also marked by scattered, well-rounded flint pebbles mixed with unabraided flint nodules with strongly limonitized crusts. The latter may have been derived from the in-situ dissolution of the Chalk below the Palaeogene cover after the latter had accumulated.

Recent work by the British Geological Survey has shown that the nature of the Chalk/Palaeogene surface in Dorset has in places been affected by tectonism. For example, the hummock of Chalk to the north of the main Chalk outcrop in Studland Bay mentioned by Arkell (1947, p. 221) is now thought to be a fault block (C.M. Barton, pers. comm.).

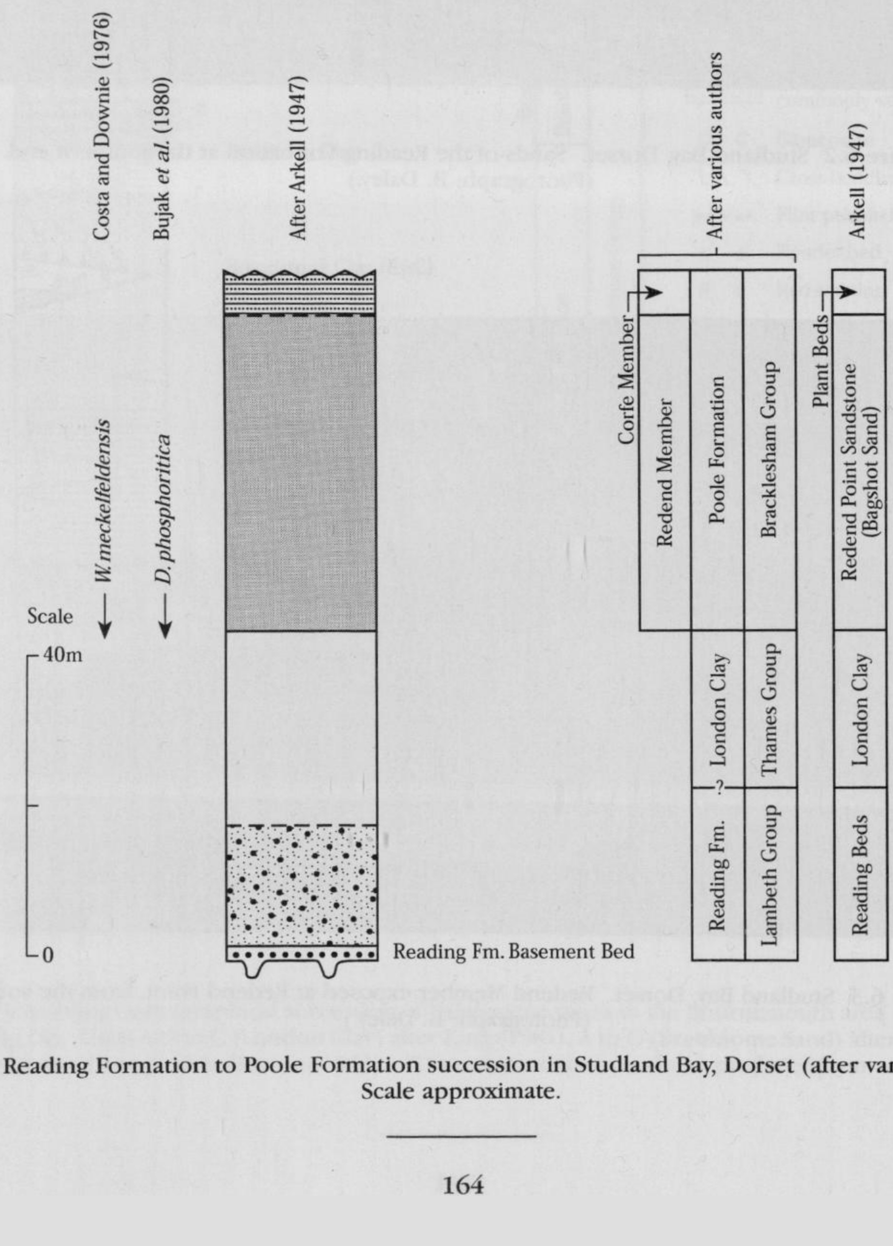

Figure 6.4 Reading Formation to Poole Formation succession in Studland Bay, Dorset (after various authors). Scale approximate.

Lithological succession

Thin basal sands and granule conglomerates of the Reading Formation occur above the sub-Palaeogene unconformity whilst the top of the succession at the northern end of the bay consists of ferruginous sandstones (the Redend Member) with a thin sequence of lignitic sands and muds above. Very few exposures occur in the central part of the bay but the succession here (the upper part of the Reading Formation and the London Clay) is predominantly argillaceous. As Arkell (1947, p. 222) pointed out, the thickness of the Palaeogene strata present in Studland Bay is difficult to measure. He estimated a total of 305 feet (93 m) of which *c.* 44 m was allocated to the Reading Formation and London Clay combined, and *c.* 42 m to the Redend Sandstone (Figure 6.4).

Stratigraphy

The lower part of the Reading Formation, including some 2 m of the Reading Basement Bed of Edwards and Freshney (1987b) (formerly the 'Bottom Bed' of earlier authors), is exposed at the southern end of the bay. At the present time, the upper part is concealed by slips and vegetation although colour-mottled muds have been observed below the London Clay (C. King, pers. comm.).

The London Clay is very poorly exposed on slumped and strongly vegetated slopes above shore level but King (1991, fig. A16) was able to recognise some 22 m resting on the muds of the Reading Formation. King assigned the lowest part of the London Clay (just over 8 m of sands and silts) to his Tilehurst Member (now included in the Harwich Formation, Ellison *et al.* 1996). This is in part glauconitic and contains the brachiopod *Lingula* one to two metres or so from the top. The next 8 m comprise mainly bioturbated silty clays assigned to his informal division A3 on the basis of their stratigraphical position, and on an assemblage of agglutinating foraminifera similar to that found by King in his division A3 in Alum Bay. A thin sand occurs about a metre below the top of this interval. It is overlain by a 1.5 m sand with a pebbly base that King (1991) considered as probably a thin representative of division B1, whilst his measured log is completed by 2 m of sandy silts with sparse pebbles at the base, tentatively referred to division B2.

An unexposed interval of uncertain thickness separates the measured 22 m log from the overlying Redend Member and it may be that, at least in part, this includes strata assignable to the London Clay.

Curry *et al.* (1978) used both the terms Redend Sandstone and Redend Member for the sandstone which succeeds the London Clay at Studland (Figure 6.3). It comprises the lowest of the three members of their Poole Formation, later formally defined by Edwards and Freshney (1987b) and included in the Bournemouth Group of these authors. The member would have been part of the Lower Bagshot Beds of Gardner (1879a) and also the 'Studland Series' mentioned briefly by King (1981, p. 32). The Redend Member is not represented at other more easterly localities.

Biostratigraphy

Bujak *et al.* (1980) reported dinoflagellate-barren sediments near the base of the London Clay but found material indicative of the Deflandrea phosphoritica dinoflagellate Assemblage Zone (LC-1) 0.9 m from the top of the formation. Costa and Downie (1976, p. 604) collected the zone fossil *Wetzeliella meckelfeldensis* within 2 m of the top, presumably from the same sample as quoted by Bujak et al. (1980). The position of this sample is *c.* 17 m above the base of the London Clay (Bujak *et al.*, text-fig. 4), which, if accurate, would place it near the division A/division B boundary. It is probable that they took the sand with a pebbly base (see above) as the base of the 'Bagshot Sands'. In sites further eastwards, in both the Hampshire Basin and the London Basin, the upper part of the London Clay contains younger zone fossils of the genus *Wetzeliella* (*sensu lato*).

The stratigraphical affinities of the Redend Member are unclear. The *W. meckelfeldensis* age of the uppermost London Clay below suggests a possibility that it corresponds to the Warmwell Farm Sand found to the north (cf. Bristow *et al.*, 1991, fig. 8) and whose lateritic cementation is compatible with the limonitization here. However, in the absence of zone fossils, its age and correlation with other strata elsewhere is far from clear (see later discussion).

Sedimentology

The Reading Basement Bed comprises sparsely glauconitic muddy sand. Above, some 15–20 m of cross-bedded, mainly clean, quartzose sands to granule conglomerates with thin beds of silty clay locally containing fragmentary plant material, contrasts with the dominantly argillaceous sequences of Alum and Whitecliff Bays to the east. Clay mineral studies by Gilkes (1968) indicated a predominantly illite–kaolinite composition at Studland. The basal 2 m was, however, exceptional in containing abundant smectite.

Whilst the London Clay is very poorly exposed, its marine origin is supported by the glauconitic nature of its lower part, the presence of *Lingula* and agglutinating foraminifera. C. King (pers. comm.) considers that the sediments present are similar to those of the London Clay elsewhere and may be interpreted as marine, although calcareous fossils have been destroyed by post-depositional decalcification.

Lithologically, the Redend Member comprises relatively well-lithified, fine to medium sandstones. These are essentially clean, well-sorted sands, now strongly limonitized. King (1981, p. 91) considered that the base is 'certainly marine', whilst suggesting that the upper part, with several fining-upwards cycles, is fluvial in origin.

Parallel-laminated, sometimes lignitic, sands and black sandy muds follow the Redend Member. Cooper *et al.* (1976) noted the abundance of plant fragments, and whilst referring this unit to the Pipeclay Series of Arkell (1947) (the Corfe Member of Curry *et al.*, 1978), remarked how different the muds here were from the 'sterile ball clays' elsewhere.

Macroflora

Chandler (1962, p. 4) referred in somewhat more detail than Cooper *et al.* (1976) to the plant macrofossils of the Corfe Member, together with references to earlier studies of this flora, and referred to the tropical affinities of some of the forms present.

Interpretation and evaluation

Studland Bay is the most westerly site in the Hampshire Basin to show the contact between the Cretaceous and the Palaeogene, together with an overlying succession of Palaeocene and lower Eocene strata. Hence, the succession here provides some insight into the palaeogeographical development towards the western end of the Hampshire Basin in early Palaeogene times. Other data which could throw light on the development of the remainder of the Palaeogene succession in this area have arisen from the local exploration and exploitation of ball clay but some of this information is commercially 'sensitive' and not in the public domain.

Comparison with other localities

Compared with the sections in Whitecliff Bay and Alum Bay on the Isle of Wight, that at Studland is limited in stratigraphical range but it demonstrates both similarities with and differences from the Palaeogene successions found further to the east.

Rounded pebbles and the presence of glauconite at the bottom of the Reading Formation indicate the presence of the Reading Formation Bottom Bed (also recognized in English China Clay's Rempstone Borehole just south of Poole Harbour; Bristow *et al.*, 1991) but the remainder of the Reading Formation at Studland varies both in thickness and lithologically from the Isle of Wight sections. The 15–20 m present here, compared with the 24.6 m at Alum Bay and around 45 m at Whitecliff Bay, indicates a considerable westerly thinning of strata above the Reading Basement Bed. Indeed, it is now known that elsewhere in the north-west part of the Bournemouth District (*sensu* BGS), it is actually overlapped by the London Clay (Bristow *et al.*, 1991).

Compared with more easterly localities, there is only a thin development of the London Clay at Studland and it is clear that it is essentially the younger part of the formation that is absent. In this regard, the discovery by Costa and Downie (1976) of *W. meckelfeldensis* within 2 m of the top of the London Clay here is particularly significant, for at Alum Bay *D. similis* occupies this position, with the even younger *D. varielongituda* at the top of the formation (*sensu* King, 1981) in Whitecliff Bay. Costa and Downie (1976) suggested that such a lateral change is a clear indication of the diachronous nature of the top of the London Clay, the consequent inference being that a regressive development began much earlier in this more westerly area. C. King (pers. comm.) believes now that the top of the London Clay may not have been diachronous and that its attenuated succession in Studland Bay may have resulted from erosion in this area prior to deposition of the Poole Formation.

Depositional environment and palaeogeography

The concentration of smectite in the Reading Formation Basement Bed was interpreted by Gilkes (1968) as insoluble residue from the Chalk. Edwards and Freshney (1987a, p. 16), who found similar concentrations of this mineral elsewhere in the Basement Bed, have, however, suggested that a volcanic origin is more likely. Such a possibility is compatible with the occurrence of contemporaneous ash bands in the southern North Sea and in the London Basin (Knox and Harland, 1979).

Above the Reading Formation Basement Bed, the sands and granule conglomerates at Studland are quite different from the colour-mottled muds so characteristic of the Reading Formation in Alum Bay and Whitecliff Bay. They are also markedly coarser than the sands from the sandy facies described by Edwards and Freshney (1987a, p. 17) from the Southampton area. These authors considered that most of the Reading Formation sands in the latter area were fluvial in origin. No detailed study has been undertaken of those at Studland, but their clean, quartz-rich composition is not immediately compatible with such an origin.

Since the London Clay is so poorly exposed at Studland, discussion must inevitably be limited. It is, however, far thinner here than further to the east, an indication that the Studland area represents the western margin of the London Clay sea. Indeed, some of the palynomorphs recently found by BGS in the Studland Bay section are paralic in character rather than marine as in the London Clay further east (J.B. Riding, pers. comm.). There is some indication that, in some places, the London Clay was subaerially exposed relatively soon after deposition since, in the north-western part of the Bournemouth District (*sensu* BGS), strata formerly considered as 'Reading Beds' are now thought of as pedogenically reddened London Clay, the latter resting directly on the Chalk (Bristow *et al.*, 1991, p. 20).

Costa and Downie (1976) suggested a major unconformity at the base of the Redend Sandstone. Although King (1981, p. 91) originally felt that this was unlikely, he now is inclined to agree (pers. comm.). Having earlier (1981) thought that this unit was probably correlatable with higher horizons in the London Clay further to the east, he now considers it to be part of a fluvial succession younger than the London Clay. However, since the unit has, as yet, yielded no zone fossils, its age remains uncertain. It is unfortunate that Townsend and Hailwood (1985) did not include Studland in their revealing magnetostratigraphical work on the Palaeogene, since this might very well have shed more light on this problem.

Recent alternative lithostratigraphical interpretation

Recent re-mapping of this part of Dorset by the British Geological Survey (BGS) (Sheet 342/343, Swanage, in press) has led to an alternative lithostratigraphical interpretation of the Studland Bay section incompatible with the assignment of the succession to the Reading Formation, London Clay and Poole Formation. C.M. Barton, C.R. Bristow and J.B. Riding of the BGS (pers. comm.) believe this tripartite assignment to be inappropriate and, on the basis of both palynology and field mapping, consider that the succession should be assigned in its entirety to the Poole Formation. Barton (pers. comm.) has suggested that the sands and granule conglomerates considered to be Reading Formation in this account should be assigned to the Creekmore Sand (Poole Formation) and, furthermore, that the Reading Formation is totally absent in the area covered by the Swanage sheet, the Weymouth sheet (341/342) (in press) and the recently published Dorchester sheet (328). BGS has the Creekmore Clay succeeding the Creekmore Sand with the younger Redend Member mapped as part of the 'Broadstone and Oakdale Sands, undivided'.

The suggestion that the London Clay is absent in the Studland Bay section is not supported by evidence of its occurrence found by King (1991). Clearly further investigation is necessary to resolve the apparent incompatibility of the two interpretations. As this account goes to press, BGS is about to re-evaluate the palynofloral evidence (J.B. Riding, pers. comm.). This may turn out to be very revealing since the palynomorphs found by BGS did not preclude the presence of the London Clay on biostratigraphical grounds but were thought to represent a different, more paralic, biofacies than that which characterized the typically marine London Clay farther to the east.

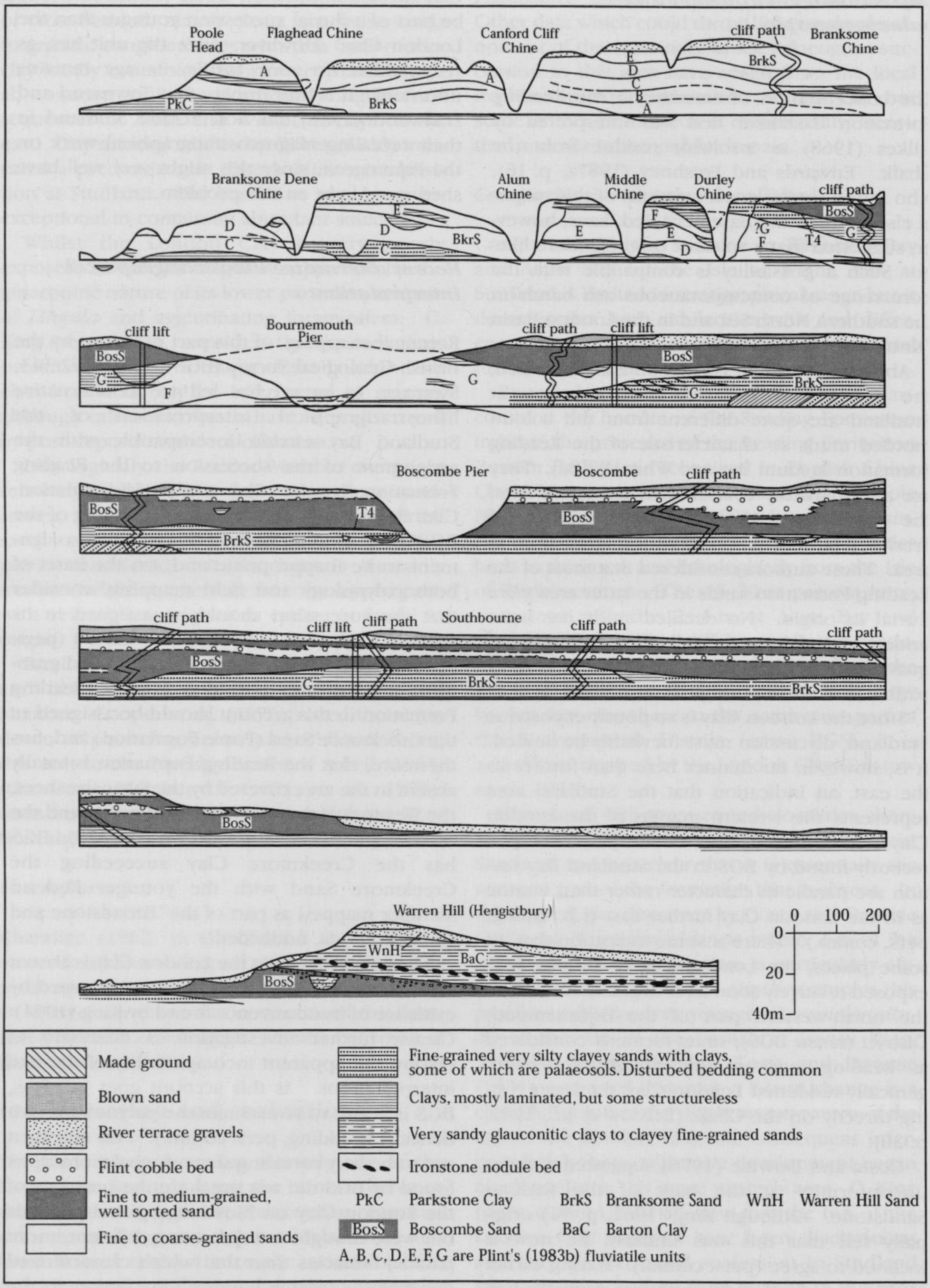

Figure 6.5 Bournemouth Cliffs and Hengistbury Head (Warren Hill), Dorset: cliff profile (from Bristow *et al.*, 1991, fig. 16).

Conclusions

Although stratigraphically limited in extent, the Studland section is important in that it throws light on the palaeogeography of Palaeocene and early Eocene times towards the western end of what is now the Hampshire Basin.

Both the Reading Formation and the London Clay are much thinner here than further to the east. Such developments appear to reflect the former close proximity of a land area not far to the west. The top of the London Clay has been dated by using species of the dinoflagellate zonal genus *Wetzeliella* and has proved to be far older here than it is further to the east in the remainder of the Hampshire Basin and in the London Basin. Either the regression of the London Clay sea began much earlier here than further east or the upper part of this formation was locally eroded away prior to the deposition of the Poole Formation.

The fluvial Redend Member, unrepresented at more easterly localities, may correlate with younger parts of the London Clay elsewhere to the east but alternatively may be younger than the latter and separated from it by an unconformity.

BOURNEMOUTH CLIFFS, DORSET (SZ 057891–SZ 138913)

Highlights

The various 'Bournemouth Cliffs' sections provide the best exposures to facilitate understanding of the western margins of the marine basin that existed in the southern British area in early Bracklesham and Barton times. Fluvial, estuarine and shallow marine conditions are represented by the Branksome Sand and Boscombe Sand whose type sections occur within the site. The succession includes flint conglomerates in the Boscombe Sand that comprise the thickest pebble beds of the British Palaeogene succession.

Introduction

Between Canford Cliffs to the west (grid reference SZ 057891) and just west of Southbourne in the east (SZ 138913), sediments of Eocene age are exposed in a number of intermittent cliff sections, originally grouped by the NCC for the purposes of conservation into two GCR sites: 'Western Bournemouth Cliffs' to the west of Bournemouth Pier (SZ 089907); and 'Eastern Bournemouth Cliffs' to the east. However, since this is geologically arbitrary, the sections of Poole, Bournemouth, Boscombe and Southbourne are here considered together as 'Bournemouth Cliffs'.

A cliff profile for Bournemouth Cliffs (from Bristow *et al.*, 1991) is given in Figure 6.5, although following cliff stabilization over a period of many years, exposures are limited. The strata present in the gently eastward-dipping succession comprise two formations, the Branksome Sand and the overlying Boscombe Sand, the former including two informal units, the Bournemouth Freshwater Beds and the Bournemouth Marine Beds.

The sediments exposed in the cliffs between Christchurch Harbour in the east and Poole Harbour in the west were first mentioned by Lyell (1827). He produced no detailed descriptions but commented on the abundance of fine sands and laminated clays with indistinct vegetable remains. He assigned all the strata present to the 'Plastic Clay Formation' which he believed underlay the 'London Clay' (what we now know as the Barton Group). He considered that the strata were horizontal and all formed from the same beds, whereas Prestwich (1849a), who examined the section in more detail, recognized that, by contrast, there were complex lateral facies variations.

The major late 19th century work on the section was that of Gardner (1877, 1879a,b,c; 1882). His 1877 paper was a general description of the section, whilst in his 1879b paper, he correlated the Bournemouth Beds (Gardner, 1879a) with the Bracklesham Beds to the east. Gardner's work on the stratigraphy of Poole Bay culminated with definitive accounts of the 'Bournemouth Beds' in which he distinguished the Bournemouth Marine Beds (1879c) and the Bournemouth Freshwater Beds (Gardner, 1882), together overlain by the Boscombe Sand. Fossil plants, first noticed by Brodie (1842) and later by Wanklyn (1869), provided a strongly palaeobotanical emphasis in certain of Gardner's papers (Gardner 1877, 1879a,b; Gardner and von Ettinghausen, 1879).

Following Gardner's work, little more was published until a visit by the Geologists' Association led by Ord (1910), who subsequently redescribed the section (1913), illustrating his

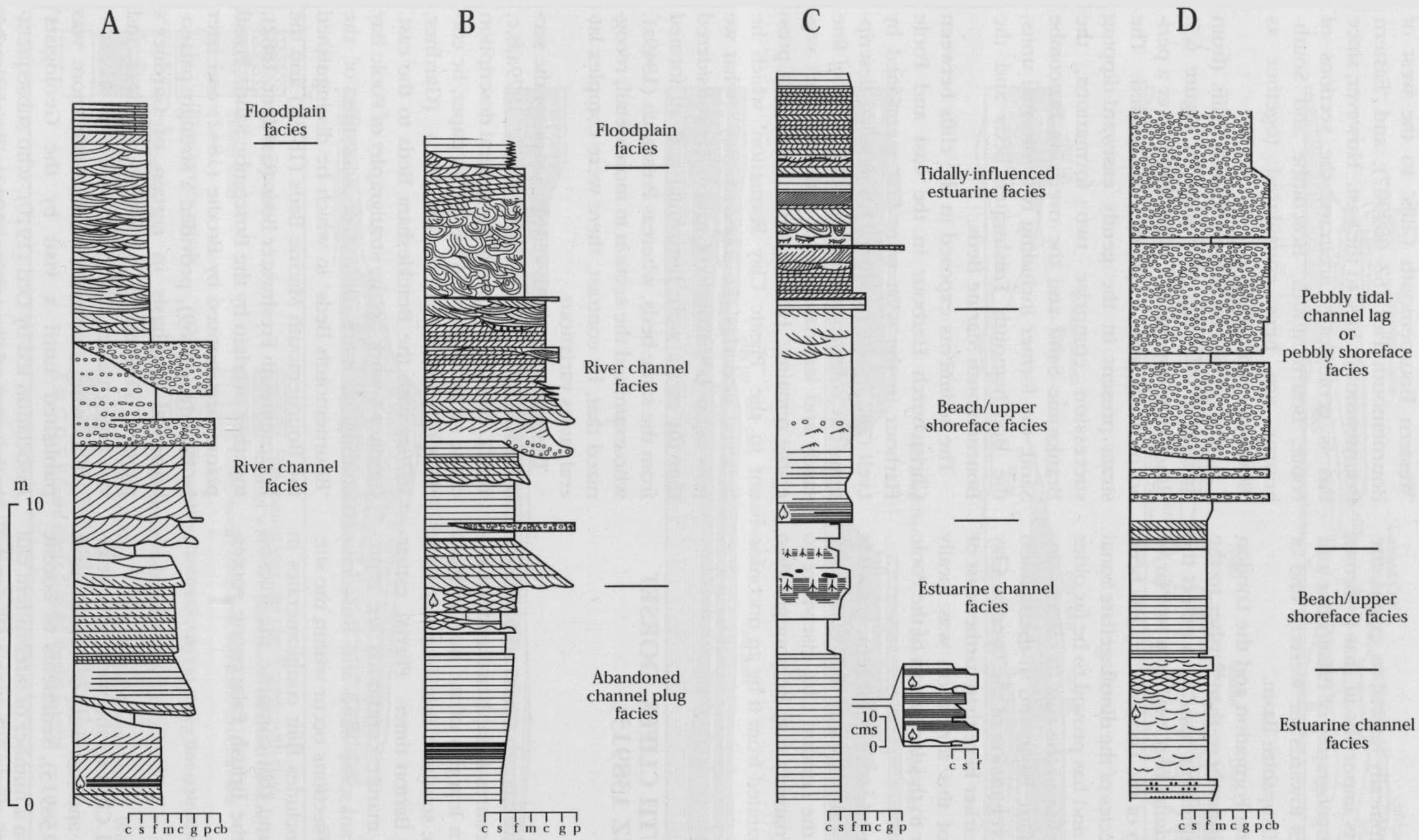

Figure 6.6 Representative vertical sections from Bournemouth Cliffs: (A) fluvial channel facies, with overbank floodplain facies at the top (Canford Cliffs); (B) fluvial facies, with the lower third channel plug facies (east of Alum Chine); (C) estuarine channel facies (Bournemouth Marine Beds) overlain by beach/upper shoreface facies, followed by tidally-influenced estuarine facies (both Boscombe Sand) (200 m west of Toft Zig-zag); (D) pebbly tidal channel lag or pebbly shoreface facies (Boscombe Sand) in upper part (east of Manor Zig-zag). Clay=c; silt=s; fine/medium/coarse sand=f, m, c; gravel=g; pebbles=p; cobbles=cb. (After Plint, 1988b.)

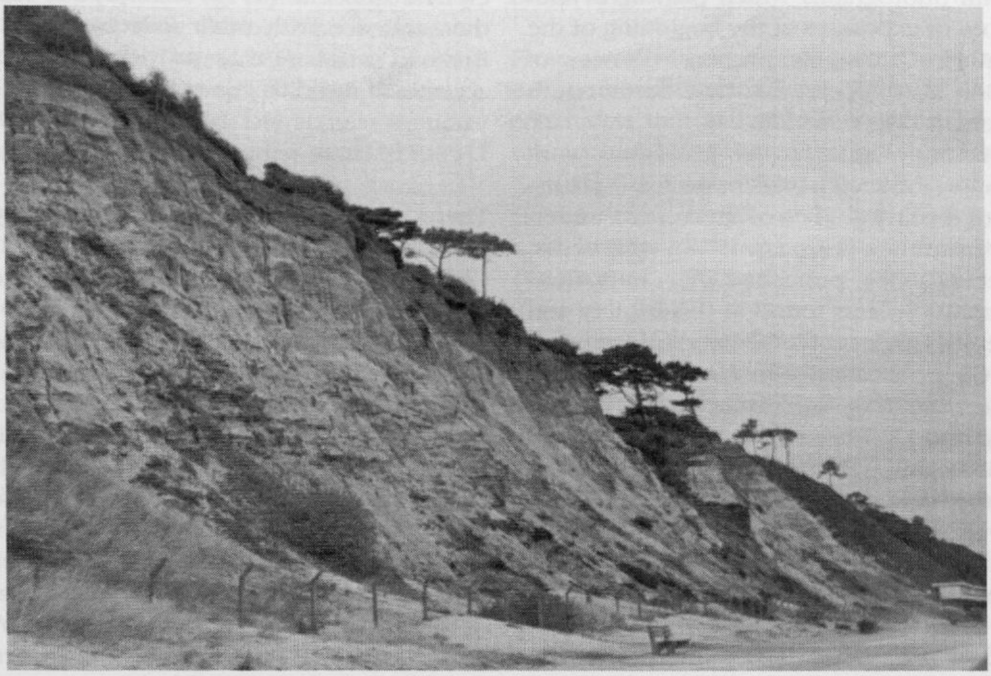

Figure 6.7 Canford Cliffs, Poole, Dorset. The Branksome Sand (overlain by thin Quaternary gravel), viewed from the west. (Photograph: B. Daley.)

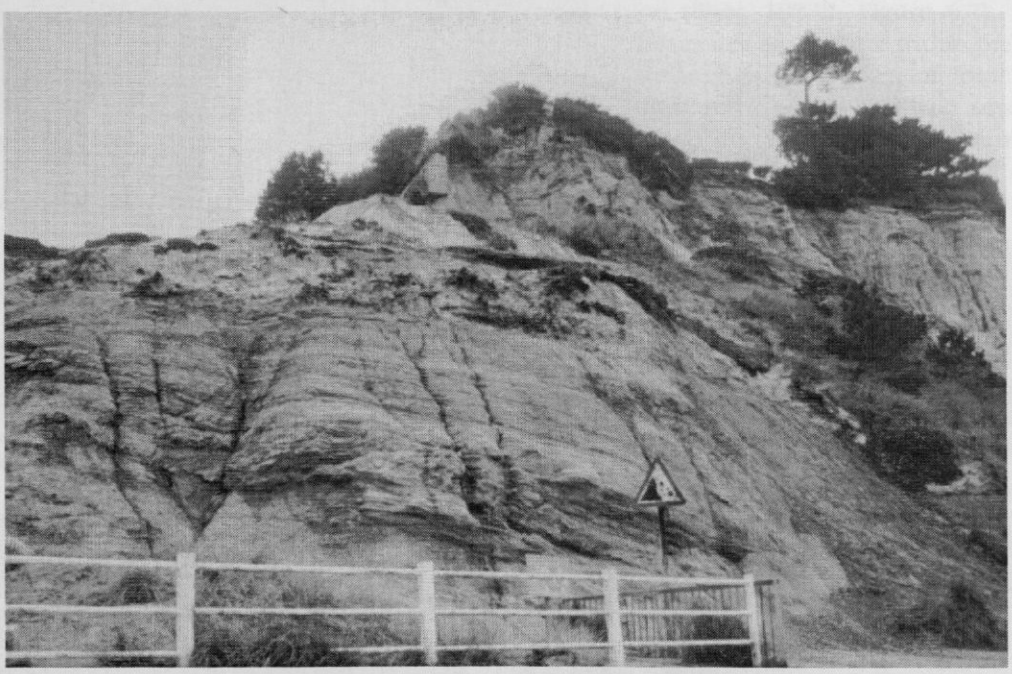

Figure 6.8 Branksome Dene Chine, Poole, Dorset. Laminated channel plug facies in the Branksome Sand, exposed immediately to the east of the chine. (Photograph: B. Daley.)

paper with photographs which provide a valuable record of exposures at the beginning of the 20th century. Quite a comprehensive review of the section also appears in the Bournemouth Sheet Memoir (White, 1917).

Until recently, little further geological work was done on the section except on fossil plants. Early 20th century studies of these were undertaken by Bandulska (1923a,b; 1928), whilst later, Chandler (1963b) published her important monograph on plants found at this locality and further eastwards near Mudeford.

The IGS publication *The Hampshire Basin and adjoining areas* (Melville and Freshney, 1982) figured Gardner's (1882) cliff profile of the section, although it is misleading as far as present-day exposures are concerned. More recent work has led to the publication of a more up-to-date geological cliff profile (Daley and Crewdson, 1987; Plint, 1988b; Bristow *et al.*, 1991).

In recent years, Plint (1980, 1983a,b, 1988b) has studied the sedimentology and palaeoenvironments of 'Bournemouth Cliffs' in the context of wider research into the Eocene geology of the Hampshire Basin. Microfloral studies undertaken by Costa *et al.* (1976) attempted to correlate the sequence with other Palaeogene sections. Bristow *et al.* (1991) provides an excellent account of the cliffs in a regional context.

Description

There are eight major present-day exposures. Four occur within the 'Western Bournemouth Cliffs' GCR site:

1. Canford Cliffs
2. Branksome Dene Chine
3. Alum Chine to Middle Chine
4. Durley Chine.

The remainder comprise part of the 'Eastern Bournemouth Cliffs' GCR site and are:

5. East Cliff Zig-zag to Toft Zig-zag
6. West of Boscombe Pier
7. Manor Zig-zag
8. Portman Ravine to Southbourne.

The significance of the 'Bournemouth Cliffs' section is that the succession is quite different

Figure 6.9 Boscombe, Dorset. Pebble bed in the Boscombe Sand, overlain by Quaternary gravel (brown), exposed immediately east of Fisherman's Walk Zig-zag. (Photograph: B. Daley.)

from those of equivalent age towards the eastern end of the Hampshire Basin. The sediments here represent the western margins of the Eocene sea, this being emphasized in 'Bournemouth Cliffs' by the, in part, lateral juxtaposition of coeval marine and non-marine strata.

Lithological succession

Two formations are represented in Bournemouth Cliffs: the Branksome Sand, overlain by the Boscombe Sand. Whilst Bristow *et al.* (1991) stated that the former has a thickness in the Bournemouth area of 70 m, it is difficult to determine its thickness in Bournemouth Cliffs in the shallow-dipping and intermittently exposed sections. A 22 m section occurs just to the east of Bournemouth Pier but this represents only a small part of the whole. The Branksome Sand comprises a variety of clastic lithotypes. At the western end of Bournemouth Cliffs, mainly medium to coarse-grained sands with subsidiary mud-clast conglomerates and 'pipe clays' (kaolinitic 'ball clays') are interbedded with and enclose lenticular, laminated mudstone bodies. To the east of Bournemouth Pier the latter are associated with finer grained sands.

The Boscombe Sand has a regional thickness of between 20 and 27 m (Bristow *et al.* (1991) but considerably less than this is exposed in the cliff sections. It first appears towards the top of the cliff just to the east of Durley Chine (Figure 6.5); it thickens generally eastwards, whence it descends the cliff to reach shore level at the eastern end of the section. The formation mainly comprises clean sands but in places contains flint conglomerates forming lenticular bodies.

Stratigraphy

Recognition that the Bournemouth sequence is lithologically distinct, led Edwards and Freshney (1987b) to establish the Bournemouth Group. Subsequently, this has been superseded by assigning these sediments to the Bracklesham Group (see discussion in Bristow *et al.*, 1991). Its local upper formation, the Branksome Sand, has the section of cliffs from Boscombe Pier (SZ 112911) westwards to Poole as its stratotype. The cliffs between Boscombe Pier and Hengistbury Head are the stratotype for the overlying Boscombe Sand, the lowest formation of the Barton Group (Edwards and Freshney, 1987b).

Biostratigraphy

From a study of the dinoflagellate flora from the Bournemouth Marine Beds, Costa *et al.* (1976) concluded that at least the upper part of this unit could be assigned to the uppermost of Eaton's (1971a,b; 1976) 'Bracklesham Zones' (his *A. undulata–D. craterum* Zone) known now as the *Cyclonephelium intricatum* Zone (Bujak *et al.*, 1980).

Sedimentology and palaeontology

The sedimentological and palaeogeographical significance of the site has recently been emphasized by the work of Plint (1980, 1983a,b, 1988b), who has described a variety of facies ranging from those of fluvial origin in the central and more westerly exposures to those of estuarine and shallow marine nature further eastwards (Figure 6.6).

Plint (1983b) described the fluvial beds in detail and recognized nine facies (reduced to four in Plint, 1988b), representing a range of environments from high-energy, active to abandoned river channels. The former are particularly well-represented by the predominantly sandy sediments of Canford Cliffs and the upper part of the section to the east of Branksome Dene Chine (Plint, 1983b; Figure 6.7). Mud-clast conglomerates are present within the sandy facies, as are lenticular bodies of 'pipe clay'. Altogether, Plint (1983a) recognized seven fining-upwards cycles in the fluvial Branksome Sand, increased to eight by Bristow *et al.* (1991) by an additional one at the base (see Figure 6.5).

Spectacular channel plugs comprising thinly laminated fine-grained sands, silts and clay are exemplified by that at the base of the cliff immediately east of Branksome Dene Chine (see Plint 1983b, fig. 7; Figure 6.8). That some of these fills reflect rapid abandonment (neck cut-offs) is shown where such sediments rest on the channel sands with a sharp contact, such as may be seen just west of Middle Chine. Some of the muds are carbonaceous, whilst plant debris may also occur. Fruits and seeds were found by Chandler (1963b, p.10) in the channel plug near Branksome Dene Chine. Marine dinoflagellates have also been recorded in some of these channel plugs (Bristow *et al.*, 1991).

A particularly striking and palaeogeographically significant section occurs between East Cliff Zig-zag and Toft Zig-zag. Towards the base of the cliff just eastwards of the chairlift, the lateral junction of the Bournemouth Freshwater Beds and the Bournemouth Marine Beds may be observed, although the former also extend below the latter for some distance further east. The junction is complex, and slump, ball and pillow, and water-escape structures are notable features, which Plint (1983a) interpreted as resulting from the gravity-induced deformation of an estuarine channel margin.

A few hundred metres east of the chairlift, thinly-bedded and laminated silty muds and fine sand, with a primary depositional dip of about 5°, have been interpreted as estuarine channel plugs by Plint (1983a, pp. 637–8). Plant debris is common and in-situ roots occur at two levels. Chandler (1963b, p. 14) listed a small number of fossil plants from this locality. Neither Ord (1913) nor Plint (1988b) could find the 'mixed' marine, brackish and freshwater molluscan fauna recorded here by Gardner (1879c).

Between Bournemouth and Boscombe, the Boscombe Sands is exposed intermittently towards the upper part of the cliffs, the base of the formation dipping eastwards to reach shore level near Southbourne. The unit mainly comprises well-sorted sands. More westerly exposures and those higher up further to the east are characterized by bidirectional cross-stratification, whilst the lower part of the formation towards the east is characterized by sands with planar lamination. Plint (1983a, 1988b) interpreted the former as indicative of an estuarine tidal channel situation, whilst the latter represents beach and upper shoreface conditions.

Just east of Manor Zig-zag, the Boscombe Sand includes an excellent exposure of lenticular pebble beds interbedded with pale sands, which Prestwich (1849a) described as forming, 'for its limited extent, the most important conglomerate bed in the English Tertiaries' (Figure 6.9). The pebble beds are clast supported and contain well-rounded and relatively well-sorted flint pebbles up to 20 cm in diameter. Plint (1983a, p. 633) suggested that the conglomerates represent beach pebbles transported into the mouth of an estuary by longshore drift.

Interpretation and evaluation

The importance of 'Bournemouth Cliffs' is that it is the only existing exposed section at which evidence for the western limits of the late Bracklesham to early Barton sea may be found. Uniquely, the junction of marine and non-marine sediments can be observed rather than just inferred as is normally the case where palaeogeographical 'boundaries' are concerned.

Dating and correlation

From a study of the dinoflagellates, Costa *et al.* (1976) were able to correlate the 'Bournemouth Cliff' sediments with the better known sections on the Isle of Wight. Costa *et al.* (1976) considered that the Bournemouth Marine Beds and the overlying Boscombe Sand together might be equivalent to Prestwich Beds 25–28 in Alum Bay. In concurring with this view, Edwards and Freshney (1987b, fig. 2) specifically matched the Boscombe Sand with Bed 28 in Alum Bay. Figure 3 of Costa *et al.* (1976) implies a correlation of the Bournemouth Marine Beds with Bed 27 of Alum Bay. Plint (1988b), by contrast, suggested a correlation with Bed 24, although the dinoflagellate assemblages of the latter considerably pre-date those found in the Bournemouth Marine Beds (Costa *et al.*, 1976, p. 282).

Stratigraphical definition and nomenclature

Lithologically, the difference between the 'Bournemouth Cliffs' sediments and those further east has long been recognized. This has led to the use of a number of nomenclatural systems for these strata, which in part have recognized their distinctiveness and yet have sought a correlation of the section with those elsewhere.

The subdivision by Gardner (1879c, 1882) into Bournemouth Freshwater Beds, Bournemouth Marine Beds and Boscombe Sand was used for many years, but has given the British Geological Survey a few problems (see Edwards and Freshney, 1987b, p. 54). White (1917), for example, found it impossible to map the first of these and the underlying 'Lower Bagshot Series' separately, and grouped them as 'Bagshot Beds'. Whilst the Bournemouth Marine Beds were allocated to the Bracklesham Beds, even that distinction is unmappable away from the coast.

The grouping together of Gardner's three units into the Bournemouth Formation by Curry *et al.* (1978) was rejected by King (1981, p. 13) as invalid due to inadequate definition. Plint (1983a) included these units within his Bracklesham Formation, but, as Edwards and

Freshney (1987b, p. 46) pointed out, his use of the term was chronostratigraphical and hence lithostratigraphically invalid.

Plint (1988b) has, however, in turn questioned the value of grouping the Bournemouth Freshwater Beds and the Bournemouth Marine Beds by these authors into a single unit, the Branksome Sand. Whilst conceding that this may be justified from the point of view of mapping, he implies that doing so plays down the sedimentological differences vital in determining palaeoenvironments. Giving these two units formal member status was not suggested by Bristow *et al.* (1991), and it is evident from recent work that neither are unequivocally freshwater and marine as was once thought.

Palaeoclimatology

Palaeontologically and palaeoclimatically, 'Bournemouth Cliffs' is of considerable importance. Although devoid of animal fossils, excepting the old record of Gardner (1879c), it is a major locality for fossil plants (Chandler, 1963b). Apart from the small macroflora described by Crane (1977) from Prestwich 'Bed' 24 in Alum Bay, the Bournemouth macroflora is the only one known at this stratigraphical level in the Hampshire Basin. Apart from its innate palaeontological importance, it is significant palaeoclimatologically. Chandler (1964, pp. 68–9) had little doubt of its tropical nature, although changes in the microflora elsewhere at this level indicate gradual climatic cooling (Collinson *et al.*, 1981).

Depositional environment and palaeogeography

Only in recent years, particularly through the work of Plint, has the sedimentological and palaeogeographical importance of the 'Bournemouth Cliffs' sequence been realized. The 'fluvial' sediments of the Bournemouth Freshwater Beds represent a wide variety of environments. Plint (1988b) interpreted the various constituent facies as representing meandering rivers in which channels, levees, channel plugs and flood basins were identifiable. The channel plug facies are some of the best examples of their type in the British stratigraphical column. Whether the fluvial facies is that of a meandering river is open to some doubt. The lack of laterally continuous overbank muds and the generally lenticular geometry of much of the sequence indicates that it may have a braided stream origin. Recently, Bristow *et al.* (1991, p. 57) have pointed out that since some of the mud units contain sparse marine dinoflagellate cyst assemblages, these deposits cannot be solely fluvial since there must have been some access to the sea.

Together, the deposits of the Bournemouth Marine Beds and much of the Boscombe Sand provide one of the best examples of estuarine facies in the British stratigraphical succession. Much of the former comprises heterolithic, but essentially muddy, sediments (facies G of Plint, 1988b, p. 132 or Cycle G in fig. 33) which accumulated in tidal areas of variable salinity (cf. Gardner, 1879b, c) and which, from the amount of plant debris present, was adjacent to rivers draining a well-vegetated hinterland. The section some 250 m west of Toft Zig-zag is a particularly fine example of low-angle, depositionally inclined stratification. Although referred to as an estuarine channel plug by Plint (1983a, p. 638), it may be considered as a very fine example of sedimentation of a laterally accreting point bar of a sluggish, muddy estuarine channel system. The shallowness of the water at times is indicated by rooted horizons (?palaeosols), presumably representing tidal (?salt) marshes, whilst thin, graded beds may represent fluctuating tidal activity or fluvial discharge. To a certain extent these sediments resemble those forming the channel plugs in the Bournemouth Freshwater Beds; both reflect muddy channel sedimentation.

The onset of the Boscombe Sand represents a transgression (T4 transgression of Plint, 1983a), with its clean, bi-directionally cross-bedded sandstones providing a fine example of deposition in a tidal channel complex, although the lower part of the succession towards the eastern end of 'Bournemouth Cliffs' is thought to represent beach and upper shoreface sedimentation (Plint, 1988b).

Pebble provenance and tectonism

The flint conglomerates developed within the Boscombe Sand represent a unique occurrence in the Palaeogene succession, since although thin flint pebble beds occur above transgressive surfaces at a number of horizons in the Palaeogene of the Hampshire Basin, there is no other instance of flint conglomerate reaching a thickness of up to 14 m (Plint, 1988b, p. 132). In composition, they are different from the petromictic conglomerates present at Bincombe and Blackdown; hence a fluvial derivation from the west seems unlikely. Clearly they indicate a source which is either exposed Upper Chalk or an earlier gravel derived from the latter. Plint (1988b, p. 132) suggested that the pebbles had probably been transported by longshore drift into an estuarine environment to accumulate in channels or in a shoreface situation whilst Bristow *et al.* (1991, p. 69) proposed a storm beach origin.

Some of the flint pebbles from these conglomerates provide vital information about the evolution and uplift of major tectonic structures during Tertiary times. Curry (1986) found that a few pebbles that had 'decayed' contained foraminifera unknown from the Chalk of the English mainland, but characteristic of late Maastrichtian levels in continental Europe. He concluded that the nearest source of such material was to the south over 50 km away near the 'Central Channel Structure' (Smith and Curry, 1975). The implication of this conclusion is that local derivation of the Boscombe Sand conglomerates by longshore drift does not adequately explain the presence of such pebbles. More significantly, the Maastrichtian pebbles in the Boscombe Sand travelled from the south across the Purbeck–Isle of Wight line, which, if active at that time, would have acted as a barrier to such movement. Curry (1986) therefore concluded that, at least at that time, the eastern half of the Purbeck–Isle of Wight structural line was quiescent or had not been initiated.

Conclusions

'Bournemouth Cliffs' provide a great deal of information to facilitate our understanding of sedimentation in the more westerly part of the Hampshire Basin.

Although apparently devoid of animal fossils, the sections contain a diverse macroflora. This site is important as it contains the only well-preserved flora at this stratigraphical level in the Hampshire Basin sequence. It perhaps represents the youngest of the 'tropical' floras of the Hampshire and London Basin successions.

'Bournemouth Cliffs' contain sediments representing a wide range of environments including fluvial, estuarine and shallow marine. Fluvial sediments are particularly well-developed towards the western end of the site, although the rivers they represent were close to the sea. Amongst the various facies present are superb examples of channel plug sedimentation. More easterly localities include sections in the Bournemouth Marine Beds and Boscombe Sand which are thought to provide some of the best examples of estuarine sedimentation in Britain.

The presence of thick flint conglomerates in the Boscombe Sand is exceptional in the local Tertiary. Pebbles probably derived from Maastrictian Chalk exposed well to the south in the central part of the English Channel indicate that no local barrier reflecting movement along the eastern half of the Purbeck–Isle of Wight tectonic line existed at that time.

The designation of the Bournemouth Group (although now superceded) recognized that at this stratigraphical level, the sequence towards the western end of the Hampshire Basin is different from the essentially coeval Bracklesham Group found further to the east. The importance of 'Bournemouth Cliffs' is apparent from its being the stratotype for both the Branksome Sand, locally the uppermost formation of the Bracklesham Group, and also the overlying Boscombe Sand. It provides a vital stratigraphical link between the marine strata of more easterly localities such as those on the Isle of Wight and the thick fluvial sediments of the Wareham Basin to the west.

HENGISTBURY HEAD, DORSET (SZ 167907–SZ 181906)

Highlights

Hengistbury is stratigraphically important since it facilitates correlation of the more westerly exposures of strata adjacent to the Bracklesham Group/Barton Group junction with those further to the east. Palaeoenvironmentally, the site has helped geologists to better understand lateral changes in the Boscombe Sand and it is also the best exposure of the marginal sandy facies of the Barton Clay.

Introduction

The site comprises a sea cliff on the southern side of the Hengistbury Head peninsula (grid reference SZ 167907 to SZ 181906; Figure 6.10). Three lithostratigraphical units of Eocene age

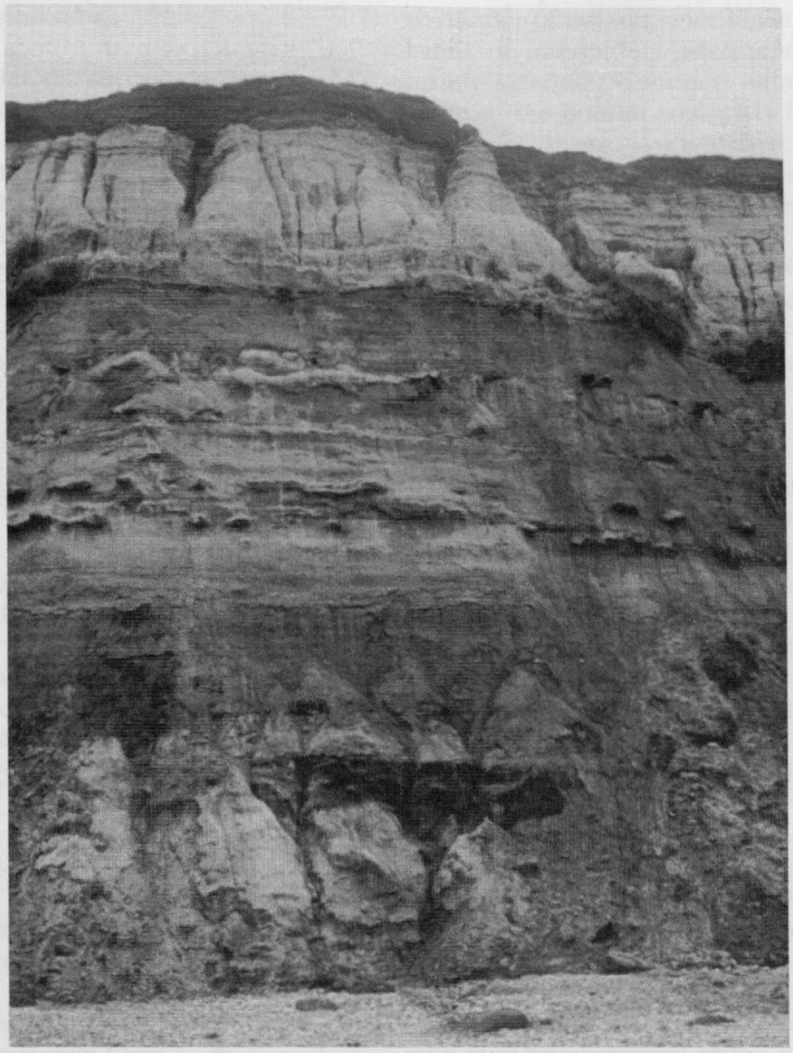

Figure 6.10 Hengistbury Head, Dorset. Succession from the Boscombe Sand at the base to the Warren Hill Sand Member of the Barton Clay at the top. (Photograph: B. Daley.)

are present. Historically, they have been referred to, in ascending order, as the Boscombe Sand, Hengistbury Beds and Highcliffe Sands. The Boscombe Sand is now recognized as the lowest formation assigned by Edwards and Freshney (1987b) to their Barton Group. The others correlate with the lowermost strata of the Barton Clay, exposed in 'Barton Cliffs' further to the east (Hooker, 1975a; Curry, 1976). Recently (Bristow *et al.*, 1991), the highest of the three has been formally renamed the Warren Hill Sand Member of the Barton Clay (Figure 6.11).

The section has attracted the interest of geologists since the early part of the 19th century. A great deal of attention has been paid to the stratigraphical position and correlation of the succession since, although now resolved, this was a matter of considerable controversy over a number of years (see below). A good stratigraphical account is given in Hooker (1975a), whilst Curry (1976, fig. 1) also provides a useful summary of the sequence.

Palaeontological work on the section includes that of Reed (1913) who listed molluscs, fish, an echinoid and a crustacean; Chapman (1913) on the agglutinated foraminifera; Curry (1942), who made the significant discovery of *Nummulites prestwichianus*; and Chandler (1960), who described the plant macrofossils. Both Hooker (1975a) and Curry (1976) include useful palaeontological data, whilst Hooker (1977a) described the mammal *Lophiodon* from

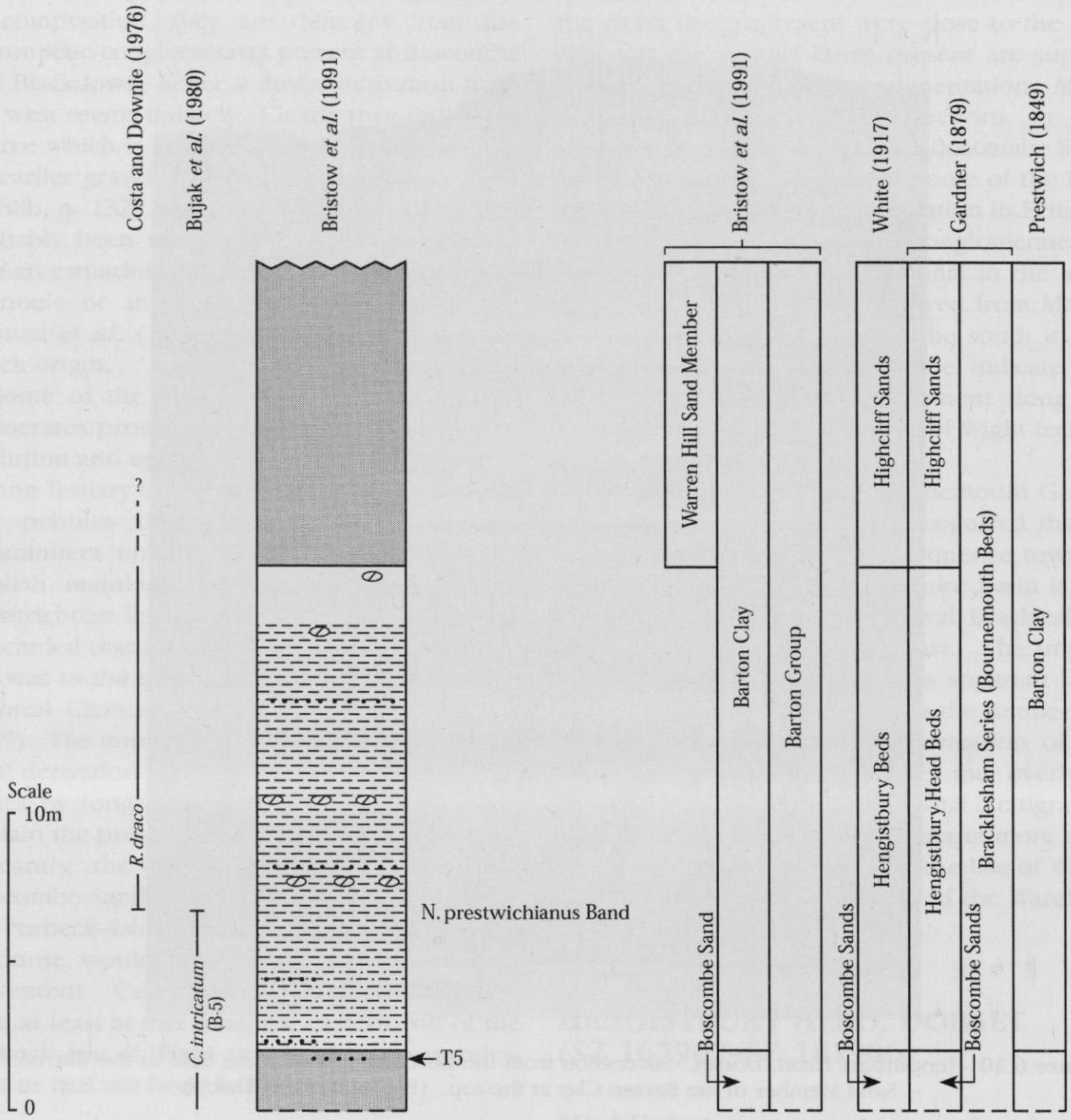

Figure 6.11 Generalized succession of the Barton Clay at the western end of Hengistbury Head, Dorset (mainly after Bristow *et al*., 1991, fig. 18). T5 refers to the T5 transgression of Plint (1983a).

the Barton Clay at this site. Costa *et al*. (1976) worked here on the dinoflagellate microflora as part of a broader correlative study.

Although Tylor (1850) considered the economic importance of the sideritic nodules in the section, it is only in recent years that the broader sedimentological aspects have been investigated. Plint (1983c) made a detailed study of the Boscombe Sand, also referred to briefly in his more comprehensive paper (1983a) on middle Eocene environments and facies and that recently published on the Eocene strata between Poole Harbour and High Cliff (Plint, 1988b). The most up-to-date account of the Hengistbury sediments is that of Bristow *et al*. (1991, pp. 66–7).

Description

The Hengistbury section is of considerable stratigraphical significance since it provides a valuable 'bridging' exposure between the more westerly sequences exposed around Bournemouth and beyond, and those further eastwards on the mainland and on the Isle of Wight.

Lithological succession

In ascending order, the succession (Figure 6.11) comprises the Boscombe Sand (about 8 m) and the Barton Clay, including what has historically been called the Hengistbury Beds (about 16 m) and the Warren Hill Sand Member (formerly the Highcliffe Sands; 9 m). The Boscombe Sand includes 'bitumen'-impregnated sands. Above, rolled flint pebbles are followed by muddy sands and sandy muds with a few flint pebble bands and ironstone nodules at four levels (Hengistbury Beds); these are succeeded by the light-coloured fine-grained sands of the Warren Hill Sand Member.

Stratigraphy

The first account of the succession was apparently that of Lyell (1827) who assigned the strata at Hengistbury to the 'plastic clay formation' (i.e. the Reading Formation), stratigraphically *below* the 'London Clay' (sic) of Barton (i.e. what is now the Barton Clay). Prestwich (1849a) took a contrary view, concluding that, on both lithological and palaeontological grounds, part of the succession represented a westerly reappearance of the Barton Clay. Over a period of years, Gardner (1879c), Reed (1913), White (1917) and Stamp (1921) expressed differing views and only relatively recently (see particularly Curry, 1976) has the matter been resolved, and the 'Hengistbury Beds' recognized as the lower part of the Barton Clay.

Microfaunal discoveries at the site helped to resolve the controversy. Curry (1942) found *Nummulites prestwichianus* 4.6 m above the base of the 'Hengistbury Beds'. In a study of the dinoflagellate flora, Costa *et al*. (1976) found that the zone fossil *Wetzeliella draco* first appears immediately above the *N. prestwichianus* band, with their *Heteraulacacysta*? sp. *A*. (*H. porosa*) about 1.5 m above. These two species define the base of Zone Bar-1 of Bujak *et al*. (1980), the oldest of the five 'Barton Beds Zones' defined by these workers.

Sedimentology

The Barton Clay below the Warren Hill Sand Member comprises some 16 m of sandy muds to muddy sands, its base being marked by a layer of well-rounded flint pebbles. The lowest 3–5 m are highly bioturbated and glauconitic. The remainder of the sequence includes five nodule bands of intermittent persistence. These are mainly sideritic ironstones, although the third set from the bottom comprises ball and pillow structures.

Lateral variation in the Barton Beds at Hengistbury Head has been referred to by Hooker (1975a, p. 118 and fig. 5). Whilst the nodule bands are less well-developed to the west, an increase in the sand and silt content in this direction is accompanied by an increase in the frequency of pebble bands within the sequence.

Good exposures of the Boscombe Sand occur at Hengistbury and comprise cross-bedded quartzose sands with flint pebbles, either scattered or in bands. The uppermost part of the Boscombe Sand comprises a clean, very well-sorted, fine-grained sand, up to 1.25 m thick, with a pebble bed locally developed at its base (Bristow *et al*., 1991, p. 66) and which Plint (1983c) considered to mark the base of his T5 transgression. Body fossils are absent from the Boscombe Sand here, but Plint (1983c) recognized the trace fossils *Ophiomorpha* and *Thalassinoides*.

A spectacular feature of the Boscombe Sand at Hengistbury is the development of what appear to be 'bitumen'-impregnated sands which have been contemporaneously deformed and eroded, thereby demonstrating the synsedimentary origin of the 'bitumen'. The bituminous sands are mainly developed in the banks and eastern flank of a mud-filled channel in the Boscombe Sand, where they reach a maximum thickness of 2.5 m. According to Plint (1983c), the bitumen has 'the characteristics of a 'type 2' bitumen, probably derived, in large part from the waxy cuticular coatings of plant leaves'. An unusual feature is the occurrence of contemporaneously eroded sand (not sandstone) pebbles, rendered cohesive by their bitumen 'cement'. These, together with fluidization and water-escape structures, have been described by Plint (1983c) in some detail. He also noted the interesting point that unlined *Thalassinoides* burrows in the bituminous sands pass into lined *Ophiomorpha* burrows in the clean sand (Plint 1988b, p. 131); an excellent illustration of how burrowing animals respond to changing circumstances.

Interpretation and evaluation

The prime importance of this site has centred around the relationship of the beds here to those further east, and secondly that it provides a link between the contrasting successions both to the west and the east.

Stratigraphical affinity of the Hengistbury Beds

Much of the interest in the section over many years has centred on the stratigraphical position and correlation of the succession. In particular, the disputes that arose concerned the question of the relationship of the 'Hengistbury Beds' to the Barton Clay succession exposed to the east of Christchurch Harbour. Was the Hengistbury Head succession, as implied by Lyell (1827), older than the Barton Beds to the east or was it, as Prestwich (1849a) suggested, that at least part of the succession represented a westerly reappearance of the Barton Clay?

Lyell (1827) was undoubtedly influenced by the apparently constant and gentle easterly dip on both sides of Christchurch Harbour, from which he assumed that the succession at Hengistbury dips below that found at Friars Cliff to the east. Gardner (1879c) supported Lyell's view and assigned all the strata at Hengistbury to the 'Bracklesham Series'. To the lowest sands he gave the name the Boscombe Sand. The clays and silts above he called the Hengistbury Head Beds (subsequently the Hengistbury Beds), whilst the sands higher up were correlated with those *below* the Barton Clay at Friars Cliff which he had called the Highcliff Sands and which we now know as the Boscombe Sand (see separate site review).

Reed (1913) supported Prestwich (1849a), for he found fossils in the 'Upper Hengistbury Beds' that had Barton Beds affinities. White (1917), however, was dismissive of Reed's view, maintaining that the molluscs listed by the latter ranged down into the Bracklesham Beds. Stamp (1921, pp. 153–4, fig. 3) followed Lyell and Gardner, regarding the Hengistbury Beds as a westerly continuation of the marine beds of the 'Upper Bracklesham Beds' cyclothem.

Curry's (1942) discovery of *N. prestwichianus* 4.6 m above the base led to a suggested correlation of this unit with the lowest Barton Beds. In 1958, he repeated this view and suggested that the sands above the Hengistbury Beds might equate to Burton's (1933) horizon A_3 of the Barton Beds at Highcliffe, i.e. the 'High Cliff clays and sands' of Wright (1851), and that the underlying Boscombe Sand at Hengistbury correlates with the 'Highcliff Sands' of Gardner (1879c). In a more recent review of the Hengistbury dispute, Curry (1976) reiterated his earlier conclusion, whilst in the same year, Costa *et al.* (1976) found dinoflagellate evidence confirming Curry's interpretation. Recent mapping by the British Geological Survey has suggested the presence of a fault, the Christchurch Fault, which provides a mechanism for the repetition of the Barton Clay at Hengistbury.

Palaeogeographical significance and depositional environment

With the resolution of the correlation 'problem', the importance of Hengistbury in helping us to understand the palaeogeography of Barton Beds 'times' is apparent. It appears that the Hengistbury Beds represent a sandy 'marginal marine' facies compared with the contemporaneous muddy 'offshore' facies found further to the east. Chapman (1913) suggested a tidal estuarine origin from the agglutinated foraminifera that he had found. Murray and Wright (1974, p. 50) concurred with the possibility of hyposaline conditions and suggested a marsh regime (p. 63), but Curry (1976) preferred to interpret the fauna as representing the open sea whilst conceding that the land was not far away.

Although, over the years, a great deal of attention was paid to the 'Hengistbury Beds', the importance of the Boscombe Sand at this site cannot be ignored. Apart from the extremely unusual bituminous sand development and associated erosional and deformational structures, the nature of the Boscombe Sand here has implications for our understanding of the palaeogeography.

Plint (1983a,c) considered that at Hengistbury, the Boscombe Sand comprises a 'lower' estuarine tidal channel facies which correlates westwards towards Bournemouth with more upriver estuarine sediments and with what he considers to be 'distributary mouth bar' facies to the east at Friars Cliff. The channel facies at Hengistbury is in part exceptional because of the development of a bituminous cement which has exercised a unique influence on both physical and biological syndepositional processes. In addition to its influence on structures already discussed, it has produced a 'clastic firm ground'. This bituminous subfacies alone merits further geochemical and sedimentological investigation.

Conclusions

The stratigraphical position and age of the strata exposed in the Hengistbury Head section emphasizes the national importance of this site in the correlation of the western sections of Bournemouth and beyond with those to the east on the mainland and the Isle of Wight. In this regard, the recognition that the 'Hengistbury Beds' are actually part of the Barton Clay has been of primary importance.

Hengistbury has proved to be a key site palaeoenvironmentally, for it has contributed to our understanding of the lateral facies changes that characterize the Palaeogene rocks in this area. The Boscombe Sand at Hengistbury comprises a 'lower' estuarine facies, linking the 'upper' estuarine facies found near Bournemouth with the 'distributary mouth bar' facies of Friars Cliff. The section also provides the best exposure of the sandy 'marginal marine' facies of the Barton Clay.

The bituminous sands in the Boscombe Sand render this site of considerable significance, since they are unique in the British Palaeogene succession and indeed exceptional in a more universal context. These sands, apparently impregnated contemporaneously by plant-derived bitumen, produced a 'clastic firm-ground' on the sea floor and influenced a quite unusual development of erosional and deformational structures.

FRIARS CLIFF, MUDEFORD, DORSET (SZ 195927)

Highlights

This site provides a link between the Bournemouth and Hengistbury sections to the west and those of the Isle of Wight to the east. The unusual Boscombe Sand sediments here represent mouth bars at the seaward end of tidal channels and also contain some of the most spectacular soft sediment deformation structures in the local Palaeogene succession.

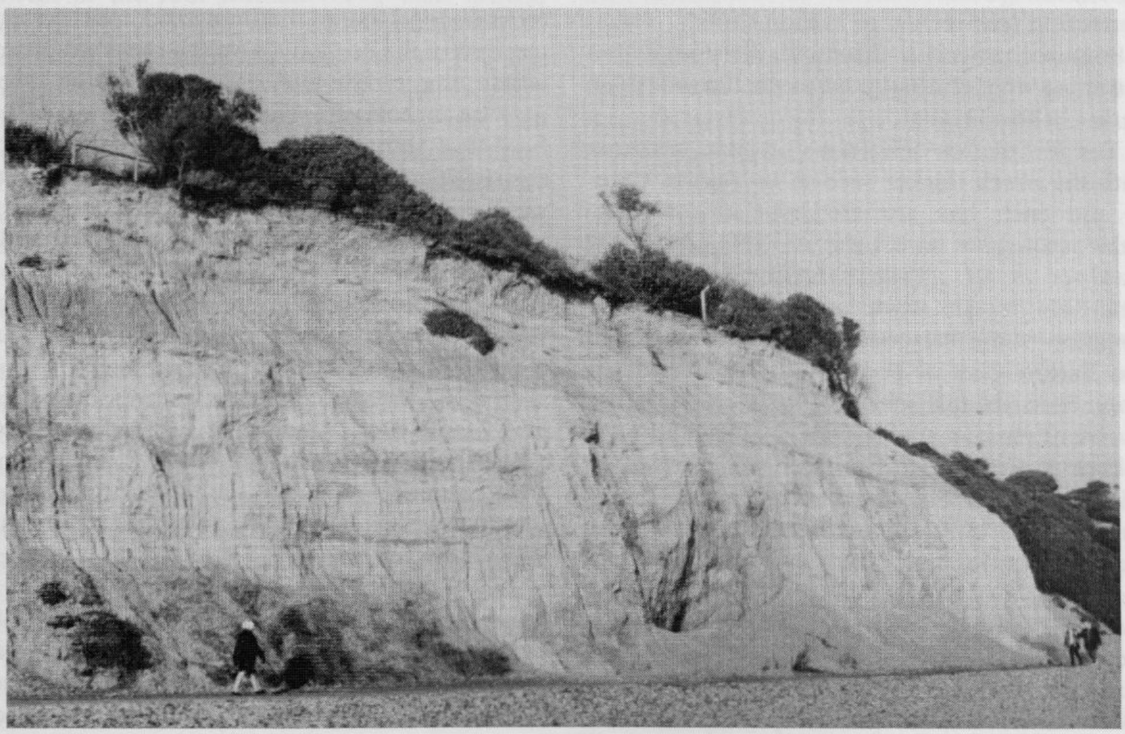

Figure 6.12 Friars Cliff, Mudeford, Dorset. Boscombe Sand (Barton Group), succeeded by the Barton Clay (greenish), below a cover of Quaternary Gravel at the top of the cliff. Water-escape deformation structures are present in the Boscombe Sand towards the right of the photograph. (Photograph: B. Daley.)

Introduction

The site comprises sea cliffs (Figure 6.12) bounded to the west by a concrete sea wall and promenade (grid reference SZ 195927), with exposures continuing westwards above the latter for a short distance. From the eastern end of the section (around SZ 199928), a well-vegetated cliff separates the site from Highcliffe and the long series of sections described elsewhere in this review under the heading of 'Barton Cliffs'. The strata present comprise the Boscombe Sand, a formation now assigned to the Barton Group of Edwards and Freshney (1987b, p. 65), and the lowest part of the overlying Barton Clay (Bed A_0).

The earliest description of Friars Cliff is probably that of Prestwich (1849a) in which he briefly surveyed the coastal geology from Christchurch to Poole Harbour and introduced such names as the Barton Beds and Boscombe Sand. In a later study, Gardner (1879c) gave the name Highcliff Sands to the sands below the Barton Clay at Friars Cliff, although the term 'High Cliff sands and clays' had already been used by Wright (1851) for what is now unit A_3 of the Barton Clay Formation (see review of 'Barton Cliffs'). Fisher (1862) recognized a threefold division within the strata which he assigned to the 'Bracklesham Series' at this locality.

The few metres of Barton Clay here, together with the much thicker section in 'Barton Cliffs' to the east, has attracted the attention of palaeontologists since the 19th century, e.g. Gardner *et al.* (1888) and Burton (1933). Relatively recent work on the dinoflagellate zonation of the Palaeogene has established that the Barton Clay of Friars Cliff lies within the Zone BAR-1 of this scheme (Bujak *et al.*, 1980). In recent years, a study of the detailed sedimentology of Friars Cliff has been undertaken by Plint (1983a, 1988b) as part of a broader investigation of clastic sedimentation in the Bracklesham Group.

A number of earlier workers have considered the relationship between this section and that of Hengistbury Head to the west of Christchurch Harbour. The controversy which has arisen and its ultimate solution has been considered in some detail by Hooker (1975a) and Curry (1976) and is summarized elsewhere in the review of the Hengistbury Head site.

Description

Although very limited in stratigraphical extent, Friars Cliff provides a useful link in the network of sites between Hengistbury and the Bournemouth sections to the west and those of the Isle of Wight to the east. It is important sedimentologically as far as the Boscombe Sand is concerned, for the facies developed here is different from what is seen elsewhere.

Lithological succession

Apart from a thin development of glauconitic muds above a flint pebble bed at the base of the Barton Clay, the succession comprises some 14 m of the silty sandy muds and clean sands of the Boscombe Sand.

Sedimentology

The Boscombe Sand at Friars Cliff comprises three 5–6 m thick, upward-coarsening sequences (Plint 1983a, 1988b). Plint referred to their upward passage from intensely bioturbated silty sandy clay with abundant fine plant debris, into clean faintly laminated sand, overlain by cross-bedded fine to medium sand. At the western end of the section above the concrete promenade, the middle and uppermost of the three may be examined. The present author noted here that no upward grading was present, with the sediment comprising essentially clean quartz sand throughout. The top of both sequences were disturbed by contemporaneous soft sediment deformation. To the east of the promenade the lowest sequence clearly coarsens upwards from a bioturbated, carbonaceous muddy sand to a clean sand.

The deformational structures are an impressive feature of the section. They vary in their lateral persistence and thickness within each of the three sequences. The boundaries of the latter are difficult to distinguish, whilst 100 m eastwards from the promenade, the general bedded nature and tripartite division of the Boscombe Sand is suddenly lost completely and the whole unit is extensively deformed. Large, elongate pillows up to 2–3 m in length are apparent here. The Barton Clay (about 3 m) here is palaeogeographically and stratigraphically significant. The base is marked by an up to 30 cm thick pebble bed comprising well-rounded flint pebbles in a matrix of muddy glauconitic sand. This is overlain by green glauconitic muds very similar to the lowest part of the 'Hengistbury Beds' but less silty (Hooker, 1975a).

Interpretation and evaluation

Friars Cliff is important from three aspects in particular: the stratigraphical assignment of the Boscombe Sand, the palaeogeographical interpretation of the facies of the Boscombe Sand present here and the well-developed soft sediment deformation structures.

Stratigraphical significance and comparison with other localities

From work on the dinoflagellate microfauna, Costa *et al.* (1976) suggested that the Boscombe Sands corresponded with the highest microplankton zone of the Bracklesham Beds (Zone B-5; see Bujak *et al.* 1980). The Boscombe Sand was included by Curry *et al.* (1978, table 1) in their Bournemouth Formation, whilst Edwards and Freshney (1987b, p. 65) considered it worthy of separate formation status (the Boscombe Sand) and the lowest of the four formations of their Barton Group. They considered that it correlated with Prestwich Bed 28 of Alum Bay and that it ultimately passed eastwards into marine clays included in the Barton Clay. Above the Boscombe Sand, the reworked pebble lag representing the initial Barton Clay transgression may be correlated with the pebble bed at the top of Prestwich Bed 28 in Alum Bay.

Palaeogeography

Plint (1988b) has emphasized the importance of this site to our understanding of the palaeogeography of Boscombe Sand times. He considered that the coarsening-upwards cycles present here may represent pro-grading mouth-bars at the seaward end of a tidal channel system. The tidal channels themselves are represented in the East Bournemouth Cliffs section (see separate review) further to the west. Plint (1988b, p. 141) believed that the Boscombe Sand of Friars Cliff correlates with lagoonal and coastal marine sediments in the Alum Bay section (Prestwich Beds 27 and 28). The Palaeogene sea at this time appears to have deepened towards the north-east, for the Boscombe Sand is absent in the Southampton Region where the Barton Clay rests directly on the underlying Bracklesham Group.

Soft sediment deformation structures

The spectacular structures that Plint (1988b, plate 9) called ball and pillow structures provide one of the few examples of soft sediment deformation in the local Palaeogene succession. They perhaps reflect the dewatering of underconsolidated sands or a response to a density inversion. Plint (1988b, p. 137) has suggested that they resulted from the rapid progradation of sands over unconsolidated water- and possibly gas-saturated muds.

Conclusions

Friars Cliff is nationally important because it provides an opportunity to study the tidal channel mouth bar facies of the Boscombe Sand which is only developed at this locality and hence provides a unique contribution to our overall understanding of contemporary geography. Furthermore, the soft sediment deformation structures present in this facies are amongst the most spectacular in the local Palaeogene succession.

In terms of correlation, the site provides a useful link between Hengistbury and the Bournemouth sections to the west and those of the Isle of Wight to the east.

'BARTON CLIFFS', HAMPSHIRE/DORSET (SZ 200930–SZ 283915)

Highlights

The 'Barton Cliffs' site has provided a major contribution to the understanding of middle to late Eocene times in the southern British area. It includes the type sections for three formations within the Barton Group and is of international importance as the type section for the Bartonian Stage.

Introduction

This account primarily concerns sea cliffs extending from Highcliffe in the west (grid reference SZ 200930) to Milford-on-Sea (SZ 283915), but includes information derived from temporary foreshore exposures sometimes

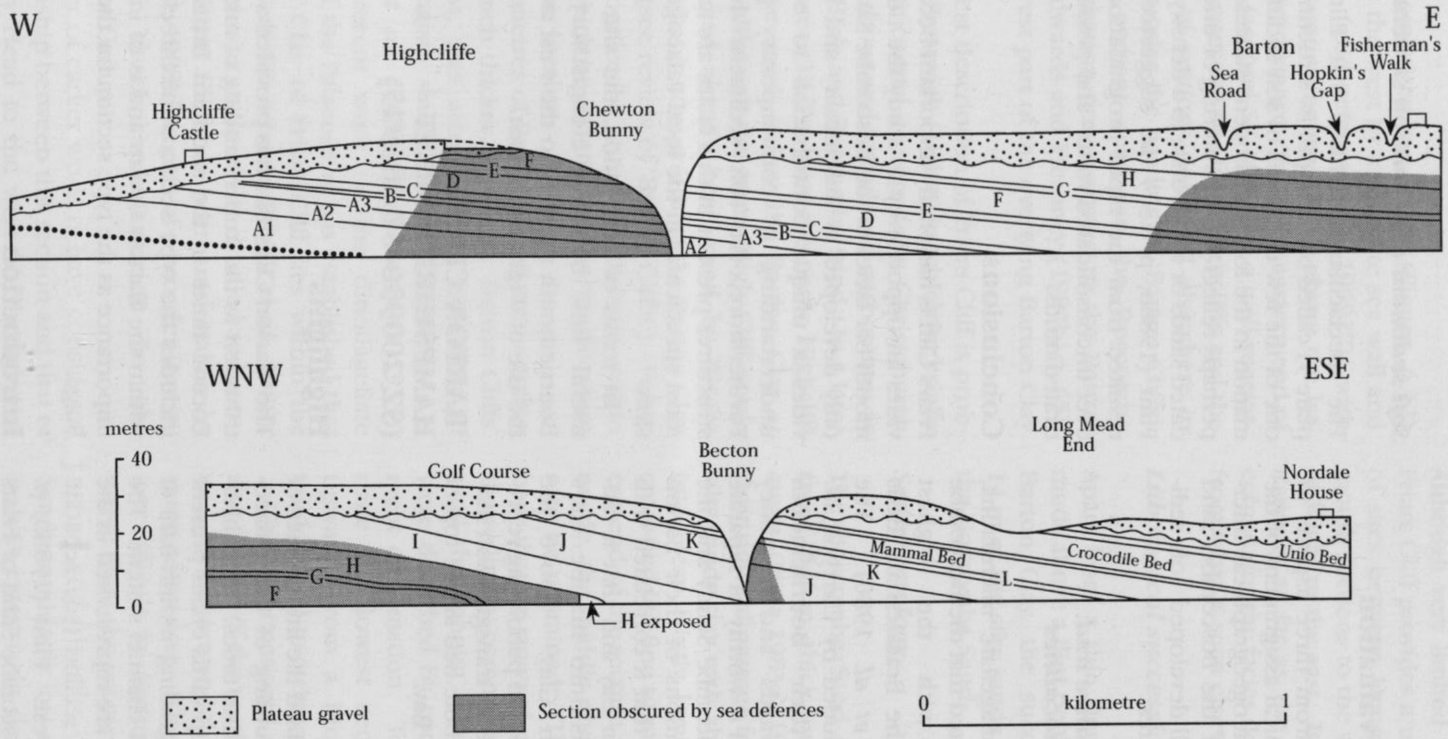

Figure 6.13 'Barton Cliffs': cliff profile to show the succession of the Barton Group and part of the overlying Headon Hill Formation. The shaded sections on the profile represent stabilized 'coastal protection' and contain few or no exposures (after Melville and Freshney, 1982).

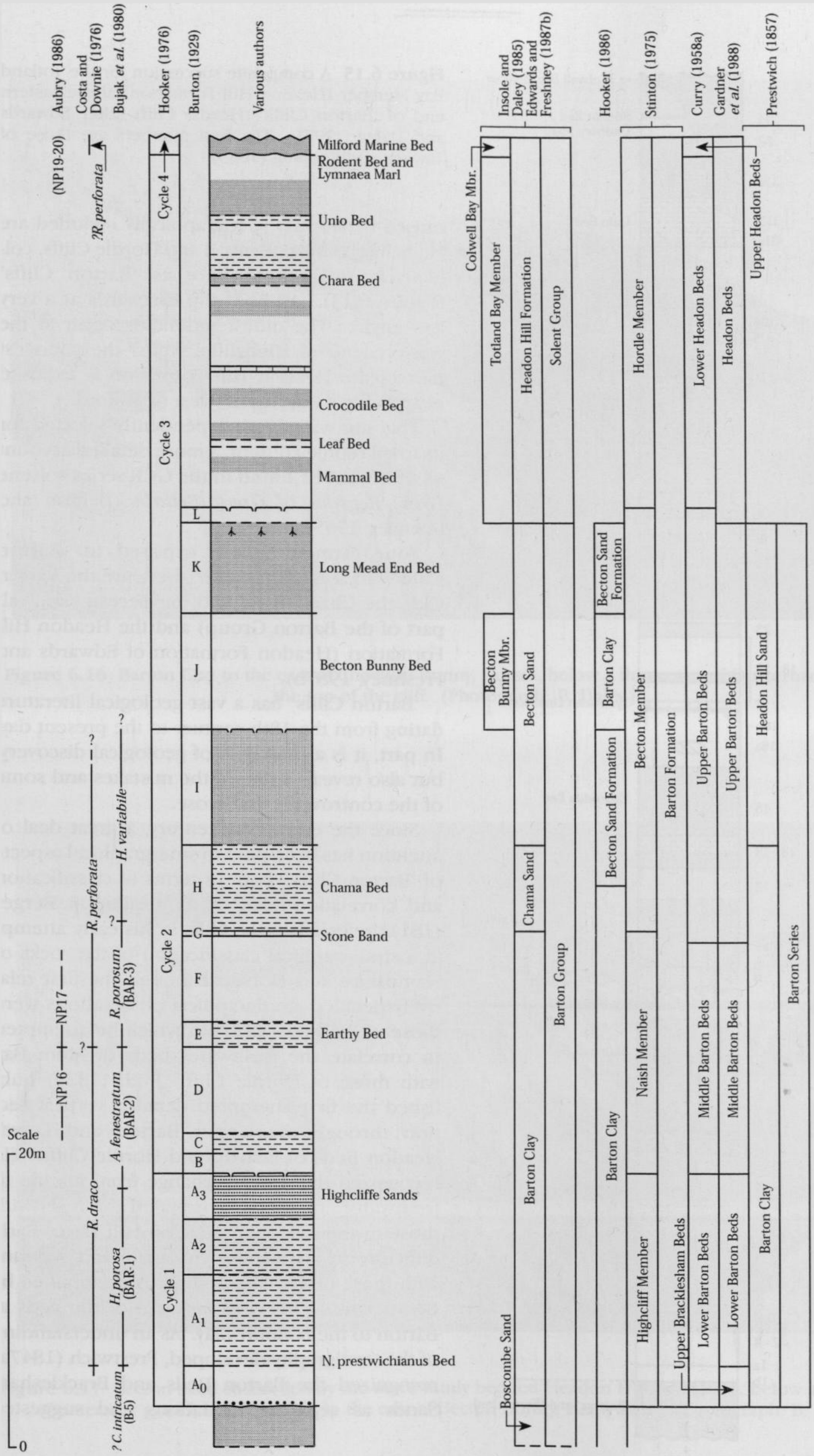

Figure 6.14 Generalized succession of the Barton Group and Headon Hill Formation at 'Barton Cliffs', Hampshire/Dorset (after various authors).

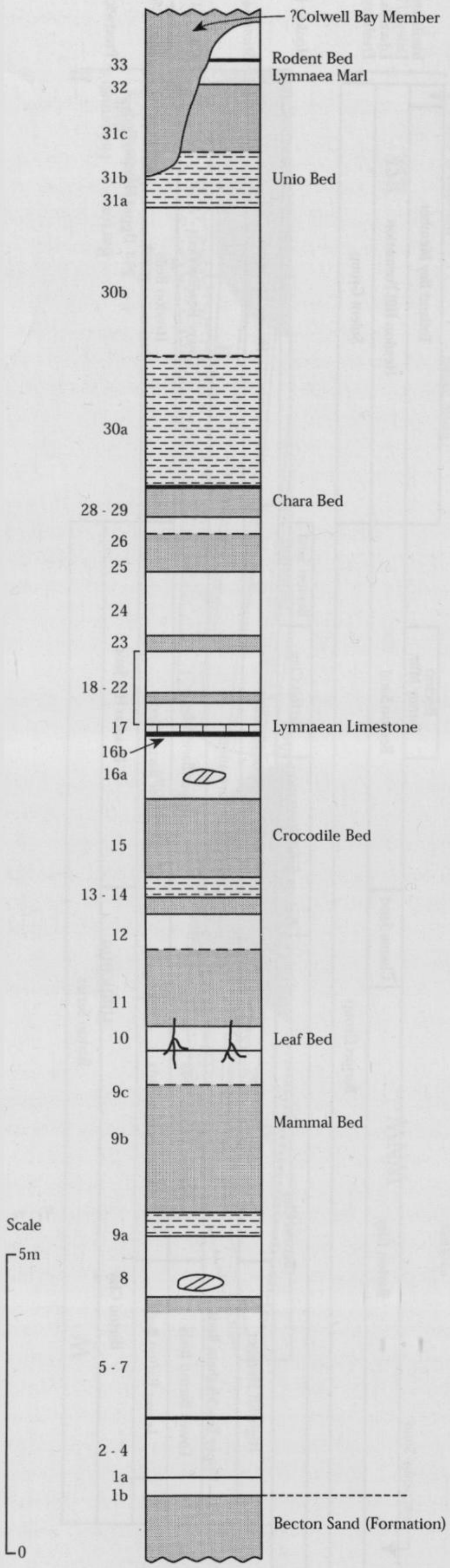

Figure 6.15 A composite succession for the Totland Bay Member (Headon Hill Formation) at the eastern end of 'Barton Cliffs' (Hordle Cliff) (after Edwards and Daley, 1997). The bed numbers are those of Tawney and Keeping (1883).

caused by storms. Geographically included are Highcliffe, Barton, Beacon and Hordle Cliffs, collectively referred to here as 'Barton Cliffs' (Figure 6.13). All beds dip eastwards at a very low angle. The oldest sediments occur at the western end of Highcliffe, whilst the youngest part of the Headon Hill Formation is exposed near Paddy's Gap to the west of Milford.

This site was also independently selected for its fossil reptile content, a more detailed account of which can be found in the GCR series volume *Fossil Reptiles of Great Britain* (Benton and Spencer, 1995).

Four formations are exposed in 'Barton Cliffs'. In ascending order, these are the Barton Clay, the Chama Sand and the Becton Sand (all part of the Barton Group) and the Headon Hill Formation (Headon Formation of Edwards and Freshney, 1987b).

'Barton Cliffs' has a vast geological literature dating from the 18th century to the present day. In part, it is a catalogue of geological discovery, but also reveals some of the mistakes and some of the controversy that arose.

Since the early 19th century, a great deal of attention has been paid to stratigraphical aspects of 'Barton Cliffs', both in terms of classification and correlation with other localities. Berger (1811) referred to the cliffs in his early attempt at a stratigraphical classification of the rocks of Hampshire and Dorset, although the first relatively detailed stratigraphical observations were those of Webster (1824) in which he attempted to correlate the freshwater beds of Alum Bay with those of Hordle Cliff. Lyell (1829) published the first attempted detailed vertical section through the Upper Barton and Lower Headon Beds of Beacon and Hordle Cliffs. He recognized the upward change from marine to freshwater faunas and correlated the beds with those in the Alum Bay/Headon Hill area. Early difficulty in correlating the mainland sections with those of the Isle of Wight is exemplified by Bowerbank's (1841) assignment of the beds at Barton to the London Clay. As an understanding of the stratigraphy developed, Prestwich (1847a) recognized the Barton Beds and Bracklesham Sands as separate formations and suggested

Figure 6.16 Barton Clay to the east of Chewton Bunny, Dorset, below a thin cover of Quaternary Gravel at the top of the cliff. (Photograph: B. Daley.)

Figure 6.17 Becton Sand succeeded by the more thinly bedded Headon Hill Formation, below a covering of Quaternary gravel, in the section to the east of Becton Bunny, Hampshire. (Photograph: B. Daley.)

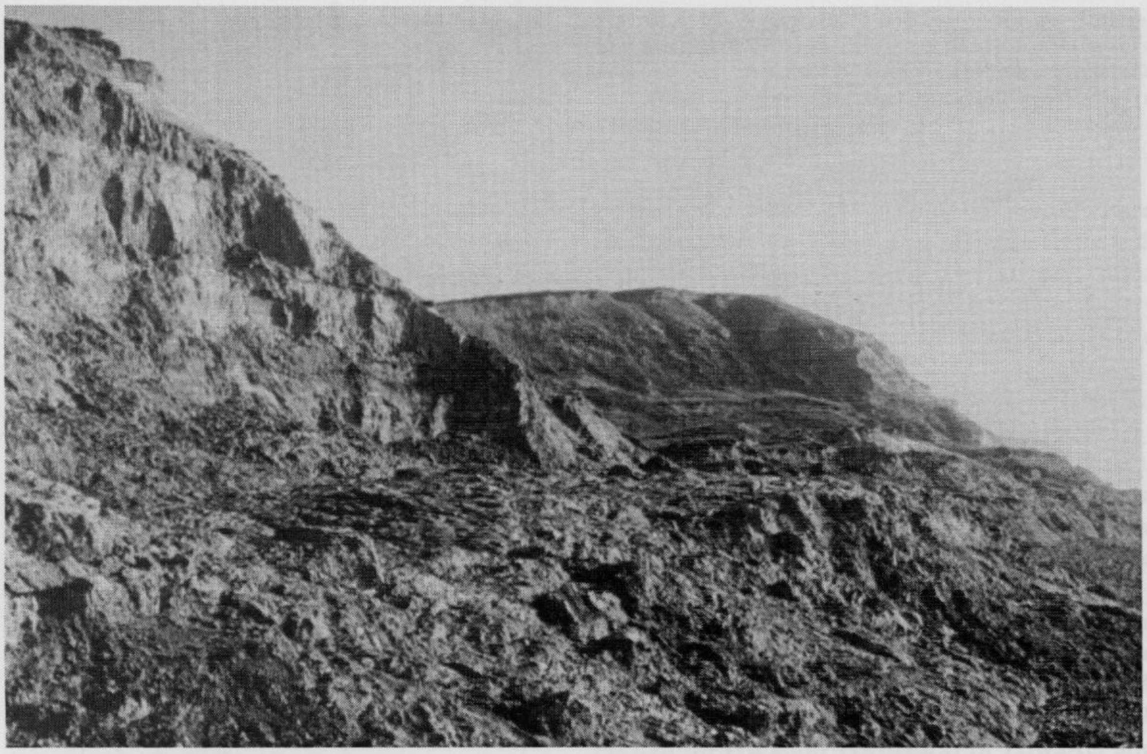

Figure 6.18 Headon Hill Formation in Hordle Cliff, Hampshire. (Photograph: B. Daley.)

(Prestwich, 1847b) that the Barton Beds of Hampshire correlate with part of the Bagshot Sands succession in the London Basin.

The first account of an 'upper marine formation' at the eastern end of the Hordle Cliff section was published in Wood (1846). The earliest detailed, reasonably accurate descriptions of the succession in Barton, Beacon and Hordle Cliffs were published by Wright (1851) and the Marchioness of Hastings (1848, 1852, 1853). Prestwich (1857a) reviewed the correlation of the Bracklesham and Barton Beds in England, France and Belgium.

Towards the latter part of the 19th century, a large number of papers of a stratigraphical nature were published. Judd (1880) correlated the 'Lower Headon Beds' of Hordle with those of Headon Hill, largely on faunal evidence. Gardner (1882) suggested a revised classification of the British Eocene, placing the Eocene–Oligocene boundary at the base of the Barton Beds on the grounds that cold-water faunas first appeared at this time. Fisher (1882) correlated the thin Lower Headon Limestone and 'Upper Marine Bed' of Hordle with the How Ledge Limestone and the Middle Headon Beds of the Isle of Wight.

Fisher's paper led to a furious controversy, quite disproportionate to its importance, over the stratigraphical relationship of the 'Upper Marine Bed' and, in particular, whether the section contained freshwater strata above the latter. Amongst the protagonists were Judd (1882a,b, 1883), Wood (1883a,b, 1884), Elwes (1883, 1884), Tawney and Keeping (1883) and Keeping (1883). Tawney and Keeping, and Elwes correctly asserted the absence of higher non-marine strata, as confirmed by more recent studies such as that of Edwards (1967). Perhaps unwittingly, some of the arguments were about *different* beds. Wood (1884), for example, based his dispute of Tawney and Keeping's observations on a complete misunderstanding, since he believed the controversy was about the 'Long Mead End Bed', a unit lower down the succession.

A few years later, Gardner *et al.* (1888) published an account of the complete succession of the Barton Clay and overlying Barton Sand. Burton's (1929) system of letters, with which he labelled the principal units of the Barton Beds, is still in use today. More recent work on the stratigraphy has been undertaken by Hooker (1986), Plint (1984) and Edwards and Freshney (1987b). These are referred to in more detail below.

Notwithstanding the importance of stratigraphical matters, the abundance of well-preserved fossils was without doubt the principal factor which attracted an early interest in 'Barton Cliffs' and ultimately led to its becoming a classic British Tertiary locality.

In the 18th century, a number of fossils from Barton were figured in Brander (1766). In the 19th century, many of the stratigraphical accounts also included references to or lists of fossils (e.g. Wright, 1851). Many references to specimens collected from Barton Cliffs were made in a series of memoirs documenting the British Tertiary biota published by the Palaeontographical Society in the second half of the 19th century. These publications include Forbes (1852) on the echinoids, Wood (1861) on the bivalves, Edwards and Wood (1849–1877) on cephalopods and gastropods, and Gardner and von Ettinghausen (1879–1882) on the flora.

Twentieth century work on the palaeontology includes Burton (1929) on the Bryozoa, the same author (1933) on the molluscan fossils, and the important studies of Curry (1937) on the large foraminifer *Nummulites*. Later macroinvertebrate studies include work on the brachiopods by Elliott (1954), on asteroids and ophiuroids by Rasmussen (1972), on decapod crustaceans by Quayle and Collins (1981) and by Lewis (1989) on the echinoids. Vertebrate studies include those on fish otoliths by Stinton (1975, 1977, 1978, 1980), Milner *et al.* (1982) on small amphibians and reptiles, and Halstead and Middleton (1972), Cray (1973) and Hooker (1982, 1986) on mammals.

Over many years, excursions to the Barton Cliffs sections have included those by the Geologists' Association (e.g. Burton and Curry, 1950) the Tertiary Research Group (Daniels, 1970a; Edwards, 1971c; Clasby, 1972, 1974; Hooker, 1975b; Daley, 1996) and parties attending national and international conferences (e.g. Curry, 1968; Daley, 1996). Descriptions of Barton Cliffs include that in the Geologists' Association Guide by Curry and Wisden (1958), a recent summary by Daley, (1998) and a detailed account of the succession of the Totland Bay Member of the Headon Hill Formation by Edwards and Daley (1997).

Description

Below Highcliffe Castle, the junction of the Barton Clay with the underlying Boscombe Sand is marked by a thin pebble bed. From here, a conformable, gently dipping succession extends for something over 8 km eastwards to Milford-on-Sea (Figure 6.13). Although at one time a continuous and mainly well-exposed section in readily degradable cliffs (Barton, 1970, 1973), it is now interrupted by sea defence works, where exposures are poor or non-existent (see Melville and Freshney, 1982, fig. 29; Clasby, 1971), and the Hordle Cliff section is much obscured by talus.

Lithological succession

The strata present (Figure 6.14) comprise, in ascending order, the Barton Clay Formation (somewhat over 30 m), the Chama Sand Formation (around 5.5 m) and the Becton Sand Formation (about 22 m), all part of the Barton Group of Edwards and Freshney (1987b), and the Headon Hill Formation (30 m). Above the basal pebble bed, the Barton Clay mainly comprises muds and sandy muds (Figure 6.16), the exception being the heterolithic 'High Cliff Sands and Clays'. Above the distinctive 'Stone band' (Bed G of Burton, 1929), the succession coarsens. Sandy muds of the Chama Sand are succeeded by the clean, fine-grained sands of the Becton Sand (Figure 6.17), although the latter is split into two units here by mainly sandy clays of the Becton Bunny Member. Lithologies in the Headon Hill Formation above (Figure 6.18) are more varied than lower down the succession (Figure 6.15; Edwards and Daley, 1997). Clastic lithologies (sands, muds and heterolithic sediments) are still predominant but some of the muds are lignitic and the sequence includes a thin, soft, brown limestone.

Stratigraphy

The long section displays what were for a long time simply called the 'Barton Beds' and, above them to the east, the 'Lower and Middle Headon Beds'. The Boscombe Sand is also exposed below Highcliffe Castle, but is best seen further to the west in Friar's Cliff, Mudeford and beyond. The stratigraphical sequence has been described on a number of occasions, but Burton's (1933) system of labelling the principal units of the 'Barton Beds' with letters is still widely used.

Tawney and Keeping (1883) divided the 'Lower Headon Beds' into 33 numbered beds, whilst the stratigraphical scheme of Edwards (1971c) split this part of the succession into eight 'divisions', each comprising a number of beds. Plint's (1984) scheme of 24 numbered beds includes Beds J, K and L of Burton and extends up into the Totland Bay Member (= 'Lower Headon Beds').

With the recognition of the need to regulate and standardize stratigraphical terminology (cf. Hedberg, 1976), new terms have been introduced at formation level and above. Edwards and Freshney (1987b) recognized three formations within the 'Barton Beds': the Barton Clay (up to and including Burton Bed G); the Chama Sand (Burton Bed H); the Becton Sand (Burton Beds I, J, K). The lithostratigraphical importance of Barton Cliffs is apparent in its choice as stratotype for all three. With the Boscombe Sand, these three formations comprise the Barton Group of Edwards and Freshney (1987b). These authors include the remainder (younger) part of the 'Barton Cliffs' section in their Headon Formation, although this part of the succession was earlier assigned to the Headon Hill Formation of Insole and Daley (1985). The formerly named 'Middle Headon Beds' of this part of the succession were renamed the Colwell Bay Member by Insole and Daley (1985) and the Lyndhurst Member by Edwards and Freshney (1987b).

Chronostratigraphy

The section is also very important chronostratigraphically as the type section for the Bartonian Stage (Mayer-Eymar, 1857). However, as Hooker (1986) has explained (see also Curry *et al.*, 1978, table 2), there are different conceptions of the Bartonian.

The 'Barton Cliffs' section is also the type locality for nannoplankton Zone NP17 (Martini, 1971), whilst more recently, nannoplankton from the section enabled Aubry (1986) to approximate the NP 16/17 boundary to Bed E of the Barton Clay. Bujak *et al.* (1980) recorded 100 species of dinoflagellate from the Barton Beds and it is significant that the first three of their 'Barton Beds Zones' (BAR-1, BAR-2, BAR-3) have Barton Cliffs as the type section. From glauconites in Burton Bed A_1 (containing *N. prestwichianus*), Odin *et al.* (1969) obtained a date of 42.0 ± 2 Ma BP for the basal part of the succession.

Invertebrate macrofauna

There is no doubt that palaeontologically 'Barton Cliffs' is one of the most important sites in the British Palaeogene succession. It is famous for its molluscan fauna, the quality and preservation of which is unrivalled in the Hampshire Basin. Burton (1933) listed some 480 species, many of which occur in large numbers. Wrigley produced many papers on the molluscs (see list in Cox, 1954). With those found in the overlying Headon Hill Formation, Barton Cliffs contains a wide variety of molluscan assemblages, representing marine, brackish and freshwater conditions (see also Edwards, 1967). An interesting specialist study by Gardner (1886) of *Teredo* (a mollusc, though sometimes called the 'shipworm') and bored wood, found that whilst the latter was abundant in the 'Barton Beds', it was absent in the 'Lower Headon Beds' of brackish and freshwater origin.

Microfauna and microflora

Work on the site has led to a number of micropalaeontological papers, including Murray and Wright (1974) on the foraminifera, Haskins (1968a,b,c, 1969, 1970, 1971a,b) and Keen (1972a,b, 1977) on the ostracods. Microfloral studies have included work by Costa and Downie (1976), the latter referring to the section in a review of the important dinoflagellate zone fossil *Wetzeliella*.

Macroflora

Plant macrofossils described from 'Barton Cliffs' have made important contributions to our understanding of contemporary geography and climate. The charophyte flora of Hordle Cliff was described by Reid and Groves (1921). In 1925 and 1926, Chandler published her study of the macroflora (leaves, fruits and seeds) from this locality, later (1961a) re-examining the flora and adding 27 new species. Fowler *et al.* (1973) described in-situ taxodiaceous conifer tree stumps and root systems assigned to the wood genus *Glyptostroboxylon* from the Leaf Bed. Roots (*Lacunoradix*), interpreted as those of a hydrophytic angiosperm, were described by Crane and Plint (1979) from the Mammal Bed. These roots had been preserved by a process of siderite permineralization, a hitherto unrecorded mode of fossilization that had preserved the cellular structure in great detail.

Vertebrate remains

Vertebrate remains from 'Barton Cliffs' have been useful stratigraphically and as palaeoenvironmental indicators, as well as being of innate palaeontological interest. Tropical or subtropical environments were indicated by some of the earlier discoveries. Wood (1844, 1846), who described a small mammalian skull and an almost complete crocodile skull, referred to the latter as 'the most interesting saurian relic yet discovered in Britain'. Other workers recorded crocodile and turtle remains (eg. Owen, 1848a; Seeley, 1876). In reviewing fossil crocodiles, Woodward (1885) alluded to the celebrated 'Crocodile Beds' of Hordle.

An early description of mammalian fossils from the site is that of Owen (1848a,b). More recently, extensive and detailed work has been undertaken by Hooker, who in 1972 described the first land mammal remains from the Barton Clay. Hooker (1986) recognized 53 mammalian species from the Bartonian of the Hampshire Basin, though this number includes material mainly from sections other than 'Barton Cliffs'. Selected orders from the 'Headon Beds' were studied by Cray (1973), whilst large vertebrae from the Barton Clay have been attributed to the whales *Zygorhiza* and *Basilosaurus*, the latter being a new record in Europe (Halstead and Middleton, 1972).

Sedimentology

The sediments of 'Barton Cliffs' represent a diverse suite of sedimentary environments: offshore and inshore shelf, littoral beach or barrier, lagoon, lake, river, marsh and swamp conditions. Furthermore, the succession provides an excellent opportunity to study the development of a succession of transgressions and regressions and how these have influenced sedimentological, faunal and floral character. Little work has been undertaken on the detailed sedimentology of the Barton Group but both Edwards (1967) and Plint (1984) have studied the Totland Bay Member of the Headon Hill Formation in some detail.

Sedimentary cyclicity

Hooker (1976) interpreted the succession as representing four transgressive–regressive cycles, although the youngest (represented by the Colwell Bay Member) is incomplete (Figure 6.14). The first two cycles are coarsening-upwards sequences in which highly glauconitic muds pass up through non-glauconitic muds, then sandy muds to sands. Cycle 1 (Beds A_0 to A_3) begins with a basal pebble bed representing a transgressive lag. Bed A_3 contains abraded fossils indicative of considerable reworking as regressive-phase shallowing developed.

Cycle 2 (Beds B to I) has no basal pebble bed, but there is a sharp burrowed junction and some rolled shells probably derived from Bed A_3. Glauconitic silty clays at the base represent a transgressive phase. An ultimate upwards shallowing is reflected in the highly winnowed lag of Bed G, whilst the sands with *Ophiomorpha* of Bed I (the bottom part of the Becton Sand) show no evidence of subaerial exposure and having accumulated in the middle to upper shoreface (Edwards and Freshney, 1987a, p. 66).

As proposed by Hooker (1976), Cycle 3 comprises Beds J, K and the Totland Bay Member of the overlying Headon Hill Formation. A marked break occurs at the base of Bed J (the Becton Bunny Member of Edwards and Freshney, 1987b), though it is less distinct where burrowing has occurred. The upward transition into the clean sands of Bed K may reflect the development of beach or barrier island conditions. The remainder of Cycle 3 differs from earlier cycles in the succession in that regressive facies are better represented. This part of the succession contains a variety of sediments and fossils, representing a range of brackish and freshwater conditions and comprising several minor transgressive and regressive cycles and a major palaeochannel fill. The palaeobiological significance of this part of the sequence is emphasized by a number of named beds: the 'Mammal Bed', the 'Leaf and Seed Bed', the 'Crocodile Bed', the 'Chara Bed', etc.

Cycle 4 is incomplete, comprising the transgressive phase ('Milford Marine Bed') of the Colwell Bay Member, more fully developed on the Isle of Wight. This unit is unconformable on sands overlying the 'Unio Bed' (N. Edwards, pers. comm., 1992).

Interpretation and evaluation

Although coastal protection works have obscured considerable areas of cliff, 'Barton

Cliffs' continues to be the major section in the Barton Group. Its importance stratigraphically is, therefore, beyond doubt.

Stratigraphical definition and nomenclature

Over the years, different stratigraphical schemes have been used to describe the succession here. Changes in both nomenclature and the definition of unit boundaries provide an example of how the application of criteria for stratigraphical classification have changed with time, culminating in the modern application of 'Hedbergian' principles and also event stratigraphy. Even so, differences of opinion persist.

Where the bottom of the Barton Clay should now be placed is widely agreed, although previously this was not the case. The presently accepted base is marked by a pebble bed resting on the underlying Boscombe Sand. This was the base of Prestwich's (1857a) Barton Series. Burton (1933), following Fisher (1862), however, placed the bottom of the Barton Clay at the *Nummulites prestwichianus* horizon 3 m above. Curry (1958a) suggested a reversion to Prestwich's usage since 'the natural break in the succession occurs at the pebble bed' and indeed this follows the lithostratigraphical code of Hedberg (1976). Furthermore, this reversion to the pebble bed at the base precisely mirrors what has been done in Alum Bay, where what were formerly called the '(?)Upper Bracklesham Beds' (Wright and Curry, 1958, p. 14) are now included in the Barton Clay.

Edwards and Freshney's (1987a) subdivision of the Barton Group into three formations follows Hedberg, as does the system of Hooker (1986) who designated two interdigitating formations the Barton Clay Formation (Beds A_0 to H (lower part) and J) and the Becton Sand Formation (Beds H (upper part), I and the pale sand component of K).

Comparison with other localities

Compared with most other localities the Barton Clay in 'Barton Cliffs' is thin. The 30+ m here compares with over 60 m in Whitecliff Bay and around 90 m in Alum Bay (cf. Daley and Insole, 1984), whilst thicknesses in excess of 90 m are found to the south of Southampton (Edwards and Freshney, 1987, fig. 32). Some 5 km west of Lymington, the succession begins to thin rapidly westwards. Together with the fact that the Hengistbury succession appears to reflect a sandy 'marginal marine' facies of the Barton Clay (see separate account), this trend appears to point to the existence of a contemporary land area not far to the west.

Both the overlying Chama Sand and the Becton Sand are thinly developed in 'Barton Cliffs' compared with many other localities. Whilst the former is 5.5 m here, it thickens to 7 m at Alum Bay and 14 m at Whitecliff Bay. The Becton Sand exhibits considerable variation in thickness. At 22 m, the thickness in 'Barton Cliffs' is greater than the 10 m near Dibden. The formation is, however, 30 m at Alum Bay and as much as 93 m in the Sandhills Borehole on the Isle of Wight (Edwards and Freshney, 1987a,b).

At around 28.5 m, the Totland Bay Member of the Headon Hill Formation is only very slightly thicker than this member at Headon Hill, but considerably thicker than the *c.* 8 m at Whitecliff Bay. Whilst the succession in 'Barton Cliffs' represents a range of brackish to freshwater environments similar to those represented by this member at other localities, the details of the successions bear little relationship to each other.

Invertebrate palaeontology

As far as the palaeontology of the sequence is concerned, it was the molluscan fauna that first attracted attention and which has proved particularly important in palaeosalinity determination, facilitating the recognition of marine, brackish and freshwater strata. The Barton Clay molluscs of this locality are, in a context of the Hampshire Basin succession, unrivalled in preservation and quality. Their high species diversity approaches that of the Bracklesham Group. Compositional differences of the various assemblages found indicate clearly that they are facies controlled. Some species are, for example, almost entirely restricted to the more sandy units (Hooker, 1986).

The microfauna, as elsewhere, has proved to be a sensitive indicator of environmental factors such as water temperature and salinity. The presence of certain foraminifera suggest a cool aspect to the fauna (Murray and Wright, 1974). Despite the considerable molluscan species diversity and the presence of such marine forms as echinoids, there is a general absence of planktonic species amongst the faunas. This points to little circulation with the open sea, and that, even during what appear to be marine phases, the water was slightly hyposaline.

Vertebrate palaeontology

The 'Barton Cliffs' section has proved to be an important vertebrate and, in particular, mammalian locality (Cray, 1973; Hooker, 1986; Collinson and Hooker, 1987). The presence of mammals in marine strata is particularly important stratigraphically, for since such fossils frequently occur in fissure fills or in non-marine or 'marginally' marine deposits, their relationships with standard marine successions are normally obscure (Hooker, 1986). The non-marine beds of the Headon Hill Formation are also important, since the lakes, marshes, etc., that they represent provided ideal sites for the preservation of terrestrial vertebrates, as in the 'Crocodile Bed'. A total of 36 species of mammal have recently been listed from the 'Mammal Bed' (Hooker, 1992).

Plant fossils

The plant fossils of 'Barton Cliffs', particularly those comprising the 'Hordle Flora' (Chandler, 1925, 1926, 1961a) from the Totland Bay Member have contributed significantly to our understanding of contemporary geography and climate. The different plant macrofossil assemblages represent a variety of environments. Fowler *et al.* (1973) suggest that open water, marsh and swamp forest communities are represented. Chandler (1964) claimed that some plants were estuarine, perhaps fully halophytic, although Fowler *et al.* (1973) were less certain that this can be substantiated. In a study of the 'Leaf Bed' flora, they pointed out that the brackish water-tolerant fern genus *Acrostichum*, which is the only possible indicator of brackish conditions present, also has extant freshwater species. Furthermore, they doubted whether the specimen of *Nipa*, another brackish water indicator, recorded from the 'Leaf Bed', actually came from that horizon.

Palaeoclimatology

From a palaeoclimatological point of view, the presence or absence of *Nipa* is important. Palynological work by Fowler (in Fowler *et al.*, 1973) suggests that this characteristically tropical palm had disappeared from the Hampshire Basin area before the deposition of the underlying Barton Group had ended. A later study (Collinson *et al.*, 1981) showed that *Nipa* pollen (*Spinizonocolpites*) did not extend higher than the Bracklesham Group. That the 'Hordle Flora' reflects a climatic change is also indicated by Collinson and Hooker's (1987) suggestion that it represents the last occurrence in the local succession of previously dominant tropical elements. Chandler (1964) had recognized the importance of temperate elements in the 'Hordle Flora' but considered them as montane-derived. Fowler *et al.* (1973) concluded that the 'Leaf Bed' assemblage is locally derived and is analogous to humid warm-temperate swamp floras, such as those of southern Florida.

Sedimentary environments

'Barton Cliffs' comprise strata representing a diverse suite of sedimentary environments from offshore shelf to lacustrine. Whilst the brackish to freshwater elements are well-represented on the Isle of Wight, the more marine strata are relatively poorly (Alum Bay) or badly exposed there (Whitecliff Bay). Only in 'Barton Cliffs' is the Barton Clay clearly exposed and the cyclic nature of the succession apparent. Broadly, the coarsening-upwards cycles represent a continuation of the transgressive/regressive pattern established during London Clay times and continued in the Bracklesham Group. Bristow *et al.* (1991) considered that the lower three cycles represented minor transgressions and regressions, the latter resulting in shoreline facies of which the most important is the Becton Sand. By the time the fourth, locally incomplete cycle, developed, however, the pattern of cyclicity showed a marked change, for in the remainder of the Hampshire Basin Palaeogene succession, transgressive sediments are poorly developed whilst those of a regressive, non-marine character predominate.

International significance and correlation

The importance of the 'Barton Cliffs' section internationally was established in the 19th century (Mayer-Eymar, 1857) when it was designated the type section for the Bartonian Stage. Pomerol (1982, table III) continued to recognize the Bartonian as a 'principal' stage of the Eocene, although as Hooker (1986) pointed out (and discussed in considerable detail), some 15

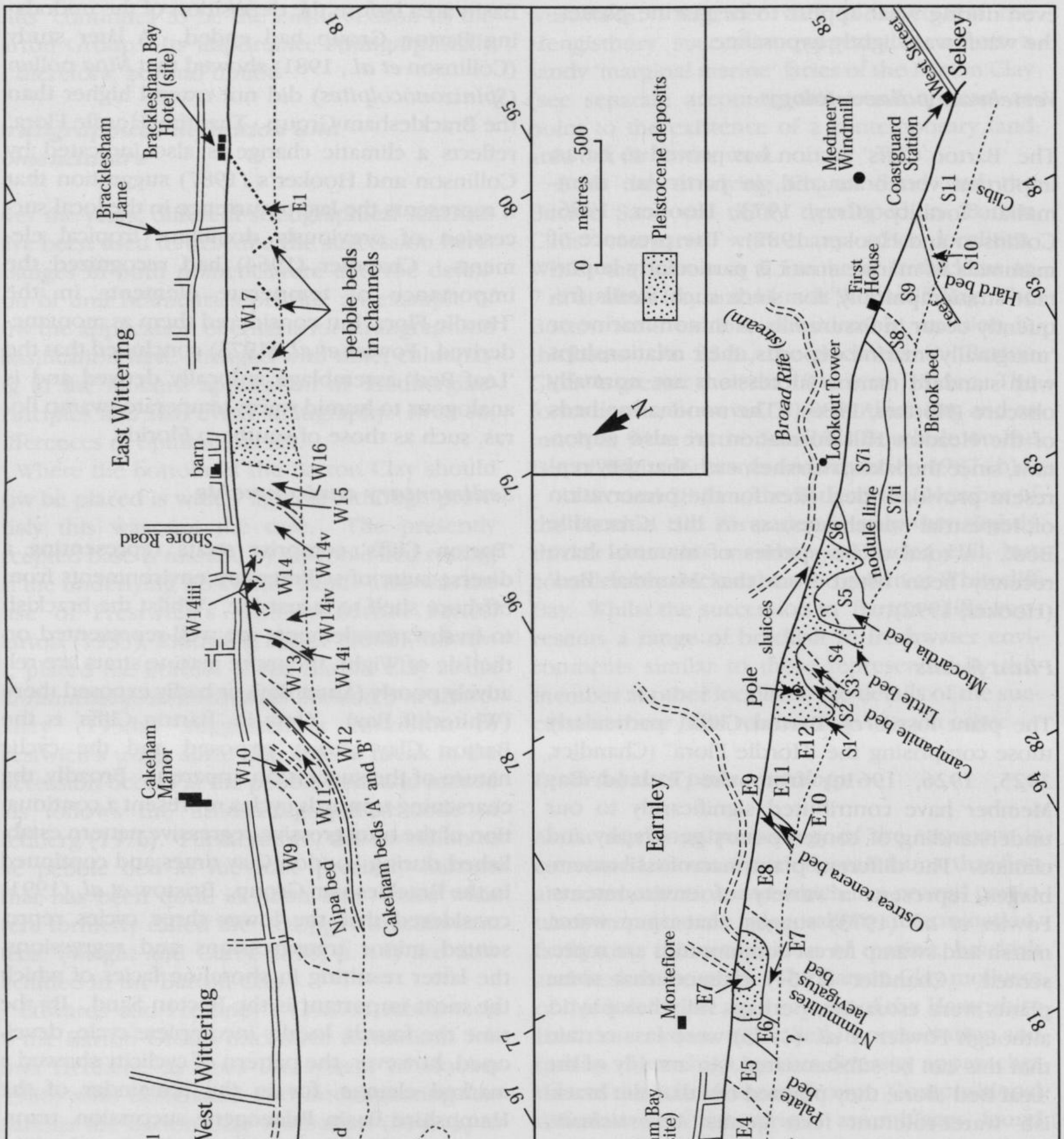

Figure 6.19 Map of the foreshore exposures from Wittering to Selsey, Bracklesham Bay, West Sussex (from Curry *et al.*, 1977, fig. 4). For the stratigraphical relationships of the beds prefixed W, E and S, see Figure 6.20.

different concepts of the Bartonian have existed over the years.

Hooker (1986) also wrote in some detail about attempts made to correlate the 'Barton Cliffs' succession with that of the Paris Basin, and hence the application of the two French substages, the Auversian and the Marinesian, to the local succession.

Châteauneuf (1980, p. 290) correlated the Colwell Bay Member with the Marnes à Lucines (overlying the Marnes à *Pholadomya ludensis*) and Beds C to F of the Barton Clay with the Sables de Cresnes, using his own dinoflagellate evidence and that of Bujak *et al.* (1980). Using ostracods, Keen (1978) suggested a general correlation of the 'Barton Beds' with the Marnes à *P. ludensis*. He also supported the Marnes à Lucines correlation with the Colwell Bay Member though, on the basis of charophytes, Grambast (1962) correlated the latter with the higher parts of the Marnes à *P. ludensis*. According to Hooker (1982), the widespread but short-lived trangression at the base of the latter may correlate with the equally short-lived transgression represented in 'Barton Cliffs' by Bed J. If this is the case, and bearing in mind the Marnes à *P. ludensis* are post-Marinesian (Pomerol, 1982, p. 74), the top of the Bartonian (or Marinesian) coincides with the top of Bed I. Towards the bottom of the succession, Châteauneuf (1980) considered the *N. prestwichianus* bed of the Barton Clay as Auversian on the basis of dinoflagellate correlation with a horizon high in the Sables de Beauchamp. He found Beds C to F to be Marinesian, using dinoflagellates again to correlate this part of the sequence with the Sables de Cresnes. Hence the Auversian–Marinesian boundary lies somewhere between Beds A_1 and C in 'Barton Cliffs'.

Conclusions

'Barton Cliffs' comprises a classic site which has been the subject of geological interest for over 200 years. Extensive research on the site since the early 19th century has made major contributions to our understanding of middle to late Eocene times.

The importance of the section lithostratigraphically is clear from its designation as type locality for the Barton Clay, the Chama Sand and the Becton Sand. Known since the middle of the 19th century as the type section for the Bartonian Stage, its chronostratigraphical importance was recently emphasized by its designation as the type locality for one nannoplankton and three dinoflagellate zones.

Despite its stratigraphical, and indeed sedimentological importance, the initial and lasting attraction of 'Barton Cliffs' is its fossils, their abundance, diversity and often superb preservation. The molluscan fauna of maybe as many as 600 species, many present in large numbers, is supplemented by the presence of other macroinvertebrates such as echinoids and brachiopods, albeit uncommon but even less common elsewhere in the local Palaeogene. Rich vertebrate assemblages occur, including fish (represented particularly by otoliths), reptiles and mammals, whilst the upper part of the succession contains the important 'Hordle Flora'. Less overtly apparent, but of considerable significance, are the ostracod and foraminiferal faunas and the dinoflagellate microflora, important both from a palaeoenvironmental and stratigraphical point of view.

As the type section for the Bartonian Stage, the 'Barton Cliffs' site continues to be important internationally as well as within the context of the English Palaeogene. Its potential for research remains considerable, particularly in aspects of palaeontology such as molluscan palaeoecology.

WITTERING TO SELSEY FORESHORE, WEST SUSSEX (SZ 765984–SZ 845926)

Highlights

Although comprising intermittently exhumed foreshore exposures, this site is important since it represents the greatest degree of marineness within the Bracklesham Group of the Hampshire Basin. It has a rich macrofauna and microfauna which have enhanced correlation both locally and in an international context.

Introduction

Along the foreshore of Bracklesham Bay, from the entrance to Chichester Harbour immediately west of West Wittering (grid reference SZ 765984) to Selsey (SZ 845926), fossiliferous, mainly sands and silts of the Bracklesham Group are intermittently exposed below a cover of Pleistocene and present-day beach deposits in a sequence which broadly dips gently to the south

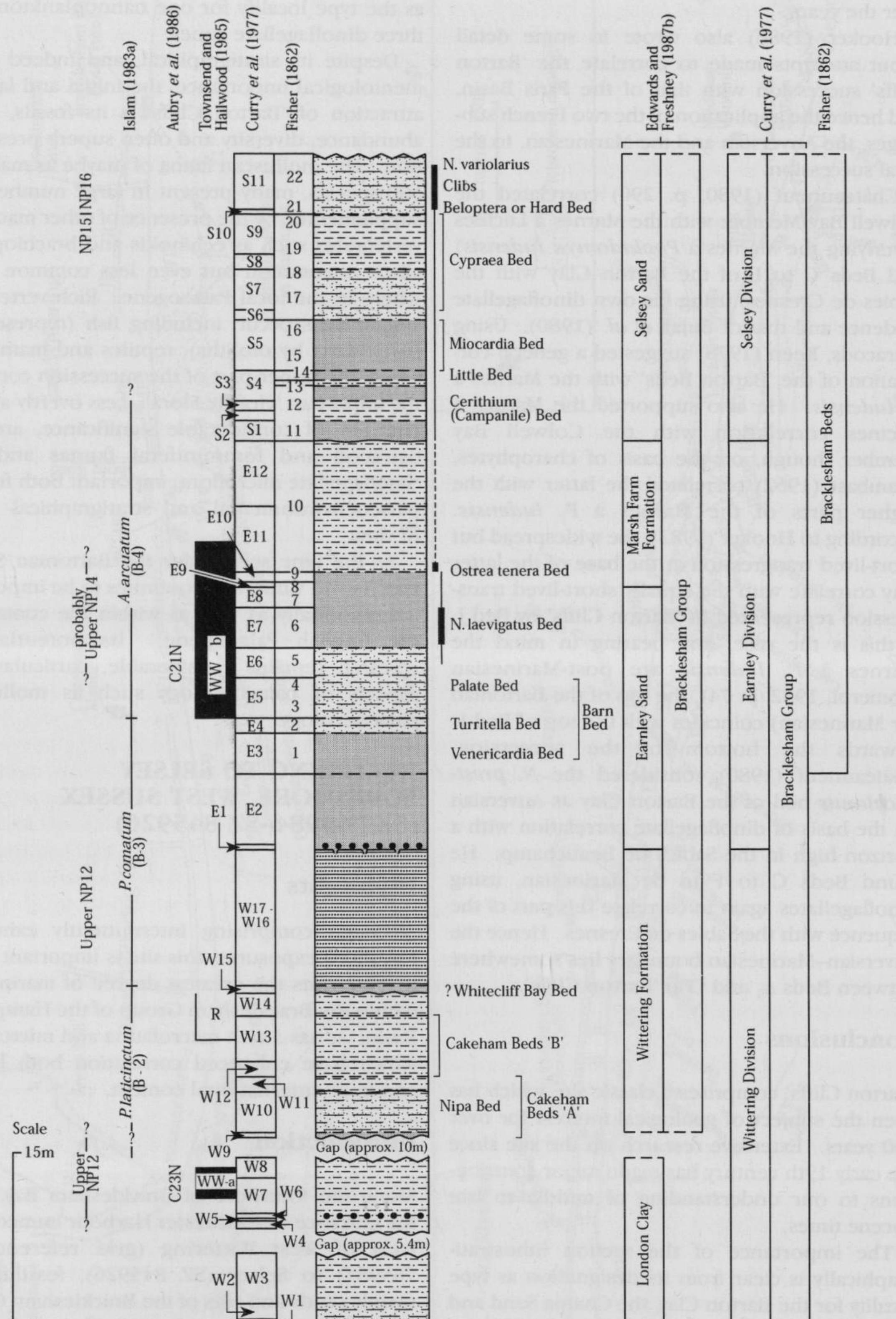

Figure 6.20 Bracklesham Group succession from Wittering to Selsey, Bracklesham Bay, West Sussex (after Curry *et al.*, 1977 and other authors).

(Figure 6.19, but see also very recent maps produced by Bone and Tracey, 1996). Wittering to Selsey Foreshore is the most easterly (and possibly the most marine) section in the Bracklesham Group in the Hampshire Basin. Following Edwards and Freshney (1987b, p. 57), the most northerly part of the succession has been reassigned to the London Clay, but this is rarely exposed.

The earliest published account of the fossils and deposits of the section was by Mantell (1822) in his *Fossils of the South Downs*. At this time, the Bracklesham Beds were thought to be part of the London Clay and the two were not separated until later (Prestwich, 1847a). Bowerbank's (1840b) paper, 'On the London Clay Formation at Bracklesham Bay' illustrates this early nomenclatural usage.

The first general account of the section was by Dixon (1850) with illustrations of many of the characteristic fossils, whilst in 1862, Fisher described the section in greater detail and introduced a bed numbering system which has continued to be of value up to the present day.

Reid (1897) was the first to describe the older part of the succession to the north-west of Bracklesham Lane (SZ 805964) which was apparently unknown to Dixon and Fisher. Heron-Allen's (1911) book *Selsey Bill* contains a substantial section on the local geology, but both Curry *et al.* (1977) and Bone and Bone (1985) have pointed out that it is, in places inaccurate and confused. White (1915) added little to previous accounts.

Wrigley and Davis (1937) provided further details of the lower part of the succession. The section was briefly summarized by Curry (1958a) whilst Curry *et al.* (1968, fig. 6) suggested a correlation between this and other contemporary sections further to the west. The description of the section by Curry *et al.* (1977) is one of the most important of relatively recent accounts, in particular since it is based on detailed mapping of the foreshore over some years, mainly between 1969 and 1973.

Considerable attention has focused on the stratigraphical significance of the succession, its correlation with other localities, and its age. Amongst those papers dealing with this aspect of the section are Stinton (1975) and Curry *et al.* (1977) on aspects of the lithostratigraphy and correlation, Odin *et al.* (1969) and Odin *et al.* (1978) on glauconite dating, and Islam (1983a), Townsend and Hailwood (1985), Aubry (1986) and Aubry *et al.* (1986) on the chronostratigraphy.

Until recently (see below), little modern work had been undertaken on the macrofauna from this section, although Bone and Bone (1985) produced a useful illustrated guide to the more common fossils. More emphasis has been placed on aspects of the microfauna (Murray and Wright, 1974) and microflora (Islam, 1983a; Aubry, 1986; Aubry *et al.*, 1986).

After this site description had been submitted to JNCC, volume 16 of the journal *Tertiary Research* was published and dedicated to the memory of a local amateur palaeontologist, Roy Fowler, who had worked on the section for many years. It contains a number of papers which considerably improve our knowledge and understanding of the geology of the site, including an update on the stratigraphy by King (1996), the results of detailed mapping of the foreshore by Bone and Tracey (1996), various aspects of the molluscan fauna (Tracey *et al.*, 1996; Tracey and Todd, 1996; Tracey *et al.*, 1996), and a review by Collinson (1996) of plant macrofossils from the section in the context of coeval British floras.

Description

Although the section comprises intermittently exposed foreshore exposures, it has long been of considerable significance palaeontologically, stratigraphically and palaeoenvironmentally. Until relatively recently (see above), the only detailed modern description was that of Curry *et al.* (1977) who assigned the sequence to three 'divisions' (see later) of the 'Bracklesham Beds'.

Lithological succession

Except for the lowest few metres which Edwards and Freshney (1987b) assigned to the London Clay, the succession (Figure 6.20) comprises Bracklesham Group strata (in ascending order, the Wittering Formation, the Earnley Sand, the Marsh Farm Formation and the Selsey Sand). Measurement derived from fig. 6 of Curry *et al.* (1977) gives a thickness for the total succession of a little in excess of 93 m, although a summation based on measurements given for the three 'divisions' described from the same paper indicated around 120 m, a thickness greater than that of the Bracklesham Group for this locality given in Edwards and Freshney (1987b). As

Fisher (1862) pointed out, it is difficult to determine the thickness of the succession and, interestingly and unusually, each of his subdivisions (pp. 74–5) is labelled not in feet but in paces!

The succession comprises a complex, more or less fossiliferous alternation of muds, silts and sands with occasional pebble beds. Glauconitic lithologies characterize much of the section. The strata present are mainly unlithified but a few horizons are more indurated and this may be reflected by the presence of low 'reefs' or 'nodules' on the foreshore.

Stratigraphy

In his classic paper, Fisher (1862) considered the importance of this locality in his study of the 'Bracklesham Beds' and concluded that 'Bracklesham Bay, both for interest and display of the beds, undoubtedly holds the highest place'. The significance of the section has been recently reiterated by Edwards and Freshney (1987b) who have designated Bracklesham Bay as the hypostratotype for all four formations within their Bracklesham Group.

The hypostratotype for the Wittering Formation is that part of the foreshore from SZ 765984 to 808961 and is equivalent to Beds W9–17 of Curry *et al.* (1977). That for the Earnley Sand extends from SZ 808961 to 823950 and comprises Beds E1–8 of Curry *et al.* (1977). This formation is the Earnley Formation of King and King (1977) who also designated this section as the hypostratotype. These authors defined the section from SZ 823950 to 825946 as their hypostratotype for the overlying Marsh Farm Formation, equivalent to Beds E9–12 of Curry *et al.* (1977). The uppermost formation of the Bracklesham Group, the Selsey Sand, has the section from SZ 825946 to 845926 as its hypostratotype and consists of Beds S1–11 of Curry *et al.* (1977).

Biostratigraphy

As well as being lithostratigraphically significant, these Bracklesham Group strata are of chronostratigraphical importance. Both *N. laevigatus* and *N. variolarius* horizons and the presence of dinoflagellates and calcareous nannoplankton have contributed to a better understanding of the correlation of these strata.

Islam (1983a) was able to recognize three of the dinoflagellate assemblage zones of Bujak *et al.* (1980) in the section. Zone B-2 includes W10–15, but may extend further down the sequence; Zone B-3 includes Beds W16 to E4; Zone B-4 extends from Bed E5 to at least S3, the highest unit sampled.

Calcareous nannoplankton, although not particularly common in the local Palaeogene succession, have been reported at three levels in the Bracklesham Bay section by Aubry (Aubry, 1986; Aubry *et al.*, 1986), although D. Curry (pers. comm.) has found that they occur at at least six horizons. The upper part of Zone NP12 is indicated by nannofossils from below Fisher Bed 1 (probably Bed W14 of Curry *et al.*, 1977). The upper part of Zone NP14 is probably represented by assemblages from Bed E7 (Fisher Bed 6). Aubry *et al.* (1986) pointed out the particular significance of the very abundant nannoflora from Fisher Beds 19, 20 and 21 (more or less equivalent to Beds S8–10 of Curry *et al.* (1977). Here, the last occurrence of *Rhabdosphaera gladius* in Fisher Bed 20 led Aubry (1986) to place the Zone NP15/NP16 boundary between Fisher Beds 20 and 21. The reference by Aubry *et al.* (1986) to scarce nannofossils representing Zone NP12 from 'glauconitic clayey silts which underlie Fisher Bed 1' (implying Bed E3 of Curry *et al.*, 1977) is misleading, as is their reference to the recording of the normal polarity event at this level, for the latter (from Townsend and Hailwood, 1985, p. 968) was in fact recorded from Beds W 7–8 of Curry *et al.* (1977) around 35 m further down the succession. The bed Aubry sampled was in fact Bed W14 (D. Curry, pers. comm.).

Radiometric dating and magnetostratigraphy

The presence of glauconitic sands permits a radiometric age determination. Two attempts have been made on glauconites from the section, both using material from Fisher Bed 2 (Bed E4 of Curry *et al.*, 1977). Odin *et al.* (1969) gave an age of 49.4 ± 3 Ma, whilst Odin *et al.* (1978) made it 46.4 ± 1.5 Ma.

More recently, Townsend and Hailwood (1985) established that two normal and one reverse polarity magnetozones could be recognized in the Bracklesham Bay succession. In Aubry *et al.* (1986), the two normal polarity zones were referred to as the Wittering magnetozone and the Earnley magnetozone respectively. Relating the magnetostratigraphy to the nannofossil biostratigraphy, these authors were able to establish that both Chron C23N and Chron C21N are represented in the Bracklesham Bay section.

Sedimentology

Apart from the logs in Curry *et al.* (1977) and useful albeit brief summaries in Edwards and Freshney (1987b), very little has been published on the sedimentary features of the succession. Plint (1983a) apparently did not study the section in detail as part of his sedimentological study of the Bracklesham Formation (sic). Glauconitic sediments are represented in all four formations and testify to the marine nature of much of the sequence.

Macrofossils

Both the Earnley Sand and Selsey Sand are dominated by glauconitic deposits and are rich in marine fossils. The other two formations contain both marine and brackish water assemblages. Both the lower and upper parts of the Wittering Formations are lignitic to some extent and oyster-rich molluscan faunas are characteristic of these parts. *Nipa* fruits occur near the base of this formation, whilst the higher beds contain an important vertebrate fauna (see Moody and Walker, 1970), most of which is as yet undescribed.

Foraminifera

Murray and Wright (1974) made a detailed study of the foraminifera of the section as part of a broader investigation of these microfossils from the Palaeocene of the Hampshire Basin. The majority of assemblages found fall just within the field of normal saline shelf seas. That from Fisher Bed 21 (Bed S10 of Curry *et al.*, 1977) proved to be particularly important. Murray and Wright (1974) found it to be characterized by many species not present at any other level in the English Eocene and also of special significance both biostratigraphically and ecologically. Such species are indicative of shallow waters with fully marine salinity and represent much warmer conditions than the other Eocene faunas which these authors examined.

Interpretation and evaluation

Although poorly and intermittently exposed, the Wittering to Selsey Foreshore section in Bracklesham Bay is of considerable stratigraphical and palaeoenvironmental importance. It is the most easterly exposure of the Bracklesham Group and, with Whitcliff Bay, it represents a higher degree of marineness compared with coeval sections found further to the west. Its rich invertebrate macrofauna continues to provide opportunities for research into the more marine assemblages preserved in this part of the Hampshire Basin. Work also needs to be undertaken on what Curry *et al.* (1977) called 'important vertebrate fauna' in the Wittering Formation.

Stratigraphical significance

The section is stratigraphically significant. It provides the name for the Bracklesham Group of Edwards and Freshney (1987b), although neither this nor any other locality was defined as stratotype for this unit. Curry *et al.* (1977) recognized the importance of the section by naming three of their informal 'divisions' from localities adjacent to the site, but prior to the publication of this paper, Stinton (1975) had given these formation status and Cooper (1976b) had referred to parts of the section as the stratotype for the 'Wittering Formation' and the 'Selsey Formation'. King and King (1977) subsequently pointed out that their 'divisions' represented sedimentary cycles and were not intended to be formations. In contrast with the above, the Wittering Formation, the Earnley Sand and the Selsey Sand of Edwards and Freshney (1987b) are valid and Bracklesham Bay is correctly given as the hypostratotype for all these formations, as well as for the fourth from the Bracklesham Group, the Marsh Farm Formation.

Comparison with other localities

Using the lithostratigraphical definitions of Edwards and Freshney (1987a,b) and data from these papers, it is possible to compare formation thicknesses in the section considered here with those of the other Hampshire Basin localities. Although the approximately 29 m for the Wittering Formation in Bracklesham Bay may be an underestimate reflecting an incompletely exposed section, the succession is far thinner than the 53 m of Whitecliff Bay, although within the 23–57 m range given by Edwards and Freshney (1987a, p. 38) for the Southampton area. At around 22 m, the thickness of the Earnley Sand is not very different from that of Whitecliff Bay (25 m) but thicker than what is generally found further to the west. By contrast, the Marsh Farm Formation, at around 12 m (13.5 m in Whitecliff Bay), is relatively thin compared with more westerly localities, such as 21.3 m at Gosport (King and Kemp, 1982) and between 18 and 25 m in the Southampton district (Edwards and Freshney, 1987a, p. 48). For the Selsey Sand, the thickness of 24.7 m in the Bracklesham Bay section is only slightly less than the 27 m of Whitecliff Bay but considerably thinner than the 30–50 m of the Southampton area.

Correlation with other sections in the eastern part of the Hampshire Basin is not difficult. The recognition of the Wittering, Earnley and Selsey cycles here facilitates 'event stratigraphy' correlation with Whitecliff Bay and further west. The bases of these cycles reflect transgressions T1, T3 and T4 of Plint (1983a), whilst his transgression T2 probably coincides with the base of Bed W11 of the Wittering formation in the Bracklesham Bay section. Higher up the latter, Beds 15 to 17 correlate with the lignite and seatearth found within the unit in Whitecliff Bay (the 'Whitecliff Bay Bed' or 'Coal Bed'; part of Fisher Bed V) and elsewhere and reflecting a major regressive phase over a wide area (Edwards and Freshney, 1986, p. 62).

International correlation

For some years, it has been clear that, with Whitecliff Bay, the fossiliferous Bracklesham Bay section has provided an opportunity for international correlation, which has proved difficult or impossible from the coeval, more westerly Hampshire Basin sections. Curry *et al.* (1978, p. 42), for example, referred to planktonic foraminifera from their Wittering Formation that are found throughout the Sables de Cuise in the Paris Basin, whilst *N. laevigatus* from the Earnley Sand is abundant in the lower part of the Calcaire Grossier from the latter area, and also occurs in the Brussels Sand in Belgium.

Palaeoenvironmental significance

Although this poorly exposed section is stratigraphically complex, Plint (1983a) recognized it as a cyclic sequence and that four distinctive erosional surfaces represent transgressive events. In a later paper (Plint 1988a, fig. 3), he interpreted some units as estuarine or lagoonal and that surfaces associated with these represent periods of marine lowstand. That there were regressive periods when salinities were lower is supported by the occurrence of more restricted or brackish water faunas as, for example, near the top of the Marsh Farm Formation. However, the general predominance of glauconitic sands and muds, rich in marine fossils, makes this the most fully marine of the Bracklesham Group sections within the Hampshire Basin.

The intra-Bracklesham Group unconformity

Work, including that which has combined magnetostratigraphical data with that of nannofossil biostratigraphy, has clarified the relationship of the succession at Bracklesham Bay with other localities. Here, too, is the apparent major hiatus identified elsewhere in the Hampshire, London and Paris basins and referred to by Aubry *et al.* (1986), Plint (1988a) and others. Its occurence is demonstrated by the absence of a record of Chron C22N and its commonly associated NP13 flora. Disregarding the anomolous reference by these authors to NP12 fossils in the 'glauconitic' clayey silts that underlie Fisher Bed 1, which would indicate that the missing Chron occurred in the lower part of the Earnley Sand, it is clear from evidence they provide elsewhere (including in Townsend and Hailwood, 1985) that the 'gap' occurs somewhere between Bed W8 of Curry *et al.* (1977) and Bed E7 (Fisher Bed 6). Islam's (1983a) suggestion that the distinctly regressive 'Whitecliff Bay Bed' is represented in Bracklesham Bay by Bed W15, suggests that it occurs around this stratigraphical level. Aubry *et al.* (1986, p. 733) consider it to be equivalent to the well-known unconformity between the upper Cuisian (NP12) and the basal Lutetian (Upper NP14) which has been interpreted as reflecting a major eustatic sea-level fall (Vail *et al.*, 1977). Neither Neal *et al.* (1994) or Neal (1996) discussed the section in their consideration of the level at which the hiatus should be placed in the Hampshire Basin succession (see description of Whitecliff Bay, this volume).

Conclusions

Whilst the foreshore exposures from Wittering to Selsey on the eastern side of Bracklesham Bay are of an intermittent nature, the section has proved to be of considerable palaeontological and stratigraphical significance since the time it was first described in the 19th century up to the present day.

Over a period of many years, these foreshore deposits have yielded a wide variety of fossils. It has a rich marine molluscan fauna together with vertebrate and some macrofossil material, whilst in more recent years the presence of various microfossils has enhanced the value of the section. Nummulitids have been known from the site for many years; latterly, other foraminifera, dinoflagellates and calcareous nannoplankton have proved particularly useful.

This site is palaeogeographically important as it is the most easterly section of its age in the Hampshire Basin. Its particular value is that its mainly glauconitic strata with their clearly marine fossils, represent a clear contrast with the inshore to non-marine, relatively poorly fossiliferous facies found further west at such localities as Alum Bay and Bournemouth. It is therefore the most marine section of its age in the Hampshire Basin.

Although not formally designated as its type locality, the section provides the name for the Bracklesham Group. It has, however, been selected as the hypostratotype for all four formations of the Group. Hence, its lithostratigraphical credentials are sound.

Within recent years, the chronostratigraphical importance of the site has become increasingly apparent. Three dinoflagellate assemblage zones are represented and facilitate local correlation, whilst the presence of nannoplankton Zones 12, 14, 15 and 16 is indicative of the site's correlative value internationally. Furthermore, the Wittering and Earnley magnetozones both take their name from parts of the Bracklesham Bay site.

BOGNOR REGIS, WEST SUSSEX (SZ 934987–SZ 889970)

POTENTIAL GCR SITE

Highlights

As the most easterly exposure of London Clay in the Hampshire Basin, Bognor has both a stratigraphical and palaeoenvironmental importance. Its value is increased by the presence of a rich and varied fossil fauna and flora and by the fossils being particularly well preserved in the unweathered foreshore sections.

Introduction

Although formally referred to here as Bognor Regis, the site comprises intermittent foreshore exposures from Bognor (SZ 934987) westwards to Aldwick and Pagham (SZ 889970). The deposits present comprise silty muds and sands of the lower to middle part of the London Clay which dip at a low angle to the south-west. Two sandstone 'reefs' form local landmarks: the Bognor Rocks (SZ 922982) and, further west at Pagham, the Barn Rocks (SZ 907978).

Early, but somewhat limited descriptions, include those of Dixon (1850), Dixon and Jones (1878) and Reid (1897), who paid particular attention to the Bognor Rocks. In the 20th century, sustained research by Venables (see Bone, 1992a,b) led to a considerable understanding of the stratigraphical succession. Early work by Venables (1929), the first detailed account of the stratigraphy, was ultimately followed by a more comprehensive study (Venables, 1963) in which he divided the succession into 'Groups', which in turn were partially subdivided into beds. Subsequently, further horizons were recorded by Bone (1978) and the stratigraphy redescribed by King (1981, pp. 71–3).

Whilst early workers such as Dixon (1850) dealt with a range of fossils, the palaeontological importance of the section has been emphasized by more recent specialist studies. These include work on the almost unique insect fauna by Britton (1960), Venables and Taylor (1963) and Jarzembowski (1993), on plant macrofossils by Chandler (1961b, 1964, 1978) and Collinson (1983a), on fish teeth by Casier (1966), fish otoliths by Stinton (1957, 1975, 1975, 1978, 1980), and crinoids and ophiuroids by Rasmussen (1972). The molluscan fauna has attracted attention over many years and has recently been reviewed by Tracey (1992). The nautilid fauna has been considered by Hewitt (1988a,b). Venables' 1963 paper included work on the microfauna (foraminifera and ostracods) from Bognor.

This account of the Bognor site draws upon an earlier unpublished description compiled by

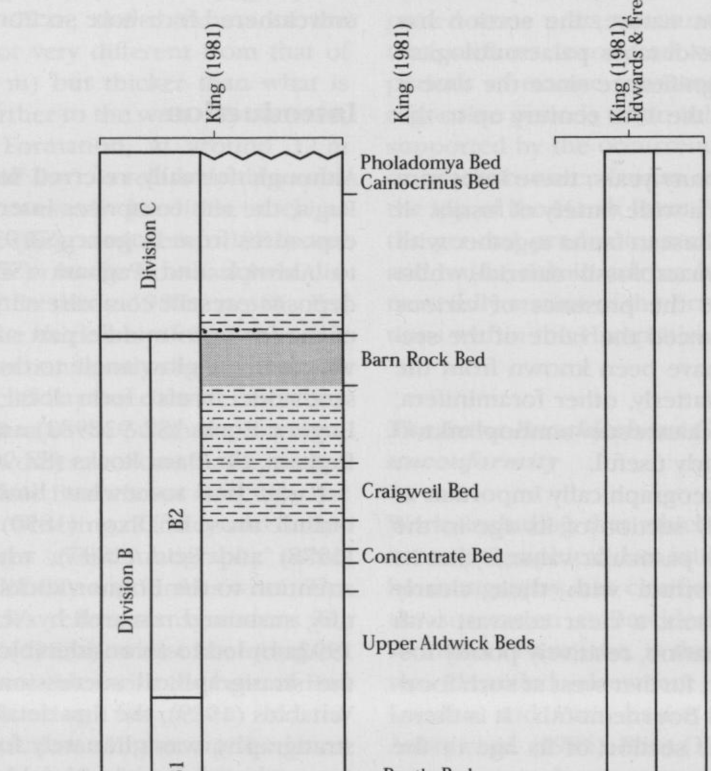

Figure 6.21 London Clay succession at Bognor Regis, West Sussex (after King, 1981, text-fig. 23).

Bone in 1985 (pers. comm.).

This site was also independently selected for its fossil plant, fish and bird content, a more detailed account of which can be found elsewhere in the GCR series (*Mesozoic to Tertiary Palaeobotany of Great Britain* (Cleal and Thomas, in prep.); *Fossil Fishes of Great Britain* (Dineley and Metcalf, 1999); *Fossil Mammals and Birds of Great Britain* (Benton *et al.*, in prep.). This site was also selected for its fossil insect content, details of which will be discussed in a future GCR volume.

Description

The foreshore section at the Bognor site comprises a sequence of silty muds and sands dipping gently west-south-west. King (1981) identified his informal divisions A, B and C of the London Clay, together with 3+ m of his Oldhaven Formation identified by augering at the eastern end of the section.

The junction with the Reading Formation is hidden by river alluvium, whilst extensive beach sediments obscure the higher part of the sequence between Barn Rocks and Pagham Harbour, with the junction of the London Clay and Bracklesham Group unexposed.

Lithological succession

King's (1981) description of the section refers to the presence of almost 90 m of London Clay, representing strata from low in his division A (*c.* 43 m), division B (*c.* 33 m) to the middle of division C (12+ m) (King, 1981, pp. 71–3), whilst conceding the difficulty of measuring the section with any degree of accuracy. The succession (Figure 6.21) mainly comprises muds (silty clays, clayey silts), but at two horizons, glauconitic sands are present. These are partially lithified and comprise the Bognor Rock Bed (Bognor Member of King, 1981) and the younger Barn Rock Bed.

Lithostratigraphy

In the succession at Bognor, King's division A1 is apparently absent, the lowest part of this division present being A2, the Walton Member. The remainder of the division (A3) comprises a coarsening-upwards sequence, terminating in the glauconitic sands of the 'Bognor Rock Bed' of earlier authors. This is the Bognor Member of King (1981, p. 26) for which the Bognor Regis foreshore (SQ 922982) is the stratotype (see also Edwards and Freshney, 1987b, p. 50). The unit both here and elsewhere is partially cemented to form large nodules of calcareous sandstone. Division B of King (1981) has a base marked by rolled black flint pebbles in a sandy mud, but overall forms a second coarsening-upwards sequence which terminates in the partially cemented, fine glauconitic sandstone of the 'Barn Rock Bed'. Division C is seldom exposed, but is considered to have a basal glauconitic pebble bed (King, 1981, p. 73).

Palaeontology

Just west of Bognor pier, division A commences with the muds of the 'Astarte Bed' and the appearance of a rich and well-preserved calcareous macrofauna, including the bivalve *Astarte subrugata*. Above a distinctive septarian band, the 'Starfish Bed' contains a similar fauna and the remains of the brittle star *Ophiura bognoriensis* described by Rasmussen (1972). Above, the 'Cyprina Bed' contains little more than fragments of *Arctica* (*'Cyprina'*) *planata*, whilst the succeeding 'sandy clay' of Venables (1929, 1963) contains *Ostrea tabulata*, *Pinna affinis*, *Panopea intermedia* and *Ditrupa plana*. The Bognor Member has a distinctive macrofauna of large bivalves and gastropods including *Glycymeris brevirostris* and *Athleta denudatus* together with the annelid *Rotularia bognoriensis*.

King (1981, p. 73) refers to the varied fauna and flora of division B. Much of B1 comprises silty clays characterized by an abundant microfauna containing elements of the 'Nodosariid-rich' fauna of the London Basin. Wright's (1972) 'planktonic foraminiferid datum' occurs near the base, shortly above the 'Lower Fish Tooth Bed'.

Pyrite occurs abundantly, ranging in size from small grains to nodules, together with a variety of pyritized fossils. Amongst these are pyritized beetles (Britton, 1960; Venables and Taylor, 1963). Britton (1960) recognized 58 different fossil insects from Bognor. No insects have been found *in situ* but, along with a large assemblage of land-derived seeds and fruits, fish teeth, bones and otoliths, occur as foreshore concentrates on the outcrops of B1 and the lower part of B2 (King, 1981, p. 73). Most insects come from the 'Beetle Bed' of Venables (1963).

Septarian nodules are common, mainly as distinct layers, which can form useful marker horizons. Scattered phosphatic nodules are also common, often containing crustacean, turtle and fish remains or nautiloids. Driftwood often occurs, frequently as large logs and usually well-bored by *Teredo*. In a recent study of pyritized twigs from the London Clay, Poole (1992) found division B at Bognor to be a good source of material albeit, like the other pyritic fossils, predominantly secondarily derived from present-day beach concentrates.

Within the relatively unfossiliferous muds higher up the B2 sequence, *Arctica* and *Pitar* are the most common macrofossils. *Cainocrinus tintinnabulum* (see Rasmussen, 1972) occurs at one horizon where abundant current-drifted crinoid, otolith and shell debris accumulated against fossil logs (Bone, 1978). At the top of B2, the 'Barn Rock Bed' contains sporadic and poorly preserved fossils, of which the most common is *Cultellus affinis* (D.A. Bone, 1985, pers. comm.).

In the rarely exposed division C, two horizons with common macrofossils, the 'Pholadomya Bed' and the 'Cainocrinus Bed', are occasionally exposed 9–12 m above the base.

Recently, Tracey (1992) has reviewed the Bognor molluscan fauna. He listed 141 species: 75 gastropods, 65 bivalves and one scaphopod. Cephalopod material is mentioned although not identified in more detail. Hewitt (1988a,b), however, referred to four nautilid genera from division B, including museum and other material found by earlier workers. These are *Cimomia*, *Deltoidonautilus*, *Euciphoceras* and *Simplioceras*.

Interpretation and evaluation

The Bognor section is one of the few coastal exposures of the London Clay in the Hampshire Basin and as the most easterly exposure of the London Clay in this area, it is significant both stratigraphically and palaeoenvironmentally. The value of the site is enhanced by wide outcrops of the constituent beds produced by the shallow dip (contrasting with the narrow exposures in the near-vertical strata of Whitecliff and Alum Bays) and this has provided an unusually good opportunity for the collection and study of faunal and floral remains.

Comparison with other localities

Compared with the London Clay in Whitecliff Bay and Alum Bay, the Bognor section is about two-thirds complete and becomes obscured towards the top of the succession. Unlike these other two localities, however, it is unweathered and in consequence, both fauna and flora are well preserved.

Lack of exposure at the western end of the section inhibits comparison above the lower part of division C, but below the latter, the succession is broadly similar to that of Whitecliff Bay. Division A1 is absent at both localities, whereas A3 is thicker at Bognor and thins markedly westwards (see King, 1981, text-fig. 36). The Bognor Member is better represented here than in Whitecliff Bay and is absent further west in the Southampton area (Edwards and Freshney, 1987a, fig. 12). Division B is less thick at Bognor than at Whitecliff Bay (where it measures 39.8 m according to King, 1981, p. 77) but is stratigraphically important since the lower part of division B at the latter locality is always badly slipped and poorly exposed.

Invertebrate palaeontology

The diverse nature of the molluscan fauna has become apparent over the years: 57 species recorded by J. de C. Sowerby (in Dixon, 1850) have, with time, increased to 62 (Venables, 1929), 128 (Venables, 1963) and presently number just in excess of 140 (Tracey, 1992). Tracey referred particularly to the well-preserved molluscs in the lowest part of division A3 (the Astarte, Starfish and Cyprina Beds) and the mainly pyritized molluscs of the Beetle Bed and Upper Fish-tooth Bed of division B.

The fossil assemblages of division B are particularly important since Bognor is the only location in the Hampshire Basin to yield material at this level in any quantity. The Beetle Bed is especially valuable since it contains the only significant insect fauna from the London Clay. Furthermore, Bognor remains the principal international source of pyritized insects (Jarzembowski, 1992, p. 93).

By comparison with the ecology of present-day relatives, the insect fauna is predominantly one of Mediterranean-subtropical woodland

(Britton, 1960). Following the assertion of Rundle and Cooper (1971) that insects from the London Clay drifted out to sea with wood, Jarzembowski (1992) has suggested that the more westerly, near-shore location of the Hampshire Basin accounts for the fact that London Clay insects are mainly from this area. This is further supported by the presence of flightless larvae, together with beetles with their wing cases in the rest position.

Work by Hewitt (1988a,b) on the nautilids has shown that these can be valuable palaeoenvironmental and, particularly, depth indicators. He considered that life assemblages of *Euciphoceras* and *Simplicioceras* probably extended to a depth of around 130 m, with *Cimonia* and *Deltoidonautilus* added to the fauna at depths of less than 70 m. Whilst referring to the Bognor section as 'near shore', Hewitt (1988b) pointed out that depths can be inferred from implosion studies of transported shells and that these have raised estimates of water depth.

Plant fossils

The Bognor flora is considerably older than that of Sheppey, and is the main source of plant material in division B of the London Clay (see Collinson, 1983a, pp. 6–7). It therefore provides a useful source of data for both palaeoclimatic and palaeoenvironmental interpretation at this stratigraphical level. Of the London Clay flora as a whole, the majority of really small fossils and seeds come from Bognor (Chandler, 1978). However, whilst about 40 species of fossil plants come only from the London Clay of Bognor, both Chandler (1964) and Collinson (1983a) considered the London Clay Flora as a whole as relatively uniform, with the differences from one locality to another reflecting the vagaries of fossilization processes and collecting. Overall, it therefore seems likely that climatic conditions were not dissimilar from those of the rest of London Clay times.

Depositional environment

The coarsening-upwards cycles represented here by King's divisions A and B represent the transgressive/regressive cyclicity characteristic of the London Clay. The glauconitic nature and the palaeontology of the sands at the tops of both units confirms that the regressive elements are fully marine in this area. However, as King (1981) pointed out, some fossil elements are clearly land-derived. Indeed, the association of plant material with insects suggested to Chandler (1964, p. 44) that, in London Clay times, there was closer proximity to land at Bognor than at Sheppey.

Conclusions

As the furthest east of the natural exposures of the London Clay in the Hampshire Basin, the Bognor site provides an important data source for regional palaeogeographical and palaeoenvironmental interpretation.

A significant feature of the site is that since the foreshore exposures are unweathered, both fauna and flora are generally well preserved. This is particularly important regarding those horizons, such as the lower part of division B, which are elsewhere badly slumped or decalcified.

A wide variety of plant and animal fossils occur. Of these, the pyritized insect fauna is almost unique, with Bognor the principal international source of pyritized insects.

SHEPHERD'S GUTTER, NEAR BRAMSHAW, HAMPSHIRE (SU 261154–SU 265152)

Highlights

This Selsey Sand site is particularly valuable for its well-preserved fauna. It is the only locality where beds of this age can be examined in the New Forest and hence provides a unique insight into local palaeoenvironmental conditions.

Introduction

The site comprises a section in the east by south-flowing stream known as Shepherd's Gutter. It occurs west of Bramshaw and extends for almost half a kilometre on either side of the stream from grid reference SU 261154 downstream to SU 265152. The small exposures present occur within the Selsey Sand (Bracklesham Group) of Edwards and Freshney (1987b), whilst a small distance upstream, the Nummulite Bed of Stinton (1970) containing *N.* cf. *prestwichianus*

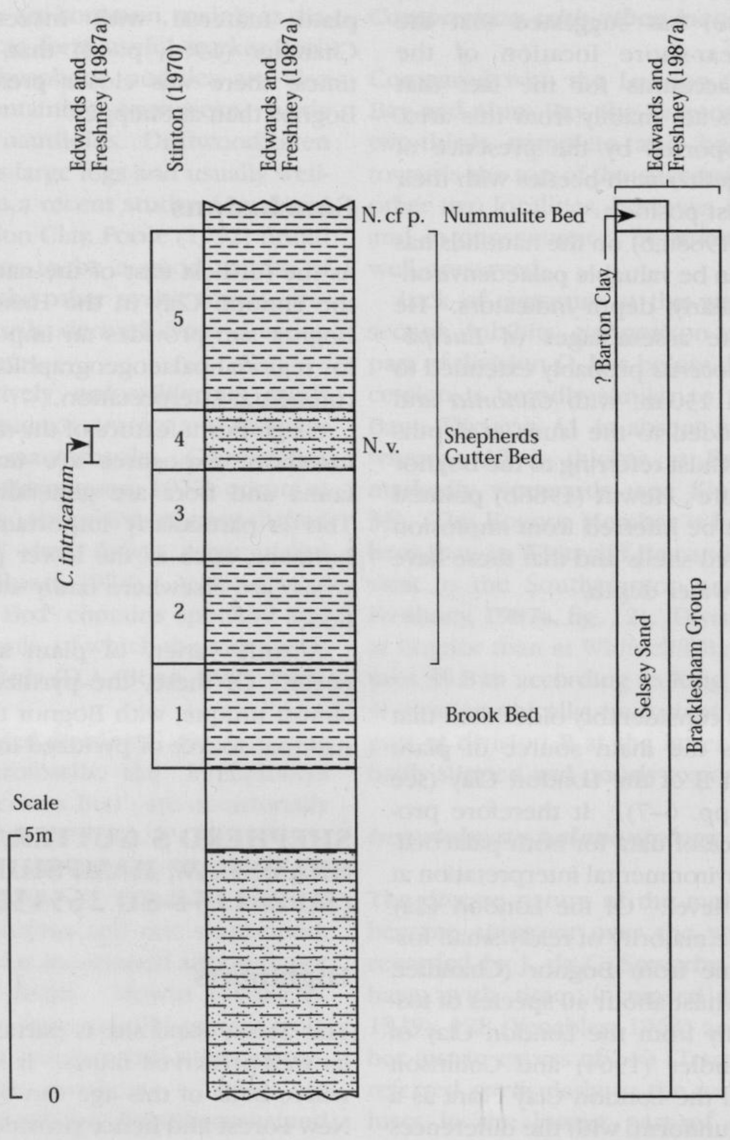

Figure 6.22 Selsey Sand succession at Shepherd's Gutter, Bramshaw, Hampshire (mainly after Edwards and Freshney, 1987a, fig. 30). N. cf. p. and N. v refer to *Nummulites* cf. *prestwichianus* and *N. variolarius* respectively.

has been found in a trial boring. This bed may represent the base of the overlying Barton Clay (see account of Studley Wood).

Apart from King's Garn Gutter, it is perhaps the earliest New Forest site to become known for its fossils, which had been collected for many years prior to its first being described by Fisher (1862). Despite more or less continuous collecting from the early 19th century to the present day, Shepherd's Gutter remains a rich source of material, unlike King's Garn Gutter where extensive pits were excavated on both sides of the stream so that now only reworked material can be found.

Only brief modern accounts of the section have been published (Stinton, 1970a, pp. 273–4; Stinton, 1970b, pp. 43–4; Curry 1968, p. 23, in French). The present account also draws upon an unpublished site description by the late F. Stinton.

Description

The succession occurs in more or less glauconitic sands, sandy clays and clays of the Selsey Sand (Bracklesham Group). Stinton (1970) described a succession of five beds from this locality, totalling some 10 m (see also slightly expanded section after Stinton in Edwards and Freshney, 1987a, p. 57; Figure 6.22). The succession is intermittently exposed, the oldest strata being exposed further downstream. In Stinton's unpublished draft, he described a prolific fauna which is a prime factor in determining the importance of this site. In addition to 128 gastropod and 29 bivalve species, he listed the scaphopod *Entaliopsis striatum*, small cephalopods (*Belosepia sepioidea*, *B. oweni* and *Vasseuria occidentalis*), the echinoid *Echinus dixonianus*, the cirrepedes *Balanus unguiformis* and *Euscalpellum turneri*, and the anthozoan corals *Paracyathus crassus*, *Siderastrea websteri* and *Turbinolia sulcata*. Stinton also listed 12 species of fishes, apart from those represented by otoliths.

Stinton's bed 1 is the 'Brook Bed', a glauconitic muddy sand, very fossiliferous towards the base. *Corbicula pisum* var. *wemmelensis* is abundant. *Turricula attenuata* occurs frequently whilst *B. sepiodea* is not uncommon. Stinton's (1970) beds 2 to 5 comprise the Shepherd's Gutter Bed of Fisher (1862) for which this is the type locality. Bed 2, a grey mud, contains numerous *Lentipecten corneus*, whilst this and intermittent sandy lenses are packed with fossils, including otoliths, echinoid spines and well-preserved small gastropods. The coral *Paracyathus*, often attached to shell fragments, is frequently found.

Bed 4 is a sandy glauconitic bed packed with *N. variolarius* and contains abundant molluscan fossils, fish remains and other fossils. Edwards and Freshney (1987a, p. 57) referred to dinoflagellates from this bed indicative of the *Cyclonephelium intricatum* Zone (B-5) of Bujak *et al.* (1980). Bed 5 has finely preserved fossils including *Turritella carinifera* and *Sassia flandrica*.

Interpretation and evaluation

Shepherd's Gutter is predominantly important for its prolific and well-preserved fauna. It does, however, also provide an insight into the Eocene stratigraphy and hence palaeoenvironmental development in an area of the Hampshire Basin where exposures are very limited.

Invertebrate fauna

Faunas characteristic of the Brook Bed have been recognized in the New Forest in Kings Garn Gutter and the Ramnor Inclosure Borehole (see Edwards and Freshney, 1987a, fig. 29). Further afield, this fauna is represented in beds L and (in part) K in the Fawley Transmission Tunnel (Curry *et al.*, 1968), in Bed 13 of Fisher (1862) at Lee-on-the-Solent, and in Bed 19 of Fisher (1862) at Whitecliff Bay. Stinton's unpublished account of the section suggests that the absence of a Brook Bed fauna in Alum Bay reflects decalcification, but recent work has indicated that this responds to a change of facies (cf. Edwards and Freshney, 1986, p. 56 and fig. 2).

Stratigraphy and comparison with other localities

Stinton (unpublished) was of the opinion that Bed 2 was the Shepherd's Gutter Bed of Fisher, whilst both Curry (1968) and Edwards and Freshney (1987a) considered the latter to include Beds 2 to 5 of Stinton (1970).

As with the Brook Bed, a consideration of the lateral equivalents of the Shepherd's Gutter Bed helps to clarify the facies distribution and palaeogeography of the times. Edwards and Freshney (1987a, p. 55) included amongst its lateral representatives in the Hampshire Basin, Bed M of the Fawley Tunnel Section (Curry *et al.*, 1968), Bed 16 of Fisher (1862) at Lee-on-the-Solent and Bed 16 of Fisher (1862) at Bracklesham Bay. At a more detailed level, Stinton (unpublished) considered Bed 2 to equate to Fisher Bed XVII at Whitecliff Bay and the 'Clibs' bed in Bracklesham Bay. By contrast, Bed 5, according to Stinton (unpublished), is peculiar to this part of the New Forest, it being absent at Whitecliff and Bracklesham Bays and in the Fawley Tunnel sequence. None of Beds 2 to 5 are represented at Alum Bay where coeval strata are predominantly continental clays and lignites.

Palaeogeography

Overall, such New Forest localities as Shepherd's Gutter confirm the existence of a NW–SE arm of the 'Bracklesham Sea' with unrestricted access to open marine conditions to the south-east. In

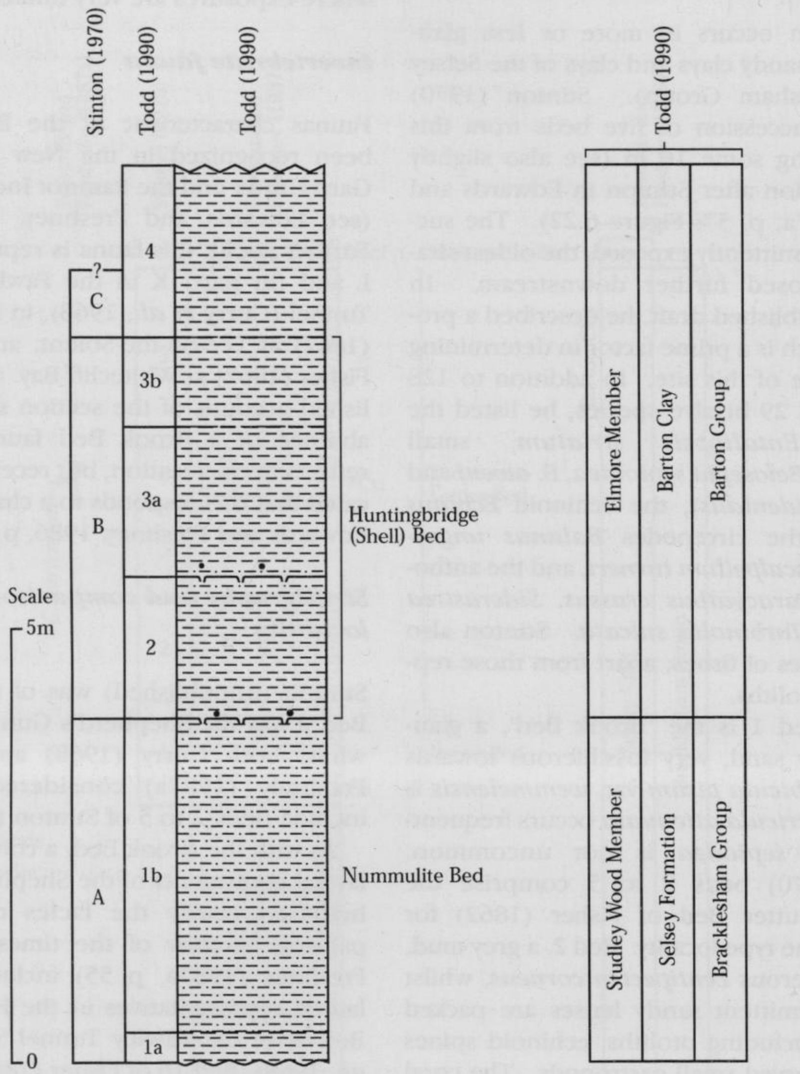

Figure 6.23 Succession across the Selsey Sand/Barton Clay boundary at Studley Wood, Hampshire (after Todd, 1990, text-fig. 2).

contrast, to the west and south (e.g. at Alum Bay) lay an area of beach and continental sedimentation (cf. Costa *et al.*, 1976, fig. 3; Plint, 1983a; Edwards and Freshney, 1987a, p. 56).

Conclusions

Shepherd's Gutter remains a rich in-situ source of fossils, in contrast with the Kings Garn Gutter, where only reworked material is available following extensive collection since the early 19th century. The fauna is prolific and well-preserved; as well as numerous molluscan species, cephalopods, echinoids and corals are present. Shepherds Gutter provides the only locality where strata of this age may be examined in the New Forest. Supplemented by local borehole material, the locality proves the former existence of a fully marine north-westerly extension of the 'Bracklesham Sea', in contrast with the beach barrier and continental conditions which occurred further towards the south and west.

STUDLEY WOOD, HAMPSHIRE (SU 227158)

Highlights

The prolific, mainly molluscan, fauna of this site represents marine conditions spanning the boundary between the Lutetian and Bartonian Stages. As the only site where this occurs in southern Britain, it is of considerable international importance.

Introduction

The site comprises a stream section near the source of the Latchmore Brook in the Studley Wood Inclosure (around grid reference SU 227158). Including sections both upstream and downstream from the latter, something around 10.5 to 11.5 m of mainly fossiliferous, sandy muds and muddy sands are present. Their precise stratigraphical assignment is not entirely agreed, although it is clear that they occupy a position adjacent to the Selsey Sand/Barton Clay boundary. A map of the exposures is given in Todd (1990, fig. 1), whose account is the most recent and comprehensive guide to the locality.

As Todd (1990) has pointed out, the section was rather surprisingly unknown to Keeping, Fisher and other 19th century workers who discovered other fossiliferous sites in the New Forest, such as that at Shepherd's Gutter. Todd referred to the discovery of typical 'Huntingbridge bed' fossils at the north-eastern end of the site by J.G. Turner some time before August 1956, although much of the section was re-discovered by C. King, following his consultation of notes made by Wrigley (currently lodged in the Natural History Museum), who noted fossils in the banks of the Latchmore Brook in the 1930s. Following current usage, the 'Huntingbridge bed' (Hunting Bridge bed of Fisher, 1862, p. 79) has informal stratigraphical status.

Apart from Todd's (1990) paper on the stratigraphy and correlation of the site, few descriptions have been published. Brief stratigraphical resumés appear in Curry (1968, in French), Stinton (1970) and Kemp *et al.* (1979), but despite the prolific fauna, no comprehensive palaeontological account has as yet been published. Certain aspects of the site are referred to by Edwards and Freshney (1987a, pp. 54–6), whilst it was sampled by Costa *et al.* (1976) in their broader study of the dinoflagellate palynostratigraphy of middle Eocene sections in the Hampshire Basin and later by Aubry (1983, 1985, 1986) as part of her investigation into the calcareous nannoplankton of western Europe.

Description

Although limited in its stratigraphical range, the Studley Wood site has contributed considerably to our knowledge and understanding of this part of the Palaeogene succession in the Hampshire Basin. It has a rich and varied fauna and, in an area of limited exposure, it provides an opportunity to investigate aspects of stratigraphy and palaeoenvironment, inland from the better known coastal exposures. However, its primary value is in providing a more or less complete, very fossiliferous sequence across the Lutetian/Bartonian boundary.

Lithological succession

The succession (Figure 6.23) comprises a little in excess of 10.5 m of mainly glauconitic muds (mostly silty, sandy clays but sometimes silts). Sand laminae and lenses are not uncommon and Todd (1990) mentioned a thicker lenticular sand which may reach as much as 1 m in thickness.

Stratigraphy

Stinton (1970) recognized three beds: in ascending order, Bed A (the Nummulite Bed), Bed B (the Huntingbridge Bed) and Bed C (the Coral Bed). More recently, Todd (1990) has recognized six 'units' at this locality. The lowest two (Units SW1a and 1b) comprise his Studley Wood Member (equivalent to Bed A above), for which the latter is the stratotype. Todd's (1990) remaining units are assigned to the Elmore Member (formerly the Elmore Formation of Kemp *et al.*, 1979), with Units SW2, 3a and 3b representing the 'Huntingbridge (Shell) Bed', Bed B of Stinton (1970). Stinton's 'Coral Bed' occurs at the base of Todd's Unit 4 (J.A. Todd, pers. comm., 1993) and not within Unit 3b as he originally thought (Todd, 1990).

Palaeontology

The site has a varied and well-preserved biota. The Studley Wood Member contains a rich and diverse foraminiferal and ostracod fauna. *Nummulites* is abundant, comprising numerous *N. aff. prestwichianus* sp. nov., a new and as yet undescribed taxon (T. Hennah, in Todd, J.A., pers. comm., 1993), and much rarer *N. variolarius*. In this communication, Todd referred to a rich macroinvertebrate fauna including sponges, corals (seven species including *Stylocoenia emarciata, Dendrophyllia* sp. and *Turbinolia sulcata)*, serpulids, crabs, echinoids and ophiuroids, but dominated by bivalves (106 species) and gastropods (264 species). Ten species of shark have been recognized, whilst teeth and otoliths of other fish have also been found.

The Elmore Member also contains a rich fauna. Todd (1990) referred to the concentration of molluscs and other invertebrates in lenticles in SW3a. Most of the macrofossils are abraded and extensively bored, whilst *Nummulites* derived from Units SW1 is also present. J.A. Todd (pers. comm., 1993) referred to a smaller fauna than in Units SW1. Amongst the fossils present are corals (6 species), bivalves (52 species), gastropods (112 species.) and one species of cephalopod. The 'Coral Bed' contains the coral *Paracyathus* and large calcareous annelid tubes.

A comprehensive review of the fossil biota of Studley Wood will be published by Todd, Tracey and Le Renard in due course.

Biostratigraphy

In a palynological study by Costa *et al.* (1976), material from this site was found to contain some 50 to 60 species of dinoflagellate, including the useful zone fossil *Wetzeliella.* Costa *et al.* (1976) found that the section could not be older than Eaton's (1976) microplankton Zone 5 (now the *Cyclonephelium intracatum* Assemblage Zone (B-5) of Bujak *et al.*, 1980). Two samples, from Stinton's (1970) Beds B and C respectively, did however yield some specimens resembling *Heteraulacacysta*? sp. A, which raised the question of whether the section is in part of B-5 age or younger (see later discussion).

Aubry (1983, pp. 71–2) recorded an abundant and diverse nannoflora of 51 species from Studley Wood. Her section (Aubry, 1986, fig. 14) is difficult to relate to that of Todd (1990) but indicated that NP15 was represented at the base, with NP16 above and including the Studley Wood Member. J.A. Todd (pers. comm., 1993) has, however, pointed out that a detailed study of her 1983 paper shows that she did not appreciate the faulted nature of the succession and that the nannoplankton flora indicates an NP16 age throughout.

Interpretation and evaluation

There is no doubt that, with its prolific and mainly well-preserved fauna, Studley Wood is a palaeontologically significant site. Its importance now as far as the 'Huntingbridge bed' is concerned is emphasized by the fact that Edwards and Freshney (1987a) were unable to find it near the locality after which it was named in King's Garn Gutter (around SU 251143). There, only material reworked by collectors can be found in the extensive pits on both sides of the stream.

Invertebrate palaeontology

According to Stinton (unpublished work), most of the molluscan species present at Studley Wood only occur in this area of the New Forest, except for the former section at Afton Brickyard (Curry, 1942). However, J.A. Todd (pers. comm., 1993) has referred to fossiliferous sediments in Whitecliff Bay, whose fauna indicates an almost certain correlation with Beds SW2–3 of Studley Wood. Unfortunately, the exposures at Whitecliff Bay are limited by slipping, with the consequence that fossiliferous Bartonian samples are difficult to collect.

Stratigraphical significance

Notwithstanding the richness of the fauna, it is the stratigraphical significance of the latter which is perhaps the most important aspect of the site. Todd (pers. comm., 1993) has pointed out that it provides a complete and very fossiliferous (foraminifera, ostracods, nannoplankton, etc.) marine sequence across the Lutetian/Bartonian boundary. As this is the only site in Britain where this occurs, it is therefore of international importance. Furthermore, Todd considers that the basal Elmore Member of Studley Wood provides the only really fossiliferous exposure of basal Auversian sediments in the UK.

Lithostratigraphy

The lithostratigraphical assignment of the Studley Wood succession has been a matter of some disagreement. Stinton (1975) referred the succession to his Huntingbridge Formation, although the latter was undefined and hence remained informal. Todd (1990, p. 47) is clearly at variance with Edwards and Freshney

(1987a) as to where the boundary between the Selsey Sand and Barton Clay should be placed at Studley Wood. Whilst he considers it to be at the base of the Elmore Member (i.e. the base of the 'Huntingbridge bed'), they place it some 16 m higher (Edwards and Freshney, 1987a, fig. 29), having presumably decided that the 'coarsely glauconitic sandy silty clays' of the Elmore Member (Todd, 1990, p. 47) are more appropriately mapped as Selsey Sand. The differing views may reflect a preference for an 'event'-generated boundary by Todd, with Edwards and Freshney following Hedberg (1976) to select a lithological boundary between two different mappable units.

Age and correlation

The precise age of the sequence in Studley Wood, particularly that of the 'Huntingbridge bed' (Stinton's (1970) Bed B), has been considered at some length by earlier workers. *Nummulites prestwichianus* is normally associated with the base of the Barton Beds, but Curry (1958b) considers the variety present in the Studley Wood succession (*N. aff. prestwichianus* – see earlier comment) as somewhat older. Todd (1990) has suggested that this variety, found only in the New Forest and in the Porchfield borehole (Isle of Wight), is associated with marine sediments which, elsewhere in the Hampshire Basin area, were never deposited or soon eroded.

From their study of the dinoflagellates, Costa *et al.* (1976) concluded that the section was probably equivalent to the uppermost Bracklesham Beds (Prestwich Beds 25–29 at Alum Bay and Fisher Beds XVIII–XIX at Whitecliff Bay), whilst conceding that the dinoflagellate evidence is not positive enough to indicate the precise biostratigraphical position of the 'Huntingbridge bed'. The absence of *W. draco* and *Heteraulacacysta* ? sp. A. (? *H. porosa* of Bujak *et al.*, 1980) might suggest a correlation with the Bracklesham Beds, although specimens somewhat resembling the latter species are present in the Elmore Member. Since *H. porosa* gives its name to the overlying BAR-1 assemblage zone, it may be, as Costa *et al.* (1976) suggested, that the Huntingbridge Bed at Studley Wood represents a high position in the underlying B-5 assemblage zone.

Todd (1990) correlated his Studley Wood Member 'in time' with the marshy and shallow lagoonal deposits of Prestwich Bed 27 of Alum Bay. The 'Coral Bed' at Studley Wood has been correlated with 'Unit 6' of Elmore (Kemp *et al.*, 1979), although Todd (1990) has shown the evidence of this to be tenuous.

Depositional environment

The fauna at Studley Wood reveals a great deal about the environment of deposition. Todd (1990, p. 48) interpreted the fauna of the Studley Wood Member, with its frequent littoral and brackish water molluscs, as representing a shallow marine, regressive environment. The abundance of *Lentidium* indicates very shallow shoreface conditions, whilst the overall fauna is characterized by diverse seaweed/seagrass epiphytes (particularly small herbivorous/detrivorous gastropods) indicating 'near-seagrass meadow' conditions in a water depth of only a few metres (Todd, pers. comm., 1993). Todd further made the point that after that of Unit S10 of Curry *et al.* (1977) at Selsey, the fauna is the most diverse known from the English Palaeogene.

Todd's (1990) recognition that the Elmore Member here contains clasts derived from the underlying Studley Wood Member led him to conclude that this unit was transgressive, following some erosion of the underlying Studley Wood Member. He considered that the lowest part of the overlying Elmore Member represents a deeper water facies, with depths around 50 m plus. Todd (pers. comm., 1993) relates the large number of carnivorous and scavenging gastropods within this member to a high abundance of soft-bodied biota. Robust shells are particularly noticeable. The frequent concentrations of shells in 'seams' is thought to represent storm lags. Where the upper part of the Elmore Member is less fossiliferous, it may be that deposition was in deeper water with unfavourable bottom conditions and low oxygen levels (Curry *et al.*, 1968).

Conclusions

Studley Wood has a prolific and mainly well-preserved fauna. Over 400 species have been found in the Studley Wood Member alone, of which 375 are molluscs, whilst a smaller but still rich fauna occurs within the Elmore Member. Many of the molluscan species found here, and at the other few New Forest sites, are not present at other extant exposures at this stratigraphical level elsewhere in the Hampshire Basin.

Other groups represented in the Studley Wood succession include corals, sponges, bryozoa, echinoids, serpulids, ophiuroids, crustaceans and fishes. The lowest beds present contain numerous microfossils include a diverse ostracod and foraminiferal fauna. The latter includes *Nummulites aff. prestwichianus*, a variety thought to be older than *N. prestwichianus* and possibly representing marine strata poorly developed or absent outside the New Forest area.

Notwithstanding its palaeontological, palaeoecological and palaeoenvironmental significance, the site is biostratigraphically unique in being the only locality in Britain to provide a rich and varied marine fauna across the Lutetian/Bartonian boundary.