Quaternary sea level landforms and sediments in southern England: description of Geological Conservation Review sites

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Abstract

The Hampshire Basin of southern England contains a number of sites, reviewed here, that contain evidence for former sea levels over a period of c. 0.5 million years and can also be used to aid in understanding of uplift over time and human activity in the landscape. They include three sites where fossiliferous sediments overlie a palaeo shore platform in either Chalk (Boxgrove and Black Rock) or softer sediments (Bembridge), which are the most robust evidence of former sea levels. The other four sites are less useful as palaeo sea level indicators, but contain rich fossil sequences (e.g., Selsey East Beach, Boxgrove, Earnley, Stone Point) or abundant archaeological artefacts (Boxgrove, Priory Bay). Black Rock is most significant for the very rare cold-stage deposits overlying the raised beach and their associated fauna.

Keywords: Geological Conservation Review, palaeosealevel, raised beach, archaeology

1. **Introduction** RMB

This paper is one of four that review Quaternary sites in south-central and south-east England that are part of the Geological Conservation Review (GCR) of England. The first covers chalk landforms (Whiteman and Haggart, this issue), this paper covers sea level related landforms and sediments and two further papers cover rivers, tufa and mires (Briant et al., this issue) and periglacial landforms (Whiteman, this issue). All seven of the sites described in this paper are located within the Hampshire Basin apart from Black Rock, which is a little way to the east (Fig. 1). They record various types of evidence for sea level change over a time period spanning approximately 500,000 years and range from the extremely well understood and studied (e.g., Boxgrove) to the more enigmatic (e.g., Earnley).

The Hampshire Basin formed during the Paleogene, with the deposition of marine sands, silts and clays with occasional pebble beds within a subsiding basin flanked by Cretaceous chalk. During the mid-Miocene, this basin was subject to compression during the Alpine Orogeny, resulting in a series of east-west trending synclines and anticlines including the Wealden anticline that separated the London and Hampshire basins from each other (Hopson, 2009). These structures can be observed in the patterns of bedrock geology shown in Figure 1a, with the Isle of Wight monocline marked by the extremely rapid shift between strata crossing the central part of the island and the edge of the Wealden anticline and associated structures to the north of Chichester and Brighton. The less extensive Portsdown and Littlehampton anticlines can be traced in the isolated patches of chalk visible to the west and east of Chichester respectively. The most significant element of the bedrock geology in this region for understanding the Quaternary sea level history is the relative erodibility of different rock types. Cretaceous chalk is more durable than the Paleogene sediments (Lambeth Group, Thames Group, Bracklesham Group, Barton Group and Solent Group), leading to the preferential preservation of former wave cut platforms in this lithology (e.g., at Boxgrove and Black Rock, although there is also a platform preserved at Bembridge in softer Paleogene rocks. This difference also means that most pebbles in the region are flint, sourced from the chalk, with smaller inputs from Greensand and Wealden Group sandstones, brought to the coast by transverse river systems (Fig. 1b), reworked Paleogene beach pebbles and some exotic lithologies.

The main Quaternary sediments in the region are fluvial gravels associated with the former Solent River, some of which are described in Briant et al. (this issue) and the landforms and sediments associated with past sea levels described here (Fig. 1b). These latter comprise the complex of 'raised beaches' on the Sussex Coastal Plain that are shown (Goodwood-Slindon, Aldingbourne, Brighton-Norton and Pagham Formations), but also a raised beach at Bembridge and possibly Priory Bay on the Isle of Wight and estuarine deposits of various ages at Bembridge (Steyne Wood Clay), Stone Point, Earnley and Selsey. This complex of marine and non-marine sediments shows the long-term interplay of high and low sea level landscapes in this region, brought up to the present day by the drowning of former river valleys with significant thicknesses of Holocene estuarine sediment (e.g., in the Arun valley to the east of Chichester) (Fig. 1b). The gradually increasing extent of the mapped marine sediments on the Sussex Coastal Plain also shows the development of a more open coastline, from the closed embayment associated with deposition at Boxgrove (Section 7) at a time prior to the opening of the Straits of Dover, to a more open coastline with a fully open Strait similar to the present day during deposition of the Pagham Formation.

All the sites reviewed in this paper play an important role in understanding past sea levels and uplift rates, with the Pagham Formation used as a tie-point in the global sea level compilation of Kopp et al. (2009). There has, however, been significant variation in the elevations used to represent past sea levels and undertake uplift calculations, with Preece et al. (1990) applying a methodology that took into account tidal range and using an altitude of 40 m for the marine deposits at Steyne Wood and Boxgrove as a single tie-point, suggesting uplift rates of 5.3 and 10.3 mm/ka for the Solent area since Marine Isotope Stage (MIS) 13. Similar rates (13mm/ka at 600 ka, decreasing to 7.5 mm/ka at the present day) were calculated by Westaway et al. (2006), using tiepoints of upper surfaces of deposits at altitudes as follows: Boxgrove, 42 m O.D. (Ordnance Datum – mean sea level, Newlyn, Cornwall), MIS13a; Aldingbourne, 25 m O.D., MIS 9 or earlier; Norton, 10 m, late MIS 7; Pagham, 4 m, MIS 5e. A recent paper by Rovere et al. (2016) sheds helpful light on how sites such as those detailed in this paper should be used to determine past sea levels based on precise understanding of the exact relationships of geomorphologically meaningful features such as the inner edge of shore platforms to mean sea level by comparison with modern analogue environments. Future work on using these deposits as sea level indicators should apply this methodology, but it should be noted that estuarine deposits do not have a clear enough relationship to mean sea level to be used as indicators of past sea level (Rovere et al., 2016).

In addition to their importance as indicators of past sea level, two of these sites contain rich vertebrate faunas - Boxgrove, and the Pleistocene vertebrate GCR site at Selsey East Beach (often known as the Lifeboat Station site – West and Sparks, 1960). In addition, Black Rock contains a rarely-exposed thickness of cold-stage sediments with an associated fauna overlying beach deposits. Boxgrove and to a much lesser extent Priory Bay are also very rich archaeologically. The site at Boxgrove represents an *in situ* landsurface, in association with which multiple archaeological artefacts have been recovered, in addition to cut-marked animal bones and hominin bones (e.g., Roberts and Parfitt, 1999). The abundance of vertebrate remains at Boxgrove has enabled the deposits there to be assigned to a time period equivalent to MIS 13 on biostratigraphic grounds. Most of these sequences, however, are much less rich in information than that at Boxgrove, preserving only less diagnostic micro or macrofossils or rarer artefacts. This has made them much harder to assign age estimates to. Amino-acid racemisation ratios are available for a few sites (e.g., Bembridge, Black Rock, Stone Point), but mostly on marine shell, for which there is as yet no reliable aminostratigraphic framework from which to suggest ages. Optically-stimulated luminescence (OSL) dating has also been used, but is only useful where the deposits are young enough and clearly stratigraphically related to OSL-dateable material, such as at Stone Point (over and underlying fluvial gravels), Bembridge or Selsey (dating beach gravels). Notwithstanding these challenges, the GCR site at Earnley remains the only site where there is no consensus about the most likely age of the deposits.

The sites are described below from west to east: GCR site 1870 – Stone Point; GCR site 1938 – Priory Bay; GCR site 1895 – Bembridge; GCR site 2016 – Earnley; Selsey – GCR (Quaternary of Southern England) site 2021 Selsey West and East Beaches and GCR (Pleistocene Vertebrate) site 1201 Selsey East Beach; GCR site 2158 – Eartham Pit, Boxgrove; GCR site 789 – Black Rock.

2. GCR site 1870 Stone Point (UK Grid Reference SZ 459 985) RMB, AH

2.1 Introduction

Stone Point is located on the northern side of the Solent seaway, almost directly opposite Cowes on the Isle of Wight. Along this coastline and inland, the main Quaternary deposits are fluvial gravels (Fig. 1b) of the erstwhile River Solent (Allen and Gibbard, 1993). In this Solent terrace sequence fossiliferous deposits are only preserved associated with the lowest terrace gravels, providing the possibility of a biostratigraphic tie-point. The deposits at Stone Point are important because they are the most continuous fossiliferous deposits associated with the extensive gravels of the erstwhile River Solent, being thicker and better exposed than those at Pennington (Allen et al., 1996) or St Leonard's Farm (Briant et al., 2013). The sequence, comprising estuarine clays intercalated with *Phragmites* peat exposed on the foreshore at Stone Point, Lepe, has been described by Reid (1893), Palmer and Cooke (1923), West and Sparks (1960), Brown et al. (1975) and the 'Palaeolithic Archaeology of the Sussex / Hampshire Coastal Corridor' (PASHCC) project – Bates et al. (2004); Briant et al. (2006a, b, 2009, 2019). The locations of all these investigations are shown on Figure 2. Summaries of research at the site have also been reported by West (1987) and Green and Keen (1987). These interglacial deposits lie stratigraphically between lower and upper cold stage gravels of fluvial origin which are in turn overlain by two brickearth units separated by a palaeosol of suggested interglacial type (Reynolds, 1985; 1987). This palaeosol is no longer exposed at the site. Initially the estuarine sediments were assigned a late Ipswichian (IIb) age largely on the basis of pollen evidence (West and Sparks, 1960). However, Keen (1995) reiterated the suggestion by Reynolds (1987) that it was likely the palaeosol separating the brickearth units was of Ipswichian (MIS 5e) age, implying the estuarine deposits must date to an earlier warm phase. Re-mapping of the Solent terrace deposits by Allen (1991; Allen and Gibbard 1993; Gibbard and Allen, 1994) led to the conclusion that the Stone Point deposits may be of MIS 7 age because of the identification of Ipswichian-age freshwater silts altitudinally lower (–3.9 to –5.3 m O.D.) at Pennington Marshes (Allen et al., 1996; Gibbard and Preece, 1999; Bridgland, 2001; Antoine et al., 2003), within the Pennington Gravel which was thought to postdate the Lepe Gravel. More specifically, a reinterpretation of the terrace stratigraphy led Bridgland (2001) to suggest an age of MIS 7a. Bridgland and Schreve, (2002), however, put forward the view that the (albeit sparse) mammal remains might point to a date in the earlier part of the MIS 7 interglacial. The relationship between the Pennington Gravel and the Lepe Gravel has since been queried by Westaway et al. (2006) who suggest that in places both fall within an alternative gravel body called the St Leonards Farm Gravel. The stratigraphy of these lower terraces was not, however, fully defined in this scheme. OSL ages bracketing the Stone Point deposits reported by Briant et al. (2006) suggest that they were deposited during the last interglacial (MIS 5e), although Amino-acid Racemisation (AAR) data correlate more effectively to MIS 7. However, due to the likelihood of reworking of the samples with AAR ratios, an MIS 5e age is most likely for this sequence at present.

2.2 Description

2.2.1 Sedimentary sequence

A simple overview of the Stone Point sequence is of a channel containing silts and peats over and underlain by gravels and further overlain by a fine-grained brickearth deposit. It was originally reported by Reid (1893), cored by West and Sparks (1960) and the extent of the upper part of the channel mapped by Brown et al. (1975) is shown in Figure 2. The brickearth was investigated and described by Reynolds (1985, 1987) and thermoluminescence dated by Parks (1990, and Rendell, 1992). The most recent and comprehensive study of these deposits was undertaken by the 'Palaeolithic Archaeology of the Sussex / Hampshire Coastal Corridor' (PASHCC) project between 2003 and 2010 – Bates et al. (2004); Briant et al. (2006a, b, 2009, 2019) – and the description below is based on this (Figs 3 – 5).

The lowest member of the Quaternary succession at Stone Point is an angular flint gravel (Unit 1 – Lepe Lower Gravel), representing a gravel aggradation of the former Solent River. It is a 2.5 m thick planar-cross-bedded gravel with thick sand beds, present both beneath the modern beach and in the lower part of the cliff succession up to a level of c. 3 m O.D. (Figs 3 and 4a) and described by Briant et al. (2009). Reid (1893) and West and Sparks (1960) both suggested that the lower gravels and estuarine deposits pass beneath the upper gravels exposed in the cliff. Following a period of cliff erosion Brown et al. (1975) traced only the lower gravels into the cliff up to a level of about 2m O.D., a metre lower than observed in 2003 (Briant et al., 2009). Brown et al. (1975) suggested that this lower gravel was succeeded by a thin bed of inorganic pebbly clay about 25 cm thick; also in some places a bleached sandy horizon and iron pan suggesting podsolisation of the upper part of the lower gravel. PASHCC excavations did not find this 'pebbly clay'. Instead, a thin sand and silt bed (Unit 3) was observed both overlying the interglacial silts in Test pit 6b and between the two gravels (Units 1 and 4) in section 1 (Figs 3 and 4a).

The full extent of Units 1 and 2 is unknown, but they are not present at Lepe Coastguard House (SZ 45049 98550), 0.6 km west of Stone Point (Reynolds, 1987), or at Cadland (SZ 468 998), 2 km to the north. At both these locations a low terrace gravel of the River Solent rests directly on Tertiary bedrock, its base at approximately the same level as the base of the upper gravel (Unit 4) at Stone Point (Green and Keen, 1987). The estuarine deposits and lower gravel at Stone Point appear, therefore, to occupy a depression cut in Tertiary bedrock to altitudes below present sea level.

Unit 2 comprises the Stone Point interglacial deposits, the bulk of which (Unit 2d, Fig. 4b) are stiff grey clay with shells, interbedded with thin discontinuous beds of compressed wood-peat, especially in the upper parts of the profile. These peat beds were labelled A to E by Brown et al. (1975) and noted to be between 2 and 24 cm thick and containing abundant *Phragmites* remains. These higher estuarine peats and clays are separated into two outcrops occupying depressions in the lower gravel separated by a gravel high (Fig. 2b). The uppermost clays show signs of weathering and attain an altitude of about 0.8 m O.D. The peat layers are highly compressed and generally dip inwards from the edge of the deposit at angles of between 1 and 6º and most contain laminae separated by thin layers of clay. West and Sparks (1960) described organic sediments from a site lower down on the foreshore, probably from a level lower in the succession than those described by Brown et al. (1975). The estuarine deposits of Unit 2d have yielded coccoliths, pollen, abundant plant macrofossils, molluscan remains, the partial tusk of a straight-tusked elephant (*Palaeoloxodon antiquus*) and a tibia of a fallow deer *Dama dama* (Reid, 1893; West and

Sparks 1960; Brown et al., 1975; Green and Keen, 1987; Preece et al., 1990; Briant et al., 2006b, 2009).

A deeper interglacial sequence was recovered by the PASHCC project from Borehole 16 (Fig. 3; Briant et al., 2019), with a thin layer of different sediments at the base. These yielded some fossils with freshwater affinities (Table 1). Unit 2c comprises an interbedded laminated brown organic clay and grey clay with lenses of fibrous peat and fine sand containing molluscs. Unit 2b is characterised by dark brown, fine sandy organic clay and fibrous peat. Unit 2a is a cemented fine sand and silt with frequent gravel including chalk.

Unit 3 is a discontinuous 5–10 cm thick bed of laminated fine sand and silt. Two samples were taken from this unit by PASHCC for thin section analysis (Briant et al., 2019). Structures observable in the field are fine laminae, distorted in places in Section 1. Thin section analysis also showed that this unit comprised interbedded sands and silts/clays, with some distortion of clays in Section 1. Neither thin section showed widespread evidence of soil formation, e.g., translocated clays or void filling. In Section 1 there was a single cross-section of an organic item (root or stem), surrounded by a void in which some clay had built up. This is probably a modern intrusion into the section because gorse scrub was cleared from the section. The similarity between the samples from the two sections suggests that this unit is an effective stratigraphic marker placing the interglacial deposits between the two gravels. It is interpreted as a period of low-energy, fine-grained deposition, later distorted either by loading of saturated sediments or periglacial activity.

The Lepe Upper Gravel (Unit 4) is 3 to 3.5 m of horizontally-bedded flint-dominated gravels with occasional thin sand lenses. It is interpreted as a fluvially-deposited gravel of the former Solent River due to its location and lithological composition (Gibbard and Allen, 1994). Cross bedding observed in some of the finer sandy material, indicated an easterly flow direction from approximately 280ºN (Brown et al., 1975). There is some evidence for periglacial modification of the upper gravel since involutions and stone erections are weakly developed in its upper levels. The surface of the gravel at Stone Point was considered by Brown et al. (1975) to equate with the terrace surface that is widespread at about 7–8 m O.D. between Calshot and Lymington. It has been mapped as Lepe Gravel by both Allen and Gibbard (1993) and Westaway et al. (2006) and shown in Figure 2a as Milford on Sea Gravel by Hatch (2014).

Unit 5 comprises 50 cm to 1 m of silty fine sand with dispersed fine pebbles. At present, this is exposed sporadically at the top of the sequence (Briant et al., 2009; Fig. 3), showing some modern soil development in places (Section 1) and bricks and roots in others (Section 5). Table 2 compares this deposit in 2010 with descriptions by Reynolds (1985) and Parks (1990), both of whom described the cliffs before the brickearth was disturbed by construction on top of the cliff (Reynolds, 1985). They described a two-part deposit, with a discontinuous lower brickearth up to 40 cm thick separated from an upper brickearth up to 80 cm thick by a line of flints (Table 2). Both these deposits showed evidence of soil development with the palaeosol separating the two units perhaps representing an interglacial soil (Reynolds, 1987). Thermoluminescence dates on both units gave ages of about 98 ka B.P. for the lower brickearth and 20 ka B.P. for the upper brickearth (Parks and Rendell, 1992).

2.2.2 Fossil assemblages

At the base of the sequence, in Units 2b and 2c, the pollen assemblage is dominated by grass and pine. Oak and birch then occur from the very base of Unit 2d upwards. The assemblages throughout this unit show mixed-oak woodland, as reported by West and Sparks (1960) and Brown et al. (1975), who assigned the sequences that they observed to zone IIb of the Ipswichian with the presence of *Carpinus* indicating a position late in this zone. Pollen of *Carya*, *Tsuga*, *Celtis* and *Sciadopytis*, and a number of well-preserved but unidentified grains are probably derived from nearby Tertiary beds. Herbaceous pollen mainly comprises Poaceae and Chenopodiaceae which reaches 54% AP in some peat beds, perhaps suggesting saltmarsh conditions during deposition of this upper organic layer (Brown et al., 1975). There is a gradual increase in hazel (*Corylus*) pollen upwards. Regionally, a similar interglacial vegetation sequence is developed at St Leonards Farm (SZ 4068 9802) at c. 0.1–1.8 m O.D., c. 5 km upstream of the Stone Point sequence (Briant et al., 2013). This sequence is not dated and contains both freshwater and marine fossils. In addition, early interglacial (birch-pine pollen) deposits with freshwater affinities occur at –3.9 to –5.3 m O.D. depth c. 17 km upstream at Pennington Marshes (Borehole X at SZ 3240 9235, Allen et al., 1996).

Aquatic fossils from the sediments of Unit 2d uniformly show brackish and marine affinities, for example Brown et al. (1975) and West and Sparks (1960) both record the occurrence of three brackish molluscan species, namely *Hydrobia ventrosa*, *Hydrobia ulvae*, and *Phytia myositis* and Preece et al. (1990) found very occasional specimens of *Emiliania huxleyi*, *Gephyrocapsa ericsonii* and *Calcidiscus leptoporus*. Terrestrial plant macrofossils include wood, buds, cupules and fruit of *Quercus robur* and fruit of *Acer,* supporting the pollen evidence for presence of these species. Other remains derived from the terrestrial vegetation include a fragment of *Pteridium aquilinum*. The clays chiefly contain the remains of saltmarsh plants with species such as *Aster tripolium***,** *Glaux maritima***,** *Scirpus maritimus* and one or more species of *Atriplex* being recorded (Brown et al., 1975, Briant et al., 2009, 2019). In the peats, however, saltmarsh and freshwater plant macrofossils are equally frequent. Such mixtures were thought to result from the periodic tidal inundation of freshwater reedswamps, an interpretation supported by the presence of clay laminations and estuarine molluscs in these peats. Freshwater species include *Carex* cf. *riparia*, *Carex* cf. *rostrata***,** *Hydrocotyle vulgaris***,** *Lemna* sp., *Lycopus europaeus***,** *Menyanthes trifoliata***,** *Ranunculus sceleratus* and *Sparganium* sp. (Brown et al., 1975, Briant et al., 2009).

Figure 5 and Table 1 show a summary of all these studies for the full depth of Unit 2. The sequence exposed is complex, exacerbated by the small size of the samples available and the fact that it was not possible to sample exactly the same horizons for the different fossil analyses. In general, brackish and estuarine elements are present throughout the sequence in all the fossil groups reported but freshwater inputs are rarer. The fossil groups do not always agree on the salinity signal (Table 2). The two opercula of the species *Bithynia tentaculata* used for AAR analysis occurred in Unit 2c (755 cm) in BH16 and are the only freshwater evidence in the mollusc sequence (Briant et al., 2019).

2.2.3 Archaeology

Reid (1893) found two or three waste flint flakes lying at the base of the gravel immediately above the estuarine clay but they were not in good condition. This contrasts with the abundant archaeology recovered from higher terrace deposits, for example at Nelson's Place, Stanswood Bay some 2.5km to the north east (approximately SU 473004) where a 'Palaeolithic flake-knife' was dug out of the undisturbed gravel about 45cm inches from the base, the gravel being about 4.5 m thick at this location (Allen and Gibbard, 1993).

2.2.4 Age estimates

Whilst most of the fossil groups give no indication of age, the Coleoptera do. Biostratigraphically, the fauna resembles most closely those that have already been ascribed to Marine Isotope Stage 5e (Coope, 2001). This resemblance includes several significant 'non-British' species such as *Onthophagus massai* and *Caccobius schreberinone* which have not yet been found in MIS 7 assemblages. It also includes distinctive fragments of unidentified species also found exclusively in MIS 5e faunas. The Stone Point fauna also includes other rare southern English species which do not occur in any MIS 7 fauna. Whilst there are some similarities with the fauna from Hackney Downs which probably dates from

MIS 9 (Green et al., 2006) and also includes several of the same thermophilous species, these are less marked.

AAR analyses were undertaken on two small individual *Bithynia tentaculata* opercula from Unit 2c within BH16 between 754 and 756 cm depth. Comparison of free and total hydrolysed fractions for both samples suggested closed system behaviour, although one sample was very small. Comparison of the Stone Point Ala amino acid ratios with the British AAR framework (Penkman et al., 2013) shows similarity to sites correlated with MIS 7 (Briant et al., 2019).

Early thermoluminescence (TL) dating of the sequence was only able to estimate the timing of deposition of the overlying brickearth (Unit 5), giving TL dates of c. 20 ka and 98/120 ka reported by Parks (1990; Parks and Rendell, 1992). However, TL dates on sediment are problematic because of the almost certainty of partial bleaching of this light insensitive signal. They were also produced using a multiple aliquot protocol which produced a single age estimate from results from multiple aliquots, masking any scatter within the sample.

Five OSL samples from Units 1 and 4 were taken in 2003 and reported in Briant et al. (2006a). Age estimates from Unit 1 (Lepe Lower Gravel) (LEPE03-01, 02, 03, 04) span 230 to 130 ka (MIS 7d-5e, Table 3), broadly coincident with the cold stage immediately preceding the last interglacial (i.e., MIS 6). Error bars for these age estimates are relatively small, however, meaning that these age estimates do not overlap. These differences are discussed in Briant et al. (2006a) and probably reflect both inter-aliquot variability and difficulties in estimating long-term water content and overburden history because of proximity to present-day sea level. There is only one sample from Unit 4 (LEPE03-05) because this unit is less sand-rich than Unit 1. The OSL age of this is between 72 and 58 ka (MIS 4-3), post-dating the deposition of Unit 1. Together these age estimates suggest that the Stone Point organic deposits are more likely to date from the last interglacial (Ipswichian, MIS 5e) than from MIS 7.

Further samples were taken from Unit 5 in 2010 and reported by Briant et al. (2019, Table 3). Two samples yielded ages in MIS 4-3, centred around 40-50 ka, only a little younger and partially overlapping the age estimate from Unit 4. The other two samples yielded anomalously young ages, attributed to bioturbation either by soil formation or burrowing by sand wasps or bees. The most likely age therefore is that Unit 5 either dates from or postdates MIS 4-3.

2.3 Interpretation

The lower gravels of Unit 1 accumulated from below present sea level to at least 3 m O.D., c. 2m above the level at which estuarine clays and intercalated peats of Unit 2 were deposited (Fig. 3). Features within Unit 1 clearly suggest that the lower gravels were deposited in a cold climate braided river environment (Brown et al., 1975; Briant et al., 2006a, b, 2009). OSL dating of this deposit (Briant et al., 2006a, Table 3) suggests that this deposition occurred in MIS 6. The gravels were then probably exposed to subaerial weathering, soil formation and, in places erosion, before the overlying estuarine clays and intercalated peats were deposited.

Rising sea level during a temperate period subsequently led to the accumulation of the intertidal muds, salt marsh and freshwater peats of Unit 2. Detailed examination of a borehole that penetrates the full thickness of these deposits (Briant et al., 2006b, 2009, 2019), shown in Figure 5 shows a complex palaeoenvironmental development, reflecting changes in both sediment accumulation, and input from freshwater and brackish sources as channels switched across the inundated area (Table 1, Fig. 5). Differences in interpretation between the different fossil groups may reflect different taphonomic pathways or difficulties in sampling directly comparable material from boreholes. However a broad pattern can be deduced of a switch from greater (if stratigraphically variable) freshwater influence at the base of the interglacial sequence (Units 2b and c) through a phase of brackish water into a final freshening towards the top of Unit 2d. This freshening is represented by the compressed wood peats observed at the very top of the sequence. Brown et al., (1975) interpreted these as a periodic interruption of sea level rise on the basis of remains of saltmarsh plants and molluscs in the lowest three peat beds (B, C, D), and the presence of fine clay laminae, suggest that the reedswamps were subject to periodic marine inundation. However, in the upper peat (A) Brown et al. (1975) noted the absence of intertidal indicators (though estuarine molluscan remains were still found) and suggested a more marked fall of sea level. However, the presence of Chenopodiaceae to levels up to 54% AP may suggest the continued presence of saltmarsh at or near the site at this time. The continuing overall rise of sea level is demonstrated by renewed intertidal mud deposition over the uppermost peat bed A.

The estuarine sediments were then in turn overlain by a brief period of fine-grained fluvial deposition and subsequent distortion and erosion (Unit 3), then emplacement of the upper gravel of Unit 4, OSL dated to MIS 4 (Briant et al., 2006a, Table 3). West and Sparks (1960) followed Everard (1954), in suggesting that Unit 4 gravels represent gravels of terrestrial origin which have been soliflucted and then resorted by marine action; in effect making them a raised beach deposit. Brown et al. (1975) and later workers (Allen, 1991; and Gibbard, 1993, Briant et al., 2006a, b, 2009, 2019) maintain, however, that the Stone Point upper gravels resemble terrace gravels of the former Solent, which are undoubtedly fluvial in origin. The flints in the upper gravel, though water worn, are mainly angular. Particle shape and orientation, the morphological expression as a broad gravel terrace and the character of the poorly developed sedimentary structures, are all consistent with deposition in a braided river environment.

The lower brickearth overlying the upper gravel was observed in the 1970s to be distinct from the upper brickearth on colour, particle size, mineralogy and micromorphology (Reynolds, 1987). It showed evidence of strong clay illuviation and low amounts of weatherable minerals, perhaps indicating a long period of weathering under temperate interglacial conditions. The upper brickearth was thought to be typical of the aeolian silty sands of Late Devensian age that occur throughout south Hampshire (Reynolds 1985). This suggested that an Ipswichian age for the estuarine deposits at Stone Point (as advocated by the early work of West and Sparks (1960) and Brown et al. (1975)) was unlikely since they would then be separated from the Devensian by a climatic cycle involving periglacial loess deposition followed by temperate interglacial pedogenesis, presumably during the Ipswichian (Reynolds 1987; Keen 1995). This two-part distinction within Unit 5 can no longer be observed at the site due to the building of a car park on top of the cliff in the 1980s.

The attribution of the Stone Point interglacial deposits to an interglacial preceding the Ipswichian was also suggested by remapping of the Solent terraces by Allen (1991; Allen and Gibbard 1993; Gibbard and Allen, 1994). Bridgland (2001) noted that while the bulk of the Solent sequence is poorly dated because of the dearth of interglacial fossil-bearing sediment, the lowest two terraces do have organic sediments contained within them. The youngest and lowest terrace contains organic deposits ascribed to the Ipswichian at two sites, Pennington Marshes (Allen et al., 1996) and at Ibsley in the Avon valley (Barber and Brown, 1987). The second youngest terrace was suggested to be that formed by the Lepe Gravel, within which the interglacial sediments at Stone Point occur. Bridgland and Schreve (2001) also suggested that the altitude of the interglacial estuarine deposits at Stone Point is similar to that of the temperate climate deposits at Selsey East Beach, described below, that contain a characteristic late MIS 7a mammalian assemblage. However, the sparse Stone Point mammal assemblage comprises only *P. antiquus* and fallow deer (*Dama dama*). The latter species is not recognised in the 'mammoth-horse' faunas that characterise the latter part of MIS 7, which led Bridgland and Schreve (2001) to suggest the Stone Point estuarine peats and clays could relate to an earlier part of this interglacial. However, because most of the fossils from the Stone Point interglacial sequence are of estuarine affinity and there are very few vertebrate remains, it is difficult to compare them with sites with a more complete freshwater biostratigraphic signature (e.g., Schreve, 2001). In contrast, the Coleoptera, studied fully for the first time only recently (Briant et al., 2006b, 2009, 2019) suggest that this sequence was deposited during the last interglacial (Ipswichian, MIS 5e).

The suggestion that the Lepe Upper Gravel may contain Palaeolithic artefacts (Reid, 1893) could fit either interpretation. They could represent reworked MIS 7 artefacts within MIS 6 gravel, since humans are considered to have left the British peninsula during MIS 6 and did not return during the subsequent Ipswichian (MIS 5e) warm stage, which seems to be devoid of evidence for human occupation (Currant, 1986; Wymer, 1988; Sutcliffe, 1995; White and Schreve 2000; Bridgland 2001, Schreve 2001; Bridgland and Schreve 2001). Alternatively they might represent a reoccupation of Britain in the last glacial period.

More recently, these dating issues were addressed by direct OSL dating of the deposits (Briant et al., 2006a,b, 2009, 2019). OSL age estimates from the upper and lower gravels (Units 1 and 4) suggest that they were deposited in MIS 6 and 4 respectively, dating the Unit 2 estuarine interglacial clays to MIS 5e by interpolation. In addition, since much of the debate over the age of this sequence hinges on the interpretation of the brickearth deposits (Unit 5), further OSL samples were taken from these brickearths in 2010 (Briant et al., 2019). Despite evidence of bioturbation, these suggest deposition of this unit at some point during or after MIS 4/3, suggesting that a last interglacial (Ipswichian) age was likely for the estuarine clays of Unit 2.

The AAR age estimates, however, from Unit 2c near the base of the sequence fit within the range of ratios seen from sequences dated to MIS 7 elsewhere in the UK (Briant et al., 2019). This conflicts with that based on OSL, which, although subject to some scatter, are based on a number of samples, replicate well and appear robust. Whilst the small size of the samples and the scatter between the different amino acids mean that a grouping with MIS 5e cannot be entirely ruled out, it is very unlikely. Briant et al. (2019) argue reworking of the *Bithynia tentaculata* opercula. The basis for this argument is that these are the only molluscs in this sequence suggesting a freshwater environment; also that the specimens are very small and found within a sand lens rather than in the finer-grained material. This interpretation would mean that the MIS 7 correlation indicated from the AAR represents a maximum age.

Whilst the evidence shows that the Stone Point organic deposits date from the Ipswichian interglacial (MIS 5e), the stratigraphic issue that originally prompted attribution to MIS 7 remains unresolved. The most recent stratigraphic scheme for this region (Fig. 2b - Hatch, 2014) maps the gravel at Lepe as Milford on Sea Gravel, but still maps it as different from the gravel within which the Pennington Marshes organic deposit is found.

2.4 Conclusion

Stone Point is an important site for the study of Quaternary stratigraphy and environmental change. A sequence of deposits on the foreshore and in the backing cliff comprises (a) a lower gravel unit occupying a depression cut into Tertiary bedrock, (b) interglacial peat and estuarine clays, containing fossil molluscan and mammalian fauna and coccolith, pollen and plant macrofossil remains, and (c) an upper gravel unit forming part of a terrace at 6-7 m above sea level. The gravels represent two separate periods of cold-environment fluvial aggradation, the earlier preceding the sea level rise during a temperate period and the latter occurring during subsequent climatic deterioration. Above the gravel were two brickearths, now no longer visible in full, predominantly derived from loess, separated by a period of soil formation interpreted as occurring during a temperate climate episode. The organic estuarine deposits at Stone Point therefore afford important information for Late Quaternary environmental change, including vegetation and sea level change. They also provide a rare data point to help determine the age of the widespread gravel terraces in the southern New Forest and along the shores of Southampton Water. Their age has been subject to debate with an original designation of late Ipswichian MIS 5e, followed by attribution to MIS 7 and then recent re-attribution to MIS 5e, although there is some conflicting evidence between OSL and AAR analyses.

Unit	**Depths and summary salinity indicated by fossils**	Pollen	Plant macrofossils (BH16 only)	Molluscs	Coleoptera	Ostracods and foraminifera	Diatoms (BH16 only)
Unit 2d – stiff grey clay interbedded in the higher parts of the sequence with compressed wood peat	**1 m to -8 m O.D. Brackish (diatoms show freshwater inputs in lowest 10 cm)**	Grass-hazel-oak-pine, temperate mixed forest. Increase in Chenopodiaceae towards the top of the sequence may indicate increased estuarine influence.	Temperate birch-alder with waterside species dominant. Sample from 750-755 cm contains the aquatic *Ruppia*, indicative of salinity. Both samples contain the brackish swamp species *Scirpus maritimus*	Temperate brackish water assemblage dominated by hydrobids, with poor preservation.	Temperate saltmarsh. Areas of open water and bare mud banks, with oak, hornbeam and hazel. Similar to faunas attributed to MIS 5e (Coope, 2001) and MIS 9 (Green et al., 2006).	TP4b and d Low Saltmarsh with creeks. TP7 tidally influenced brackish mudflat. BH13/BH16 brackish creek.	215-216 cm – barren 334-335 cm – fragmentary preservation, marine-brackish. 529-530 cm – marine-brackish. 746-746 cm – lower salinity, some freshwater species.
Unit 2c – interbedded laminated brown organic clay and grey clay with a fibrous peat lens at 753 cm and a lens of fine sand and molluscs at 753-756 cm	**c. -8 to -8.15 m O.D. Brackish (ostracods, forams, diatoms) with freshwater inputs (plant macrofossils, molluscs).**	Grass-pine-sedge-spruce, interpreted as boreal forest	Temperate birch-alder with waterside species dominant. Both samples include *Hydrocharis morsus-ranae* which requires still, freshwater conditions.	Two small fragments of *Bithynia tentaculata* operculum from sand bed at 755 cm. Other shell mostly hydrobids	-	Intertidal mudflats and creeks – very low diversity assemblages. A few freshwater ostracods are present.	756-757 cm – full tidal conditions.
Unit 2b – interbedded brown sandy organic clay / fibrous peat / fine sand. Gravel in lowest 10 cm.	**c. -8.15 to -8.35 m O.D. Brackish (diatoms), freshwater (Coleoptera) and mixed (plant macrofossils).**			Dominated by hydrobids	Temperate fen dominated by *Typha* and *Phragmites*. No evidence for saline conditions or open water.	773 cm - barren	771-772 cm – fragmentary preservation, evidence for tidal influence.
Unit 2a – cemented sands and silt with gravel		-	-	-	-	-	-

Table 1. Summary of paleoenvironmental analysis undertaken on sediments from Unit 2 at Stone Point by Briant et al. (2019). Locations shown on Figure 2 and grid references on Figure 3.

	Reynolds (1985)				Parks (1990)			Section 1 (Briant et al, 2009)		
	Thickness (m)	Description	Particle size	Thin section features	Thickness (m)	Description	Particle size	Thickness (m)	Description	Particle size
'Upper brickearth'	Ah horizon 0.3 (0-0.3 m depth) Particle size sample 0.15-0.25 m depth	Dark greyish brown (10YR 4/2) very slightly stony sandy silt loam with fine gravel; roots and earthworm channels.	Modal size fraction 4-3 phi; 33% sand.	Yellowish brown (Holocene) clay illuviation, 75% as undisturbed argillans.	0.9 – 1.1 (c. 0.5-1.5 m depth - contacts irregular) LP1/2 at a depth of 1.1 m below ground surface	Reddish yellow (7.5 YR 6/6) medium silt / loess	Median particle size 25.5 microns	0.51 (0-0.51 m depth) LEP10-01,02 at 0.38 m depth below ground surface	Fine sand / silt, becoming slightly clayey below c. 35 cm; occasional wasp/bee burrow and roots; occasional flint clasts; pale yellow (2.5 Y 7/4).	LEP10-01/X4102: modal size fraction 125-175 microns / 2.5-3 phi LEP10-02/X4103: modal size fraction 88-125 microns / 3-3.5 phi
	Eb horizon 0.18 (0.3-0.48 m depth)	Dark yellowish brown (10 YR 4/4) very slightly stony sandy silt loam; roots and earthworm channels.	-	-						
	Bt horizon 0.3 (0.48-0.78 m depth) Particle size sample 0.5-0.68 m depth Thin section sample 0.63-0.75 m depth	Strong brown (7.5 YR 4/6) very slightly stony clay loam; roots.	Modal size fraction 4-3 phi; 45% sand.	-						
'Lower brickearth'	2Bt horizon 0.4 (0.78-1.18 m depth) Particle size sample 0.8-0.9 m depth Thin section sample 1-1.08 m depth	Strong brown (7.5 YR 5/8) with yellowish brown (10YR 5/6) very slightly stony silty clay with very rare dark red (2.5 YR 3/6) mottles. Few roots and earthworm channels. Thin irregular stone lines of fine to medium gravel at 0.78 and 0.96 m depth.	Bimodal – main peak at 7-6 phi (silt fraction), secondary at 2-1 phi (sand). Total silt 90.3%; sand 9.7%.	74% egg-yellow illuvial clay, of which only 57% is undisturbed. 26% yellowish-brown illuvial clay (Holocene), of which 90% is undisturbed.	0.6 – 0.8 (c. 1.5-2.2 m depth - contacts irregular) LP3/4 at a depth of 1.75 m below ground surface	Reddish yellow (7.5 YR 6/8) medium silt / loess	Median particle size 7.5 microns	0.45 (0.51-0.96 m depth) LEP10-03,04 at 0.76 m depth below ground surface	As above, but yellowish red (5YR 5/8).	LEP10-03/X4104: modal size fraction 31-44 microns / 4.5-5 phi LEP10-04/X4105: modal size fraction 31-44 microns / 4.5-5 phi

Table 2. Summary of descriptions of Unit 5 at Stone Point from various studies. Note that in Briant et al. (2009), descriptions are simply of two overlying units – it was not clear which were equivalent to the previously defined upper and lower brickearths, although the Munsell colours described are similar to the lower unit only.

Section / test pit / borehole of Briant et al. (2009, 2019) – see Figure 3	Field code	Laboratory code	Age estimate (ka)	Age range (ka)	MIS attribution
S1	LEP10-01	X4102	4.8 ± 3.7	1.1-8.5	1
S1	LEP10-02 (replicate of -01)	X4103	54 ± 13.1	41-67	4-3
S1	LEP10-03	X4104	2.2 ± 1.3	0.9-3.5	1
S1	LEP10-04 (replicate of -03)	X4105	32.9 ± 15.8	17-49	3-2
S5	LEPE03-05	X1729	57± 6	63-51	4–3
S1	LEPE03-01	X1725	198 ± 15	213-184	7–6
S1	LEPE03-02 (replicate of -01)	X1726	146 ± 10	156-136	6
TP4a	LEPE03-03	X1727	141±11	152-130	6–5e
TP4a	LEPE03-04 (replicate of -03)	X1728	165±14	179-151	6

Table 3. OSL dosimetry, equivalent dose and age estimates for samples from the Stone Point sequence, Hampshire, England published by Briant et al. (2019). Error quoted as one standard error (standard deviation / $\sqrt{n}$). MIS boundaries are taken from Shackleton et al. (1990) and Bassinot et al. (1994).

3. GCR Site 1938 Priory Bay (SZ 635 900) AH, RMB

3.1 Introduction

The sands and subangular flint gravels at Priory Bay outcrop in the coastal cliff between 29 and 33 m O.D. sandwiched between early Oligocene Bembridge Marls below and a thin (~1m) unit of brickearth above. Over a thousand artefacts including several hundred handaxes have been recovered both from the beach below and *in situ* within the outcrop since the late 19th century. Priory Bay is the richest source of Lower Palaeolithic artefacts on the Isle of Wight, and probably one of the richest in the country. The first published report on the site and artefacts was by Poulton (1909). Further large collections were made by Poole between about 1910 and 1930 (Poole, 1924; 1932; 1939). Subsequent analysis of the site and its contained archaeology has been provided by Basford (1980), Samson (1976), Preece and Scourse (1987, reporting on a section opened in 1986 for a QRA field trip), Preece *et al*., (1990) and Loader (2001). The coastal slope at Priory Bay has been designated a Site of Special Scientific Interest due to the importance of the gravels and their contained Palaeolithic artefacts. However, the site is currently under pressure from coastal erosion and the expansion of tourism (Loader, 2001). In January 2001 English Heritage commissioned Southampton University to investigate whether the deposits containing significant Palaeolithic archaeology were under threat by coastal erosion. Further field investigations were carried out in the period between January and September 2001 (Wenban-Smith, 2001; et al., 2009).

Throughout there has been debate about the age of the gravels and their depositional environment, with some workers proposing marine, and others a fluvial origin.

3.2 Description

The Priory Bay site is located on the northeast coast of the Isle of Wight between Bembridge and Seaview (Fig. 6). The bay is backed by a steep coastal slope showing signs of instability including a series of rotational slumps. The steep coastal slope is presently heavily wooded and overgrown by trees which were planted in the early twentieth century in an attempt to induce stability (Loader, 2001).

The first of many implements was found on the beach east of Horestone Point by Poulton in 1888. In 1902 a handaxe was discovered *in situ* in gravel exposed at the top of the cliff and by 1909 150 implements, mostly handaxes, had been recovered (Poulton, 1909). Some of those *in situ* within the gravel were in fresh condition, the others were abraded. This suggests the possibility that two assemblages might be present, one undisturbed, perhaps an occupation horizon, the other representing secondary deposition (Wenban-Smith, 2001). However the majority of the material has been discovered on the beach below, concentrated in a small area at the southern end of the bay near Nodes Point where downslope movement brings material to the beach (Loader, 2001).

The local antiquarian Hubert Poole frequently visited the site during the early twentieth century, made records and collected material (Poole, 1924; 1932; 1939; Loader 2001). Since then further material, comprising over 300 artefacts, has been recovered from the beach by Mr Brian Elcox. This collection was subsequently examined by Samson (1976).

3.2.1 1986 excavations

In April 1986 a section at SZ 63515 89975 approximately 1.75m wide was cleaned and described as part of the Nature Conservancy Council's Geological Conservation Review programme (Fig. 7) and described by Preece and Scourse (1987). The gravel occurred between 29.12 and 32.70 m O.D., being underlain by Bembridge Marls and overlain by about a metre of brickearth (Fig. 7). Samples were taken from the upper and lower levels of the gravel for lithological and clast-shape analysis (Preece et al., 1990). Both samples had modal classes in the subangular category and their lithological composition was also very similar comprising about 88% flint, 11% chert and traces of quartz and

Wealden-type ironstone (Bridgland, 1990). A rounded clast of granite found in the excavation spoil was assumed to have come from the gravel (Preece et al., 1990).

Thirty-eight flint flakes were recovered during the 1986 excavation from about 1–2 m^3 of sediment. They ranged in preservation from very fresh material to highly rolled and patinated. Loader (2001) suggested the very fresh material may not be Palaeolithic in age. A worn handaxe and some flakes were found *in situ* halfway down a bed of coarse gravel at about 31.5m O.D. (Preece and Scourse 1987; Preece et al., 1990; Loader, 2001; Wenban-Smith, 2001).

3.2.2 2001 excavations

More recently, in September 2001, two excavations directed by F.F. Wenban-Smith and supervised by G. Marshall and J. Tipper were undertaken close to the 1986 GCR section (Figs 6, 8 – 10). Despite its small scale, the excavations produced over 110 *in situ* Palaeolithic flint artefacts including 9 handaxes. The artefacts from within the gravels were mostly abraded but those from the surface of the gravel and within the overlying sands and silts were in a fresh unpatinated condition, suggesting the possibility of an undisturbed archaeological horizon. Several of the handaxes were in pristine condition including a fine twisted ovate specimen 135mm long (Wenban-Smith, 2001). The excavations in Areas 1 and 2 showed a broadly similar stratigraphy to the 1986 section, but with more detail (Table 4, Figs 8 and 9).

In Area 1 (Fig. 8), the basal deposit (bed III) corresponded with the main body of the gravel recorded in 1986 (Loader, 2001), overlying Oligocene Bembridge marl at c. 29 m OD. The lower unit III-A consists of reddish-brown flint gravels that are typically well-bedded at the base and contain sub-horizontal sand lenses (sometimes cross-bedded or laminated) 2–15 cm thick. The upper unit III-B, by contrast, is generally structureless and less well-sorted. At the southeastern end of Area 1, a further bed (IV-A) of gravel occurs. This is coarse-grained and very poorly sorted, including common well-abraded flint nodules up to 25 cm maximum length. These are overlain by finer (medium-coarse) better-sorted and more sandy gravels of bed IV-B. The upper unit C of bed IV is equivalent to the brickearth recorded at the top of the 1986 section (Table 4) and comprises moderately to well-consolidated sandy/clayey silts. A further small discontinuous unit (Unit IV-C) is a fine silty sand, gravelly in its lower part. This deposit (where present) and unit IV-C were both capped by topsoil (bed VI) across Area 1 (Wenban-Smith et al., 2009).

In Area 2 (Figs 9 and 10, Table 4), the basal gravel unit (bed VII), the base of which was not reached, was a well-consolidated sandy flint gravel with some sand-rich pockets; most clasts were medium to very coarse angular to sub-angular flint pebbles, moderately to well-abraded, with occasional cobbles up to c. 15 cm, in coarse sand and very fine gravel matrix. The part of the deposit seen lacked bedding and the flint pebble clasts did not seem preferentially oriented, bar three bifacially knapped handaxes which were lying flat within (or on) the upper part of the deposit. This bed is overlain, apparently conformably, by a body of firm yellowish-brown fine silty sand (bed VIII). Bed VIII was overlain at Area 2 by a mottled light grey/yellowish-brown sandy clay-silt bed (IX), likely equivalent to the 1986 brickearth (Table 4). This deposit was capped by topsoil (bed VI).

Seven locations within the sequences at Areas 1 and 2 were sampled for OSL dating by Wenban-Smith et al. (2009) (Table 4; Figs 8 and 9).

1986 GCR section (Preece and Scourse, 1987; Preece et al., 1990)	Wenban-Smith et al. (2009) Area 1						Wenban-Smith et al. (2009) Area 2		
	Bed/unit	Depositional interpretation	Artefacts	OSL sample [lab code]	OSL age (ka)	MIS correlation (Wenban-Smith et al. (2009)	Artefacts	Depositional interpretation	
	VI	Topsoil						Topsoil	VI
c. 1 m thickness of brickearth	V			Area 1 1 [x-1560]	41.3 ± 2.7	MIS 3			
				Area 2 9 [x-1568]	216 ± 20	MIS 7			IX
	IV-C			Area 1 3 [x-1562]	284 ± 29	MIS 8			
c. 4 m of gravel	IV-B		Well abraded and fresh handaxes	Area 2 11 [x-1570]	327 ± 22	MIS 9	Well abraded and fresh handaxes at surface	Alluvial or colluvial / aeolian	VIII
	IV-A	Solifluction	Well abraded and fresh handaxes						
	III-B	Periglacial modification (gravel structureless)	Well abraded and fresh handaxes	Area 2 7 [x-1566]	Area 2 305 ± 39	MIS 9	Three very fresh handaxes at the surface including pointed ovate with twisted profile	Alluvial or colluvial / aeolian	VII
	III-A	Fluvial gravel or reworked beach gravel (bedded)	Well abraded handaxes found both 1986 and 2001 – cordate and ovate forms	Area 1 5 [x-1564]	367 ± 49	MIS 11/10			

Table 4. Summary of sequence and dating at Priory Bay from Wenban-Smith et al. (2009).

All the OSL dates from Wenban-Smith et al. (2009) are in stratigraphic order in relation to local sequences apart from in Area 2, where the stratigraphically lowest date (OSL-7, from a sand pocket in the upper part of bed VII) gives a result of c. 305 ka BP, and the immediately overlying bed is dated to c. 325 ka BP (OSL-11, from the middle of bed VIII). However, the date ranges overlap within the standard error bars, suggesting that the upper part of bed VII and bed VIII were laid down in close succession.

The 2001 excavations (Wenban-Smith et al., 2009) found over 100 Palaeolithic flint artefacts including eight handaxes. The basal gravel at Area 1 (bed III-A) contained moderately abundant well-abraded artefacts, including a cordate and an ovate handaxe, and numerous debitage. Some of the artefacts are very abraded. The overlying disrupted gravel beds (beds III-B, IV-A and IV-C at Area 1; bed VII at Area 2) contained both well-abraded artefacts derived from the underlying gravels and fresher condition artefacts, including a small ovate handaxe (Fig. 11iii). A further abundance of fresh and mint condition material occurred in the top part of bed VII at Area 2, including three handaxes, including a pointed ovate with a twisted profile (Fig. 11ii). A further mint condition large tranchet-sharpened cordate handaxe was found at the top of bed VIII (Fig. 11ii).

The sequence excavated in 2001 (Wenban-Smith et al., 2009) is dominated by handaxe manufacture. Handaxe shape is predominantly cordate or ovate throughout the sequence, with a slightly abraded specimen from bed VII at Area 2 (equivalent to bed III-B) with a twisted profile and the specimen from the top of bed VIII at Area 2 having a tranchet-sharpened tip. Wenban-Smith et al. (2009) also reinvestigated the larger collection made by Poulton (1909) of over 150 handaxes and found that its typological range was also dominated by cordates and ovates.

3.3 Interpretation

3.3.1 Depositional environment

There has been considerable debate as to whether the Priory Bay gravels are marine or fluvial in origin, and how they relate to the Bembridge Raised Beach which is exposed in the cliff face some 3-4 km to the south of Priory Bay (Preece and Scourse 1987; Preece et al. 1990).

The two Priory Bay gravel samples taken for lithological analysis from the 1986 excavations (equivalent to unit IIIA in Area 1 – Fig. 8) show less rounding and diversity in clast lithology than the Bembridge Raised Beach gravel which also has a different altitudinal range, between 5 and 18m O.D. Despite being mapped as a single marine gravel on the 1:50,000 Geological Survey map, the altitudinal and clast lithological differences led Preece et al. (1990) to suggest the Priory Bay gravel and the Bembridge Raised Beach represent two quite different aggradations and that there was no certainty the Priory Bay gravel had a marine origin.

However Bridgland (1999) stated that the Priory Bay gravel seen in the 1986 section (bed III-A) contains a higher proportion of pebbles in the rounded categories than any of the fluviatile Thames gravels. Furthermore, there were a number of very abraded flint pebbles with percussion scars, but insufficiently rounded to relate to reworking from Palaeogene deposits. This contributed to his conclusion that the balance of evidence favoured interpretation as a raised beach gravel. He also suggested that the rounded clast of granite found in spoil beneath the 1986 GCR section, and presumed to have fallen from it, would tend to confirm this view since such material is not found in fluviatile gravels. He attributed the low degree of rounding and the scarcity of non-flint material in the Priory Bay gravels compared with the Bembridge Raised Beach to the fact that Priory Bay is in a comparatively more sheltered position within the eastern mouth of the Solent. Indeed, many modern beaches along the Solent do contain highly angular pebbles because the fetch is limited by the narrow width between the Isle of Wight and the mainland.

By contrast Wenban-Smith (2001) and Wenban-Smith et al. (2009) suggested a complex sequence of depositional environments summarised in Table 4, with significant thicknesses of slope deposits and periglacial / solifluction deposits. However, for the main gravel (their III-A), whose depositional environment is the one that has been debated, they interpret this as a reworked marine gravel, on the basis of more abraded artefacts (interpreted as coming from an original beach gravel) occurring alongside fresher artefacts thought to be contemporaneous with a later depositional event.

3.3.2 Archaeological significance

Samson (1976) studied the Elcox collection and based on considerations of size, refinement and abrasion concluded that the material included both Acheulian and Mousterian of Acheulian Tradition. The ‘Acheulian’ assemblage contained a large proportion showing ovate tradition mostly of tranchet finish though with rarer twisted ovates. The ‘Mousterian’ assemblage contained common pointed and twisted ovates and tranchet finish types. She considered the material represented a contemporary assemblage because handaxes, retouched flakes and débitage were all present.

The 2001 excavations (Wenban-Smith, 2001; Wenban-Smith et al., 2009) found both abraded tools and fresh material within the sequence, with possible ages of MIS 11 and older (Table 4). They note possible undisturbed landsurfaces at the tops of Bed III-B in Area 1 and Beds VII and VIII in Area 2, yielding fresh handaxes of both cordate and ovate types (Fig. 11) that seem to date from MIS 9. This suggests two components are present at the site. Wenban-Smith at al. (2009) suggest that the abraded material may be due to reworking of artefacts from a nearby raised beach, possibly that exposed at the GCR site of Boxgrove. The archaeological importance of this site has been recognised in a number of publications and published research priorities, since Basford (1980), whose work drove the 1986 excavation, following breaching of sea defences and increasing artefact discoveries on the beach from the 1960s onwards. More recently, Wenban-Smith et al. (2014a, b) also identified Priory Bay as a site with high priority for further study, noting that ‘fieldwork at Priory Bay has confirmed the importance of the site and identified important horizons, but the site remains vulnerable to erosion and requires further investigation to mitigate it’s impact’ (Wenban-Smith et al. (2014b, p.59).

3.4 Conclusions

Cliff sections at Priory Bay reveal Pleistocene gravels overlying Bembridge Marls. The gravels here contain a prolific Acheulian (Palaeolithic) industry, the richest on the Isle of Wight. Over a thousand artefacts have been recovered since the late 19th century, most from the beach below the gravel outcrop. There is a suggestion of two flint assemblages, one derived and the other *in situ*. In addition, the site provides an important comparison with the nearby Bembridge raised beach site, which is at a lower elevation. There is ongoing debate about the age and depositional environment of the gravels with some researchers arguing for a fluvial origin and others marine. The explanation of the fluvial/marine sequence in this part of the island is currently of high priority. This, and the presence of Palaeolithic material, makes Priory Bay a site of considerable scientific importance. The site is currently under threat from cliff erosion.

4. GCR Site 1895 Bembridge (SZ 870 650) AH, RMB

4.1 Introduction

Two locations in the Bembridge area provide critical evidence for Quaternary sea level history in southern Britain. At Bembridge School (SZ 641 865, sites A and B on Fig. 12), the high-level (c.38-40 m O.D.) fossiliferous Steyne Wood Clay was deposited in a marine-estuarine environment during the post-temperate stage of a mid-Quaternary interglacial. Further east, at lower elevations of between c.5-18 m O.D. (SZ 656 880, Fig. 14), coastal sections display one of the finest shingle raised beaches in southern England. This beach, termed the Bembridge Raised Beach, is inferred to be of Ipswichian (MIS 5e) interglacial age. It is underlain by Lower Oligocene Bembridge Marls and overlain by Devensian solifluction deposits of MIS 5d-b age, which are in turn succeeded by a Late Devensian loessic unit. The close proximity of these two sites makes Bembridge a key area for understanding the mid and late Quaternary sea level and tectonic history of southern England. Key research activity is introduced below for each site separately.

4.2 Bembridge School (SZ 641 865)

At between c. 38 and 40 m O.D. is a fossiliferous, fine-grained marine-estuarine deposit, the Steyne Wood Clay, that rests on Lower Oligocene Bembridge Marls. Its occurrence in the grounds of Bembridge School has been known for over eighty years (Jackson, 1924; Reid and Chandler, 1924; Preece et al., 1990). In 1924 the excavation of a sewer trench exposed an organic clay containing ‘peat’ and plant macrofossils including *Picea* (spruce) and *Ranunculus hyperboreus* (arctic buttercup) in the upper layers (Reid and Chandler, 1924). Reinvestigation by Holyoak and Preece (1983) demonstrated that it also contained diatoms, Mollusca, Ostracoda and Foraminifera. They concluded that the Steyne Wood Clay was laid down in a marine-estuarine environment during the post-temperate phase of a mid-Quaternary interglacial (Holyoak and Preece, 1983). Later, Preece et al. (1990) also found a diverse coccolith assemblage within the Clay and reinvestigated ostracods and forams, favouring an earlier date, based on correlation with the site at Boxgrove in West Sussex where the vertebrate fauna is suggestive of a pre-Anglian age (Roberts and Parfitt, 1999). Overlying the Steyne Wood Clay is up to 3 m of mottled orange-brown clay with scattered flint pebbles which has been interpreted as a solifluction deposit (Holyoak and Preece, 1983; Preece and Scourse, 1987; Preece et al., 1990).

4.2.1 Description

The Steyne Wood Clay is a greyish-brown clay with sand and shell fragments which occurs between c. 38 and 40 m O.D. in the grounds of Bembridge School. It rests on Lower Oligocene Bembridge Marls and is overlain by up to 3 m of mottled orange-brown clay with scattered flint pebbles and the modern soil (Holyoak and Preece, 1983).

Jackson (1924) suggested that the clay extends over several hundred metres from near the old school buildings in the south, northwards to Hillway Road (Fig. 12). He described four stratigraphic units from the base upwards:

(d) 60 cm of waterlogged clayey sand, full of flint chips and pebbles merging into
(c) a variable mass of sandy and pebbly clays, and an extremely tough bluish-grey clay; irregular seams and lenticles of compact peat full of fragments of wood and bark some 130 cm in thickness
(b) above lay between 270–330 cm of stiff clay with scattered flint pebbles and occasional sandy and gravelly streaks and lenticles
(a) capping the sequence was the modern soil 60cm thick (Jackson, 1924; Holyoak and Preece, 1983).

Holyoak and Preece (1983) reinvestigated the site in 1979 and 1980. They described the stratigraphy from two auger boreholes about 50 m apart, located at A (SZ 6418 8657) and B (SZ 6419 8664) (Fig. 13). The stratigraphy was almost identical in both boreholes. Overlying the Bembridge Marls was up to 195 cm of olive-grey clay with sand and shell fragments including *Cerastoderma edule* which merged into a dark greyish-brown clay containing traces of dark brown organic matter. Above a sharp contact lay up to 330 cm of mottled yellowish-brown silty clay with a few flints and angular chalk pellets. The 1979 and 1980 boreholes were therefore considered to be representative of the stratigraphy described from Jackson’s more extensive sewer trench, though the irregular lenses of compact 'peat' more than 10 cm thick and full of wood fragments reported towards the top of the deposit in the south of Jackson’s outcrop were not relocated (Holyoak and Preece, 1983). Samples for pollen, plant macrofossils, diatoms, Mollusca, Ostracoda and Foraminifera were taken from both auger boreholes.

In 1985 a deep pit (SZ 6421 8652) was excavated about 50 m south of borehole A of Holyoak and Preece (1983) where the overlying clay was only 2 m thick (Preece et al., 1990). Here the Steyne

Wood Clay was virtually devoid of shells but did contain discrete lenses of carbonised wood, perhaps representing the compact 'peat' noted by Jackson (1924).

Pollen diagrams (Fig. 13) from the boreholes reported by Holyoak and Preece (1983) shows high frequencies of *Pinus* and *Picea* pollen with *Abies*, presumably indicating regional coniferous forest, though these taxa are often over-represented in waterlain deposits. Deciduous trees including *Betula* and to a lesser extent *Quercus* appear only at lower frequencies. Frequencies of Poaceae and Cyperaceae pollen expand towards the top of the profile and Chenopodiaceae values record their highest frequencies in the middle of the sequence. The high coniferous pollen frequencies, the presence of various spores such as *Lycopodium* and scarcity of deciduous tree pollen may suggest cool or cold climatic conditions (Holyoak and Preece, 1983).

Picea abies and *Pinus sylvestris* were the most abundant plant macrofossils, supporting the pollen record in suggesting presence of coniferous forest. Others include a range of species, most of which are unlikely to have grown in the shade of coniferous trees. For instance *Agrimonia eupatoria* (agrimony), *Artemisia* sp. (mugworts) and *Ranunculus hyperboreus* would not tolerate shading, while mosses of the genus *Thuidium* are calciphiles that are unlikely to grow on acid mor humus. *Alisma* (water plantains), *Eleocharis palustris* (common spike-rush) and *Rorippa amphibia* (great yellow-cress), also present, probably grew in the shallow margins of the river upstream of the tidal limit. Plants of saline habitats are absent from the macrofossil record, despite pollen records of Chenopodiaceae. *Ranunculus hyperboreus* is not presently native to the British Isles and has a circum-polar montane distribution implying cold climatic conditions prevailed (Holyoak and Preece, 1983). The mixed nature of this assemblage probably represents transport from the original terrestrial communities and secondary deposition in a marine-estuarine environment.

Diatoms from the Steyne Wood Clay in both boreholes were characterised by low frequencies and poor preservation with all valves being broken and degraded or showing signs of corrosion. Few valves were found in the samples from borehole A or in any of the organic-rich material in the upper levels. Neither core showed a discrete, recognisable diatom assemblage at any level and therefore no statistical counts were attempted. Diatoms encountered included the oligohalobian forms *Achnanthes affinis*, *A. lanceolata*, *Cocconeis pediculus*, *Fragilaria capucina*, *Fragilaria* (*Staurosirella*) *pinnata*, *Gomphonema angustatum*, *G. parvulum*, *Navicula cincta*, *N. cryptocephala* var. *cryptocephala*, *N. graciloides*, *Nitzschia tryblionella* var. *levidensis* and *Pinnularia viridis*.. More salt tolerant mesohalobian forms included *Amphora veneta*, *Camplodiscus echeneis*, *Cyclotella striata*, *Navicula avenacea*, *N. digito-radiata, Nitzschia filiformis and Synedra* (*Ctenophora*) *pulchella*. Finally the fully marine polyhalobous forms included *Cymatosira belgica*, *Paralia sulcata*, *Pseudopodosira westii* and *Podosira stelligera* (Holyoak and Preece, 1983). Most of these species today are part of the benthos in lower salinity fresh-brackish to brackish water conditions, probably in an upper river estuary, saltmarsh or sheltered littoral environment. The few fully marine taxa identified were interpreted as brought in by tidal or storm activity (Holyoak and Preece, 1983).

The preservation of the Mollusca in the two boreholes was variable, with most taxa represented by both fresh and worn fragments, many of them juveniles. The upper levels contain fewer shells and there is some evidence for decalcification with shells being badly pitted or corroded, with some represented only by pyritised internal casts. Species present included *Littorina* cf. *saxatilis*, *Hydrobia* spp., *Retusa obtusa*, *Odostomia* sp., *Modiolus* or *Mytilus* sp., *Macoma balthica* and *Cerastoderma edule*. According to Holyoak and Preece (1983) there is little doubt that these species reflect an estuarine environment. In borehole A there is an increase in the frequency of *Hydrobia* towards the top of the clay which could reflect reduced salinities in a saltmarsh environment.

Boreholes A and B were reinvestigated for calcareous nannofossils by Preece et al. (1990). The coccolith assemblages recovered from the lower section of borehole B contain 11 Quaternary species and are dominated by *Gephyrocapsa oceanica*, *G. caribbeanica*, at least two *Reticulofenestra* species and *Dityococcites productus* with *Discosphaera tubifera*, *Syracosphaera pulchra*, *Braarudosphaera bigelowii*, *Coccolithus pelagicus* and *Calcidiscus leptoporus*. The sediments also contained reworked

Mesozoic nannofossils and some derived Tertiary forms comprising over 25% of the total assemblage (Preece et al., 1990). Coccoliths first decline and are then absent towards the top of the Steyne Wood Clay, which could be due to either a change from open intertidal mudflats to a saltmarsh environment or loss through post-depositional decalcification - or a combination of both (Preece et al., 1990). Coccoliths can be useful for biostratigraphic correlation because the first occurrence datum (FOD) and last occurrence datum (LOD) of a species are considered to be broadly synchronous. An important nannofossil event in the Middle Pleistocene is the extinction of *Pseudoemiliania lacunosa,* which occurs during the middle of MIS12 at c.450,000 ka BP (Preece et al., 1990). The absence of *P. lacunosa* and *Emiliania huxleyi*, a species that has a FOD at 275,000 ka BP, from the Steyne Wood Clay suggests an age range between these two dates. The coccoliths therefore suggest the Steyne Wood Clay was likely to have been deposited during MIS 11 or 9.

Ostracods and forams were initially examined using an intial 100 g of dry sediment wet sieved to 140 microns (Holyoak and Preece 1983). Subsequent re-examination used 500 g of initial sediment wet sieved to 125 microns (Preece et al., 1990) and resulted in an extended faunal list.

The Ostracoda from borehole B comprised 30 Quaternary species dominated by the leptocytherids, notably *Leptocythere castanea* which is common in near-shore, intertidal environments*; L. lacertosa,* a euryhaline species that also thrives in the intertidal zone; *L. psammophila,* which normally prefers sandier substrates; and *L. steynewoodensis*. Because the species present contain adults of both sexes and juvenile stages, they were considered to represent an *in situ* assemblage. The ostracods therefore suggest fully marine, tidal flat conditions were present at least initially though perhaps with a shallowing upwards through the sequence.

A re-examination of forams from Borehole B gave a total of 28 Quaternary taxa dominated by three shallow, euryhaline species: *Elphidium williamsoni*, *Haynesina germanica* and *Aubignyna perlucida.* Low frequencies (4-5%) of *Elphidium excavatum* forma *selseyensis* at the base of the marine sequence which decrease upwards suggest a change from open tidal flat to a more restricted brackish environment (Preece et al., 1990). *Aubignyna perlucida* is common in Holsteinian/Hoxnian deposts in the southern North Sea area but is also found in Cromerian deposits in the Netherlands. The foraminiferal content of the Steyne Wood Clay therefore points to a Hoxnian age (MIS 11) or older, whilst the coccoliths might suggest MIS 11 or 9 (Preece et al., 1990).

Preece et al. (1990) also undertook palaeomagnetic and amino acid analyses. Palaeomagnetic analysis indicated that the Steyne Wood Clay was deposited during a period of normal geomagnetic polarity. Amino acid analysis on four subsamples from nine fragments of the bivalve *Macoma balthica* from borehole B (Holyoak and Preece, 1983) gave a mean D-alloisoleucine to L-isoleucine ratio of 0.32 ± 0.04. These data were taken to support a Middle Quaternary age for the Steyne Wood Clay, with ratios suggesting a date older than the Hoxnian. (Preece et al., 1990). However, recent work by Penkman et al. (2008) has shown that analyses undertaken on the full protein fraction of shells are likely to contain contamination, with only the intracrystalline fraction reliable, so these results should be treated with caution. In addition, there is currently only an AAR framework for terrestrial sequences in Britain (Penkman et al., 2011), so nothing suitable to compare these marine samples to.

4.2.2 Interpretation

The high coniferous pollen frequencies, the presence of coniferous macrofossils, the occurrence of various spores such as *Lycopodium* and scarcity of deciduous tree pollen and presence of *Ranunculus hyperboreus* suggests cool or cold climatic conditions. In the absence of any diagnostic features indicating age, other than the high frequencies of *Picea* and presence of *Abies* suggesting a pre-Ipswichian date, the pollen record was interpreted by Holyoak and Preece (1983) as representing the post-temperatate zone of a mid-Quaternary interglacial.

Preece et al., (1990) suggest a more specific age, i.e. that the Steyne Wood Clay and the Slindon Sand at Boxgrove are of similar age. This is based on their similar altitudes (c. 40 m O.D.) and amino acid ratios on *Macoma balthica* between the Steyne Wood Clay and a sample from a section in the Slindon Sand at Waterbeach. Both also exhibit normal magnetization. Finally the coccolith assemblages from both sites are similar in diversity and composition.

The coccolith assemblages from both deposits lack *Pseudoemiliania lacunosa*, with a LOD at c. 0.475 Ma BP, and *Emiliania huxleyi*, with a FOD at c. 0.275 Ma BP which suggest an age of MIS 11 or 9. However if both deposits are of similar age the vertebrate assemblage from Boxgrove strongly suggests a pre-Anglian warm stage, perhaps MIS 13 (Roberts and Parfitt, 1999). It must be remembered that the correlation indicated by the coccolith assemblages is based on negative evidence. It could be that the lack of *P. lacunosa* might not represent genuine absence. Preece et al. (1990) therefore favoured a pre-Anglian age for the Steyne Wood Clay during the later part of the Cromerian complex.

A further clue to the age of the deposits is that the occurrence of diverse coccolith assemblages in the Steyne Wood Clay, including abundant gephyrocapsids, with subdominant *Calcidiscus leptoporus, Syracosphaera pulchra* and *Discosphaera tubifera*, strongly suggests that a thermocline was present in the central English Channel at the time of deposition (i.e. the Straits of Dover were closed). These species are only found today in sediments underlying a watermass with pronounced thermocline development. Recent sediments in the English Channel deposited from tidally mixed waters contain sparse nannofossil assemblages usually with six or fewer species characterized by dominant *Emiliania huxleyi* and *Coccolithus pelagicu*, rare gephyrocapsids and *C. leptoporus* is absent. Recent sediments in the Solent region are even more neritic, being limited to four species dominated by *C. pelagicus*. This indication that the Straits of Dover were closed when the Steyne Wood Clay was deposited dates this deposit to prior to the Anglian glaciation at c. MIS 12, c. 450 ka (Gupta et al., 2007; Busschers et al., 2008).

The altitude of the Steyne Wood Clay at c.38-40m O.D. can be used to determine regional tectonic movements. Preece et al. (1990) suggested that the marine isotope record shows interglacial highstands during the mid- to late-Quaternary to have been been within ± 10m of present values. Therefore, the fact that the Steyne Wood Clay is now at a significantly higher altitude must imply regional crustal uplift. Using an estimated age for the deposit of 487 ka BP and a eustatic variation ± 10m that of present day they calculated the rate of uplift to be within the range 0.53 – 1.03mm per century.

4.3 Bembridge Raised Beach (SZ 650 870)

The low-level interglacial deposits are represented by the Bembridge Raised Beach which occurs at an altitude between c. 5-18 m O.D. Its occurrence was described by early workers such as Godwin-Austen (1855) and Forbes (1856). Prestwich (1859) was the first to suggest it was a marine deposit and later gave a description of its lithological content (Prestwich, 1892). Codrington (1870) also gave a detailed account of the deposits, noting two discrete peat-beds and distinguishing between a lower iron-stained 'deep red-brown shingle gravel' and an upper white clay-rich gravel which lacked the iron staining of the lower unit (Preece and Scourse, 1987). He also described the brickearth above the raised beach deposits within which he recorded an *in situ* Acheulian hand axe from a section at Howgate. Reid and Strahan (1889) and White (1921) also described the sections at Bembridge. Arkell (1943) considered the Bembridge gravels to have been deposited under cold conditions and correlated it with the ‘Boyn Hill or Middle Acheulian Interglacial’, however more recently an Ipswichian (MIS 5e) age has been suggested (Jones, 1981; Holyoak and Preece, 1983; Preece and Scourse, 1987: Preece et al., 1990). In 2002, further investigations were undertaken in advance of coastal defence works in front of the Warner Bembridge Coast Hotel (Wenban-Smith et al., 2005). These enabled a series of optically stimulated luminescence (OSL) dates to be undertaken that have confirmed a MIS 5e age for the Bembridge Raised Beach and a MIS 5d-b age for the overlying solifluction deposits (Wenban-Smith et al., 2005). Capping the sequence is a Late Devensian loessic unit dated to between 17-18 ka B.P. by TL dating (Parks and Rendell, 1992).

4.3.1 Description
4.3.1.1 Sediments

The ground surface in the Bembridge area forms a terrace-like feature that rises from c.5.5m O.D. at Lane End to c. 20.5 m O.D. at Howgate (Fig. 14; Preece et al., 1990). A steeper slope then separates the terrace from the hill on which the Steyne Wood Clay occurs in the grounds of Bembridge School. The terrace is dissected by a former river valley that reached the sea near Lane End (Fig. 14).

Underlying the terrace, an erosion surface cut into Lower Oligocene Bembridge Marls marks the base of the Quaternary succession. This erosion surface occurs at around 3.5 m O.D. near Lane End and is nearly horizontal for about 1.4 km to the south west, then it rises at a steeper gradient to reach the surface at 27.5m O.D., 100 m to the southwest of site U (Fig. 14). The Bembridge Marls then underlie the ground surface between this point and the higher level Steyne Wood Clay sequence (Preece et al., 1990).

Above the erosion surface are three units that comprise the Bembridge Raised Beach. First is a unit of well-bedded clast-supported orange flint gravel up to 12m thick. The heavily iron-stained clasts increase in size toward the west and are inclined throughout the section with a true dip of between 8-13° towards the north east. Usually the unit is clast supported, though sand beds do occur containing occasional matrix-supported flint gravel. Lithological analysis shows a predominance of flint but with significant amounts of Greensand and Jurassic chert, ironstone and quartz. There are also traces of *Rhaxella* chert (Portlandian), some igneous rocks, tourmalinized schorl-rock and a distinctive low-grade metamorphic clast, probably from Start Point, all indicating a provenance from the west. The flint clasts have a degree of rounding and show microfeatures such as crescentic chatter-marks, which suggest a beach origin (Preece et al., 1990).

Second, about 50 metres southwest of site Z, finer interbedded orange-white sands and light blue-grey silty clays overlie the orange gravels, reaching a maximum of 1.5 m at site A. The sand varies from 2 mm to 63 μm in size, and from bleached white to iron-stained orange in colour. The unit is structureless, but contains frequent partings of light blue-grey silty clay that become thicker and more frequent towards the base. Samples were analysed for coccoliths and diatoms but were found to be devoid of both (Preece et al., 1990).

Third, the interbedded sands and silty clays grade into a highly organic, homogeneous, dark grey-brown silty clay towards the north east (Fig. 14). It contains occasional rounded to subangular black flints and occasional pale grey lenses of coarser sands with reduced organic content and though containing pollen, it lacks both plant macrofossils and microfauna (Preece et al., 1990).

At Lane End (SZ 656 880) Preece et al., (1990) relocated a thin sedge peat bed underlain and overlain by gravel first discovered by Edward Forbes and described by Godwin-Austen (1855) and Codrington (1870). Neither of these authors commented on the stratigraphic relationship of these deposits to the Bembridge Raised Beach. However, Reid and Strahan (1889) noted that the peat and gravel at Lane End filled a valley within the raised beach gravel which was probably cut by fluvial processes (Fig. 14). The section reported by Preece et al. (1990) comprised from the base upwards; 20cm very dark grey (10 YR 3/l) silty gravel, becoming sandier and stonier downwards; 27cm humified sedge-peat with a clearly erosional upper contact; 40cm brownish-yellow (10 YR 6/8) silty sand, passing downwards into olive (5 Y 5/4) silty sand; and finally 150cm of matrix-supported angular flint gravel which underlay the modern soil. The upper matrix-supported gravel at Lane End was largely subangular with a local lithology, clearly a different deposit from the Bembridge Raised Beach. It was considered by Preece et al., (1990) to be of local fluvial origin.

Above the Bembridge Raised Beach are white, predominantly matrix-supported clay-rich gravels which have been interpreted as a solifluction deposit (Preece et al., 1990). It is up to 2.5 m thick between sites Y and Z and near to sites U and W; it overlies the interbedded sands and silty clays. It overlies the organic silty clays between sites Z and C; and from site C to Lane End directly overlies the Bembridge Marls, reaching a maximum thickness of 3.5 m near the Bembridge Chalet Hotel slipway (Fig. 14). The sediment fabric and matrix are variable both laterally and vertically and the unit contains cryoturbation structures including discrete well-sorted sand bodies and concentrations of white flints forming localized clast-supported 'nests'. In the upper levels the unit also shows a marked vertical orientation of clasts. These features are indicative of periglacial ground-ice processes.

Overlying both gravel units between site W and Lane End is a thin brickearth, comprising a well-sorted silt with some clay and fine sand and occasional flints (Fig. 14). Preece et al. (1990) suggest it to be very similar to other brickearths from southern England that have been interpreted as loess reworked by colluvial or fluvial processes. In places it is clearly bedded, containing pebble stringers, and forms a thin cover rarely exceeding 1.5 m over most of the section. At Howgate Cliff however, where it overlies the white matrix-supported gravel, the brickearth thickens to 10.5m infilling a depression. Here it is in turn overlain by a second, higher, unit of white matrix-supported gravel (Preece et al., 1990).

In 2002 further investigations were undertaken in advance of coastal defence works in front of the Warner Bembridge Coast Hotel (Wenban-Smith et al., 2005). Two vertical sections (Sections 1 and 2; Fig. 15) were cleaned, drawn, photographed and surveyed and samples taken for pollen, diatoms, testate amoebae and OSL dating.

4.3.1.2 Fossils

Pollen analysis was undertaken from the organic silty clay exposed on Bembridge Foreland (Fig. 16). The pollen diagram shows high frequencies of *Quercus*, Poaceae, *Corlyus*/*Myrica* type and Chenopodiaceae. It has been divided into two local pollen assemblage zones, the boundary being defined by the rise in *Carpinus* (Preece and Scourse, 1987; Preece et al., 1990). The lower assemblage zone is dominated by *Quercus*, *Fraxinus*, *Corylus*/*Myrica*, Poaceae and Chenopodiaceae whilst the upper contains *Carpinus* values of between 4 and 17% TP+S, reduced *Quercus* values, increased Poaceae values and continuous but low frequencies of *Pinus* pollen. The pollen record was interpreted to reflect a saltmarsh environment, shown by the high Chenopodiaceae values, with temperate closed forest to landward including *Quercus*, *Corlyus* and *Carpinus* as the main components with *Alnus*, *Fraxinus* and *Acer* as subsidiary elements (Preece and Scourse, 1987; Preece et al., 1990). Preece et al., (1990) suggested that the pollen evidence showed correlation with substages IIb and III of the Ipswichian interglacial.

Section 2 of Wenban-Smith et al. (2005) was only a few metres away from the previous Bembridge Foreland pollen site (Preece et al., 1990), but showed only 50 cm of deposits between 2.25m and 2.75m below the ground-surface (cf. lm thick, between 1.45m and 2.45m). The pollen spectra were almost identical to those in the lower assemblage zone of the Bembridge Foreland pollen diagram but the sequence seems to have been truncated before the rise in *Carpinus* noted in the earlier diagram. This sequence does however have higher resolution within the lower assemblage zone and shows a clear decline in Chenopodiaceae suggesting a slight increase in the freshwater influence (Wenban-Smith et al., 2005).

At Lane End, eight pollen samples were counted through the sequence, six from the peat and one each from the deposits above and below. The samples were dominated by Poaceae (grasses) and Cyperaceae (sedges) pollen, presumably of local origin and representing a temperate wetland environment. The presence of *Pinus*, *Picea* and *Quercus* pollen led Preece et al. (1990) to suggest that it might tentatively equate in age to a post-temperate substage of the Ipswichian interglacial.

Three samples were taken from the Lane End sequence for plant macrofossil analysis with the lowest coming from the upper levels of the unit immediately underlying the sedge-peat. *Ranunculus* macrofossils were common including *R. flammula* (lesser spearwort), *R. sceleratus* (celery-leaved buttercup) and achenes of batrachian ranunculi, indicating quiet, slow-moving water with a muddy substrate. There is also a transition from *Carex rostrata* (bottle sedge) in the lower part of the peat to *Eleocharis palustris* in the upper.

Insect remains were present in the Lane End peat but they were not common and were poorly preserved. Taxa recovered included *Elaphrus* cf. *cupreus*, *Dyschirius* sp., *Bembidion* spp., *Hydrobius* spp., *Thanatophyllus* sp., Byrrhidae gen. et sp. indet., *Plateumaris* cf. *sericea* and *Notaris* sp. Most are typical of freshwater swamps and reed-beds and have wide modern ranges. *Plateumaris* is rare or absent from cold faunas (Preece et al., 1990).

4.3.1.3 Geochronology

TL dating of a sand lens at site X (Fig. 14) gave ages of 104.3 ± 14.1 and 115.1 ± 10.4 ka B.P. suggesting the Bembridge Raised Beach was deposited during MIS 5 (Preece et al., 1990). Further TL dates from the brickearth cliff at Howgate and from the thinner spread that immediately overlies the Bembridge Foreland pollen site gave Late Devensian ages, in the range 16.0 ± 1.5 to 21.5 ± 2.0 ka B.P. (Parks and Rendell 1988).

Eight OSL samples from beach deposits from 2002 (Fig. 15) support correlation of the raised beach sequence with the high sea level event of MIS 5e. The five dates for the Bembridge Raised Beach (OSL 3-7) all fall in the range 111 to 190 ka. The two oldest of these dates (OSL 6 and 7), both from Section 2, are much older (157 ± 9 ka; 183 ± 8 ka) and are considered erroneous (Wenban-Smith et al., 2005), possibly due to complex water content histories. Thus the accepted range of ages for the raised beach is 111 to 153 ka.

Three OSL dates from the overlying solifluction deposits (Fig. 15, OSL 1, 2 and 8) range between c. 82 ka and 115 ka BP, corresponding with the period MIS 5d to 5b. The youngest (OSL 2) at 82 ka BP was considered to have an unreliably high dose-rate so Wenban-Smith et al. (2005) believed the other two to be more reliable. The older date of 115.7 ± 8.3 ka BP (OSL 8) is from the solifluction deposit which directly overlies and truncates the estuarine organic silt of the Bembridge Raised Beach, suggesting a possible MIS 5d age. The younger date of 102.5 ± 7.2 ka BP (OSL 1) is from the succeeding unit, suggesting a possible MIS 5b age.

4.3.1.4 Archaeology

One Acheulian ovate handaxe in fresh condition has been found *in situ* along with some waste flakes within the brickearth at Howgate (Codrington, 1870; Wenban-Smith et al., 2005). However, it is thought to have been derived from earlier deposits since handaxes were not produced in the Late Devensian when the brickearth was laid down (Wenban-Smith et al., 2005). All other lithic artefacts, including several from the grounds of Bembridge School, two from Bembridge and a dozen or so from the beach between Culver Cliff and Bembridge Lifeboat Station are from uncertain stratigraphic contexts (Wenban-Smith et al., 2005).

4.3.2 Interpretation

The lower gravel of the Bembridge Raised Beach represents one of the thickest and laterally most extensive high-energy raised beach deposits in southern England (Preece et al., 1990). Its position in the landscape and internal structure suggests it might represent a fossil spit or cuspate foreland. The overlying interbedded sands and silty clays, and the saltmarsh organic silty clays suggest the presence of lower energy depositional environments adjacent to the raised beach. Preece et al. (1990) suggest all three units of the Bembridge Raised Beach were deposited during the Ipswichian and during the same period of high sea level. This is backed up by the OSL ages of Wenban-Smith et al. (2005).

One distinctive feature is the steep incline of the upper surface of the beach gravels, which falls in altitude from 18 m O.D. near Howgate Cliff to 5 m O.D. near the Bembridge Foreland pollen site, a gradient of 11.8 m/km. Preece et al. (1990) propose four possible explanations for this; post-depositional modification of the upper surface by solifluction; differential tectonic uplift; a fall in sea level; and local topographic differences at a time of stable sea level. They note that present-day Chesil Beach reaches 14 m O.D. near Chesilton and Hurst Castle Spit has crest elevations of 4.9 m proving that in high energy environments it is possible for shingle to accumulate many metres above the contemporary sea level. They favoured this latter explanation coupled perhaps to a regression in sea level during the later stages of the interglacial.

This temperate high sea level event was then followed by a period of solifluction under cold climatic conditions. OSL dates from the unit directly overlying the Bembridge Raised Beach suggest it probably began during MIS 5d and the succeeding solifluction unit was deposited during MIS 5b. A substantial further and as yet undated body of solifluction gravels are capped by a Late Devensian brickearth dated to 17-18 ka B.P.

The bedding structures and lithological composition of the Bembridge Raised Beach indicate eastward transport of material. *Rhaxella* chert from the Late Jurassic Portland Chert Member and low-grade metamorphics from South Devon perhaps indicate the continued existence of the Wight-Purbeck Ridge during MIS 5e. This is because if the Ridge had been breached before the Ipswichian then this material would have been incorporated into shingle structures, such as a proto-Hurst Castle Spit, in the western Solent and not the Bembridge Raised Beach.

There is also a question about the source of wave energy needed to construct the Beach. Similar modern structures, such as Chesil Beach, Hurst Castle Spit and Dungeness, occur in exposed high-energy situations, but the Bembridge Foreland coast faces south east and today is principally a low-energy environment. It would need a different coastal configuration and bathymmetry for Atlantic waves to refract and have sufficient energy to construct a prograding shingle structure at Bembridge. Preece et al. (1990) suggest significant shallowing inshore off Bembridge would be needed to produce refraction and this could have been associated with sand bars or shoals at the mouth of the proto-Solent estuary. As an alternative proposal they suggest prevailing wind directions may have been markedly different during MIS 5e.

In contrast, the Lane End sequence is of fluvial or freshwater origin with no marine influence discernible. Insects, plant macrofossils and pollen indicate that the sedge-peat is an autochthonous freshwater swamp/marsh deposit. The basal silty gravel was probably deposited in a muddy, slow-flowing stream which gave way to standing water as sedge peat accumulated perhaps in an abandoned channel or cut-off. An increase in flow is suggested as first sands and then gravels were deposited over the peat. The whole sequence at Lane End can be explained as a product of local environmental changes within a small floodplain under temperate conditions. The age of the sequence remains indeterminate because its fossil content is temporally undiagnostic and its stratigraphic relationship to the Bembridge Raised Beach remains to be clarified.

4.4 Conclusions

Two sites at Bembridge provide critical evidence for Quaternary sea- level history in southern Britain. At Bembridge School, the high-level (c.38-40 m O.D.) richly fossiliferous Steyne Wood Clay was deposited in a marine-estuarine environment during a sea level highstand, probably relating to a pre-Anglian temperate episode. At lower elevations (c.5-18 m O.D.) on Bembridge Foreland is one of the finest shingle raised beaches in southern England, OSL-dated to Ipswichian (MIS 5e) age representing a spit or cuspate foreland. Above are OSL-dated Devensian solifluction deposits of MIS 5d-b age, which are in turn succeeded by a Late Devensian loessic unit. Between them, these two sites provide information for investigating both regional tectonic uplift and palaeogeography (e.g. of the Wight-Purbeck Ridge) of southern England during the mid and late Quaternary.

5. GCR Site 2016 - Earnley (SZ 827 947) AH, RMB

5.1 Introduction

Earnley is a key Quaternary site because of its sequence of channel-fill deposits which outcrop on the foreshore at Bracklesham Bay, Sussex. It is one of a series of channel fills along this stretch of coast (Fig. 17a, c), of which three are designated as GCR sites: Earnley (GCR site 2016), Selsey East Beach (GCR site 1201, Pleistocene Vertebrate block), Selsey West Beach and East Beach (GCR site 2021, Quaternary of Southern England block). The sediments and the microfossils they contain indicate deposition in shallow marine to intertidal environments under temperate conditions. Pollen analysis indicates the presence of a late temperate mixed coniferous and deciduous forest that has been interpreted as older than the Ipswichian and perhaps of late Hoxnian or late Cromerian age (West et al., 1984). The stratigraphy, diatom and foraminiferal analyses indicate a fining upwards sequence, with higher energy tidal channel deposition at the base and intertidal mud flat deposition towards the top, perhaps indicating a period of falling relative sea level. As one of the few sites in Britain providing evidence for mid-Quaternary sea levels, Earnley is a locality of the highest importance for Quaternary studies. West et al., (1984) provide the main source of stratigraphic and biostratigraphic information, with amino acid dating being reported by Preece et al., (1990). Further considerations of the age of the site are given in Bates et al., (1997) and Bates et al., (2000), the latter suggesting deposition during one of MIS 11, 13 or 15.

5.2 Description

During investigation of the Eocene sediments at Bracklesham Bay (Curry et al., 1977) fish otoliths were recovered from post-Eocene deposits and subsequently identified as Quaternary. The sediments occupy a shallow channel on the foreshore that is cut into Bracklesham Beds and covered by a veneer of modern beach sand and gravel. The modern deposits are variable in amount and location, which means the channel-fill sediments may be exposed from time to time at low spring tides. West et al. (1984) recorded exposures in 1979 and proved the channel to be between 200-250 m wide (Fig. 17b). Four boreholes, made with a gouge auger, together with an excavation, showed its greatest depth to be 275 cm. The level surface of the channel filling is near 0.65 m O.D. (West et al., 1984).

The sedimentary fill of the channel largely comprises laminated grey silty clays of intertidal origin (Figs 18 and 19). However, towards the base there are coarser sandy and pebbly horizons containing *Ostrea* shells and also sandy layers containing organic-rich detritus. West et al. (1984) noted the presence of clay conglomerates and horizons showing small polygonal cracks that may suggest periods of subaerial exposure and desiccation. They also stated that the sediment sequence suggested shallow marine conditions at the base changing to intertidal conditions higher in the sequence. The uppermost sediments are weathered brown silty clays that have been subject to penetration by rootlets (West et al., 1984).

Two large granite erratics were noted resting on the Eocene Bracklesham Group, one to the east, the other to the west of the channel. A number of smaller erratics were also found near the western edge of the channel. However, no erratics were seen resting on the channel fill itself. West et al. (1984) suggested this might be consistent with the erratics having been being emplaced before the channel was filled with sediment.

Pollen analyses were undertaken on the upper and lower parts of the channel fill at sites 2, 3 and 5, and from the more organic horizon near the top of site 4. The resulting pollen assemblages showed a high degree of similarity, so a single more detailed investigation was made at site 3 in the deepest part of the channel (Fig. 20).

There are no major changes in the pollen diagram and therefore no subdivision into local pollen assemblage zones was attempted (West et al., 1984). Overall tree pollen (63-87 %) dominates the spectra with *Pinus, Abies, Alnus, Quercus, Carpinus, Corylus* and *Taxus* well-represented, and with lower but consistent frequencies of *Picea*, *Betula*, *Ulmus*, *Tilia cordata* and the unknown tricolpate-reticulate grain 'type x' (Phillips, 1976). Pollen of *Salix*, *Fraxinus*, *Acer*, *Ilex*, *Buxus* and *Hedera* is less frequent. Ericales and *Empetrum* pollen, indicating heathland, are also recorded but in very low frequencies. Poaceae, Chenopodiaceae, *Artemisia* and Asteraceae, show consistent frequencies throughout with Cyperaceae, *Armeria*, *Plantago maritima*, *Circaea*, Leguminosae and *Ranunculus* occurring sporadically. Of the spores, Filicales is consistently present, with *Polypodium* and *Pteridium* spores infrequent. Tests of Foraminifera were also found on the pollen slides in consistent frequencies.

The assemblage probably reflects a regional mixed coniferous and deciduous forest with a local component derived from salt-marsh communities as shown by Chenopodiaceae, *Armeria, Plantago maritima* and probably Poaceae, *Artemisia* and Asteraceae.

West et al., (1984) considered the mixed coniferous-deciduous forest assemblage with *Abies* and *Carpinus* to be characteristic of the later part of a temperate stage and similar to pollen assemblages of Cromerian III and Hoxnian III age in the Midlands and East Anglia (West, 1980). They did not favour either of these tentative correlations but did suggest the channel filling is older than Ipswichian because of the high frequencies of *Abies* which had not hitherto been recorded in British Ipswichian deposits.

Diatom analysis was also undertaken at site 3. The majority of the fossil diatom species identified are still common and characteristic today of the southern North Sea and English Channel areas with the exception of *Glyphodesmis williamsonii* which has a more northerly distribution (Hendey, 1964).

The diatom assemblage is relatively poor in species with most levels containing less than 20 taxa. Towards the base of the profile numbers of species are particularly low, only rising significantly above 150 cm. Many valves were broken or degraded with the more robust form *Melosiru sulcata* being least affected. *Podosira stelliger*, *Meolosira sulcata* and *Melosira westii* are dominant throughout, with *Melosira sulcata* rising of 70% of total valves above 85 cm. *Grammatophora oceanica* var. *macilenta* forms a consistent but low component in the assemblage, though at 180 cm it reaches a peak of 85% of total valves. *Coscinodiscus excentricus*, *Actinocyclus ehrenbergii*, *Cerataulus smithii*, *Auliscus sculptus* and *Raphoneis amphiceros* occur consistently in low frequencies.

The assemblage is dominated by marine polyhalobous diatoms which make up >86% of total valves throughout the sampled sequence. Most species are benthic forms though *Grammatophora* spp., *Synedra tabulata, Coscinodiscus nitidus* and *Cocconeis scutellum* are epipelic, episammic or epiphytic in life form. A few more taxa tolerant of more brackish conditions such as *Diploneis didyma*, *Campylodiscus echeneis, Scoliopleura* spp. and *Nitzschia* spp. occur in the upper levels. though they were often in a broken and abraded state.

Although the diatoms suggest an intertidal environment there are a number of factors which suggest a change in the depositional environment through time. Between 105-225 cm a higher energy intertidal or subtidal environment is indicated by the high proportion of broken and degraded valves, the selective preservation of the more robust species and an increase in marine planktonic forms. There is supporting evidence of a higher energy environment from a subjective examination of the particle size of the preparation residues. Below 180 cm a coarse to medium sand sized fraction is dominant accompanied by fragments of *Ostrea edulis* and angular fine flint gravel. Above this level, however, there is a fining upward sequence to silt and fine sand that is mirrored by a decrease in the number of broken valves and an increase in species numbers. West et al., (1984) suggested these variations are consistent with a change from a lower to upper intertidal environment.

Two samples were analysed for Foraminifera, one from the uppermost clays of the channel filling at site 4 and the second from the basal shelly facies at the channel margin at site 1. The uppermost clays contained intertidal mudflat species such as *Ammonia beccarii* var. (69 %) with the presence of

Elphidium williamsoni (10%) and absence of arenaceous, Textulariine, species suggesting a position towards the upper part of the tidal range but not within a saltmarsh. The basal shelly deposits contained species similar to the upper clays but with an increased proportion of *Ammonia beccarii* (18%) suggesting closer proximity to a tidal channel. It also contained numerous remains of bivalves, gastropods, barnacles and ostracods, and an echinoid spine. The dominant bivalve is *Ostrea edulis***,** which is accompanied by *Nucula* sp. and *Sphenia binghami* in some abundance, *Mysella bidentata, Chlamys varia,* and fragments of *Abra* cf. *alba***,** and occasional ***'Cardium'*** sp. These species have varying environmental tolerances but a subtidal environment just below low tide mark is most likely (West et al., 1984). The gastropods include *Gibbula* sp., *Odostomia unidentata, Turbonilla elegantissima, Bittium reticulatum,* and *Akera bullata* again indicating a shallow subtidal source. Barnacle remains, probably of *Balanus crenatus,* suggest a position on the lower shore below the range of the common intertidal barnacle species (West et al., 1984).

The foraminifers, bivalves, gastropods and barnacles suggest a tidal channel environment to which shell material was introduced from the subtidal zone and with a contribution from intertidal mud flats and through erosion and reworking of local Eocene and Cretaceous deposits.

The upper clays probably represent an intertidal mud flat at about mean high water neaps and the basal shelly deposits were probably deposited close to mean low water springs. Using modern tidal parameters, and assuming a similar tidal range at the time of accumulation of the channel fill, sea level was within + 2.5 m of present-day levels. Deposition probably took place during a period of falling sea level when values may have declined from as much as + 2.35 m to - 0.75 m, relative to those of the present day (West et al., 1984)

The seven samples were collected for their ostracod content were all dominated by *Cyprideis torosa* which ranged between 17-40%. Both male and female adults as well juveniles were present suggesting stable brackish water conditions. Phytal species including *Hirschmannia viridis***,** *Hemicythere villosa, Leptocythere* spp., *Heterocythereis albomaculata* and *Loxoconcha rhomboidea* were also present. West et al., (1984) suggested that overall the ostracod assemblages were compatible with an intertidal environment with a muddy substrate near to a deeper water channel and with patches of anchored weed.

82% of the Earnley ostracod fauna can be found within the living ostracod fauna of the Channel coast. Comparisons with the the fauna from the Cornish Late Pliocene St. Erth Formation (Maybury and Whatley, 1980) and the channel fill at Selsey (Whatley and Kaye, 1970), where 25% and 99% of species found are still in the contemporary fauna support the suggestion of a mid-Quaternary age for the deposits at Earnley (West et al., 1984).

Calcareous nannofossils were examined from three samples from 'the borehole at Earnley' – presumably borehole 3 (Preece et al., 1990). Four coccolith species were recovered but only *Reticulofenestra* spp. and *Gephyrocapsa oceanica* were common with *Dictyococcites productus* and *Coccolithus pelagicus* also being recorded. Some dissolution was observed on many coccoliths while strong overgrowth (secondary inorganic growth of calcite) occurred on *C. pelagicus*. Both these features are probably post-depositional and of diagenetic origin. Absence of coccoliths of *Pseudoemiliana lacunosa* with a last occurrence datum of about 475k yr B.P. and *Emiliania huxleyi* with a first occurrence datum of about 275k yr B.P may suggest a deposition within this time interval (Preece et al., 1990).

5.3 Interpretation

Evidence from the sediments, fauna and flora demonstrate that the Earnley site was an area of coastal marine deposition in the later part of a Quaternary temperate stage. The stratigraphy, diatom, foraminifers, molluscs, ostracods and coccoliths suggest an intertidal environment. Sediment accumulation appears initially to have been under relatively high energy conditions, possibly close to a tidal channel. However, the absence of any freshwater influence in the sediments or contained fossils suggests the channel was probably formed by tidal scour. The sedimentary sequence fines upwards and together with the changes in the flora and fauna suggest a change to an environment higher in the intertidal zone. This may indicate a regressive sequence as the channel was filled in under conditions of high sediment supply, or perhaps from changes in coastal configuration.

The key question that remains unresolved from the Earnley sequence is that of the age of the channel fill at Earnley. West et al. (1984) suggested the pollen evidence indicates a late Cromerian or late Hoxnian date. Whilst researchers might now be more cautious about attributing an age based on pollen analysis alone, the pollen evidence does suggest the Earnley deposits are different in age to the channel filling at Selsey, 4.5 km to the south-east that West and Sparks (1960) attributed to the Ipswichian (MIS 5e). Little more can be said on the basis of the pollen because of the fragmentary nature of this sequence compared to lake sequences (cf. Thomas, 2001). The ostracod evidence only constrains these deposits to a period post-dating the Pliocene and pre-dating the Ipswichian, whereas the calcareous nannofossils (based on absence of evidence) suggest deposition between 475 ka B.P. and 275 ka B.P., i.e. correlating with either MIS 11 or MIS 9 (Lisiecki and Raymo, 2005).

The only geochronological evidence is from a single valve of the Baltic tellin (*Macoma balthica*), collected by R. Fowler from an unknown location in the channel, which returned a L-isoleucine: D-alloisoleucine ratio of 0.33 (AAL-5499; Preece et al., 1990). This is very similar to a mean value of 0.320 ± 0.04 (AAL-4612a-d; Preece et al., 1990) from nine fragments of *Macoma balthica* from the Steyne Wood Clay, Bembridge and a single determination of 0.386 from the Slindon Sand at Waterbeach (Bowen and Sykes, 1988). However, as noted in relation to the Steyne Wood Clay, recent work by Penkman et al. (2008) has shown that analyses undertaken on the full protein fraction of shells are likely to contain contamination, with only the intracrystalline fraction reliable, so these results should be treated with caution. In addition, there is currently only an AAR framework for terrestrial sequences in Britain (Penkman et al., 2011), so nothing suitable to compare these marine samples to.

It is also unlikely that Waterbeach and Steyne Wood Clay marine interglacial sites are contemporaneous with Earnley because of the large (c. 40 m) altitudinal difference between them. Even if it were suggested that the Earnley sediments represent a regressive phase related to the high sea level event at Steyne Wood and Waterbeach, the presence of temperate elements within the faunal and floral assemblage at Earnley are not considered compatible with the magnitude of climatic change needed to achieve a relative sea level fall of 40 m (Bates et al., 1997). A second factor mitigating against this correlation is that the pollen flora at the lower Earnley site contains a more thermophilous mixed coniferous-deciduous assemblage than the higher Steyne Wood site which is dominated by conifers (Holyoak and Preece, 1983). The age of these deposits is currently unknown.

5.4 Conclusions

Earnley is a key Quaternary site for a sequence of marine deposits of Middle Pleistocene interglacial age. The stratigraphy together with pollen, diatoms, coccoliths, ostracods and foraminifera from the foreshore channel-fill at Earnley confirm deposition initially in a higher energy tidal channel, then an intertidal mudflat. The deposits temporally represent only a small fraction of that temperate stage. Pollen analysis indicates the presence nearby of a mixed coniferous-deciduous forest perhaps representing a late-temperate phase of an interglacial older than the Ipswichian. Biostratigraphy and early AAR analysis are inconclusive at to age. As one of very few sites in Britain providing a record of Middle Pleistocene sea levels, Earnley is very important, but further advances are needed to clarify the age of the deposit before its full potential to elucidate mid-Quaternary vegetational change, sea level change and land movements is met.

6. GCR Pleistocene Vertebrate Site 1201 Selsey East Beach (SZ 860 925)
GCR Quaternary of Southern England Site 2021 Selsey West and East Beaches (SZ 843 931 and SZ 860 925) AH, RMB, DCS

6.1 Introduction

Between West Wittering and Selsey on the seaward edge of the West Sussex Coastal Plain are a series of interglacial fossiliferous deposits preserved within channels lying at or below current sea level (Fig. 17a, c). At Selsey there are two sequences of interglacial clays and silts preserved within channels on the foreshore containing rich assemblages of pollen, plant macrofossils, ostracods, molluscs and vertebrates together with a small number of flint artefacts. Well rounded flint gravel up to 3.7 m thick, interpreted as marine, overlies the finer grained sediments and attains 7 m O.D. west of Selsey Bill. Above the gravel is a silty brickearth unit about 1m thick.

It is important to note that there are actually two sequences at Selsey – one each side of Selsey Bill (Fig. 21). These have separate and overlapping GCR designations and are described separately below. Selsey West Beach is designated as site 1201 in the Pleistocene Vertebrate block. Both Selsey West Beach and Selsey East Beach are included in site 2021 of the Quaternary of Southern England block.

Remains of Quaternary mammals and molluscs in the Selsey area have been known since the middle of the 19th century. The first published reports were of the discovery in 1841, by a coastguard, of a jaw of a straight-tusked elephant (originally reported as mammoth) on the west side of Selsey Bill (Dixon, 1850). The profusion of remains of mammoth was also commented on by Godwin-Austen, who remarked that the mammoth remains "*are tolerably abundant, and there is this point of geological interest attaching to these specimens, that they do not here occur as single and detached teeth, or portions of tusks, as happens in the overlying gravel beds; but so many parts of the animal have been found together, as to leave no doubt but that entire skeletons lie embedded in this deposit*" (Godwin-Austen 1857, p. 50). In March 1909, the skeleton and teeth of a young 'mammoth' were exposed in a detrital mud at very low tide to the east of the Bill, following severe easterly gales (Heron-Allen 1911) and further finds have since been periodically eroded out of the shoreline deposits up until the present day.

The sequences at Selsey have an extensive literature. They were first described by Dixon (1850), Godwin-Austen (1857), Bell (1871; 1892), Reid (1892; 1897; 1903), Heron-Allen, (1911), Palmer and Cooke, (1924) and White (1913; 1924). Fossil content of the sequences has been reported by West and Sparks (1960), Whatley and Kaye (1971), Parfitt (1998) and Bates et al. (2009). Age measurements have been supplied by Bowen et al., (1989), Parks and Rendell, (1992) and Bates et al. (1997) and comments on the sequences ages and correlation have been provided by West and Sparks (1960), Berry and Shepherd-Thorn (1982), West et al., (1984), Stinton (1985), Keen (1995), Stuart (1995), Sutcliffe, (1995), Bone (1996), Bates et al. (1997), Bates et al. (2000, 2009), Bates (2001), Schreve (2001) and Aldiss (2002).

Initially an Ipswichian (MIS 5e) age was assumed for the Lifeboat Station / East Beach deposits (West and Sparks, 1960). However, Bates et al. (1997) suggested that these channel deposits are of mid- to late MIS 7 age. This attribution is in agreement with vertebrate biostratigraphy (Parfitt, 1998), molluscan biostratigraphy (Keen, 1995) and archaeology (Wymer, 1999). The overlying marine gravel is now considered to be of MIS 5e and the brickearth Late Devensian in age (Parks and Rendell, 1992; Bates et al., 1997).

Another contentious point is that West and Sparks (1960) suggested that the sediments present in the channel near the lifeboat station at Selsey were deposited initially in a freshwater environment which later turned estuarine during a transgressive episode. However, ostracods from the same locality suggest that the basal part of the channel contains marine sediments, the upper estuarine (Whatley and Kaye, 1971) representing a regressive episode. Other workers have also observed marine deposits at the base of the channel fills in the area (Godwin-Austin, 1857; Reid, 1892; Heron-Allen, 1911; Palmer and Cooke, 1923).

A final controversy is that in 1892, Reid described hundreds of erratic boulders occurring in 'pits' cut into the underlying Eocene strata which were uncovered following coastal erosion by a storm in the autumn of 1891. These were also reported by Godwin-Austin 1857; Codrington, 1870; Lyell, 1871 and Prestwich, 1892). Kellaway et al. (1975) interpreted these as having been deposited directly by a glacier advancing from the south-west during the Wolstonian, terminating at the 'Selsey Moraine' that blocked drainage, thus forming Glacial Lake Solent. Reid (1892) however considered them to have been emplaced by floating ice, which is the modern consensus (Bates et al., 2000).

6.2 Selsey East Beach (Lifeboat Station site – east of Selsey Bill)

6.2.1 Description

6.2.1.1 Sedimentary sequence

The channel on the eastern side of Selsey Bill near the Lifeboat Station on the foreshore (SZ 860 925, (Fig. 21b) was studied by R.G. West, B.W. Sparks and A.T. Sutcliffe between 1956 and 1961 (West and Sparks, 1960; Parfitt, 1998). The channel fill has yielded richly fossiliferous assemblages of pollen, plant macrofossils, ostracods, molluscs, vertebrates and flint artefacts (West and Sparks, 1960; Parfitt, 1998; Whatley and Kaye (1971). The deposits fill a channel trending north-west to south-east cut into Bracklesham Beds and when uncovered are only accessible for a short period at low tide.

Reid (1892) described a basal greenish clay which contained a fauna including the southern marine molluscs *Chiton siculus* (now *Chiton olivaceous*) and *Rissoa cimex* (now *Alvania aarseni*), the 'Selsey mud-deposit'. West and Sparks (1960) were unable to discern the relationship of this temperate marine unit to the four units they described.

West and Sparks (1960) described four sedimentary units (Fig. 22). From top to bottom they comprise:

Bed 4. A brown-grey silty clay with *Scrobicularia* and *Hydrobia* sharply separated from Bed 3.

Bed 3. A grey silty clay with abundant *Hydrobia;* a high content of organic mud at the base where there is a gradual transition from Bed 2.

Bed 2. A dark brown coarse detritus mud with fragments of wood, some of them large. Shelly except at the base. Conformable through a rapid transition with Bed 1 in the centre of the channel, but clearly unconformable with Bed 1 at the edges of the channel.

Bed 1. A variable green or brown silt or clay, with varying proportions of organic mud, with bands of pebbles and frequent black flints. On the west side of the channel this bed contains erratic boulders, including hard sandstone, liver-coloured quartzite, whitish weathered granite and pink quartz porphyry. The colour variation from green to brown may be due to weathering

To seaward, the channel deposits dip below sea level while to landward they disappear beneath the modern beach. A small cliff about 1 m high is exposed above the modern shingle where brickearth can be seen to overlie the rounded pebbles of a raised beach. West and Sparks (1960) concluded that although the actual contact between the channel deposits and those found in the cliff was not observed, it was probable that raised beach shingle postdated the channel deposits, which accords with the earlier findings of Palmer and Cooke (1923). West and Sparks (1960) suggested that both the brickearth and the cryoturbation structures within the gravel are indicative of cold climatic conditions subsequent to the formation of the raised beach.

Whatley and Kaye (1971) sampled from what they described as 'the same location' as West and Sparks (1960). They measured a section in March 1965 which comprised:

0 - 3ft (91cm) Bed 4: Stratified shingle and sand.

3ft - 6ft (183cm)	Bed 3: Dark blue/black clay with numerous wood fragments and plant debris. *Scrobicularia* and *Hydrobia*.
6ft – 8ft (244cm)	Bed 2: Green/grey silty clay. *Ostrea*, *Chlamys*.
8ft (244cm)	Bed 1: Eroded platform of Eocene Bracklesham Beds

Whatley and Kaye (1971) conclude that Bed 2 is the same as that first described by Dixon (1850) as the 'Selsey mud-deposit' and not observed by West and Sparks (1960).

6.2.1.2 Palaeobotany

A series of pollen samples were taken by West and Sparks (1960) from excavations at site A through beds 1 to 3 and at site D through beds 3 and 4 (see Figs 22 and 23). Plant macrofossil samples were also taken. West and Sparks (1960) described five pollen assemblage zones (Fig. 23).

The lowermost zone b is characterised by high levels of non-arboreal pollen, *Betula* and *Pinus* being the only trees represented in any numbers. This probably indicates an open, relatively treeless regional vegetation. Apart from the freshwater aquatics *Sparganium*-type and *Typha latifolia*, Poaceae and Cyperaceae are the most frequent herbs. The macroscopic remains from zone b include terrestrial species such as *Atriplex*, *Chenopodium*, *Polygonum*, and *Potentilla* (of which *Atriplex* and *Chenopodium* also suggest saline conditions) with seven aquatic taxa and eleven suggesting shallow water or marsh vegetation (West and Sparks, 1960). West and Sparks (1960) suggested this was representative of a marshy environment bordering either a small lake or a river with slowly flowing fresh water in a regional setting with low open vegetation with few trees and shrubs. Saline elements reinforce the finding of marine ostracods and shells in the basal unit by Whatley and Kaye (1971).

Zone c has similar macroscopic plant remains, but pollen show a decrease in Poaceae and Cyperaceae and a large increase in Filicales. West and Sparks (1960) thought this might reflect simply a local change given the lack of change seen in the macroscopic plant remains.

The base of pollen zone d coincides with the transition from bed 1 to bed 2 and a rapid increase in organic content, with many wood fragments. *Pinus* pollen expands, *Betula* pollen declines and the pollen of the thermophilous tree *Quercus* appears in significant quantity for the first time. The aquatic species identified both in the pollen record and macroscopically reduce (e.g. *Sparganium*-type and *Typha latifolia*). West and Sparks (1960) suggested that the change in the sediment, the reduction of the aquatic environment and the spread of carr communities, as indicated by a rise in *Salix* and Cyperaceae pollen, could indicate a fall in water level

There is continued increase in the frequency of tree pollen in zone e. *Quercus* becomes the dominant tree, represented by over 50 % of the total tree pollen at the end of the zone, while *Betula* and *Pinus* both decline and *Fraxinus* and *Hedera* appear for the first time. Herb pollen exists but in low frequencies suggesting the environment comprised regional oak forest with occasional birch. The macroscopic remains include a high proportion of shallow water or marsh species. Climatic amelioration is indicated by the spread of *Quercus* and the presence of thermophilous plants such as *Thelycrania sanguinea* and *Hedera.*

Zone f is characterized by high frequencies of the pollen of *Quercus* (up to 81%) and the rise of *Corylus* (up to 78% AP). The regional vegetation at this time must have been dominated by *Quercus,* with *Corylus* as a prominent shrub and some *Pinus* (frequencies between 10 and 30% AP throughout the zone). Herbaceous pollen continues at low frequencies in zone f, mainly Poaceae and Chenopodiaceae (West and Sparks, 1960). In the lower part of zone f there is again a rich aquatic and marsh flora, containing *Hydrocharis morsus-ranae*, *Lemna* cf. *minor* and *Stratiotes aloides.* These three species rarely or never fruit in Britain today, so their presence indicates greater summer warmth than that of the present day.

West and Sparks (1960) placed the change from fresh water to estuarine environments at 27 cm at site A. There is not much change in the pollen diagram at this level though the macrofossil data do show a decrease in many freshwater aquatic and marsh species, for example, *Ceratophyllum demersum, Najas minor, Oenanthe aquatica,* and *Sparganium erectum.* Others increase their frequency rapidly as the change to estuarine conditions takes place, for example, *Potamogeton* c.f. *friesii, P. pectinatus, Ruppia maritima* and *Zanichellia palustris. Najas marina* occurs in both the freshwater and estuarine sediments, though it is most abundant just after the water becomes brackish (West and Sparks, 1960).

6.2.1.3 Molluscan analysis

Six samples were taken from the face of Pit A and five from site D for mollusc analysis. The most striking change shown by the fauna in Pit A is the large increase of brackish water species, notably *Hydrobia ventrosa*, in the sample between 20-30cm in Pit A, which coincides with the change in stratigraphy from Bed 2 below to Bed 3 above. *H. ventrosa* inhabits water of low to moderate salinities in quiet estuaries, ponds behind shingle ridges and coastal lagoons. *H. ulvae* is present in smaller numbers. This species prefers more saline, brackish to marine conditions and is commonly found in the upper half of the intertidal zone within estuaries, intertidal mudflats and saltmarshes where it can tolerate subaerial exposure at low tide. The frequency of these two species suggests a low salinity, more sheltered, environment with low or no tidal activity (Kerney, 1999).

Below 30 cm at Site A there are much smaller frequencies of *H. ventrose.* Instead *Gyraulus* (*Planorbis*) *laevis* and *Gyraulus* (*Planorbis*) *crista* are the dominant elements of the fauna. *G. laevis* is today found in clean, quiet water, usually among weeds and it can tolerate slightly brackish water (Kerney, 1999). There is some evidence for slow flowing water since *Bithynia tentaculata* is also present which is often found in large bodies of slow-moving well-oxygenated water, particularly favouring muddy-bottomed situations where there are dense growths of aquatic plants (Kerney, 1999). This is supported by the presence of *Valvata piscinalis* and *V. cristata* which have similar ecological requirements.

The succession in Site D represents a continuation of the brackish conditions found in Bed 3 at Site A. Conditions may have become more saline towards the top, as shown by the rise in *Hydrobia ulvae* frequencies and the appearance of *Scrobicularia.* There is a sharp colour change between Bed 3 and Bed 4 but there is no accompanying ecological change which seems to confirm that the change is due to weathering (West and Sparks, 1960).

6.2.1.4 Ostracod analysis

Whatley and Kaye (1971) took 5 samples for ostracod analysis, two from Bed 2 and three from Bed 3. In both units the proportions of male, female and juvenile ostracods suggested *in situ* life assemblages, at least for the dominant marine species. Bed 2 showed high species diversity, dominated by marine taxa, the largest contribution being from *Cyprideis torosa*, *Loxoconcha rhomboidea* and *Hemicythere villosa*. Bed 3, by contrast, showed lower species diversity but a higher number of individuals per species. This unit was considered to represent a brackish environment with *Cyprideis torosa* dominant in all but the uppermost sample and *Loxoconcha elliptica* and *Leptocythere lacertosa* also present in high frequencies.

Whatley and Kaye (1971) concluded that Bed 2 represented a marine environment with salinity in the range 25-30‰, a shallow water, low energy environment with a muddy bottom and some degree of weed growth. Bed 3 was formed in an estuarine environment with salinities in the range 5-20‰; the presence of *Hydrobia* and the large amount of plant material suggesting an intertidal saltmarsh.

6.2.1.5 Vertebrate analysis

Excavations by the Natural History Museum in 1956 and 1961 at Selsey East Beach yielded a collection of mammals including the almost complete skeleton of *Stephanorhinus hemitoechus* (narrow-nosed rhinoceros) and a partial skeleton of *Palaeoloxodon antiquus* (straight-tusked elephant). In 1988 the channel was exposed again and samples were taken for micro-vertebrate analysis from Bed 1 (Parfitt, 1998).

Table 5 shows species lists for the two Selsey, West Wittering and East Wittering channels from various authors and sources. Parfitt (1998) suggested that the Selsey Lifeboat Station channel deposits contain two distinct assemblages. Bed 1 contains six mammal species comprising a characteristic open-ground (but not cold climate) fauna, including *Mammuthus trogontherii* (previously listed as *Mammuthus primigenius* 'Ilford-type') and *Stephanorhinus hemitoechus*. In contrast, Bed 2 contains a temperate woodland mammal fauna with a mixture of grassland, woodland and riparian species including *Palaeoloxodon antiquus* cf. *Cervus elaphus,* (red deer) and *Capreolus capreolus* (roe deer). This change reflects a transition in environment from an open, relatively treeless landscape to temperate broad-leaved forest and seems to be in accord with the findings of West and Sparks (1960), based on the palaeobotanical and molluscan evidence. No arctic or subarctic indicators were recovered (West and Sparks, 1960) and the combination of thermophilous aquatic and marsh flora and treeless parkland elements suggests an environment that may have no modern analogue. The presence of *Emys orbicularis,* (European pond terrapin) suggests temperatures warmer than today existed at the peak of this interglacial (Parfitt, 1998) A find of *Hippopotamus* was reported by Sutcliffe in West and Sparks (1960). This attribution apparently was an erroneous determination based on a single imperfect specimen (Sutcliffe, 1995) and should be deleted from the faunal list. Similarly, no evidence for *D. dama* (also listed by Sutcliffe, in West and Sparks 1960) could be found during a subsequent review of the material (Schreve, 1997).

6.2.1.6 Geochronology

Four AAR ratios are available from Bed 1 at Selsey Lifeboat Station (Bowen et al., 1989; Bates et al., 1997) on specimens of *Lymnaea* sp. (0.164±0.016), *Corbicula fluminalis* (0.165±0.019), *Bithynia tentaculata* (0.139±0.007) and *Valvata piscinalis* (0.154±0.019). These were interpreted as consistent with a MIS 7 age (Bates et al., 1997) though the figure for *Bithynia tentaculata* is rather low. However, AAR on shell largely comprised of aragonite is less reliable, especially if not pretreated with a bleach using the protocol of Penkman et al. (2008). Therefore, these age estimates are of limited usefulness. AAR on shell from 'R.G. West monolith sample' tied into the more reliable calcitic framework on opercula of the freshwater species *Bithynia tentaculata* suggested correlation with MIS 7 (Penkman et al., 2013).

6.2.2 Interpretation

Reid (1892) and Bell (1871; 1892) argued that the channel deposits were of marine origin. Indeed Reid (1892, p. 356) stated that this deposit was marine and that the fossils clearly showed "the influence of warmer seas than those which now wash our shores". In contrast, West and Sparks (1960) suggest that this deposit is of freshwater origin and that it accumulated under conditions colder than those of the present day. West and Sparks (1960) concluded that freshwater Beds 1 and 2 were overlain conformably by the estuarine deposits of Beds 3 and 4 by marine transgression. The altitude of the transition at site A was recorded at -1.76 m O.D. They also considered the channel fill and overlying raised beach shingle to represent a single cycle of marine transgression which reached 7 m O.D. west of Selsey Bill. This is in contrast to the findings of Whatley and Kaye (1971) who suggested that ostracods from the same sediments implied infilling of the channel under regressive conditions.

Bates (2001) suggests that this apparent contradiction may be resolved by a consideration of the character of these channels and how they were infilled. These channels are characteristically less than 3 m deep, much smaller in scale than Holocene channels currently existing to the east and west of Selsey Bill. For example in the Arun Valley, Holocene fills may exceed 20 m in thickness. The smaller

Pleistocene channels would have been filled under different conditions. They are likely only to contain shorter sequences within the interglacial. The lower gradient of these channels and the shifting nature of sedimentation patterns in the coastal zone may have led to local transgressive/regressive events superimposed on the longer-term trends. Bates (2001) therefore suggests that the significance of the apparent trends in marine transgression/regression within the shallow channels should be treated with caution.

Initially the channel fill and raised beach were both assigned to the Ipswichian (MIS 5e) on the basis of similarities in the pollen stratigraphy compared to other sites then thought to be Ipswichian (West and Sparks, 1960) and the occurrence of *Hippopotamus*, now known to be erroneous.

The raised beach deposits in the overlying low cliff are OSL dated to MIS 5e at Selsey West Beach and have been attributed to the Pagham Formation by Bates et al. (1997, 2010), but the underlying channel deposits may not be the same age. Indeed, there is evidence that the Selsey East Beach channel deposits date from an earlier interglacial.

The vertebrate assemblages from Beds 1 and 2 contain taxa that are typical of the Sandy Lane Mammal Assemblage-Zone, which has been correlated with the later part of the MIS 7 interglacial by Schreve (2001) and Candy and Schreve (2006) and more specifically, given recent revision of the MIS 7 by Berger et al. (2016), with MIS 7c-a by Schreve (2019). The characteristic features include the combination of horse, narrow-nosed rhinoceros and steppe mammoth. The small size of the mammoth molars and their low plate count fall within the range of the 'Ilford type' mammoth, now recognised as *Mammuthus trogontherii* and considered to be a biostratigraphic indicator of MIS 7 (Schreve, 2001; Lister and Sher, 2001). The presence of *Mammuthus trogontherii*, in association with *Equus ferus* and *Homo* at Selsey argues very strongly against an Ipswichian age.

The frequency of the mollusc *Corbicula fluminalis* may be an overestimate since its count was based on all recognisable pieces of hinge (West and Sparks, 1960) but its presence is interesting since there is significant evidence that it was absent from Britain during MIS 5e (Meijer and Preece, 1995, Stuart, 1995; Sutcliffe, 1995; Keen, 2001). The channel fill of Bed 2 has also yielded a small number of flint artefacts including a hand-axe, Levallois core and some flakes (Wymer, 1999). This indicates the site is probably younger than the MIS 9/8 boundary (Bridgland, 1996) and the very presence of archaeological material may discount a MIS 5e age (White and Schreve, 2000). Both these lines of evidence and the AAR results reported above concur with the suggestion above that the channel fill is of MIS 7 age.

	2021 Selsey East Beach (Selsey Lifeboat Station) – West and Sparks (1960) stratigraphy					**1201 Selsey West Beach (Selsey West Street Channel)**					**East Wittering Channel (Parfitt, 1998)**	**West Wittering Channel (Parfitt, 1998)**
	A.J. Sutcliffe Appendix 2 in West and Sparks (1960) ($)		**Schreve (1997) - from NHM collection**	**Parfitt (1998) – published data and 1988 collection**								
	Bed 1	**Bed 2**	**Beds 1 and 2**	**Bed 1**	**Bed 2**	**Dixon (1850)**	**Fowler collection**	**Parfitt et al. collection (1988-89)**	**Bates et al. WSS 03**			
									8.2	**2.1**		
Amphibians												
Bufo bufo, common toad					+							
Bufo calamita, natterjack toad					+							
Bufo sp., a toad					+							
Rana sp., a frog					+	+?	1?					
Reptiles												
Emys orbicularis, European pond terrapin					+							+
Natrix natrix, grass snake							1					
Birds												
Aves indet.							+	+				
Mammals												
Sorex minutus, pygmy shrew				+			5(1)		1			
Sorex cf. *araneus*, common shrew			1(1)			+	19(5)	1	1			

Homo sp., hominin (artefacts)					+							
Palaeoloxodon antiquus, straight tusked elephant			33(1)		+	(+)					+	+
Mammuthus trogontherii, steppe mammoth (*)			15(2 – 1 juv, 1 adult)	+							+	
Stephanorhinus hemitoechus, narrow-nosed rhinoceros		+	141(2)	+	+							cf.
Rhinocerotidae sp.	+		5(1)									
Equus ferus, horse	+		2(1)		+						+	
cf. *Cervus elaphus*, red deer			2(1)		+	+						
Capreolus capreolus, roe deer			2(1)		+							
Megaloceros giganteus			1(1)									
Cervidae, deer		+ (2 types)						1				
~~*Hippopotamus* sp.~~Ø		~~+~~										
Bos primigenius, aurochs			35(2)									+
Castor fiber, beaver			1(1)		+							
Dicrostonyx torquatus, collared lemming				+								
Lemmus lemmus, Norway lemming				+								
Clethrionomys glareolus, bank vole			1(1)				31(4)	3				+
Arvicola terrestris ssp A, water vole							1			1		
Arvicola sp., water vole			4(2)		+	+?						
Microtus arvalis or *agrestis*, common / field vole			1(1)		+	+?	5(3)					
Microtus oeconomus, northern vole											+	

Microtus sp., vole				+	+	+?				1		
Apodemus maastrichtiensis, extinct mouse											+	
Apodemus sylvaticus, wood mouse							13(3)	2(1)				
Ochotona sp. pika								1				

Table 5. Vertebrate fauna from both Selsey sites, compared with the East and West Wittering channel fills. Data from Parfitt (1998), Bates et al. (2009) and Schreve (1997). + is presence data. Figures are numbers of identifiable specimens and in brackets the minimum number of individuals. ($) Sutcliffe only identified *Stephanorhinus hemitoechus* to species level. (*) This was previously listed as *Mammuthus primigenius* (Ilford type). Ø *Hippopotamus* was originally listed but has since been discounted during reinvestigation of museum specimens (DCS).

6.3 Selsey West Beach (West Street, Selsey)

6.3.1 Description
6.3.1.1 Sedimentary sequence

West and Sparks (1960) described a section in the low cliffs on the south-west side of Selsey Bill, opposite Thorney Coastguard Station, (SZ 843 931; Selsey West Beach, Fig. 21a) which showed:

0-30 cm	Made ground.
30-130 cm	Brickearth.
130-500 cm	Shingle with partings of sand (raised beach), disturbed by frost action at the top.

In the late 1980s, a sample was taken for thermoluminescence dating of the brickearth, at TQ846925 (no section drawing), from 0.55 m below ground surface (Parks and Rendell, 1992), suggesting a Late Devensian age, in common with many other such deposits.

This cliff was redescribed by Bates et al. (2009) who found the same sequence (Figs 24 and 25) showing extensive evidence of cryoturbation and cold climate frost-heave processes within the brickearth and the upper parts of the gravels. They note that the base of the gravels extends below the level of the modern beach and the nature and depth of the contact with the underlying bedrock remains unknown. OSL samples were taken from the raised beach deposits, at 2.6 and 3.55 m below ground surface (Bates et al., 2010).

Fine-grained channel deposits are also present below the foreshore at this more westerly site. To investigate this, Bates et al. (2009) excavated nine test pits on the foreshore (Fig. 21a) that produced evidence of a sequence of sands, gravels and organic silts resting in a channel incised into the Eocene Bracklesham Group (Figs 26 and 27). The total width of the channel appears to be 80 to 100 m wide and is aligned approximately west to east across the foreshore. It was assumed, but not observed, that the channel deposits underlie the low cliff. All the channel deposits lie below -1.5 m O.D.

Bates et al. (2009) found two different sequences of sediments in the channel. The northern part of the channel is filled with sands that occur extensively in test pits 3, 6 and 9 (Fig. 26). Here the sands are up to 2m thick and contain abundant mollusc remains. In the southern half of the channel (Fig. 26) clay-silts resting on black gravels replace the sands; these sequences were seen in test pits 4 and 7. These fine-grained sediments contain traces of organic material (including wood) in places and remains of shell debris. A single pit (8) was located intermediately between these two areas and contains a thick sequence of sandy gravels.

6.3.1.2 Pollen analysis

Bates et al. (2009) report results from twelve samples prepared for pollen analysis from test pit 2, core 1 and test pit 7 core 3, of which seven contained enough grains to analyse (Fig. 28).

The single sample from test pit 2 core 1 (2-4 cm depth) contains 75% tree and shrub pollen, mainly oak (*Quercus*) but with very low hazel (*Corylus*) and pine (*Pinus*) pollen. The herb pollen component is very limited. The six samples from Core 3 are dominated by oak and hazel pollen, with low numbers of other deciduous tree pollen taxa, including maple (*Acer*). Spruce (*Picea*) pollen increases upwards, with low values of pine pollen continuously present. The presence of pre-Quaternary pollen and spores suggest the reworking of earlier sediment.

Assemblages from the two cores both indicate fully temperate deciduous forest vegetation (Bates et al., 2009). The small amounts of pine pollen may originate from a distance as pine produces vast quantities of pollen and, if growing locally, would be expected to occur at much higher values. The increasing quantities of spruce (*Picea*) pollen, a taxon producing very little pollen compared with pine, suggest the possible migration of this tree towards the site during the period of deposition. The occurrence of high values of Chenopodiaceae pollen, accompanied by the presence of thrift/sea lavender (*Armeria/Limonium*) and tasselweed (*Ruppia*) pollens and the remains of acid-resistant hystricospheres (marine dinoflagellate cysts) are characteristic of brackish/saline water. However, the pollen assemblage also includes pollen of burreed/bulrush (*Sparganium/Typha angustifolia*-type) and pondweed (*Potamogeton subgenus Potamogeton*) which grow in fresher water conditions. The pollen therefore suggests that the sediments were probably laid down in brackish water in salt marshes.

6.3.1.3 Foraminifera and Ostracoda

Bates et al. (2009) report foram and ostracod assemblages from fifty samples taken from seven test pits (2, 3, 4, 6, 7, 8, 9) and two cores (Tp2, Core 1, and Tp7, Core 3). Three biological facies were recognised, each with their own distinctive microfauna:

FACIES 1. A sandy facies, characterised by the association of the common foraminifera: *Elphidium macellum, Ammonia falsobeccari*i and miliolids (*Quinqueloculina* spp. and *Massilina secans*), and the ostracods: *Heterocythereis albomaculata, Pontocythere elongata, Leptocythere pellucida* and *Loxoconcha rhomboidea*. This facies covers the sediments from test pits 6, 3, 9 and possibly 8. This is a fully marine fauna which would have been living in the littoral/sublittoral and shallow inner shelf. It contains both benthonic (sediment dwelling) and washed-in phytal (sea-grass and algal dwelling) species, of relatively high diversity. Most significant amongst the foraminifera is the presence (in large numbers) of *Ammonia falsobeccarii*. This “southern” species was first described from the Bay of Biscay and its northernmost occurrence today would be NW France and SW Ireland. It does not live in Southern England today. Of the ostracods there are three species which have “southern” affinities, *Carinocythereis whitei, Aurila convexa* and *Callistocythere curryi*, although none is particularly common in these samples. Bates et al. (2009) interpreted Facies 1 as representing marine sediments laid down in a temperate interglacial, and on the evidence of the *Ammonia* spp. (*A. falsobeccarii* in particular), somewhat warmer than the present day.

FACIES 2. A grey organic-silt facies observed by Bates et al. (2009) was characterised by the association of the common foraminifera: *Ammonia tepida/aberdoveyensis, Elphidium williamsoni* and *Haynesina germanica*, and the ostracods: *Loxoconcha rhomboidea, Xestoleberis nitida, Leptocythere castanea, Cyprideis torosa* and *Heterocythereis* sp. This facies incorporates the sediments from Test pits 4 and 7. These are interpreted as representing an intertidal brackish facies, supported by large numbers of such foraminifera as *Ammonia aberdoveyensis, Elphidium williamsoni and Haynesina germanica, and the ostracods Xestoleberis nitida, Cyprideis torosa* and *Leptocythere* spp. The ostracod assemblage contains 5 “southern” species, the most remarkable being *Heterocythereis* sp. Conversely, in the lower part of Test pits 7 and 4, three species are present whose modern distribution is today restricted to northern climes (Scotland and further north). These “non-analogue” faunas either signify reworking from a colder interval or more likely, the presence of former Pleistocene distributions which do not match the present Holocene “norm”, making temperature hard to interpret.

FACIES 3. The fauna in this facies is identical to that described from Stone Point (Briant et al., 2019, see above). This is an organic clay facies, which from its fossiliferous content, indicates a brackish salt-marsh and near-terrestrial environment, in all samples from Test pit 2 and Core 1. Sample 2.1 exhibits a low diversity of foraminifera and ostracods and seems to indicate a brackish lower saltmarsh with associated mudflats and creeks.

6.3.1.4 Molluscs

Mollusc preservation is mostly good in the channel deposits (Bates et al., 2009), but many samples contain also abraded shell probably reworked from older Bracklesham Beds sources. The condition of the land and freshwater shells is also poor, likely due to damage in transport, although most are still identifiable to species.

The assemblage from sandy deposits in test pits 3, 6, 8 and 9 is of marine and brackish taxa. The marine Mollusca are found either low in the shore zone, or in immediately sub-littoral conditions. The vast majority of the taxa recorded currently live in normal salinities (circa 35‰), but most also have a tolerance of reduced salinities down to about 25‰ (Peacock, 1993) suggesting deposition on a coast influenced by inputs of fresh water from an estuary or rivers. The occurrence of *Patina pellucida* indicates areas with the marine algae *Laminaria* spp., the usual host plant of this limpet. The Selsey marine fauna has a number of species (e.g. *Ostrea edulis, Venus casina, Ensis ensis*) whose modern northern limit is in south Norway or Denmark (Tebble, 1966; Seaward, 1990) suggesting that water temperatures during deposition of the sediments were no colder than the present Channel. Numerical values summarised by Peacock (1993) for a number of the species present at Selsey indicate summer sea water temperatures no lower than 15º C for species such as *O. edulis* and *Ensis siliqua*.

By contrast, from elsewhere (test pits 2, 4 and 7), Bates et al. (2009) report large numbers of Hydrobiidae suggesting a shift in environmental conditions. The brackish-dominated faunas are totally dominated by species of *Hydrobia*, although other taxa tolerant of low salinities such as *Retusa* spp.*, Bittium reticulatum, Scrobicularia plana* and *Cardiacea* are all present in numbers in the samples where Hydrobiidae dominate. The majority of *Hydrobia* in almost all samples are *Hydrobia ulvae* which has salinity tolerances between 10 and 40 ‰ (Peacock, 1993). This suggests that salinities were in the middle range, perhaps around 20 ‰.

Two samples (2.1 and 8.2) contain land species and also the majority of the freshwater taxa (Bates et al., 2009). The numbers of land and freshwater species and individuals are very low, most taxa being represented by single individuals, so environmental reconstructions can only be tentative. However, the freshwater taxa indicate derivation from standing or slow flowing water, with some aquatic vegetation (*Gyraulus crista*) and with areas perhaps prone to drying (*Anisus leucostoma*). The land taxa were probably incorporated into the sediments by way of stream transport into the brackish estuary or lagoon. Most of the species recorded are from marsh or wetland environments (*Vertigo angustior, Vertigo antivertigo, Vallonia pulchella*), but *Discus ruderatus* may also be found in scrub and woods, an environment which would also be suitable for members of the Clausiliidae. *Pupilla muscorum* is a species of short turf calcareous grassland such as occurs in stabilised coastal dunes (Kerney and Cameron, 1979).

Climatic reconstruction based on so few individuals of land and freshwater shells cannot be exact, but *V. angustior* and *V. antivertigo* have present distributions which reach only as far north as southern Sweden indicating terrestrial conditions no colder than Sussex today. *D. ruderatus* is extinct in Britain, but is a typical interglacial species of Middle and Late Pleistocene sites. Its current distribution reaches into the boreal forests of Scandinavia, but it is also found in coniferous woods in Central Europe and the Balkans (Kerney and Cameron, 1979) perhaps suggesting conditions of continental summer warmth for the time of deposition of the Selsey sequence.

6.3.1.5 Vertebrates

Bates et al. (2009) updated a vertebrate list originally published by Parfitt (1998) which summarised Dixon's collection from 1850 and vertebrates collected from foreshore exposures by Roy Fowler in the 1970s (Table 5). Fish otoliths were described by Fred Stinton (1985) from 'Bed H1', described as a 'blue-grey marine sand' with abundant otoliths and molluscs (including *Bittium reticulatum, Chiton and Retusa retusa*), which may be equivalent to the sandy silts of Bates et al. (2009)'s test pits 4 and 7. Fowler's collection of small mammal material remained unpublished. Parfitt's summary also includes additional samples collected during fieldwork undertaken in the late 1980s and Bates et al. (2009) include further individuals retrieved during 2003/2004.

Table 5 lists the vertebrates from West Street with the number of teeth and mandibles identified to small mammal taxa by sample and collection. The results show clear differences in the number of identifiable remains between the different collections. The most recently collected samples ('Bates WSS 2003') yielded only sparse remains, but these did include teeth of water vole (*Arvicola* sp.) and an undetermined vole (*Microtus* sp.), as well as pygmy shrew (*Sorex minutus*) and common shrew (*S. araneus*). Of these, *S. araneus* is the only element in common with the species list compiled from the samples collected in the 1980s. Roy Fowler's collection contains the vast majority of specimens, many of which are finely preserved. Traces of digestion on the teeth suggest that these remains derive from disaggregated pellets deposited at the site by owls.

Bates et al. (2009) suggest that the small mammals in the Fowler collection (Table 5) give a clear picture of the former presence of woodland with dense ground cover and nearby grassland bordering the waterbody. The most abundant remains are those of woodland small mammals such as *Clethrionomys (=Myodes) glareolus* and *Apodemus sylvaticus*, which can occur together with *Microtus agrestis* in open woodland or forest-edges. The shrews *Sorex araneus* and *S. minutus* have wider ecological tolerances, but they also require plenty of ground cover. Finally, open grassland or well vegetated waterside habitats are indicated by the water vole. All of these species can be found today in southern England and they also co-occur commonly during earlier temperate stages.

The rich fish otolith assemblage studied by Stinton (1985) is dominated by shallow marine species, but no truly freshwater fishes (e.g. cyprinids) were present. There are several southern fish species, such as peacock wrasse *Symphodus tinca* and the sea perch *Epinephelus aeneus*, which today are rare or unknown north of the coastlines of Spain or southern France (Stinton 1985, 213-4). Stinton (1985) suggested that these southern species provide unambiguous evidence that sea water temperatures were significantly warmer than those of the present day. Samples collected by Bates et al. (2009) also yielded remains of the three-spined stickleback *Gasterosteus aculeatus.*

Pika (*Ochotona* sp.), identified on the basis of a fragmentary upper cheek tooth, is the only small mammal in the assemblage that no longer lives in the British Isles. Its occurrence at West Street constitutes its first record from Sussex and, given the associated environmental evidence for deciduous woodland, is quite unexpected. Today, pikas are associated with continental and dry climates in Eurasia and North America (Smith and Lissovsky, 2016). Most pika species are found in the mountains of central Asia, but others occur in the Eurasian steppe and the steppe pika (*O. pusilla*) has a range that extends into eastern Europe as far as the Volga. Pleistocene fossils show that during cold stages the range of *Ochotona* expanded, with Late Pleistocene records as far west as Wales, although always found in association with rocky, upland environments (Price, 2003). These Late Pleistocene pikas are now considered to be a subspecies of *O. pusilla* (Erbajeva and Currant, 2003), but the taxonomy of earlier European fossil pika is unresolved (Erbajeva et al., 2001); the West Street specimen is too fragmentary to contribute to this debate. Given its fragmentary state and highly unusual discovery within deposits that otherwise bear only proxy evidence of temperate climates and deciduous woodland, it is tentatively suggested that this find may represent a reworked find from a preceding episode of cooler and drier climate and more open ground conditions.

6.3.1.6 Geochronology

TL dates are available for the brickearth at Selsey West Beach. Both the regeneration method and additive dose method returned Late Devensian ages of 13.6 ± 2.1 and 17.0 ± 2.5 ka years B.P. respectively (Parks and Rendell 1992).

OSL ages from the raised beach gravel (Bates et al., 2010, Fig. 24 and 25), yield the following ages: SEL01-1 (2.6 m below ground surface) - 139 ± 11 ka; SEL01-2 (3.55 m below ground surface) – 126 ± 10 ka. These suggest that the overlying beach correlates with MIS 5e.

6.3.2 Interpretation

The evidence presented by Bates et al. (2009) clearly confirms the interglacial character of the sequences of sediments infilling the West Street channel. However, the age of the sequence is unclear because none of the faunal or floral remains are temporally diagnostic and no dating techniques are currently applicable to the sequences (e.g. the small mammal taxa are all known from throughout the British Middle and Late Pleistocene, although the distribution of the enamel in the *Arvicola* molar is suggestive of a late Middle Pleistocene or Late Pleistocene age).

It is likely that marine conditions in the northern part of the channel (test pits 3, 6 and 9) gave way to estuarine and near-terrestrial conditions in the southern part of the channel (test pits 2, 4 and 7) and the channel location shifted as the sea level changed (Bates et al., 2009). Comparing the pollen evidence from West Street with that reported from the Lifeboat Station Channel (West and Sparks, 1960), it is likely that the majority of the estuarine sediments accumulated during zone f or within zones IIa and IIb of West's interglacial scheme (1980). It should be noted that this does not necessarily imply an Ipswichian age for the West Street samples but simply accumulation within a similar substage during an interglacial.

The interpretation of the West Street sequences also needs to take into account similar sequences preserved elsewhere within the Bracklesham Bay area (Fig. 17). A range of ages can currently be suggested for these channels. For example, Earnley (West et al., 1984) has been ascribed an indeterminate age within the Middle Pleistocene. Recent works by Bates et al. (2004, 2007) have indicated the strong probability that the channel reported by Reid (1892) at West Wittering is probably of MIS 9 age. Consequently, a number of channels of different ages all appear to be present, incised into bedrock and sealed beneath temperate marine or cold stage deposits, within the area. This is probably a function of changing local geographies, abrupt channel shifting in response to current changes and infilling of depressions. It also suggests a polycyclic evolution of the coastal estuarine channels, representing a series of highstand events in the district.

6.4 Conclusions

GCR Quaternary of Southern England Site 2021 Selsey West and East Beaches (SZ 843 931 and SZ 860 925)

Selsey is a key Quaternary site. It comprises two channel fills with varying freshwater, estuarine and marine affinities (one at Selsey West Beach and one at Selsey East Beach) overlain by raised beach deposits that are best exposed and OSL dated at Selsey West Beach where they reach an elevation of c. 7 m O.D. The channel at Selsey West Beach contains pollen, ostracods and foraminifera and some vertebrates. The northern part of the channel represents marine conditions and the southern part estuarine and near-terrestrial environments within zone II of an interglacial of unknown age. The channel at Selsey East Beach (also known as the Lifeboat Station site where the 'Selsey mammoth' was found in 1909) contains pollen, ostracods, plant macrofossils and abundant vertebrate remains and indicates rapid climatic amelioration at the beginning of an interglacial and a marine transgression at about 1.8m OD in Zone IIb. The faunas include beaver, straight-tusked elephant, an extinct rhino *Stephanorhinus hemitoechus*, horse, European pond tortoise and the 'Ilford-type' mammoth, now recognised as *Mammuthus trogontherii*. Correlation with the Sandy Lane Mammal Assemblage-Zone suggests an age for the Selsey East Beach Channel deposits of the later part of MIS 7, an interpretation backed up by the presence of the mollusc *Corbicula fluminalis*, archaeological artefacts and recent AAR analyses on *Bithynia tentaculata* opercula. The overlying raised beach gravels have been OSL dated at Selsey West Beach to MIS 5e age and are overlain by a silty brickearth unit of Late Devensian age. This is an important and intriguing site giving information on environmental change during MIS 7 and an unknown interglacial and it has the potential to inform on late Quaternary relative sea level change and crustal movement in southern England.

GCR Pleistocene Vertebrate Site 1201 Selsey East Beach (SZ 860 925)

Selsey East Beach comprises a channel fill overlain by raised beach deposits that are OSL dated to MIS5e at the adjacent Selsey West Beach. The channel at Selsey East Beach (also known as the Lifeboat Station site where the 'Selsey mammoth' was found in 1909) contains pollen, ostracods, plant macrofossils and abundant vertebrate remains and indicates rapid climatic amelioration at the beginning of an interglacial and a marine transgression at about 1.8m OD in Zone IIb. The faunas include beaver, straight-tusked elephant, an extinct rhino *Stephanorhinus hemitoechus*, horse, European pond tortoise and the 'Ilford-type' mammoth now recognised as *Mammuthus trogontherii*. Correlation with the Sandy Lane Mammal Assemblage-Zone suggests an age for the Selsey East Beach Channel deposits of the later part of MIS 7, an interpretation backed up by the presence of the mollusc *Corbicula fluminalis*, archaeological artefacts and recent AAR analyses on *Bithynia tentaculata* opercula.

7. GCR Site number 2158 Eartham Pit, Boxgrove (SU 923 087) AH, RMB, DCS

7.1 Introduction

Eartham Pit, Boxgrove is arguably the most significant Middle Pleistocene site in North-West Europe, internationally important for its geology, palaeontology and Lower Palaeolithic archaeology. The quarry complex, which lies about 7 km north-east of Chichester and 10 km north of the present coastline (Figs 1 and 29), was subject to a series of excavations between 1982 and 1996 directed by Mark Roberts (Roberts et al. 1986; 1997; Roberts and Parfitt, 1999). Two quarries were excavated, of which Quarry 2 is designated as a GCR site. Currently the site is attributed to the later part of the British Cromerian Complex, MIS 13 interglacial (533 – 478 ka) and the ensuing cold of MIS 12 (478 – 424 ka; Roberts and Parfitt, 1999; Lisiecki and Raymo, 2005). The site is famous for the discovery of a largely complete hominin tibia (Roberts et al., 1994; Stringer et al., 1998) and two lower incisors attributed to *Homo heidelbegensis* (Hillson et al., 2010) in Quarry 1, which remain the oldest human fossils known from Britain. The site is also notable for the exceptional preservation of a palaeo-landsurface with its largely *in situ* archaeology and fossil content (Roberts and Parfitt, 1999).

The Pleistocene sediments at the site are located on the northern edge of the West Sussex Upper Coastal Plain and form a depositional wedge resting on an erosional marine platform and confined by a cliff to landward, both cut into the Cretaceous upper chalk of the South Downs. The marine platform and cliff, together with the associated marine gravels, sands and silts of the Slindon Formation represent an interglacial sea level highstand with an inner platform edge at c. 38 m O.D. attributed to MIS 13 (Roberts and Parfitt, 1999). They are succeeded by a palaeosol which formed under subaerial conditions and then by a mineralized and compressed organic deposit initially laid down in a freshwater alder/fen carr environment (Roberts and Parfitt, 1999). A further thick sequence of freshwater deposits (the 'water hole' sequence) are found only in Quarry 1, outside the GCR site (Table 6). This is then overlain by the Eartham Formation - terrestrial sediments derived from the erosion of the chalk cliff and the downland block to the north of the site. They comprise a brickearth, chalk rubble and a series of gravels emplaced by mass movement and aeolian processes under cold climate conditions and considered to date from MIS 12 (Roberts and Parfitt, 1999).

The sequence at Eartham Pit contains one of the most diverse vertebrate faunas from a Lower Palaeolithic site in western Europe. Excavations between 1985-1991 produced a vertebrate assemblage representing a minimum of 88 species, 11 species of fish, 9 of reptiles and amphibians, 19 birds and 50 mammals (Roberts and Parfitt, 1999). Later excavations between 1995 and 1996 raised this figure to over one hundred, with the remarkable diversity ascribed to the scale of the archaeological excavations covering many hundreds of square metres, and the bulk sieving of more than 150 tons of sediment for small vertebrate remains (Parfitt, 1999). In addition to the vertebrates there is an extensive record of foraminifera, ostracods and molluscs. The faunal assemblage from the upper Slindon Silt, palaeosol and alder carr confirm temperate conditions with horse, roe deer, fallow deer, two species of extinct giant deer, two species of extinct rhinoceros, wild boar, rabbit and water vole. It also includes large carnivores, including hyena, wolf and an extinct cave bear species. Local grassland with damper areas and small ponds is suggested by species of fish, amphibians, reptiles and wildfowl (Roberts and Parfitt, 1999). Mutual Ostracod Temperature Range (MOTR) analysis on ostracods suggests summer temperatures were similar to today in the area and winter temperatures were probably colder, with mean annual air temperature similar to or slightly cooler than present (Holmes et al., 2010).

In addition to its raised beaches, the site and local area has long been known for its Lower Palaeolithic archaeology (Curwen 1925, 1946; Fowler, 1929, 1931; Calkin, 1934; Pyddoke, 1950). Exploratory investigations at the site beginning in the 1970s (Shephard-Thorn and Kellaway, 1973, 1977; Woodcock, 1977, 1978, 1981) were followed by full-scale excavation between 1983 and 1996, under the direction of Mark Roberts (Roberts, 1986, 1998; Roberts et al. 1997; Roberts and Parfitt, 1999; Bates et al., 1998a, b). Whilst artefacts have been recovered throughout the sequence, by far the most prolific unit has been the soil horizon developed on top of the Slindon Silt. Representing a palaeo-landsurface it has produced tens of thousands of artefacts, including extensive scatters of Acheulian handaxes of strongly symmetrical ovate and limande (elliptical) form, often with tranchet (chisel-like) tips, and handaxe manufacturing debitage (Pettitt and White, 2012). Waste flakes can often be refitted which suggests much of the lithic material is *in situ* (Roberts et al., 1986; Bergman et al. 1987; Bergman and Roberts, 1988; Austin, 1994),

In several cases i*n situ* lithic assemblages are associated with animal remains, showing signs of butchery, including those of horse and rhinoceros (Roberts and Parfitt, 1999; Pope et al., 2021). These are best developed in GTP17 in Quarry 2. The cut marks indicating butchery always appear to precede signs of subsequent carnivore damage to the bones. This, and the presence of a possible spear injury identified on a horse scapula, suggests the hominins at Boxgrove were active hunters with primary access to the carcasses of a large range of prey species and that they had the ability to protect them from other predators which could have included lion, hyaena and wolf (Roberts and Parfitt, 1999; Smith, 2013).

The site is perhaps most famous for the discovery in December 1993 of an almost complete hominin left tibial diaphysis from Unit 8ac, a complex sequence of silts, sands and chalky gravels with a restricted distribution overlying the freshwater deposits of Unit 4d in Quarry 1/B outside the GCR site (Roberts et al., 1994; Stringer et al., 1998). Subsequently during 1995 and 1996 two lower hominin front incisors were recovered from the base of a shallow channel directly beneath the colluvial sediments and cutting into the underlying intertidal Slindon Silt (Hillson et al., 2010).

Between 2001 and 2006, the Boxgrove Project team undertook the Raised Beach Mapping Project to determine the wider extent of the surviving Boxgrove temperate depositional sequence. Results confirmed that the Slindon Formation was deposited in a semi-enclosed and sheltered marine embayment extending about 26 km in an east-west direction which cut through the Portsdown and Littlehampton chalk anticlines (Fig. 30). The thin organic horizon which overlies the palaeosol developed in the uppermost part of the Slindon Member has also been traced over 15 km between Adsdean Farm and Slindon Park suggesting widespread preservation of this palaeo landsurface (Roberts and Pope, 2009; 2018). Excavations in 2006 and 2007 at The Valdoe, a quarry 6 km to the west of the Boxgrove site confirmed an essentially similar stratigraphy and archaeology (Pope et al. 2009; Pope and Roberts, 2011; Preece and Parfitt, 2022), but recent investigations of molluscan asemblages suggest significant differences between Boxgrove and the Valdoe, much of which reflects true environmental heterogeneity (Preece and Parfitt, 2022).

<table>
<tr><th>Member</th><th>Description and interpretation</th><th colspan="2">Standard</th><th>Q1/B</th><th>Description and interpretation</th></tr>
<tr><td rowspan="2">Eartham Upper Gravel</td><td>Head gravels derived from downland Clay-with-flints regolith.
Mass movement deposits, with arctic soils</td><td colspan="2">Unit 11</td><td>Unit 11</td><td>Head gravels derived from downland Clay-with-flints regolith. Mass movement deposits, with arctic soils</td></tr>
<tr><td>Calcareous head. Mass-movement deposit</td><td colspan="2">Unit 10</td><td>Unit 10</td><td>Calcareous head. Mass-movement deposit</td></tr>
<tr><td rowspan="4">Eartham Lower Gravel</td><td>Path gravel. Freeze-thaw-sorted flint gravel</td><td colspan="2">Unit 9</td><td>Unit 9</td><td>Very restricted tongues of flintier sorted gravel</td></tr>
<tr><td>Chalk pellet gravel. Water-lain, weathered and sorted chalk clasts</td><td colspan="2">Unit 8</td><td rowspan="2">Unit 8</td><td rowspan="2">Chalk pellet gravel. Dewatering structures initiated</td></tr>
<tr><td>Cliff collapse</td><td colspan="2">Unit 7</td></tr>
<tr><td>Calcareous muds/brickearth. Colluvial and water-lain silts</td><td rowspan="8">Unit 7</td><td>Units 5b, 6</td><td>Unit 6b</td><td>Calcareous muds/brickearth. Colluvial and water-lain silts</td></tr>
<tr><td rowspan="5">Slindon Silt</td><td>Mineralised and compressed organic deposits. Alder/fen carr</td><td>Unit 5a</td><td>Unit 5a</td><td>Mineralised and compressed organic deposits. Alder/fen carr</td></tr>
<tr><td>Soil horizon developed on top of the silts. Polder-type soil</td><td>Unit 4c</td><td>4d2, 4d3, 5ac</td><td>Spring discharge sediments with colluvial input towards the top (Unit 5ac)</td></tr>
<tr><td rowspan="3">Intertidal laminated muds laid down in a semi-enclosed marine bay</td><td>Unit 4b</td><td>Unit 4d1</td><td>Spring discharge sediment. Intraformational calcretes</td></tr>
<tr><td rowspan="2">Unit 4a</td><td>Unit 4</td><td>Massive silt from freshwater reworking of Units 4a and 4b. Heavily deformed</td></tr>
<tr><td>Unit 4u</td><td>Massive fine silt from freshwater reworking of Units 4a and 4b. Includes subunits 4u(s) and 4*</td></tr>
<tr><td rowspan="2">Slindon Sand</td><td rowspan="2">Nearshore marine sands</td><td rowspan="2">Unit 3</td><td>Units 3/4, 3c</td><td>Freshwater channels and freshwater scoured land surface, from springs at cliff base</td></tr>
<tr><td>Unit 3</td><td>Nearshore marine sands with a truncated upper surface</td></tr>
</table>

Table 6. Correlation table of units across the site and brief description of environments. Source: Roberts and Pope (2018).

7.2 Description

7.2.1 Sedimentary sequence

The conformable Pleistocene sediments of the Slindon and Eartham Formations at Eartham Pit (Figs 31, 32, Table 6) rest on a marine platform cut into the Upper Chalk reaching about 38 m O.D. The deposits occupy a corridor up to 250 m wide extending southwards from the former cliff. Foraminiferal analysis of the Chalk at the base of the cliff and from a chalk raft or debris flow 30-40 m south of the cliff, interpreted as a cliff collapse episode, suggest a minimum of 60 m for the original height of the cliff (Roberts and Parfitt, 1999).

Overlying the erosion surface in both quarries (Fig. 29) is the Slindon Gravel Formation (unit 2) a variable deposit of partially clast-supported flint gravel with a medium to coarse sand matrix. The gravel ranges from well-rounded to angular and is consistent with a high-energy beach environment (Collcutt, 1999).

In Quarry 2 (Q2, GCR site), section Q2 SEP 3 the gravels are locally overlain by about 50 cm of finer deposits including clays with heterolithic (flaser and lenticular) bedding suggesting deposition in a lower energy tidal environment, giving way to medium sand with planar cross-bedding, implying a slightly higher energy environment. Above is a strongly cemented deposit with few depositional structures comprising clays with silt and fine sand containing isolated gravel particles and with massive lenticular doggers several metres across and a few centimetres in thickness in the upper part. A similar sequence is found at GTP 35 (Collcutt, 1999). The cemented horizon was noted by Prestwich (1859), by Shepherd-Thorn and Kellaway (1977) and by Woodcock (1981). The environmental and temporal significance of the finer marine deposits and cemented horizon remains to be explained but it could suggest the marine platform is a multi-phase feature with the clays, sands and cemented horizon representing the remnants of an earlier marine occupation.

The overlying Slindon Sand (unit 3) comprise**s** up to 10 m of coarser beach and cliff-fall deposits interspersed with fine yellowish brown, slightly micaceous and glauconitic marine sands probably laid down in a nearshore environment. Collcutt (1999) identified 3 cycles of transgression and regression within the unit based on changes in sedimentology and trace fossils which were best seen at the holostratotype section of the Slindon Formation at Q2/GTP 13 (Fig. 32).

Overlying the Slindon Sand and representing a regressive phase is a relatively thin (c. 1 m) finer deposit of laminated silts, the Slindon Silt (unit 4 a-c), probably laid down in an intertidal mudflat environment or lagoon. The transition between the two Members is most noticeable as a colour change to grey green which may be due to the reduction in grain size and increase in carbonate content rather than a change of sediment source. Unit 4c represents a thin calcaric-alluvial soil now only about 40 mm thick in places which developed through subaerial weathering of the uppermost levels of unit 4b. This process of soil ripening involved decalcification, a loss of mass by weight of between 20 to 30% and probably took about a century (Macphail, 2017).

At Q1B in Quarry 1, adjacent to the GCR site, the stratigraphic sequence is significantly different at the time period equivalent to unit 4c (Table 6, Roberts and Pope, 2009; Holmes et al. 2010). Known as the water hole or pond sequence, there is evidence for localized erosion and re-deposition of the Slindon Sand and Silt by spring-fed freshwater emanating from the base of the cliff line some 50-80 m to the north. One larger channel (up to 0.8 m deep and trending north-west to south-east) and several smaller channels were cut into the Slindon Sand. This channelling and erosion created a water body with dimensions of some 100 m from east to west and a proven south to north distance of 40 m, which is likely to be a minimum value if, as expected, it extends up to the cliff line a further 50 m to the north. This sequence is significant because Quarry 1 is the only location at which such deposits are found.

Infilling the main channel at Q1B (Table 6) is unit 3c, a coarse gravel deposit with flint beach pebbles, worked flint and fragments of bone succeeded by fine silts with increasing amounts of whitish chalky clay derived from the spring discharge. Adjacent to the main channel the eroded surface of unit 3 shows signs of soil formation and weathering. The channel deposits are overlain by the freshwater pond sequence. The basal unit, 4u is a massive silt with occasional traces of bedding and a sandier sub-unit 4u(s) suggesting a slightly higher energy environment. These are overlain by Unit 4, a massive silt that shows signs of disturbance by dewatering notably in the upper parts as shown by pore water release deformation structures. Analysis of soil micromorphology suggests three phases of deposition; firstly, erosion and redeposition of unit 4u sediments, secondly an increase in plant detrital material and bioturbation, and lastly massive calcareous silting suggestive of increased wetness (Holmes et al., 2010).

The upper pond sequence at Q1B (Table 6) consists of a highly calcareous white silt containing intraformational calcrete nodules (unit 4dl) overlain by the poorly sorted coarse silt with sub- rounded chalk clasts and quartz sand of unit 5ac. This latter unit probably represents a mixture of redeposited pond sediments and colluvial material. Above unit 5ac there is a return to calcareous spring deposition shown by units 4d2 and 4d3.

The final unit of the Slindon Formation, 5a, is widespread across the site in both quarries. It comprises micro-laminated, and often ferruginous, compressed detrital organic material about 10 mm thick that developed on top of the Slindon Silt in an alder/fen carr environment, perhaps with seasonal ‘winterbourne’ stream activity (Macphail, 1999). Towards the top of the unit there is evidence of crusting, cracking and microfaulting which suggests drying out of the marsh surface. These Slindon Organic Bed deposits have subsequently been mapped over 15 km between Adsdean and Slindon Park indicating widespread wetland development in the region (Macphail, 2017; Roberts and Pope, 2009; 2018).

The overlying sediments of the Eartham Formation (Table 6) are mainly derived from the downland block to the north. Unit 5b is a massive micritic marl with included silt usually 1 to 2 cm thick though locally reaching up to 13 cm in Q2 GTP 13 (Fig. 32), where it conformably overlies unit 5a. At other locations including Q2 GTP 3 and 13 there is coarser material including rounded chalk pellets, sand-sized soil and brickearth in the lower levels, while at GTP 10 in Quarry 2 there is evidence of almost total post-depositional decalcification. Macphail (1999) notes that in two locations near the former cliff line there is the suggestion that the unit may have initiated as an erosive high energy slide or flow. The unit probably represents flooding of the marsh with calcareous waters forming a freshwater ponded landscape.

The succeeding unit 5c has very limited distribution, only being described from GTP 17 in Quarry 2 but it is important because it is as rich in mammalian remains and artefacts as the highest levels in the main interglacial sequence (Macphail, 1999). It comprises a finely laminated dark brown clay loam with a high sand content and detrital organic matter up to 1 m wide and 8 cm thick. It has a transitional lower boundary from unit 4c directly beneath and laterally at its base with unit 5a. Laminated very fine sand and organic fine silty clay gives way to a very thin 1-2 mm *in situ* layer of peat that shows signs of desiccation and cracking. Above is a massive pale grey calcareous silt with mineralised peat soil fragments in turn overlain once again by stratified very fine organic sands and finally by a mixed deposit containing large clasts of probable unit 5b/8 material. It is interpreted as a colluvial tongue deposit that has brought sands, perhaps from the raised beach, and organic material from further upslope during the period of calcareous pond development (Macphail, 1999).

Unit 6 is a coarse silty brickearth over 1 m thick in places, a non-calcareous silty clay loam with many small cut and fill features. Throughout the brickearth are inclusions of flint, medium sand-sized clasts of brickearth, clay curls and soil fragments. It probably represents a low energy fluvial environment with still water ponds. Catt (1999) suggested that the silt component may have come from wind erosion of units 3 and 4 of the Slindon Formation, which would have been exposed during marine regression as the climate cooled, resulting in loess deposition on the Chalk dip slope, which then could be brought downslope by subsequent fluvial action. The clay component may have originated from erosion of downland soil.

Unit 7 comprises angular chalk debris from cliff collapse that interdigitates with all levels of the Boxgrove sequence until the cliff was no longer actively eroding and so is coeval with Members of the Slindon Formation and units 5b-8 of the Eartham Lower Gravel Member.

Unit 8 is another diachronous unit and was divided into an upper and a lower division by Roberts (1999). The (lower) white chalk pellet gravels are only found near to GTP 25 in Quarry 2 and were laid down under temperate conditions. Near to the cliffline sediments of this unit overlie the Slindon Organic Bed (unit 5a) while further to the south they are in turn overlain by the calcareous marl of unit 5b and the brickearth, unit 6. They are draped over the earlier sediments at moderate angles of between 15 and 20° and probably represent weathered cliff collapse or scree slope deposits.

The (upper) brown chalk pellet gravels also attributed to unit 8 were laid down later under colder conditions and extend further southwards where they become totally decalcified. The lower parts are finely laminated calcareous silts, fine sands and micritic marl which includes fragments of brown soils, papules and relic chalk material. The upper sediments are more massive coarse to fine rounded to sub- rounded chalk gravel and chalky soil clasts. Taken as a whole, they represent the mass movement of calcareous material downslope under periglacial conditions. At Q2 GTP 25 soil formation was observed resembling the A/C horizon of a grey rendzina with evidence of rooting and earthworm activity. Up to 150 m from the cliff the upper chalk pellet bed interdigitates with the underlying unit 6 brickearth beds and the overlying unit 9 angular fan gravels (Macphail, 1999).

The Fan Gravel Beds (unit 9) comprise quite well sorted angular (nearly 80% angular and very angular) and sub-rounded flint fine gravel. These are clast-supported and manganese stained towards the base but with a strong brown silty matrix in the upper parts. It has been extensively decalcified by subsequent downward movement of water. Observations from GTP 13 and GTP 5 in Quarry 2 suggest generally coarser deposits near at the cliff line emplaced in a high energy or debris flow environment giving way to finer deposits reflecting a lower energy fluvial environment.

Units 10 and 11 comprise the Eartham Upper Gravel Member. They were laid down in increasingly cold conditions in several phases of deposition. Unit 11, the Decalcified Head Gravels, is a crudely stratified angular flint gravel in a matrix of reddish-brown silty clay with common manganese staining. Some flints show evidence of frost shattering. Within the gravels are up to 3 major seams of finer brickearth-like material up to 2 m thick termed the Lower, Middle and Upper Silt Beds (Collcutt, 1999). The emplacement of both gravel units protected finer Slindon Formation units near to the cliff but further away the effect was more erosive and at distances as little as 250 m from the cliff line they cut down significantly into the Slindon Silt and Slindon Sand. Collcutt (1999) reports the existence of patterned ground in a temporary exposure in the western part of Quarry 2 within unit 11, perhaps representing stone polygons or stone stripes, persisting for at least 100 m of exposure.

In summary the beds of the Eartham Upper Gravel Member (units 9-11) represent cold climate mass movement gravels showing a variety of energy levels ranging from solifluction, through creep and wash to flow. Catt (1999) has suggested a dominantly local mineralogy and therefore it is probable that both the gravel units represent material derived from the nearby downland block clay-with-flints regolith. Within the silt beds of the gravels there is evidence for arctic soil formation perhaps under humid rather than dry conditions (Macphail, 1999).

7.2.2 Foraminifera and ostracods

Foraminifera and ostracods were examined from the Slindon Sand and Slindon Silt in GTP 13, Quarry 2 (Whittaker, 1999) and from Quarry 1 (Whittaker and Parfitt, 2017). Foraminifera occur within all three marine cycles of the Slindon Sand Member and also the Slindon Silt Member, with the highest diversity occurring in the later part of marine cycle 1 and in cycles 2 and 3. *Ammonia falsobeccarrii* and *Elphidium crispum* are common in the Slindon Sand and indicate a fully temperate interglacial, both being restricted to the south of Britain today and areas even further to the south, a suggestion supported by the occurrence of the extinct form '*Rosalina margareli'*. Whittaker and Parfitt (2017) note the lack of miliolids which may suggest a lack of marine algae/seagrass and/or turbid conditions and agglutinating foraminifera which could indicate absence of a fringing saltmarsh.

The ostracods from the Slindon Sand however contain both 'northern' and 'southern' species. The most notable member of the 'northern' assemblage is *Baffinicythere howei* which has a modern pan-Arctic distribution, together with *Hemicytherura clathrata* and *Finmarchinella finmarchica* which have a modern northern European distribution. On the other hand, *Semicytherura robertsi* lives today in the Mediterranean. The presence of *Cyprideis torosa* is also interesting because it is a species usually considered to reflect brackish tidal flats and creeks and yet other species suggestly a more strongly marine environment in the Slindon Sand. In addition, freshwater species including *Scordiscia marinae*, an important pre-Anglian marker, and *Cytherissa lacustris* suggest the Boxgrove embayment may not have had a fully marine salinity. Whittaker and Parfitt (2017) report a MOTR analysis undertaken by David Horne (Horne, 2007) on the freshwater ostracods indicating a mean July air temperature of between 12-23°C and a mean January temperature of between -10-+3°C, which implies similar summer temperatures as today and winter temperatures that were at least 1°C cooler and which may have been much colder.

The earlier report on ostracods (Whittaker, 1999) noted their complete absence in the Slindon Silt Member but this is now considered to be due to differential preservation. A more recent sample (95/10) taken from Quarry 1/A from beneath a calcrete layer contained a very high diversity ostracod assemblage dominated by *Leptocythere* species including *L. psammophila*, *L. lacertosa*, *L. castanea*, *and L. steynewoodensis*, indicating a marine tidal flat environment. Samples from above the calcrete layer were devoid of ostracods suggesting decalcification. (Whittaker and Parfitt, 2017).

More recently, attention has turned to the waterhole site in Q1/B, in Quarry 1, adjacent to the GCR site. Ostracods were sampled from units 3c, 4u and 4u(s) (see Table 6). The samples contained a low diversity assemblage with species presence in order of decreasing abundance *Candona neglecta*, *Ilyocypris* cf. *bradyi*, *Herpetocypris reptans*, *Prionocypris zenkeri*, *I. quinculminata*, and *Potamocypris zschokkei*. The presence of adults and a range of juvenile moults suggest the ostracod assemblages are *in situ* (Holmes et al. 2010). Taken together the ostracod species present suggest permanent, small, shallow freshwater ponds probably fed by springs from the base of the cliff or by groundwater seepage. Rich aquatic vegetation is suggested by the abundance of charophyte oogonia. Ostracods which might indicate higher salinities are absent suggesting the ponds were largely freshwater.

MOTR was employed on five of the ostracods species detailed above from Q1/B (Holmes et al. 2010). The reconstructed mean annual air temperature was within the range 5-11°C (July temperatures between 14-20°C, January temperatures between -4-+4°C). This suggests summer temperatures similar to the present day whilst winter and mean annual temperatures could have been similar but may have been significantly colder. These reconstructed temperatures were very similar to those obtained through a herpetile Mutual Climatic Range (MCR) analysis (see below) performed by Sinka (1993).

Holmes et al. (2010) also combined these quantitative palaeoecological reconstructions with geochemical analyses of ostracod calcite to inform on the source and salinity of the pond water and the nature of the precipitation. Sr/Ca ratios were measured in 16 samples from 3 species of ostracod from unit 4u in Q1/B. Using a two-component mixing model with marine water as one end member and meteoric water from a modern analogue at Greywell, Hampshire as the other, Holmes et al. (2010) suggested the Boxgrove ponds may have contained about 0.4% seawater. Sr-isotope values were also used to estimate palaeosalinity and Holmes et al. (2010) estimated seawater percentages of between 0.7 and 1.8%, slightly higher than that calculated from the Sr/Ca ratios.

The $\delta^{13}C$ values in ostracod calcite from the Boxgrove pond sequence were also used by Holmes et al.

(2010) to suggest the pond water may have had a short residence time. The $\delta^{18}O$ values of ostracod calcite suggest that former precipitation values during deposition of the Slindon Silt may have been up to ~0.4 ‰ heavier than modern precipitation but that given the uncertainties involved it is more likely that the ^{18}O content of palaeo-precipitation during the later part of MIS 13 was comparable with that of the present day (Holmes et al., 2010).

7.2.3 Mollusca

Marine molluscs were recorded in units 3, 4a, and 4b where they were frequent. In the upper chalk raft and lower beach deposits of unit 3 there are species typical of rocky shores including *Nucella lapillus*, *Littorina littorea* and *L. saxatilis* agg. sp. In unit 4b a second group comprises *Mytilus edulis* (many with articulated valves) and *M. modiolus* suggesting the presence of mussel beds. Notable also in unit 4b is the common occurrence of the large sinistral whelk *Neptunea* together with *Nucella lapillus* often associated with discrete clusters of well-rounded flint gravel. Preece and Bates (1999) suggested four possible origins for these clusters; material deposited by seaweed rafting, the decayed remnants of armoured mud balls, erosion of a pre-existing deposit and material intentionally collected and emplaced by man. They discounted the third option because of a lack of evidence for extensive erosion at this level but could not decide between the other three possibilities. Vervoenen et al. (2014) ascribe the Boxgrove *Neptunea* to *N. inversa*, common in the Norwich Crag and Wroxham Crag Formations deposited during the Early and Early Middle Pleistocene, which they suggest has a last occurrence in the Middle Pleistocene at Boxgrove.

Non-marine Mollusca were sampled from units 4c-d, 5 a-c, 6 and 8 from both quarries. Concentrations of shells per 1 kg sample were very low and preservation was generally very poor, with many exhibiting fragmentation and decalcification. Some degree of differential preservation was also suggested (Preece and Bates, 1999). At least thirty species were recognized, mostly from units 4 and 5, suggesting a moist, well-shaded land surface with occasional pools supporting the aquatics *Anisus leucostoma*, *Lymnaea peregra* and *Pisidium* spp. *Lymnaea truncatula* and *Succinea oblonga* are indicative of bare muddy surfaces and *Vallonia spp.* and *Pupilla muscorum* suggest drier more exposed open ground nearby. However shady conditions are suggested by *Aegopinella pura*, *A. nitidula* and members of the Clausiliidae which occur in high frequencies, especially in unit 5b and subunit LGC, a calcareous silty clay of variable thickness derived from weathering of chalk cliff collapse (unit 7) and the lowermost white pellet gravels (unit 8). This is supported by the sporadic presence of shade-demanding *Spermodea lamellata* and *Acanthinula aculeate* (Preece and Bates, 1999). More recent detailed analysis by Preece and Parfitt (2022) from sequences both here and at the Valdoe state that the presence of *Spermodea lamellata* also suggests that the land surface (unit 4c) was exposed for longer than the 20–100 years previously suggested and that woodland conditions persisted into units 5a and 5b.

7.2.4 Vertebrate fauna

7.2.4.1 Ichthyofauna

The fish remains from Boxgrove are notable as the first large ichthyofaunal assemblage from the early Middle Pleistocene (Parfitt and Irving, in Roberts and Parfitt, 1999). The Slindon Beach Gravel and Slindon Sand Members, units 2 and 3, were screened for fish remains without success save for a small assemblage containing vertebrae of the Clupeidae (herring family), Pleuronectidae (flounder family) and *Conger conger* (conger eel) recovered from the upper part of the 'chalk raft' at the base of marine cycle 3 (Parfitt and Irving, 1999).

Unit 4 a/b in the Slindon Silt contains a sparse but diverse fish fauna including *Raja clavata* (thornback ray), *Muraena helena* (Mediterranean moray eel) or *C. conger*, Salmonidae (salmon family), Gadidae (cod family), *Gadus morhua* (Atlantic cod), *Gasterosteus aculeatus* (three-spined stickleback), Labridae (wrasse family), *Thunnus thynnus* (Atlantic bluefin tuna), *Platichthys flesus* (European flounder) and Pleuronectidae. All these species can be found in shallow freshwater environments and saltwater lagoons save for the Atlantic cod and Atlantic bluefin tuna, which may be derived from carcasses washed into the lagoon by wave or tidal action (Parfitt and Irving, 1999).

Unit 4c, the thin calcaric-alluvial palaeosol at the top of the Slindon Silt contained a large quantity of fish remains which probably reflects the concentration of sampling at this horizon. The assemblage is diverse and includes marine, freshwater and diadromous taxa, i.e. those that migrate between fresh and saltwater environments during their life cycle. Species recovered include *G. aculeatus*, *Salmo trutta* (brown trout), a salmonid, a labrid, a triglid (gurnard family), *P. flesus* and a pleuronectid.

Parfitt and Irving (1999) put forward four possible scenarios for the accumulation of such a diverse assemblage in the palaeosol horizon: as a natural death assemblage that accumulated in the sediments prior to soil formation, reworking from underlying deposits, natural death assemblages due to periodic flooding of the land surface transporting bones or carcasses after death or allowing fish to colonise temporary pools, and lastly as predator accumulation. They found support for periodic flooding in the micromorphological evidence of Macphail (1999), especially in the upper part of the sequence. However, in addition to the well-preserved bones, a significant proportion showed signs of breakage, rounding, pitting and surface corrosion which can be matched with damage produced by predator activity. They noted several piscivorous species in the Boxgrove assemblage including bear, mink, wildcat, black-headed gull, kittiwake and great auk which may have been partly responsible for the accumulation. Supporting evidence for this theory includes discrete pockets of microvertebrate remains from the pond sequence in Q1/B in Quarry 1, adjacent to the GCR site, which contain a wide variety of small mammals, amphibians, reptiles, birds and fish and are consistent with the diet of the mink. Unit 4d from the upper part of the pond sequence in Q1/B produced the richest fish assemblage from the site. *Gasterosteus aculeatus* dominates with a minor contribution from *Platichthys flesus*, *Anguilla anguilla* (European eel) and a salmonid (Parfitt and Irving, 1999).

7.2.4.2 Herpetofauna

At least nine species of amphibians and reptiles have been recorded from the terrestrial sequence, notably from the palaeosol, unit 4c (Holman, 1992; 1999). These include *Lissotriton helveticus* (palmate newt) or *L. vulgaris* (common or smooth newt), *Pelobates fuscus* (common spadefoot toad), *Bufo bufo* (common toad), *Epidalea calamita* (natterjack toad), *Rana arvalis* (moor frog), *R. temporaria* (common frog), *Anguis fragilis* (slow worm), *Zootoca* cf. *L. vivipara* (common or viviparous lizard) and *Natrix natrix* (grass snake). Two of these species, the common spadefoot toad and the moor frog are not native to Britain today. Taken together it suggests the presence of pools where the newts, toads and frogs would be able to breed with surrounding vegetation cover that would also support the slow worm and viviparous lizard. The common spadefoot toad has quite narrow habitat requirements since it is fossorial and prefers to burrow in sandy friable soils (Eggert et al., 2006) and is also intolerant to salinity during early ontogeny (Stănescu et al. 2017). The natterjack toad also prefers sandy or heathland habitats which together suggests an environment with freshwater pools and sandy areas in the vicinity (Holman, 1999).

Sinka (1993) used the slow worm, common frog, moor frog, common toad, common spadefoot toad and smooth newt to perform a MCR analysis on the Boxgrove herpetofauna. The mean temperature of the warmest month (T_{max}) ranged between 15-24° C; the mean temperature of the coldest month (T_{min}) was between -12 to +4°C; and the reconstructed mean annual air temperature (MAAT) 2-13°C.

Since the original monograph, additional species have been identified from the pond sequence at Q1/B, adjacent to the GCR site, by the late J.A. Holman including *Triturus cristatus* (crested newt), *Pelophylax* (*ridibundus*) sp. (indeterminate European water frogs), *Pelodytes punctatus* (common parsley frog) and *Coronella austriaca* (smooth snake). These additional species have not been added to the herpetofauna MCR but it is thought they would be unlikely to change the reconstructed temperatures significantly (Holmes et al., 2010).

7.2.4.3 Avifauna

Boxgrove has the largest open-air avifauna from the British Middle Pleistocene. The remains are fragmentary and fragile, often single incomplete bones. Despite this the site has yielded a bird fauna of 19 taxa including waterfowl, seabirds, songbirds, a gamebird, a wader, an owl and a swift (Harrison and Stewart, 1999). Waterfowl dominate the assemblage in units 4c-d at the waterhole site in Quarry 1, adjacent to the GCR site, whilst smaller birds, mostly passerines, were more abundant in Quarry 2, perhaps the result of an avian predator. Of interest is the occurrence of *Pinguinus impennis* (great auk) from unit 4c in Quarry 2 which may represent the oldest known record for this species. It was a flightless seabird with a distribution covering the cold and temperate parts of the North Atlantic Ocean (Harrison and Stewart, 1999).

7.2.4.4 Mammalian remains

The majority of the faunal remains were recovered from the terrestrial units of the Slindon Silt, units 4c and 5a, and from the base of the Eartham Lower Gravel Member comprising the palaeosol and cliff collapse.

Whilst containing marine fish remains, the mammalian fauna of the Slindon Sand Member is relatively sparse comprising only 3 species, *Cervus elaphus* (red deer), *Apodemus sylvaticus* (wood mouse) and *Microtus* cf. *subterraneus* (European pine vole). The bones are generally rolled or abraded, consistent with transport and deposition in a marine environment. A fragment of red deer tibia from the top of the Slindon Sands is well preserved and shows cut marks and marrow fracture impact damage suggesting sporadic human use of the foreshore perhaps during low tides.

Units 4a and 4b within the Slindon Silt Formation formed in a mud flat/lagoonal environment and again the mammalian remains are sparse. However, the majority of large mammal bones are unweathered and are found in discrete clusters with flint knapping debris. They show cut marks and marrow fracture and probably represent short-lived episodes of tool manufacture and butchery. Small mammal remains occur throughout these two units, some showing evidence of digestive corrosion suggesting an avian predator could have been involved in these bone accumulations. Fish bones tend to dominate in the lower unit whilst the upper is dominated by small mammal bones suggesting a change from marine to more terrestrial environments. Sixteen species of small mammals have been recovered from unit 4b including *Arvicola terrestris cantiana* (water vole) and *M.* cf. *subterraneus*, the majority of which suggest open grassland. However, the presence of *A. sylvaticus* and some of the larger mammals such as *Capreolus capreolus* (roe deer) and *Felis sylvestris* (wild cat) imply woodland or denser vegetation nearby (Parfitt, 1999). The taxonomic habitat index suggests a post-peak interglacial conditions for or this unit with mixed deciduous woodland but with a notable proportion of boreal and tundra elements.

Unit 4c, the thin calcaric-alluvial soil, contains the richest and most diverse vertebrate fauna at Boxgrove. There is an abundance of large mammal remains which are dispersed across the site with no signs of concentration. Their taphonomy is complex with indications of carnivore gnawing, subaerial weathering, post-depositional corrosion and evidence for human modification. Quite probably the fauna represents an attritional death assemblage accumulating on the land surface and buried within the upper soil layers. Refitting bone fragments are rare and along with evidence for carnivore gnawing and trampling damage it suggests the carcasses were dispersed by a variety of natural processes (Parfitt, 1999).

There is also an abundance of small mammal remains in this unit, again dispersed across the site although dense clusters of bones have been recorded from the margins of the waterhole in Q1/B, adjacent to the GCR site. Modifications including digestive corrosion of the teeth, rounding of bone fragments and tooth puncture marks indicate that these concentrations of bones resulted from a mammalian predator. The range of prey species including fish, amphibians, reptiles, birds and small mammals suggests *Mustela lutreola* (European mink) as the likely cause.

Overall, the small mammal assemblage from unit 4c suggests a mosaic of habitats in the vicinity of the site including grazed grassland, scrub, woodland and open water. Remains of *M.* cf *subterraneus*, *M. agrestis* (field vole), *M. arvalis* (common vole) suggest open grassland. The presence of *Myodes glareolus* (bank vole) and *A. sylvaticus* which are well represented suggests temperate mixed woodland conditions. Other woodland species are common including the arboreal *Sciurus* sp. (squirrel), semi-arboreal *Sicista* cf. S. *betulina* (birch mouse), *Muscardinus avellanarius* (hazel dormouse) and *Meles* sp. (badger), *Capreolus capreolus* (roe deer) and *Dama dama* (fallow deer). *Myotis mystacinus* (whiskered bat) and *Myotis bechsteinii* (Bechstein's bat) also suggest mixed deciduous woodland. Soil micromorphology of unit 4c (Macphail, 1999) suggests open grassland in front of the cliff line and it is likely that grazing by large herbivores limited colonisation by scrub and woodland.

Aquatic environments are indicated by species such as *A.t. cantiana* (water vole), *Neomys* sp, (water shrew), *Microtus oeconomus* (northern vole) and especially *Mustela lutreola* (European mink). The water hole sequence at Quarry 1/B, adjacent to the GCR site, may have provided just such a suitable habitat for the species.

The taxonomic habitat index for unit 4c suggests a temperate mixed coniferous-deciduous woodland environment though with the small mammals suggesting indications of a cooler more continental climate than the present day with the area of maximum sympatry in the living species found in western Ukraine and eastern Poland (Parfitt, 1999).

In unit 4d of the water hole sequence, in Quarry 1, adjacent to the GCR site, fish remains, herpetofauna and water bird remains suggest slow-moving and/or still freshwater environments. The small mammal fauna comprises 11 species dominated by *A.t. cantiana* which would support this interpretation. There is also a diverse large mammal fauna which includes *D. dama* (fallow deer), an indeterminate cervid, *Stephanorhinus hundsheimensis* (extinct rhinoceros), *Panthera leo* (lion), and *Castor* or *Trogontherium* (beaver).

Unit 5a, the thin organic bed laid down in a fen-carr environment contains a similar mammal fauna to unit 4c though perhaps with slightly higher proportions of boreal and tundra elements implying climatic cooling. The first record of *Microtus gregalis* (narrow-skulled vole) at Boxgrove supports this suggestion; it is a species of tundra, steppe, mountain steppe and open areas in mountain forests. Otherwise, the presence of *D. dama*, *Capreolus capreolus*, *Plecotus auritus* (common long-eared bat) and woodland rodents such as *Castor fiber, M. glareolus*, *Muscardinus avellanarius* and *Eliomys quercinus* (garden dormouse) suggest woodland or dense scrub vegetation.

The lowermost subunit of the Eartham Lower Gravel Member (informal unit designations 6'20, LGC, GCF, 1129) is a silty clay with chalk pellets and abundant molluscs. The amalgamation of faunas from different excavation areas suggests it is rich in small mammal remains. Relatively common are *M. arvalis, M. glareolus* and *A. sylvaticus* and there are records of *M. avellanarius, S.* cf. *betulina* and *E. quercinus.* Taken together these suggest similar habitats to those inferred for unit 5a.

Overlying is a stratified series of angular chalk gravel derived from cliff falls interspersed with layers of rounded white chalk pellet gravel probably of colluvial origin. Whilst it contains artefacts, the large mammal fauna is sparse comprising *Cervus elaphus*, *Bison* sp., and possibly *Equus* sp. and the small mammal component is lacking (Parfitt, 1999).

Further from the cliff line the white chalk pellet gravels are replaced by a thin calcareous silty clay brickearth of the Eartham Upper Gravel Member (informal unit designation 6'3) resting on unit 5a. The small mammal fauna is dominated by boreal forest and tundra elements including *M. oeconomus* although woodland species such as *M. glareolus* and *A. sylvaticus* are present. Immediately overlying is a thin iron-stained clay unit (6'3'Fe), perhaps representing soil development, contains a small mammal fauna, indicating a return to temperate mixed woodland. It is dominated by *A.t. cantiana*, *M.* cf. s*ubterraneanus, M. agrestis, M. arvalis, M. glareolus* and also includes *M. avellanarius*. Species representative of cold or boreal habitats are absent.

Unit 5b the calcareous marl contained only one large mammal, *Canis lupus* (wolf), and a limited small mammal assemblage comprising 12 species including the first occurrence at Boxgrove of *Lemmus lemmus* (Norway lemming). The taxonomic habitat index distribution suggests a return to cold and more open conditions.

The brickearth beds of unit 6 contain rare large mammals, one of note is a member of the Caprinae which is only found in cold stage deposits in north-western Europe during the Middle and Late Pleistocene (Parfitt, 1999). The inference of cold conditions is also reinforced by the presence of *Clethrionomys rufocanus* (grey-sided vole), *L. lemmus*, *M. gregalis* and *M. oeconomus.* The taxonomic habitat index is therefore dominated by boreal/tundra elements, though there is a small contribution from deciduous woodland species.

7.2.5 Archaeology

Artefacts have been recovered throughout the conformable sequence, mostly *in situ* or with minimal amounts of post-depositional movement. Over ninety separate areas have been systematically investigated within the quarry complex and over half of these have produced artefact assemblages (Pope and Roberts, 2005). These are characterised by Acheulean handaxes dominated by finely made ovate and limande (elliptical) forms usually with tranchet (chisel-like) tips and their associated debitage; flake tools are rare (Pettitt and White, 2012). However, what makes the site exceptional is the remarkable preservation of the artefacts, some associated with butchery of large mammals, on temporary surfaces within Unit 4b and the slightly longer-lived paleo-landsurface represented by the soil horizon (Unit 4c) which developed on the Slindon Silt. Cut marks and impact damage indicative of butchery underlie secondary carnivore gnaw marks suggesting the Boxgrove hominins had primary access to complete carcasses and were able to defend them from scavengers. There is also the suggestion that a puncture mark on a horse scapula at GTP 17 in the GCR site of Quarry 2 may represent a projectile wound (Roberts and Parfitt, 1999; Pope and Roberts, 2005) which might indicate active hunting rather than confrontational scavenging, although this was questioned by Parfitt and Bello (2020). These rare conditions of a spatially extensive yet short duration palaeo landscape together with *in situ* signatures of hominin activity also allow interpretations to be made of patterns of individual behaviour (Pope, 2002; 2004; Pope and Roberts, 2005)

Experimental knapping and debitage analysis of the archaeological material have shown that both hard and soft hammers were used in the production of bifaces (Wenban-Smith, 1989; 1999). Wenban-Smith (1999) was able to distinguish between the use of hard stone hammers such as rolled flint beach pebbles, soft stone hammers such as cortical flint and soft organic hammers such as antler and bone. His analysis of archaeological samples suggested that soft organic percussors were commonly being used to thin and finish handaxes at Boxgrove. During the 1995-1996 excavations at Q1/B, adjacent to the GCR site, 36 bone and three antler hammers were recovered, the latter representing the earliest known occurrence of such tools prior to the Upper Palaeolithic (Pope, 2003; Stout et al., 2014; Bello et al. 2016).

A recent study on the entire handaxe and rough out sample from Boxgrove Q1/B, adjacent to the GCR site, using technological description, metrical analysis, geometric morphometry and experimental reproduction of shaping processes suggested that knapping strategies were flexible and adapted to the characteristics of the blanks. There seem to be no clear relationship between initial nodule or blank morphology and final handaxe shape; the symmetrical ovate may represent a favoured form at this time during the British Acheulean (Fig. 33, García-Medrano et al. 2019).

The first large area excavation took place between 1983-87 at Q2/A within the GCR site of Quarry 2 (Bergman and Roberts, 1988; Bergman et al. 1990; Roberts and Parfitt, 1999) approximately 250 m south of the former cliff line (Fig. 29b). A spread of debitage some 7 m across within the palaeosol (Unit 4c) yielded 1,236 flakes (>10 mm), four bifaces and two cores. Material representing all stages of biface manufacture from roughing out and thinning to finishing was recovered, though no complete reduction sequences were documented (Pope, 2002). One refit group represented the later stages of biface manufacture, though the finished tool was not recovered suggesting transport off-site. Conversely, the four bifaces were probably brought on-site in an already finished state, only one of them having flakes conjoinable to the tip suggestive of tranchet sharpening. Unfortunately, faunal remains were absent in this area due to decalcification (Roberts and Parfitt, 1999) so the tasks the tools were manufactured for remain unknown.

By contrast, the sediments in the 90 m² excavated area of Q1/A, adjacent to the GCR site, were largely calcareous, leading to good preservation of the faunal remains. Within Unit 4c, the majority (86%) of the lithic assemblage consisted of small fragments with a maximum dimension of less than 20 mm; only 317 pieces exceeded this threshold, over half showing varying degrees of patination (Austin et al., 1999). All stages of biface production were present in this horizon though perhaps with an over representation of thinning and finishing elements (Austin, 1994). No distinct knapping concentrations were identified; a more even scatter of artefacts being the norm. Five well-made ovate handaxes with tranchet tips were recovered, all without conjoinable flakes, suggesting manufacture elsewhere and transport on-site. The site probably represents accumulation of material following a number of short-term occupation events during which existing tools and roughouts were transported to the site for thinning and finishing (Austin et al., 1999; Pope, 2002; 2004).

Continued excavation down to unit 4b recovered fresh unpatinated lithic material usually comprising a low-density scatter. These included three already finished handaxes which were associated with fragmentary remains of *Megaloceros* sp. (giant deer) exhibiting cut marks to the teeth.

One remarkable discovery in unit 4b was a small, highly concentrated, intact knapping scatter some 0.25m ² in extent (Austin et al. 1999). The edges of the scatter were so clearly defined as to suggest the preservation of the outline of the knapper's legs and the accumulation of flakes on the inside of their right thigh. This geographical distribution suggests the knapper had been holding the hammer in their left-hand, with the original core/handaxe resting on the right thigh (Austin et al., 1999), though this interpretation of handedness has been questioned (Wenban-Smith, 1997). A small group of larger flakes were located some centimetres away from the rest, apparently put to one side during knapping, perhaps for future use as flake tools

In 1988 an area of 12,000 m² in Quarry 2 (designated as the GCR site) was identified as being under threat from sand and gravel extraction. A rescue excavation was organized, (Boxgrove Project B), and the area was sampled in 1989 with 17 test pits, each of 6 m² concentrating on the Unit 4c palaeosol (Roberts et al., 1997). The lithic assemblage was dominated by debitage from the later, thinning, stages of biface manufacture, though only two finished handaxes were recovered. Five tranchet flakes provided additional evidence for handaxe manufacture and/or use and could represent the final stage of manufacture or the resharpening of an existing tool. Two areas of higher artefact concentration were identified at TP/O-TP/L and TP/C which informed on the siting of larger area excavations Q2/C and Q2/D which were carried out in 1990 and 1991 respectively (Roberts et al., 1997).

Eight handaxes were recovered from Q2/C within the GCR site, along with percussors, cores, flake-tools and a large component of debitage relating to the later stages of biface manufacture. Included in the latter were 30 tranchet flakes suggesting biface edge preparation. Wenban-Smith (1989) suggested that typically 50-70 flakes >20 mm are produced from the manufacture of a single handaxe. Using the number of proximal pieces, he calculated the Minimum Number of Debitage (MND) at 751 which would mean between 10 and 15 tools could have been manufactured. The fact that only eight were recovered along with the large number of tranchet flakes may suggest that some bifaces finished at the site were subsequently transported elsewhere (Pope, 2004).

No cores or bifaces were amongst the 751 lithic artefacts recovered from Q2/D within the GCR site though their original presence is indicated by 11 tranchet flakes. The Minimum Number of Debitage was calculated at 480 suggesting between 6 and 10 bifaces had been manufactured and subsequently exported (Pope, 2004). A further interesting find was that a higher proportion of the debitage was from primary reduction compared to Q2/C which is surprising since the latter is some 30 m closer to the source of raw material at the cliff line.

GTP 17 in Quarry 2, which became known as the Horse Butchery Site, was excavated between 1997-1991 as part of Boxgrove Project C. The site represents a short-term butchery locality within unit 4b, with all the lithic artefacts linked to the processing of a single horse carcass (Pope, 2004; Pope and Roberts, 2005) which has recently been written up in more detail by Pope et al. (2020). Artefacts were widespread through the sequence with 325 flakes and bifaces in units 4c and 5a. Continued excavation revealed lithic artefacts associated with a fine-grained horizon within Unit 4b probably representing a temporary inter-tidal surface. Here, eight *in situ* knapping scatters were found in association with the butchered remains of a single horse. Pope et al. (2020) show that multiple phases of activity can be recognized as the horse was processed, associated with different phases of tool manufacture and use. For example, refitting of RG50 shows movement and modification of a tool, with flakes removed from the tip. The stratigraphic setting of the Horse Butchery Site is crucial to understanding patterns of movement of material through the landscape, since the rapid sedimentation in unit 4b means that previous artefacts were less available for reuse. All seven refit groups show on-site reduction of elements (three roughouts, one biface and nodules) that were transported to the site. The lack of recovery of any of the bifaces suggested also subsequent removal off-site (Pope, 2004; Pope and Roberts, 2005). Analysis of refit distances for some of the groups suggests movement of flakes by individuals and the use of flake tools as well as bifaces, either in the butchery process or at a later date (Pope et al., 2021). Two bone tools were recovered from the site – an acetabulum percussor and an ilium percussor. Analysis of wear marks suggests that both were used in retouching and sharpening bifaces (Parfitt and Bello, 2020). A small fragment of a flat piece of bone (specimen F182) is newly reported and suggested to be the broken tip of a hide-working tool (*lissoir* – Parfitt and Bello, 2020). New analysis of the taphonomy of the horse remains (Parfitt, 2020) suggests that the horse was between 4 and 5 years old, weighed c. 700 kg and was butchered on a dry land surface. Furthermore, it is clear that both death and the complete butchery sequence took place *in situ*, with intensive filleting, but also breakage of marrow and cancellous bones to extract bone marrow and juices. Whilst there is some evidence of poor health in the dental records, the previously reported spear injury is not conclusive. Carnivore alteration to bones all post-dates the butchery, but after this, burial was rapid because there is little evidence of exposure (Parfitt, 2020).

The early excavations of the Q1/B site, adjacent to the GCR site, in 1987-88 are reported by Austin et al. (1999), the archaeology recovered during this period being derived from Units 4c and d. An area totalling 120 m² was opened in four 5m x 6m trenches numbered consecutively from the west. The two easternmost trenches were only partly excavated and a further fifth trench was opened in 1993. A total of 706 flint artefacts >20 mm were recovered, mostly from the two westernmost trenches, including cores, percussors, flakes and eight handaxes. None of the debitage, apart from three removals from one handaxe, related to the handaxes recovered in this area suggesting it derives from the production of tools which were transported out of the area. Refitting suggested that at least three knapping events took place in Trench 2, probably spread out over a period of time, suggesting it was a favoured location (Austin et al., 1999).

The three easternmost trenches displayed a more complicated stratigraphy comprising highly calcareous waterlain silts, unit 4d, interdigitating with and therefore time correlative with the palaeosol unit 4c. During late 1993 with the excavations winding down, Roger Pedersen excavated 1.5 m spits at the northern end of each of the Q1/B trenches and in December found a hominin tibia in the upper levels of Trench 5 (Pitts and Roberts, 1997). This momentous discovery led to further investigations during 1994 and two seasons of more extensive large area excavations in 1995 and 1996 (Austin et al., 1999; Pope, 2002).

The full detail of the 1993-1996 excavations at the Q1/B Waterhole Site, adjacent to the GCR site in Quarry 2, remains to be published but in brief, about 20,000 lithic artefacts were recovered alongside the butchered remains of large mammal species, including rhinoceros, bovids, horse and deer, largely concentrated in the freshwater deposits (Pope, 2002). Within unit 4u there seems to be an over representation of bifaces with 74 (3% of MND) recovered suggesting this was a favoured place for biface discard probably representing a regularly exploited location spanning between about 20-100 years (Pope, 2004; 2005). This contrasts with the single event recorded at the Horse Butchery Site (GTP 17 in Quarry 2, within the GCR site) where bifaces were removed from the site (Pope, 2005).

Micro-wear analysis on about 400 handaxes from Q1/B identified use traces suggesting they were used for butchery tasks (Mitchell, 1997). These traces together with the morphology of cut marks indicate they were used with a slicing action to process large mammal carcasses (Bello et al. 2009) including rhinoceros, bison, horse, giant deer and red deer. There are very few cut marks recorded on bones from smaller animals such as roe deer suggesting these may have been transported elsewhere intact (Roberts et al., 1997).

Comparisons of cut marks on fossil mammal remains from Boxgrove with experimental butchery of a roe deer using a replica handaxe showed the latter to have been shallower with a more acute cross-sectional angle and smaller floor radius. Bello et al. (2009) suggest this could be due to greater robusticity of *Homo heidelbergensis* imparting more force during butchery compared to modern humans.

7.2.6 Human remains

In December 1993 an almost complete hominin left tibial diaphysis, Boxgrove 1, was discovered by Roger Pedersen from within unit 8ac in Trench 5 (Figs 29, 34a) within the waterhole site in Quarry 1/B, adjacent to the GCR site in Quarry 2. This unit comprises a complex sequence of poorly sorted silts and chalky gravels with a restricted distribution that were deposited during the final temperate stages of the Eartham Lower Gravel. The sediments were probably laid down either by fluvial activity or as a mudflow and were subsequently modified by cryoturbation. The Boxgrove tibia has been assigned to non-modern *Homo* sp. with further reference to *Homo* cf. *heidelbergensis* on temporal and geographical grounds (Stringer et al., 1998).

The tibia, lacking epiphyses, was reassembled from four major proximal portions and two distal separated by a clean transverse break close to the midshaft with two smaller proximal pieces also preserved (Stringer and Trinkaus, 1999). The surface of the bone is largely well preserved, though there are areas of modification including surface polish, pits, furrows, scratches and incisions. The surface polishing may have been produced by abrasion during sedimentation or post-burial during pedoturbation. The distribution, morphology and location of the pits and furrows close to the articular end and the loss of epiphyses and thin compact bone at the end of the diaphysis is suggestive of carnivore damage. Finally, the scratches and incisions closely resemble marks produced during trampling by large mammals (Stringer et al., 1998).

Using proximal and distal landmarks on the tibia and a reference collection of archaic and modern *Homo* tibiae an estimate of 373 mm was derived for the articular length which provides an average stature estimate of 175.3 cm (Stringer et al. 1998). The tibia showed a pattern of robusticity with minimal overlap between Early/Middle Pleistocene archaic *Homo* specimens, Neanderthals and early modern humans suggesting exceptional diaphyseal strength and/or cold-adapted body proportions. Using a maximum tibial length estimate of 397 mm and a hyperarctic model of body proportions, Trinkaus et al. (1999) suggested a body mass of about 90 kg. Histomorphometric analysis of one of the smaller proximal fragments of bone suggested an age at death of 39.5 years with a range of 31-48 years (Streeter et al., 2001).

During 1995 two hominin permanent lower front incisors, Boxgrove 2 and 3 (Fig. 34b), were also recovered within the Q1/B sequence adjacent to the GCR site in Quarry 2 (Hillson et al., 2010). The teeth were recovered from the base of a shallow channel (Boxgrove 2 from unit 4C in Trench 9 and Boxgrove 3 from the lower contact of unit 4 at the junction with unit 3M, also in Trench 9 – Fig. 29). Subsequently in 1996 a small fragment of root apex that refits to the Boxgrove 2 incisor was recovered through wet sieving of spoil (unit 4u from Baulk 9-10). Boxgrove 2 was interpreted as a permanent right central incisor and Boxgrove 3 a permanent left lateral incisor. The similar degree of wear, their recovery and close proximity and morphological similarities indicate they probably come from one individual (Hillson et al., 2010) but their stratigraphic position being earlier in the succession than the Boxgrove tibia suggests the teeth and bone are unlikely to come from the same individual.

The broken end of Boxgrove 2 exposed a transverse section of the cement, dentine and root canal which is partly filled deposit of secondary dentine consistent with a middle-aged adult. Extensive calculus deposits on the labial side of both teeth running down the root surface suggests a dehiscence fully exposing the roots. There is polishing and scratching of the labial surfaces of crown and root implying hard objects came into contact for almost the full height of both teeth including the roots. Two groups of scratches have been distinguished. Firstly, fine scratches 50-200 µm in length and less than 20-30 µm in width (microware) that are the only scratches present on the lingual surface of both incisors assumed to be related to the mastication of food. Secondly, coarser scratches, greater than 248 µm in length and 25 µm in width, on the labial crown and root surfaces which are non-masticatory and are consistent with incisions made by the edge of a stone tool. The coarser striations on the root were predominantly right oblique orientated and may imply right handedness (Hillson et al., 2010).

Further analysis using an Alicona 3D InfiniteFocus imaging microscope (Bello, 2011) suggested there were three types of non-masticatory scratches; straight scratches on the enamel of the crowns, semicircular scratches on the enamel also on the crowns and wider and deeper scratches on the roots, all consistent with having been made by a stone tool. Cross-sectional analysis of the straight scratches on the crown suggests the tool was held almost perpendicular to the tooth surface and probably used in a vertical motion. This would be consistent with cutting up food or other materials that were held between the front teeth with occasional penetration of slippage leading to tooth damage. The cross-sectional profile of the wider and deeper root scratches again suggests the tool was held almost perpendicular to the root surface but produce irregular, deeper, wider cuts. Their greater dimensions may be explained by differences in the hardness of the dentine and enamel or perhaps stronger cutting action (Bello et al., 2009). Profile analysis of the semi-circular scratches on the grounds suggest the tool was held at an acute angle to the surface of the tooth producing wide but shallow cuts. They have a different shape, dimensions and orientation which suggests that a different action was employed. They cut across all other non-masticatory scratches, possibly suggesting they were made post-mortem. Bello (2011) notes that similar cuts on the roots of red deer teeth from Upper Palaeolithic sites in Britain have been attributed to butchery activity. She postulates that the semi-circular scratches were possibly the result of post-mortem treatment of the body or cannibalistic ritual.

7.3 Interpretation

The sedimentary sequence at the site represents the regressive sequence of the Slindon Formation preserved on a shore platform cut into the Cretaceous Chalk by later coverage with the slope deposits of the Eartham Formation (Table 6). The nearshore marine sands of the Slindon Sand are succeeded, probably as sea level fell, by the intertidal laminated muds of the Slindon Silt. The latter is interpreted as having been laid down in a semi-enclosed marine bay, on the basis of both the laminations suggesting very still water between tides and also the mapped extent of the deposits (Fig. 30). To the west, at the water hole site of Q1/B outside the GCR site, there is a more complex sequence of freshwater deposits that are interpreted as freshwater reworking of intertidal sediments, capped with calcrete-rich deposits suggesting spring activity. Th Slindon Sand and Silt sequence is best developed in the GCR site at Quarry 2. The upper part of the Slindon Silt represents further regression and the terrestrialisation of the intertidal sediments, with the formation of a soil horizon overlain by organic deposits interpreted as having been laid down in a fen carr environment with alder trees. Human activity at the site is strongly concentrated into this time period, although also evident at lower levels. The Eartham Formation (Lower and Upper Gravels) is interpreted as a complex series of mass movement deposits, including cliff collapse sediments. Evidence of periglacial activity in upper parts of the deposit suggests that they were partly laid down in a glacial environment.

The environment during the deposition of the Slindon Sand is not unexpectedly that of a rocky shore platform, possibly with mussel beds, based on marine mollusc records. The climate during deposition of the Slindon Sand is that of a fully temperate interglacial, evidenced by southern foraminifera and ostracod species (although there are also some northern ostracod species). Summer temperatures may have been similar to today and winter temperatures at least 1°C cooler (MOTR analysis). Salinity may not have been fully marine, even at the base of the sequence, because of the presence of freshwater ostracods.

The environment during deposition of the Slindon Silt is suggested from mollusc evidence to be a moist, well-shaded land surface with occasional pools, with both bare mud and drier open ground in the near vicinity. The fish species found suggest both shallow freshwater environments and saltwater lagoons, except for two possibly transported open water species. During deposition of the water hole sequence at Q1/B, outside the GCR site, the environment was also fully temperate, but here it was freshwater. The ostracods suggest permanent, small, shallow freshwater ponds regularly visited by waterfowl and probably fed by springs from the base of the cliff or by groundwater seepage with rich aquatic vegetation. MOTR analysis suggests that summer temperatures may have been similar to today, but winter temperatures may have been the same, or maybe colder.

The environment during deposition of the palaeosol and alder carr at the top of the Slindon Silt (unit 4c) was similar to that of the Slindon Silt as a whole, with evidence of both terrestrial and aquatic environments and both salt- and freshwater (e.g. in the fish remains). The mammalian evidence suggests a mosaic of terrestrial habitats including grazed grassland, scrub and temperate mixed woodland. Increasing freshwater influence is suggested by the presence of the natterjack and spadefoot toads, who prefer freshwater pools and sandy soils. MCR analysis of the herpetofauna suggests summer and winter temperatures similar to the present day.

The only environmental evidence from the Eartham Formation is from the mammal remains. These show a gradual increase in boreal and tundra elements suggesting climatic cooling, with a slight increase in temperate-mixed woodland within unit 5a before returning to boreal conditions, with more open conditions in units 5b and 6 and evidence of cold climates.

It is the archaeology that is the most significant feature of this site, in addition to the tibia and incisors that show direct evidence of hominin presence which were found in Quarry 1 outside the GCR site in Quarry 2. Artefacts are characterised by Acheulean handaxes, mostly ovate in form; flake tools are rare (Pettitt and White, 2012), but may have been in use at selected locations (Pope et al., 2021). These artefacts are extremely well preserved in primary context, showing evidence of tool manufacture locations and butchery of large mammals, on temporary surfaces within unit 4b and the soil horizon (unit 4c) which developed on the Slindon Silt. Cut marks and other evidence of butchery underlie secondary carnivore gnaw marks suggesting the Boxgrove hominins had primary access to complete carcasses and were able to defend them from scavengers. The completeness of this site allows behavioural interpretations to be made that are not possible from other locations.

The sequence clearly records an interglacial period followed by a glacial period, but there has been significant debate about what age this interglacial period was. A wide array of dating techniques has been employed at the site with varying success including uranium series, TL, OSL, electron spin resonance, AAR, palaeomagnetism, calcareous nannoplankton biostratigraphy and mammalian biostratigraphy which gave results ranging between MIS 6 and 13 (Roberts and Parfitt, 1999). A more recent programme of ESR dating of quartz grains from the Slindon Sand at the Valdoe, a site considered to be equivalent in age to Boxgrove, gave mean dates falling within MIS stages 11 and 10 which at first would appear problematic. However, there are large error margins associated with these dates meaning that they overlap with the later part of MIS 13 (Voinchet et al., 2015).

The currently accepted ages are a late Cromerian Complex MIS stage 13 for the temperate deposits of the Slindon Formation and an Anglian MIS 12 stage for the overlying sediments of the Eartham Formation based on mammalian biostratigraphy (Roberts and Parfitt, 1999). The Cromerian Complex contains at least five separate temperate biostratigraphic assemblages (Preece, 2001; Preece and Parfitt, 2000, 2008, 2012), all of which are thought to have normal magnetic polarity. The Brunhes-Matuyama boundary is currently placed at about 770 ka (late within MIS 19) which suggests the British Cromerian sites date from MIS 17-13 (Candy et al., 2015).

The mammalian biostratigraphic age estimate is based on multiple strands of evidence. Firstly, a pre-Anglian age for the Slindon Formation is suggested by the presence of shrews *Sorex runtonensis*, *Sorex savini*, the vole *Pliomys episcopalis*, the cave bear *Ursus deningeri*, rhinoceros *Stephanorhinus hundscheimensis*, and the giant deer *Megaloceros dawkinsi* and *M.* cf. v*erticornis*, all of which became extinct during the Anglian, MIS 12 (Roberts and Parfitt, 1999). Secondly, a date later in the Cromerian Complex is indicated by the small form of the extinct mole *Talpa minor*, the appearance of the field vole *Microtus agrestis* (Roberts and Parfitt, 1999) and the presence of a larger form of the caballoid horse (Lister et al. 2010).

Thirdly, the presence of the water vole *Arvicola terrestris cantiana* and the absence of its ancestor species *Mimomys savini* can also be used to constrain the age estimate. Transitional forms between *Mimomys* (which has rooted molars) and *Arvicola* (which has continuously growing molars) have been dated to about 610 ka at Isernia in Italy and Mauer in Germany (Coltorti et al., 2005; Wagner et al., 2010) suggesting a late MIS 15 date. Therefore, pre-Anglian sites that contain *A. t. cantiana* are likely to be restricted to late MIS 15 or 13 (Candy et al., 2015).

Whittaker and Parfitt (2017) suggest that the Slindon Silt is coeval with the Steyne Wood Clay at Bembridge based on many ostracod species common to both sites, including *Leptocythere steynewoodensis* and *Baffinicythere howei*, and their similar present altitude at about 40 m O.D. Unlike Boxgrove, at Steyne Wood, pollen and plant macro fossils are well preserved with high pollen frequencies of *Picea abies* and *Pinus sylvestris* with *Abies* and lower proportions of deciduous trees including *Betula*, *Quercus*, *Ulmus* and *Alnus* (Holyoak and Preece, 1983; Preece et al., 1990). Among the plant macro fossils was *Ranunculus hyperboreus* (arctic buttercup) suggesting colder climatic conditions. Both sites therefore seem to represent the post-temperate stage of the same interglacial, presumably MIS 13, characterised by marine regression and climatic cooling.

Finally, the lithic archaeology may provide an estimate of age. Candy et al. (2015) argued that all British pre-Anglian sites with Mode II Acheulean lithic technology date to MIS 13 and early MIS 12, based on a combination of lithostratigraphy, biostratigraphy, modern aminostratigraphy (Penkman et al., 2013) and uplift modelling (Westaway, 2009). Support for this idea may be provided by White et al. (2018) who suggest the first securely dated British Acheulean handaxes occur in late MIS 13 contexts at sites such as Boxgrove, Waverley Wood and Warren Hill and are all exclusively of Roe's Group VII less-pointed ovate tradition (Roe, 1968, 1981). To this list could be added the ovate handaxe from Happisburgh Site 1 (Lewis et al., 2019). This raises the possibility that the finely made symmetrical ovate and limande handaxes may have temporal significance and perhaps were the customary and preferred form at this time in the British Acheulian (White et al., 2018).

Preece et al. (1990) calculated uplift rates of between 5.3 and 10.3 mm/ka for the Solent area since MIS 13 based on an altitude of 40 m for the marine deposits at Steyne Wood and Boxgrove, a maximum of +10 m and minimum of -10 m for the interglacial global eustatic sea level from a correlation of raised coral terraces and the marine oxygen isotope record (Chappell and Shackleton, 1986; Shackleton, 1987), a midpoint age of 487 ka based on the sedimentation rate timescale of Shackleton and Opdyke (1973; 1976), and modern tidal range values. Similar rates (13 mm/ka at 600 ka, decreasing to 7.5 mm/ka at the present day) were calculated by Westaway et al. (2006), using tiepoints of upper surfaces and altitudes as follows: Boxgrove, 42 m O.D., MIS13a; Aldingbourne, 25 m O.D., MIS 9 or earlier; Norton, 10 m, late MIS 7; Pagham (Selsey West Beach), 4 m, MIS 5e.

MIS 13 (533-478 ka) is considered globally to be the coolest interglacial of the last 800,000 years

(Lang and Wolff, 2011). It occurred after the Mid-Pleistocene transition (MPT) 1.2 – 0.6 Ma during which glacial-interglacial cycles shifted from 41 to 100 ka (Shackleton and Opdyke, 1976; Pisias and Moore, 1981; Clark et al. 2006; McClymont et al. 2013). It also occurred before the Mid-Brunhes Event at about 450 ka when there was an increase in the amplitude of glacial cooling and interglacial warming (Jansen et al., 1986; EPICA Community Members, 2004; Lang and Wolff, 2011). However, there remain questions about how these events impacted on climate and environmental change at the regional scale in NW Europe (Candy et al., 2015). A recent study using a regional reconstructed sea-surface temperature series suggests MIS 15-13 experienced the longest period of consistently warm conditions in the last 1 million years in the northeast Atlantic (Candy and Alonso-García, 2018). This long period of relative warmth may have influenced the spread of hominin groups into NW Europe and coincides with a major proliferation of archaeological sites in the region. (Hosfield, 2011; Candy et al., 2018; Moncel and Ashton, 2018).

7.4 Conclusion

Eartham Pit, Boxgrove is an internationally important Middle Pleistocene site for its geology, palaeontology and Lower Palaeolithic archaeology. Meticulous excavation since 1982 and the myriad of multidisciplinary post-excavation studies have developed a corpus of material whose quantity, range, depth and quality of preservation has few peers globally. The GCR site in Quarry 2 is located immediately to the south of a fossil shoreline, a buried Chalk cliff forming the northern boundary of the site. Banked against this cliff is an extremely complex sequence of deposits showing firstly sea level regression from near shore marine sands to intertidal silts (Slindon Sand and Silt Members of the Slindon Formation), then land surface stabilisation (at the top of the Slindon Silt Member) with a concentration of archaeological and environmental finds, then an overlying series of mass movement deposits of various types (Eartham Formation). Most importantly, the finer-grained intertidal sediments, where they are deeply buried and thus not decalcified, contain an extensive interglacial small mammal fauna, while large mammals, other vertebrates, molluscs and other microfauna also occur. Palaeolithic artefacts of a well-developed Acheulian culture are found throughout the sequence, but their most important occurrence is on an occupation horizon at the top of Slindon Silt, where they appear to be in primary context. Further evidence of hominin presence at the site is found in a hominin tibia and incisors that were collected from the 'water hole site' Q1/B, adjacent to the GCR site in Quarry 2, in the late 1990s. The age of the site is widely recognised on biostratigraphic grounds to correlate to MIS 13, during the latest Cromerian. The combination of an early-Middle Pleistocene age and a well-developed Acheulian culture with *in situ* archaeological material has major implications for Pleistocene and Palaeolithic chronology in Britain and in Western Europe and makes the Boxgrove site one of the most important British Pleistocene sites.

8. GCR Site 789 Black Rock (**TQ 339 033)** CAW, RMB, DCS

8.1 Introduction

Black Rock has attracted scientific interest for more than 180 years. It contains the only visible exposure of the Brighton-Norton Raised Beach (second lowest in altitude of the raised beach sequence in the Sussex Coastal Plain) and also a very comprehensive sequence of cold-stage solifluction deposits overlying it, which contain a rare cold-stage mammal fauna. The site is located at the eastern extremity of the West Sussex Coastal Plain where a fossil cliff at the back of the plain intersects the current cliff line (Fig. 35). The significance of the site is as part of the 'staircase' of marine deposits on the coastal plain that includes the other GCR sites at Boxgrove and Selsey, whose age and relationships have been extensively explored since the 1980s (e.g. Shepherd Thorn et al., 1982; Lovell and Nancarrow, 1983; Bates et al., 1997, 2010). The fossil evidence has also been reinvestigated by Schreve (1997) and Parfitt et al. (1998), although the stratigraphic context of museum specimens is often not recorded in detail. There are no modern detailed descriptions of the Black Rock site, with many publications relating to Black Rock being substantially derived from nineteenth and early twentieth century work (Parfitt et al., 1998, Hutchinson and Millar, 1998). There is significant potential for detailed investigation and dating of the cold-stage deposits to more effectively determine their age and mode of deposition.

8.2 Description

The first mention of the stratigraphy at the Black Rock site is often attributed to Mantell (1822), but he was preceded by Daniell (1818) who described the original exposures, which at that time, extended from the Old Steyne in the centre of Brighton eastwards as far as Rottingdean (Mantell, 1822, 1833; Tylor, 1869). Daniell reported a section with solid Cretaceous chalk at the base, overlain, in turn, by a bed of generally cemented shingles (2.4 – 3.0 m thick), consisting chiefly of rounded flint but with erratics of granite, slate and porphyry, “the product of the agitation of waters” (p. 231), and a thick bed (24.27 – 30.33 m) of “calcareous matter of loose texture” (p. 227), the latter containing angular flints, pieces of chalk and blocks of very hard siliceous sandstone (sarsens), and interpreted as “the result of confused and disturbed deposition” (p.23 ibid). Daniell also reported increasingly abundant chalk clasts in the “calcareous matter” towards the east, and some in the shingle, features reflected in the current exposure close to the buried cliff. With the exception of an involuted layer at the top of the section, Daniell’s original description was remarkably accurate and is still observable.

However, it was Mantell (1822) who characterised the “former cliff’, interpreted the shingle as an “ancient beach” and corrected Daniell’s mistaken view that flint veins traversed all three units. Mantell recorded 0.91 – 1.22 m of fine sand, beneath 1.50-2.44 m of shingle, resting directly on a shore platform cut into Chalk. The shingle consisted of rounded flint pebbles with a variety of erratics (including granite, porphyry, slate, limestone, Eocene sandstone and breccia) and some masses of broken shells. The upper part of the shingle was cemented. The shingle was overlain by 15.2 -18.3 m of chalk debris, “formed of the ruin of the chalk strata, with an admixture of clay” (Mantell, 1833, p. 31). Mantell (1833) subsequently referred to this unit as the “Elephant Bed” (the “Elephant-breccia” or “Brighton Breccia” of Murchison, 1851), after an elephant molar was found in a well in the deposit in 1822. Bones and teeth of “ox”, deer and horse were also collected although no systematic excavations have ever been undertaken at the site and fossil material appears to have been collected as and when new exposures became available.

Subsequent investigations have refined the stratigraphy and sedimentology of these early descriptions, especially in relation to the “Elephant Bed” or Coombe rock, and have added or subtracted units, partly in response to the retreat of the cliff. Lyell (1835) presented a section but added nothing to Mantell’s work. Murchison’s (1851) extended review of the flint drift of southeast England includes a discussion of the Black Rock site, with several references to Mantell’s work and a comparison with the modern beach, showing how “pebbles accumulated around large fragments of chalk, as in the old beach” (p. 365). Murchison’s section (1851) excludes the sand beneath the shingle of the raised beach but provides more detail of the overlying Coombe Rock, “which, from its brecciated and tumultuous condition, presents the most lively contrast to the [beach] ….. indicating that they must have resulted from violent dislocation” (p. 364). Above he refers to finer bedded sediments with alternations of yellowish sandy and whitish chalky materials with angular flints or “irregular layers of sandy and loamy detritus, with some flints, [that] have assumed fantastic forms” (p. 365). Some beds in the upper part of the Coombe rock are shown as overturned, though this type of structure is not apparent in the present-day exposure. Murchison (1851) recognized the following sequence from the surface down:

1. Alluvial soil
2. Upper flint drift
3. Irregular courses of sand and blocks of grey-wether-sandstone
4. Lower drift; in parts a very coarse chalk rubble with some flints, in parts fine laminae of sand and chalk-rubble
5. Old raised beach with rounded pebbles
6. Chalk with flints

Murchison (1851) also added *Rhinoceros tichorhinus* (= *Coelodonta antiquitatis*, woolly rhinoceros) to the fossil list from the “Elephant Bed” (Coombe rock or Brick Earth) and remains of woolly mammoth (*Mammuthus primigenius*) were described by Adams (1877-81).

Tylor (1869) depicted the raised beach resting against a mass of slightly rolled chalk debris and describes alternating beds of chalk clasts and very large beach-rolled flints. His depiction of the Coombe rock also shows its bedding to be overturned at the top, beneath a thin, horizontal "covering bed and gravel" (p. 80). Prestwich (1892) also shows overturning of the uppermost beds of the Coombe rock ("Head"). In addition, he was shown "a thin bed of fine pinkish marl, with indistinct vegetable impressions, having much the character of seaweeds" (p. 269) but could not relocate it later. Prestwich lists 22 types of rock found in the beach, other than flint. In a footnote he reports a personal communication from Mr W.J.L. Abbott who considered that some quartzite and quartz specimens he had found were ice-scratched. Prestwich (1892) argued that the erratics had an eastern provenance from the North Sea Basin, rather than a western provenance in southwest England or Brittany.

Martin (1910, p. 291) noted that between 1892 and 1897 the sand beneath the shingle decreased from 0.91- 1.21 m to "a mere trace, and since [the last date] has not again appeared, as the cliff has worn back. White (1924) summarised much of the earlier work, drawing attention to "a bold overturn, similar to that figured by A. Tylor in 1869 …. visible in the upper third of the cliff close to the Abergavenny Arms" (p.83) but also drew attention to old beach material interbedded with Coombe rock just above the junction between these two units, suggesting that "climatic conditions responsible for the latter deposit had set in before the close of the Brighton raised-beach epoch" (p. 74). There was little further interest until Zeuner (1959) mentioned a notch at the base of the buried cliff and referred to the raised beach as Monastirian at a level of +7.5 m above mean sea level. Kellaway (1967) was the first to note cryoturbations at the top of the cliff in the horizontally bedded sediments above the Coombe rock, a view shared by Williams (1987), though, in his three-dimensional perspective sketch of the site (Williams, 1971), the cryoturbations do not extend from the chalk area onto the coombe rock. Williams separated the coombe rock into three units, cliff fall debris at the base of the buried cliff, coarse and then fine head, the latter containing sarsens, a sequence subsequently repeated by Castleden (1982) and Parfitt et al. (1998). To this evolving stratigraphy, Kellaway and Shepherd-Thorn (1977) added a thin bed of wind-blown sand resting on the raised beach deposits.

The most recent depiction of the Black Rock sediments and structures occurs in the memoir of the British Geological Survey (Young and Lake, 1988, Fig. 36) as a scale field sketch. This omits the cliff-fall material but shows that the cryoturbations extend across the top of the coarse head. The depositional dip is different between the two deposits, which Keen (1995) records as 20^{o} for the lower coarse head and 10^{o} for the fine head. Keen (1995) proposed that a reddened palaeosol may be present in the surface of the lower coarse head but this has not been tested. Parfitt et al. (1998) note the lack of detailed descriptions of the sequence, but the scale and logistical challenge of doing this is such that there are still no detailed descriptions, nor any fully published age estimates of the site. A composite summary of the sediments recorded at Black Rock and shown on Figures 36 and 37 follows:

1. Topsoil
2. Pale fawn chalky debris with occasional sarsens over the fine head merging laterally into a cryoturbated (involuted) layer with a clearly defined base over the coarse head (Young and Lake, 1988)
3. Bedded fawn-brown fine-grained chalky debris with occasional large chalk blocks in the apparent form of a gentle syncline. Unconformable boundary with
4. Bedded pale fawn chalk debris dipping at about 10^{o}, generally fine-grained (fine head, Williams, 1971), though with occasional coarser layers near base. Unconformable boundary with
5. Very crudely bedded coarse chalk debris, dipping at about 20^{o}, in pale fawn chalky matrix (coarse head, Williams, 1971). Layer immediately below upper boundary considered reddened, possibly a palaeosol (Keen, 1995).
6. Sub-horizontally bedded, dominantly well-rounded flints with occasional erratic rock and some lenses of sand. Contains chalk blocks, some in a chalky matrix at the eastern end of the section (Figs 38 and 39).

7. Angular chalk blocks both at the base of buried cliff in the east and further west, intermittently underlain (i.e. not shown on Fig. 36 and exact locations not known) by blown sand (Keen, 1995) and a thin bed of fine pinkish marl (Prestwich, 1892).
10. Gently sloping eroded platform of *in situ* chalk.

The sediments contain important vertebrate and molluscan fossil evidence obtained both from the Black Rock site itself and from the cliffs to the west before they were obscured (Mantell, 1822; Murchison 1851; Prestwich, 1892; White, 1924). Cetacean (whale) bones *(Balaena mysticetus* in Murchison, 1851; *Balaenoptera borealis* (Lesson) in White, 1924) were recovered from the beach sediments, White specifying the sand beneath the shingle as the source. Key species recorded from both beach and overlying 'Coombe rock' deposits are *Equus ferus* (horse, both units), *Bison priscus* (bison, definitely from the Coombe rock, maybe from the beach) *Mammuthus primigenius* (woolly mammoth) and *Coelodonta antiquitatis* (woolly rhinoceros) (Table 7). The horse, in particular, is vital to the interpretation of the age of these sediments and environments in which they were deposited. Unfortunately, the potential value of the early collections is diminished because their precise provenance was often not recorded. However, some fossils have been provenanced to either the raised beach or the 'head' deposits by reference to archive records, museum catalogues or matrix adhering to the specimens. It seems likely that most of the mammalian remains came from the lower part of the chalky Coombe Rock deposits (bed 5 in the scheme above). This is based on the presence of lumps of pebbly conglomerate, which are frequently encountered adhering to the bones (Kellaway and Shephard-Thorn, 1977). Schreve (1997) and Parfitt et al. (1998) prepared a revised faunal list [following] a re-examination of the mammal remains in the Booth Museum of Natural History (Brighton), [the] Natural History Museum (London) and the British Geological Survey (Keyworth). The list of species (Table 7) is similar to that given by the nineteenth and early twentieth century authors with the important exceptions of *Sus scrofa*, *Hippopotamus amphibius* and *Cervus elaphus*, now removed from the list. Carreck (1972) notes that these records were probably in error since he was unable to trace the original specimens. Although there is a canine tooth of hippopotamus in the Booth Museum, this specimen was apparently recovered from a location to the north of the Brighton cliff line and is therefore likely to be of recent origin.

Fauna	Raised beach deposits	'Coombe rock'
Equus ferus (horse)	+	99 (4 juvenile, 3 adult)
Mammuthus primigenius (woolly mammoth)		9 (3)
Coelodonta antiquitatis (woolly rhinoceros)		4 (1)
Bison priscus (bison)	?	7 (2)
Cetacean (undetermined whale)	+	

Table 7. Mammal fauna of the Brighton Raised beach and associated deposits after table in Parfitt et al., 1998). Specimen numbers and Minimum Numbers of Individuals in brackets from Schreve (1997).

The beach material contains fragments of temperate climate marine shells, dominated by *Mytilus* sp. and also including *Cerastoderma edule* (Linne), *Littorina littorea* (Linne) and *Nucella lapillus* (Linne) (Parfitt et al., 1998). A more diverse range of species are reported from these deposits from a borehole in Worthing (Martin, 1937, cited in Young and Lake, 1988). Keen (1995) mentions amino acid ratios from the PhD research of Davies (1984) on shells within the beach that were indicative of an MIS 7 age, but full details have never been published. 10 samples were taken from beds 2-5 in 2005 for mollusc analysis (Whiteman and Keen, unpublished data), of which only 3 yielded shell and that of a restricted number of species (Table 8). Preservation was poor, likely due to decalcification, evidenced by the disproportionate number of remains of the more robust calcite plates of the slug species *Limax*.

The species preserved have quite a wide environmental tolerance and modern-day geographical spread. *Trichia hispida* and *Pupilla muscorum* both indicate open, dry ground, but *Vitrina pellucida* is found in marsh and wetland conditions. All these species are common in cold-stage faunas.

Species	Sample 2 (bed 2)	Sample 3 (bed 3)	Sample 6 (bed 4)
Pupilla muscorum (Linné 1758)	8		
Vitrina pellucida (Müller 1774)			1
Limax sp.	9	1	4
Trichia hispida (Linné 1758)	6	1	
Trichia sp.			1
Total	23	2	6

Table 8. Mollusc fauna from beds 2-4 at Black Rock, Brighton (Whiteman and Keen, unpublished data).

In addition, two handaxes were reported from the sections by Smith (1914). The first, which is pictured on Figure 40 and illustrated in Figure 1 of Smith (1914) was found by Mr W. Deane of Brighton and now located in the British Museum, having been found *in situ* in the beach deposits of bed 6. Smith (1914, p.3) notes that 'only the point of the implement was showing in the perpendicular face of the cliff, and it was still coated with hard sand when removed; hence there is no possibility of its having fallen from the overlying Coombe-rock, which has also yielded a palaeolith, now in Brighton Museum.' The handaxe from the beach is ovate, while that from the overlying Coombe rock was not described. Both could be considered part of a Late Acheulean technology.

8.3 Interpretation

The depositional processes forming the sequence at Black Rock are clear: erosion of the shore platform, followed by mass movement slope processes. Within the mass movement sediments, the coarser bed 5 probably results from cliff collapse. The finer beds 2, 3 and 4 are generally assumed to be due to various cold-climate subaerial solifluction processes (e.g, Young and Lake, 1988). The laminated nature of some of the finer sediments may reflect slopewash, and the coarser lenses higher-energy running water, perhaps within the now dry Whitehawk Valley (Fig. 40). There is also a clear shift from a marine environment in beds 6 and 7 to a terrestrial one in the overlying beds 1 to 5. A cold, humid environment in which frost creep was dominant could also account for the overturning of strata observed near the top of the coombe rock, though whether related to seasonal freezing or the decay of permafrost (Murton, 1996) is not certain.

When interpreting the environment represented by the vertebrate fauna, the species in the raised beach (beds 6 and 7) are too sparse to be useful. In the overlying Coombe rock (beds 2-5) Parfitt et al. (1998) interpret the species as indicating grassland conditions, probably the steppe-tundra environment common from the northern European Middle and Late Pleistocene cold stages. This is supported by the sparse molluscan fauna.

The question then remains of the age of the deposits. The Brighton-Norton cliff line can be traced west to Norton Farm (Fig. 1b), where OSL dating of marine sands have yielded a convincing MIS 7 age for the raised beach deposits (Bates et al., 2010). This would place the overlying Coombe rock into MIS 6. This is supported by biostratigraphic evidence. For example, the occurrence of horse in the raised beach itself indicates an age other than the Ipswichian Interglacial when this species is unknown (Sutcliffe, 1995; Currant and Jacobi, 2001). In addition, the remains of *Equus ferus* from the Coombe Rock deposits are of particular interest because of their small size. This is considered to be a feature of biostratigraphic significance, since it has been recorded in the late Middle Pleistocene only in cold-climate deposits immediately pre-dating the Ipswichian (Schreve, 1997). For example, the same reduction in body size has also been noted in *Equus* remains from cold-climate solifluction deposits between the MIS 5e and MIS 7 interglacial channels at Marsworth, Buckinghamshire (Murton et al., 2001), the basal sands below MIS 5e deposits at Bacon Hole, Gower (Currant et al., 1984) and at Norton Farm (Bates et al., 2000). A decrease in body size in these animals may be a direct response to worsening climatic conditions (Forstén 1996). The mammoth appears to be represented by a fully evolved morphotype, similar to those noted from other MIS 6 age sites (Lister and Brandon 1991).

AAR analyses by Davies (1984), if valid (McCarroll, 2002), add further support for an MIS 7 age for the beach. This would relate the Brighton-Norton beach at Black Rock to others to the west at Portland (Davies and Keen, 1985) and Torbay (Mottershead et al., 1987).

The distinctive unconformities in the coombe rock sequence and the variety of structures suggest multiple episodes of deposition. Given the age of the raised beach (MIS 7) these could have occurred in either or all of the cold stages MIS 6, 4 or 2. If the interpretation of the reddened palaeosol in the top of the coarse head unit is valid (Keen, 1995) the coarse head could date from MIS 6, the palaeosol from MIS 5e and the other cold environment deposits and structures from MIS 4 and/or MIS 2 (Parfitt et al. 1998). Micromorphological analysis of this horizon would be valuable.

8.4 Conclusions

The modern sea cliff at Black Rock obliquely intersects a fossil cliff and shore platform cut into Cretaceous Chalk that has been known of and reported since the early 1800s. The platform is overlain by raised beach deposits of sand and shingle which contain shell fragments and some vertebrates and are likely to date to the penultimate interglacial (MIS 7) by correlation with OSL dated sands further west at Norton Farm. Overlying the beach deposits are a complex sequence of solifluction and mass movement deposits, referred to as 'Coombe rock' in the literature, the lowest comprising coarse chalk rubble apparently derived from the weathering and erosion of the cliff. Above this, chalk muds, and fine chalk gravel and grit, are banked against the rubble on the west, probably relating to solifluction under periglacial conditions, given the involutions also observed at the top of the sequence. The 'Coombe rock' is particularly notable for the fossil remains of four key cold-stage mammals, *Equus ferus, Mammuthus primigenius, Coelodonta antiquitatis* (woolly rhinoceros) and *Bison priscus.* These have been dated to the penultimate cold stage (MIS 6) biostratigraphically, particularly because of the small size of the *Equus* specimens. The landforms, stratigraphy and mammal remains at Black Rock have the potential to provide an extremely valuable record of former sea levels and changing environmental conditions during one or maybe more cold stages. At present, relatively little is known of the sediments overlying the beach, though these are some of the finest exposures of cold-climate deposits in Britain. There is significant scope for future work at this site using new techniques and detailed sampling, although some logistical challenges in doing so. The controversial suggestion that two of the cold-climate units are separated by an interglacial palaeosol further enhances the scientific value of this famous site.

Figures

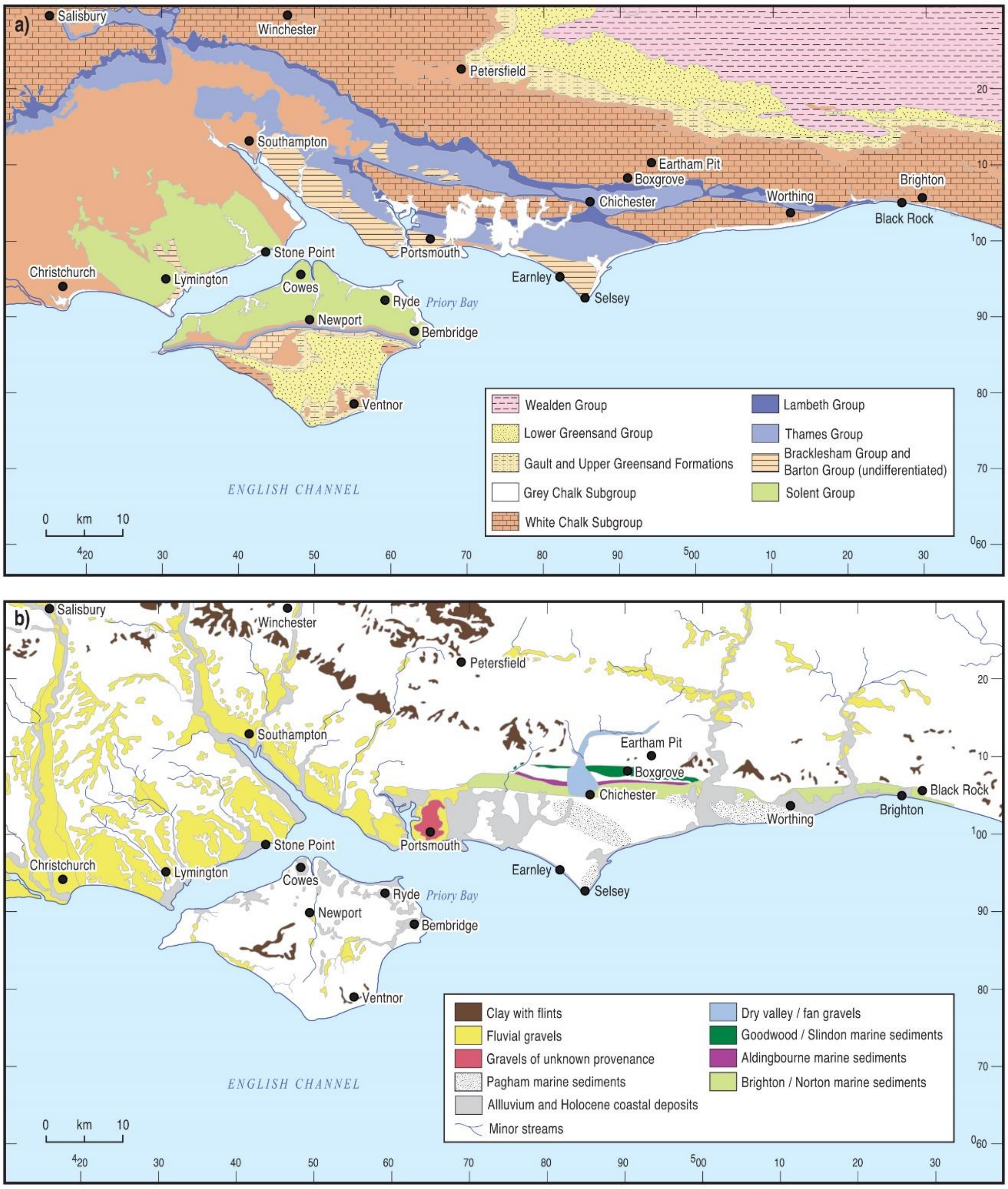

Fig. 1. a. Bedrock and b. Quaternary geology of the Hampshire Basin and Sussex Downs and location of all Geological Conservation Review sites in this paper, after Figures 1.3 and 1.4 of Hopson (2009).

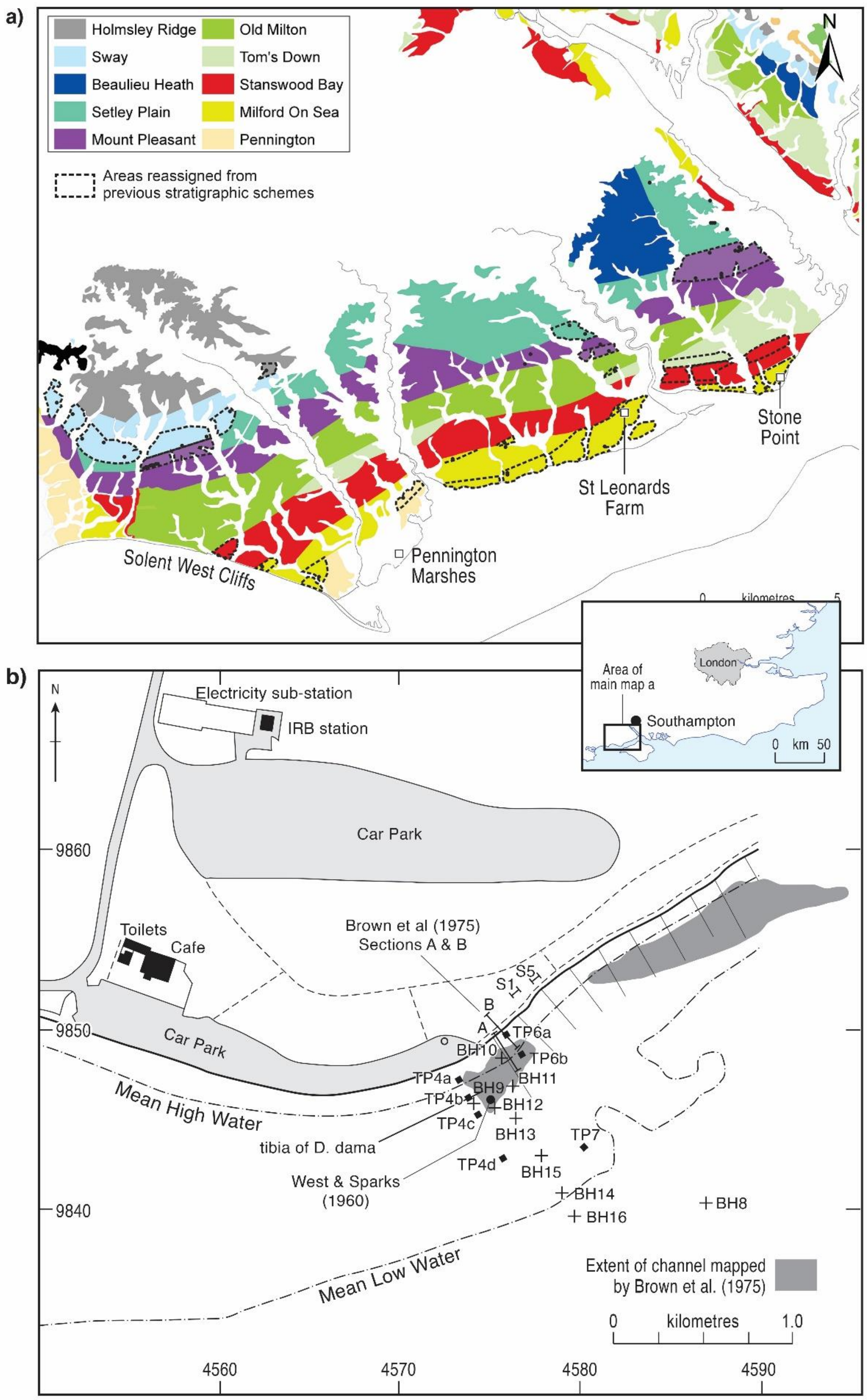

Fig. 2. a. River terrace geology (after Hatch, 2014), showing the location of Stone Point (areas surrounded by dotted lines are reassigned from previous stratigraphic schemes) and b. location of investigations described in the text. TP = test pit; BH = horehole.

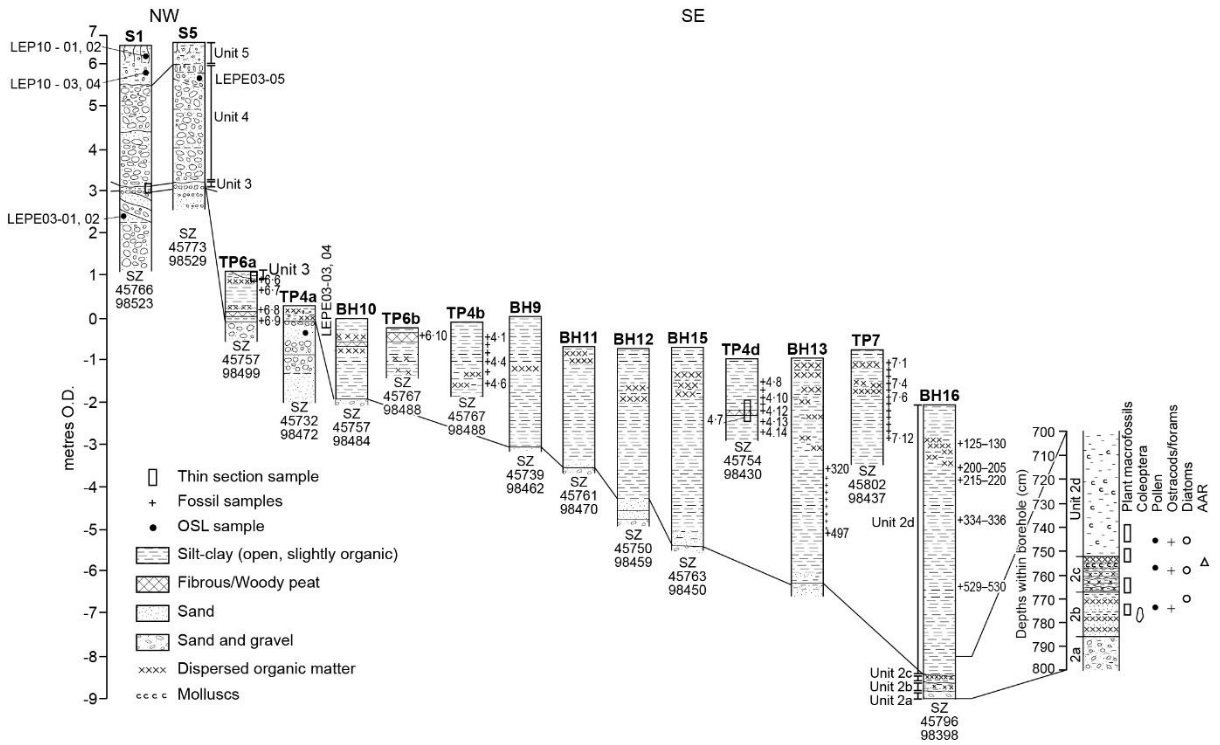

Fig. 3. Key sections and boreholes from Stone Point (SZ459985, locations mapped in Fig. 2) investigated by the PASHCC project between 2003 and 2005 (Briant et al., 2019).

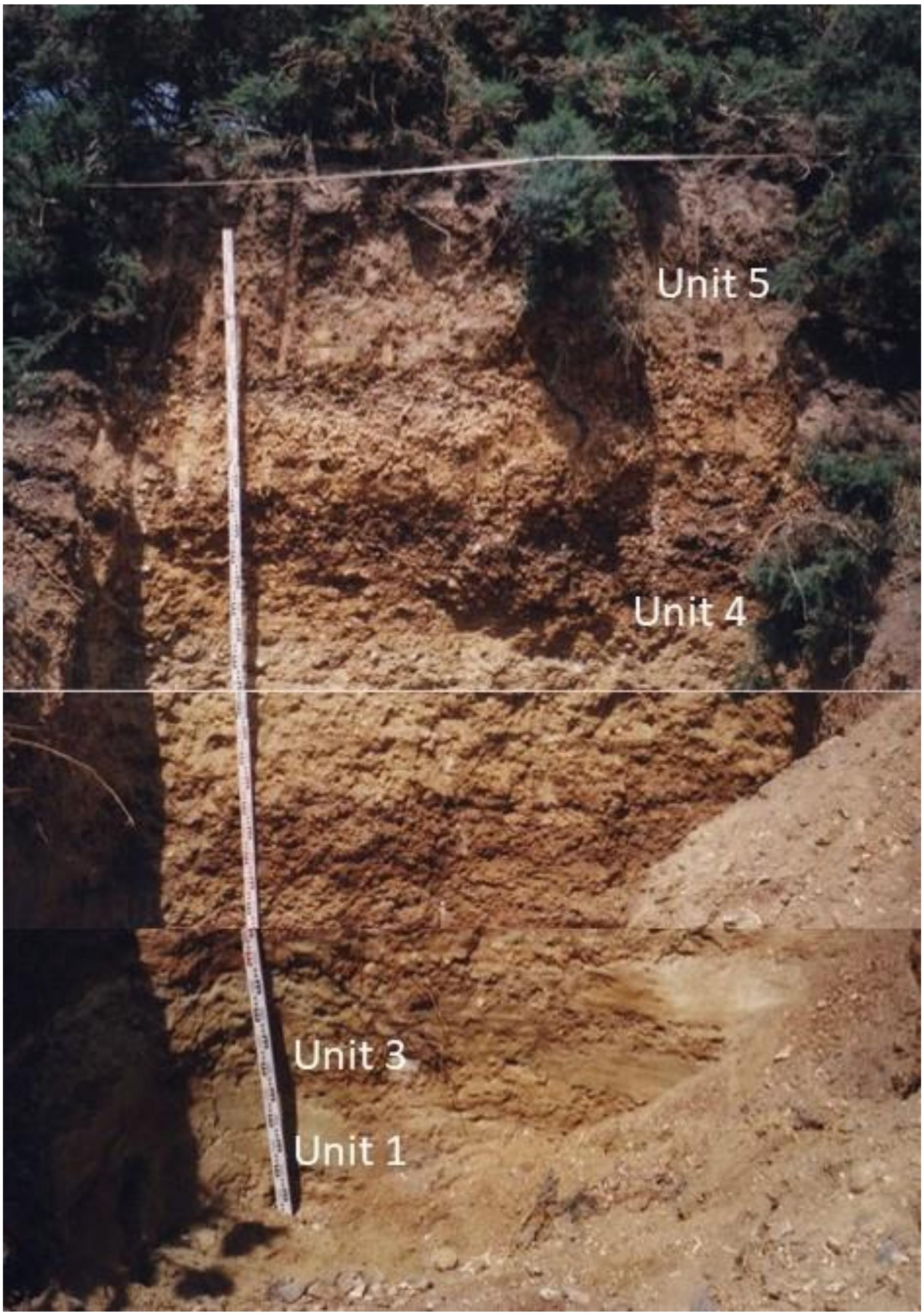
Unit 5
Unit 4
Unit 3
Unit 1

Fig. 4. a) Photograph of Section 1, exposed at Stone Point in 2003, showing the relationship between Units 1 and 4 in the cliff – photograph credit RMB; b) Photograph of test pit 4a, showing the onshore edge of Unit 2 overlying Unit 1 – photograph credit Martin Bates. SZ459985, locations mapped in Figure 2.

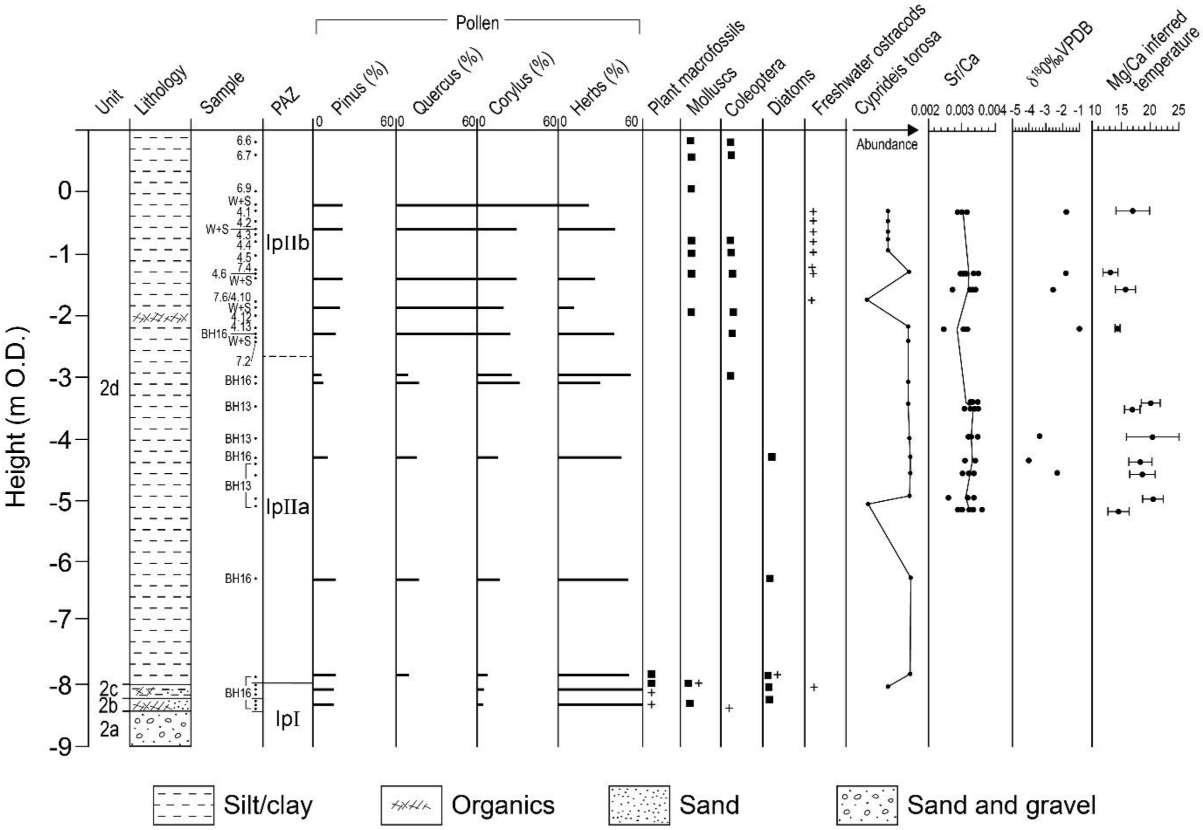

Figure 5. Summary of palaeoenvironmental and isotopic data from the Stone Point organic deposits.

Data has been collated from West and Sparks (1960) – W+S, test pits 4a, 4b, 4d, 6a, 6b, 7 and boreholes 13 and 16 (SZ459985, Fig. 2, Briant et al., 2019). Filled squares denote brackish conditions and crosses freshwater conditions or presence of freshwater ostracods.

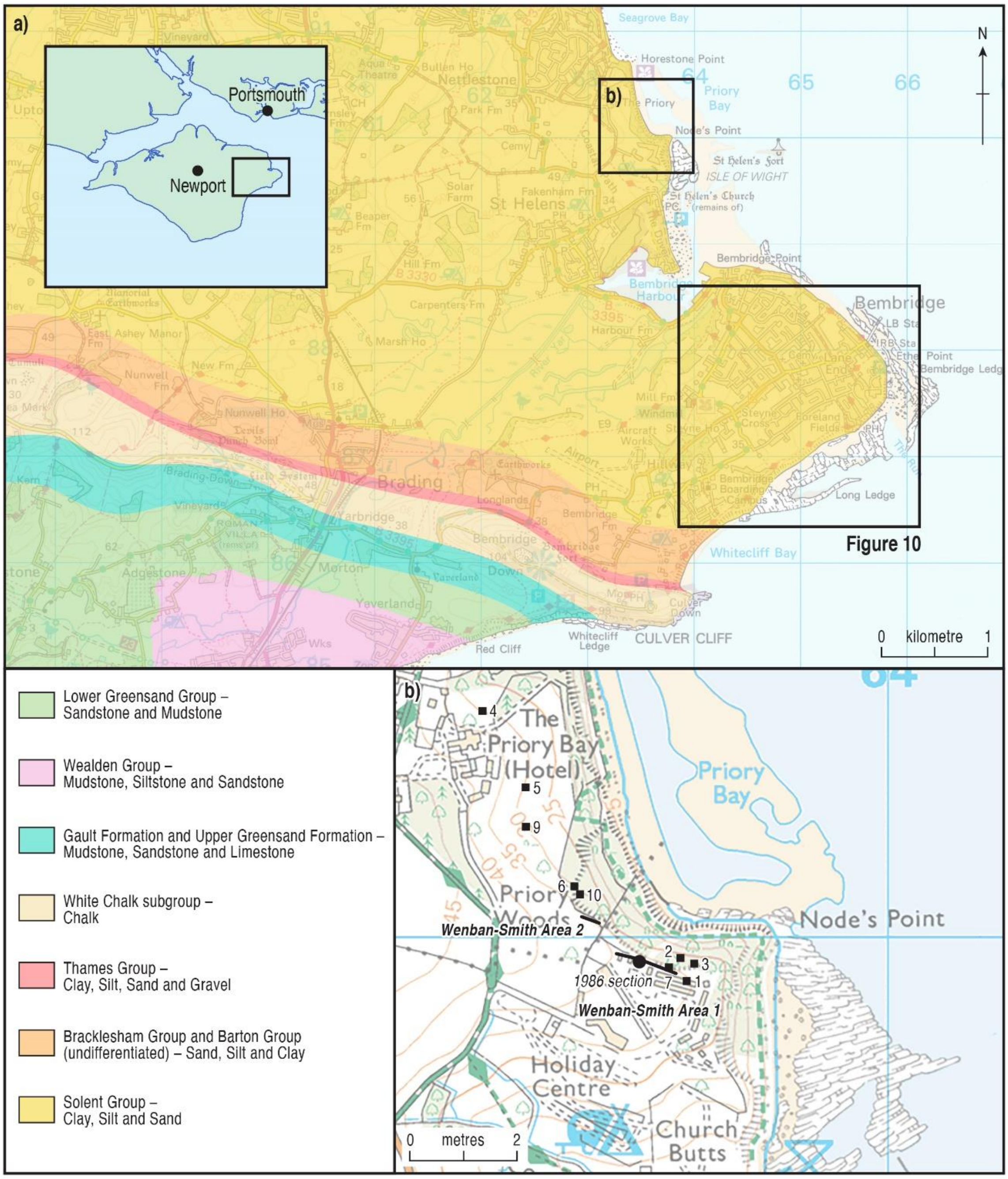

Fig. 6. a) Geology and location of Priory Bay and Bembridge Geological Conservation Review sites, showing b) location of research at Priory Bay (filled circle = 1986 section, filled squares = 2001 Wenban-Smith test pits). Ordnance Survey mapping used under license to Birkbeck, University of London, via EDINA Digimap.

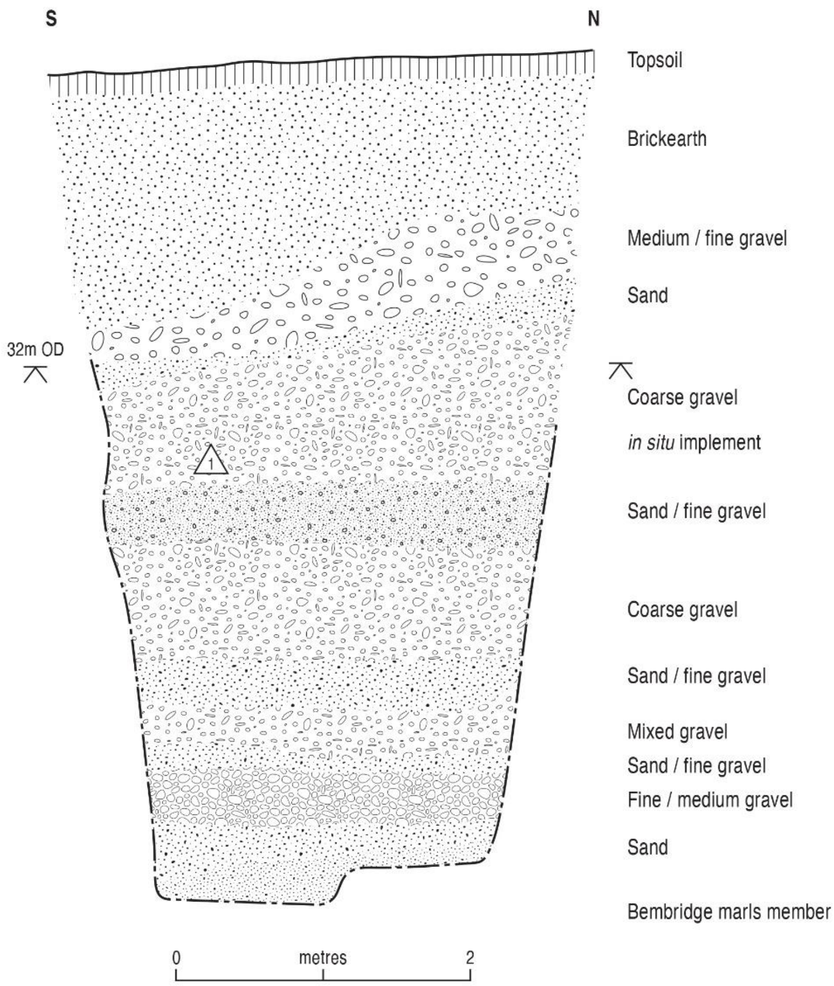

Fig. 7. Priory Bay GCR section from 1986. Location shown on Figure 6 (Preece and Scourse, 1987).

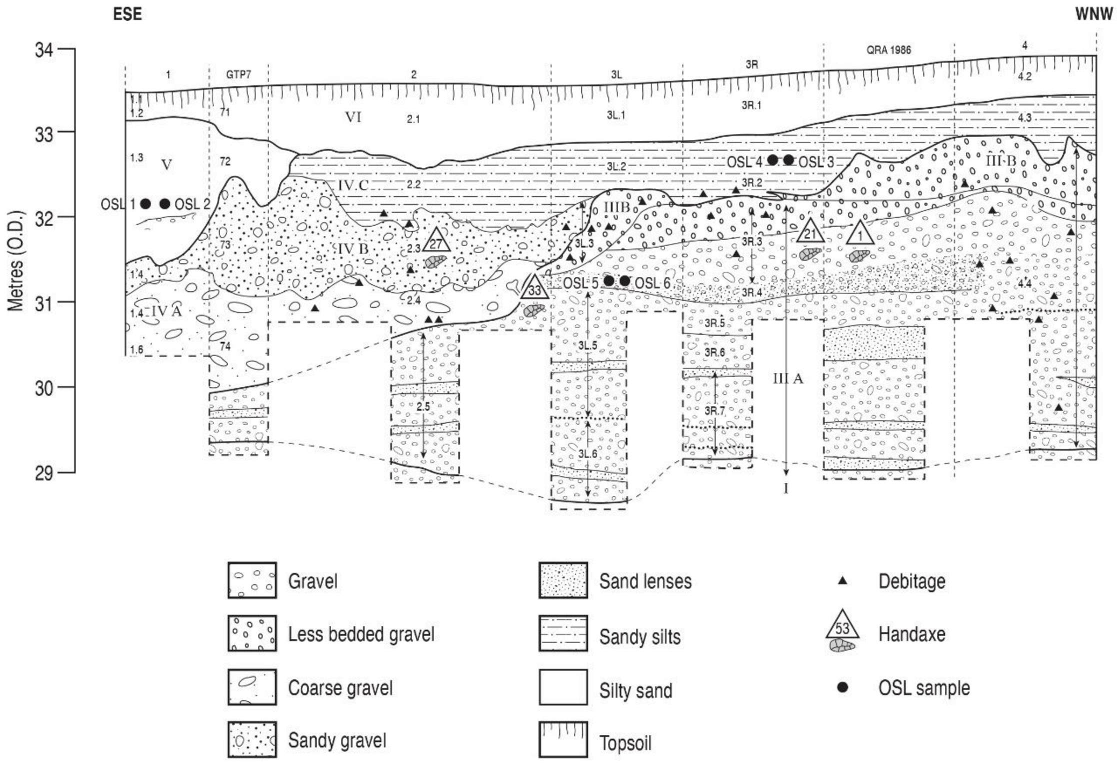

Fig. 8. Stratigraphy and location of artefacts at Priory Bay Area 1 (SZ 6357 8996, see Fig. 6 for location). Redrawn from Wenban Smith et al., 2009 Figure 7.2.

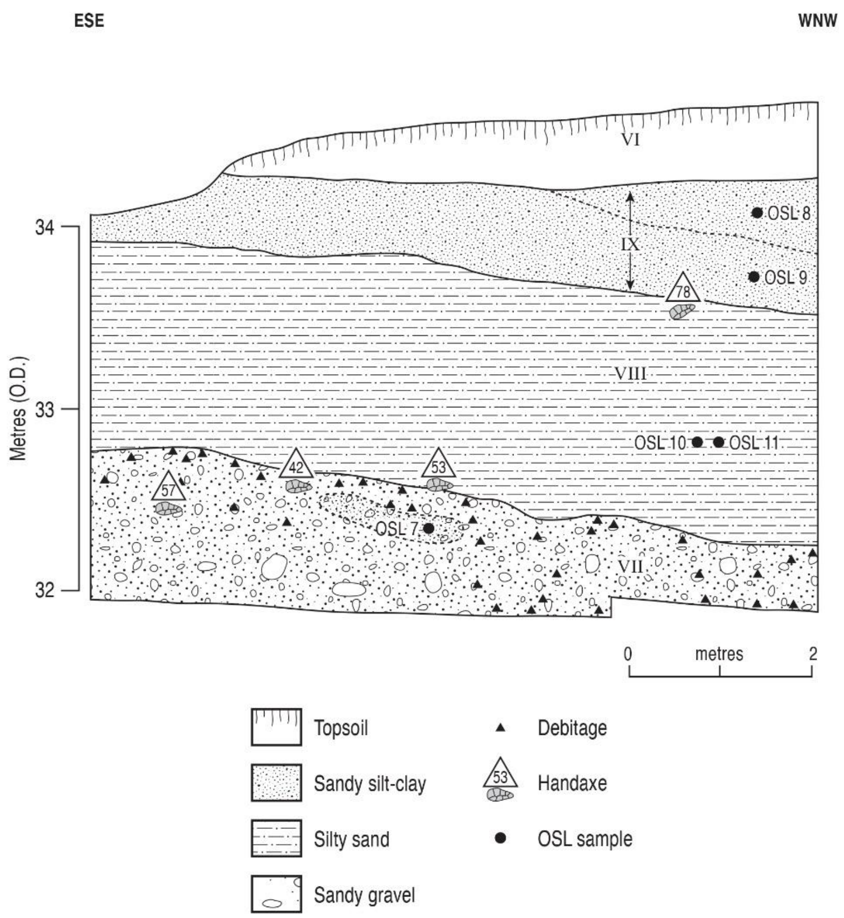

Fig. 9. Stratigraphy and location of artefacts at Priory Bay Area 2 (SZ 6342 9004, see Fig. 6 for location). Redrawn from Wenban Smith et al., 2009 Figure 7.3.

Fig. 10. Photograph of section opened at Priory Bay Area 2 (SZ 6342 9004, see Fig. 6 for location) and reported by Wenban-Smith et al. (2009). Stratigraphy in Figure 9. Photo credit: Francis Wenban-Smith.

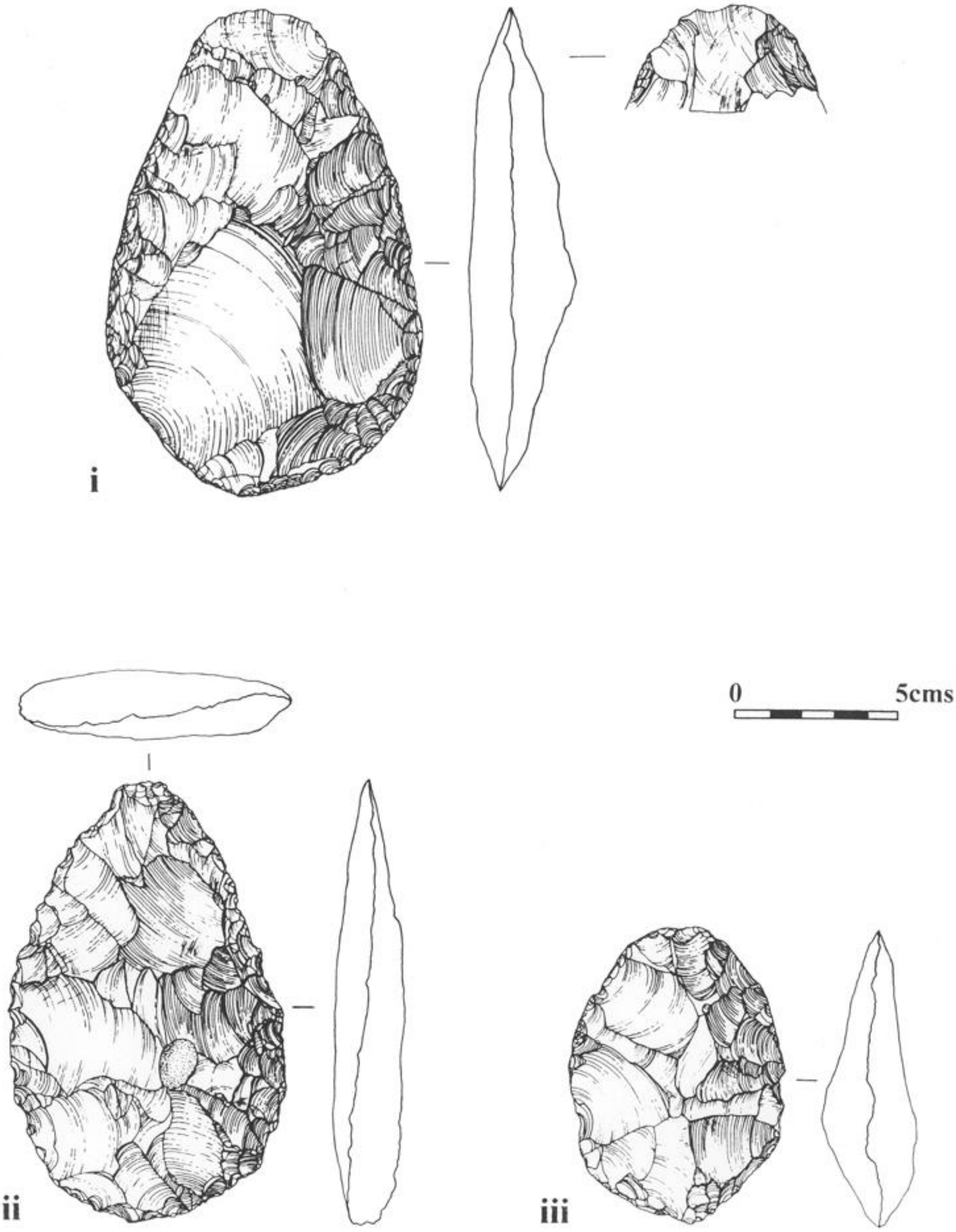

Fig. 11. Priory Bay Handaxes: (i) cordate from top of bed VII (upper buried landsurface), Area 2 (L. 78); (ii) twisted ovate from top of bed VIII (surface of disrupted fluvial gravel), Area 2 (L. 53); (iii) ovate from beds IV A-C (solifluction gravels), Area 1 (L. 27) [illustrations by Barbara McNee]. Figure 7.4 of Wenban-Smith et al. (2009).

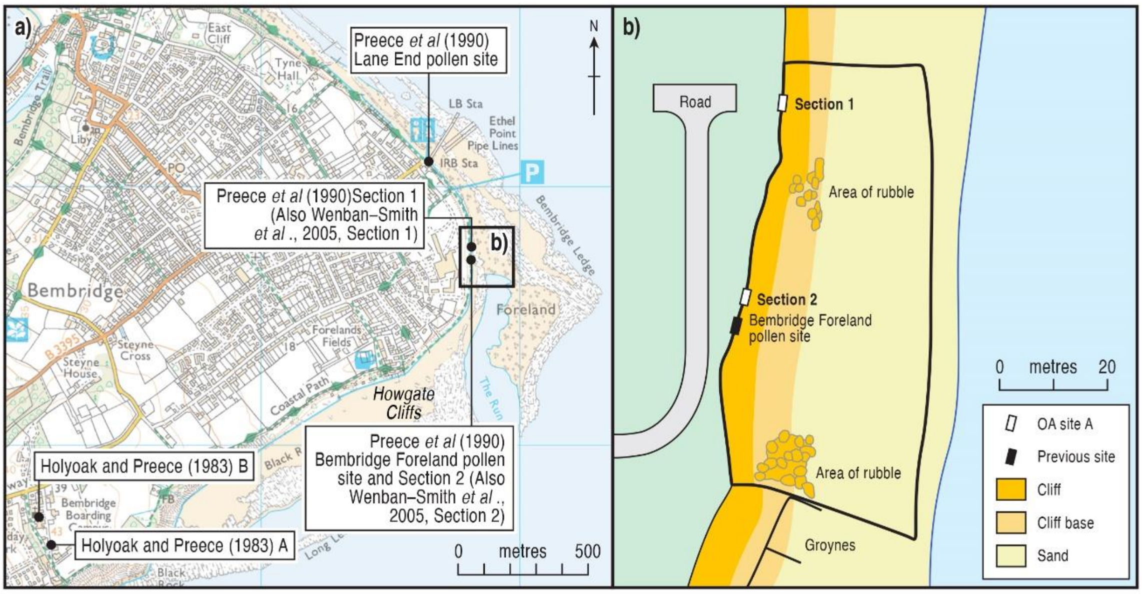

Fig. 12. Location of GCR sites at Bembridge and research undertaken at them. Ordnance Survey mapping used under license to Birkbeck, University of London, via EDINA Digimap.

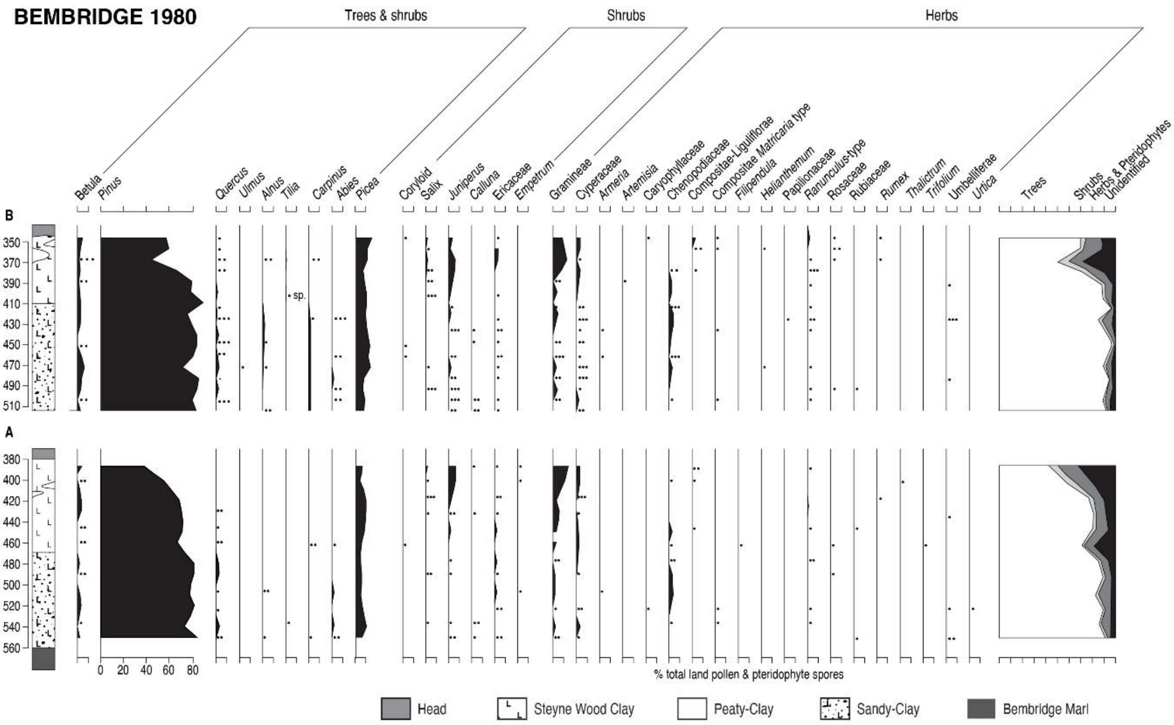

Fig. 13. Pollen analysis of two boreholes (A located at SZ 6418 8657 and B located at SZ 6419 8664) through the Steyne Wood Clay after Holyoak and Preece (1983).

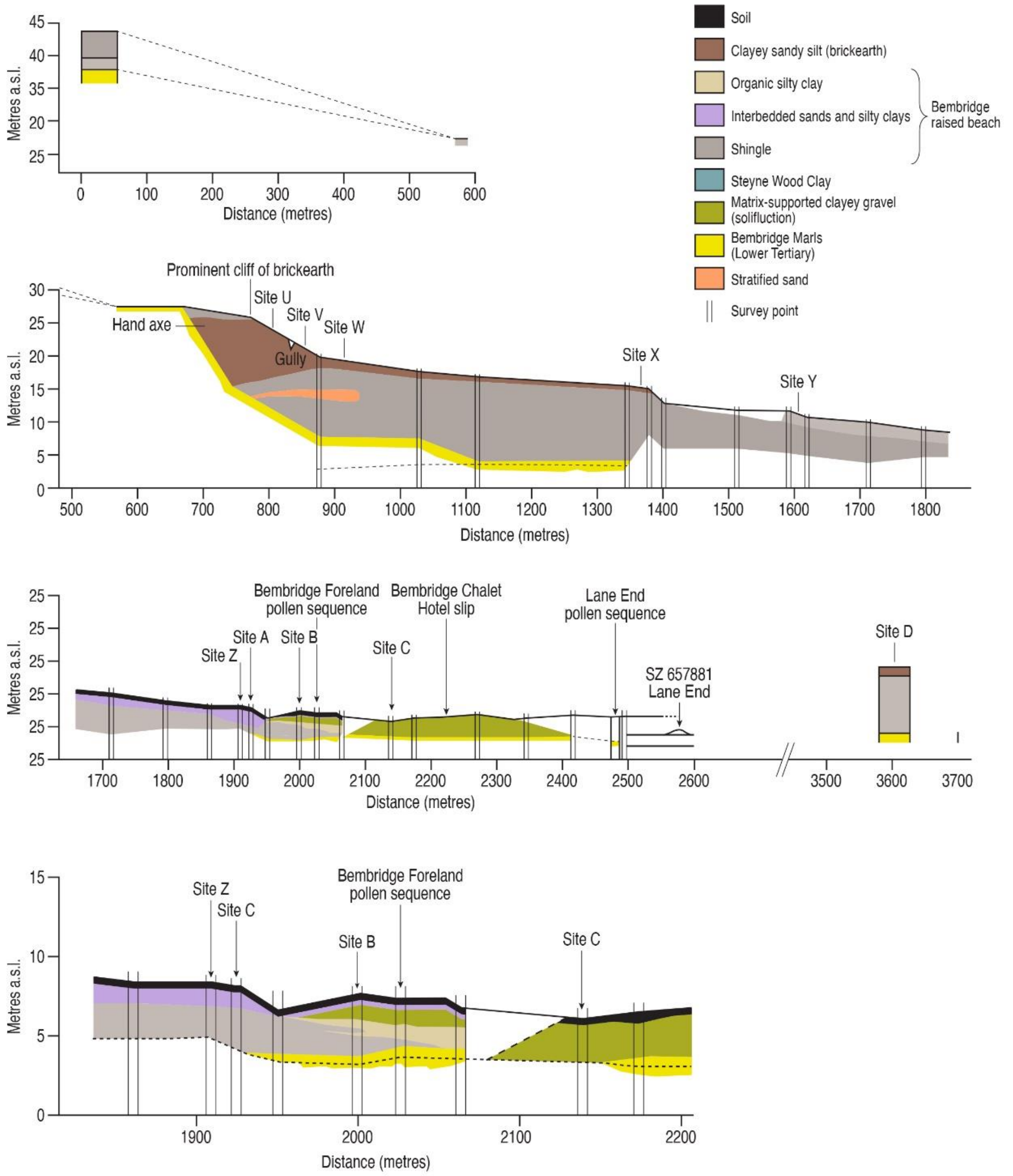

Fig. 14. Cliff section between Bembridge School (SZ 6421 8665) and Lane End (SZ 6560 8806), after Preece et al. (1990).

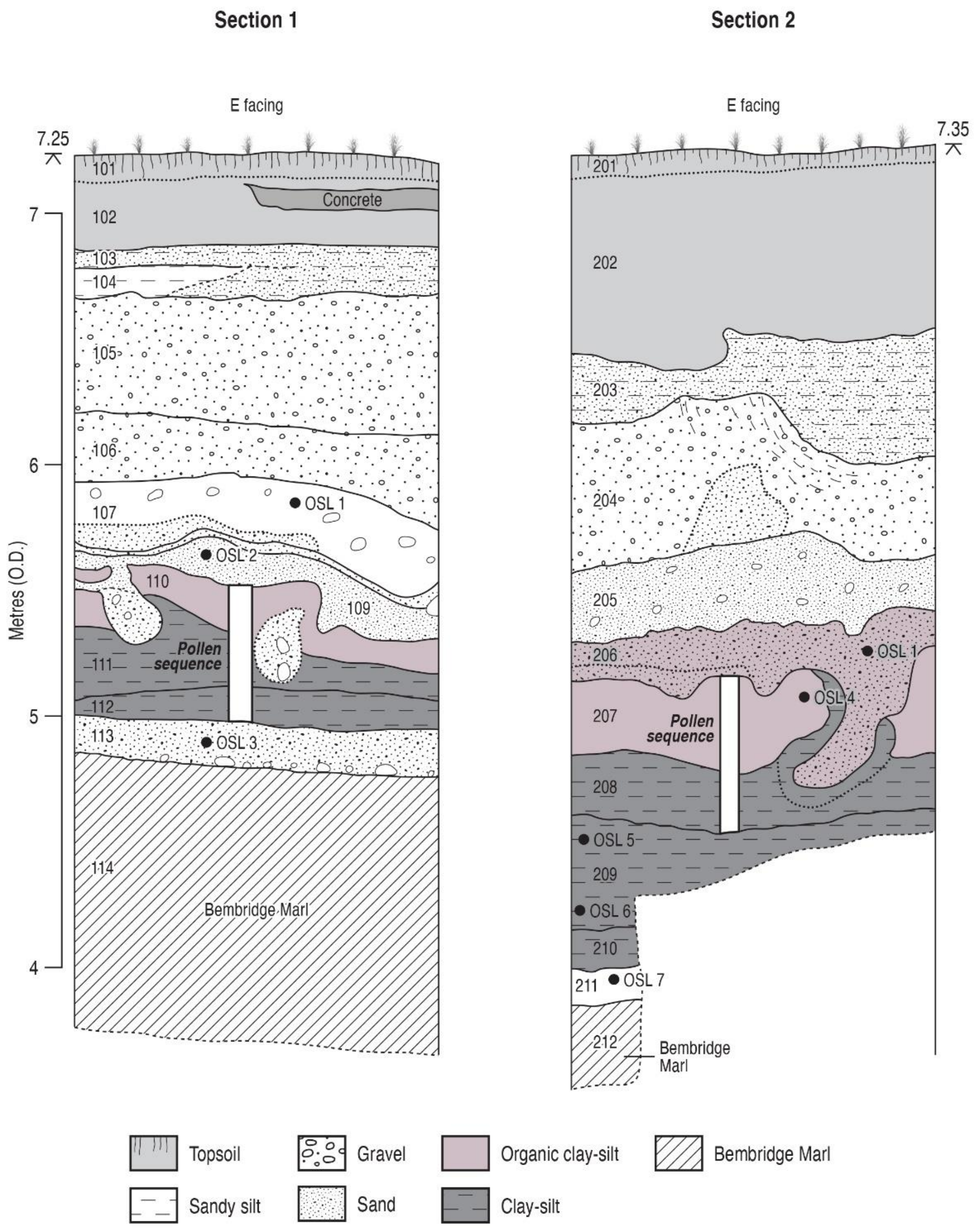

Fig. 15. Stratigraphy and location of OSL samples at Bembridge Foreland sections 1 (SZ 65792 87645) and 2 (SZ 65787 87603). Redrawn from Wenban Smith et al., 2005 Figures 3 and 4.

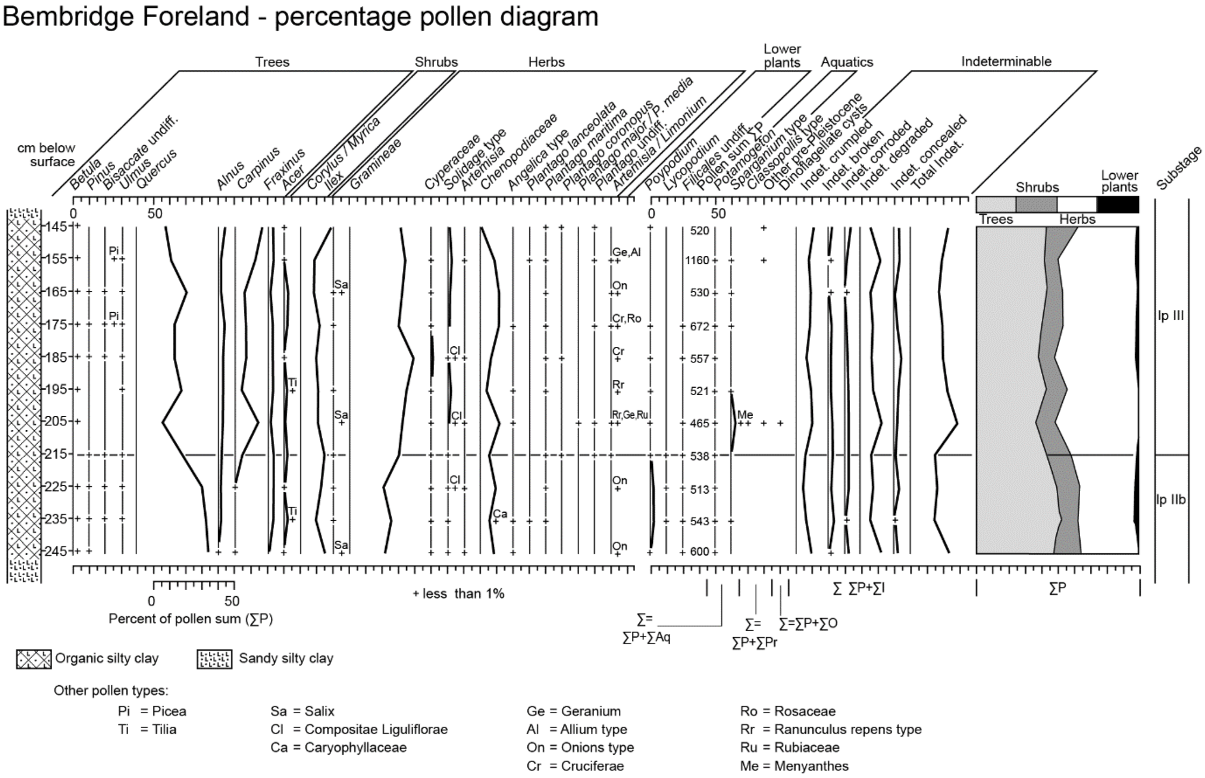

Fig. 16. Bembridge Foreland pollen diagram (Preece et al 1990).

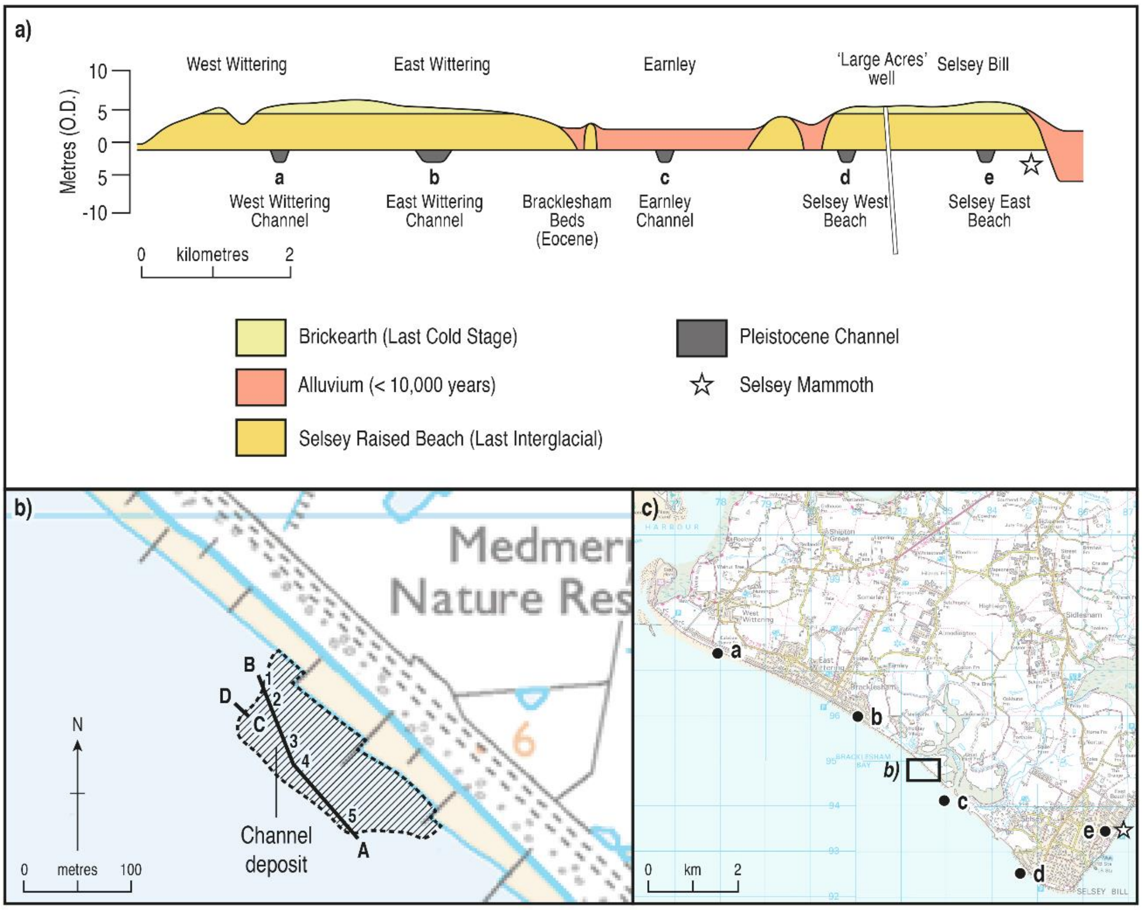

Fig. 17. a) schematic cross section of Pleistocene channel fills along the Manhood Peninsula to the west and east of Selsey Bill after Parfitt (2013). b) plan view of Earnley foreshore, showing extent

of channel fill above mean low water and location of cross sections (A-B and C-D) and boreholes (1-5) from West et al. (1984) and shown in Figure 18. Central groyne is at SZ 826948. c) Location of all sites shown in a and b. Ordnance Survey mapping used under license to Birkbeck, University of London, via EDINA Digimap. Note: the Bracklesham Beds are now called the Bracklesham Group.

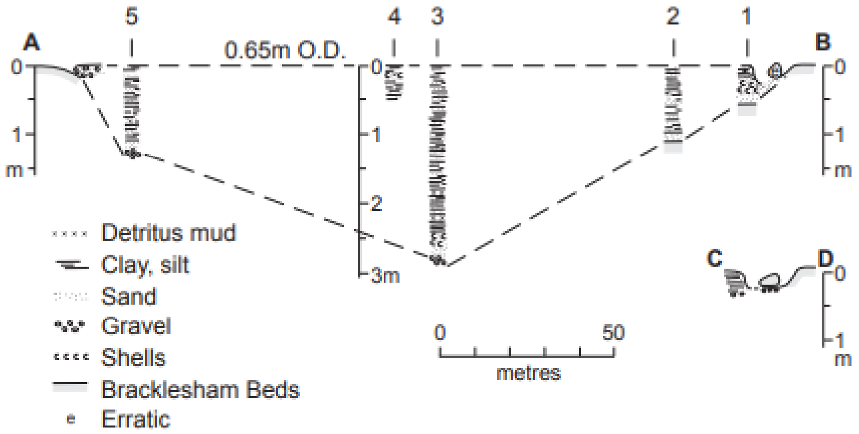

Fig. 18. Cross section across channel fill at Earnley at SZ 826 948 (after West et al 1984).

Fig. 19. Exposure through channel at Earnley (SZ 826 948). Photo credit: Martin Bates.

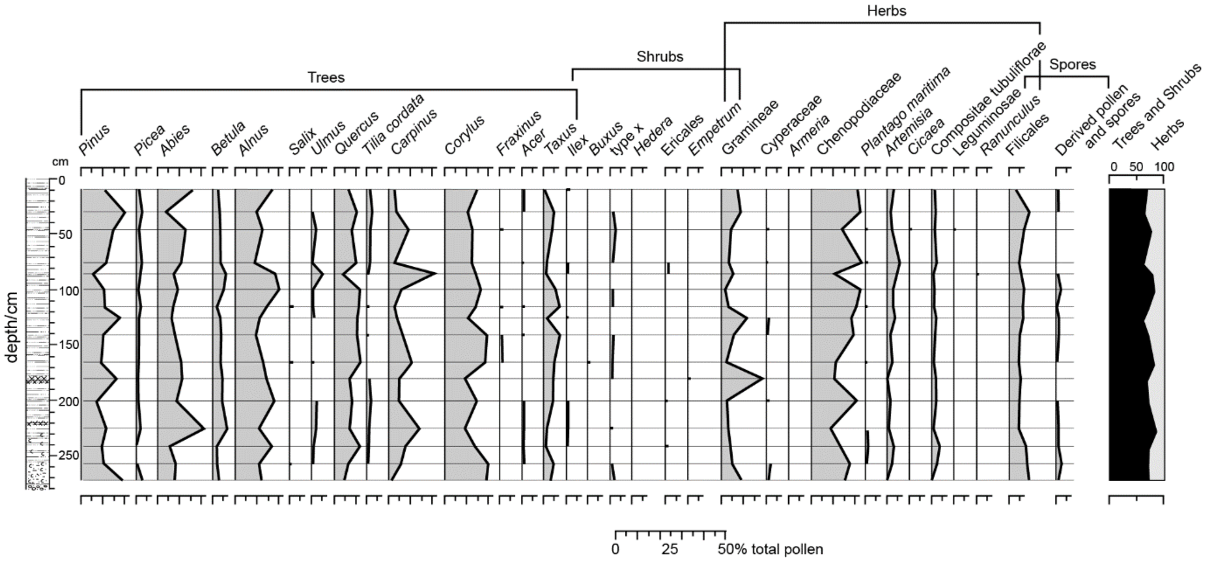

Fig. 20. Pollen diagram at Earnley site 3 (location on Fig. 17b), after West et al., 1984, Figure 3.

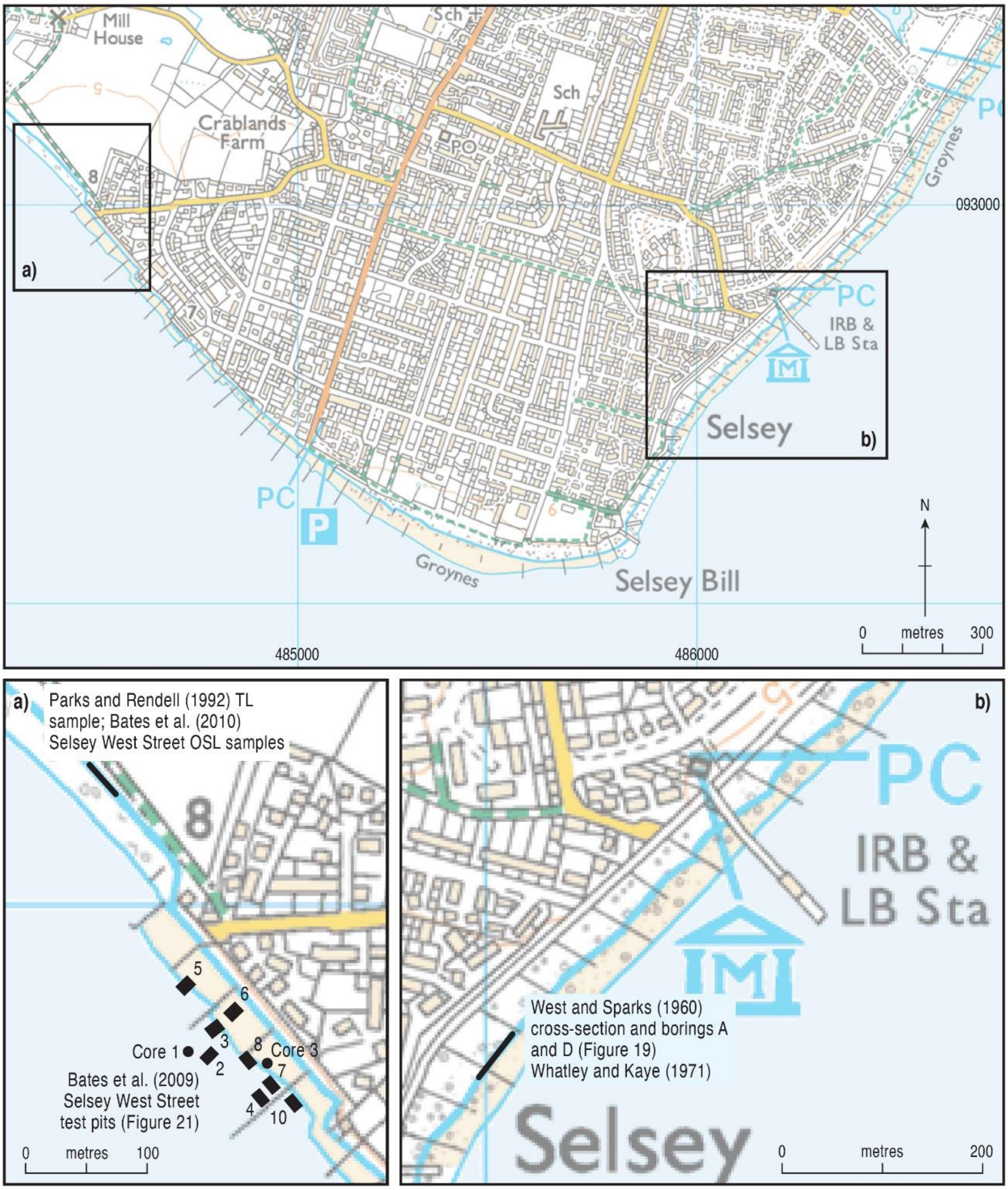

Fig. 21. Location of the two Geological Conservation Review sites Selsey West Beach and Selsey East Beach, together comprising the Quaternary of Southern England site 2021, showing location (where known) of past investigations at the sites. Selsey East Beach is also Pleistocene vertebrate GCR site 1201. Ordnance Survey mapping used under license to Birkbeck, University of London, via EDINA Digimap.

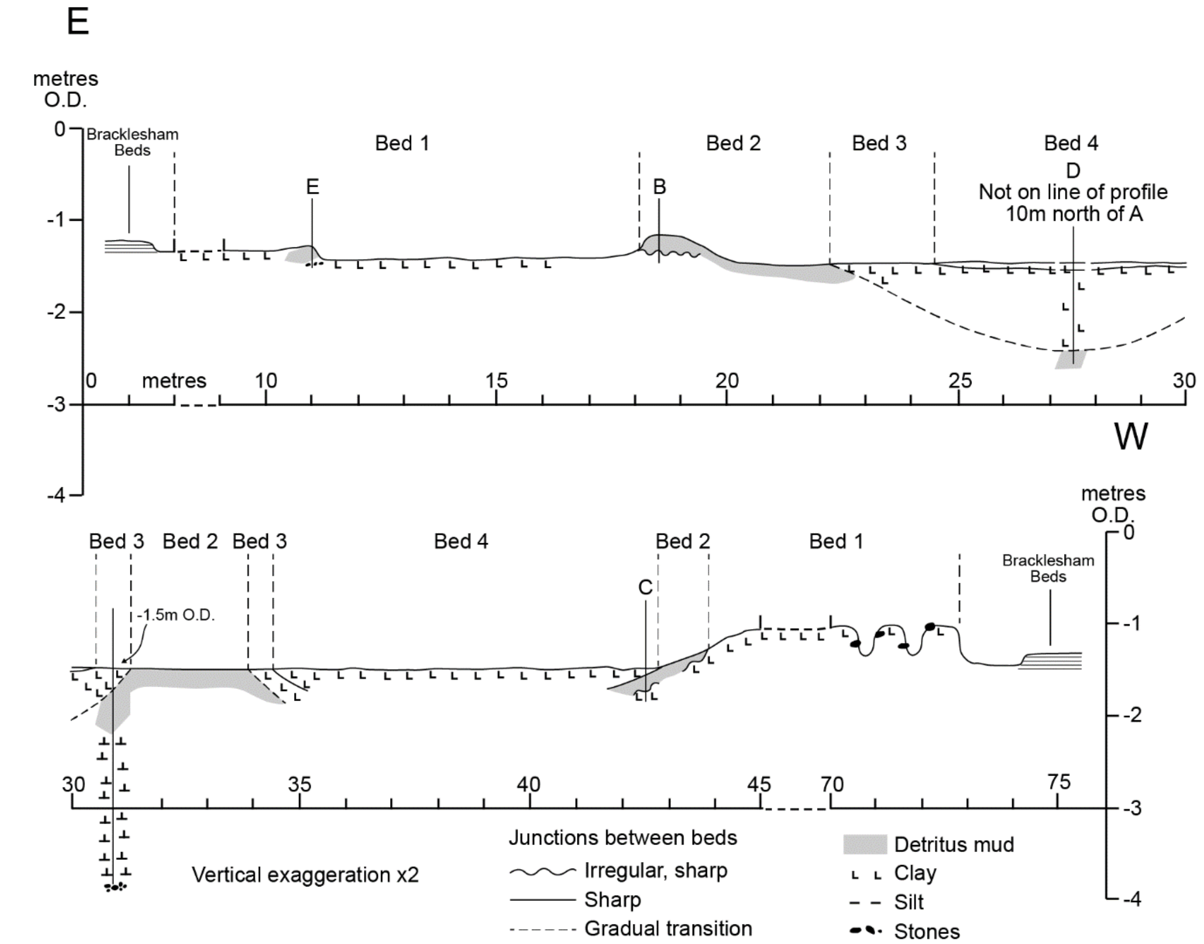

Fig. 22. East-west section across channel at Selsey East Beach / Lifeboat Station SZ860925 (after West and Sparks, 1960, Figure 4). Note: the Bracklesham Beds are now called the Bracklesham Group.

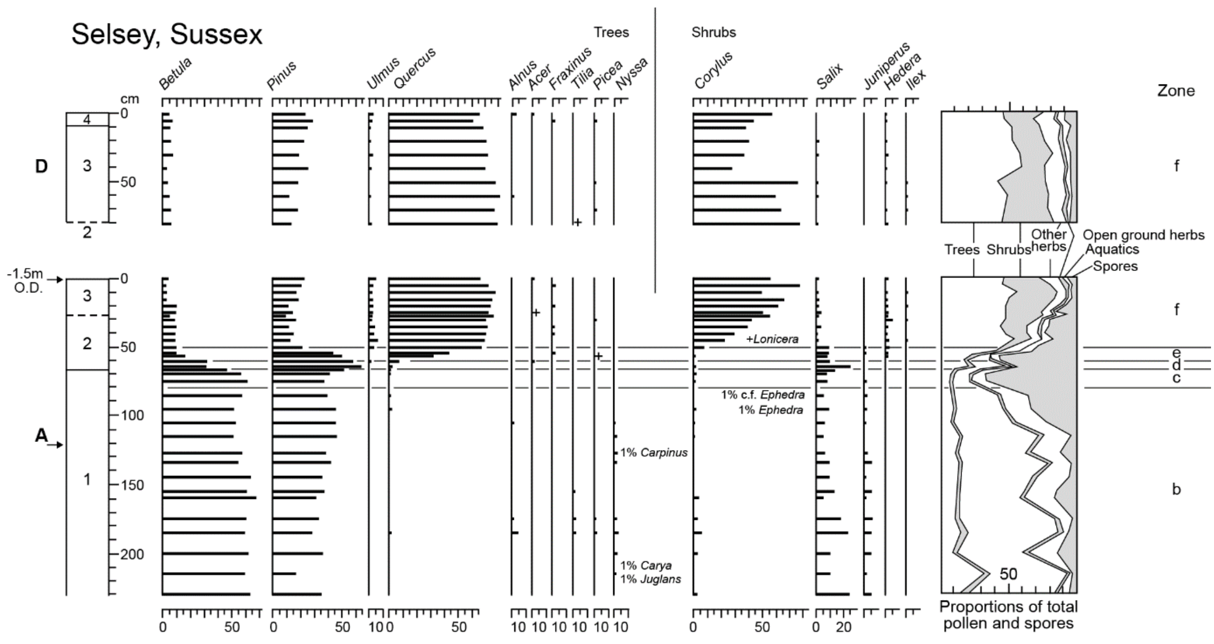

Fig. 23. Pollen analyses from sites A and D at Selsey East Beach / Lifeboat Station SZ860925 after

West and Sparks (1960) Figure 5.

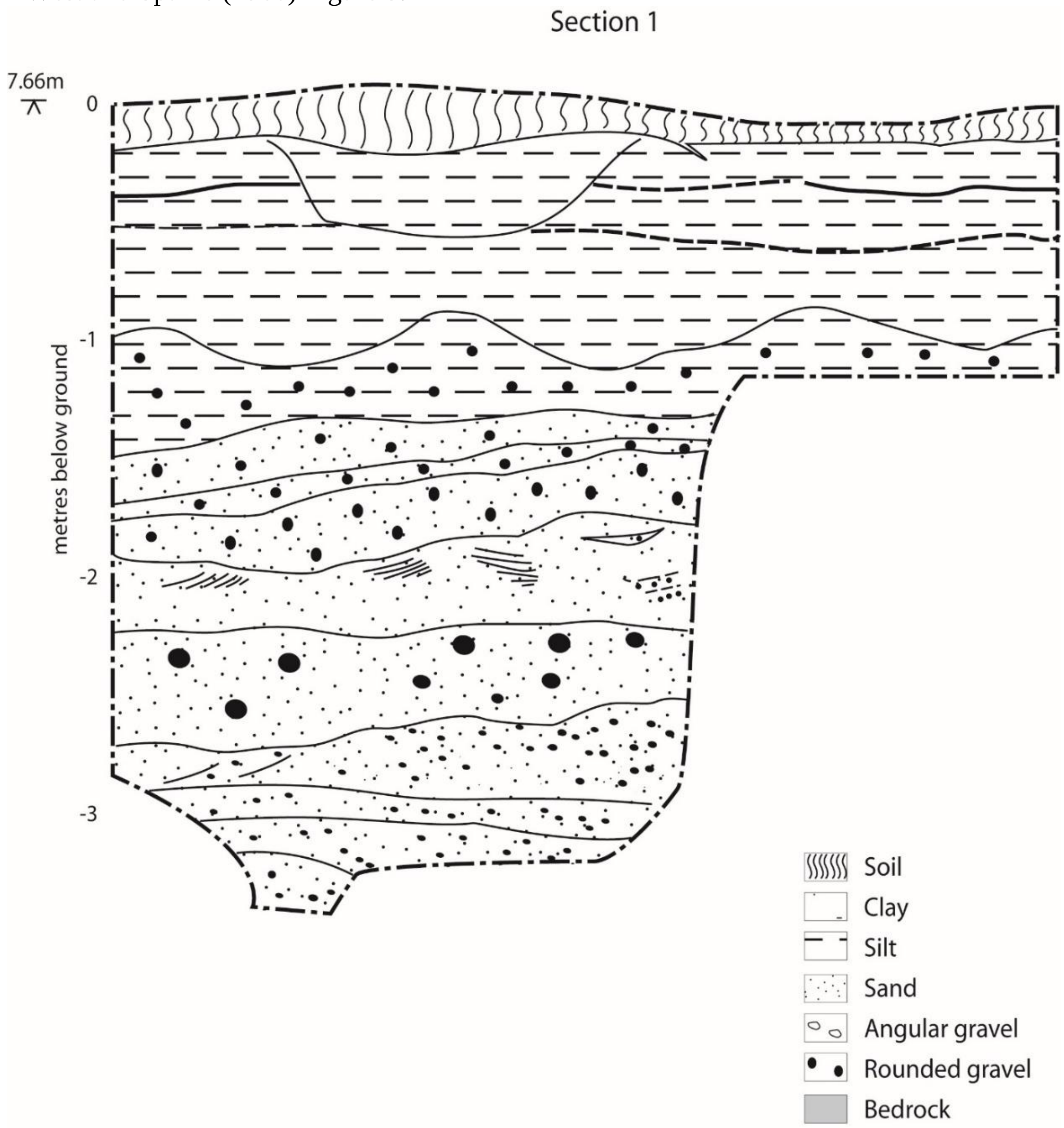

Fig. 24. Section through upper part of raised beach to north of coastguard station at Selsey West Beach SZ 843 931 (West Street, Selsey) from Bates at al. (2009), Figure 5.4. OSL samples were taken at 2.6 and 3.55 m below ground surface (SEL01-1 - 139 ± 11 ka and SEL01-2 - 126 ± 10 ka respectively).

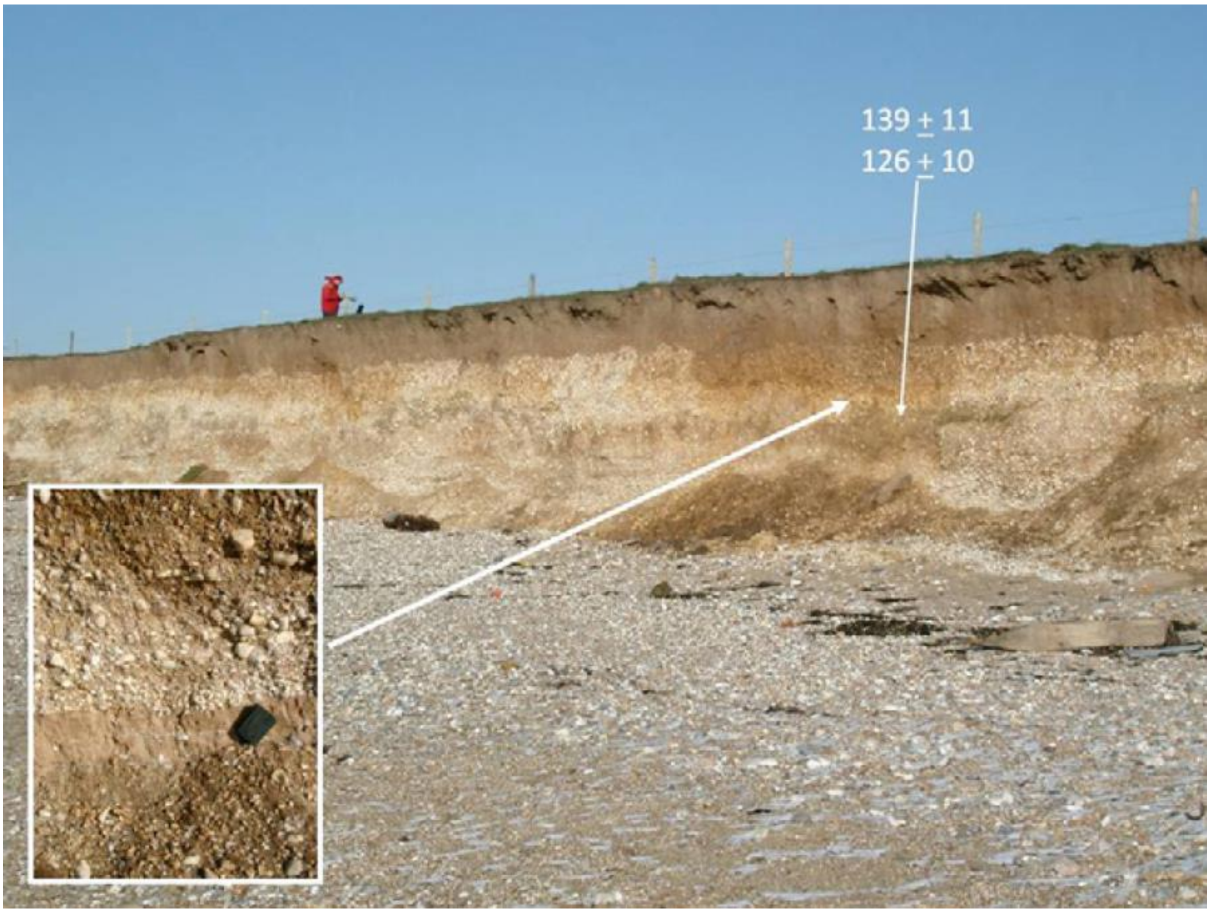

Fig. 25. Photograph of raised beach at Selsey West Beach SZ 843 931, from Bates et al. (2010), Figure 12.

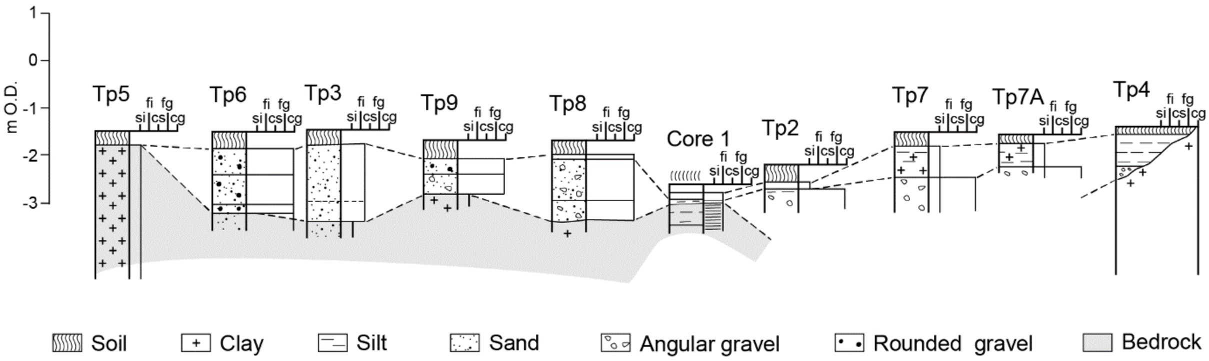

Fig. 26. Cross section through channel at Selsey West Beach (SZ84393, see Fig. 21) showing differences between northern (sand-filled) and southern (clay/silt/gravel-filled) parts of channel after Bates at al. (2009), Figure 5.3.

Fig. 27. Photograph showing transition between northern and southern parts of the Selsey West Beach channel (SZ84393) in 2003. Photo credit: Martin Bates.

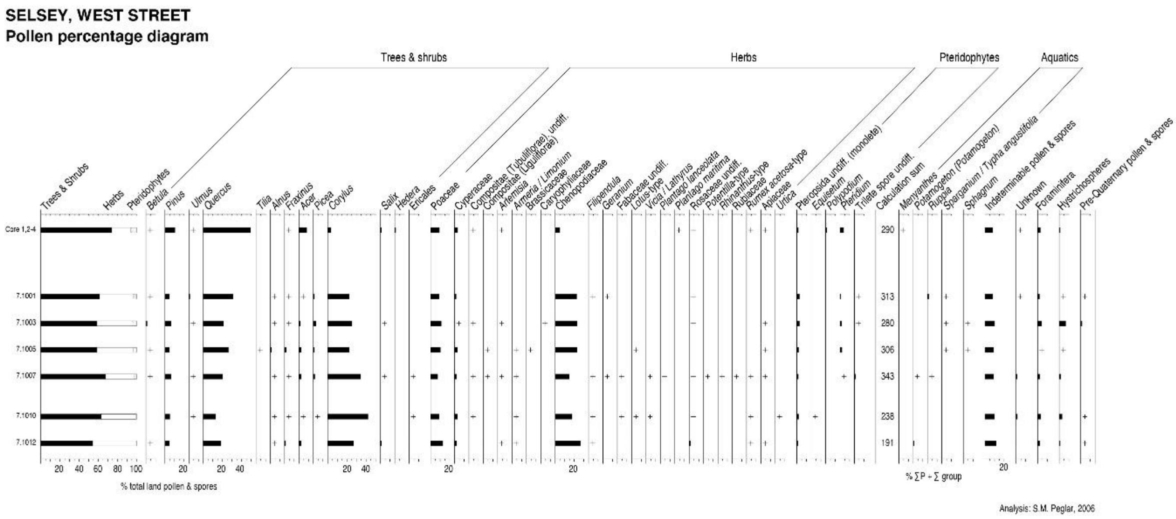

Fig. 28. Pollen diagram from cores 1 and 3 at Selsey West Beach SZ 843 931 (West Street, Selsey) from Bates at al. (2009), Figure 5.5.

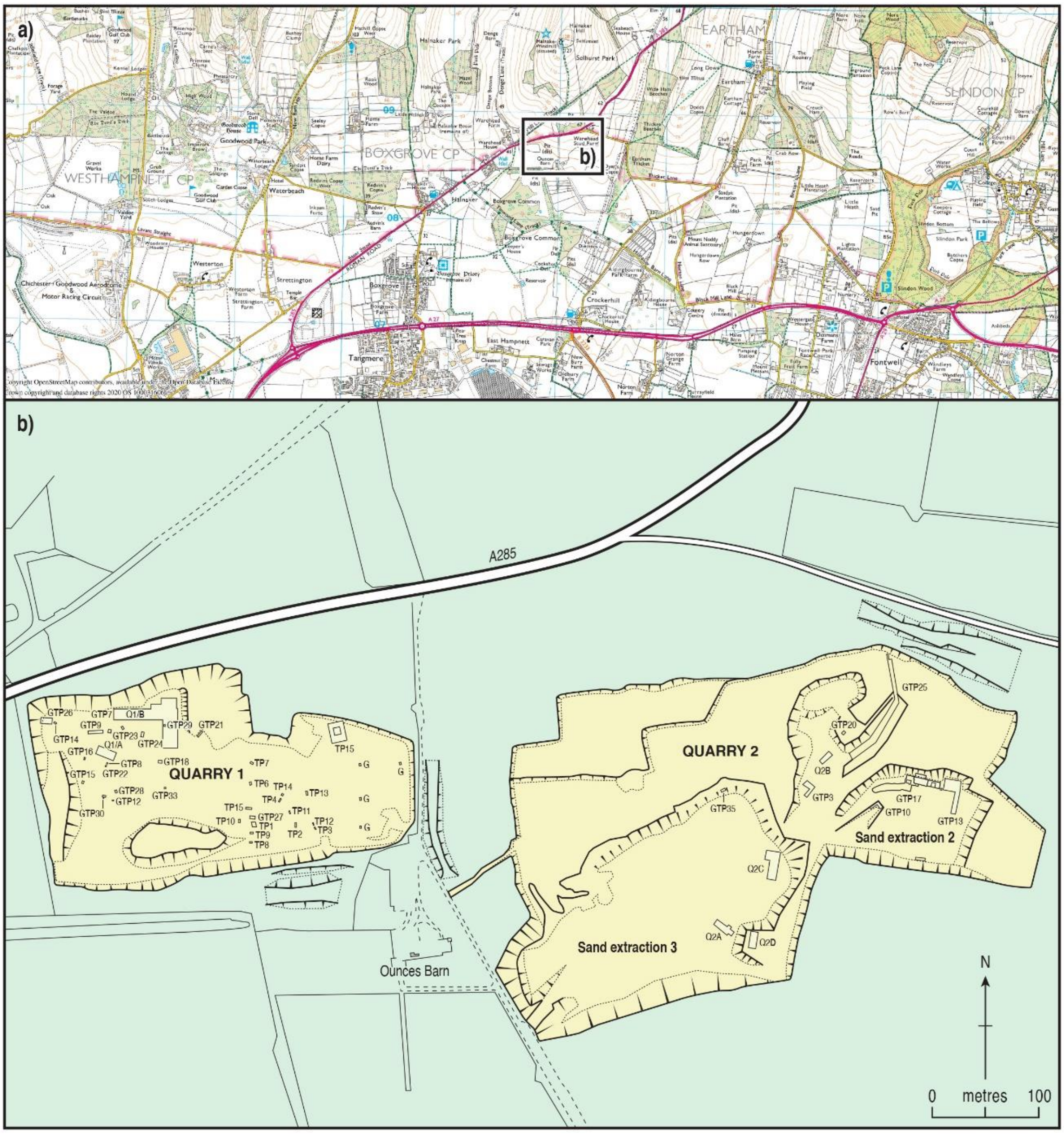

Fig. 29. a) Context and b) Detailed site plan of all the excavations undertaken at Eartham Pit, Boxgrove. The GCR site covers sequences in Quarry 2. Ordnance Survey mapping used under license to Birkbeck, University of London, via EDINA Digimap.

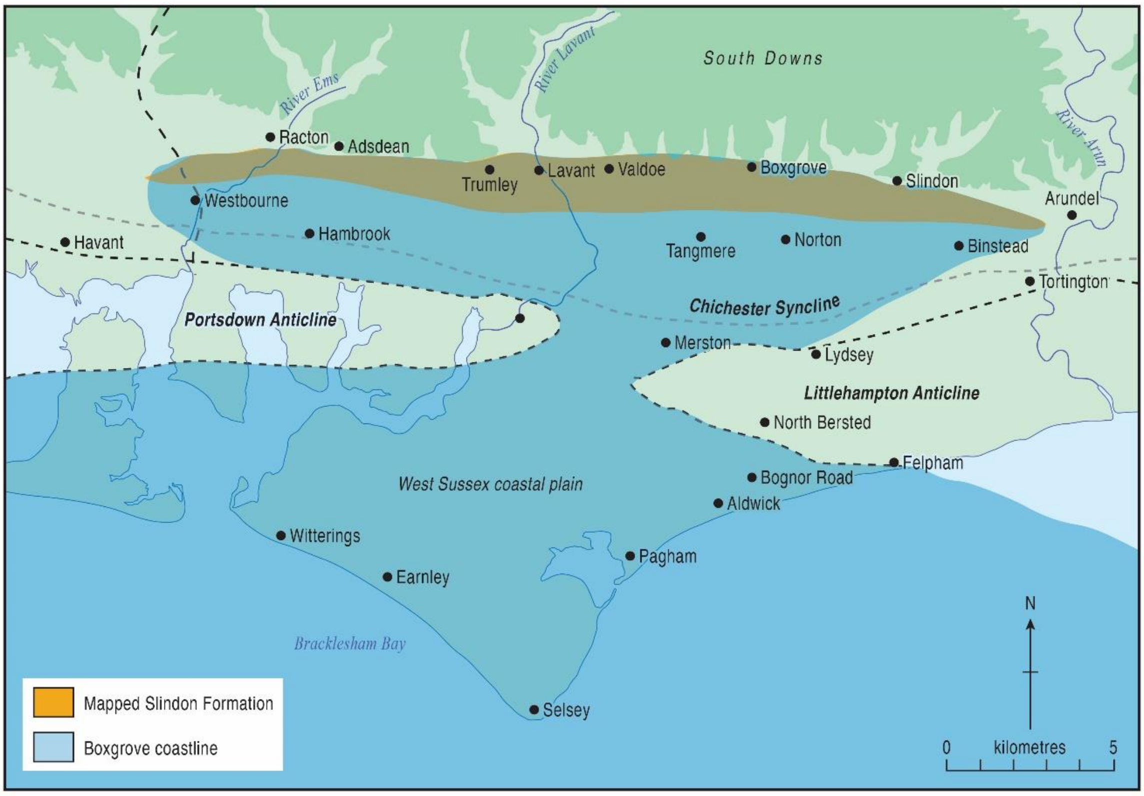

Fig. 30. Geology and location of Eartham Pit, Boxgrove GCR site, including suggested coastline during the high sea level event. Redrawn after Pope et al. (2020).

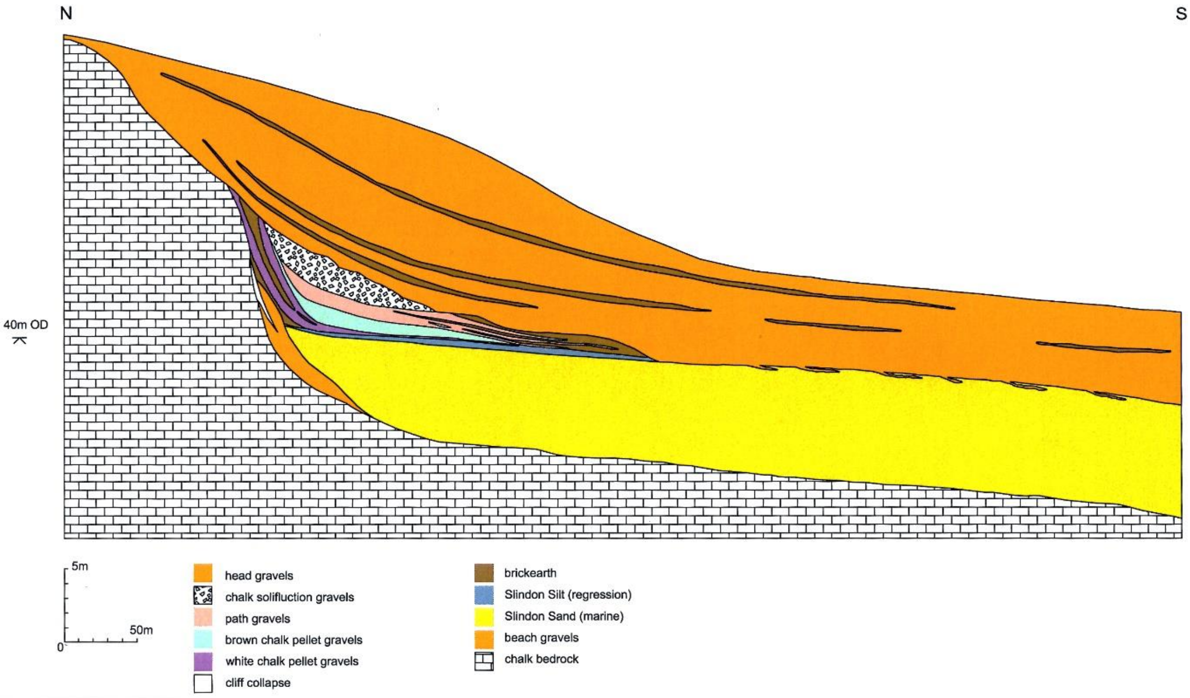

Fig. 31. Schematic stratigraphy of the Eartham Pit, Boxgrove sequence at Quarry 2 (GCR site, SU 923 087), after Roberts et al., 1999, Figure 34.

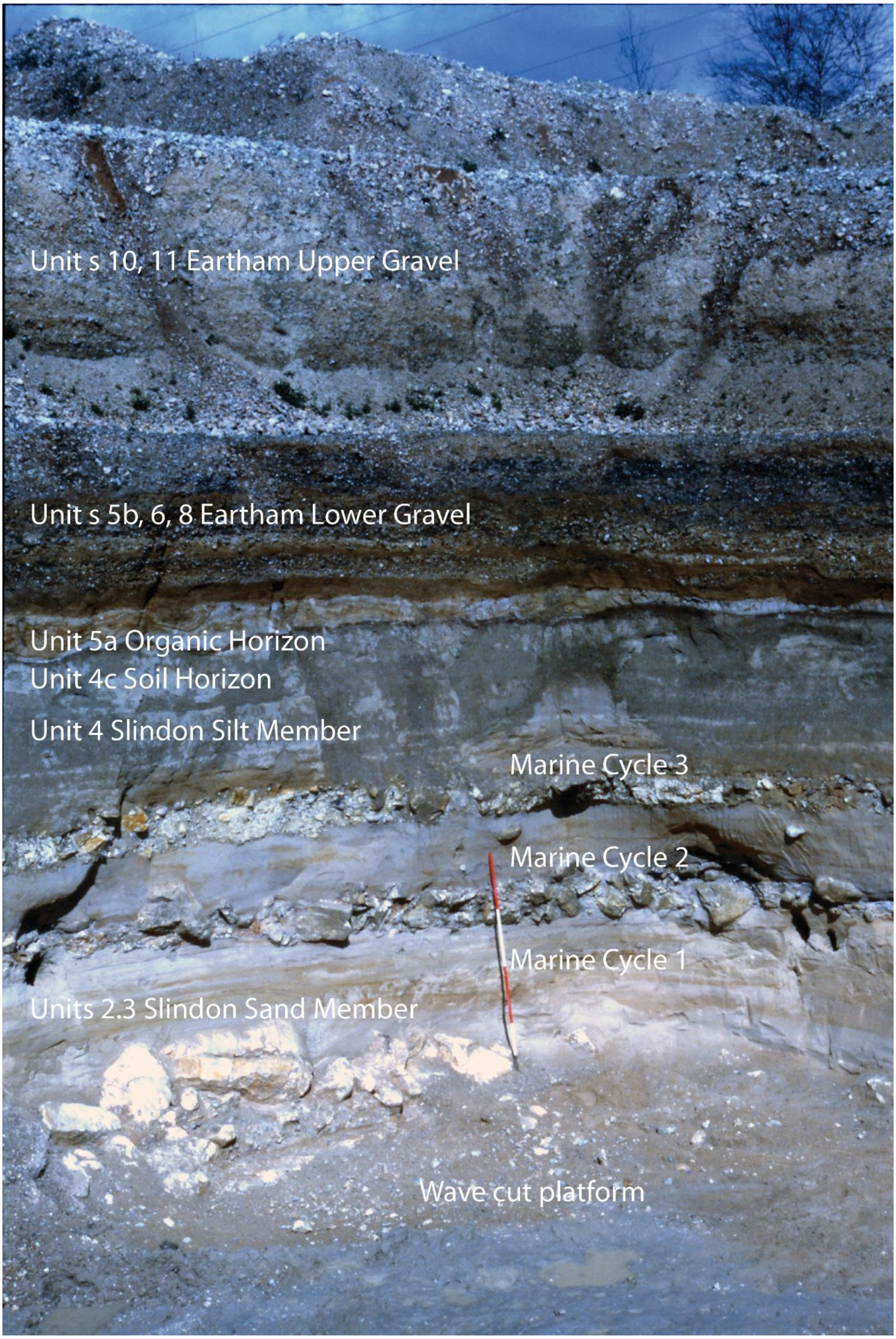

Fig. 32. Annotated photograph of important sedimentary units exposed at the holostratotype Quarry 2 GTP13 (location in Fig. 29) within the GCR site of Eartham Pit, Boxgrove. Photograph credit: BAH.

Fig. 33. Typical ovate handaxe from Eartham Pit, Boxgrove, pictured by Roberts and Pope (2018).

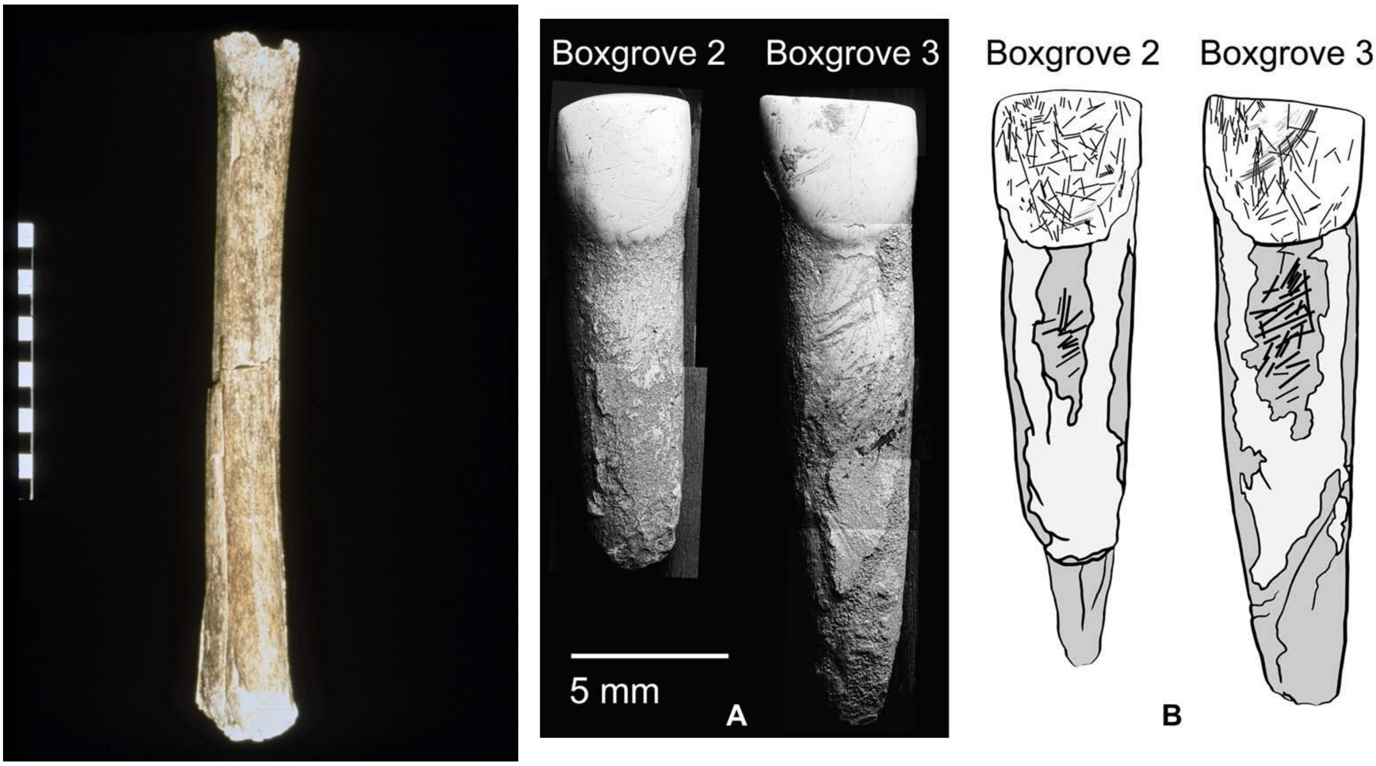

Fig. 34. Eartham Pit, Boxgrove. A. hominin tibia from within unit 8ac in Trench 5 in Q1/B (Quarry 1, adjacent to GCR site) (reported by Pitts and Roberts, 1997, photograph from the Boxgrove Project). B. hominin incisors - Boxgrove 2 from unit 4C in Trench 9 (with a root refit from unit 4u in Baulk 9/10) and Boxgrove 3 from the lower contact of unit 4 at the junction with unit 3M, also in Trench 9 (Hillson et al., 2010).

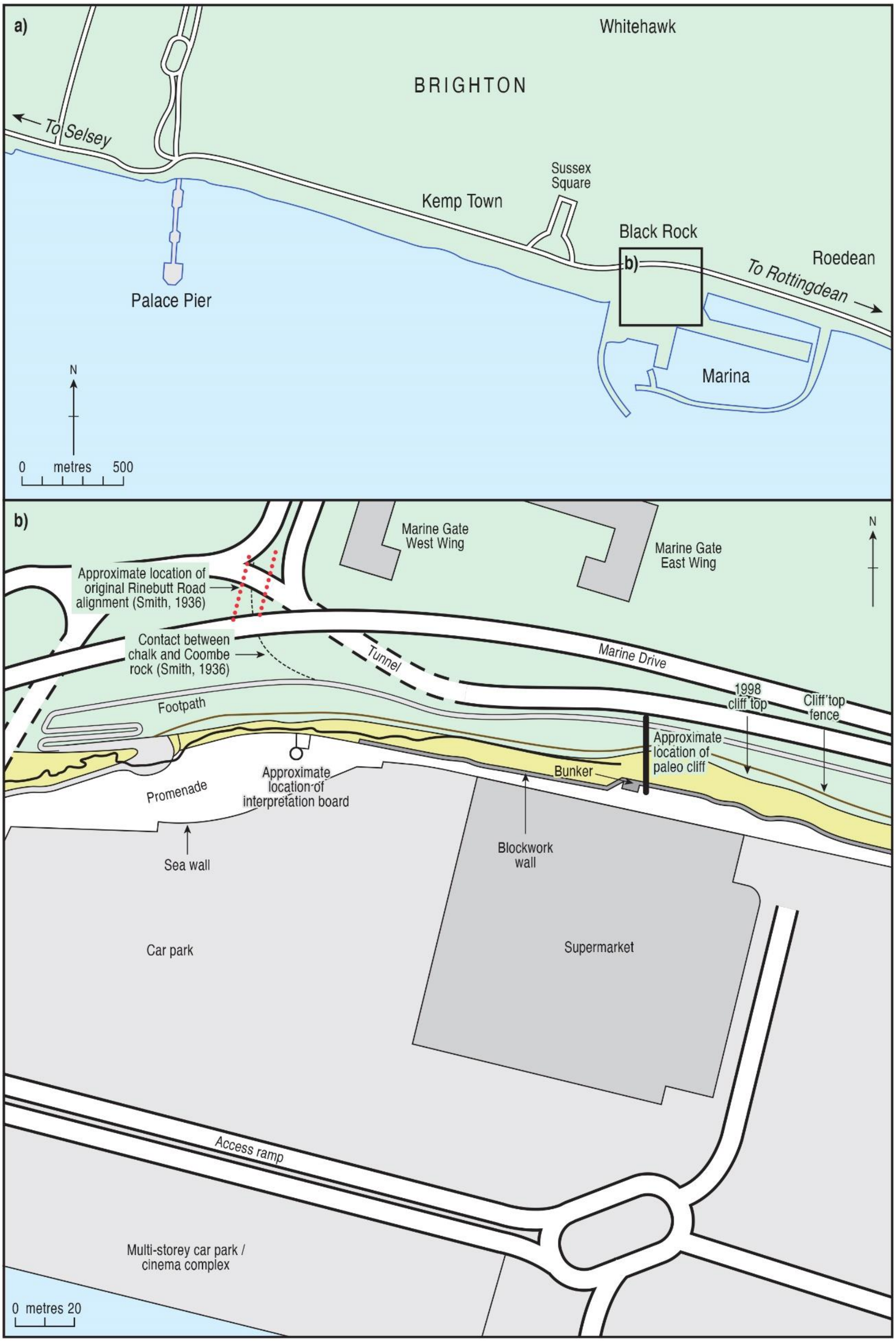

Fig. 35. Location of exposures within the larger GCR site at Black Rock, after Hutchinson and Millar (1998, Figs 5.1 and 5.2).

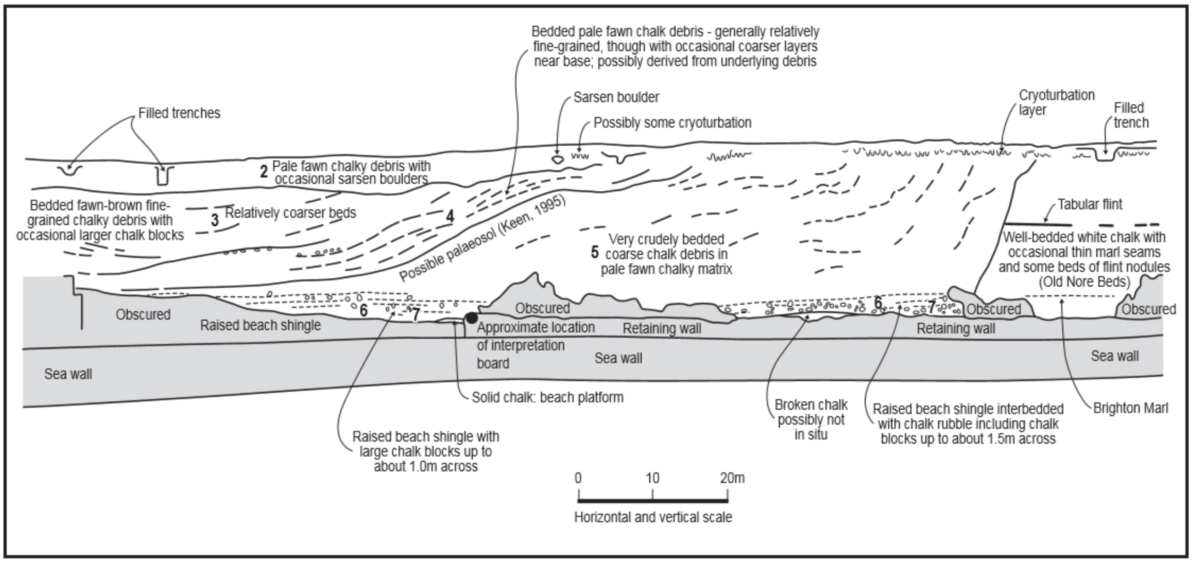

Fig. 36. Cross section at Black Rock GCR site (TQ339033) after Young and Lake (1988). Beds numbered are described in the text.

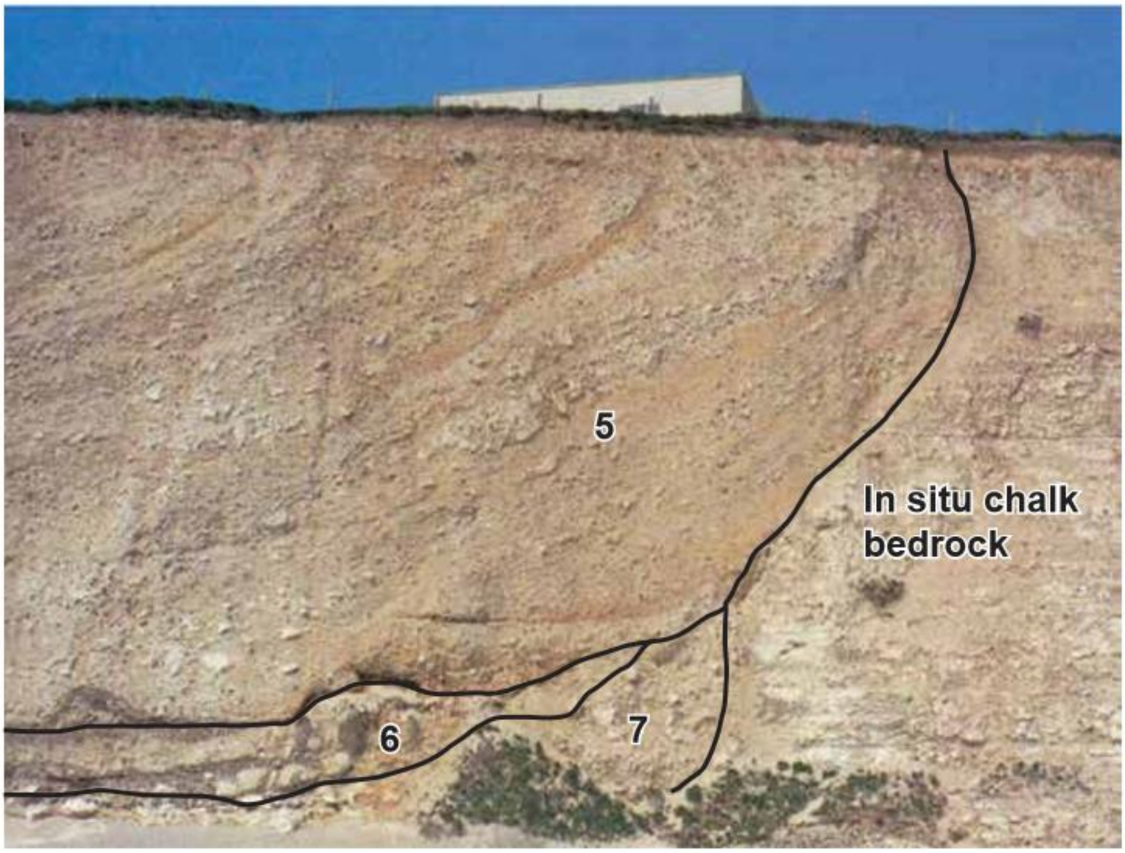

Fig. 37. Photograph of the palaeocliffline at Black Rock, showing beds 5, 6 and 7 (TQ 33723 03354). Photograph and annotations by CAW.

Fig. 38. Close-up photograph of the Black Rock raised beach deposits (bed 6) at the east of the section, near the base of the palaeocliffline (TQ 33723 03354). Photographed by CAW.

Fig. 39. Close-up photograph of the Black Rock raised beach deposits (bed 6), near the interpretation board (TQ 33602 03353). Photograph by CAW.

Fig. 40. Photograph of interpretation board at Black Rock GCR site (TQ 33602 03353, location shown on Figs 35 and 36).Photograph credit: RMB.

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