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Quaternary rivers, tufas and mires of southern England: Description of Geological Conservation Review sites

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ABSTRACT

Southern England contains a wealth of sites, reviewed here, that contain evidence for past deposition in freshwater environments over a period of over 0.5 million years and have been designated as Geological Conservation Review sites for their representativeness of a range of such environments. They include nine sites from two complete terrace sequences (the Solent in Hampshire [Solent Cliffs West, Calshot Cliffs, Hillhead Cliffs, Dunbridge Pit, Wood Green Gravel Pit] and Stour in Kent [Fordwich Pit, Sturry Gravel Pits, Wear Farm Pit, Chislet, Bishopstone to Reculver Cliffs]), alongside a further fluvial gravel site at Aylesford, in the valley of the Medway in Kent. Sites from the Thames catchment, although geographically nearby, are not included, having been previously described by Bridgland (1994). Many of these sites contain abundant Palaeolithic artefacts and some also fossils of multiple groups. A further four sites record fluvial landforms (Mole Gap, Surrey) and ancient 'high-level gravels' that may relate to very Early Pleistocene river activity (Upper Common, Mountain Wood, Upper Hale). Tufa and mire sites are relatively rare in this region, making those which are preserved more significant. The tufa sites at Blashenwell Farm and Wateringbury provide context for adjacent archaeological sites and record landscape development in the early and mid Holocene. The mire deposits at Cranes Moor, Mark Ash Wood, Cothill Fen and Rimsmoor together record vegetation history from key regional ecosystems for the entirety of the Holocene.

1. Introduction

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. In addition to the Introduction to the volume (Briant et al., this volume a), papers cover chalk landforms (Whiteman and Haggart, this volume), sea-level related landforms and sediments (Briant et al., this volume a, b) and periglacial landforms (Whiteman, this volume). This paper covers freshwater deposits from sites shown in Figure 1. These include those from rivers (fourteen sites), tufas (two sites) and mires (five sites).

Most of the sites within river terrace sequences have been chosen in networks to characterise significant terrace sequences (three stretches of significant cliff exposures in the West and East Solent, the four sites in the Kentish Stour). In addition to representative sites which are important for understanding the sedimentology and stratigraphy of these sequences, this review also includes some more unique sites. One of the advantages of Quaternary river terrace sequences is that they provide a clear stratigraphical framework for understanding and providing relative age control on archaeological artefacts and fossil remains, including vertebrates (Bridgland et al., 2004). This review includes several such sites, including Dunbridge Pit and Wood Green

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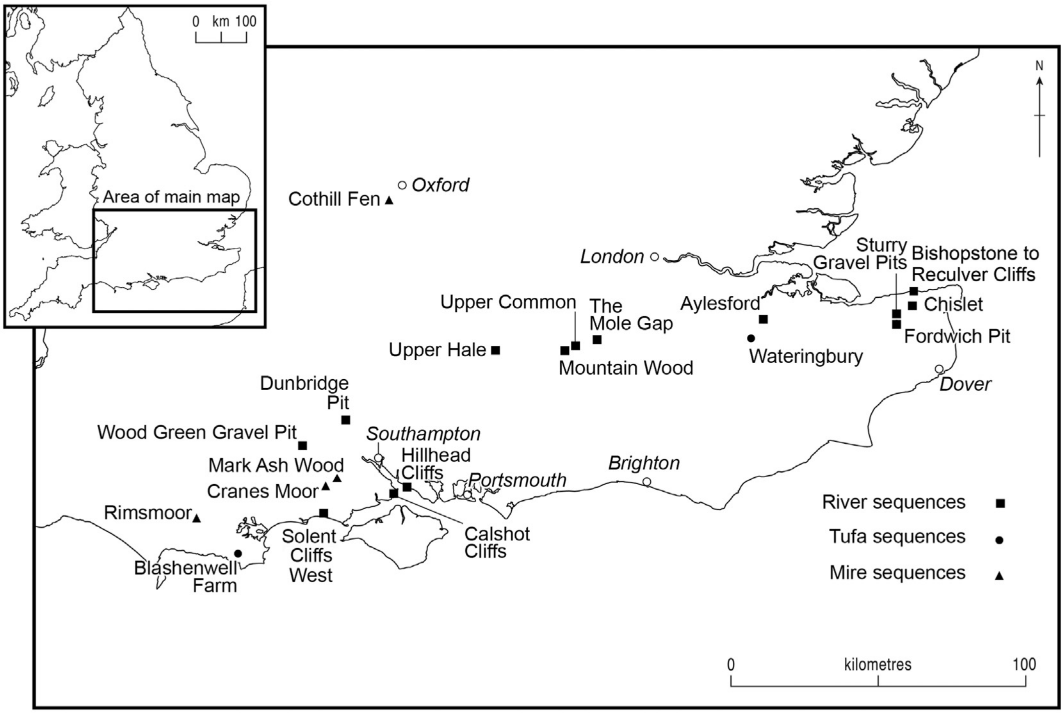

Fig. 1. Locations of all Geological Conservation Review sites described in this paper. Different types of sites are indicated using different shapes.

Gravel Pit in the Solent system and Aylesford in the Medway. The archaeologically rich sites at Fordwich Pit, Sturry Gravel Pits, Wear Farm Pit, Chislet and Bishopstone to Reculver Cliffs also yield a representative sequence through successive terraces in the Kentish Stour. Networks of sites like these work together to represent the geological history of a river system or time period. All need to be protected to enable interpretation of the whole network (Ellis et al., 1996). Wear Farm Pit, Chislet and Aylesford also have significant vertebrate assemblages reported from them. In addition to these sites which definitely record past river activity, this paper reviews three more enigmatic sites that seem to record high elevation Early Pleistocene river activity predating the current valley configuration, either directly or through periglacially reworked material These are seen at Upper Common, Upper Hale and Mountain Wood in addition to the geomorphologically important site of The Mole Gap with its rich sequence of periglacial sediments.

In the past, archaeological artefacts and vertebrate assemblages have had a double importance, as they have also provided the main way in which relative ages have been assigned to river terrace deposits. Whilst extremely useful in places with very complete sequences such as the Lower Thames (*e.g.*, Bridgland et al., 2004), in many locations, such as those reviewed here, the archaeology and vertebrates are too fragmentary or poorly provenanced to reliably suggest relative ages. In addition, as is shown in Section 2.1, most terrace sequences have highly disputed correlations and mapping such that even if a local relative age sequence can be established, it is very difficult to extend this across the entire terrace sequence. Many terrace sequences need detailed and careful re-examination of both lower and upper surfaces (*e.g.*, Hatch, 2014; Hatch et al., 2017) before correlations between different parts of the system can be trusted. Furthermore, given the potential for diachronous arrival of artefact types in different river systems, it is wiser to establish an independent age control where possible (*e.g.*, Briant et al., 2012; Davis et al., 2021a).

The most ubiquitous approach to establishing independent absolute age control on river terrace deposits in lowland Britain is the use of optically-stimulated luminescence (OSL) dating on sands (relative age control can be established using amino-acid racemisation [AAR] *e.g.*, Penkman et al., 2011). Concerns over unpredictable 'fading' of the age signal in feldspar minerals led to most of the studies reported in this review (which are concentrated in the Solent — Briant et al., 2006, 2012, 2019a; Hatch et al., 2017) being conducted on quartz grains using the single aliquot regenerative protocol of Murray and Wintle (2000). This is a robust protocol that allows for assessment of potential incomplete bleaching by analysis of scatter patterns between sub-samples (aliquots) but has the disadvantage that the signal 'saturates' at relatively young ages (Rixhon et al., 2017) and therefore there are no reliable age estimates from the sequences reviewed in this paper beyond *c.* 250 ka (at Calshot Cliffs and Aylesford). Since many of the sequences seem to date from considerably older than this, other techniques need to be applied, for example Electron Spin Resonance which has some potential (Voinchet et al., 2015; Lewis et al., 2021), as do some new protocols on feldspars that bypass the signals that are prone to fading, *e.g.*, post-IR-IRSL (Thomsen et al., 2008). Of these techniques that date older sediments, only infrared-radiofluorescence has yet been applied and this only at Fordwich Pit (Key et al., 2022). Effective independent absolute dating approaches would be particularly useful for shedding more light on the 'high level' sequences at Upper Common, Upper Hale and Mountain Wood.

In addition to these river sites, all of which are Pleistocene in age, there are seven sites that record landscape development during the Late Glacial and/or Holocene, including human influence on the landscape. Blashenwell Farm and Wateringbury comprise thick tufa deposits that cast light on landscape development in the early- and mid-Holocene through detailed analysis of the contained molluscan assemblages and radiocarbon dating. Blashenwell Farm is particularly important for adjacent archaeological sites and Wateringbury because it is a small enough area of tufa accumulation that there are significant numbers of terrestrial species in the assemblages, enabling reconstruction of the wider landscape.

The five mire sites comprise a network of three sites in the New Forest and two separate sites. The three New Forest sites together give a full picture of vegetation changes in the region. Cranes Moor is rare for southern England having become largely or solely ombrogenous from the early Holocene, enabling dry and wet phases to be reconstructed alongside charcoal and pollen records, but is truncated by peat cutting of the surface (Grant et al., 2014). Mark Ash Wood contains evidence from the Late Glacial Windermere (Bølling-Allerød; Greenland

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Interstadial 1) Interstadial and Loch Lomond (Younger Dryas; Greenland Stadial 1) Stadial onwards into the middle Holocene at Church Moor (Grant et al., 2009b). This high-resolution record then continues at Barrow Moor, also within the Mark Ash Wood site, covering the last *c.* 4000 years, including evidence of past woodland management (Grant et al., 2009b). Cothill Fen is another early- to mid-Holocene sequence, notable for its rarity due to its location within an area of calcareous soils in central southern England (Day, 1991a), and Rimsmoor is a uniquely long (18 m) peat sequence in a subsiding doline immediately south of the chalk Dorset Downs, with significant potential for high resolution studies; this site has not been studied in detail since the 1980s (Waton, 1982; Waton and Barber, 1987) and would benefit from the application of modern techniques.

The sites are grouped below by type and region, as follows:

2. 'Solent River', including the tributary valleys of the Test and Hampshire Avon
    2.1. Introduction
    2.2. GCR Site 2045 Solent Cliffs West (SZ 200 930) (CAW, RMB, MH)
    2.3. GCR Site 2339 Calshot Cliffs (SU 473 003) (CAW, RMB, MH)
    2.4. GCR Site 2046 Hillhead Cliffs (SU 522 030) (CAW, RMB, MH)
    2.5. GCR Site 1941 Dunbridge Pit (SU 316 257) (BAH, RMB, EE)
    2.6. GCR Site 1940 Wood Green Gravel Pit (SU 172 170) (BAH, RMB, EE)
3. GCR Site 991 Aylesford (TQ 727 596) – Medway (Kent) (BAH, RMB, DCS, PST, FFWS)
4. Stour (Kent)
    4.1. GCR Site 992 Fordwich Pit (TR 179 587) (BAH, RMB, PGK)
    4.2. GCR Site 1171 Sturry Gravel Pits (TR 174 607) (BAH, RMB, PGK)
    4.3. Provisional GCR Site Wear Farm Pit, Chislet (TR 224 650) (BAH, RMB, DCS, FFWS, PGK)
    4.4. Provisional GCR Site Bishopstone to Reculver Cliffs (TR 205 686 to TR 222 691) (PGK, DRB, MJW, RMB)
5. GCR Site 1234 The Mole Gap (River Mole, Surrey) (TQ165 531 and TQ175 516) (CAW, RMB)
6. 'High Level' sands and gravels
    6.1. GCR Site 454 Upper Common (TQ 084 499) (CAW, RMB)
    6.2. GCR Site 845 Mountain Wood (TQ 093 509) (CAW, RMB)
    6.3. GCR Site 1172 Upper Hale (SU 823 494) (CAW, RMB)
7. Tufa deposits
    7.1. GCR Site 2249 Blashenwell Farm (SY 952 805) (CAW, RMB)
    7.2. GCR Site 2260 Wateringbury (TQ 688 534) (BAH, RMB)
8. Mire deposits
    8.1. GCR Site 1905 Cranes Moor (SU 194 028) (BAH, RMB, MJG)
    8.2. GCR Site 1900 Mark Ash Wood (Church Moor) (SU 247 069), including provisional site extension to Mark Ash Wood (Barrow Moor) (SU 250 076) (BAH, RMB, MJG)
    8.3. GCR Site 2884 Cothill Fen (SU 463 999) (CAW, RMB)
    8.4. GCR Site 1903 Rimsmoor (SY 814 922) (CAW, RMB).

2. 'Solent River' (CAW, RMB, EE, MH)

2.1. Introduction

Five of the GCR sites described in this paper form a network associated with the erstwhile River Solent – either the main trunk system or smaller tributaries (Fig. 2). These deposits are and have historically been very well exposed in both quarry and cliff sections and often contain very rich Palaeolithic artefact assemblages. The concept of the 'Solent River' in Hampshire is generally attributed to Fox (1862), writing about the timing and mechanism of separation of the Isle of Wight from the mainland. The 'Solent River' was seen as the main axial stream of the Hampshire Basin, its headwaters a forerunner of the present River Frome, its northern tributaries the Piddle (Trent), Stour, Avon and Test rivers, its southern tributaries the East and West Yar of the Isle of Wight, and its southern flank broadly formed by the extension of the chalk ridge of the Purbeck monocline between 'The Needles' of the Isle of Wight and Studland Head, Dorset (Reid, 1915; Fig. 2), although there is evidence that its southern tributaries extended south of this ridge having incised valleys through the chalk (Edwards and Freshney,

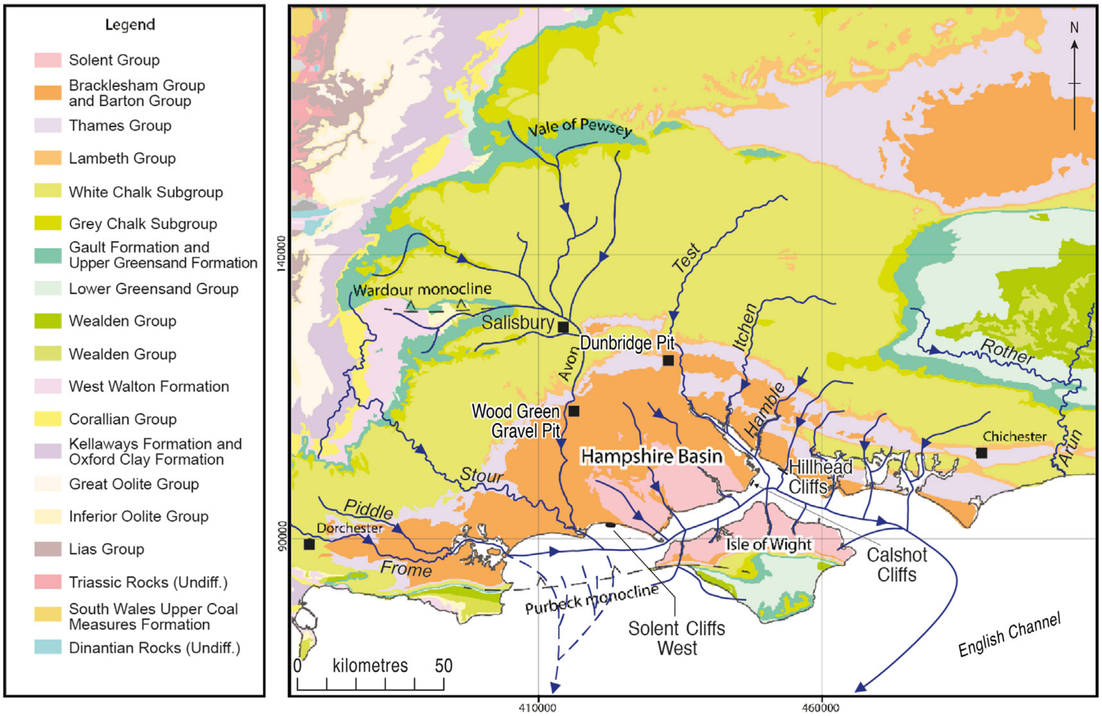

Fig. 2. Bedrock geology of the erstwhile Solent River basin, showing the locations of GCR sites described and the inferred 'Solent River' network according to Reid (1915) in solid lines, with the more recently inferred separate course of the Piddle and Frome after Velegrakis et al. (1999) in dashed lines.
Map data from the British Geological Survey under a JISC Airbus licence to Birkbeck, 2019.

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1987; Bristow et al., 1991; Allen and Gibbard, 1993). The remote origins of the 'Solent River' in Hampshire may lie in Miocene crustal flexure (Wooldridge and Linton, 1955; Jones, 1980; Gibbard and Lewin, 2003), though a precursor probably existed further west (Gibbard and Lewin, 2003).

Evidence for this long-established river system is contained in a suite of gravel deposits, terrace morphology and bedrock surfaces (Figs. 3–7) first described in detail by Reid (1902a, 1902b) towards the end of the 19th Century. These sediments and landforms extend widely across southeast Dorset, south Hampshire and the Isle of Wight and, below sea level, in the East and West Solent. The very highest terraces, which are devoid of gravel and exist as eroded chalk platforms, were originally thought to be marine in origin (Green, 1943; Everard, 1954a, 1957). However, current views are that river systems have existed in the region of the 'Solent River' since at least Pliocene times (Allen and Gibbard, 1993; Gibbard and Allen, 1994) and probably for much longer (Gibbard and Lewin, 2003), meaning that all the associated geomorphology is of fluvial origin. Channels visible in bathymetric mapping beneath Southampton Water and to the east of the Isle of Wight show that beyond the Hampshire Basin the river changed course, turning sharply south-westwards to join the 'Channel River' flowing westwards across the area now occupied by the English Channel (Gibbard, 1988; Hamblin et al., 1992; Bellamy, 1995; Antoine et al., 2003; Gupta et al., 2007). Other channels have recently been found further west, between Dorset and the Isle of Wight, and have led to refinements of the 'Solent River' story. The Frome, formerly interpreted as the former upper reaches of the 'Solent River' (*e.g.*, Reid, 1915; Fig. 2), is now considered to be a separate fluvial system since at least the Middle Pleistocene and probably much earlier (Velegrakis, 1994, 2000; Bridgland, 1996, 2001; Velegrakis et al., 1999; Fig. 2). Indeed, Brown et al. (2019) have suggested an earlier Quaternary or even pre-Quaternary date, predicated on the very large wave-cut platforms forming Weymouth and Christchurch Bays, as well as historic observations of Quaternary organic sediments in the Char and Brit. Fluvial aggradation and terrace formation were probably driven by alternating cold and warm environmental stages (Allen and Gibbard, 1993) coupled with progressive uplift during the late Paleogene and Pleistocene (Maddy, 1997; Bridgland, 2001). Sedimentological analysis of sections has shown that the 'Solent River' system was predominantly braided in form. Whilst some intraformational ice wedge casts that suggest periglacial conditions during deposition have been reported (*e.g.*, Lewin, 1966), they are not common. Bridgland (2001) proposed that altitudinally separated terrace gravels formed both during the cooling phase from interglacial to glacial conditions and as the climate changed from cold to warm.

The 'Solent River' no longer exists. It was eventually drowned by Holocene sea-level rise (Hodgson and West, 1972; Devoy, 1982) and the southern side of its catchment destroyed following erosion of the chalk ridge between the Isle of Wight and Dorset (Allen and Gibbard, 1993; Gibbard and Allen, 1994; Velegrakis et al., 1999; Nowell, 2001). Exactly when the latter event occurred is disputed (see discussion below) but marine encroachment resulted in substantial changes in the position of the coastline and the extent of the river network. Following the breaching of the Wight–Purbeck ridge, the former Solent River system split into several parts: Bournemouth and Christchurch

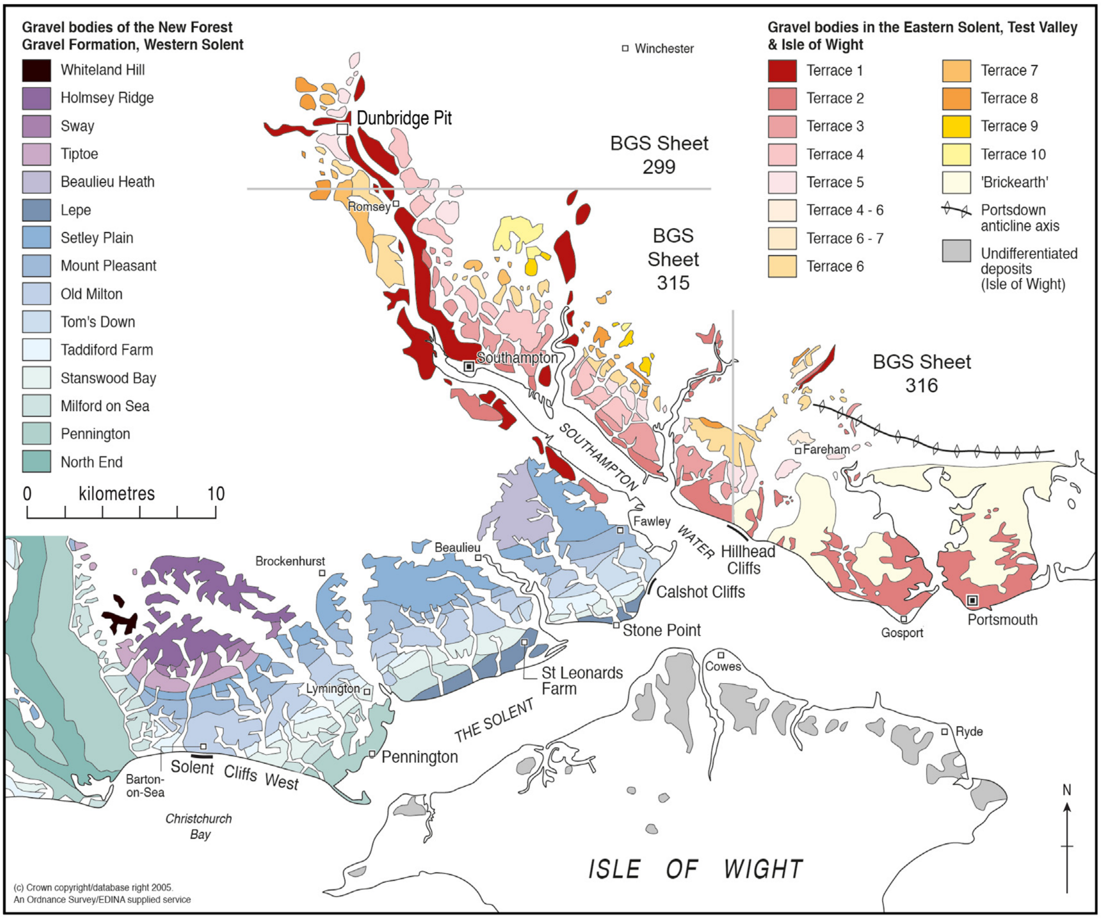

Fig. 3. Gravel deposits of the West and East Solent after Allen and Gibbard (1993); Edwards and Freshney (1987) and Booth (2002) with suggested correlations between the latter two by Briant et al. (2006) and Briant et al. (2012). GCR sites described are shown.
Base map from Ordnance Survey *via* Digimap licence to Birkbeck.

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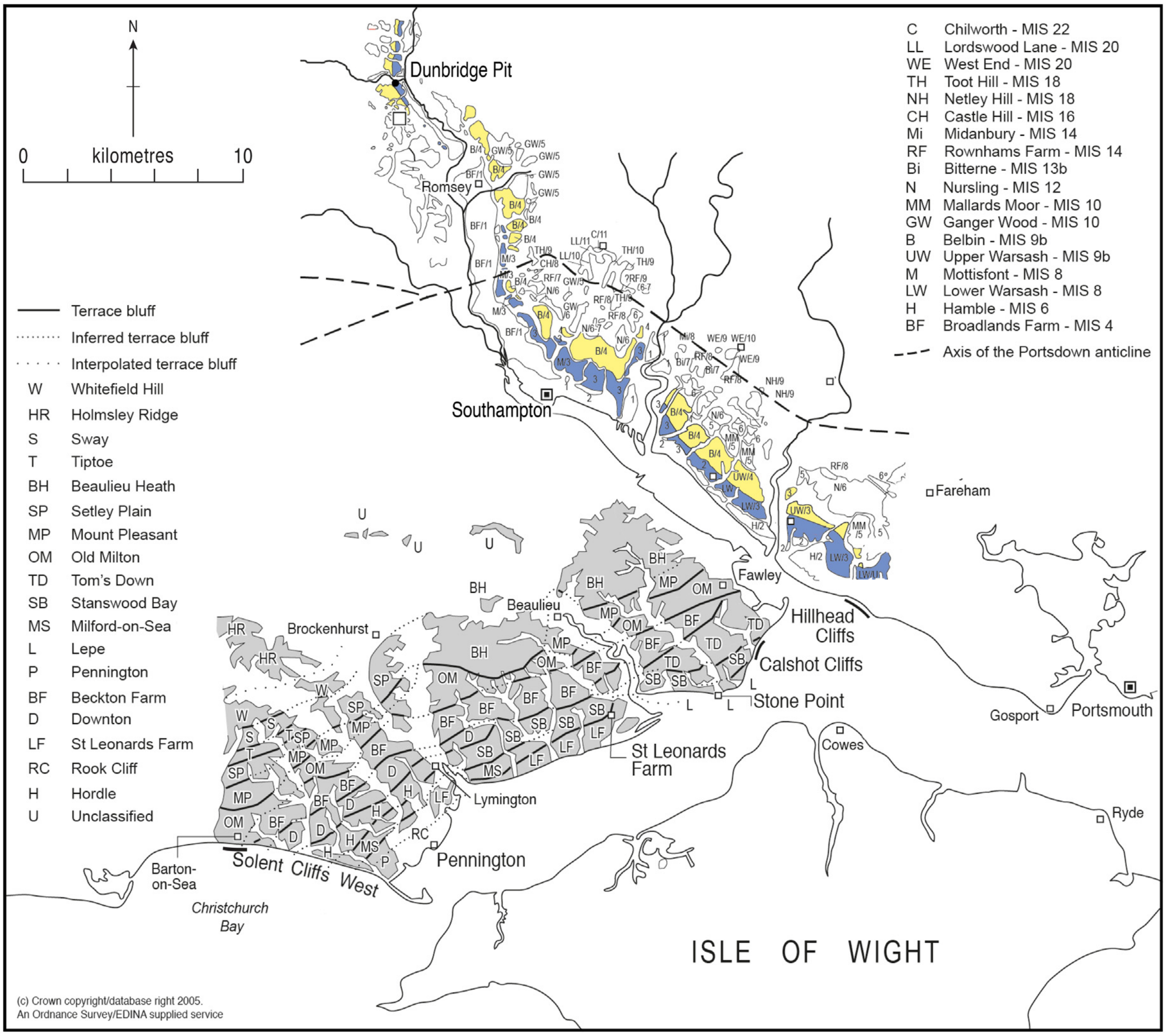

Fig. 4. Gravel deposits of the West and East Solent after Westaway et al. (2006), updated by Harding et al. (2012). GCR sites described are shown, as are other relevant non-GCR sites. Base map from Ordnance Survey *via* Digimap licence to Birkbeck.

embayments and the rivers upstream from these (Nicholls, 1987), the Solent and Southampton Water and the Test river. Around these water bodies are extensive cliffs, which, as part of the network of GCR sites, preserve key evidence for substantial parts of the former fluvial system known as the 'Solent River'.

Early mapping in the Hampshire Basin region, mostly by the Geological Survey, recognised a number of gravel units, at first subdivided according to altitudinal position into 'Valley' and 'Plateau' types (Codrington, 1870; Reid, 1898, 1899, 1902a, 1902b, 1915; Reid and Strahan, 1889; White, 1913, 1915, 1917, 1921; Bury, 1923; Green, 1946, 1950). Morphology and surface altitude were used by Chatwin (1936), Green (1946), Everard (1952, 1954a) and Swanson (1970) to further subdivide the gravels into terrace stages, subsequently rationalised by Keen (1980) into terrace groups termed 'high', 'middle' and 'low'. The fluvial origin of all these gravels has not always been recognised: Codrington (1870) and Everard (1954a) invoked, at least in part, a marine origin; Kellaway et al. (1975) a glaciofluvial origin; and Palmer and Cooke (1923) and Green (1946) a mixed fluvial and marine origin. It was, however, White (1915, 1917, 1921) who originally postulated that the gravels were deposited by braided rivers responding to cold environmental conditions, a view now widely supported (*e.g.*, Keen, 1975, 1980; Fisher, 1975; Allen and Gibbard, 1993; Bridgland, 2001) and generally accepted.

Detailed mapping by various researchers has revealed a series of gravel terraces running broadly west to east in the Hampshire Basin (Figs. 3–6), roughly parallel with the present coastline (Everard, 1954a; Dyer, 1975; Clarke and Green, 1987). Everard (1954b) showed that some of these terraces were submerged and could be traced beneath the East Solent. In the 1980s and 1990s there was a major resurvey of the region by the British Geological Survey (BGS) (Kubala, 1980; Clarke, 1981; Clarke and Green, 1987; Mathers, 1982a, 1982b; Edwards and Freshney, 1987; Bristow et al., 1991). This was followed by an extensive and detailed sedimentological and lithostratigraphical analysis of the gravels by (Allen, 1991; Allen and Gibbard, 1993; Gibbard and Allen, 1994). Between these studies the fluvial origin of the gravels was firmly established. The BGS identified up to sixteen fluvial terraces in the Bournemouth–Southampton area and nine between Dorchester and Wareham in the Frome catchment.

These terrace gravel units have been rationalised into three separate suites of terrace sediments (Gibbard and Allen, 1994; Gibbard and Preece, 1999). The most westerly suite, unrepresented by GCR sites, lies in the Wareham–Dorchester region of Dorset and is known as the Frome–Piddle Formation. Nine gravel members are recognised in the Frome Valley and seven in the Piddle Valley, of which only three are named by Allen and Gibbard (1993). In contrast, Brown et al. (2010; Brown et al., 2019) recognise 14–15 terrace bodies. A second more extensive suite of terrace gravels occurs in the Bournemouth–Southampton area which was called the New Forest Formation by Allen and Gibbard (1993). It is the most extensively studied since this time and can usefully be split into the West Solent, East Solent and Avon. This

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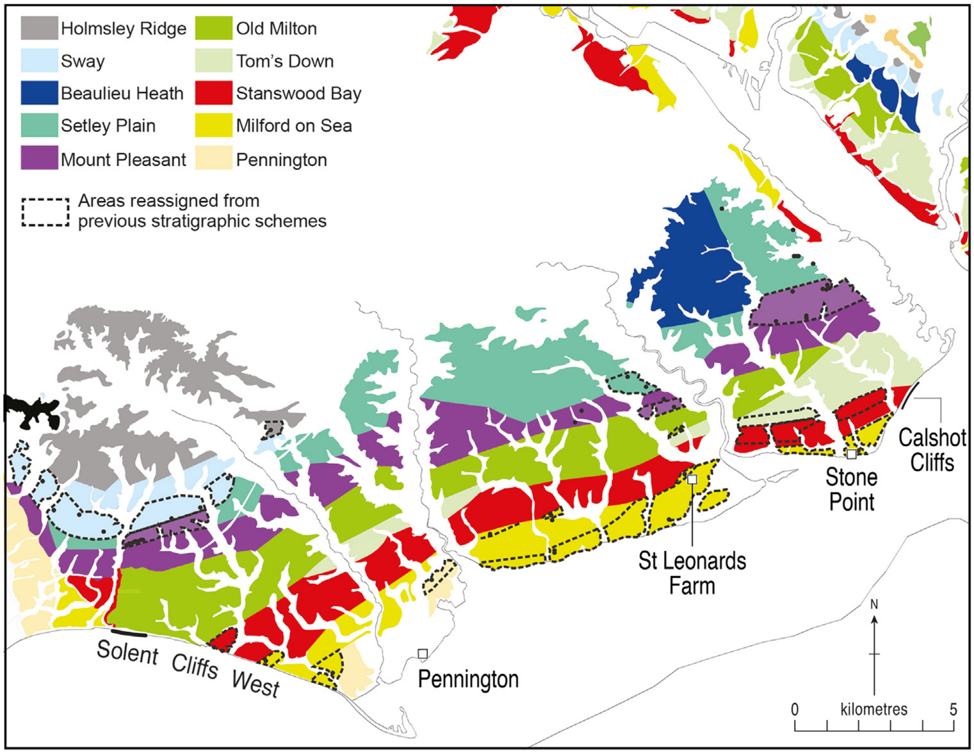

Fig. 5. Gravel deposits of the West Solent after Hatch (2014). GCR sites described are shown.
Base map from Ordnance Survey *via* Digimap licence to Birkbeck.

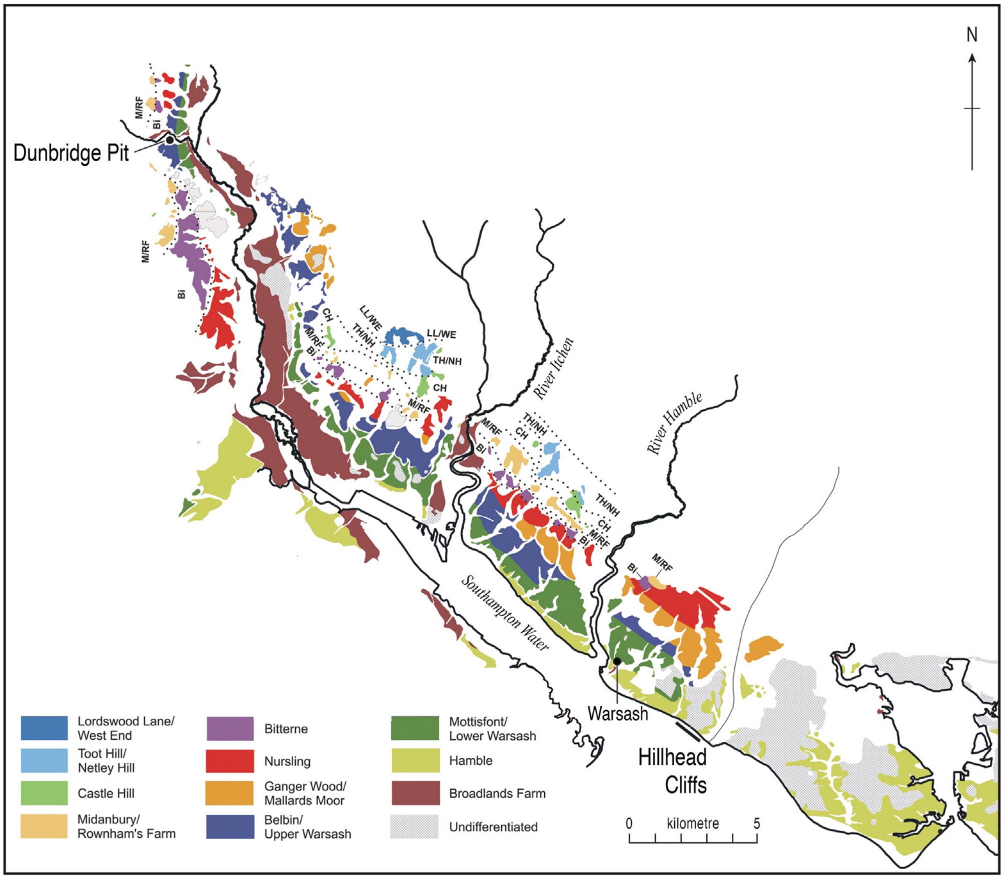

Fig. 6. The most recent stratigraphic scheme for the River Test, based on Harding et al. (2012), with local reassignments in the Warsash area by Hatch et al. (2017). Figure adapted from Figure 12 of Hatch et al. (2017). GCR sites described are shown.
Base map from Ordnance Survey *via* Digimap licence to Birkbeck.

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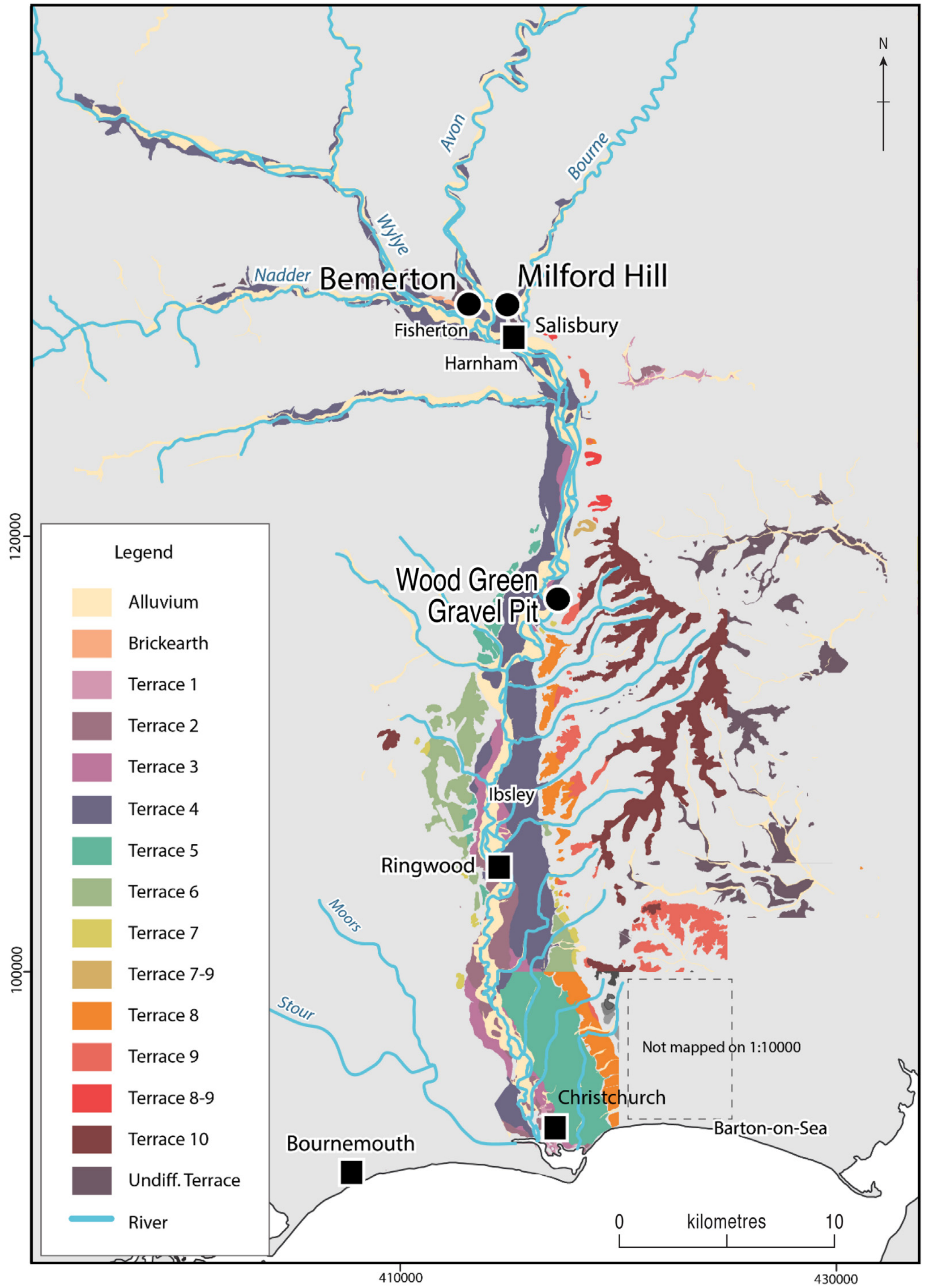

Fig. 7. Gravel deposits of the Avon based upon 1:10,000 scale geology data, with permission of the British Geological Survey and 1:10,000 scale OS VectorMap Local [water line shape file], Digimap Licence after Briant et al. (2019a). GCR sites described are shown.

suite of gravels is represented by a network of five GCR sites described in this paper and another in the companion paper on marine sequences (Briant et al., this volume a, b). The third suite of gravels, named the Solent Formation, was deposited by south bank tributaries of the Solent River in the north of the Isle of Wight (Everard, 1954a; Allen and Gibbard, 1993).

There are four features of the terrace sequences of the Solent system that make correlation both within and between sub-catchments problematic. First, the clast lithological composition of all the terraces is very similar. Thus, whilst Keen (1980) presented mean lithological data from his 'high', 'middle' and 'low' suites of terraces that differentiated 'high' from 'middle' and 'low' terraces the more detailed lithological work of Allen (1991) and Allen and Gibbard (1993) made it clear that differentiation of the numerous gravel terraces solely on the basis of lithology is unreliable. Even though there are subtle differences between some terraces and 'Solent' gravel units near Bournemouth have been correlated with those in the tributary Avon Valley, Allen and Gibbard (1993) note no large-scale patterns. Second, there is significant dissection of main trunk deposits by tributaries. Third, different criteria have been used by researchers to define either terrace surfaces (Westaway et al., 2006) or bodies of terrace gravels (Allen and Gibbard, 1993; Briant et al., 2012). The uncritical use of surface

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morphology coupled with altitude has been questioned (*e.g.*, Gibbard, 1985; Briant et al., 2012). More recently, a more robust approach has used the base of deposits, sometimes determined using geophysical techniques (Hatch, 2014; Hatch et al., 2017). This has facilitated correlation of the 'Solent River' terraces. Fourth, the acidic nature of the bedrock means that there is no preservation of fossils except in the very lowest terraces, and even this is variable due to decalcification. For this reason, it was for a long time not possible to suggest an age for any of these terrace deposits, although correlation of these gravel units has been attempted on the basis of Palaeolithic implement typology (*e.g.*, Bury, 1923, 1925; Calkin and Green, 1949). The technique fell into disrepute, but has recently been revived, as discussed below. As will be seen below, improved OSL dating on sand has also been applied and improved the age control somewhat.

Despite these limitations, the network of sites provides significant insight into development of the Solent system. Of these, three long cliff sections, Solent Cliffs West, Calshot and Hillhead, provide a unique insight into the sedimentology, lithostratigraphy and morphology of a typical British braided river system in the area beyond glacial influence. The remaining two, Wood Green Gravel Pit in the valley of the Avon River, and Dunbridge Pit in the Test valley are of great archaeological importance as well as providing links with the 'Solent' tributary network. Together, they characterise critical components of landscape evolution and use in the area of Britain's most extensive fully extra-glacial former fluvial system, probably driven by significant climate change episodes and tectonic uplift, of a substantial part of these fluvial systems.

In addition, with the gravels, particularly at Dunbridge Pit and Wood Green Gravel Pit, yielding Britain's most abundant supply of prehistoric human implements, the importance of these GCR sites cannot be overstressed, particularly in the context of a more extensive ancient, evolving landscape, containing early evidence for human occupation in Great Britain at Boxgrove (Roberts et al., 1994; Roberts and Parfitt, 1999). Indeed, synthesis of these findings by Ashton and Hosfield (2010) has suggested that human occupation densities declined earlier in the Solent than in the Thames, possibly due to the greater difficulty for hominins to travel into Britain across the deep, fast-flowing channels of the channel–river braidplain, than the shallow, marshy areas of the southern North Sea deltas. However, defining human occupation densities based on differentially preserved and recovered artefact findspots and sites is not without its problems and their paper does not contain any direct dating of the relevant sequences.

2.1.1. West Solent

The Solent River sequence is best developed in the western Solent, for which numerous stratigraphical schemes have been proposed over a period of more than a century; the three most recent of these are summarised in Table 1 and Figures 3–5 (Allen and Gibbard, 1993; Westaway et al., 2006; Hatch, 2014). The earliest mapping, by Green (1946) and Mathers (1982a, 1982b), was first revised by Allen and Gibbard (1993; Fig. 3), whose scheme involved steeper downstream terrace gradients than the earlier work. More recently, Westaway et al. (2006; Fig. 4) introduced a scheme with a revised nomenclature, partly reverting to the shallower gradients proposed by Green and Mathers. Further field investigation of the fluvial sediments in the Western Solent area was undertaken in 2010 and 2011 as part of the 'Palaeolithic Archaeology of the Solent River' project, funded by the Arts and Humanities Research Council, comprising sedimentary descriptions, Imaging Station surveying of coastal sections, ground penetrating radar (GPR) and OSL dating. This re-evaluation of the terrace stratigraphy in the Western Solent region has already resulted in a number of revisions to terrace attributions and mapping in the area (Hatch, 2014; Fig. 5) and further research by Hatch is ongoing. The current re-evaluations are based on detailed interpretation of boreholes, using the Stanswood Bay/Hordle terrace, whose spatial extent has the greatest consensus, being agreed on by both Allen and Gibbard (1993) and Westaway et al. (2006), as a tie-point. Borehole records altitudinally higher and lower were then reassigned to a smaller number of terrace bodies than previously suggested, but with similar gradients. Locations of reattributions are shown in Figure 3. Further fluvial deposits have been observed offshore (Dyer, 1975; Allen and Gibbard, 1993), and it seems likely that some of these correlate with the lower aggradations mapped onshore, although it is hard to determine how they do so.

Biological evidence that might help determine the age of these gravel bodies is limited in extent, because only the younger terrace gravels of the New Forest Formation have yielded detailed evidence. At Stone Point, south of Fawley, an organic layer was found within the terrace sequence (Reid, 1893). This is a GCR site (1870) for sea level information and is discussed in detail in Briant et al. (2009, 2019c) and summarised in Briant et al. (this volume a, b). It is currently interpreted as of Ipswichian (IpIIb) age. The earliest detailed investigations of this sequence assigned these deposits to the Ipswichian (West and Sparks, 1960; Brown et al., 1975). This was later questioned on the basis of altitudinally lower Ipswichian age freshwater silts associated with the Pennington Gravel (Allen and Gibbard, 1993) to the west of Stone Point at Pennington Marshes (Allen et al., 1996) and thermoluminescence dating of loessic sediments thought to contain a 'temperate' palaeosol (Reynolds, 1985, 1987) at the top of the succession (Parks and Rendell, 1992) and an age equivalent to MIS 7 was suggested (Gibbard and Preece, 1999).

More recent research and dating (Briant et al., 2006, 2009, 2019c) of the Stone Point deposits complicate this story further. Amino-acid racemisation results from a potentially reworked *Bithynia tentaculata* operculum within the sand lens at the base of the interglacial sequence

Table 1
Age models suggested for fluvial gravel aggradations in the West Solent region. A dash shows where there is no reliable OSL dating evidence.

Allen and Gibbard (1993) model		Westaway et al. (2006) model		Bridgland (1996, 2001) MIS	MIS based on OSL (Briant et al., 2006)	Hatch (2014)	
Terrace	MIS	Terrace	MIS			Terrace	MIS
Sway	?	Sway	–	–	–	Sway	?14/12
Tiptoe	?	Tiptoe	–	–	–	Sway	?14/12
Beaulieu Heath		Beaulieu Heath				Beaulieu Heath	?14/12
Setley Plain	?	Setley Plain	13b	13	–	Setley Plain	?12–9
Mount Pleasant	?	Mount Pleasant	12	12	–	Mount Pleasant	?12–9
Old Milton	?	Old Milton	10	11	–	Old Milton	?12–9
		Becton Farm	9b				
Tom's Down	?	Downton	8	10	–	Tom's Down	9–7
Taddiford Farm	?			9		Stanswood Bay	8–7
Stanswood Bay	?	Hordle	7b	8	8–7b (*c.* 276–215 ka)	Stanswood Bay	8–7
Milford-on-Sea	?	Milford-on-Sea	6	?7b–e	–	Milford-on-Sea	6
Lepe (lower)	Pre 7	Rook Cliff/St Leonards Farm (lower)	late 6	?7b–e	7d–6 (*c.* 230–130 ka)	Milford-on-Sea	6
Pennington (lower)	6	Pennington (lower)	late 6	6	–	Pennington	6
Pennington Marshes	5e	Pennington Marshes	5e	5e	5e	Pennington Marshes	5e
Pennington (upper)	5d–2	Pennington (upper)	5d-2	5d–2	5d–3 (*c.* 105–43 ka)	Pennington	5d–3

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Table 2
Regional stratigraphic context of the three interglacial sequences preserved within the former Solent River system between Christchurch and Southampton Water.

	Pennington Marshes	St Leonard's Farm	Stone Point SSSI
Name of associated gravel (Allen and Gibbard, 1993)		Lepe Gravel	Lepe Gravel
Name of associated gravel (Westaway et al., 2006)	Pennington Gravel	St Leonard's Farm Gravel	Lepe Gravel
Name of associated gravel (Hatch, 2014)	Pennington Gravel	Milford on Sea Gravel	Milford on Sea Gravel
Altitudinal range of interglacial deposit	*c.* −3.9 to −5.3 m O.D.	*c.*0.1 to 1.8 m O.D.	*c.* 1 to −8 m O.D.
Salinity suggested by fossils within interglacial deposit	Freshwater (Allen et al., 1996)	Freshwater with brackish/tidal elements (Briant et al., 2013)	Brackish/marine with freshwater elements (West and Sparks, 1960; Brown et al., 1975; Briant et al., 2019c)
Suggested age of interglacial deposits	Last interglacial/MIS 5e (Allen et al., 1996)	Last interglacial/MIS 5e (Westaway et al., 2006)	Last interglacial/MIS 5e (West and Sparks, 1960; Brown et al., 1975; Briant et al., 2006, 2009, 2019c) Penultimate interglacial (Allen et al., 1996) Not stated (Westaway et al., 2006)

have confirmed a maximum age of MIS 7 for the Stone Point deposits (Briant et al., 2019c). OSL dating at this site, however, suggests that an MIS 5e age for this sequence is more likely (Briant et al., 2006, 2009, 2019c). Recent re-investigation of the overlying fine-grained deposits ('brickearth') yielded no evidence of a palaeosol but suggested an age of *c.* 70–40 ka, despite the introduction of younger material *via* bioturbation (Briant et al., 2019c). The relationship between these deposits and other fossiliferous deposits at both lower (Pennington — Allen et al., 1996) and higher altitudes is complex. Higher altitude fossiliferous deposits are found at St Leonards Farm (Briant et al., 2013), west of Stone Point and east of Pennington. These overlie the Lepe Gravel as mapped by Allen and Gibbard (1993). This is mapped at St Leonards Farm Gravel by Westaway et al. (2006) and possibly Milford on Sea Gravel by Hatch (2014), although this correlation is still under investigation. They may also be Ipswichian in age, although decalcification means that fossils are poorly preserved and there is no age control on this sequence. If, as seems possible, all three sequences date from the Ipswichian, this suggests significant complexity within the Solent estuary/seaway during this interglacial (Table 2) because of their significantly different stratigraphic relationships and altitudes.

Ages have been suggested for Solent terrace gravels using both these deposits and Palaeolithic artefact types as tie-points (Bridgland, 1996, 2001). This has since been supplemented by uplift modelling at key locations and associated adjustment of some tie-point ages (Westaway et al., 2006; Table 1). Use of Palaeolithic artefacts as tie-points was based on ideas on the earliest occupation of southern England in MIS 13 and the development in this region of (a) twisted-ovate-dominated assemblages in MIS 11 (White, 1998b) and (b) Levalloisian technology in late MIS 9/early MIS 8 (Bridgland, 1996; Bridgland and White, 2014), although recent research suggests that not all sites with flakes attributed to the Levallois technology may be of this age (White et al., 2024).

In addition, Aggregate Levy — funded research in the 'Palaeolithic Archaeology of the Sussex/Hampshire Coastal Corridor' (PASHCC) project (Bates et al., 2004; Briant et al., 2006, 2019c) and an Arts and Humanities Research Council (AHRC) studentship (Hatch, 2014) sought to date by OSL key gravel aggradations both west and east of Southampton Water. Of these, the earliest reliable ages are from Allen and Gibbard's (1993) Stanswood Bay Gravel in the Calshot Cliffs GCR site (2339). For this part of the sequence there is good agreement with the previously suggested age models of Bridgland (1996, 2001) and Westaway et al. (2006).

2.1.2. East Solent

Gravels on the eastern side of Southampton Water and the lower part of the Test Valley are less well exposed due to urban development. Mapping by Edwards and Freshney (1987) recognised up to 11 terrace levels at various heights trending north-west/south-east up the Test Valley between Romsey and Portsmouth (Fig. 3) and a further three submerged terrace levels offshore, the lowest of which is infilled with various Holocene sediments. The upper part of the valley was later mapped by Booth (2002) and the two schemes do not directly correlate. Since this mapping, a number of workers have suggested new terrace correlations between these two mapped sheets (Table 3), with

Table 3
Terrace correlations between BGS sheets 299 (Winchester) and 315 (Southampton) after Hatch et al. (2017), with added OSL ages and MIS attributions. T = terrace.

Booth (2002)	Briant et al. (2012)	Westaway et al. (2006)	Harding et al. (2012)	Edwards and Freshney (1987)	Published reliable OSL ages	Suggested MIS attribution
BGS sheet 299	BGS sheet 299	Upstream	Downstream	BGS sheet 315		
T1	T1	Broadlands Farm	Broadlands Farm	T1	HUF03-01: 69 ± 5 ka (Bates et al., 2010; Briant et al., 2012)	4
	T2	Hamble	Hamble	T2	SB03-03: 212 ± 25 ka	7
	T3				SB03-03: 204 ± 17 ka	
					SB03-03: 231 ± 24 ka	
					SB03-03: 221 ± 20 ka	
					(Bates et al., 2010; Briant et al., 2012)	
					Minimum age: BRW08-02Qz: 200 ± 23 ka (Hatch et al., 2017)	
T2/3	T4	Mottisfont	Lower Warsash	T3	X3641: 183 ± 11 ka	8 (8–7)
					X3642: 203 ± 30 ka	
					X3643: 196 ± 29 ka	
					X3646: 247 ± 13 ka	
					X3647: 233 ± 6 ka	
					X3648: 293 ± 34 ka	
					(Harding et al., 2012)	
					Minimum age: HAP10-03Qz: 229 ± 24 ka (Hatch et al., 2017)	
	T5	Belbin	Upper Warsash	T4		9 (12–9)
T4	T6	Ganger Wood	Mallards Moor	T5		
	T7					
T5/6	T8	Nursling	Nursling	T6		
		Bitterne	Bitterne	T7		
		Midanbury	Rownham's Farm	T8		

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significant variations. The most recent assessment of these deposits by Hatch et al. (2017; Fig. 6) uses the most comprehensive set of data and suggests a number of important local reattributions to the Harding et al. (2012) scheme in Figure 4. The Hatch et al. (2017) approach used 280 borehole records, 30 synthetic borehole records based on ground-penetrating radar and 41 records from published work, all concentrating on both the base and the top of the deposits. Correlations were tested by first establishing the extensive spreads of gravel in the Broadlands Farm and Hamble Terraces and then correlating more fragmentary deposits. In contrast, earlier terrace schemes in the East Solent region are all based only on elevations of the top surface of the terrace deposits.

The most hotly debated part of the terrace correlation has been its significance for the contemporaneity or otherwise of the important Palaeolithic archaeological assemblages from Dunbridge Pit (GCR site 1941) and Kimbridge in the middle Test and Warsash in the lower Test, both of which have yielded handaxes and Levallois artefacts (both cores and 'proto-Levallois' cores). Both are also characterised by decades of historical collecting within gravel deposits at multiple altitudes and therefore insecure provenancing of museum specimens in relation to terrace deposits. Detailed reinvestigation of both assemblages published in the last ten years has significantly clarified the relationship between these assemblages. At Dunbridge and Kimbridge, Harding et al. (2012) reported on over 20 years of an archaeological watching brief and reinvestigation of historical quarrying to suggest that the Dunbridge assemblages that contain Levallois (5 artefacts *cf.* > 1000 handaxes) can all be attributed to their Belbin/Upper Warsash Terrace and the Kimbridge assemblages without Levallois to their Mottisfont/Lower Warsash Terrace. Reliable OSL age estimates from the Mottisfont gravel at Kimbridge range from 172 to 327 ka, with a suggested correlation to the marine isotope stratigraphy of MIS 8 or 9 (Harding et al., 2012, Table 3). At Warsash, Hatch et al. (2017) showed that those Levallois artefacts for which a provenance can be traced reliably (30 from 34) were all associated with the Mottisfont/Lower Warsash Terrace and in all likelihood overlying it within fine-grained deposits. In contrast, the handaxes associated with the Mottisfont/Lower Warsash Terrace are all rolled and found within the gravels. OSL age estimates from the Mottisfont/Lower Warsash Terrace yielded minimum age estimates ranging from 50 to 253 ka (Hatch et al., 2017). The Mottisfont/Lower Warsash Terrace at Warsash has been correlated with MIS 8 to 7.

A full reinvestigation of the Lower and early-Middle Palaeolithic record of the River Test, including these sites in the context of other less abundant locations by Davis et al. (2021a) showed that the earliest evidence for human presence in the Test valley was associated with the Midanbury Terrace. Levallois technology first appears in the Belbin Terrace assemblage and is most numerous in the Lower Warsash Terrace record. Reworking of handaxes was common as shown by the increasing degree of rolling in younger and lower terraces. Typological interpretation was therefore based only on the freshest material from each terrace deposit; for example, the Nursling Terrace is characterised by ovates and in the Belbin Terrace, at Dunbridge, Romsey and Southampton, pointed forms are dominant.

Determining the ages of these deposits is more complex than in West Solent, because there are no preserved biological remains. Westaway et al. (2006) suggested an age model based on archaeological tie-points and uplift modelling (Table 3). More recently, a number of workers have published OSL ages from this sequence, although some of these (especially the older ones) are considered to be unreliable (Briant et al., 2012; Harding et al., 2012; Hatch et al., 2017). Of the more reliable age estimates, sediments within the Broadlands Farm Terrace yield an age of *c.* 69 ka (MIS 4; Briant et al., 2012) and multiple samples from the Hamble Terrace place aggradation of this unit within MIS 7 (Briant et al., 2012; Hatch et al., 2017). Altitudinally above this, the Mottisfont/Lower Warsash Terrace is dated to MIS 8 (Harding et al., 2012; Hatch et al., 2017).

2.1.3. Hampshire Avon

The Hampshire Avon is a significant north-bank tributary of the former Solent. Avon terraces have been extensively studied since the nineteenth century, partly because abundant Palaeolithic artefacts occur within their deposits (*e.g.*, Blackmore, 1864; Reid, 1898, 1902b; Green, 1946; Sealy, 1955). Significant Palaeolithic archaeological assemblages occur near Salisbury at Harnham (Bates et al., 2014), Bemerton and Milford Hill (Roe, 1968b; Wymer, 1999). Further south is the most prolific site in the Avon, at Wood Green Gravel Pit, GCR site 1940 described below, which has yielded 635 artefacts (Roe, 1968b; Wymer, 1999; Egberts, 2017; Egberts et al., 2019, 2020). Understanding the terrace stratigraphy is complicated by a discontinuity in mapping between the Lower Avon in the Bournemouth area and the Middle Avon (Fig. 7) and a number of stratigraphical schemes have been proposed (Table 4). Most recently, the British Geological Survey developed two different schemes for the Middle and Lower Avon terraces (Bournemouth area, Fig. 7). This resulted in the identification of five 'Older River Gravels' (O5–O1) and ten lower river terraces (T10–T1) in the Middle Avon (Kubala, 1980; Clarke, 1981) and fourteen terraces around Bournemouth (Bristow et al., 1991). Allen and Gibbard (1993) remapped only the Lower Avon (Fig. 3). Westaway et al. (2006), whilst suggesting ages for these deposits, did not conclusively state any new correlations or remap them (Fig. 4), being largely a desk-top reinterpretation of the correlations of Clarke and Green (1987). Correlation between the Lower Avon and Middle Avon is hindered by a lack of direct dating of the deposits, a lack of detailed study of individual terrace stratigraphy and sedimentology and insufficient data on the precise height of terraces and their respective thicknesses.

The highest terraces of the Avon are found up to 100 m above the valley floor and span a maximum width of 12 km. The lower terraces are between 6 and 3 km wide, extending alongside and below the present-day river (BGS sheets 298, 314 and 329; Fig. 7). The altitudinal separation of the highest terraces is limited, as has been observed in more westerly catchments (Clarke and Green, 1987; Brown et al., 2010; Basell et al., 2011a, 2011b). The middle terraces (T10–T5) result from bedrock incision and fluvial sediment aggradation and exhibit clear altitudinal separation, whereas the lowest terraces in the modern valley have been formed by cut-and-fill processes (Clarke and Green, 1987). It is generally thought that the highest gravel deposits in the Avon valley date to the Pliocene or early Pleistocene (Allen and Gibbard, 1993; Westaway et al., 2006) and that the terrace deposits decrease in age with decreasing altitude. It has been suggested that the change in type of terrace formation between O5–1 and T10–T5 relates to a change in fluvial processes due to a change in dominant climate cycles from 41 ka to 100 ka during the Mid-Pleistocene Transition at *c.* 0.9 Ma (Maddy et al., 2000; Westaway et al., 2006). Egberts et al. (2020) support this suggestion on the basis of their OSL dating reported below (Table 4) and associated assumptions about formation of terrace deposits in relation to climatic cycles.

The preservation of organic deposits is rare in the Avon valley but three fossiliferous deposits in the lower terraces provide some chronological evidence. First, in the Nadder tributary, the Fisherton brickearths overlie T4 and contain fauna that has been assigned to either MIS 5 (Delair and Shackley, 1978) or early middle MIS 2 (Green et al., 1983). The latter interpretation has led some researchers to suggest that T4 dates from MIS 4 with a MIS 3 attribution for the overlying fossiliferous deposits (Westaway et al., 2006). Second, at Ibsley, peat from beneath T3 has been dated to MIS 5e (Ipswichian IIb) based on its specific pollen spectra, which are dominated by herbaceous plants of temperate affinity (Barber and Brown, 1987; Allen et al., 1996). This could indicate that the overlying T3 deposits post-date MIS 5e and are related to one of the later substages or stadials. Third, at Harnham, just downstream of Salisbury, artefacts and faunal remains were recovered above river gravels and below solifluction deposits (Bates et al., 2014). The limited faunal assemblage from two different depositional phases (II and IV) suggests a post-MIS 11/pre-MIS 5 date. Amino acid racemisation data from two *Bithynia tentaculata* opercula from phase II yielded MIS 8 or

Table 4
Overview of terrace schemes in the Avon Valley, adapted from Egberts et al. (2020), full details of original sources found therein. O = 'Older River Gravels', T = terrace.

Historic schemes				Recent BGS schemes					Suggested age model
Lower and Middle Avon				Middle Avon			Lower Avon		
Westlake (1889)	Reid (1902b)	Green (1946)	Sealy (1955)	Fordingbridge (Kubala, 1980)	BGS map (2004)	N of Bournemouth (Clarke, 1981)	BGS map (1991)	Bournemouth (Bristow et al., 1991)	Egberts et al. (2020)
175 ft	High Plateau/Higher terraces		Higher surfaces	O5		O5			
				O4 a + b		O4 a + b			
				O3	T10	O3			
				O2		O2			
				O1		O1			
		Upper Ambersham	VIII	T10	T9–T10	T10	T14	T14	
		Ambersham	VII			T9	T10–T13	T10–T13	T10 – predate MIS9/10 HALE02 223 ± 19 ka HALE01 264 ± 23 ka HALE03 262 ± 25 ka HALE04 375 ± 38 ka
150 ft	Eolithic Terrace	Sleight Terrace	VI	T8–T9	T9	T8			
100 ft	Palaeolithic Terrace	Boyn Hill	V		T8	T7	T9	T9	
				T7	T7				
50 ft		Upper Taplow	IV	T6	T5	T6	T8	T8	
		1st Lower Taplow	III	T5		T5		T7	Predating MIS 9/10 WGRE01 269 ± 25 ka WGRE02 354 ± 35 ka WGRE03 312 ± 31 ka
	Valley Gravels	2nd Lower Taplow	II	T4		T4		T6	MIS 8 SOM01 247 ± 27 ka SOM02 336 ± 34 ka SOM03 219 ± 23 ka SOM04 285 ± 44 ka SOM05 310 ± 30 ka
		Mustcliff Terrace Christchurch Terrace	I						
				T3		T3	T5	T5	MIS 6 ASH01 143 ± 12 ka ASH02 198 ± 23 ka ASH03 271 ± 28 ka ASH05 114 ± 12 ka ASH04 323 ± 37 ka
					T1–T4				
				T2		T2			
								T1–T4	MIS 5–1 T4 BICK01 25 ± 3 ka BICK02 14 ± 1 ka BICK03 20 ± 2 ka BICK04 19 ± 2 ka T3 (Hengistbury Head – Briant et al., 2019b) *c.* 40 to 80 ka
				T1		T1			

early MIS 7 ages. OSL dating suggests the accumulation of phase II sediments during the later part of the cold phase of MIS 8 or the very beginning of MIS 7, between *c.* 276 and 235 ka; a MIS 8 age for the phase I gravel deposition was suggested (Bates et al., 2014). The deposit at Harnham is mapped as undifferentiated, so these dates offer minimal assistance in resolving questions of terrace correlation and landscape change. Whilst it has been suggested on altitudinal grounds that the gravels and Palaeolithic artefacts from Milford Hill (*cf.* Harding and Bridgland, 1998) are of broadly similar age (Bates et al., 2014), these also come from deposits mapped as undifferentiated.

More recently, a comprehensive dating scheme has been carried out in the Avon valley, directly dating the terrace sequence in the valley. This research targeted areas where terraces were most clearly defined and have good exposure, and succeeded in securing OSL dates for T4, T5, T6, T7 and T10 in the main Avon valley, as well as brickearth deposits overlying undifferentiated terrace deposits at Bemerton (Egberts, 2017; Egberts et al., 2019, 2020). There is significant overlap between the individual OSL ages produced, but Egberts et al. (2020) integrate these with additional information from Ibsley and stratigraphic relationships between terraces and propose that T10–7 predate MIS 10/9, T8 relates to MIS 8, T5 to MIS 6 and T4–1 to MIS 5–1 (Table 4). Further OSL dating at the very downstream end of the sequence in Terrace 3 at Hengistbury Head suggests that deposition here dates from the last glacial period during MIS *c.* 40 to 80 ka (Briant et al., 2019b).

2.2. GCR Site 2045 Solent Cliffs West (SZ200930) (CAW, RMB, MH)

2.2.1. Introduction

The geological sections exposed in the Solent Cliffs West (Fig. 8), along the coast immediately adjacent to Barton-on-Sea, east of

Fig. 8. General view of Solent Cliffs West.
Photograph: Colin Whiteman.

Bournemouth, expose in cross-section a unique and extensive record of sedimentation of a flight of terrace gravels (Figs. 3–5). The number of gravels represented varies depending on the stratigraphic scheme: Allen and Gibbard (1993; Fig. 3) include their Old Milton and Taddiford Farm Gravels; Westaway et al. (2006; Fig. 4) their Old Milton and Downton Gravels and Hatch (2014; Fig. 5) their Old Milton Gravel. Beyond the GCR boundary to the east, the exposure of further gravel units continues. In addition, the cliffs have yielded a variety of prehistoric flint implements. The exposure of the Taddiford Farm Gravel near Barton-on-Sea is one of the richest sources of Palaeolithic artefacts in the Hampshire Basin, if not in Britain. None of the Solent Cliffs West exposures have yielded reliable OSL age estimates, although samples were taken from the Old Milton Gravel at Barton on Sea (Briant et al., 2006). Application of OSL age estimates from further east to determine the age here is reliant on robust correlation of deposits, which is much disputed, as discussed in Section 2.1.1.

2.2.2. Description

Whilst the GCR site of Solent Cliffs West is limited to exposures in the cliffs immediately adjacent to the town of Barton-on-Sea (from Naish Holiday Village to Barton-on-Sea Golf Club), cliffs comprising fluvial gravels extend for some 8.5 km between Highcliffe Castle (SZ 200 930) and Barton-on-Sea (SZ 238 928) in the west, and Milford-on-Sea (SZ 283 915) in the east. The full cliff succession exposes a series of morphologically differentiated gravel units in the form of terrace aggradations resting unconformably on Paleogene Barton Formation sediments (Figs. 3–5). Both Allen and Gibbard (1993; Fig. 3), and Westaway et al. (2006; Fig. 4) show six units here, whereas Hatch (2014; Fig. 5) shows only three (Table 5). All three schemes recognise the extensively exposed Old Milton Gravel around Barton-on-Sea and the Milford-on-Sea Gravel but differ in other attributions. Only the Hatch (2014) scheme is based on detailed topographic surveying of the cliff sections.

The Allen and Gibbard (1993) gravel units are all members of the New Forest Formation (Gibbard and Preece, 1999) and have been differentiated on the basis of clast lithological assemblage, altitude and gradient. According to the detailed lithological analyses of Allen (1991; Allen and Gibbard, 1993), all the gravel units are dominated by flint, and contain only subordinate amounts of quartz and quartzite and a variety of cherts, though subtle differences have been detected. The Taddiford Farm Gravel is also distinguished by its archaeological richness. Nevertheless, within-unit clast variability is such that single clast analyses cannot be relied upon to distinguish individual gravel units. The Milford-on-Sea Gravel contains intraformational wedge structures interpreted as ice-wedge casts (Allen and Gibbard, 1993; Fig. 9). Palaeocurrent measurements from 'Solent River' gravels, such as the Old Milton Gravel, indicate a current flowing towards the east. Topographical measurements from the Taddiford Farm Gravel indicate a terrace surface gradient of 0.63 m km^{-1}, whilst the surface of the upper Lepe Gravel has a gradient of 0.35 m km^{-1}, although not all Allen and Gibbard (1993) gradients are as steep. In contrast, Westaway et al. (2006) used much lower gradients, for example, 0.4 m km^{-1} for their Rook Cliff terrace. Hatch (2014) started his reassessment of the terrace sequence with the Stanswood Bay Gravel over which there was the most agreement on gradients and extent (Westaway et al., 2006 —

Table 5
Overview of terrace gravels exposed between Highcliffe and Milford-on-Sea in different stratigraphical schemes. Stratotypes are shown, where defined.

Allen and Gibbard (1993)	Westaway et al. (2006)	Hatch (2014)
Old Milton Gravel (stratotype SZ 242 929: alt. 31.0 m)	Old Milton Gravel (stratotype SZ 235 943, alt. 36.0 m) Becton Farm Gravel (stratotype SZ 2547 9320, alt. 29.6 m)	Old Milton Gravel
Taddiford Farm Gravel (stratotype SZ 259 924: alt. 26 m) and equivalent Avon valley High Cliff Gravel (stratotype SZ 212932: alt. 31.0 m)	Downton Gravel (stratotype SZ 2698 9392, alt. 26.3 m)	Stanswood Bay Gravel
Stanswood Bay Gravel	Hordle Gravel (stratotype SZ 2724 9213, alt 19.0 m)	
Milford-on-Sea Gravel Lepe Gravel Pennington Gravel	Milford-on-Sea Gravel Rook Cliff Gravel	Milford-on-Sea Gravel

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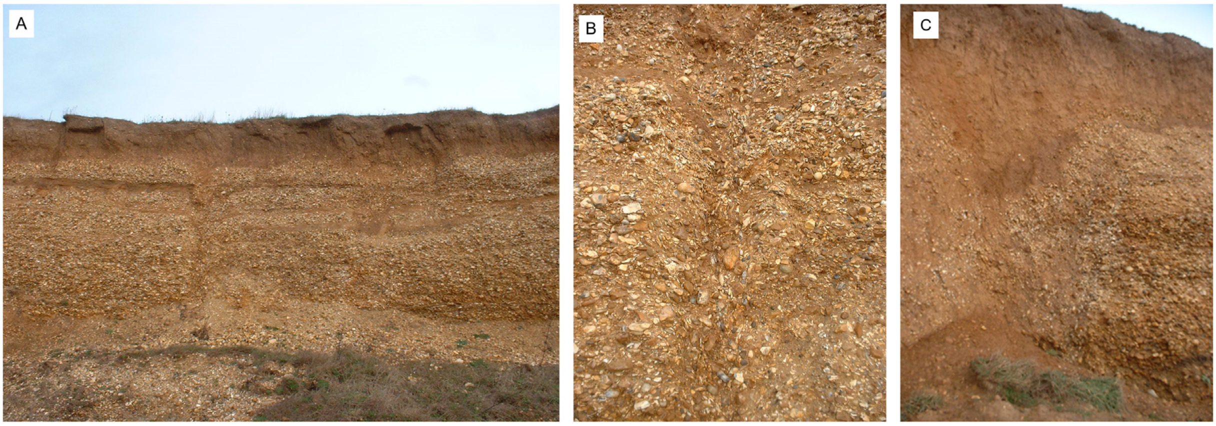

Fig. 9. a–c. Wedge structures in the Milford-on-Sea Gravel to the east of the GCR site 2045 Solent Cliffs West. Photographs: Colin Whiteman.

0.4 m km^{-1}, Allen and Gibbard, 1993 — 0.44 m km^{-1}). All the other gravel bodies in their scheme have similar low gradients.

The sequence exposed in this cliff is the main source of Palaeolithic material in the Western Solent region. The Southern Rivers Palaeolithic Project (SRPP) database lists 227 handaxes and two Levallois artefacts from this section of shoreline, along with 32 flakes, cores and other lithic artefacts combined (Wessex Archaeology, 1993). Much of this material was collected during the late 19th Century (Evans, 1897). The majority is recorded as coming from 'beneath Barton Cliff', *i.e.*, within the GCR site boundaries (SZ 230 920; 194 handaxes, 1 Levallois core, 1 Levallois flake and 29 other flakes), with much smaller collections from Hordle Cliff (SZ 270 920; 15 handaxes and three other), Highcliffe (SZ 210 931; eight handaxes), Milford-on-Sea (SZ 293 915; seven handaxes) and Chewton Bunny (SZ 217 931; three handaxes).

2.2.3. Interpretation

Early research suggested that the fluvial gravels of south Hampshire and east Dorset represented three or four terraces (Green, 1946; Everard, 1954a; Keen, 1980), but this has since been shown to be an underestimate, as discussed in Section 2.1.1 and shown in Table 5. The sedimentology, surface morphology and regional context of the gravel deposits within the Solent Cliffs West GCR site and adjacent cliffs leave no doubt of their association with the former 'Solent River' or its surviving north bank tributary, the River Avon. The location and altitude of the individual terraces reveal the southerly migration of the river. The dominance of horizontal bedding suggests deposition in a braided river with multiple ephemeral channels and preservation only of bar forms. The presence of intraformational ice-wedge casts (Fig. 9) confirms the presence of permafrost during the deposition of some of these gravels, supporting the interpretation that the gravels were deposited during periods of periglacial climate. The precise timing of these events, and hence the age of the gravels, has not yet been determined directly, though some indirect geochronological evidence has been obtained, as discussed above. Given the significant differences in terrace correlations between these sections and those to the east, direct OSL dating of these deposits would be of value. Previous research has, however, shown that the Old Milton Gravel is too old to be reliably dated using Quartz SAR methods (Briant et al., 2006). New methods that allow for dating of older deposits should be considered (see Rixhon et al., 2017). 'Brickearth' resting on Old Milton Gravel at Barton-on-Sea has been dated by thermoluminescence to the late Devensian (18–14.8 ka BP) (Wintle, 1981) but this is of very limited geochronological value in dating the terrace deposits.

Most of the artefacts are likely to have been eroded from the Solent gravels exposed in these cliffs. However, with multiple terraces present and the potential for material being moved by longshore drift, as well as potentially (by reworking) down through a terrace sequence, it is difficult to assign material to specific terraces (Briant et al., 2009; Brown et al., 2010). This difficulty in determining provenance is important in relation to the use of the handaxe assemblage from Barton Cliff as an age marker (MIS 11) by Westaway et al. (2006) for the Old Milton Gravel. Whilst this assemblage does indeed contain *c.* 15 % of the ovate forms that have a distinctly twisted profile (Roe, 1968a; Davis, 2013) it is a heavily beach-rolled mixed assemblage characterised by a high degree of morphological variability that is not clearly a twisted ovate dominated assemblage (Wymer, 1968). This is in addition to the uncertainty about which terrace deposit it came from. A similar lack of contextual certainty affects a Levallois core and flake in the Barton Cliff assemblage which has also been used as a chronological indicator.

2.2.4. Conclusion

The cliffs from Highcliffe to Milford-on-Sea provide a unique opportunity for the detailed study of a flight of Pleistocene terrace gravels in cross-section. Opinions are divided as to the number of separate terraces represented, most authors claiming three or four, decreasing in height, and therefore age, from west to east. The site enables studies of gravel sedimentology to be combined with a wider geomorphological consideration of the terraces themselves. The Solent Cliffs, both here and in two other GCR sites within the network at Calshot Cliffs and Hillhead Cliffs are the only place in Britain where large continuous exposures of Pleistocene terrace gravels are available for study. Furthermore, the gravel at Barton-on-Sea, within the specific area selected as the GCR site, is one of the richest sources of Palaeolithic artefacts in the Hampshire Basin.

2.3. GCR Site 2339 Calshot Cliffs (SU473003) (CAW, RMB, MH)

2.3.1. Introduction

Cliffs to the south–southwest of Calshot village (SU 475016), adjacent to Stanswood Bay, expose lower 'Solent River' terrace gravels which provide excellent evidence of their sedimentology and stratigraphy. The gravels exhibit a striking array of sedimentary structures, including impressive channel fills and planar and trough cross-sets, with potential for the interpretation of both flow direction and the hydrology of the former river. The gravels at Calshot Cliffs have been dated by OSL to *c.* 276–215 ka (MIS 8–7b — Briant et al., 2006). Palaeolithic artefacts have also been recovered.

2.3.2. Description

Calshot Cliffs GCR site 2339 is a cliff section, together with a few metres of foreshore, extending for some 550 m between SU 4716 0005 and SU 4743 0054 on the north side of The Solent (Figs. 3–5). The cliff exposes a sequence of Pleistocene gravels and sands (Fig. 10), recognised as the Stanswood Bay Gravel by all recent researchers

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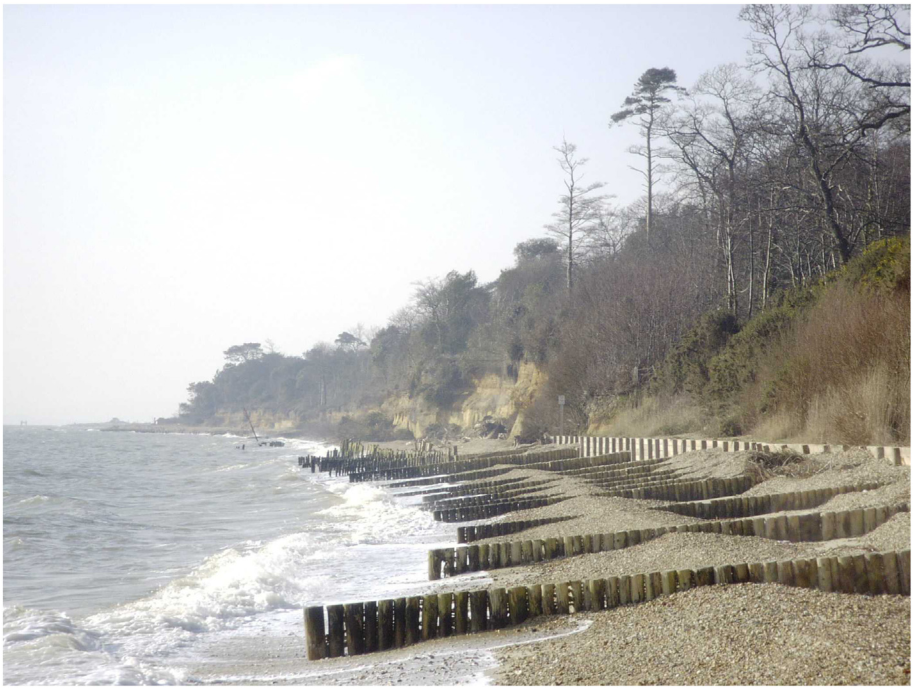

Fig. 10. General view of GCR site 2339 Calshot Cliffs looking west.
Photograph: Colin Whiteman.

(Allen and Gibbard, 1993; Westaway et al., 2006; Hatch, 2014), resting on Paleogene Barton Group bedrock and overlain in places by up to 1.5 m of clays, silts and sands with occasional pebbles. The surface of the gravels and sands is broadly planar and appears to form a terrace surface at about 15 m O.D. that declines gently north-eastwards. The boundary between the gravels and sands and the Paleogene bedrock is usually planar and horizontal or very gently undulating (Fig. 11A), but in places the bedrock has been deeply incised by a series of

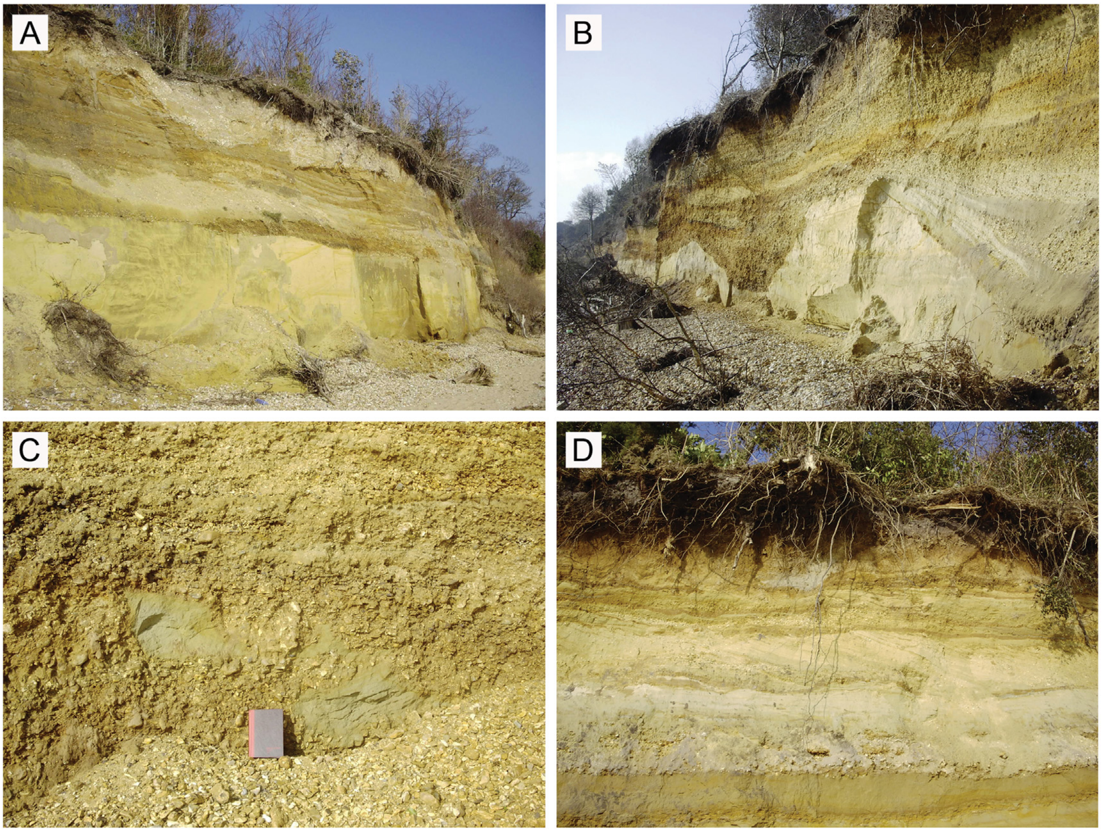

Fig. 11. Sedimentary structures at GCR site 2339 Calshot Cliffs. A) Planar boundary between Paleogene sands (lower) and Pleistocene gravels; B) incised surface of Paleogene sands filled with Pleistocene sands and gravels; C) weakly bedded gravels with sand lenses and 'rip-up' clasts; D) large-scale planar cross-bedded sands and gravels.
Photographs: Colin Whiteman.

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curvilinear- and straight-sided channels (Fig. 11B). Channel depths are up to at least 2 m, and channel widths vary from a few tens of centimetres to about 10 m. Channel fills of alternating sandy gravel and sand beds show troughs of decreasing amplitude (Fig. 11B) reflecting intermittent filling and cutting during net aggradation of the fills. Gravel thickness varies from about 2 m up to about 5.4 m at the site of the deepest channels, whose location varies with exposure.

The sandy gravel, commonly stained yellowish or dark brown with iron oxide, is dominantly clast-supported with occasional open-work lenses. Some fines occur in the matrix of trough structures in the lowermost part of the gravel, and occasional 'rip-up' clasts of sand also occur near the base of the gravels (Fig. 11C). The structure of the gravels varies. Crude horizontal bedding (Fig. 11A), indicated by frequent vertical textural changes, is common throughout the exposure. Large-scale (30–40 cm thick) planar cross-beds (Fig. 11D) of sandy gravel also occur and the gravels are commonly interstratified with small-scale planar cross-bedded sand lenses yielding palaeocurrent data indicating current flow towards the northeast. Small-scale channels up to a few metres in width and less than 1 m deep are incised into the more horizontal bedding. At SU 474 005 the gravel is sharply overlain by up to *c.* 2.7 m of cross-bedded and then horizontally-bedded sand with occasional lenses of sandy gravel and pebble stringers. The sand thins laterally and appears to occupy a very broad (185 m), shallow channel in the gravel. Towards the south-western end of the site a narrow (5–10 cm) wedge-like structure penetrates downwards from the gravel surface (Fig. 12), with some of the enclosed pebbles showing sub-vertical a-axis orientation and inclusion of overlying finer sediment in small involutions.

Two Palaeolithic artefacts have been reported from the sediments forming this cliff (Wymer, 1999), recorded as a stone tool of estimated provenance from Nelson's Place (SU 470 005) and another of known provenance from Eaglehurst (SU 478 010).

Fig. 12. Narrow wedge structure below surface of Pleistocene gravels, GCR site 2339 Calshot Cliffs. Upper unit is slightly stony sands and silts loaded into top of the gravels. Photograph: Colin Whiteman.

2.3.3. Interpretation

The main body of sands and gravels exposed at this site shows erosional and depositional features consistent with rapidly migrating channels typical of a cold climate, aggrading, braided river system. Following Green (1946) and Everard (1954a), Keen (1980) recognised that the gravels at Calshot were part of a suite of 'low' Solent River terraces with associated 'middle' and 'high' suites extending to the north-west. Subsequently, the scheme of Solent River terraces in this area has been refined a number of times following detailed mapping by the BGS, analyses of sedimentology and lithology carried out by Allen (1991) and Allen and Gibbard (1993) and more recent topographic surveying and ground-penetrating radar undertaken by Hatch (2014). All these authors agree that the gravels at Calshot form part of the Stanswood Bay Member of the New Forest Formation. Allen and Gibbard (1993) demonstrated that the course of the Solent River migrated southwards through time, and the relatively southerly position of the gravel terrace at Calshot Cliffs indicates that it is a young feature, as backed up by OSL dating of the channel shown in Figure 12 to *c.* 276–215 ka (MIS 8–7b — Briant et al., 2006).

2.3.4. Conclusion

Cliff exposures to the south-west of Calshot represent a continuous well-exposed section through the Stanswood Bay Gravel of the Solent River system. The cliff sections at Calshot are of importance because they form a network of sites (including those to the west – Solent Cliffs West – and on the opposite side of Southampton Water — Hillhead Cliffs), they allow study of the sedimentology and stratigraphy of the Solent terrace gravels. Sedimentological studies, in particular, require access to large clear exposures over wide areas. The cliffs of the Solent coast provide an opportunity for this type of work which is unique in Britain.

2.4. GCR Site 2046 Hillhead Cliffs (SU522030) (CAW, RMB, MH)

2.4.1. Introduction

The gravels in the cliffs northwest of Hillhead, Hampshire (SU 518 033 to SU 526 027) occur at the easternmost extent of the Solent River system (Figs. 3, 4, 6). Bates et al. (2000) suggested that they represented the deltaic facies of the Solent River and form an important link between the Solent River terraces to the west and the Sussex raised beaches to the east (Bates et al., 1997, 2000; Bates, 2001). Besides the geomorphological importance of the site, significant archaeological implements have been obtained from the cliffs at Hillhead since at least the middle of the nineteenth century (Evans, 1872, 1897). They are the third in the network of GCR sites in cliff exposures that between them exemplify the sedimentology and stratigraphy of the Solent River gravels. Their contained archaeological artefacts also provide a regional context for other archaeologically significant sites nearby, such as the GCR site at Boxgrove (Roberts and Parfitt, 1999).

2.4.2. Description

The Hillhead Cliffs GCR site is a cliff section extending for approximately 1 km along the eastern shore of Southampton Water northwest of the Meon valley from Sea House at SU 518 033 to White House at SU 526 027 (Fig. 13). The land behind the cliff shows an extensive flat terrace surface, ascribed to Terrace 2 (Edwards and Freshney, 1987), also known as the Hamble Terrace (Harding et al., 2012; Hatch et al., 2017). The cliffs at Hillhead were first formally described in the early Geological Surveys of White (1915, p. 54), who recorded 10–20 ft (3.05–6.10 m) of bedded flint gravel resting on the southeastwards-declining, bevelled, undulating surface of the Paleogene Bracklesham Formation. The gravels contained lenses of roughly-laminated loam "partly replaced by speckled loamy sand…with seams of bleached

Fig. 13. View looking south-east at Hillhead Cliffs showing gently declining surface of Paleogene Bracklesham Formation below Pleistocene gravels.
Photograph: Colin Whiteman.

shingle as well as of ordinary gravel" and were acknowledged as "well-known localities for Acheulian implements" (see Evans, 1897). Recent observations confirm the general stratigraphy of gravels resting unconformably on Paleogene sandy Bracklesham Formation, but also revealed a more complex stratigraphy within the Pleistocene sediments. In a few places the planar surface of the Bracklesham Formation has been incised (Fig. 14A) and the resulting shallow channels infilled by trough cross-bedded gravel up to the level of the Bracklesham Formation surface.

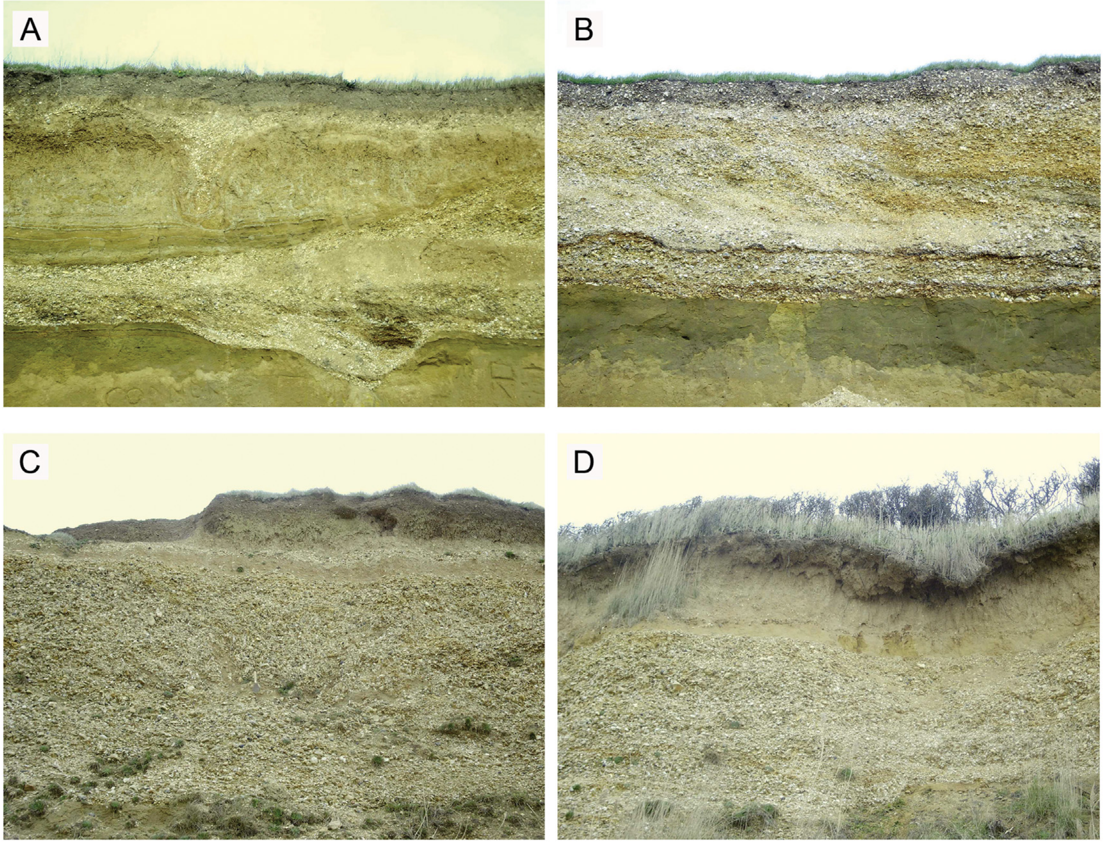

Fig. 14. Sedimentary features at Hillhead Cliffs. A) Incised surface of Paleogene sands below Pleistocene sands and gravels; B) large-scale planar cross-bedded gravels in massive Pleistocene gravels; C) large-scale depression structures in massive and weakly bedded gravels; D) loam and stony loam above massive gravels.
Photographs: Colin Whiteman.

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Beds of planar cross-bedded or massive gravel and sand (Fig. 14B), and weakly horizontally bedded gravel extend to within 20–30 cm the surface where they are sharply overlain by a fine-grained soil (Fig. 14D). The higher gravel beds are frequently distorted into the underlying gravels (Fig. 14C) within noticeable depression structures (Fig. 14C). In places its clasts have a preferred vertical orientation and are often angular or sub-angular in shape. Towards the south-eastern end of the section these gravels are overlain by 20–30 cm of stone-free loam and at least a metre of stony loam (Fig. 14D). Similar features have been observed at Solent Breezes, to the west of these sections, described by Briant et al. (2012) and topographically surveyed by Hatch (2014). Table 3 summarises the OSL-based age estimates from this terrace, which are centred around *c.* 200 ka and correlate with MIS 7. These were all taken further west, by Briant et al. (2012) and Hatch (2014).

Numerous archaeological artefacts have been reported from 'Rainbow Bar' (an offshore gravel spit exposed at low tide) just east of the GCR site at SU 5306 0214 (Wymer, 1999). It is usually assumed that this material is accumulated only from Terrace 2 sediments, which is in line with the measured sediment transport at the present day (New Forest District Council, 2017) and the mapped exposure of Terrace 2 in cliffs. Sommerville and Tetlow (2011) reinvestigated this material and found a range of artefacts, 78 % flakes of various types, 16 % cores, also blades, core fragments, flake tools, bifaces and choppers, in much lower numbers. Only 4 % of these were in fresh condition; 66 % were moderately rolled, and 31 % very rolled. This secondary collection is of less value diagnostically than the Levallois dominated assemblage recovered from the altitudinally higher Terrace 3 to the west of the GCR site at Warsash (Davis et al., 2016).

2.4.3. Interpretation

Everard (1954a) included the gravels in the Hillhead area in his 35′ (10.7 m) terrace and interpreted them as marine in origin, apparently on the basis of a perceived horizontality of the terrace surface. In contrast, his mapping suggests that they are probably associated with the younger phases of fluvial gravel aggradation recognised by Allen and Gibbard (1993) on the west side of Southampton Water. Mapping by the BGS (Edwards and Freshney, 1987) in the area immediately to the north of Hillhead suggests that the Hillhead gravels are part of their Terrace 2, also considered to be of fluvial origin, a view apparently supported by Hopson (2000).

Archaeology has been proposed as a tool for correlating the 'Solent River' sediments (Bridgland, 1996, 2001), but, although Hillhead has produced a "considerable number" of implements (Evans, 1897, p. 625) they are not useful for correlation purposes (Sommerville and Tetlow, 2011). Bates et al. (1997) and Bates (2001) suggested an age of MIS 6 for these deposits by relating the 'Solent River' gravels in the region of Hillhead with raised marine marginal sediments and palaeoclifflines further east in West Sussex. This age was also suggested by Westaway et al. (2006) on the basis of archaeological tiepoints and uplift modelling, whilst renaming the deposits as the Hamble Terrace. OSL dating from this terrace immediately to the west of the Hillhead cliffs site at Brownwich Lane and Solent Breezes, however (Table 3), suggests an older age of *c.* 190–255 ka (Briant et al., 2012), minimum age *c.* 200 ka (Hatch, 2014), correlating with MIS 7 and the Stanswood Bay Gravel of the West Solent.

2.4.4. Conclusion

The cliffs north of Hillhead provide important exposures in terrace gravels of the former Solent River system, in the area of its confluence with the tributary Test valley, as part of a network of GCR sites that together exemplify the Solent River gravels. They allow the study of gravel sedimentology over a large continuous exposure, adding significantly to the understanding of this geomorphological and geological phenomenon. These cliffs are also important as a source of Palaeolithic artefacts.

2.5. GCR Site 1941 Dunbridge Pit (SU316257) (BAH, RMB)

2.5.1. Introduction

Dunbridge gravel pits (SU 316 257) are located in the valley of the Test just below the confluence of the Test with the River Dun, and about 6 km north-west of Romsey. Dunbridge is the most prolific site for Palaeolithic artefacts in Hampshire, if not Britain (Roe, 1968b, 1981; Shackley, 1981; Wymer, 1999), with around 1000 hand-axes and other material including a few Levallois flakes being reported, most having been collected in the early twentieth century (Dale, 1912a, 1918; White, 1912; Sturge, 1912; Smith, 1926).

The gravel deposit rises from both rivers, reaching an altitude of about 47 m O.D. (Fig. 15). Gravel exploitation has mainly been concentrated at lower altitudes on the northern edge of the site facing the River Dun. There are further low-level gravel pits on the eastern edge of the deposit facing the Test nearby at Kimbridge which have produced about 90 artefacts, mainly handaxes (Dale, 1912a; Williams-Freeman, 1915; Roe, 1968b; Bridgland and Harding, 1987, 1993; Wessex Archaeology, 1993; Hosfield, 2001).

Dale (1912a) was the first researcher to describe the gravel deposit at Dunbridge, recording three different levels with differences in artefact preservation. White patinated handaxes were present in pristine condition in the upper white gravel whilst the middle yellow–brown gravel and lower dark red gravel contained only rolled handaxes. This complexity and the presence of gravels at more than one altitudinal level have led to differences in the literature regarding stratigraphic detail, whether the deposits represent one or more periods of deposition, their environment of deposition and age attribution (Dale, 1912a, 1912b, 1918; White, 1912; Bridgland and Harding, 1987, 1993; Wessex Archaeology, 1993; Harding, 1998). A long-term archaeological watching brief at this site (Harding et al., 2012) has, however, resolved much of this confusion.

2.5.2. Description

Dale (1912a) described up to 7 m of gravel overlying an irregular erosion surface cut in the clay and sand of the Paleogene Woolwich and Reading Formations. He observed that different stratigraphic levels in the gravel contained palaeoliths with different types of preservation. Based on his work in the Romsey area he subdivided the gravel units at Dunbridge by colour into a lower dark red gravel, a middle yellow–brown gravel and an upper white gravel (Bridgland and Harding, 1987), the colour differences being attributed to iron translocation. The upper bleached gravel contained white-stained palaeoliths in perfect condition suggesting little transport since manufacture. The middle gravel produced yellowish and brown rolled implements, whilst those from the basal dark red gravel were also rolled and exhibited a double patina with the lower side the colour of the bedrock on which they formerly rested and the upper side deeply iron stained (Bridgland and Harding, 1987).

Dale (1918) later modified his interpretation and suggested that the gravel represented two periods of aggradation with a lower gravel of darker colour separated from an upper paler deposit by a 'ferruginous band', presumably an iron pan, which extended widely around the pit. Bridgland and Harding (1987) inferred that Dale had combined the middle and lower units of the earlier tripartite subdivision into the new lower, darker division.

According to Bridgland and Harding (1987), Dale (1912b) considered the gravels at Dunbridge and Kimbridge to be closely related yet, in accordance with prevailing models, he recognised separate '100 ft' and '15 0 ft' stages of terrace gravel formation. The geological map, too (Booth, 2002; Table 3), shows only one gravel spread south and west of the confluence of the Test and Dun, yet White (1912) also differentiated two groups or stages of terrace gravel formation. He identified an upper Belbins Stage, *c.* 70 ft (21 m) above river level (named after Belbin's Pit, Romsey), and a lower Mottisfont Stage, *c.* 40 ft (12 m) above the river. He attributed the gravel at Dunbridge to the earlier Belbins Stage and that at Kimbridge to the later Mottisfont Stage, whilst

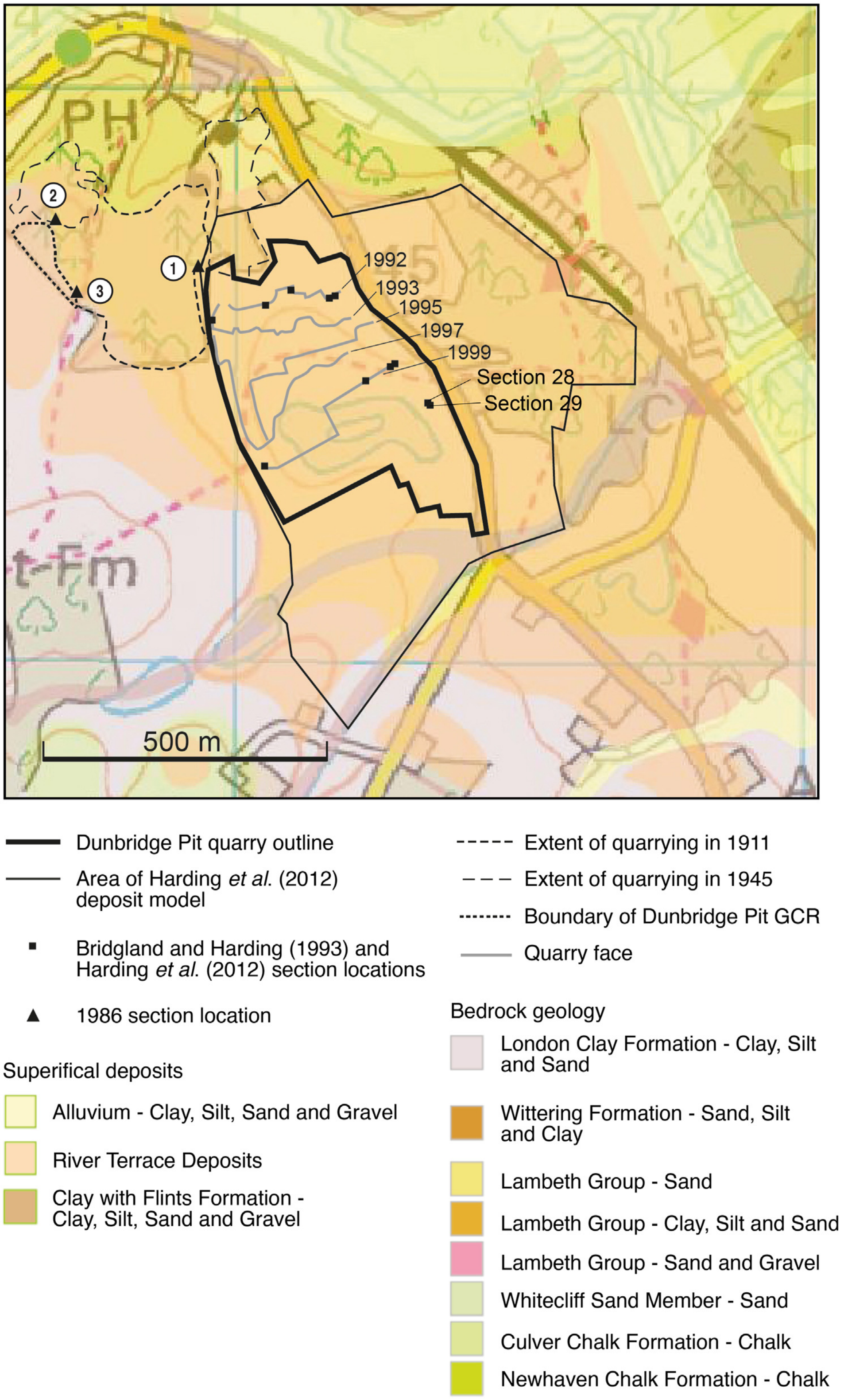

Fig. 15. Map showing location of Dunbridge and Kimbridge Pits at various times in the past and the local geology, sections described in April 1986 and June 1992 and positions of the working face during the watching brief 1992–1998.
After Harding et al. (2012); British Geological Survey data under licence to Birkbeck, University of London through JISC Airbus (2019).

still noting that these deposits were connected by gravel covering the intervening distance.

Dale (1912a, 1912b) suggested that the gravels at Dunbridge may be of subglacial origin. This was based firstly on his observation of a large detached lenticular mass of Reading Formation clay which he interpreted as having been glacially transported. Secondly the very uneven erosion surface of the Reading Formation sand suggested to him that it was frozen when the gravels were laid down on it. This view was not supported by White (1912) who favoured a fluvial depositional environment.

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Roe (1981) re-examined the artefacts from the site. He confirmed the Dunbridge material comprises a mixture of worn and fresh, pointed and non-pointed hand axes, the majority of which were deeply patinated and stained yellow–brown or deep red (Bridgland and Harding, 1987). However, he was able to separate about 100 hand axes which had a distinctive pure white patination and were markedly less worn. Proportionately, this 'white series' was dominated by well-made pointed types, although white ovates and 3 Levalloisian flakes were also present (Roe, 1968b, 1981; Bridgland and Harding, 1987).

Bridgland and Harding (1987) cleared and excavated three sections at Dunbridge Pines (SU 320 257) in April 1986 (Fig. 16) as part of the then Nature Conservancy Council's Geological Conservation Review. They revealed up to 3.5 m of fluvially bedded flint gravels with subordinate sarsen. The deposits were generally of a brown, iron-stained appearance but were not capable of being differentiated into upper white and lower darker units (*sensu* Dale, 1918), nor could they locate a single 'ferruginous band', though iron (or possibly iron–manganese) panning was observed within the sequence at more than one level. White patinated flints were recorded in the upper layers of Sections 2 and 3 (Fig. 16), and they were also noted from lower down in Section 3 well below any 'upper' gravel.

In 1987 Halls Aggregates (South Coast Limited) applied for planning permission to extract gravel from land adjacent to the former gravel pits at Kimbridge Farm, Dunbridge. The process was lengthy during which time a further evaluation was carried out (Colcutt et al., 1988). A transect of test pits confirmed that the gravels were fluviatile and that a lower, previously unrecorded, terrace lay to the east (Harding, 1998). Permission was granted in 1991 subject to an archaeological watching brief, which was to take place throughout topsoil removal and gravel extraction. Hall Aggregates also commissioned the recording of sections through the gravel then exposed (Bridgland and Harding, 1993). This watching brief was in operation at the Kimbridge Farm Quarry, Dunbridge between 1991 and 2007. The project was eventually published with support from the Aggregates Levy Sustainability Fund (Harding et al., 2012).

In June 1992, four sections were recorded at Kimbridge Farm Quarry adjacent to the old Dunbridge pits after the renewed quarrying commenced in White's (1912) lower Mottisfont Stage (Fig. 17; Bridgland and Harding, 1993). The bedrock comprised highly variable Reading Formation comprising usually cross-bedded medium-fine sand with beds of well-rounded flint pebbles and, less frequently, large lenses of clay. Eroded into this was a system of elongate scoured troughs or 'deeps' trending north-east to south-west, with widths up to 20–25 m. In all four sections. Bridgland and Harding (1993) identified a lower, well-bedded, generally unbleached flint gravel, up to 5 m thick in the northeast corner of the site (Fig. 17). The bedding was characterised by a general horizontal disposition of elongated clasts with rare cross-bedding. Cross-bedded pebbly sands were described from Section 1 (Fig. 17) with a single measurement on the orientation of the foreset planes suggesting a palaeocurrent flow towards the south–south-west (14°/207°).

The gravel clasts comprised either angular fresh material, subangular whitened (patinated) material or rounded pebbles reworked from the underlying Paleogene Reading Formation. These latter are only abundant in basal parts of the gravel adjacent to occurrences of pebble beds within the bedrock. Fragile clay clasts encrusted by iron ('boxstones') were occasionally found in the lowermost gravel. These have presumably been reworked from the underlying Reading Formation and indicate limited transport (Bridgland and Harding, 1993). Overlying the generally well-bedded sands and gravels is a poorly bedded or unbedded, generally bleached gravel. No sharp break was observed between these two units, rather the bedding became progressively less clear in the upper 2 m, usually disappearing completely 1.5 m from the surface. Bridgland and Harding (1993) suggested that the lack of bedding may suggest post-depositional modification either by cryoturbation or pedogenesis. Vertically orientated clasts are abundant in the upper part of the sequence suggesting cryoturbation.

The two gravel units were separated by a prominent iron–manganese pan which did not necessarily coincide with the top of the lower gravel. The iron–manganese pan is usually 1.5 m to 2 m below the top of the sequence and can be traced throughout the north-eastern corner of the quarry. It extends westwards to between Sections 2 and 3 and is present in Sections 4a and 4b (Fig. 17). Above the iron–manganese layer much of the gravel is whitened and it contains abundant white patinated flint. The greater part of the gravel below the pan is stained brown, though white patinated flints are still common. The iron–manganese pan suggests that translocation of mineral salts in ground

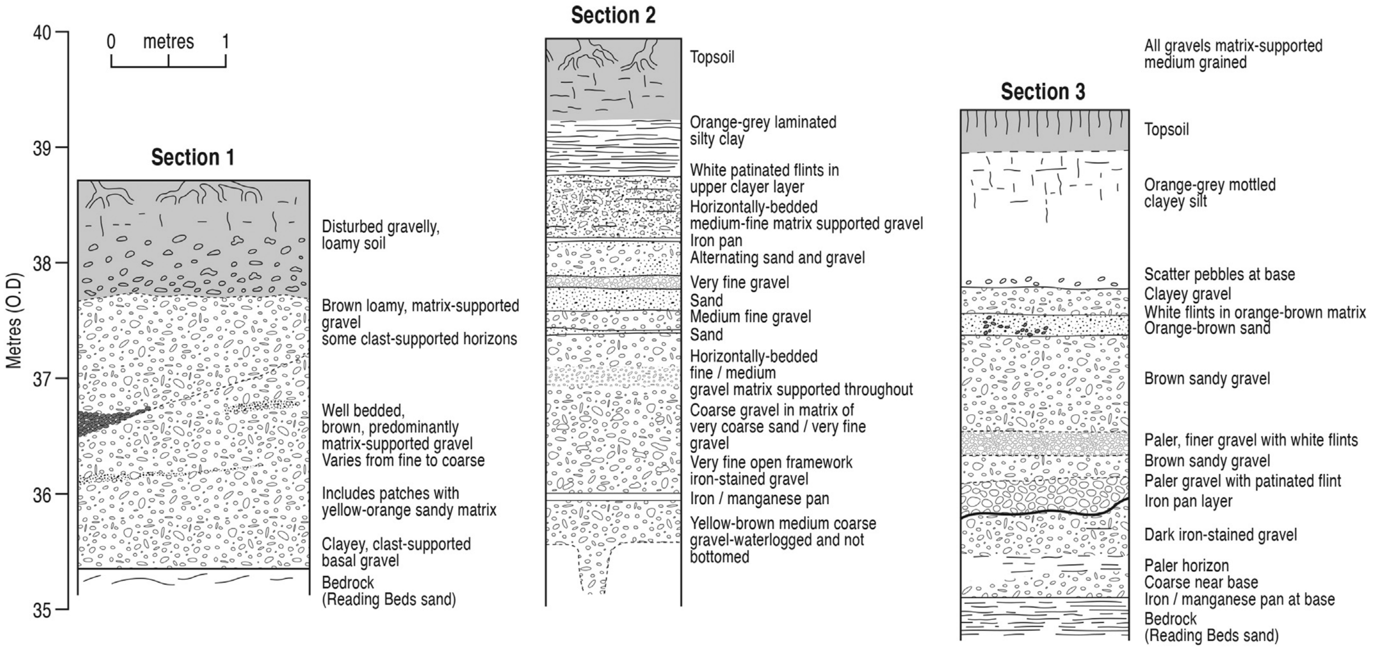

Fig. 16. Sections described in June 1986 (from Bridgland and Harding, 1987, with permission), within the Belbin Gravel at Dunbridge GCR site. Locations shown in Figure 15.

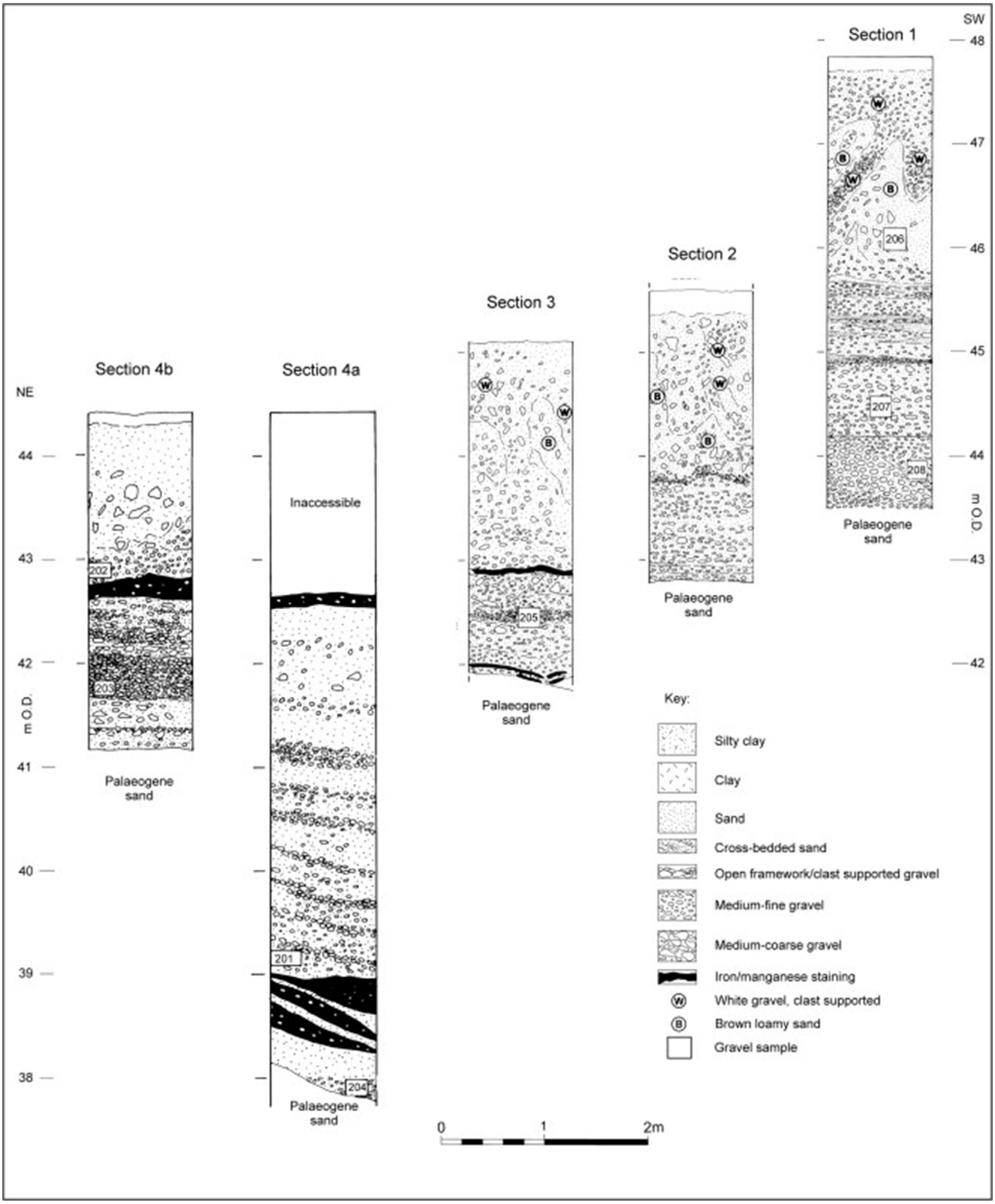

Fig. 17. Sections described in April 1992 through the Belbin Gravel, Dunbridge GCR site shown from north-east to south-west along the 1992 quarry face shown in Figure 15. (From Bridgland and Harding (1993), with permission.)

water may be responsible for the bleaching of the upper gravel (Bridgland and Harding, 1993). The subdivision of lower well sorted gravel, upper bleached gravel and iron pan, not apparent in the 1986 sections, may support Dale's (1912a, 1918) interpretation of the stratigraphy (Bridgland and Harding, 1993; Hosfield, 2001).

The long-term monitoring of the Dunbridge quarry, coupled with geotechnical site investigation data, further enabled construction of a deposit model extending across the quarried site and adjacent areas, showing resolution of the Pleistocene gravels into two terrace formations (see Grant, 2011), adopting the terminology of White (1912) and Dale (1912a) of the Belbin (after Belbin's Pit, Romsey) and Mottisfont (after a nearby abbey and estate) Formations. The upper Belbin Formation is the richer of the two in terms of Palaeolithic artefacts and is comparable to the deposits observed in the Dunbridge Pit GCR. During the 1991–2007 watching brief, working faces were recorded and sampled during visits (at variable intervals), first in the

Belbin Formation and, as the quarry extended southwards and downslope, later in the lower Mottisfont Formation. A database of section drawings and clast-lithological analyses was compiled and selectively incorporated into the final report (Harding et al., 2012).

Ten OSL dating samples from the Mottisfont Formation were reported in Harding et al. (2012), taken from Sections 28 and 29 (Fig. 15). The samples were analysed using the Single Aliquot Renegerative (SAR) protocol on quartz and gamma radiation for dose rate calculation was undertaken *in situ*. Internal OSL characteristics were good for all the samples (*e.g.*, fast decay curves, minimal feldspar contamination, recycling ratios close to unity). They range from 456 ± 101 to 262 ± 43 ka and are indistinguishable at 1σ. However, a number of the samples had very large scatter between individual aliquots (*e.g.*, samples 3 and 10 — error margins *c.* 99 and 49 Gy). This is very common with quartz SAR samples close to the limit of the technique, because as the luminescence signal reaches saturation, interpolation on this curve can yield very different equivalent doses from similar natural luminescence values. Once the scatter is too great, it becomes impossible to determine an age from the sample and the authors decided that these ages were unreliable on this basis. Harding et al. (2012) also excluded samples 7 and 8, citing large scatter, although the error margins (*c.* 30 Gy) were very similar to samples 1B, 1C and 6 which were not excluded and no further reason was given for their exclusion from the final result. The weighted mean age of the remaining measurements (1A, 1B, 1C, 4, 5, 6) is given by Harding et al. (2012) as 305 ± 25 ka (±2σ). This is slightly older (late MIS 9) than previously modelled for the Mottisfont Gravel by Westaway et al. (2006), whose modelling suggested an age of MIS 8.

Roe (1968b) suggested that the site records the appearance of Levallois technology (Middle Palaeolithic) in the Solent catchment, based on three Levallois flakes in the Dunbridge collection. This is reinforced by the material from the Kimbridge Farm watching brief. There were 198 additional artefacts, the find-spots for 190 of which could be located with reasonable accuracy (Fig. 18), with reference to quarrying activity in relation to arrival of material at the screening plant. Of these, three 'proto-Levallois' and three developed Levallois cores were found. The 'proto-Levallois' cores were recovered at the processing plant before quarrying of the Mottisfont Formation began, and so must have come from the Belbin Formation. The developed Levallois material, also primarily from the processing plant, is of less certain provenance. Core 538 was unequivocally from the area of the Belbin Gravel, as was flake 500. However, both are in a sharp condition, and might be from a surface rather than a fluvial context; Core 671 could have come from either terrace formation (see Harding et al., 2012). Also of considerable potential significance is the record of what appears to be the butt of a

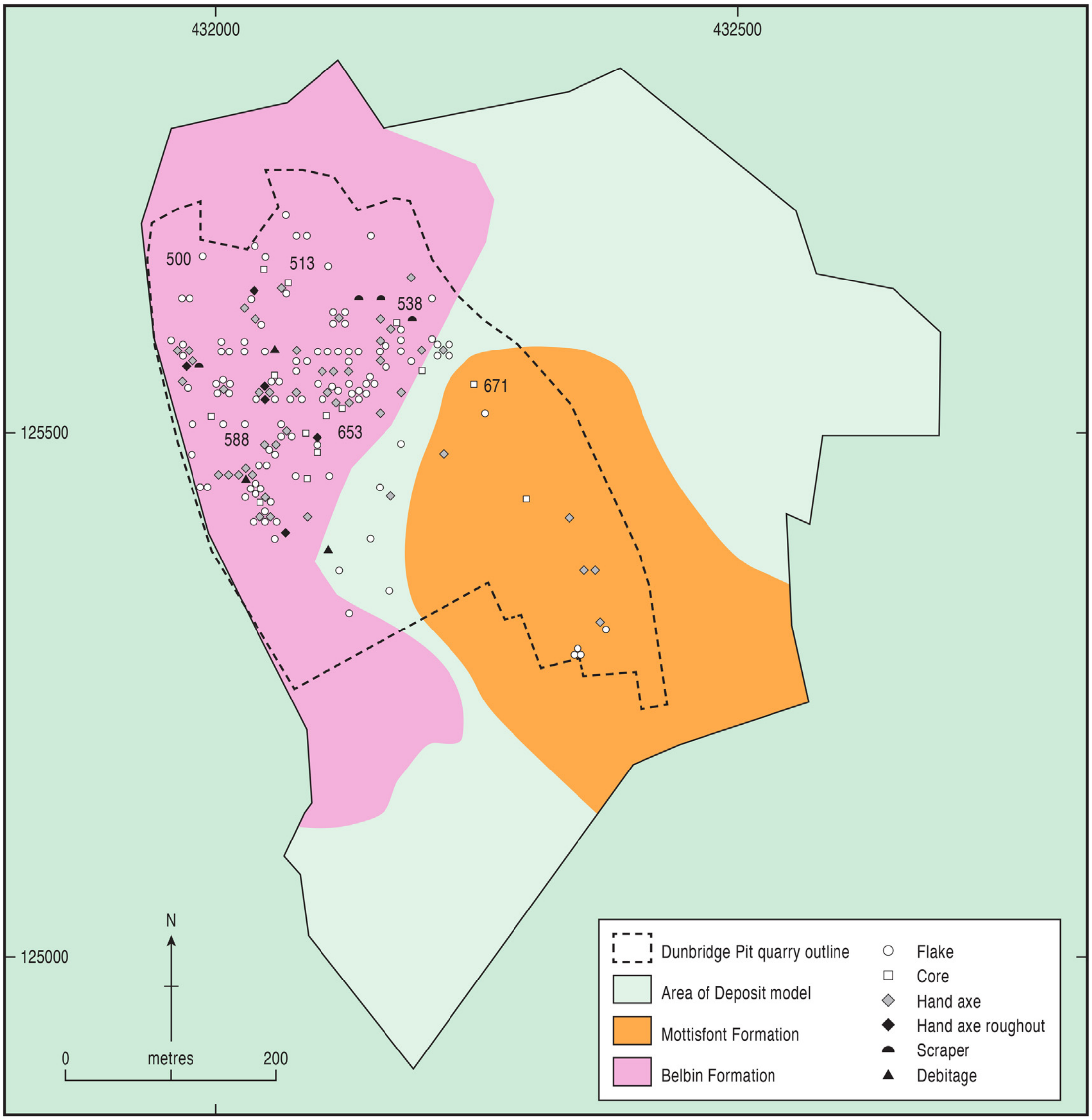

Fig. 18. Artefact distribution plotted over the approximate terrace footprints as derived from the deposit modelling (see Grant, 2011). Numbered points show the reconstructed location of key finds. After Harding et al. (2012; their Figure 8). Location shown in Figure 15.

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bout coupé hand axe (Harding, 1998), found when the Belbin Gravel was being exploited and, from its rolled condition, an artefact that was from the contemporaneous fluvial bedload. Given that this handaxe type is generally regarded as indicative of hominin activity during the (mid-Devensian) MIS 3 interstadial (White and Jacobi, 2002; Westaway et al., 2006; Bridgland and White, 2014) however, this discovery must be regarded as anomalous.

2.5.3. Interpretation

The reported sedimentology of all the sections from the Dunbridge GCR site (both Belbins and Mottisfont levels) is consistent with deposition in a periglacial fluvial system. The dominant bedded gravels are the result of overlain bar forms and occasional cross-bedded trough infills from ephemeral shallow channels. Vertically oriented clasts and less distinct bedding (Bridgland and Harding, 1987, 1993) suggest cryogenic disturbance after deposition. As such, it is very similar to other Solent River deposits. The significant thickness of deposits here is characteristic of tributary settings. This thickness and the contribution of sediments from two rivers has led to confusion in the past over the number of gravel bodies represented at the site. This debate was largely resolved by Harding et al. (2012) but is detailed below.

The British Geological Survey (Edwards and Freshney, 1987; Edwards et al., 1987) mapped nine terraces of the Test as far as the northern side of Romsey but the survey did not extend as far north as Dunbridge. Wymer suggested they may be equivalent to Terrace 5 or 6 of the Test (Wessex Archaeology, 1993 p. 88; Wymer, 1996) although elsewhere in the Southern Rivers Project first report, an equivalence to Terrace 4 is also proposed (Wessex Archaeology, 1993, p. 92). Later mapping (Booth, 2002; Table 3) assigned these gravels to Terrace 2/3 (Table 3).

Later work has focussed on establishing how many gravel bodies are represented here. Colcutt et al. (1988) confirmed that a lower terrace formation occurs in the south-eastern part of the site which may be equivalent to the upper or western edge of the terrace deposit exploited by the former Kimbridge pits which were laid down during the Mottisfont Stage (White, 1912). Bridgland and Harding (1993) suggested that despite the decline in the altitude of the bedrock surface from west to east within the quarry, the continuity of bedded gravel throughout the area indicates that a single terrace formation of the River Test is represented. They proposed this is the same deposit that was exploited in the early part of the century in the Dunbridge pits and which was deposited during the 'Belbins Stage' of White (1912). However, they concede it is possible that the lower gravel recognised in the 1988 transect could equally represent a previously unrecognised formation between the Belbins and Mottisfont units.

Subsequently, the deposit modelling of Harding et al. (2012) showed two deposits — a Belbin and Mottisfont Formation. The Belbin Formation, first defined by Westaway et al. (2006), can be projected downstream into Terrace 4 of Edwards and Freshney (1987), Terrace 5 of Bates and Briant (2009) and their own Upper Warsash terrace, terminology also used by Hatch et al., 2017 (Table 3). Westaway et al. (2006) proposed a MIS 10 age for this formation, but Harding et al. (2012), swayed in part by the identification of 'proto-Levallois' artefacts from this gravel (although the chronological significance of this technology has recently been questioned by White et al., 2024) and also OSL dating results from the West Solent sequence (Briant et al., 2006) attributed it to MIS 9b. The Mottisfont Formation projects downstream to a Lower Warsash terrace (Table 3). Modelling by Westaway et al. (2006) assigned this to MIS 8. Harding et al. (2012) assigned this formation to either late MIS 9 or MIS 8, based on the OSL dating outlined above, from which some samples were excluded due to scattered and unexpectedly old ages. If the older samples were included, the weighted mean would have been closer to the start of MIS 9.

A key point of archaeological interest is the occurrence of Levallois type material within the Dunbridge gravels. Roe (1981) associated the Levallois material within the sample he studied with the upper bleached gravel. Whilst handaxes are present at both levels, the three 'proto-Levallois' cores from Dunbridge were undoubtedly derived from the Belbin Formation (Harding et al., 2012), with Levallois artefacts, whilst not found *in situ*, also likely to have been found in this level.

2.5.4. Conclusion

Dunbridge Pit provides exposures in terrace gravel of the River Test. The gravel here contains abundant Palaeolithic artefacts, the site representing the most prolific in Hampshire and one of the most prolific in Britain. Work early in the twentieth century suggested the site contained up to 7 m of fluviatile gravel containing many handaxes, predominantly pointed in form. A differentiation was made between a lower darker-stained gravel containing more rolled forms and upper, lighter gravel containing fresh white patinated forms. Since this time, it has been established that gravel deposits occur at two elevations in the vicinity, with the artefacts containing both handaxe and Levallois elements. The GCR site is located within the higher gravel, named the Belbin Formation, within which Levallois artefacts are more abundant, which is thought likely to date to MIS 10. The lower Mottisfont Formation is thought to date from MIS 8. Dunbridge Pit is important because there are very few sites where different Palaeolithic industries can be demonstrated to be in superposition. It is also significant for the reconstruction of the terrace sequence in the Solent Basin and Pleistocene and Palaeolithic chronologies on a broader scale.

2.6. GCR Site 1940 Wood Green Gravel Pit (SU172170) (BAH, RMB, EE)

2.6.1. Introduction

Wood Green Gravel Pit is located on the western edge of a gravel terrace on the eastern side of the Wiltshire/Hampshire Avon valley, 3 km north-east of Fordingbridge. The pit, now overgrown and partly used as a cemetery, has yielded about 580 artefacts, making the site one of the most prolific in the Solent. As discussed in Section 2.1.3, the site is a key member of the group of Palaeolithic sites near Salisbury whose stratigraphical interrelationships are not known but which appear to be typologically different (Egberts et al., 2019, 2020). Such Palaeolithic assemblages provide important additional information for the correlation of the terrace sequences in the area especially owing to the dearth of other palaeontological evidence. The site and/or material from it have been referred to by Westlake (1889, 1903); Reid (1902b); Crawford et al. (1922); Bury (1923); Smith (1926); Bridgland and Harding (1987); Wessex Archaeology (1993) and Hosfield (2001). Most recently, Egberts (2017; Egberts et al., 2019, 2020) has reinvestigated the artefacts from this site and provided OSL ages for it (Table 4) which suggest an age older than MIS 9/10.

2.6.2. Description

The now-disused pit once worked Avon terrace gravels that span a thickness of 58 to 64 m O.D. (Bridgland and Harding, 1987; Fig. 19). It has proved to be extremely rich in Palaeolithic artefacts. The earliest reference to the site was by Westlake (1889), who listed 24 handaxes and 4 flakes having been found by the late 1880s at depths of between 0.3 and 3 m from the surface of the gravel. He also recognised that many of the artefacts had been weathered and abraded before being incorporated in the gravel (Bridgland and Harding, 1987). During the 1890s Westlake recorded more than 900 collected artefacts in his personal field notebooks. This contrasts markedly with the figures given in Roe's (1968b) gazetteer that listed 409 handaxes and 171 other artefacts. The difference may reflect a wider definition of Palaeolithic material by Westlake (Hosfield, 2001). Crawford et al. (1922) recorded a 'Chellean chopper' from the site, which was also mentioned by Bury (1923) who remarked on the unusual coarseness of the gravel (Bridgland and Harding, 1987). Smith (1926) also documented artefacts from the Wood Green Pit.

The site has been placed in the wider context of the Avon terrace system by several researchers. Westlake (1889) referred the gravel deposit

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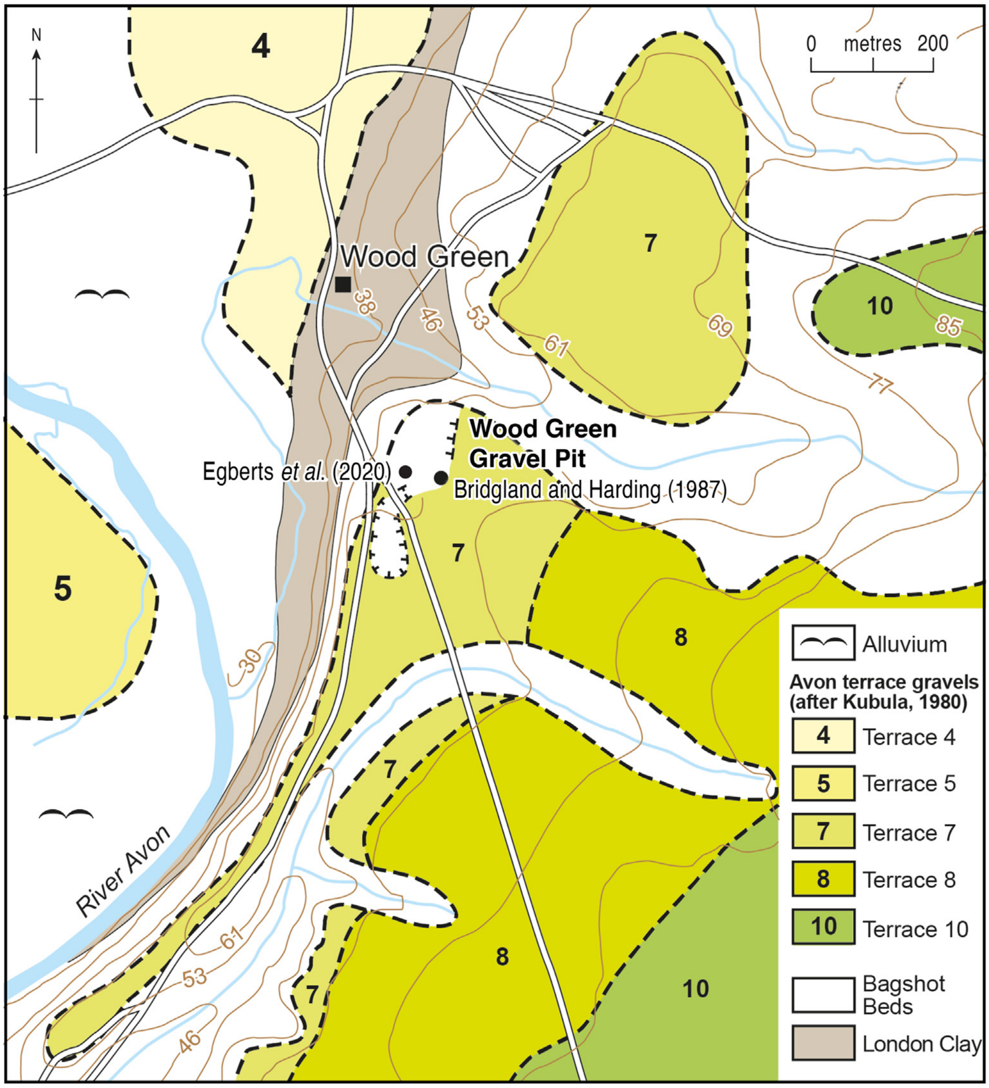

Fig. 19. Location of Wood Green Gravel Pit in the context of local terrace mapping by Kubala (1980) after Bridgland and Harding (1987).

at Wood Green to the '100 ft Terrace' of the Avon (where the terrace altitude was reflected height above river level rather than with respect to O.D.). In the geological memoir, Reid (1902b) assigned the site to his 1st or Palaeolithic terrace. He was the first to describe the nature of the gravel deposit, noting the abundance of flint and the presence of Greensand chert, sarsen, quartz and schorl-rock (Bridgland and Harding, 1987). Bury (1923) and Green (1946) concentrated on the Bournemouth and Southampton areas and attempted correlation with the Avon terraces. Sealy (1955) mapped 8 terraces in the lower Avon valley below Salisbury assigning the Wood Green gravel to his Boyn Hill terrace.

An extensive programme of borehole drilling was carried out by staff of the British Geological Survey during 1976/7 in the Bournemouth and Fordingbridge areas as part of a national study of sand and gravel resources (Clarke, 1981; Kubala, 1980). A numbered terrace system was established which recognised 15 separate terraces divided into three broad categories; lower, middle and upper. The lower terraces (1–4) form extensive areas of terrace flats that lie within the main Avon valley below 40 m O.D. and stretch from the outskirts of Bournemouth to Fordingbridge. The middle terraces (5–10) have an altitudinal range between 40 and 90 m O.D., each separated by a vertical interval of at least 10 m and which appear to be equivalent to the Palaeolithic and Eolithic terraces of Reid (1902b). The higher and oldest terraces lie above 90 m O.D. and comprise a series of gravelly deposits occurring as thin and sinuous dissected spreads on the higher parts of the New Forest Plateau (Clarke and Green, 1987). The Wood Green Gravel Pit has been excavated into Kubala's (1980) terrace no. 7 (Fig. 19) which rises from about 46 m O.D. at St Catherine's Hill on the outskirts of Bournemouth to about 66 m O.D. in the vicinity of the site (Clarke and Green, 1987).

In April 1986 a section (SU 173 170) was cleared and described as part of the Nature Conservancy Council's Geological Conservation Review process (Bridgland and Harding, 1987). Just over 4 m of fluvial gravel was exposed (Fig. 20). It varied between fine and coarse, horizontally and cross-stratified, matrix-supported and open frameworks (Bridgland and Harding, 1987). The bedrock that was reached slightly above 58 m O.D. comprised the Bagshot Formation, the exposed surface of which showed small-scale relief in the form of apparent scour features with an amplitude of some 23 cm (Fig. 20; Bridgland and Harding, 1987). A small abraded handaxe was found *in situ* in the lower part of the section, in open framework cross-bedded gravel 0.9 m above the bedrock surface (Fig. 20). It was described as a crude pointed biface 59 mm long, 3 mm wide and 22 mm thick with heavily crushed edges. Two unstratified flakes were also found in a stained and abraded condition.

More recently, two sections were cleared in the southeast corner of the former gravel workings, only 6 m apart, to provide samples for a wider programme of OSL dating within the Avon valley (Egberts et al.,

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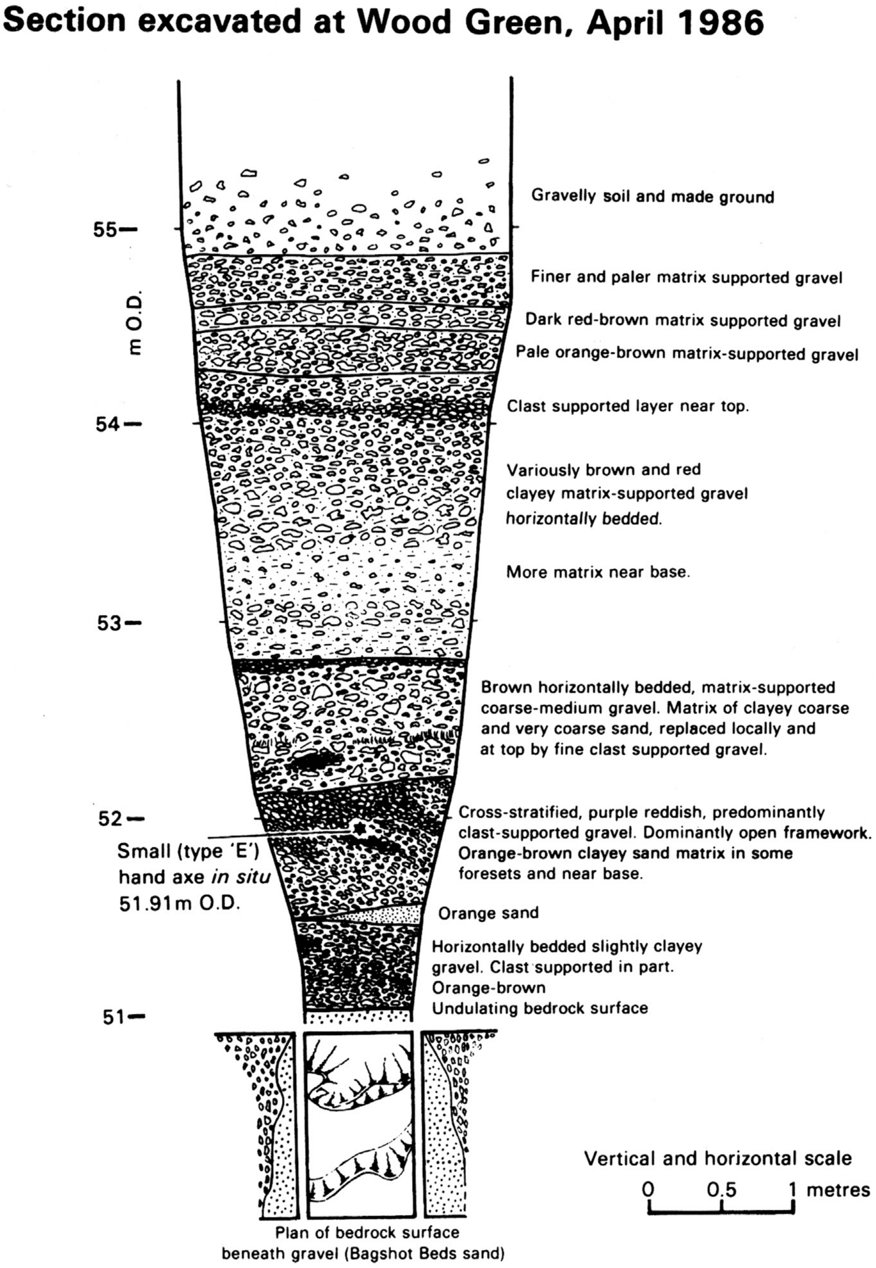

Fig. 20. Section excavated at Wood Green, April 1986 (SU 173 170). From Bridgland and Harding (1987), with permission.

2020; Fig. 21). Section 1 consisted of a sandy channel fill, the upper part of which was sampled for OSL dating, overlain by bedded gravels, 4.5 m depth section in total. Section 2 consisted of 2.5 m of cross-bedded, moderately to poorly sorted, coarse to medium, matrix-supported flint gravel. Egberts et al. (2020) published three OSL ages on quartz grains from Section 1, calculated using the SAR protocol. There is significant scatter both between and within samples, so they should be treated as a minimum age estimate predating MIS 9/10: WGRE01 269 ± 25 ka; WGRE02 354 ± 35 ka; and WGRE03 312 ± 31 ka.

Egberts (2017) studied 635 artefacts from Wood Green Gravel Pit, most of which are made on flint (all except 9 chert bifaces and 1 other chert artefact). These comprised 389 (60 %) bifaces, 137 (25 %) flakes, 5 cores, 104 miscellaneous artefacts and 5 possible Levallois flakes. All the bifaces were intensively knapped and found in various shapes, 49.6 % pointed, 46.3 % ovate and 4.1 % cleavers as defined by the shape ratios developed by Roe (1968a). Many of the artefacts are rolled or slightly rolled.

2.6.3. Interpretation

Bridgland and Harding (1987) suggest that if the total area of excavation is taken into account, the concentration of palaeoliths at Wood Green Gravel Pit is probably greater than that at the other archaeologically rich GCR site of Dunbridge Pit in the Test valley. Artefacts from the site consist primarily of ovate handaxes with some mixed pointed forms (Roe, 1981). Both crude and refined implements are present and the ovates include some with a twisted profile. The handaxe found during the 1986 excavation lies at the smallest end of the size range but is consistent with other Type E handaxes (Wymer, 1968) and small ovates from the site (Bridgland and Harding, 1987). Fragile thinning flakes are also present in the collection, which suggests that the retrieval of artefacts was both unbiased and thorough (Bridgland and Harding, 1987). Most handaxes from Wood Green are rolled and often show a yellow patina with iron staining.

The mapping of Kubala (1980) does not reach as far north as Salisbury and so precise correlation of the Wood Green Gravel Pit with other rich archaeological sites such as Bemerton and Milford Hill

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Fig. 21. Section 1 excavated at Wood Green Gravel Pit at SU 1719 1700 around 2015. From Egberts et al. (2019, 2020). The black sampling holes show the location of OSL samples WGRE01, WGRE02 and WGRE03, whose results are given in Table 4.
Photograph: Ella Egberts.

(Harding and Bridgland, 1998) in the Salisbury area is not possible with any degree of confidence. Wymer (1999) infers on the basis of altitude and similarity of archaeology, that the Milford Hill and Bemerton sites correlate either to Terrace 7 or 8 lower down the valley, which means a correlation with Wood Green Gravel Pit is a possibility. However, long-profile projections by Egberts (2017) suggest that it may actually fall stratigraphically between the two (Egberts et al., 2019).

The age of the Wood Green gravels is clearly important, given the significant Palaeolithic record from the site. Previously, this was hard to assess because of a lack of fossiliferous sites within the Avon terrace system. Fine-grained sediments overlying terrace gravels between 50 and 52 m O.D. in the Salisbury area at Fisherton are thought to date from the early Devensian, perhaps MIS 4 or 3 (Delair and Shackley, 1978; Green et al., 1983). South of Wood Green at Ibsley there are temperate organic deposits with an unusual pollen spectrum containing high proportions of *Ilex aquifolium*. These lie beneath Terrace No. 3 between about 15 and 18 m O.D. and have been attributed to the MIS 5e (Barber and Brown, 1987). It seems certain, based on their higher altitude and position in the terrace staircase, that the Wood Green gravels are older than both aforementioned sites. Another suggested age is based on a few ovate handaxes in the Wood Green assemblage with a twisted profile, which might suggest an age of late MIS 11/early MIS 10 (White, 1998b), signifying a deliberately imposed form that represents a short-lived knapping tradition. Wymer (1999) also suggested a relatively old age for this site, noting that whilst none of the Middle Terraces (5–8) of the Avon can be dated with any more precision than the Middle Pleistocene, an age corresponding to MIS 10 or 8 is likely. Recent OSL dating in the Avon valley using SAR on quartz (Egberts et al., 2020) suggests that the site predates MIS 9/10, but cannot give a more exact age.

2.6.4. Conclusion

Wood Green Gravel Pit is situated within terrace No. 7 of the Avon system. It has been a prolific source of Palaeolithic material since the 1880s perhaps in higher concentrations than Dunbridge Pit. Bifaces predominate, most if not all of which, are rolled suggesting they were incorporated into the Avon terrace gravels at a date subsequent to manufacture. The age of the site is not known with certainty but the presence of twisted ovates, its altitude and position within the Avon terrace staircase, may indicate an age of late MIS 11 or early MIS 10. OSL dating at this site suggests that it predates MIS9/10.

3. GCR Site 991 Aylesford (TQ727596) — Medway (Kent) (BAH, RMB, DCS, PST, FFWS)

3.1. Introduction

Aylesford Sand Quarry lies *c.* 4 km north-west of Maidstone and provides excellent exposures of up to 5 m thick of Quaternary fluviatile sands and gravels overlying Folkestone Formation sand and Gault Clay (Fig. 22, mapped as Terrace 2 by the British Geological Survey). These Medway gravels have long been recognised as a prolific source of large vertebrate remains (Bensted, 1861a, 1861b; Anon., 1862; Foster and Topley, 1865) and later, Palaeolithic flint artefacts (*e.g.*, Bennett, 1917). It is important to note that the site has an extensive quarrying history, and its footprint includes sand/gravel beds attributed to both Terraces 1 and 2 as mapped by the British Geological Survey. Its position at the foot of the Wealden scarp slope also suggests a high incidence of slopewash input (with artefacts and fossils) through the Pleistocene. These factors explain the chronologically and climatically mixed character of the abundant faunal and artefactual material associated with the site, none of which are well provenanced.

Aylesford Quarry was an important part of the mid-nineteenth century controversy that human artefacts could be found in association with extinct animals. Much of the evidence had hitherto come from cave sites where such associations were usually explained through the intermixing of deposits of different ages. The Aylesford finds supposedly provided convincing stratigraphical evidence of the contemporaneity of early humans and mammoth in southeast England during the last ice age. However, many of the artefacts attributed to Aylesford in the past have not come from secure stratigraphic settings. Whilst there was a suggestion in the literature that some may have been fabricated (Bird and Hume, 1895), there is definite evidence since this date for *bona fide* artefacts. Use of vertebrate assemblages to assign an age to these deposits suggests an age of *c.* MIS 6 to 4 with mixed Ipswichian and Devensian elements (Bridgland, 2003), although elements of the fauna are inconsistent with the Last Interglacial (MIS 5e) and other features could be both older or younger. However, OSL dates published in full for the first time in this paper (Table 6) date the Terrace 2/Aylesford Gravel Formation outcrops at the Sand Quarry to between 236 and 308 ka (MIS 9 to 7) (Toms, 2004; Wenban-Smith et al., 2007).

3.2. Description

Whilst Benjamin Harrison, the famous amateur archaeologist from Ightham, recounted a visit to view the Aylesford river gravels as a young teenager on a school trip in 1851 (Harrison, 1928), the earliest published references to the exposures at Aylesford Sand Quarry appears to be two brief reports in *The Geologist* by the Maidstone antiquarian and stone merchant, W. H. Bensted (1861a, 1861b) who noted the frequent occurrence of molars and tusks of woolly mammoth and the potential of the sand quarry as a source of Palaeolithic implements. In the following year the discovery of well-preserved mammoth remains at Aylesford was recorded, including an impressive tusk and a lower jaw with molars still in their sockets (Anon., 1862). The reputation of the site subsequently rose such that in 1862 The Post Office Directory of Kent noted that "Aylesford is a favourite place of resort to the geologist,

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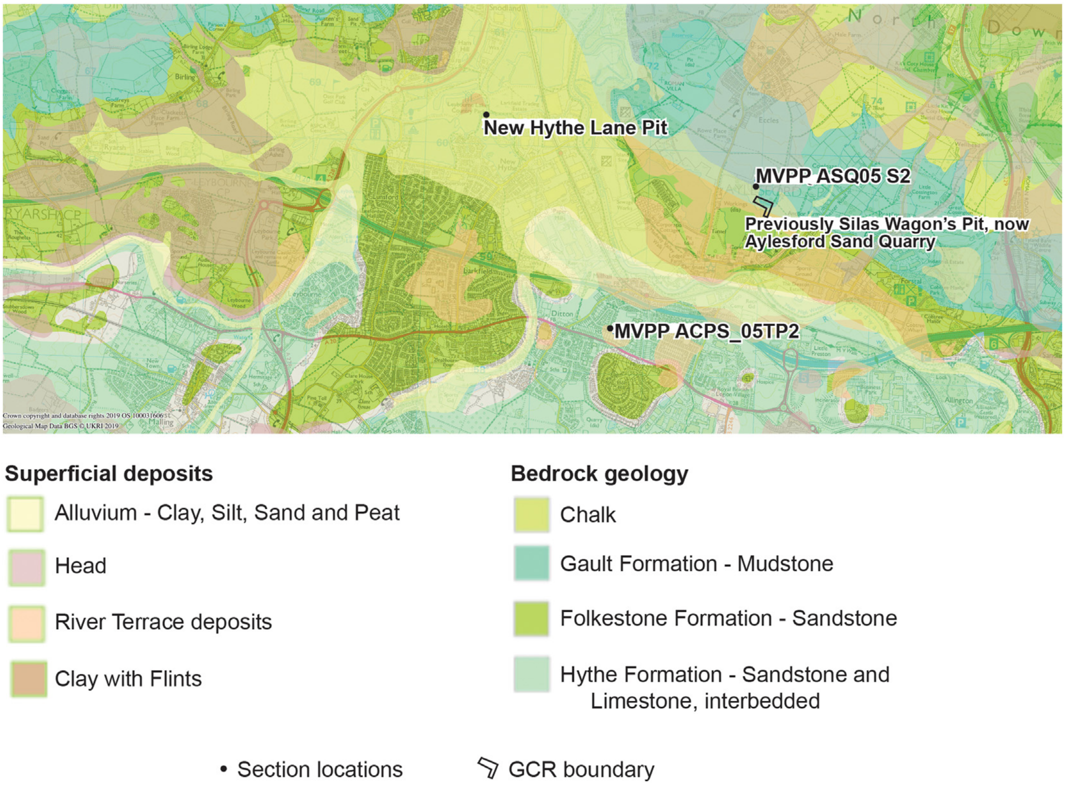

Fig. 22. Local geology near Aylesford Sand Quarry showing former quarry boundaries, GCR boundary and sections investigated during the Medway Valley Palaeolithic Project (Wenban-Smith et al., 2007). MVPP_ASQ05_S2 is shown in Figure 23 and yielded the OSL dates in the text. Map contains geological data available under an Open Government licence from the British Geological Survey © UKRI [2024].

who, among the stone quarries, chalk works and sand pits, pursues his favourite study, and obtains valuable additions to his collection of geological discoveries" (Anon., 1862, p. 732).

In the latter part of the 19th century a number of Geologists' Association excursions visited Aylesford Quarry/Silas Wagon's Pit (Fig. 22) (Jones and Bensted, 1873; Hudleston, 1876; Morris, 1880; Lobley, 1883; Boulger, 1886; Bird and Hume, 1895). Other quarries operating in the area and yielding artefacts were the closely associated Nickel/Nico Pit and Preston Hall Pit (Cook, 1923) and New Hythe Lane Pit on the other side of the river. The earliest stratigraphical description of the site is that by Foster and Topley (1865), in their review of the superficial deposits of the Medway basin. These authors reported 18 to 20 ft (6 m) of gravel overlying the Folkestone Formation in a pit north-east of Aylesford Church, underlying a terrace surface more than 40 ft (13 m) above the level of the Medway. The matrix of the gravel becomes increasingly loamy towards the surface and in places it is overlain by 'brickearth' (Worssam, 1963). The pit was again mentioned by Topley (1875) in his *Geology of the Weald*, in which he claimed the gravel to be part of a continuous terrace from Burham to Cobtree. In the report of the May 1876 excursion, Hudleston (1876) described "a splendid series of mammaliferous gravel and sand, bearing evidence of much erosion, hollowing out and redeposition by current action; indications of ice action are also noticeable" (p. 504). The presence of Wealden (Wadhurst Clay) material in the gravel was also considered to be important evidence against the once popular theory that flow through the Medway gap had formerly been from the north, into a Wealden sea. The Quaternary sands and gravels unconformably overlie the Cretaceous Folkestone Formation at about 11 m O.D., the erosion contact being essentially horizontal, though rising southwards towards the river Medway (Carreck, 1972).

In June 1904 a party from the Southeastern Union of Scientific Societies (Anon., 1904) reported a description by F. J. Bennett of a 'scarp drift', composed partially of chalk, which thickened to the north and overlay the fossiliferous gravels at Aylesford. This 'scarp drift' was again described at Aylesford by Bennett (1907) and likely represents the thick overlying solifluction deposits alluded to later by Wenban-Smith et al. (2007).

A section through the Terrace 2 deposits exposed at the north side of the pit in 2003 was recorded (Kent RIGS, 2004) and re-located (ASQ 05, Section 2: TQ 7295 5975) as part of the Medway Valley Palaeolithic Project (Wenban-Smith et al., 2007; Fig. 23). Here, a 2.6 m thickness of gravel is reported overlying Gault Clay at *c.* 17 m O.D. and underlying a 40 cm thick massive clayey sand 'brickearth'. The gravels are clast supported and poorly sorted, displaying cross-bedding and some horizontal bedding and including a thin lens of green–grey clay. This section was sampled for OSL dating (Table 6), yielding previously unpublished age estimates based on use of the SAR protocol (Murray and Wintle, 2000) on quartz grains of 278 ± 30 ka (GL04003) and 250 ± 14 ka (GL04004), a range of *c.* 236–308 ka (MIS 7 to 9). Mean De values are the weighted (geometric) mean De calculated using the central age model outlined by Galbraith et al. (1999) and are quoted at 1δ confidence (standard error). Ages were assessed for the presence of partial bleaching by the use of De(t) plots (Bailey et al., 2003). Toms (2004, p. 6) noted that 'given the presence of rising De (t) associated with both the natural signal and laboratory simulation of partial bleaching and absence of rising De (t) associated with both zero and repeat regenerative-dose data, aliquots within sample GL04004 likely contain partially bleached grains', making this age possibly an overestimate, although GL04003 appears to be reliable on the basis of this test. These are a little older but overlap with other dates from Medway Terrace 2 at Cuxton of 233 ± 14 ka (CXTN4 05-03/X2561) and 198 ± 17 ka (CXTN4 05-05/X2563) (range of *c.* 181–247 ka — MIS 6 to 8), reported in Wenban-Smith et al. (2007).

The coarse gravel includes large blocks of flint, Lower Greensand chert, ragstone and sandstone, as well as among the smaller pebbles, Wadhurst Clay siltstones, sandstones and ironstones, Ightham Stone,

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Table 6
Dosimetry, D_e and age data obtained during optical dating of samples of terrace deposits in the Aylesford excavation. Moisture content expressed as a fraction of wet weight.

Laboratory code	Grain size (μm)	Moisture content	NaI γ-spectrometry (*in situ*)			Total γ dose rate (Gy·ka^{-1})	ICP-MS analysis			Total β dose rate (Gy·ka^{-1})	Cosmic dose rate (Gy·ka^{-1})	Total dose rate (Gy·ka^{-1})	Mean D_e (Gy)	Age (ka)
			K (%)	Th (ppm)	U (ppm)		K (%)	Th (ppm)	U (ppm)					
GL04003	125–180	0.08 ± 0.02	0.30 ± 0.02	5.16 ± 0.17	1.87 ± 0.10	0.53 ± 0.02	0.30 ± 0.00	4.02 ± 0.02	1.36 ± 0.01	0.44 ± 0.02	0.17 ± 0.02	1.15 ± 0.04	318.8 ± 32.5	278 ± 30
GL04004	125–180	0.10 ± 0.02	0.27 ± 0.02	4.45 ± 0.18	1.89 ± 0.11	0.49 ± 0.02	0.46 ± 0.00	5.56 ± 0.03	1.62 ± 0.01	0.59 ± 0.04	0.18 ± 0.02	1.26 ± 0.05	314.4 ± 13.0	250 ± 14

Folkestone Formation ironstone, Paleogene flint pebbles and chalk (Worssam, 1963; Carreck, 1964, 1972; Bridgland, 1983a, 1983b). Lenses of finer gravel and sand, seams of clay and beds of silty material are interbedded with the coarser gravel (Bridgland, 1983a). Two samples reported by Bridgland (2003) from TQ 7257 5966 and TQ 7257 5965 comprise 41–53 % flint, 40–54 % Greensand chert and 2–5 % Wadhurst Clay, among other elements.

The Aylesford deposits were referred by Cook and Killick (1924) to their Low or 25 ft Terrace of the Medway. Most authors have, however, attributed them to the 2nd, Middle, Taplow or 50 ft Terrace (*e.g.*, Worssam, 1963; Carreck, 1964, 1972; Kirkaldy and Middlemiss, 1976). True 25 ft (Low) Terrace deposits occur to the east of Aylesford village (Burchell, 1933; Worssam, 1963) where they have yielded molluscan fossils (Burchell, 1933; Burchell and Davis, 1957). These are unrelated to the mammaliferous sediments at Aylesford, which have to date not yielded molluscs. Bridgland (2003) named these deposits the Aylesford Gravel and correlated it with the Middle Thames Kempton Park Gravel on the basis of the contained fauna and long-profile projections.

Wenban-Smith et al.'s (2007) review identified up to ten different Medway terraces in the Maidstone area (Terraces A–D, D/E, and F to I, working up from A being the buried Devensian channel below the current floodplain). Detailed borehole analysis of the Aylesford area (Wenban-Smith et al., 2007, pp. 26–30, their Table 15) suggested that the Terrace 2 deposits actually comprised three levels:

Terrace E — in which was found the Preston Hall Sand/Gravel Pit
Terrace DE — in which was found the New Hythe Lane Pits
Terrace D — in which was found the Silas Wagon's/Nico Pits complex (Fig. 22; Table 6).

In relation to the Terrace D deposits that are the focus of the GCR site, Wenban-Smith et al. (2007, p. 29) state 'it is worth noting (a) that lower terrace (B-C) deposits outcrop in the southern side of the quarry and (b) that the original quarry landscape was overlain by extensive sheets of solifluction gravels sweeping down the south-facing slope of the Wealden scarp. Both these factors could have led to the discovery at the site of archaeological material not related to Terrace D.'

Foster and Topley (1865) noted the discovery of mammoth, rhinoceros and horse remains from the Aylesford gravel, although Dawkins (1869) recorded only straight-tusked elephant and woolly mammoth. Hudleston (1876) reported on an excursion where members of the excursion party collected numerous teeth and other remains of mammoth, and two rhinoceros teeth. A large mammoth tusk, over 10 ft (5 m) long, prominent in the face during this visit eventually yielded to repeated blows of a pick-axe.

Most recently, the Aylesford mammalian faunal assemblage in Maidstone Museum (around 100 specimens) was reviewed in 2004 for the Kent RIGS (Regionally Important Geological Sites) Group by Danielle Schreve, who also studied a small collection from Aylesford in the Natural History Museum in London (Schreve, 2005). The assemblage is dominated by remains of woolly mammoth (*Mammuthus primigenius*) and woolly rhinoceros (*Coelodonta antiquitatis*), with smaller numbers of horse (*Equus ferus*), wild boar (*Sus scrofa*), giant deer (*Megaloceros giganteus*), red deer (*Cervus elaphus*), musk ox (*Ovibos moschatus*) and probable aurochs (*Bos primigenius*). Additional remains of lion (*Panthera leo*), bison (*Bison priscus*) and straight-tusked elephant (*Palaeoloxodon antiquus*) reported by Cook (1923) and Skempton and Weeks (1976) could not be verified during the 2004 review. The species list given by the latter authors was drawn from earlier published sources and it is possible that there were either misidentifications of material or that additional specimens exist in collections other than at Maidstone Museum which have not been relocated in recent years.

With the exception of material collected by John Carreck in the 1950s that is often labelled 'Wagon's Pit', the majority of the material studied bore no further locality information other than 'Aylesford' and no stratigraphical provenance. This is particularly problematic since, as

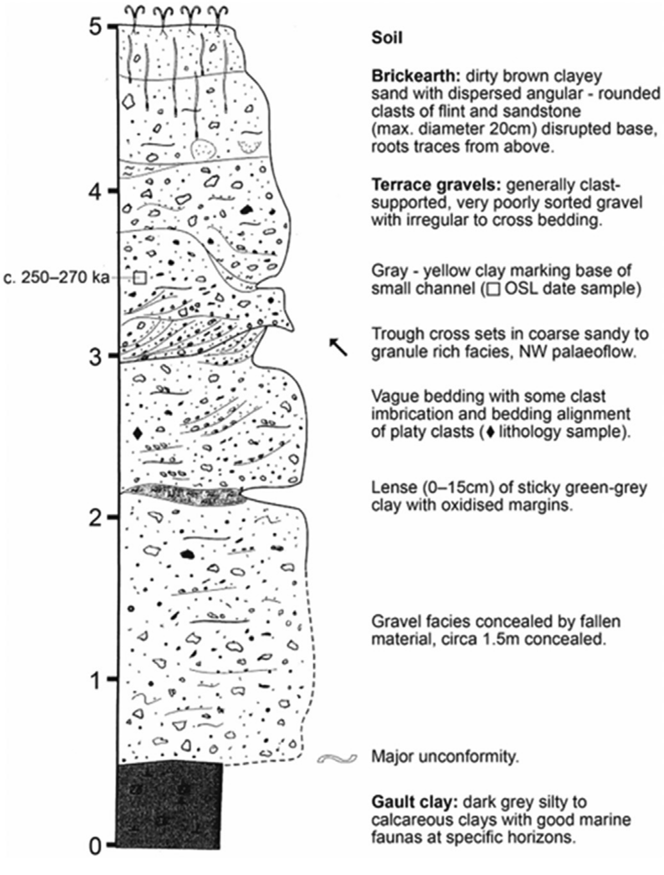

Fig. 23. Kent RIGS section at Aylesford Sand Quarry (Kent RIGS, 2004; Wenban-Smith et al., 2007; ASQ05 Section 2). Section located at TQ 7295 5975, figure used with permission.

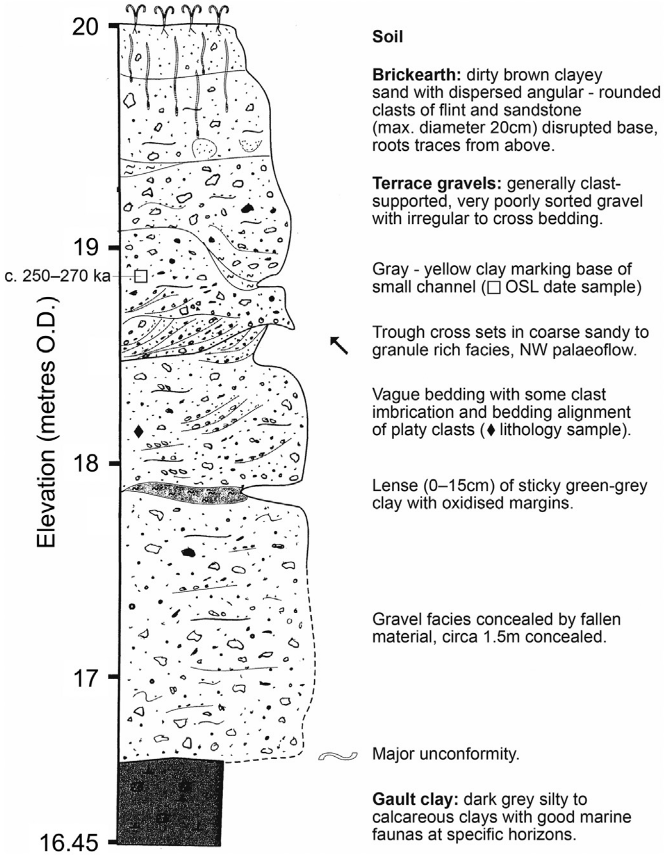

Fig. 23 (*continued*).

stated above, there have been numerous pits open in the Aylesford district for the extraction of aggregates and there is the possibility that not all of them occur within the same terrace and are of comparable age. Only three specimens bear stratigraphical data: 'Aylesford 12' a right deciduous fourth premolar of *M. primigenius* from 'base of gravels a few inches above surface of Folkstone Sands', 05-085 a right first lower molar of *C. antiquitatis* labelled 'brickearth' and an un-numbered partial left upper molar of *M. primigenius* from 'solifluction deposits overlying the gravel'. The material therefore appears to span a range of depositional contexts and is also time-transgressive. As well as the lack of provenance, there is an evident bias towards the more robust skeletal and dental elements of the larger Pleistocene taxa. The material overall shows a high degree of rolling and abrasion, which would be consistent with deposition in a coarse fluvial gravel. In addition, weathering was noted on several specimens, indicating that some material had been exposed for an undetermined period (probably under periglacial conditions) prior to its burial.

Palaeolithic implements were first found *in situ* in the Aylesford area in May 1881 by Arthur Hickmott, a student of Benjamin Harrison, during an excursion of the Maidstone Scientific and Natural History Society (Harrison, 1928). The find, however, seems to have come from higher terrace gravels overlying Gault Clay at Aylesford Pottery to the east of Aylesford Quarry. Two years later and 30 years after Benjamin Harrison's first visit to the Quarry, a workman who had been taught to recognise a palaeolith by Hickmott apparently discovered a fine specimen in the terrace gravels there. According to Harrison (1928) further finds were quickly made, and the gravel pit at Aylesford became known as one of the most productive of implement-bearing sites.

Roe (1968b) records 42 handaxes of all types from Aylesford Quarry with smaller numbers of cores and flakes. In the Aylesford area generally he notes records of 315 handaxes of all types, a smaller number of cores and flakes and one Levallois core and eight Levallois flakes.

However, as can also be seen from Historic Environment Records, very few of the artefacts have unambiguous and secure stratigraphic contexts and there is the possibility that some finds attributed to Aylesford Quarry may have been brought in by workmen from other sand and gravel quarries in the vicinity (Roe, 1981). Hinton and Kennard (1906) noted that some of the artefacts had been imported from a newer pit on a higher terrace at New Hythe and sold as Aylesford implements. Concerns about the true attribution of the Aylesford lithic material were also raised by Roe (1968b) and Wymer (1999). There is also some evidence to suggest deliberate fabrication (Evans, 1897; Bird and Hume, 1895).

Cook (1923) assigned these artefacts from the Aylesford gravels to the Chellean, Acheulian I, Acheulian II (all now considered Acheulian) and the Mousterian, of which only the latter were unabraded. Jessup (1930) suggested that the Mousterian implements had been found near the top of the gravel. Wenban-Smith et al. (2007) are more cautious, citing poor provenance and significant mixing of material as barriers to understanding the lithic assemblage characteristics of any specific terrace deposits at Aylesford. They therefore report few artefacts from the GCR site itself, noting 114 from Aylesford (general), 56 from Boxley, 29 from Ham Hill Pits, 12 from Nickel/Nico Pits, Aylesford, 1 from Allington Lock, Maidstone, 3 from Bryce's Sand Pit, Aylesford, 141 from New Hythe Lane, 8 from Preston Hall Sand Pit and only 7 from Silas Wagon's Pit, Aylesford. Wenban-Smith's (unpublished) examination of the general unprovenanced Aylesford lithic collection in 2005 identified a few Levalloisian elements – several large blade-like flakes and one *bona fide* Levallois flake – and numerous handaxes, almost all well-abraded, of very varied shapes from ovate to pointed, representing a mixture from all stages of the British Lower/Middle Palaeolithic.

3.3. Interpretation

The sections from Aylesford are little described – with the one exception presented here (Fig. 23) – but clearly from a fluvial depositional environment, likely braided in form, due to the dominance of horizontal bedding and evidence for small ephemeral scour forms. Periglacial history during deposition is unclear because there is no evidence of cryogenic features. However, the thick solifluction deposits overlying the gravels do strongly suggest later periglacial processes.

Because of the lack of data about the stratigraphical location of fossils and the multiple terraces known from the site, the Aylesford faunal assemblage cannot be treated as a single, coherent unit for palaeoenvironmental reconstruction. However, the presence of wild boar and probable aurochs in an assemblage of predominantly cold-climate and open ground indicators (notably woolly mammoth, woolly rhinoceros, horse and musk ox) would be incongruous, since both (like the straight-tusked elephant reported by Skempton and Weeks, 1976) are restricted to temperate, wooded periods in the Pleistocene. The conditions of the single find of wild boar and the three specimens of *cf.* aurochs are heavily abraded and, in the case of the aurochsen, occasionally weathered. This would strongly support the notion that specimens representing an earlier period of temperate conditions were derived into the main Aylesford terrace during an ensuing cold stage.

Hinton and Kennard (1906) correlated the Aylesford gravel with their 3rd Terrace of the Lower Thames, in which they included the brickearths of Crayford, Ilford and Grays. Carreck (1964) equated the Aylesford terrace deposits to the Taplow Terrace of the Thames and interpreted the mammalian fauna as an Ipswichian assemblage. From an examination of mammoth molars in Maidstone Museum, Carreck concluded that the Aylesford form was an early true *Mammuthus primigenius* intermediate between the Ilford and Crayford forms, and similar to that from the Ebbsfleet channel deposits at Baker's Hole (Carreck, 1972), which might support the MIS 7–9 age suggested by the OSL dating. The most recent correlation with the wider Thames

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sequence is with the Lower Thames East Tilbury Marshes Gravel and Middle Thames Kempton Park Gravel (Bridgland, 2003). There is, however, a complicating factor in the presence of both lower and upper gravel members in the Aylesford terrace, separated by an interglacial 'brickearth' (the Kingsnorth Member), which has been attributed to MIS 5e by Bates et al. (2002) although this has yet to be confirmed on biostratigraphical or geochronological grounds (Bridgland, 2003). The Aylesford gravel deposits apparently 'sandwich' these interglacial sediments and thus appear to cover both a pre-Ipswichian period of cold climate conditions, potentially equated with MIS 6, and parts of the Devensian (last cold stage). It is not known from which part of the Aylesford Gravel Formation (*i.e.*, pre- or post- the Kingsnorth interglacial Member) the fossil mammal remains come from and certainly, on the basis of the limited stratigraphical data preserved on the specimens, they could easily come from both. Unfortunately, there is nothing of biostratigraphical significance in the Aylesford assemblage that can help resolve this issue, since all cold-climate species encountered are present in both periods.

The First and Last Appearance Data of key taxa can only give a very broad age range for the assemblage. *C. antiquitatis* first appeared in Britain during the late Middle Pleistocene, in the period of cold-climate conditions correlated with MIS 8 at sites such as Baker's Hole in Kent (Schreve et al., 2002). It disappeared from Britain by *c.* 30 ka cal BP (Stuart and Lister, 2012). Fully evolved *M. primigenius* appears slightly later in Britain, in the late part of MIS 7, around 200 ka (Lister and Sher, 2001) and is present until *c.* 14.5–14.0 ka cal BP (Lister, 2009). Although the assemblage of complete mammoth molars is small, two third molars have a minimum plate count of 24 in the molars, indicating *M. primigenius*. Nothing in the collections currently supports the presence of the steppe mammoth (*Mammuthus trogontherii*), which coexisted with *M. primigenius* in part of MIS 7 (Lister and Sher, 2001) and which might have been expected given Carreck's (1972) observations and proposed correlations of the mammoth molars with those from other MIS 7 sites. Horse is unknown in Britain for an extended period from a point in MIS 6 to the Last Interglacial (MIS 5e) and the Early Devensian (MIS 4), only returning in the Middle Devensian (MIS 3) (Currant and Jacobi, 2001, 2011). Therefore, the Aylesford fauna, if viewed as a single assemblage, would be compatible with an age anywhere between MIS 6 and MIS 2, with the exception of MIS 5–4. This is in close correspondence with the age inferred from the terrace stratigraphy above. Despite the problems associated with the temporal coherence of the site, the bulk of the Aylesford assemblage is most reminiscent of faunas of the Middle Devensian (MIS 3), characterised particularly by the presence, among others, of woolly mammoth, woolly rhinoceros and horse, all of which were absent during the Early Devensian in Britain (Currant and Jacobi, 2001, 2011).

New OSL dating from this site reported above casts doubt on this age estimation, suggesting an age instead of between MIS 9 and MIS 7. This is consistent with the mixed Lower/Middle Palaeolithic character of the flint implements (Wenban-Smith et al., 2007), which have probably mostly been re-worked into the Terrace 2 deposits. It is, however, inconsistent with an Ipswichian–Devensian (MIS 5 to 2) dating of the mammal assemblage by Bridgland (2003) and the downstream relationship with the Kingsnorth site (Bates et al., 2002). An explanation for the disparity may be the fact that the mammalian assemblage is clearly a palimpsest of specimens (largely unstratified) of different ages that may span a considerable period of time in the late Middle and late Pleistocene.

3.4. Conclusion

This 100-year old pit provides excellent exposures through the second terrace gravels of the Medway overlying Folkestone Formation. This terrace has since been renamed the Aylesford Gravel Formation and thought to correlate with the Thames Kempton Park Formation. It has yielded considerable quantities of mammalian remains, together with artefacts of Acheulian and Levallois types. However, most finds are historic and very poorly provenanced, which is problematic given the different terrace deposits present adjacent to the site from which they might have come. Recent reinvestigation of the fauna suggests that it is a temporally-mixed assemblage that could range in age from MIS 6 to 2. OSL ages are consistent with an age between MIS 7 and 9. The remaining exposures at this important Medway Pleistocene site would benefit from further investigation to yield lithic and faunal material with a secure provenance and further OSL samples that would help to date the site more reliably.

4. Stour (Kent)

GCR Site 992 Fordwich Pit (TR179587) (BAH, RMB, PGK)
GCR Site 1171 Sturry Gravel Pits (TR 174 607) (BAH, RMB, PGK)
Provisional GCR Site Wear Farm Pit, Chislet (TR 224650) (BAH, RMB, FFWS)
Provisional GCR Site Bishopstone to Reculver Cliffs (TR 205 686 to TR 222 691) (PGK, DRB, MJW, RMB)

The Stour, Kent's second longest river, was formerly the easternmost south-bank tributary of the Thames. It has two main branches; the Great Stour which rises just to the south of Lenham and flows through Ashford, the Wye Gap, Chilham and Canterbury; and the Little Stour/Nailbourne which rises on the North Downs dip-slope near Lyminge and flows generally northwards to Bridge, then northeast to meet the Great Stour at Plucks Gutter on the Wantsum Marshes (Fig. 24). Downstream of Canterbury, the Stour splits into two, with one channel – which only silted up in Medieval times – passing north into the Thames Estuary through the Wantsum Channel to the west of Thanet, and the other channel passing east into the North Sea to the south of Thanet at Pegwell Bay. Dewey et al. (1925) suggested that it formerly flowed northwards from Chilham through a gap between Shottenden Hill and The Blean (dotted line in Fig. 24), a largely wooded London Clay ridge north of Canterbury. This is based on a '200 ft Platform' (61 m) running across the western side of The Blean thought to represent an early course of the Stour. This was later traced downstream by S.W. Wooldridge and J.F. Kirkaldy and found to be associated with two lower Stour terraces at 150 ft (46 m) and 100 ft (31 m) O.D. (Coleman, 1952). More recent work on terrace altitudes, morphology and deposits together with offshore seismic profiling confirms that the Stour formerly flowed towards the north, crossing the North Kent coast and meeting the now submerged offshore extension of the Thames east of Burnham-on-Crouch (Coleman, 1952; D'Olier, 1975; Bridgland et al., 1998a; Fig. 24).

Early descriptions of the Stour terraces were given by Whitaker (1872), Topley (1875) and Dewey et al. (1925) and their contained fossils by Reid (1891) and artefacts by Evans (1872). Coleman (1952) provided more complete morphological information and her mapping (Fig. 24) remains the most complete appraisal of the Stour terrace system (Bridgland et al., 1998a).

Within the present valley near Canterbury, Dewey et al. (1925) identified upper, middle and lower terraces at about 60 ft (18 m), which included the deposits at Sturry, 30 ft (9 m) and −15 ft (−5 m). More detailed field mapping by Coleman (1952) showed a staircase of 10 terrace 'flats' some 13 miles (21 km) wide descending eastwards from the summit of the Blean at 400 ft (122 m) O.D. to the present floodplain which lies a few metres above Ordnance Datum (Fig. 24). She suggested this represented evidence for sustained eastward migration of the Stour caused by tilting of east Kent towards the southern North Sea Basin. At about the 100 ft (31 m) stage, however, the river became entrenched into the chalk and ceased to migrate. Terraces below the 100 ft stage were considered by her to be markedly different from those at higher altitudes because they are smaller in area, are backed by definite bluffs, occur on both sides of the valley, show a greater variation in surface

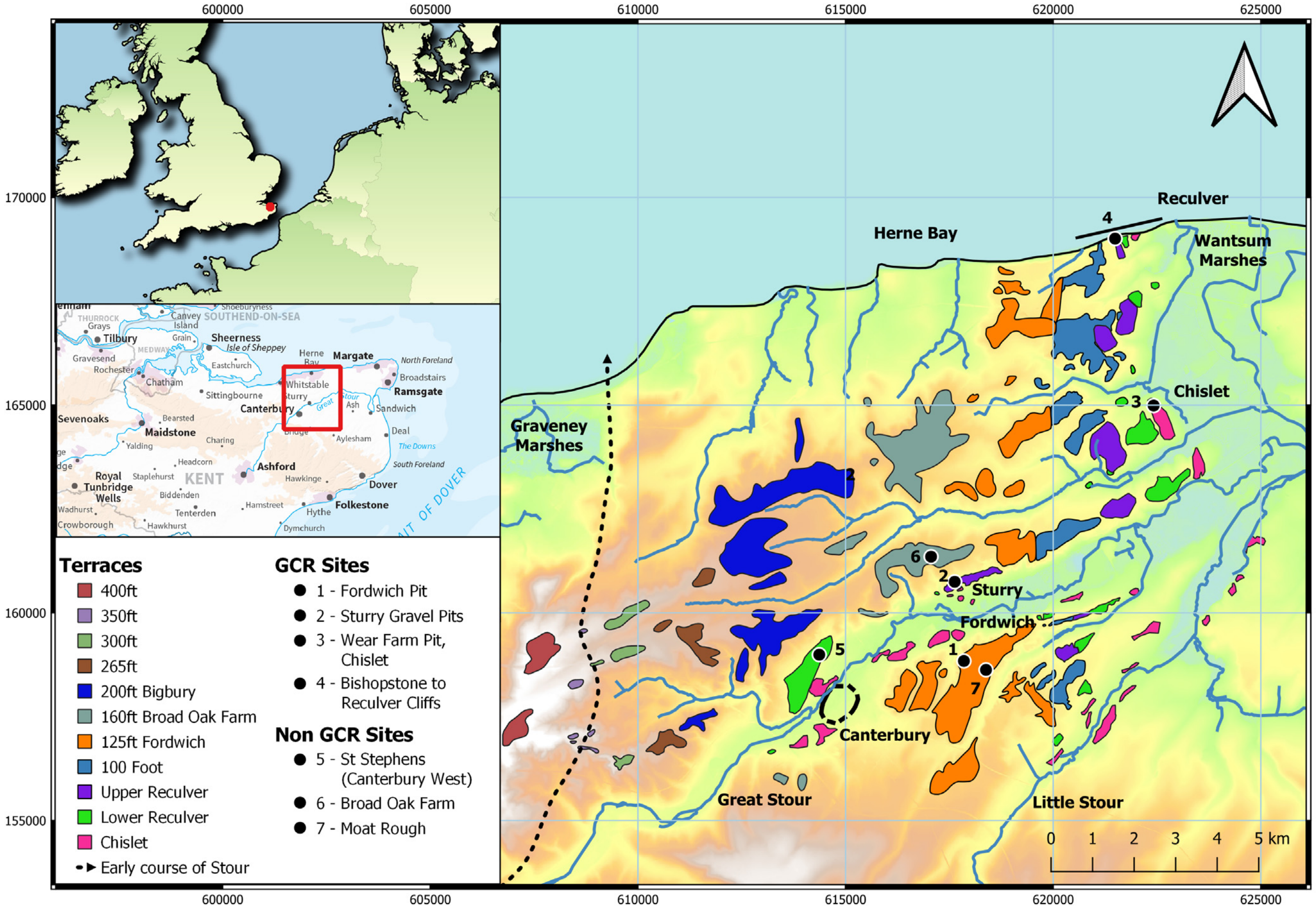

Fig. 24. Map of the Stour terrace system after Coleman (1952), with renaming of the lower terraces by Bridgland et al. (1998a). The location of the Fordwich Pit, Sturry Gravel Pits, Wear Farm Pit, Chislet and Bishopstone to Reculver Cliffs sites is shown, along with other non-GCR sites discussed and an early course of the Stour in a dashed arrow after D'Olier (1975). (Inset map: Ordnance Survey (GB) MiniScale®.)

level and cannot be easily differentiated on the basis of altitude. For this reason, she designated them as being 'Reculver Stage'. She included the gravels at Fordwich in her 125 ft (38 m) stage; two terrace levels above the Sturry gravels, which she attributed to her 'Upper Reculver Stage'. Smart et al. (1966) mapped five terraces in the Canterbury area with the third terrace subdivided into three distinct levels (Fordwich Pit in the middle of these). Holmes (1981) then mapped three terraces of the river Stour, all considered to be of Ipswichian age, suggesting the deposits at Sturry Gravel Pits to belong to his Third Terrace stage equivalent to Dewey et al.'s (1925) Upper Terrace. Bridgland et al. (1998a) note that the 100 ft gravels (not represented in the immediate Fordwich/Sturry area but seen at the Bishopstone to Reculver Cliffs site) appear to be only marginally higher within the terrace sequence than those at Sturry, which raises questions about their stratigraphical separation. There is considerable scope remaining for understanding the Stour terrace sequence.

In light of increasing development pressure in this area of complex Middle–Late Pleistocene deposits rich in faunal and Lower/Middle Palaeolithic remains, Kent County Council (in collaboration with F.F. Wenban-Smith) initiated and carried out the Stour Basin Palaeolithic Project between 2012 and 2015 (Kent County Council, 2015; Wenban-Smith et al., 2015). The goals of this project included: to enhance Palaeolithic and Pleistocene information in the Kent Historic Environment Record, to provide an improved dating framework and subsurface deposit model for river terrace and Head/Brickearth deposits in the Stour Basin, and to identify key areas of high Palaeolithic/Quaternary potential. A substantial fieldwork programme, complemented by OSL and amino acid dating, and by a range of palaeo-environmental analyses, was carried out on the east side of the Blean, where the historic Stour heads towards the Thames estuary, and where numerous gravel patches mapped as Head gravel are more likely to be terrace gravels of fluvial origin. This work identified five distinct fluvial terraces with bench levels at 28 m, 22 m, 18 m, 12 m and 5 m O.D. The latter terrace represents the Wear Farm Pit, Chislet provisional GCR site, dated to *c.* MIS 9 by amino acid racemisation and OSL, although faunal analyses indicated a warm interstadial within a cold stage rather than a full interglacial such as MIS 9. Since the terrace sequence at Canterbury was *c.* 4 km upstream, Bridgland et al.'s (1998a) Sturry terrace was correlated with the 18 m or 22 m aggradation, and the 100 ft terrace with the 28 m aggradation.

The GCR sites described below form a network concentrated on the north bank of the Great Stour near Canterbury. A higher elevation non-designated site has also recently been studied in a recent developer led archaeological evaluation at Broad Oak Farm (Knowles et al., 2023) on the northern bank of the Stour. Here, two northeast trending channels filled with fine-grained fluvial sediments overlying coarse gravels are cut into the bedrock London Clay at elevations of *c.* 50 m, downstream of and higher than the sequences at Fordwich and correlating with Coleman's (1952) 160 ft terrace. The former gravel pit at Fordwich High Pit (Old Park and Chequers Wood SSSI) was reported briefly by Smith (1933), whilst the lower GCR site at Sturry Gravel Pits and Centenary Wood SSSI benefitted from systematic recording by local GP Dr Ince (1921–1923), reported by Henry Dewey of the Geological Society and Reginald Smith of the British Museum (Dewey et al., 1925; Roe, 1981). The principal geological interest lies in their claim of a stratigraphical superposition of flint industries here, with both crudely fashioned pick type handaxes and more refined bifaces at Fordwich Pit, possibly indicating multiple pre-Anglian occupations (Kent County

Council, 2015; Knowles et al., 2024). An early age for this location has been suggested by recent dating work yielding ages *c.* 600 to 485 ka from lower levels and *c.* 400 to 325 ka from higher ones (Key et al., 2022). More refined Acheulian and Mousterian industries with a putative Levallois component are found at Sturry Gravel Pits (Smith, 1933; Roe, 1968a, 1968b, 1981; White, 1998a). Altitudinally between Sturry Gravel Pits and the GCR site at Wear Farm Pit, Chislet sits a further site at St Stephens in Canterbury at *c.* 20 m O.D. Originally reported by Dewey and Smith (1925), recent reanalysis produced an assemblage containing handaxes of both ficron and cleaver types (Knowles, 2023a), which were interpreted as suggesting these deposits were of equivalent age to late MIS 9 after typological analysis by Bridgland and White (2014) and Dale et al. (2024). A third provisional GCR site at Wear Farm Pit, Chislet is a former gravel and chalk quarry at a lower altitude still. This was noted by Prestwich (1855) as being fossiliferous and has been rediscovered, proving to be rich in molluscan and vertebrate remains (Bridgland et al., 1998d). Fieldwork at this site during the Stour Basin Palaeolithic Project (Kent County Council, 2015; Wenban-Smith, 2015) has yielded an OSL age of *c.* 250 ka and an AAR value suggesting correlation with MIS 9. A fourth provisional GCR site at Bishopstone to Reculver Cliffs is the most enigmatic yet, yielding evidence of fluvial gravels in channel fills at three elevations, but with no well-provenanced artefacts or age estimates published as yet, despite the prolific quantities of Palaeolithic material that have been recovered.

A full reinvestigation of the Stour sequence is in progress by Knowles, facilitated by the exposures of multiple adjacent terrace gravels in the newly proposed Bishopstone to Reculver Cliffs GCR site and using OSL and Electron Spin Resonance (ESR) of quartz for dating. Further work is being undertaken by Key at the Fordwich Pit GCR site and White in an AHRC funded project entitled ‘Digital technologies, Acheulean handaxes and the social landscapes of the Lower Palaeolithic’. The implications of the age estimates that are currently available are discussed below in relation to each individual site.

4.1. GCR Number 992 Fordwich Pit (TR179587) (BAH, RMB, PGK)

4.1.1. Introduction

The fluviatile gravel deposits at Fordwich Pit overlie a bench cut into Eocene sands. The site has been a prolific source of Palaeolithic artefacts, mostly collected by local amateur archaeologists, notably Drs Ince, Willock and Bowes, in the 1920s and 1930s. Its importance lies in its stratigraphic position within the Stour terrace sequence and the fact that the lithic assemblage may include an early Acheulian biface tradition lacking in refinement (Roe, 1968b). Early research was conducted by Dewey and Smith (1925) and Smith (1933), with later comment by Howell (1966), Roe (1968a, 1977, 1981), Ashmore (1981), Holmes (1981) and Wymer (1968, 1999). Modern excavations and lithological descriptions (Fig. 26) were undertaken by Bridgland et al. (1998b), whilst the archaeological evidence was reviewed by White (1998a). More recently, Key et al. (2022) revisited these sections, discovering *in situ* artefacts and sampling for infrared-radiofluorescence (IR-RF) dating of the sequences.

4.1.2. Description

Dewey and Smith (1925) reported that flint implements had been found by the local antiquarian Dr Ince in a gravel lying at about 160 ft (49 m) above O.D. at Sandpit Wood, Fordwich. The stratigraphy, described by Smith (1933), recorded the gravel varying from 7 ft (2 m) at the eastern end to 20 ft (6.5 m) at the western end of the pit. The gravel was seen to overlie Paleogene bedrock at about 130 ft (40 m) O.D., the horizon in contact with the basal gravel probably lying near the junction of the Thanet and Woolwich Formations. It is composed mainly of flint, derived from the Paleocene and Eocene deposits, as well as from the Lenham Formation (Bridgland et al., 1998b). Smith (1933) noted that the gravel also contained ironstone, probably also derived from the Lenham Formation. Wooldridge (in Smith, 1933) described the deposit as not well bedded, yet clearly water-lain. In the lower parts gravel was interstratified with sand. This was in turn superseded by the main mass of gravel which was described as “almost without structure” (Smith, 1933, p. 165). Above the gravel was a unit of markedly current-bedded sand, in turn overlain by a further thin layer of gravel.

Two sections were excavated in November 1997 (Fig. 25) which provided exposures through about 5 m of the deposits, although the underlying bedrock was not reached. The sands and gravels showed clear evidence of bedding with mainly sandy matrix-supported gravels, containing lenses of sand, silt and even clay. The finer-grained sediments showed mainly sub-horizontal bedding, giving little indication of palaeocurrent direction (Bridgland et al., 1998b). The upper boundary of the sands and gravels lay at about 47.1 m O.D. in Section 2 where it was overlain by just over a metre of brickearth.

Further new excavations were initiated at the site in 2020, the first season of which was reported by Key et al. (2022). Further results are yet to be published at the time of writing. They report dating results and artefacts found in two adjacent 1 × 1 m trenches dug into a portion of preserved gravel terrace on the edge of the west quarry and also one of Bridgland et al.'s (1998b) sections, which was reopened during the excavation (Fig. 26). The new locations are *c.* 100 m north and *c.* 30 m east of the Bridgland et al. (1998b) sections and chosen because historical evidence suggested that most handaxe artefacts were found in this location. Other artefacts reported were recovered through *ad hoc* field walking, or from surface finds in the immediate vicinity of the two trenches. This paper provides the most detailed description of the sedimentary sequence at Fordwich Pit yet and describes two clear stratigraphic levels in each new trench. The upper level is composed of topsoil intermixed with fine sand and flint gravel with a thin band of loose gravel and organic matter at the base. Smith's ‘main gravel mass’ is spatially variable, presenting differently in each section. In the two new trenches (Fig. 26), Key et al. (2022) found no evidence of Smith's (1933) overlying clear band of sand, nor the upper thinner layer of gravel and loam, although these were observed in Bridgland et al.'s (1998b) sections. Key et al. (2022) ascribe this observation either to lateral facies variation or to a reduction in the depth of the gravel from east to west and these upper deposits being cut out. Beneath this upper layer is the ‘main gravel mass’ which is again thicker at the location of the 1998 sections, which were further east within the west quarry. Key et al. (2022) split the main gravel as follows:

- ‘upper main gravel’, *c.* 50 to 80 cm thick with several sand lenses
- ‘intermediate coarse flint layer’, *c.* 30 cm thick, flint gravel regularly reaches 10–15 cm maximum diameter, with sand lenses
- ‘middle sands’, *c.* 10 cm thick, possibly equivalent to the sand beds previously observed near the base of the sequence
- ‘lower main gravel’, *c.* 70 cm thick, flints typically 1 to 7 cm in diameter and supported in a cemented matrix of fine-grained clasts containing iron.

Key et al.'s (2022) initial interpretation is that these gravels were laid down within a braided river system, accounting for the lateral facies variability, the lack of clays and silts and the presence of bedding structures, although it can be seen in Fig. 26 that the channel structures are not as well defined in the new sections as in Bridgland et al.'s (1998b) original section.

Infrared-radiofluorescence (IR-RF) dating from multiple samples taken throughout the depth of the sequence by Key et al. (2022) is interpreted as comprising three age clusters. Two clusters are located in the recent 2020 excavation, with a collated age of *c.* 372 ± 7 ka for the upper main gravel and intermediate coarse flints (correlated with MIS 11/10); and *c.* 542 ± 30 ka in the middle sands (correlated with MIS 14) (ages from specific samples not given). The samples from Bridgland et al.'s (1998b) section returned age estimates of *c.* 379 ± 21 and *c.* 455 ± 24 ka for the upper sand layer and loam, and a date of *c.* 433 ± 23 ka for the middle sand layer.

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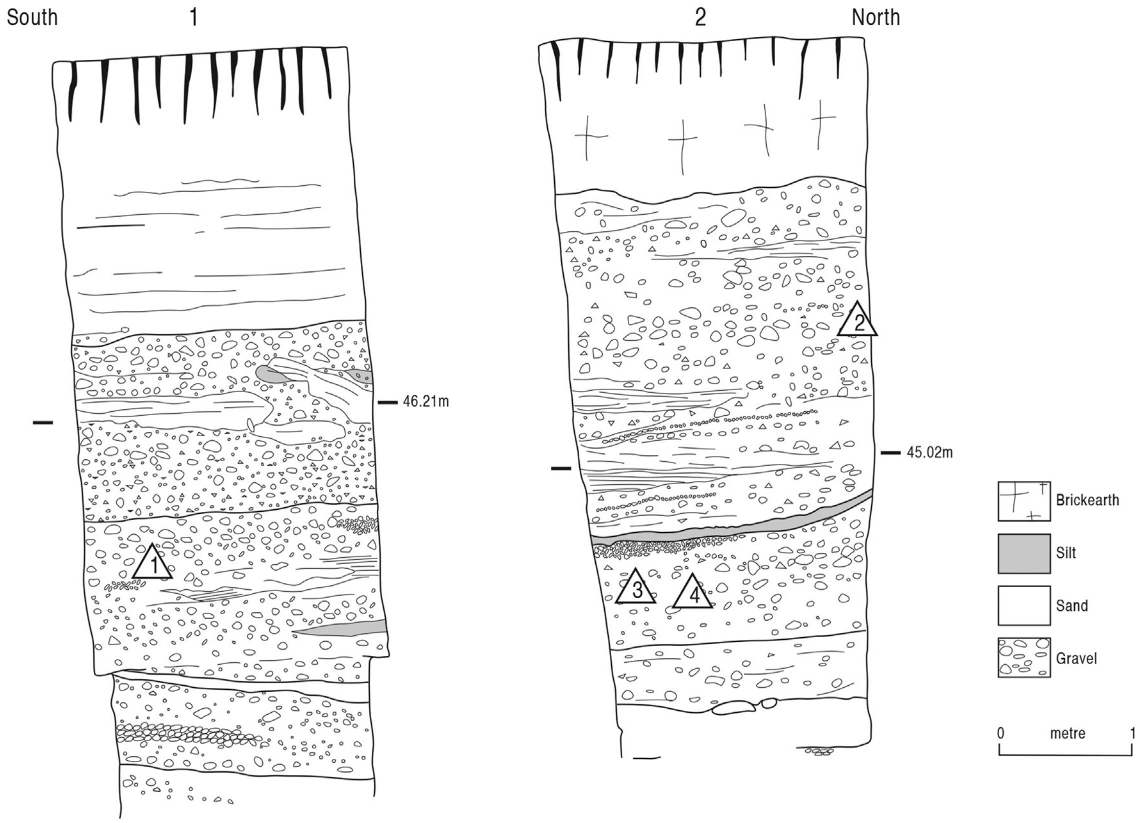

Fig. 25. Sections at Fordwich Pit (TR179587) in November 1997, showing locations of the 4 artefact finds. The sections were located at each end of a single east-facing quarry — no further location details are given.
After Bridgland et al. (1998b, Figure 3.3).

The historically reported biface assemblage is dominated by crude, thick, narrow, pear-shaped forms of limited technological sophistication, variously termed Chellean, Abbevillian or Early Acheulian (Smith, 1933; Roe, 1968b, 1981; White, 1998a). The largest palaeolith assemblage is the collection made by Dr Bowes, in which Smith identified Clactonian (five cores, three scrapers, numerous large flakes), St Acheul type handaxes (n = 67) and crude 'pear-shaped handaxes of the peculiar Fordwich facies' (n = 288, 267 unrolled) (Smith, 1933; Roe, 1968b, 1981; White, 1998a; Knowles et al., 2024). Through investigation of historic letters and notes, Key et al. (2022) argue that the majority of the artefacts previously recovered come from the lower main gravel and thus the 330 handaxes recovered from Fordwich during the 1920s are likely older than approximately the *c.* 542 ka age estimate from the middle sands, most plausibly relating to the MIS 15 interglacial.

A further *c.* 1000 lithics were extracted during Key et al.'s (2022) excavation, of which 251 were identified artefacts, but none handaxes. Whilst present throughout the sequence, artefacts were most abundant

Fig. 26. Sections reported from Fordwich in Figure 3 of Key et al. (2022). The section on the left was newly opened in 2020 whilst that on the right reopened a section from Bridgland et al. (1998b), also in 2020. Scales are different, with the sequence to the right approximately three times as deep as that on the left. Yellow circles indicate the location of the IR-RF age estimates reported.

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in the upper main gravel (n = 113, 45.0 %) and lower main gravel (n = 112, 44.6), with a concentration within the lower main gravel at *c.* 110–120 cm depth (n = 31, 12.4 %). Of these 251 artefacts, 238 were flakes and flake fragments, four were cores and the rest potentially retouched artefacts: three scrapers, one double-pointed implement, and two notched flakes. Key et al. (2022) argue that the flakes reported are consistent with having been detached during the manufacture of 'crude' minimally flaked handaxes, as is generally suggested for the Fordwich bifaces, although not all, with some displaying evidence of extended reduction sequences. The presence of scrapers below a *c.* 542 ka dated sand layer is argued by Key et al. (2022) to make them among the oldest known scrapers in Britain.

In addition, Knowles (2023b) shows that the artefact bearing sediments on the Fordwich plateau are more widespread than previously thought, including a previously unrecognised former gravel pit at Moat Rough yielding a crude handaxe of the 'Fordwich pear' type within a deep (5 m) sequence at *c.* 42 m O.D., including fluvial sands with ripple laminations, coarse gravels and two distinct clay bands. In addition, GIS mapping of the various terrace deposits of the Great and Lesser Stour may suggest that the interfluve of these two rivers migrated eastwards since the Middle Pleistocene and may in the past have been at the Fordwich Pit site (Knowles, unpublished data).

4.1.3. Interpretation

The sedimentology described by Key et al. (2022), Bridgland et al. (1998b) and earlier workers clearly suggests a fluvial origin for these deposits, likely in a braided form. There is no evidence of periglacial modification of these sediments.

Whilst still somewhat enigmatic, the handaxe assemblages discovered from Fordwich Pit are important because it is possible that they comprise the earliest evidence of human presence in the Stour. The analysis of Knowles et al. (2024) shows that the sequence contains two groups of handaxes — both crude pick handaxes and more refined ovates of the Boxgrove type. The co-occurrence of these two handaxe types has previously been reported from the Silchester Gravel of the Kennet (Roe, 1981), the 'Ancient Channel Gravel' of the Middle Thames (Wymer, 1961, 1968), both attributed to the Anglian Black Park Terrace (Bridgland, 1994), and the enigmatic gravels at Warren Hill, Mildenhall, now attributed to the Bytham River (Hardaker, 2012); in all cases the Boxgrove type, belonging to Roe's (1968b) Group VII are in fresher condition, suggestive of a younger age (White et al., 2018). More recently, work on the Bytham sequence in Suffolk has confirmed this supposition and demonstrated that there is a higher and older 'Timworth Terrace', dated to MIS 14, in which only the Roe Group V ('cruder') handaxes occur, suggesting that they represent occupation during MIS 15 (Davis et al., 2021b; Lewis et al., 2021). This Timworth Terrace would thus seem to be a prime candidate for correlation with the gravels yielding 'Early Acheulian' artefacts at Fordwich.

It is possible that there were multiple occupation phases at the Fordwich site. This interpretation seems to be supported by new age estimates from the site. The deposits at the western and northern edges of the Fordwich Pit have now been dated directly by infrared-radiofluorescence (IR-RF) dating of feldspar giving dates that span from *c.* 570 ka to *c.* 350 ka (Key et al., 2022). Further work is in progress at the site by Key that will add additional data in future. They are older than the Sturry and Chislet sequences and the significance of the relationship between the handaxe industries at Fordwich and those at Sturry Gravel Pits is discussed in detail below in relation to Sturry Gravel Pits.

4.1.4. Conclusion

This site exposes gravels of a high terrace of the Kentish Stour. The gravel here has yielded a rich Acheulian industry of primitive type and seems likely to represent a rare example of the Early Acheulian in Britain. It compares with the Middle Acheulian site in a lower terrace at nearby Sturry Gravel Pits. There is direct evidence available for the age of the sediments here although relating the previously collected Palaeolithic artefacts to their correct stratigraphic locations requires further work. It is now evident that the sequence at Fordwich is pre-Anglian and probably represents at least two occupation phases of early hominins during MIS 15 and 13. The dating of this site may help clarify the chronologies of the other GCR sites in this network at Bishopstone to Reculver Cliffs, Sturry Gravel Pits and Wear Farm Pits, Chislet. Assigning the Fordwich gravels and their Early Acheulian industry to their correct position in the Thames chronology is one of the key requirements for the formation of a convincing Palaeolithic stratigraphy in the London Basin. The Fordwich Pit is, therefore, of considerable importance and worthy of further detailed study to further understand the evolution of the pre-Anglian Stour.

4.2. GCR Number 1171 Sturry Gravel Pits (TR 174 607) (BAH, RMB, PGK)

4.2.1. Introduction

Like Fordwich Pit, the fluviatile gravels at Sturry Gravel Pits overlie the Thanet Formation, although they are at a lower altitude and occupy a west–east trending channel cut into the Paleogene deposits. The Sturry Gravel Pits have also been a prolific source of Palaeolithic artefacts, mostly of Acheulian and Mousterian type. The site's importance lies in its stratigraphical position within the Stour terrace sequence intermediate between Fordwich Pit and Wear Farm, Chislet and the fact that the lithic assemblage may reflect later, more refined, Acheulian and Mousterian traditions with a putative Levallois component. The British Museum excavations of 1921–3 constitute the first systematic research at the site (Dewey and Smith, 1925; Dewey et al., 1925; Dewey, 1926; Smith, 1926) with later contributions by Roe (1968a, 1977, 1981), Holmes (1981) and Wymer (1999). In October 1997 three new sections (TR 1758 6077, TR 1762 6079, TR 1767 6080) were excavated (Figs. 27 and 28; Bridgland et al., 1998c).

4.2.2. Description

During the early 1920s the gravels at Sturry Gravel Pits were worked by several contractors, each giving their name to a pit. Dewey and Smith concentrated their research between 1921 and 1923 at Homersham's West Pit (TR 176 607) which lay directly to the east of the Sturry to Herne Bay Road and today forms part of the GCR site (Dewey and Smith, 1925; Dewey et al., 1925). Local antiquarian Dr A. G. Ince mapped in detail the sections and the precise location of each artefact discovered as the quarry face was worked backwards. At the time it was commented that "no other pit in England has ever been so carefully watched or so systematically mapped" (Dewey et al., 1925, p. 280). Ince's original records, giving details of the location and height above bedrock of many of the artefacts, were rediscovered in the early 2000s by staff of the Canterbury Archaeological Trust (Bridgland et al., 1998c) then subsequently lost again. After exhaustive searches they were recently located in the archives of Canterbury Museum where the original copies are now archived. Other finds from Sturry Gravel Pits and surrounding area have been reported by Bowes (1928) and Anon. (1929). The gravels in the Sturry area are largely unfossiliferous with the exception of a fragment of elephant tusk from a pit in Hoades Wood, about 1 km north-east of Homersham's West Pit (Dewey and Smith, 1925).

The deposits at Homersham's West Pit occupy a west to east trending channel cut into the Thanet Formation, the latter rising in the northern and southern parts of the pit (Dewey et al., 1925; Dewey and Smith, 1925). Dewey and Smith (1925) reported about 30 ft (10 m) of fluvial deposits overlying the Thanet Formation with the contact being just below 70 ft (22 m) O.D. They described a basal red matrix-supported clay and gravel up to 3 ft (0.9 m) thick, often succeeded by a black band of manganese staining. This in turn was succeeded by current-bedded sands and gravels and then by a variable thickness of brickearth.

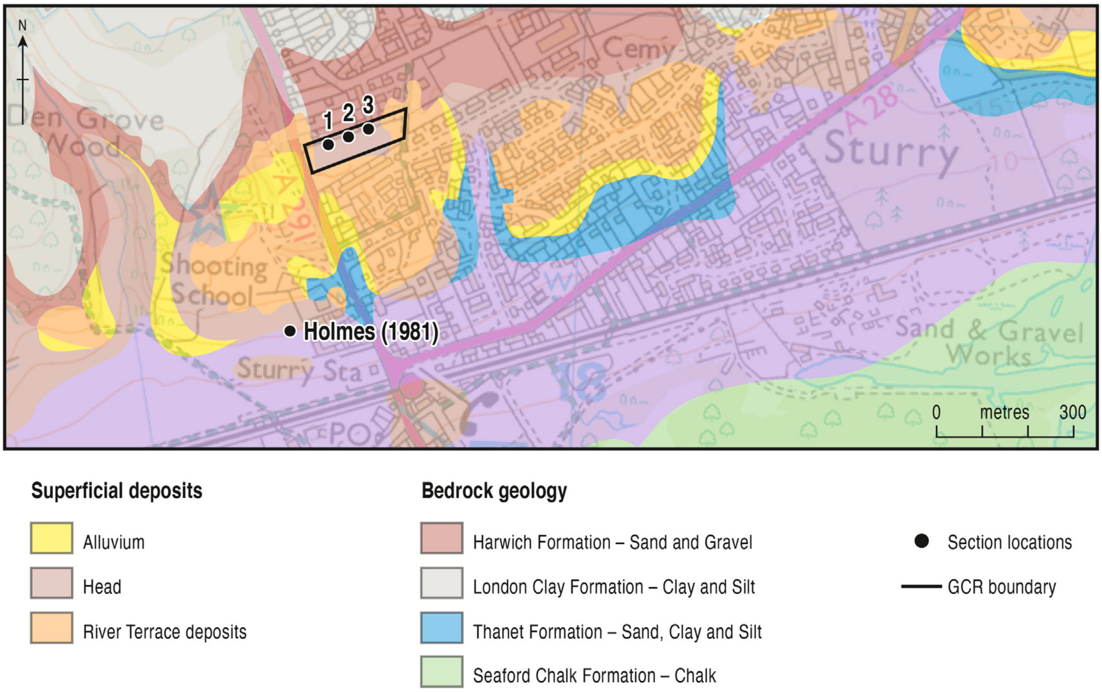

Fig. 27. Location and geology of the sections at Sturry Gravel Pits described by Holmes (1981) and Bridgland et al. (1998c): 1 situated at TR 1758 6077, 2 situated at TR 1762 6079, 3 situated at TR 1767 6080). Map contains geological data available under an Open Government licence from the British Geological Survey © UKRI [2024].

The sands and gravels contained evidence of periglacial processes at the time of their deposition in the form of rafts of unconsolidated laminated (Paleogene) sand (Dewey and Smith, 1925; Smith, 1926; Dewey, 1926; Breuil, 1934). Breuil described detailed sections from the School Pit (worked by Brett) on the west side of the A291. He referred to the blocks of unconsolidated sand as 'raft(s) de sable

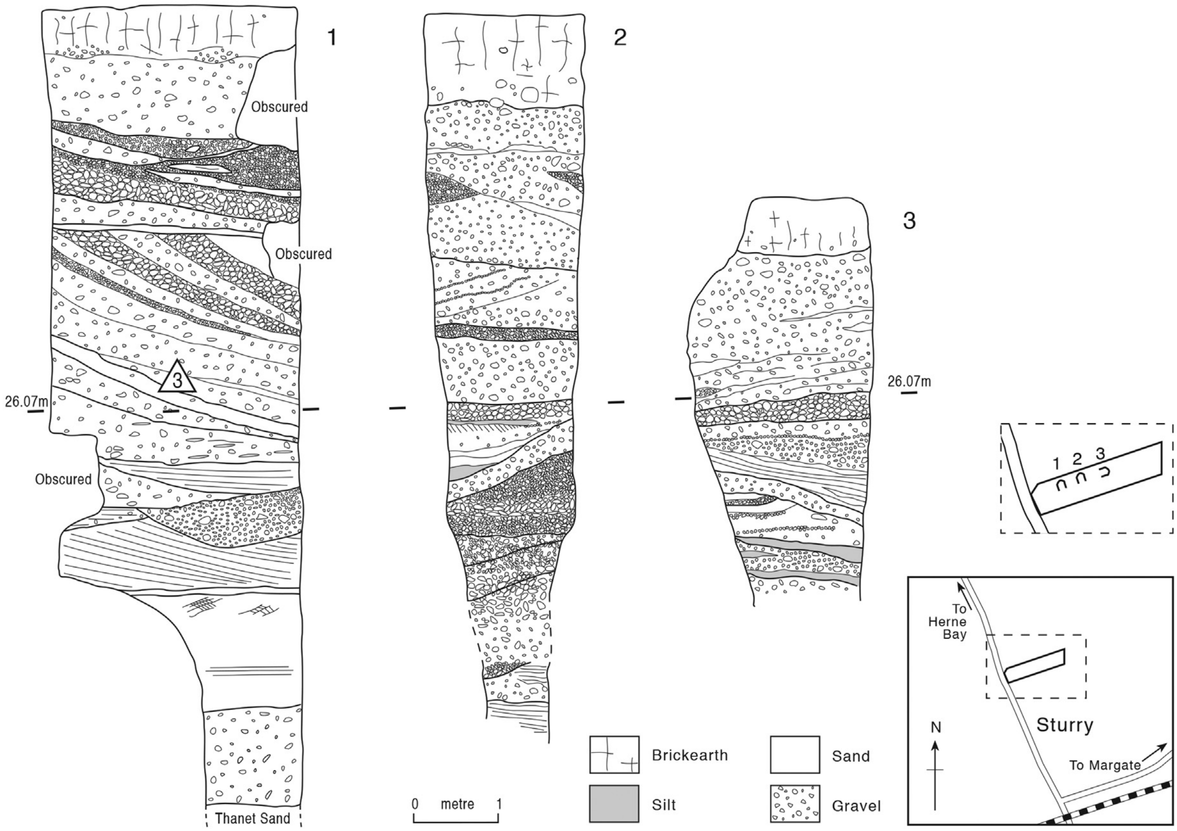

Fig. 28. Sections at Sturry in October 1997 — locations shown in Figure 26. The relative size and packing of gravel clasts are shown by the application of the gravel ornament. (After Bridgland et al. (1998c, Fig. 3.4).)

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tertaire glissé' suggesting they were emplaced by the river whilst still frozen and also suggested all the gravels in each section had been formed by periglacial processes, with additional periods of solifluction activity. This interpretation, in particular the recognition of multiple periglacial episodes and their correlation with continental equivalents, was considered unsubstantiated by Holmes (1981).

Holmes (1981) described a section recorded after the Second World War (TR 1756 6051, Fig. 27) in the pit on the west side of the A291, which showed 3.7 m of cross-bedded gravel and sand overlying the Woolwich Formation. These gave way to 2.1 m of buff-coloured sand with subsidiary gravel, 2.4 m of orange–brown sands, silts and clays and finally 4.3 m of brown head–brickearth.

Three new sections were excavated during October 1997 to the east of the A291 (1 — TR 1758 6077, 2 — TR 1762 6079, 3 — TR 1767 6080; Figs. 27 and 28), although only two of these exposed the full thickness of the fluvial deposits (Bridgland et al., 1998c). The Sturry Gravel Pits gravels generally contain less sand than at Fordwich Pit, with most of the sequence comprising loose, open-framework gravel. The new exposures revealed variable gravels up to 9 m thick overlying Thanet Formation at about 21.3 m O.D. in Section 1. The gravel is variously sandy and matrix-supported, or loose and matrix-free, this latter often manganese-stained. Several of the gravel beds show large-scale cross bedding. Finer units of sand and silt are interbedded with the gravels, which also exhibit cross bedding, together with sub-horizontal bedding and ripple lamination. The sections confirm most aspects of Dewey and Smith's descriptions, but neither the black manganese-stained layer overlying the basal gravel nor the derived rafts of unconsolidated laminated (Paleogene) sand were observed (Bridgland et al., 1998c). The western two sections opened in 1997 are no longer available for inspection, having been entombed in casements in 2023 to shore up the pit face from collapse and protect the adjacent properties.

The artefacts recovered from Sturry Gravel Pits represent refined Acheulian and Mousterian industries with a putative Levallois component. Dewey and Smith (1925) divided the sequence into three distinct cultural zones, unrelated to specific divisions in the sedimentary sequence: a basal Saint Acheul (Acheulean) zone, overlain by a Le Moustier (Mousterian) Zone containing a small but significant element which they assigned to the Levallois, with a zone of Chellean artefacts presumably reworked from older higher terraces present in the uppermost deposits. Whilst most of the Sturry handaxes are different from those found in higher deposits, some 'Fordwich-type' handaxes are found within the Sturry terrace gravels, either in worn condition in the uppermost deposits or in fresh condition within the blocks of sediment considered to have been 'rafted' in a frozen state from higher terraces (Dewey and Smith, 1925; White, 1998a).

Initial reassessment of the artefact sequence (Knowles, unpublished data) suggests that artefacts from the highest unit are all rolled or very rolled, and contain pointed types, often with cortex and cruder types. The middle zone (previously named Mousterian) and lower zone predominantly contain small cordate handaxes that are more finely worked, without cortex, they are generally fresh or in a slightly rolled condition. The middle zone also contains a significant proportion of small twisted ovates, which are all likely contemporary with the sediments in which they were recovered. Chronologically, twisted ovate handaxes may suggest an age of MIS 11a, by comparison with other sites in north Kent (White et al., 2019). The Sturry assemblage is not large enough or from a sufficiently secure archaeological context to accurately characterise the flake tools previously noted as Levallois (White et al., 2024).

4.2.3. Interpretation

The sedimentology described by Bridgland et al. (1998c) and earlier workers clearly suggests a fluvial origin for these deposits, likely in a braided form. The 'rafts' of unconsolidated sediments may suggest some frozen ground during deposition, although there is no evidence of periglacial modification of these sediments.

Roe (1981) used the distinction between the Fordwich Pit and Sturry Gravel Pits assemblages to underpin a model of cultural evolution for the British Isles. However, such typological distinctions were regarded with caution after the discovery of well-made Acheulian handaxes at earlier pre-Anglian sites such as Boxgrove (Roberts and Parfitt, 1999), High Lodge (Ashton et al., 1992) and Warren Hill (Wymer et al., 1991).

It was previously argued that the variation in biface technology and typology at Sturry merely reflected the size, shape and quality of the available raw materials (White, 1995, 1996, 1998a, 1998b). White (1996, 1998a) argued that the use of poor-quality flint at Fordwich Pit severely restricted the options open to biface-making hominids and that the nature of the Fordwich Pit bifaces merely reflects an adaptive response to difficult raw material rather than having a temporal or cultural significance. Ace (2000) carried out experimental flint knapping on raw material from the November 1997 excavations at Fordwich Pit to try to settle the debate. He concluded the poor quality elongate, sub-cylindrical 'burrow' flint nodules did indeed impose conditions on the final form of the handaxe because of the increased probability of end-shock when using traditional secondary thinning/shaping techniques. However, more recent work (Bridgland and White, 2014, 2015) is now increasingly suggesting that artefact assemblages carry chronological significance and might relate to the cultural preferences of different human groups over time, an interpretation previously abandoned. This interpretation is based on biostratigraphy and geochronology in the Lower Thames (Bridgland, 1994; White et al., 2018).

The deposits at Sturry Gravel Pits have not been dated directly and their age is therefore not known robustly. Holmes (1981) considered the Sturry gravels to be part of the 3rd Terrace of the Stour and of Ipswichian age (MIS 5e). This attribution arose from a chronostratigraphy of the Faversham area built up by Holmes based largely on the differentiation of the various head deposits and their ascription to distinct phases of solifluction. Despite equating the Sturry gravels to the Ipswichian, Holmes (1981) elsewhere inferred that the 3rd Terrace of the Stour within which it sits might relate to the Boyn Hill Terrace of the Thames, which is now attributed to MIS 12/11/10 (Bridgland, 1994, 2006).

Bridgland (1996) suggested that the presence of the putative Levallois assemblage at Sturry Gravel Pits can be used as a temporal marker in the British Quaternary, arguing that its first use occurred in the Thames Valley near the MIS 9/8 boundary, some 300,000 years ago at Purfleet (Schreve et al., 2002). Following Bridgland's (2000) model of terrace development aggradation, an age range of MIS 10, 9 and 8 was thus suggested for the Sturry Gravel Pit deposits (Bridgland et al., 1998e). Using the uplift model of Maddy (1997) the height of the terraces above the level of the present river was used to calculate an age estimate. Using a suggested uplift rate of '7 cm per thousand years' (Preece et al. 1990; Bowen, 1994; Maddy, 1997), the ages for the terrace surfaces at Fordwich Pit (46 m), Sturry Gravel Pits (30 m) and Wear Farm, Chislet (*c.*, 10 m) were suggested to be 650 ka, 410 ka and 140 respectively (Bridgland et al., 1998e). Recent IR-RF dating at Fordwich Pit (Key et al., 2022; Section 4.1) corroborates a pre-Anglian age for these deposits (MIS 15 and MIS 13). This might suggest that Sturry Gravel Pits is an immediately post-Anglian aggradation, perhaps MIS 12/11/10, and Wear Farm Pit, Chislet a post MIS 7 aggradation. Following recent reanalysis of putative Levallois flakes at Purfleet, the relationship between such flake artefacts (as found at Sturry) and an MIS 9 age has been called into doubt where no cores are preserved (White et al., 2024). This recent suggestion would back up an older age for the sequences at Sturry Gravel Pits. New AAR results from Wear Farm Pit, Chislet also likely suggested a later age for the Sturry Gravel Pits deposits closer to the Anglian Stage (Kent County Council, 2015; Wenban-Smith, 2015). The implications of this for the terrace stratigraphy are discussed below in relation to Wear Farm Pits, Chislet.

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4.2.4. Conclusion

The Pleistocene gravels of Sturry Gravel Pits, which belong to the 3rd Terrace of the Kentish Stour, have yielded numerous Middle Acheulian handaxes and a putative Levallois component. They provide an important comparison with the Early Acheulian industry from the nearby, and higher, Fordwich Pit gravel. The interpretation of these two industries is critical for the development of Palaeolithic and Pleistocene terrace chronologies in the Thames Basin. There is no direct evidence available for the age of this sequence, with currently suggested ages of immediately pre-Anglian or slightly later very dependent on the ages assigned to the other GCR sites in this network at Sturry Gravel Pits and Wear Farm Pit, Chislet. Further work will be required before the true relationship between the Sturry gravels and the Thames terrace sequence can be established, and the remaining deposits and exposures at Sturry Gravel Pits are therefore of considerable geological significance and would be an ideal location for application of new dating techniques when these become available.

4.3. Provisional GCR Site Wear Farm Pit, Chislet (TR 224650) (BAH, RMB, DCS, FFWS, PGK)

4.3.1. Introduction

The deposits and fossils from Wear Farm Pit, Chislet were first described by Prestwich (1855). Apart from a passing reference in Kennard and Woodward (1901) no further work was carried out at the site until it was rediscovered in 1997 (Bridgland et al., 1998d; Figs. 29 and 30) and then further work was carried out in 2103 and 2014 for the Stour Basin Palaeolithic Project (Wenban-Smith et al., 2015). The importance of the site lies in its stratigraphical position within the Stour terrace system and its rich molluscan and vertebrate assemblages which may aid the building of a chronology.

4.3.2. Description

Prestwich (1855) was the first to describe a sequence of fossiliferous beds exposed in two pits at Wear Farm, Chislet. He described shell-bearing sands, gravels and brickearth overlying chalk. The sands included both freshwater and marine taxa, among which was *Corbicula fluminalis* (Bridgland et al., 1998d). Later another section was opened up by Dowker (1864). Kennard and Woodward (1901) included the site in their survey of the post-Pliocene non-marine mollusca of southern England and Evans (1872) commented on the importance of the site, but both added little to Prestwich's account. Bridgland et al. (1998d) reported the rediscovery of one of the pits described by Prestwich near to the former location of Wear Farm (Fig. 29). They excavated three sections in the edge of the disused quarry and a temporary excavation was undertaken about 3 m from Section 1 in an adjacent field (Fig. 30).

The sands and gravels at Wear Farm Pit, Chislet, within the GCR site boundary, overlie rubbly chalk, probably coombe rock and are in turn overlain by brickearth (Fig. 30). In Section 1 a channel some 3.5 m wide and 1.8 m deep was noted incised into the coombe rock. It, and several smaller examples, was filled with a coarse loamy gravel up to 3.8 m thick, attaining an altitude of about 10.4 m O.D. The gravel thickens westwards and is interbedded with well-bedded silty sands. The sediments are sporadically shelly, the greatest concentration being from a lens of shelly gravel immediately beneath the brickearth in Section 1. The brickearth here is a poorly bedded sandy loam containing shell fragments and secondary 'race' nodules, reprecipitated calcium carbonate clasts perhaps indicative of desiccation. In Section 2, however, the brickearth is clearly water-lain and is interbedded with gravel. A solitary struck flake was recovered from the fossiliferous silt in Section 2, at around 6.5 m O.D. (White, 1998a).

Analyses of material collected in 1997 from shelly horizons confirmed all the species recorded by Prestwich (1855) and Kennard and Woodward (1901), and greatly extended the molluscan list. The shelly gravel in Section 1 was dominated by the freshwater species *Valvata piscinalis* and *Bithynia tentaculata*, with *Corbicula fluminalis* also present but in low numbers. The vast majority of species in this deposit are from fluvial environments suggesting that deposition was in a medium-sized river with moderate flow rates (Keen, 1998). Land shells are far less in number, yet 14 taxa were recorded. The occurrence of the Hydrobidiiae may suggest the presence of brackish environments but their small number and very corroded condition suggest caution should be exercised with this interpretation (Keen, 1998). The poorly bedded sandy loam 'brickearth' in Section 1 contained 55 corroded and broken shells from 8 taxa. Of these 44 were of *Pupilla muscorum* suggesting a grassland environment. There were four freshwater species recorded but they were extremely weathered (Keen, 1998).

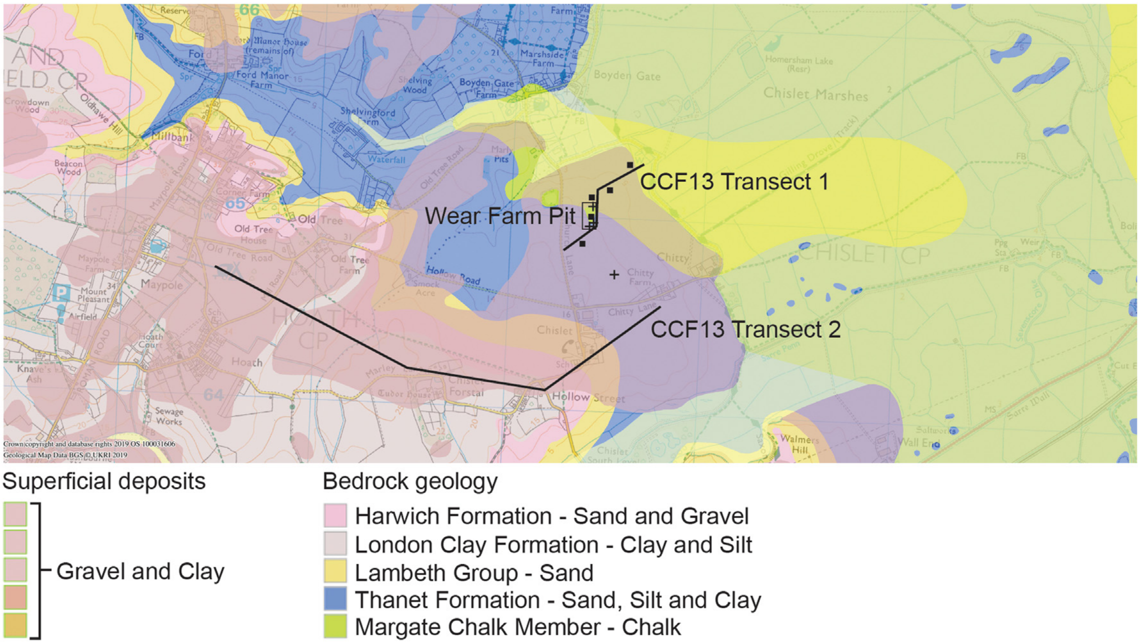

Fig. 29. Location and geology of the sections at Wear Farm Pit, Chislet as crosses (Bridgland et al. (1998d) and test pits at Court Farm, Chislet as filled squares, also two test pit transects (Kent County Council, 2015; Wenban-Smith, 2015). Map contains geological data available under an Open Government licence from the British Geological Survey © UKRI [2024].

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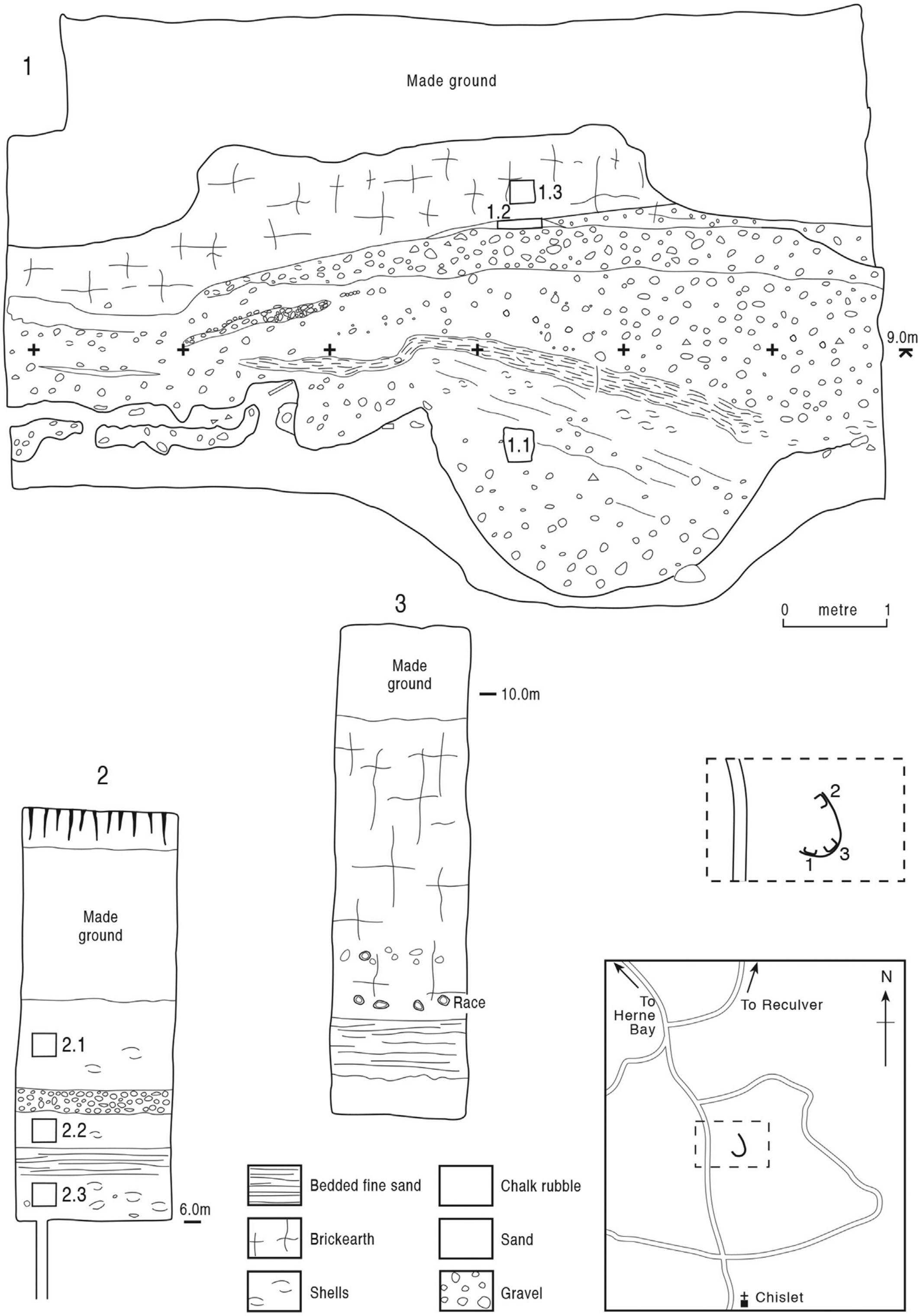

Fig. 30. Sections at Chislet in 1997 — locations shown in Figure 28. The positions of samples taken for both mollusc and vertebrate analyses are indicated. After Bridgland et al. (1998d, Figure 3.5).

In addition to the Mollusca, an important mammalian assemblage was reported for the first time (Bridgland et al., 1998d). The vertebrate assemblage contained three species of mammal no longer native to the British Isles: *Desmana moschata*, the Russian desman, which is today restricted to Russian rivers, *Dicrostonyx torquatus*, the collared lemming, which inhabits maritime Arctic regions and *Microtus oeconomus*, the northern vole. The last is widely distributed throughout the northern tundra and taiga zones of continental Europe, and in the more southerly wooded steppe, stretching from Scandinavia to Siberia (Schreve, 1998a).

A range of habitats is suggested by the microfauna from the 1998 investigations ranging from rough, damp grassland to mature, mixed deciduous woodland. The proximity of a body of water is indicated by *Desmana moschata* and *Arvicola cantiana terrestris*, the water vole, and by fish and amphibian remains. The prevailing climate appears to have been somewhat cooler than at the present day with the presence of *Dicrostonyx torquatus* suggesting seasonal snow cover perhaps similar to that encountered in present-day north-west Russia (Schreve, 1998a).

Further investigations were carried out at Chislet during the Stour Basin Palaeolithic Project (Kent County Council, 2015; Wenban-Smith et al., 2015; Figs. 29 and 31), following two broadly west–east transects across land at Chislet Court Farm, with the aim of contextualising the Wear Farm Pit deposits within an improved dating framework and sub-surface deposit model for river terrace and Head/Brickearth deposits down the side of the Stour valley, supported by palaeoenvironmental information. Test pits were machine-dug along two transects: Transects 1 (0.5 km, within and adjacent to the GCR site) and 2 (2 km, outside the GCR site) (Figs. 29 and 31), with additional geophysical investigation near Transect 1 to create a model of the subsurface deposits. These yielded both palaeoenvironmental and dating samples. All palaeoenvironmental samples came from a group of test pits in the vicinity of the old Wear Farm Pit, *i.e.*, the GCR site.

Vertebrate samples came from a similar altitude within test pits 6 and 22. The remains from TP 6 included fish (vertebra and pike teeth), amphibians (unidentified limb bones) and many voles (field voles, *Microtus oeconomus* and *Microtus arvalis/agrestis*, water vole, *Arvicola* sp. and possibly bank vole *Clethriomymus* sp.), mole (*Talpa europaea*) and a possible bird limb bone. The remains from TP 22 included pike teeth and numerous cyprinid fish remains including tench (*Tinca tinca*), frog/toad limb bones, multiple voles (*Microtus oeconomus*, *Arvicola cantianus* and *Microtus agrestis/arvalis*), pika (*Ochotona* cf. *pusilla*), shrew and wood lemming (*Myopus schisticolor*). Small vertebrate remains were also recovered towards the bottom of test pit 5, between *c.* 5 m and 6 m O.D., including fish, water vole and field vole. All three assemblages are consistent with fluvial deposition and Wenban-Smith et al. (2015) suggest that these deposits represent the same depositional event. The environment reconstructed was a continental climate with very harsh winters and warm summers, thought to be indicative of a warm interstadial within a cold stage.

Mollusc samples from test pits 3, 5, 6, 21 and 22 comprised the same species as previously reported, clearly showing that the *Bithynia tentaculata* opercula used for AAR analyses were deposited *in situ* in a freshwater environment, as does "the presence of some complete bivalves with both shells joined at the hinge" (Kent County Council, 2015, p. 38). The species that are present (clausiliids, *Belgrandia*, *Pisidium* (pea mussels) and *Bithynia* opercula) together seem to suggest fluvial deposition in a temperate environment. Ostracod analysis demonstrated some brackish influence, as previously seen in the presence of hydrobid mollusca. A brackish influence is particularly seen at the base of test pits 3 and 22, but also less strongly in test pit 21.

Four lithic artefacts were recovered during SBPP fieldwork — two flakes and an abraded handaxe (Kent County Council, 2015; Wenban-Smith et al., 2015). None of these are diagnostic of any industry and the handaxe was rolled and found out of context. The two flakes are in fresh condition. One came from TP10, from fluvial deposits at the base of the 1 m terrace bench, and the other from TP5, from sandy fluvial deposits at the base of the 5–6 m bench (associated with the Chislet fossiliferous sequence). Thus they probably represent contemporary hominin presence during formation of these deposits, from MIS 9 and/or an interstadial in the period MIS 10 through to 8. In addition, a Canterbury Archaeological Trust field investigation between 1992 and 1994 in conjunction with construction of the Herne Bay Pipeline through the site (Parfitt, 1996) yielded two handaxes and two struck flint waste flakes near to Church Lane (TR 224 648). One handaxe was

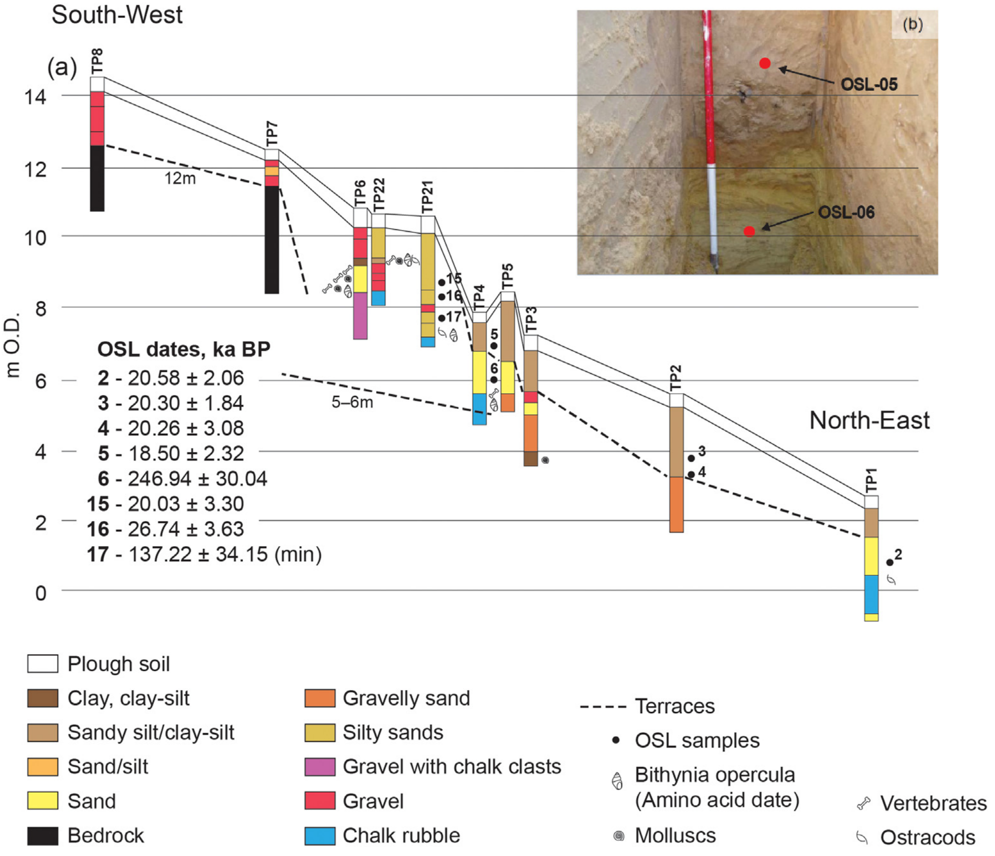

Fig. 31. a) Transect 1 from Court Farm Chislet (CCF13), showing fossil presence and OSL dating of fluvial gravels and brickearth, including b) inset of bedded fluvial sands beneath brickearth in test pit 5. OSL ages yielded are shown.
From Kent County Council (2015), with permission, after Wenban-Smith (2015).

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recorded from coming from the gravels underlying brickearth in a trench at this location, with "two other pieces of struck flint… gleaned from the gravels some distance further north and a second handaxe … recently recovered from an adjacent field" (Parfitt, 1996, p. 25).

OSL dates from the site are largely on the overlying brickearth deposits (Fig. 31). Only three are from the fluvial gravels, and of these two (OSL-17 from test pit 21 in Transect 1 and OSL-10 from test pit 13 in Transect 2) yielded minimum age estimates only because they were nearing saturation. The most robust OSL age estimate from the fluvial gravels is OSL-06 from test pit 5 in Transect 1. This yielded an age of 247 ± 30 ka BP – *c.* 220 to 280 ka BP (Kent County Council, 2015; Wenban-Smith et al., 2015; Fig. 31).

Four AAR samples of *Bithynia tentaculata* opercula came from test pits 5, 6, 21 and 22 (Fig. 31). Kent County Council (2015; Wenban-Smith et al., 2015) placed these into the widely-accepted British AAR framework of Penkman et al. (2011, 2013) and all the samples suggested attribution to MIS 9 (between *c.* 350 and 300 ka BP). Wenban-Smith et al. (2015) concluded, however, that the strong continentality indicated by preliminary small vertebrate analysis suggests that the deposits are associated with an interstadial rather than an interglacial episode. This in turn suggests that the deposits most likely date to the warm episode MIS 9a at the end of MIS 9 (which is sometimes regarded as the first interstadial within MIS 8, labelled as MIS 8.5) or the warm episode MIS 9c in the middle of MIS 9.

4.3.3. Interpretation

The sedimentology of these deposits suggests a fluvial environment of deposition at Chislet. Palaeoenvironmental analyses suggest a broadly temperate climate during deposition, although possibly not a full interglacial. The age of these deposits has been much debated and the recent (Wenban-Smith et al., 2015) AAR and OSL dating, together with new faunal sampling, suggests an age of late MIS 9/early MIS 8, *c.* 250–300 ka BP. This is older than some previously suggested ages for the sequence, and younger than others. Uplift modelling by Bridgland et al. (1998e) was used to suggest an age of MIS 8/7/6. In contrast, the presence within the mammalian assemblage from Chislet of the rare *Desmana moschata* was taken to suggest an age older than MIS 10 because it was previously known only from one post-Anglian temperate episode in Britain, the Hoxnian Interglacial, considered to equate with MIS 11 and never discovered in any younger interglacial deposits (Schreve, 1998b). All these suggested ages are in line with the other biostratigraphical evidence from the presence of the less derived morphotype of *Arvicola cantiana terrestris*, which suggests a pre-MIS 7 age. The presence of *Corbicula fluminalis* also suggests an age of MIS 7 or earlier (Keen, 1998). There is no evidence that the mammalian assemblage from Chislet is reworked. Indeed, the richness of the assemblage and its excellent quality of preservation seem to strongly preclude this, unless large scale rafting of earlier sediments has occurred (Bridgland et al., 1998e). The most likely age, however, is that given by recent dating of late MIS 9/early MIS 8.

The key question to be investigated at Wear Farm Pit, Chislet, therefore, is the existence of relatively old deposits only 10 m above the present river at Chislet. This pushes back the suggested ages of the Sturry Gravel Pits and Fordwich Pit aggradations. Whilst Bridgland et al. (1998e) suggested an age of MIS10–8 for the Sturry Gravel Pits deposits, using the presence of the Levallois assemblage as a temporal marker in the British Quaternary for the MIS 9/8 boundary (Bridgland, 1996), recent research (White et al., 2024) calls this relationship into doubt, making this change of age attribution for Sturry Gravel Pits more plausible than once thought. Alternatively, there has been little scientific study of the Stour terrace sequence since Coleman's (1952, 1954) work. Verification of her separate '100 ft' and Sturry terrace levels, not recognised by earlier workers, is required. It could be that they represent the front and back of the same feature, in which case the more condensed terrace sequence might allow for older deposits such as those at Wear Farm Pit, Chislet to be found near the present valley floor (Bridgland et al., 1998e).

Finally, a younger age for the Wear Farm Pit, Chislet sequence strongly suggests that the previously suggested Last Appearance Datum in the UK for *Desmana moschata* of MIS 11 should be revised.

4.3.4. Conclusion

Terrace sediments of the River Great Stour at Chislet, overlying bedrock chalk, are unique in this important former tributary valley of the Thames[1] in that they contain a wealth of molluscan and vertebrate fossils. They also contain Palaeolithic artefacts, of value in making comparison with other sites in the Stour valley (notably the GCR sites at Fordwich and Sturry), which has an extensive terrace system, and in the wider Thames system. Chislet represents one of the lowest of the Stour terraces but its age is not known equivocally. It is likely to represent one of the more recently recognised late Middle Pleistocene interglacials, probably MIS 9. There is great potential for future investigation of the deposits exposed here, and their fossil and artefact content, with the aim of enhancing chronological knowledge of the Stour and wider Thames terrace sequences.

4.4. Provisional GCR Site Bishopstone to Reculver Cliffs (TR 205 686–TR 222 691) (PGK, DRB, MJW, RMB)

4.4.1. Introduction

Quaternary deposits capping the cliffs between Bishopstone and Reculver represent a series of at least three fluvial channel fills cut into underlying bedrock that represent river terraces of the ancient northward-flowing River Great Stour (Figs. 24 and 25). The cliffs are particularly noteworthy for the abundant and diverse Palaeolithic archaeology that occurs within the higher Stour terrace sediments. The archaeology comprises various Acheulean (handaxe) industries. Recent research indicates that these distinct artefact assemblages can, on the basis of differing handaxe typologies, provide an indication of the age of the river deposits in which they are found; this site therefore has significant potential to contribute to this debate. The highest terrace sediments at Reculver are the 100 ft terrace; archaeology has not yet been securely attributed to this terrace. It seems likely that the next lower terrace (Upper Reculver) sediments date back approximately 400,000 years, because the handaxes they have yielded are similar to those from well-dated sites elsewhere (Swanscombe, Hoxne). The evidence for lithic industries from the lower terrace sediments (Lower Reculver) is less certain, although these are possibly a continuation of the Chislet terrace. There are also Devensian loess deposits preserved at the top of the cliff section near its eastern end.

4.4.2. Description

The combination of earlier mapping (Coleman, 1952; Fig. 24) and modern survey indicates that three separate Stour terraces are represented at the GCR site (Fig. 32), channelled into the Paleogene bedrock for which the cliffs have been previously designated (Herne Bay, GCR 2911). An almost continuous sequence through Paleocene and Lower Eocene strata is exposed in the foreshore and cliffs (Prestwich, 1850, 1852, 1854; Whitaker, 1866, 1872). The Quaternary deposits exposed in the cliff sections fill truncated fluvial channels (Fig. 33).

In the earliest published description Evans (1861, pp. 63–70) observed that "when proceeding eastward from Herne Bay, once the ravine at Old Haven Gap (Bishopstone Glen) is passed the cliffs become nearly vertical, and it is at once apparent that above these beds of the Lower Tertiary period there is a capping of drift, or possibly of two distinct drifts". He described 'a capping of drift' that varied from 5 or 6 ft (2.5–3 m) to as much as 11 or 12 ft (*c.*, 4 m), in some places filling depressions eroded into the surface of the Thanet Formation. Evans (1861, p. 66) then described a section in which the cliffs reached 50 ft

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[1] Having joined the Thames during the last 0.5 million years in the area now offshore from the North Kent coast, the Stour became detached from the Thames during the late Holocene, with a new exit to the English Channel to the SW of the Isle of Thanet.

(15 m) O.D., close to a spot where several implements had been found, with thicknesses as follows: "surface soil and clay 2 feet; blue and grey clay, with angular and sub-angular flints and many Tertiary pebbles 3 feet; reddish-yellow loam, with few angular flints and tertiary pebbles – traces of carbonaceous matter 7 feet; gravel at base, in places coarse 6 inches". His description of the fluvial sequence is not generally applicable to the disparate terrace deposits now recognised, however. The cliff-top exposures generally reveal medium to coarse fluvially bedded gravels channelled into the Paleogene bedrock overlain by fluvial sands and then by variable thicknesses of finer-grained overburden and soil (Fig. 33).

There is a unique representation here, in this important former tributary valley of the Thames, of a preserved sequence of channels forming an eastward-descending staircase of three terraces, declining towards the most recent valley of the Stour (the Wantsum Channel). Coleman's terrace nomenclature has generally been retained, those represented at the GCR site being, in descending sequence, her 100 ft, Upper Reculver and Lower Reculver terraces. Bridgland et al. (1998a, 1998e) used the names Sturry and Chislet for the Upper and Lower Reculver terraces, respectively (Fig. 24), implying correlation with those named sites, described in Sections 4.2 and 4.3. These palaeochannels represent former valley floors from a time when the Great Stour flowed northwards across the area to join the contemporaneous Thames, which would have been at a similarly higher level than its modern valley floor.

Descriptions in the text below are based on archaeological evaluation by Canterbury Archaeological Trust during consolidation and drainage works by Canterbury City Council in response to increased coastal erosion at Bishopstone Glen (Fig. 32; Allen, 2003); a geophysical survey using ground penetrating radar (GPR) (Hatch and Lewis, 2020), core sampling (2021) and test-pitting (2023) by Knowles (unpublished data). The highest sediments, at *c.* 30 m O.D. (100 ft terrace), are part of a wide well-defined terrace, with coarse gravels and sands directly overlying the Eocene London Clay at *c.* 28 m O.D. The GPR survey indicated that the lower channels (below the 100 ft terrace) are northeast-trending (Fig. 7 of Hatch and Lewis, 2020). A test-pit cut in 2023 at *c.* 30.4 m O.D. revealed a sequence of topsoil, solifluction gravel and poorly sorted fluvial gravel with coarse sand lenses overlying the London Clay. This test pit revealed the edge of a channel cutting into brecciated London Clay (Fig. 34B). The channel's long axis aligned southwest to northeast deepened towards the northwest whilst the beds showed a pronounced dip to the north. The eastern section of the test pit revealed homogenous and undisturbed London Clay capped by a loamy soil. There is no physical linkage to the next lower channel, which has been attributed to the Upper Reculver terrace. A trial trench was excavated on the western edge of this channel at *c.* 24.5 m O.D. Further test-pits found that the channel deepens to the east and consists of sands and silts bedded onto a shallow seam of gravel in a sandy clay matrix, emplaced above Eocene Thanet Formation at 20 m O.D. A minor cliff collapse in March 2023 presented a fresh opportunity to observe some of the fluvial gravelly deposits sandwiched between Eocene bedrock sands, at *c.* 20 m O.D. (Fig. 34A), and overlying silts (brickearth). The fluvial sands revealed on the western edge of the channel attributed to the Upper Reculver Terrace contain fresh lithic artefacts, suggesting that they have been deposited in a primary or almost primary context. There are also silts, clays and loams indicative of slow-moving water. A succession of these deposits then continues

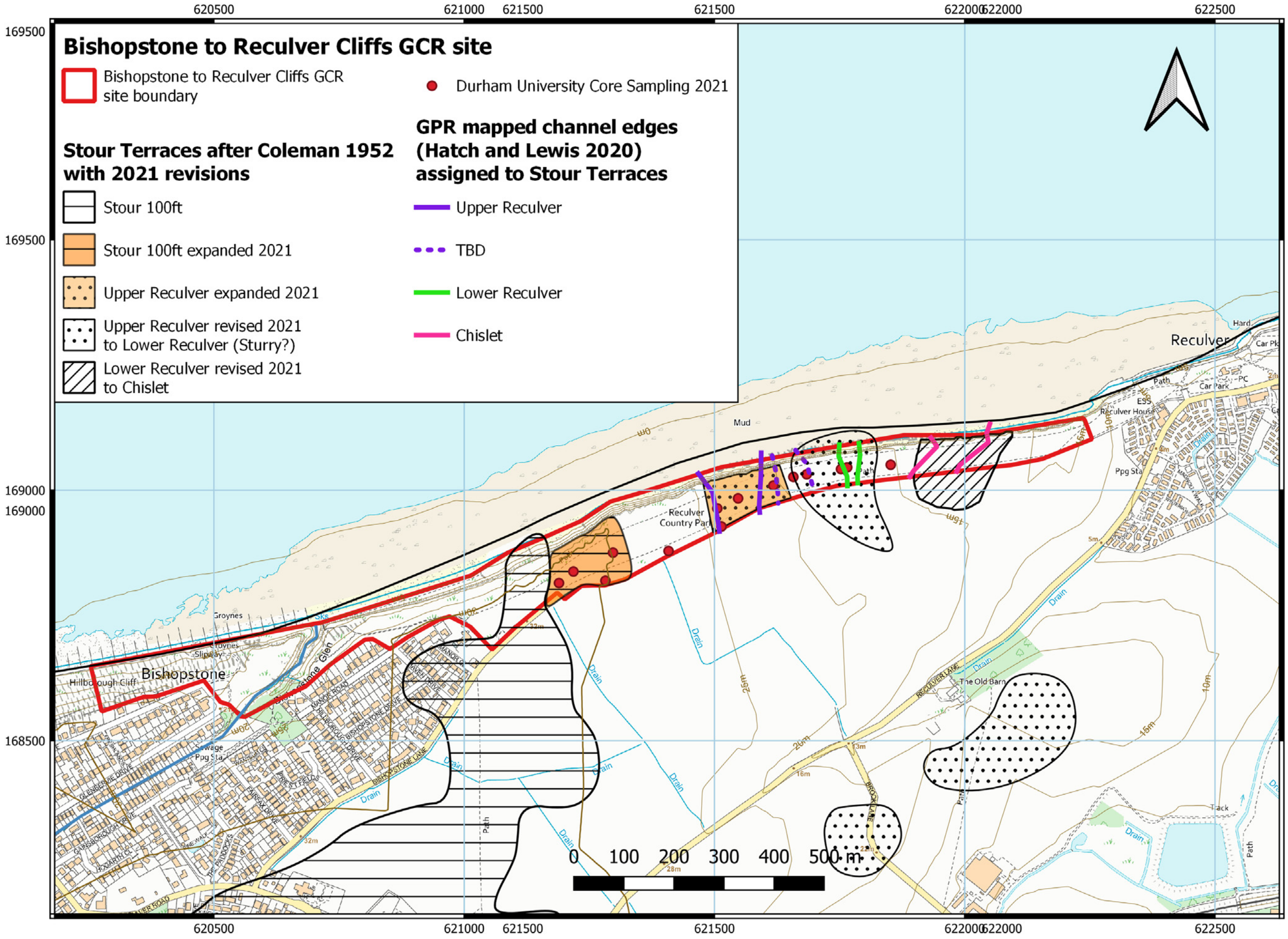

Fig. 32. Location of the Bishopstone to Reculver Cliffs GCR site, showing mapping of terrace remnants (after Coleman, 1952). Basemap: Ordnance Survey (GB) VectorMap® Local.

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Fig. 33. Cliff section between Bishopstone and Reculver (grid reference TR 21604 69042), showing a *c.* 300 m north facing section. The cliff top on the right of the image is *c.* 20 m O.D., showing truncated fluvial palaeo-channels of the Upper Reculver terrace. Channels to the left are at a lower elevation and their correlations with upstream equivalents less clear.

eastward, with at least two other deep filled channels, with base levels at *c.* 17 and *c.* 16 m O.D. In places these lie below *c.* 3–4 m of fine-grained sediments and clay (brickearth). A long-profile projection with a gradient of 0.5–0.7 m km^{-1} suggests that these lower channels correlate with the base of the channel in Homersham's West pit, part of the Sturry Gravel Pits GCR (Section 4.2) 9 km upstream. These lower channels could be assigned to the Lower Reculver/Sturry Terrace. One further lower channel with a base at 5 m O.D. might now be assigned to a lower terrace: the Chislet Terrace.

At the eastern extremity of the site, a shelly silt occurs at the top of the cliffs, here somewhat lower than further west, lying directly on Thanet Formations. A molluscan assemblage from this silt was documented by Preece (1990), comprising *Pupilla muscorum*, *Succinea oblonga*, *Columella columella* and *Trochulus hispidus*; he considered this assemblage to be characteristic of loess (wind-blown silt) and of periglacial conditions. Preece reported thermoluminescence dates from this silt in the range 23–17 ka, placing its accumulation within the Last Glacial Maximum (late Devensian; MIS 2). Although significantly younger than the River Stour deposits that form the primary scientific interest at the GCR site, this well-dated sediment capping provides a useful minimum age constraint of the geological record and is of significant interest in its own right, representing a rare UK occurrence of primary (wind-deposited) loess.

The Stour deposits in the Bishopstone to Reculver Cliffs have produced a significant artefact assemblage consisting of hundreds of handaxes, cores and flakes, mostly collected unsystematically from the base of the cliffs over a 170-year period and invariably catalogued as simply coming from Reculver without recognising the different terrace levels from which they could have come. Specimens continue to be found as fresh material is eroded from the cliff face. More recent provenancing is better because systematic recovery of palaeoliths from the foreshore over the last fifteen years by Knowles has all come from immediately below the western edge of the Upper Reculver channel. The site at Reculver first became important in the 1860s, when a Mr Leech brought handaxes found at the bottom of the cliffs to the attention of Sir Joseph Prestwich (Evans, 1861, 1872, 1897; Prestwich, 1861; Harris et al., 2019) and was pivotal in a debate in the late 19th Century about the antiquity of humanity based on the recognition of stone artefacts in river-terrace deposits (Prestwich, 1861; Lyell, 1863; Evans, 1872; Lubbock, 1890; McNabb, 2012; Bridgland, 2014; Gamble, 2021; White, 2022). Despite this, few (if any) of the earlier reports acknowledge the occurrence of multiple artefact-bearing deposits, nor assign finds to these separately. Similarly, limited study has been made of the handaxe typologies represented, although this forms part of the ongoing research by Knowles previously noted.

4.4.3. Interpretation

There is little doubt that the channel-fill sediments capping the Bishopstone to Reculver Cliffs represent gravel terraces of the River Great Stour, as established by Coleman (1952). The occurrence of multiple river terraces within a single site is extremely rare and is unknown elsewhere in the Thames system, although large quarry workings have sometimes migrated across contiguous terrace outcrops, as with Willington Quarry, Derbyshire, in the Trent valley (Bridgland et al., 2014) and at Dunbridge GCR (Section 2.5, this paper) and cliff sequences such as the GCR site of Solent Cliffs West (Section 2.2, this paper). The juxtaposition of these deposits provides an important opportunity to examine the relationship between the adjacent sediment bodies.

The correlation of the terraces represented in the Bishopstone to Reculver Cliffs with the sequence in the Stour valley around Canterbury and with the wider fluvial record of Southern Britain, as exemplified by the terrace record of the Thames (Bridgland, 1994, 2006) is the subject of current research. In the absence of palaeontological evidence or geochronological data from the fluvial deposits at Bishopstone to Reculver Cliffs, the primary evidence is from terrace stratigraphy, which tentatively suggests MIS 11 and 9, and from the Lower–Middle Palaeolithic artefact assemblages from the gravel bodies. The latter has come to the fore as potential dating evidence in recent years with reappraisal of work on the typological grouping of handaxe forms that was undertaken in the 1960s by Roe (1968a). Bridgland and White (2014, 2015) and White et al. (2018) now argue that these can be interpreted as meaningful in terms of age, at least within the region of SE Britain. There is a substantial Palaeolithic archive from the Bishopstone to Reculver Cliffs (Evans, 1861, 1872, 1897; Brent, 1875; Munro, 1912; Burchell, 1924; Dalton, 1926; Perkins, 1999a, 1999b; Roe, 1968b,

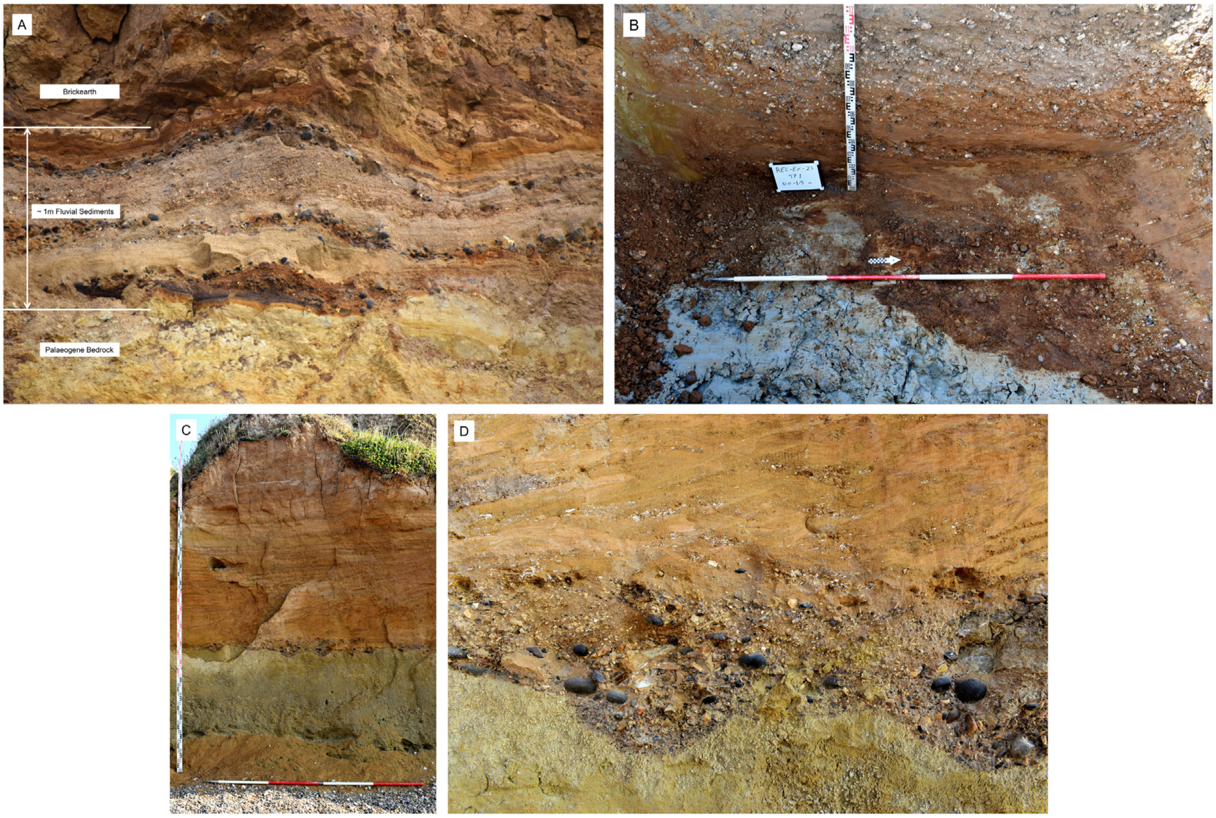

Fig. 34. A. Section of Middle Pleistocene fluvial sediments within the Upper Reculver Terrace at *c.* 20 m O.D. (Stour Upper Reculver Terrace). Photographed using a high magnification DSLR camera from below the cliff (grid reference TR 21542 69030). B. REC-EX-23 Test Pit1 section facing east. Channel running northeast and cutting bedrock London Clay. C. The lowest fluvial sediments visible in the cliff at Reculver are the 'Lower Reculver' (Chislet) terrace, here clearly bedded (with involutions) on the Paleogene sands (grid reference, TR 21998 69103). D. Close up of section in S4 showing, fine grained sands and silts with indeterminate molluscan fragments, gravels with tertiary clasts (*c.* 2–3 cm) and an undulating contact with the underlying Paleogene sands (scale *c.* 50 cm).

1981; Wymer, 1999). In his 1968b survey of British Palaeolithic collections, Roe reported 176 artefacts from Reculver, and 40 from Bishopstone. However, Roe (1968a, 1968b) was not able to assign these to one of his groups, likely because collections catalogued under that name are combinations of material from more than a single terrace, as described above. The substantial Palaeolithic assemblage from the site requires further detailed research.

A sample of 86 handaxes from the British Museum, Seaside Museum (Herne Bay) and the Knowles collection was recently subjected to a limited formal analysis following Roe's (1968a) methodology (P. Knowles and L. Dale, unpublished). The results indicate that the Reculver assemblage is almost certainly mixed but generally falls into Roe's Group II, which is characterised by dominant pointed handaxes with some ovates (Fig. 35). It is noteworthy that Wymer (1999) previously noted a similarity between the Reculver assemblage and material from the Swanscombe Middle Gravels (Swanscombe Skull Site SSSI, GCR, NNR), which have produced a Group II assemblage (Roe, 1968a), dated to MIS 11 at Swanscombe.

4.4.4. Conclusion

The Bishopstone to Reculver Cliffs GCR site is important because there is preservation here of multiple terraces in a single exposure. It is also important due to its historical role in establishing the genuine antiquity of humans, this being one of the first places where such evidence was associated with Quaternary river deposits. In terms of the wider Stour network of GCR sites, it contributes to the understanding of the post-Anglian development of the Stour, within the wider Thames system, by providing evidence of the downstream extent of gravel bodies mapped upstream at Fordwich, Sturry and Wear Farm Pit, Chislet. The Stour network of sites represents human occupation phases from the Pre-Anglian (Fordwich) through to MIS 7 (Chislet). At present, the age of the terrace deposits at Bishopstone to Reculver Cliffs is not known, since there are no absolute age estimates from these sequences. Many of the Palaeolithic artefacts which might be used to suggest relative ages are insufficiently provenanced, but those which have been provenanced to date suggest an MIS 11 age. Further research into these questions is required.

5. GCR Site 1234 The Mole Gap (River Mole, Surrey) (TQ165531 and TQ175516) (CAW, RMB)

5.1. Introduction

The Mole Gap is one of several valleys incised across the chalk outcrop of southeast England. Within the Gap, the River Mole meanders for 7 km between steep chalk slopes of the western North Downs, from Dorking in the south to Leatherhead in the north. A particularly large, steep, right-bank river cliff near the southern end of the Gap, known as 'The Whites', forms one of two separate areas comprising The Mole Gap GCR Site (Fig. 36). The other is Cowslip Bank, a much smaller right-bank river cliff 1.5 km to the north-west, which exposes a rare section in Devensian sediments. Of particular Quaternary interest are the 'Taele' gravel deposits forming periglacial debris fans that have been suggested to be the largest on the chalk. More significantly, The Mole Gap is seen as a classical geomorphological locality because of its swallow holes and associated dry river bed. The dramatic effect of these swallow holes on the discharge of the Mole, such that drainage within The Mole Gap is below the bed of the river during exceptionally dry periods, has been noted for centuries by mapmakers (*e.g.*, Speed, 1610, cited in Dines and Edmunds, 1933), historians (*e.g.*, Brayley,

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Fig. 35. A sample of typical Palaeolithic handaxes from the fluvial sediments in the Bishopstone to Reculver Cliffs. All collected by Knowles on the foreshore immediately below the western edge of the upper Reculver Channel following a cliff section collapse in 2013.

1849, cited in Fagg, 1958), travel writers (*e.g.*, Defoe, 1724, cited in Young, 1915), poets (*e.g.*, Spenser, 1596, cited in Dines and Edmunds, 1933) and geologists (*e.g.*, Topley, 1875). Topley (1875, p. 258) observed that “the Mole passes over some 3.5 miles [of chalk land]; it partially sinks *into* the chalk for a short distance, rising again in powerful springs well charged with bicarbonate of lime”.

Other landforms, in particular terraces, and sediments generally attracted less attention from students of The Mole Gap until the studies in the early 1920s and 1930s of Wooldridge and the Weald Research Committee (Wooldridge and Bull, 1925; Bull et al., 1934), and the Geological Survey (Dines and Edmunds, 1933). These workers were equally concerned to establish a history of landscape development in the area. Wooldridge continued this interest until the late 1950s (Wooldridge and Hutchings, 1957), though subsequent writers (*e.g.*, Docherty, 1969; Gibbard, 1999) have cast doubt on some of his interpretations. Since the 1980s, when Sallnow (1981) and Holmes (1986) rehearsed The Mole Gap issues there has apparently been little additional interest in the geology and geomorphology of the area, perhaps reflecting the limited exposure of critical sediments. It should be noted that swallow holes are not well represented within the existing GCR site boundaries, though a few may occur at the foot of ‘The Whites’ river cliff and some have been mapped in the river adjacent to Cowslip Bank.

5.2. Description

The Mole Gap comprises the short middle section of the River Mole valley, which extends for about 6 km where the river crosses the chalk of the North Downs (Figs. 36 and 37). The slopes of the valley are cut mostly into Upper Chalk Formation, especially in the northern half of the Gap and at higher elevations in the south. The Middle Chalk Formation forms the lower slopes in the southern half of the Gap, and the Lower Chalk Formation extends for about 1 km into the Gap at the base of ‘The Whites’ and its corresponding left bank slope. Its striking morphology has been summarised diagrammatically by Wooldridge and Bull (1925) and Wooldridge and Hutchings, 1957; Fig. 38a). Their figures show a marked break of slope at around 400 ft (121.92 m) O.D., and a slope break at 200 ft (60.96 m) O.D. Bull et al. (1934; p. 44) refer to a “500-foot (152.4 m) peneplain”…now mostly lying between 400 and 500 ft (121.92 m and 152.4 m) above sea-level and about the same height as the top of ‘The Whites’ river cliff. However, detailed cross-sections through the two parts of the GCR site (Figs. 38b and c) indicate that the height of the upper break is far more variable than suggested by Wooldridge and his colleagues, and that the lower change of slope, if it exists at all, also occurs at heights other than 200 ft (60.96 m). Wooldridge and Bull (1925) describe 6 ft (1.88 m) of coarse flint ballast resting on a piped and irregular chalk surface at 200 ft (60.96 m) at Camilla Lacey (*c.*, TQ 162521) as river drift, with the apparent implication that it was deposited by the Mole. Apart from this possible Mole sediment, however, these two surfaces appear to be associated exclusively with bedrock.

Below these high bedrock surfaces a series of terraces occur that are associated with sediments described as ‘river gravels’ (Fig. 36). They are depicted on the Reigate ‘Drift’ map (British Geological Survey sheet E286), which shows extensive ‘low terrace’ remnants occurring on both sides of the river throughout the Gap, and much less extensive ‘high terrace’ remnants.

In the central part of the valley, around the right-bank village of Mickleham, a ‘higher terrace’ (30–50 ft (9.14–15.24 m) above the current river) occurs underlain by ‘river gravels’ (Fig. 36). Smaller fragments of this ‘higher terrace’ can be seen near Vale Lodge, south of Leatherhead, and at Westhumble near the southern end of The Mole Gap. Dines and Edmunds (1933) report 8 ft (2.44 m) of gravel seen near Mickleham, 6 ft (1.83 m) of sand and flinty gravel WSW of Thorncroft and similar material south of Vale Lodge. They also associate the 6 ft (1.83 m) of coarse flint gravel sediments recorded by Wooldridge and Bull (1925) at Camilla Lacey with this ‘higher terrace’ though the latter authors implied that this material was associated with their higher 200 ft (60.96 m) surface. Bull et al. (1934) refer to this ‘terrace’ as the ‘Mickleham Flat’ and record its level as varying from 160 ft (48.77 m) O.D. at Mickleham Church to 175 ft (53.34 m) O.D. where it abuts the chalk valley side. Docherty (1969, p. 25) uses the term ‘Mickleham Terrace’ for the same feature, but describes it as having the morphology of a ‘low asymmetrical cone’ with the surface in places actually sloping *away* (author's italics) from the river. He contrasts this morphology with what he calls ‘typical [river] terrace fragments’, which he considers do not occur in this area. According to Docherty (1969, p. 25) the Mickleham Terrace grades upwards into the floors of tributary valleys and outwards into the Low Terrace of

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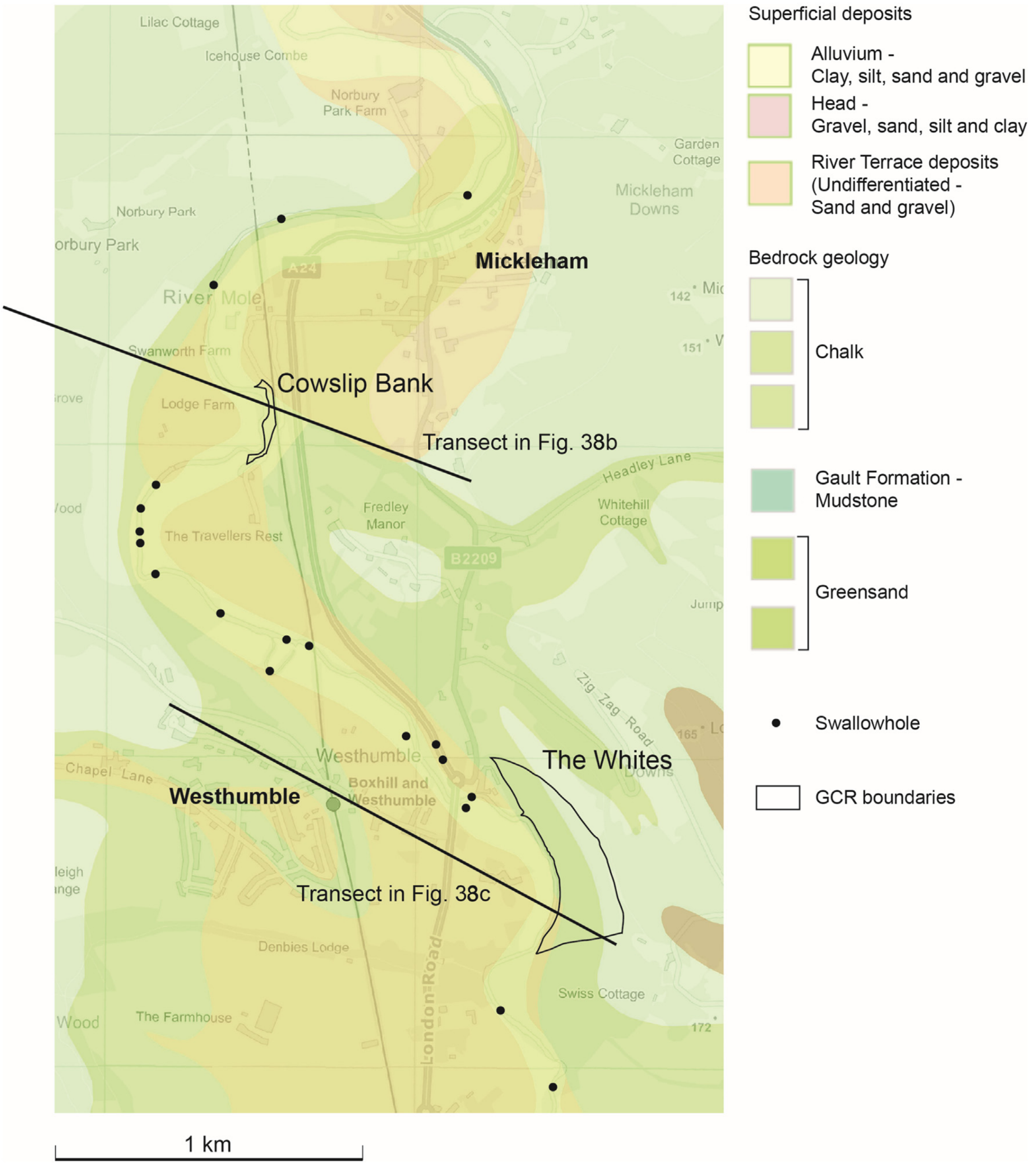

Fig. 36. Location and geology of 'The Whites' and Cowslip Bank, comprising The Mole Gap GCR site. Locations of swallow holes mapped by Dines and Edmunds (1933), Fagg (1958) and Sallnow (1981) are shown. Map contains geological data available under an Open Government licence from the British Geological Survey © UKRI [2024].

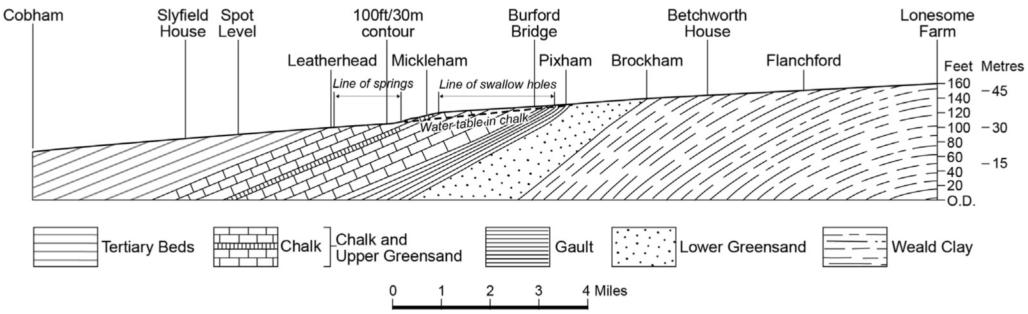

Fig. 37. Diagrammatic long profile of River Mole showing water table in the chalk and zones of swallow holes and springs. Mole Gap extends approximately from Pixham to Leatherhead. (After Dines and Edmunds (1933).)

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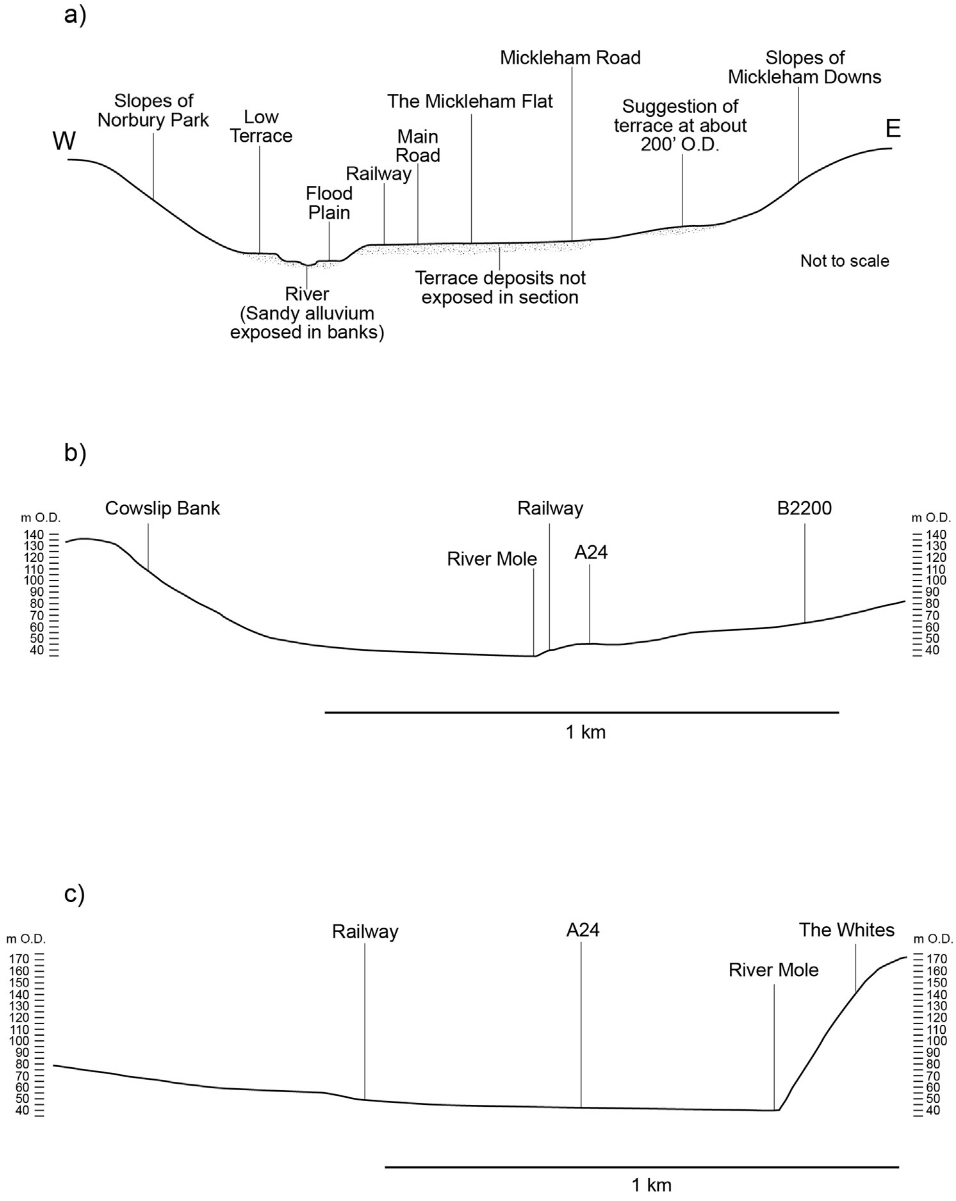

Fig. 38. a) Diagrammatic cross-section of The Mole Gap after Wooldridge and Hutchings (1957). Actual cross-sections through b) Cowslip Bank and c) 'The Whites' derived from JISC Airbus Ordnance Survey mapping data.

the Mole and is composed of 'Taele' gravels like those recognised just beyond The Mole Gap by Dines and Edmunds (1933). The Mole Gap displays prominent meanders and Docherty (1969) asserts that each of the prominent river cliffs on the outside of these meanders opposes the toe of a taele fan. The presumed direction of deposition of these fans is illustrated by Sallnow (1981, their Figure 2), though no evidence for this is provided and some directions appear unlikely relative to the topography.

The extensive 'lower terrace' is about 6 m below the 'higher terrace' (Docherty, 1969). Dines and Edmunds (1933) recorded a number of temporary sections in 'lower terrace' sediments within The Mole Gap, which revealed up to 9 ft (2.74 m) of chalky gravel or chalky and sandy gravel. At Betchworth Castle (TQ 188 501) just south of The Mole Gap 2 ft 6 in (0.76 m) of stratified sandy gravel consisting of flints, Lower Greensand material and Weald Clay shale was recorded beneath 3 ft and 6 in (1.07 m) of sand, chalky drift and soil. The flood plain is narrow, rarely more than 150 m wide, and incised about 2 m beneath the 'lower terrace'. Unfortunately, none of these 'river gravels' are readily apparent within the two parts of the GCR site, though mapping by Dines and Edmunds (1933, their Figure 6) suggests that they may occur marginally at both sites, at the base of 'The Whites' and at each end of Cowslip Bank. According to Bull (1933, p. 313), "Coombe Rock, (presumably the chalk débris of Wooldridge and Bull, 1925) abounds in the [G]ap".

'The Whites' river cliff comprises the larger of the two units of the GCR site. It is a high (>100 m), steep (*c*., 32°) curvilinear slope on the outside of the southernmost large, east-facing meander of The Mole Gap (Figs. 38c and 39). This impressive feature extends along the right bank of the river for about 0.6 km between TQ 174 514 and TQ 173 520 (Fig. 34). The slope is extensively wooded, but bare areas of loose chalk cobbles and gravel occur in places especially towards the northern end. Debris fan morphology, largely obscured by modern tree growth (*cf*., 'The Stonebreaker' painting by John Brett, 1857; Fig. 16 of the English Nature geological site document/management brief of Wonham, 1993) occurs at the foot of the slope. Wonham (1993, their Figure 17) also illustrates a "sink hole…50 m from the River Mole at the foot of 'The Whites' (TQ 175 515) developed within chalk debris fan material of clayey chalk conglomerate". Swallow holes occur at the base of The Whites cliff adjacent to the river.

Fig. 39. View of 'The Whites' showing white chalk scars, from Druids Grove (TQ157533), Mole Gap. Photograph: Colin Whiteman.

The Cowslip Bank river cliff (Figs. 37, 38b and 40), the smaller of the two units of the GCR site, occurs where, according to Wooldridge and Bull (1925), the Mole has cut into the western edge of the 'Mickleham Terrace' and "the end of the Headley Valley was seen to hang by 25 ft (7.62 m) above the present flood plain" (p. 11). A section in the river cliff was illustrated by Wooldridge and Bull (1925, their Plate 3B). Unfortunately, their photograph shows little of value; the upper part being obscured by vegetation and the lower part mostly obscured by loose debris. No mention was made of the sediments in the exposure, but sediments at a similar height, further south near Box Hill Station, were described. These comprised "4 feet (1.22 m) of sandy alluvium resting on 10 feet (3.05 m) of typical coombe-rock" (p. 5). Bull et al. (1934; p. 63) refer to "the presence of brickearth and more or less sandy loams" on the 'Mickleham Terrace' surface, though without specifying a particular site. Dines and Edmunds (1933, their Figure 6) mapped chalk and the Upper Greensand Formation at Cowslip Bank, and Fagg (1958, their Figure 6) later depicted the cliff as chalk throughout. However, this is not entirely consistent with the current exposure. Sallnow (1981) observed what he described as reworked chalk sludge, flints and clay adjacent to Cowslip Bank at TQ 166 532. A preliminary investigation of the present exposure at, TQ 165 530 (Fig. 41), shows at least 4 m of fragmented chalk with isolated flint clasts at the base, overlain by about 0.3 m of coarse flint gravel in a silty/sandy matrix. V-shaped structures containing this sediment penetrate downwards into the chalk for 0.3 to 0.4 m. A sharp horizontal upper boundary separates this unit from over 1 m of brown sandy silt and a dark organic rich topsoil. The sandy silt unit can be divided into a lower subunit with grey linear mottles, and an upper subunit without these features. There is currently no evidence of swallow holes at this site although they have been previously mapped (*e.g.,* Dines and Edmunds, 1933; Fagg, 1958; Sallnow, 1981), and observed in the 1940s (Ivor Browning, pers. comm., 8th November 2004).

5.3. Interpretation

It is difficult to interpret the geological and geomorphological features of The Mole Gap GCR sites without considering The Mole Gap as an entire landscape unit, distinguished by its particular relationship to the chalk. This applies especially to The Mole Gap swallow holes. As outlined above, these features have attracted attention for several centuries, though the outcome of this interest was descriptive rather than analytical. Apart from acknowledging the permeability of the chalk, and its ability to absorb water rapidly, no attempt to explain their distribution appears to have been published until the work of British Geological Survey officers in the 1930s. Explanations were apparently proffered during some of the many excursions, for instance that reported by Wooldridge and Bull (1925), but details of these field discussions did not reach the printed page. Dines and Edmunds (1933, p. 19) attributed the concentration of swallow holes within The Mole Gap essentially to "the presence of chalk Rock, a bed of chalk harder than that of the main mass" (as seen in Fig. 37). The outcrop of this distinctive chalk stratum appears to coincide with a steepening of the longitudinal profile of the Mole in the area of Mickleham. The water table is controlled by "the impervious clays of the Paleogene Beds above and the Gault Formation below the chalk (including the Upper Greensand). A line joining the base of the outcrop gives the level of the normal water-table along the valley; this is seen to be below the bed of the stream south of Mickleham" (Dines and Edmunds, 1933, p. 19). Consequently, between Dorking and Mickleham swallow holes occur whilst between Mickleham and Leatherhead, springs arise. Dines and Edmunds' map (Fig. 36) shows swallow holes distributed apparently randomly along the river. In contrast, Fagg (1958) emphasised their concentration at the apex of meanders, a characteristic also suggested by the observation of Wooldridge and Hutchings (1957) that where erosion exposes fresh joints and fissures in the solid chalk at the foot of meander river cliffs, water leaks away more freely.

Dines and Edmunds (1933) assumed that the relative steepness of valley side slopes in The Mole Gap is due to the fact that the water table has generally been below the level of the river since very early in the history of the gap, with the result that the river incised by solution below its bed, in preference to meandering and widening. Wooldridge and Bull (1925, p. 5) attribute the abnormal size and steepness of 'The Whites' river cliff to long-term incision at this site. In their view "the older [400 ft/121.92 m] and 'newer' [200 ft/60.96 m] river-cliffs here

Fig. 40. Cowslip Bank and its topographic context.
Photograph: Colin Whiteman.

Fig. 41. Detail of Cowslip Bank section.
Photograph: Colin Whiteman.

coincide", though, in the absence of sedimentary evidence this must be conjectural. The fact that the steep slopes below 400 ft (121.92 m) cease at about 200 ft (60.96 m) may be due to structural control by the Middle Chalk Formation as this unit outcrops at an appropriate height in the southern half of the Gap. No detailed analysis of the sediments and morphology of 'The Whites' appears to have been reported. It is therefore difficult to judge the extent to which the slope is due to fluvial erosion of a high chalk slope by the apex of a Mole meander, or a variety of slope processes such as the passage of humans and animals, burrowing by animals, tree throw, solution and frost.

A similar paucity of detailed analysis applies to the Cowslip Bank section. Wooldridge and Bull (1925) implied that the exposure revealed a section through the 'Mickleham Terrace' and the end of the Headley Valley where it disgorged into The Mole Gap. They compared this to a site at the same height, further south, near Box Hill Station, where sandy alluvium overlies coombe rock. Unfortunately, their illustration of a Cowslip Bank exposure reveals little of interpretative value. In contrast to the view of Wooldridge and Bull (1925), both Dines and Edmunds (1933) and Fagg (1958) in respective figures show chalk bedrock outcropping at the site. The key to this difference of interpretation probably lies in the nature of the chalky sediment currently exposed at Cowslip Bank. In the absence of published data, only a preliminary interpretation of the sequence can be attempted here. The chalk with scattered flints is shattered, probably by frost and partially disturbed, again probably by periglacial heave processes, but is essentially *in situ*. Young (1915) attributed similar material at the confluence of the Polesden and Mole valleys, probably at Camilla Lacey, to chalk solution alone but this is unlikely in view of our current understanding of the dominant processes of chalk weathering during the Quaternary (Murton, 1996). The thin layer of coarse flint clasts apparently mixed with the finer overlying sediments has the appearance of a lag deposit on top of the chalk, though whether this indicates a period of subaerial weathering and solution of the chalk, or reflects fluvial activity is unclear. The v-shaped structures which intrude this deposit into the chalk, and the relatively unrolled nature of the flints support the former interpretation. The structures are not considered to be periglacial in origin. The fine brown sediment forming the uppermost stratum could be river alluvium, brickearth, or less likely, primary loess. Its primary origin has been obscured by pedogenesis: there is evidence of soil horizonation, mottling and possibly clay illuviation. Whatever the eventual interpretation of these sediments, it is clear that this exposure presents a rare opportunity to provide much needed modern information on the Quaternary evolution of The Mole Gap.

Few locations in southern Britain can have attracted so much interest over such long period, and yet inspired so little attention from the modern Quaternary community. Although swallow holes have attracted most attention, they are probably not the most useful elements of the landscape in terms of its Quaternary history. The two discrete parts of The Mole Gap GCR site undoubtedly represent its most impressive extant, morphological and sedimentological features, the latter probably of greatest significance. Early morphology-based views of river development have been frequently rehearsed and occasionally criticised, but no detailed sedimentological analyses have been undertaken in support of either view, perhaps due to a paucity of natural exposures. Cowslip Bank offers a rare, if not unique, modern opportunity to study exposed Quaternary sediments within The Mole Gap. A more extensive investigation of sediments within the Gap, beginning with the Cowslip Bank section, has considerable merit. Although the dual GCR site of Mole Gap encompasses two key landscape elements, it cannot fully do justice to The Mole Gap as a whole, and scientifically there must be scope for considerably extending the GCR site boundaries. The Mole Gap is a feature which is worthy of designation as a GCR site at a scale related to the broader landscape. It undoubtedly has a great deal to contribute to the understanding of landscape development in southeast England during the Quaternary Period.

5.4. Conclusion

The Mole Gap is one of the classic geomorphological localities of south-east England, long noted for its variety of landforms which include periglacial debris fans, river cliffs and swallow holes. The fans of The Mole Gap are the largest on the chalk, and Cowslip Bank provides rare sections in deposits of this type. River cliffs are particularly well-developed where the fans have deflected the River Mole against the valley sides, especially at The Whites — the most imposing river cliffs in the chalk and a landform landmark of southern England. The site is understudied and would benefit from further systematic mapping and analysis of the sediments preserved.

6. 'High Level' sands and gravels (CAW, RMB)

GCR Site 454 Upper Common (TQ 084 499) (CAW, RMB)
GCR Site 845 Mountain Wood (TQ 093 509) (CAW, RMB)
GCR Site 1172 Upper Hale (SU 823 494) (CAW, RMB)

The three GCR sites considered together in this section, Mountain Wood, Upper Common and Upper Hale (Fig. 42) are distinguished from other sites, not so much by their similarity to each other, but by their individuality and hence the difficulty of correlation between members of this group and with other sites in the region. They do possess some common factors: all occur just north of the North Downs chalk escarpment in either Surrey or Hampshire, at a height noticeably above adjacent, well-defined fluvial terrace sequences, all show some stratigraphical complexity, and all appear to be devoid of numerically datable material. In contrast, the sites are markedly different from each other in terms of stratigraphy and the texture and lithology of their sediment. Nonetheless, together they form a network of sites exemplifying different elements of deposits preserved at this higher level within the landscape.

The site at Upper Common, Netley Heath, is an isolated patch of sandy sediment with some flint and Lower Greensand clasts which has often been compared with other sites within the London Basin and distributed across the North Downs and the Chiltern Hills, at altitudes between about 120 m and 200 m above O.D., because it contains fossils. The site at Mountain Wood possesses similar sandy deposits, but here the sand is overlain by a possibly unique gravel deposit composed largely of Lower Greensand chert and sandstone. The Upper Hale site is distinguished by the very coarse texture of its flint gravel and the paucity of Lower Greensand material. Both Upper Common and Upper Hale have been compared to an intervening site at Newlands Corner, but this may have more to do with proximity than any precisely measured properties of the sediments.

Investigation of deposits, both in Surrey and elsewhere in the London Basin, by means of heavy mineral analysis, was attempted to enable correlation, but did not lead to unanimity regarding correlation. Davies (1915–16), working in Surrey, distinguished the sands from Paleogene counterparts and Wooldridge (1927), following a larger survey, confirmed their distinctive mineralogy throughout the London Basin. Sherlock (1929), however, cast doubt on the validity of this correlation in view of the fact that the Lenham beds (a site in Kent to which these sites had been compared — Prestwich, 1858; Whitaker, 1866, 1872) and Netley Heath beds at Upper Common were considered to be of different ages and that mineral provenance may be the same at different times or vary between sites within a given period.

In the past all of these sites have contributed to the interpretation of landscape development in both the Weald and the London Basin, culminating in the full-scale, and very influential, model of the evolution of landscape in south-east England proposed by Wooldridge and Linton (1939, 1955). This was based on the correlation of sediments at Netley Heath (Upper Common), Lenham, and a similar site at Rothamsted in the Chilterns (Dines, 1930), by Wooldridge (1927), who used them to infer the transgression into the London Basin of a Pliocene sea which cut an erosional platform (*c.* 150–200 m O.D.) across the inclined Sub-Eocene Surface into the Summit Surface of the chalk. Subsequent work by Pinchmel (1954), Green (1974, 1985), Catt and Hodgson (1976), John (1980; John and Fisher, 1984), Jones (1980, 1999) and others has criticised the Wooldridge and Linton model to an extent that it is no longer tenable. However, this does not negate the importance of the sites at Mountain Wood, Upper Common and Upper Hale (Jones, 1999) which must be accommodated in any explanation of the complexity of landscape development in south-east England.

6.1. GCR Site 454 Upper Common (TQ084499) (CAW, RMB)

6.1.1. Introduction

Upper Common, Netley Heath, Surrey (Fig. 43), located on the southern margin of the London Basin (Fig. 42), contains the celebrated 'Netley Heath Deposits' (Dines and Edmunds, 1929) that, for various reasons, remain difficult to interpret and correlate with other sites. It possesses rare marine fossils, generally correlated with the Red Crag Formation of Suffolk (Gibbard, 1999), but the poor preservation of these fossils, the complex structural relationships within the sediments, and the irregular boundary between these deposits and the underlying chalk bedrock have ensured that the site has remained controversial. Key issues are the origin and age of the different sedimentary units, and the stratigraphical context and environmental significance of the fossils. Their presence on the North Downs is critical for the interpretation of the evolution of the southern English landscape including the Weald and the London Basin.

6.1.2. Description

John and Fisher (1984) have provided the most recent and best description of the 'Netley Heath Deposits' at Upper Common, which they exposed in three pits about 10 m apart (Fig. 43) opened at the eastern edge of the GCR boundary (TQ 084499). These exposures (Fig. 44) revealed a very irregular chalk surface, probably due to chalk solution, overlain by a complex of more recent, usually disturbed, sediments.

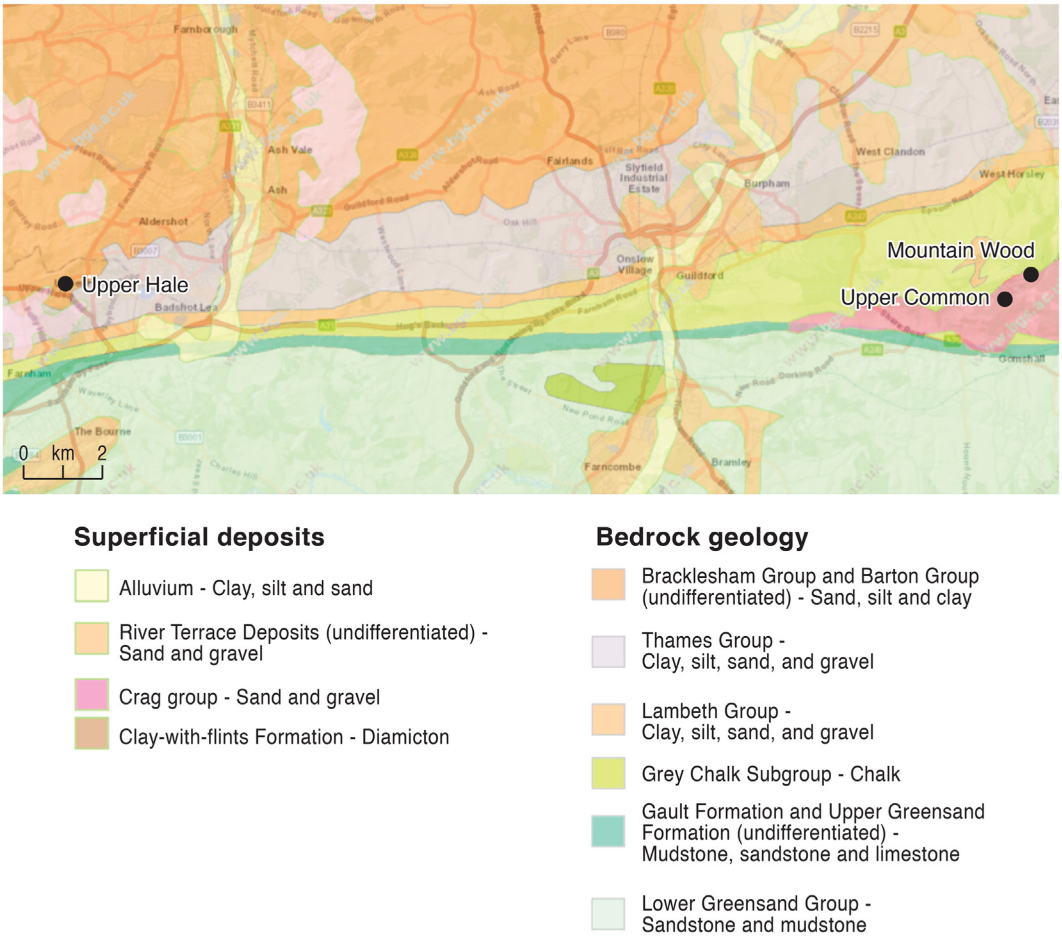

Fig. 42. Geology and location of the GCR sites at Upper Common (Netley Heath), Mountain Wood and Upper Hale. Map contains geological data available under an Open Government licence from the British Geological Survey © UKRI [2024].

The most disturbed beds, in the north face of Pit 1, extended downwards from an unconformity for nearly 3 m into the inclined strata. These structural features and heavy minerals from the ironstone matrix are all consistent with descriptions of Red Crag material recovered from the site early in the twentieth century (Chatwin, 1927) and now lodged with the British Geological Survey (then the Institute of Geological Sciences). The new specimens obtained by John and Fisher (1984) are lodged in the Ipswich Museum collection (Number R. 1983–86).

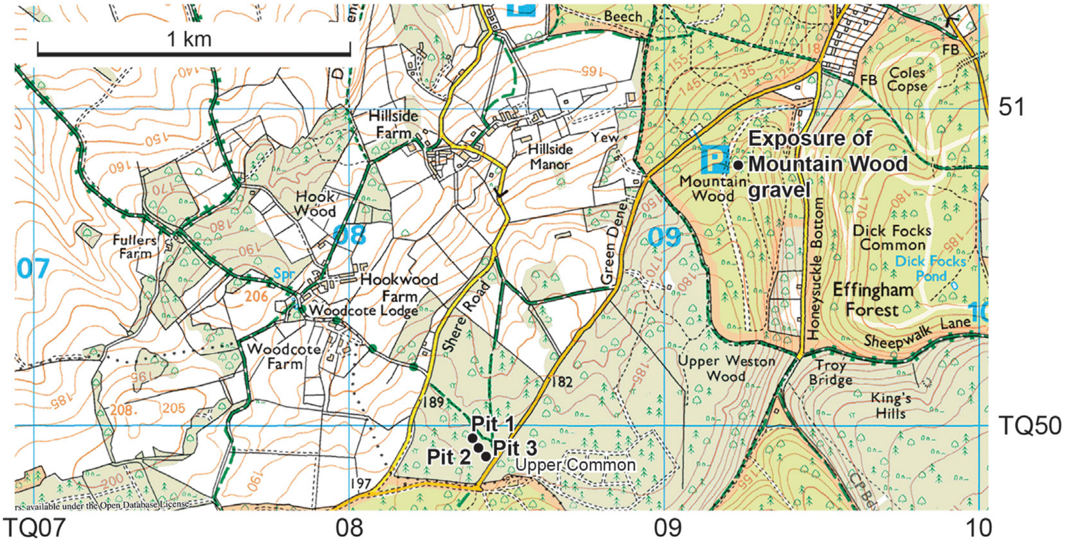

Fig. 43. Detailed location of sequences described from the Upper Common (Netley Heath) and Mountain Wood GCR sites by John and Fisher (1984, their Figure 1). Map from Ordnance Survey data under Digimap licence to Birkbeck University of London.

Descriptions of their exposures are summarised below. Pit 1 (Fig. 44A) exposed the following stratigraphy:

Unit	Thickness	Description
3	*c.*, 1 m	Flinty sand with podzolic soil development truncating subjacent sediments along a sharp sub-horizontal unconformable boundary
2	*c.*, 3 m	An irregular, depression feature containing a heterogeneous mass of generally poorly sorted sediment including fine-gravel to cobble-size, angular and nodular flints and rounded Paleogene flints, gravel-size, sub-rounded Lower Greensand clasts in a matrix of dark yellowish brown (10YR 3/6) sand with variable admixtures of clay with heavy mineral Zircon: Rutile ratio of approximately 1. One sample contained microfossils derived from chalk. The depression feature also possessed sub-vertically orientated gravel- to cobble-size platy fragments of at least two varieties of ironstone, one of which contained numerous comminuted fossil casts of bivalves and gastropods. The heavy mineralogy of this sediment is distinguished by a high garnet component with subsidiary muscovite and tourmaline.
1	*c.*, 5 m	Moderately dipping, partly cross-bedded, medium to fine, reddish-yellow (7.5YR 7/6) sand with occasional fine-gravel size chalk clasts, interbedded with thin layers of brown (7.5YR 5/6) clayey sand disrupted at irregular intervals by near-vertical normal faults with throws of about 10–20 cm. The heavy mineral suite is dominated by zircon with lesser amounts of rutile. The Z:R ratio > 2.

In Pit 2 (not shown in Fig. 44), 10 m south–southeast of Pit 1, 6 m of Unit 1 was overlain unconformably by Unit 3 and Unit 2 was absent.

Pit 3 (Fig. 44B), a similar distance south–southeast of Pit 2, also revealed the most complex stratigraphical relationships. The stratigraphy in Pit 3 is summarised below:

Unit	Thickness	Description
6	1 m	Soil, apparently equivalent to that of Unit 3 of Pit 1 with similar unconformable basal boundary
5	*c.*, 2 m	A U-shaped structure containing interbedded, grey to white sand and clayey sand indistinguishable except for colour from that outside and to the west of the structure and indistinguishable from the main body of stratified sand in Pits 1 and 2. Within the structure, however, the stratification is not uniform as in the other sections but shows apparent evidence of fracture.
4b		A stoneless layer of strong brown (7.5YR 5/6) clay defining a shaped structure.
4a		Flinty, sandy drift apparently similar to Unit 2 within the depression feature of Pit 1
3	1–1.5 m	Strong brown (7.SYR 5/6), variably flint-rich clay giving way to Unit 4a or 4b in different parts of the pit.
2	0.2–0.3 m	Very dark grey clay containing numerous dark-stained nodular flints.
1	*c.*, 2 m	Chalk bedrock becoming increasingly shattered and deformed towards its very irregular truncated upper surface.

6.1.3. Interpretation

From the field sketches and description published by John and Fisher (1984) it is possible to distinguish at least six different sedimentary units at Upper Common resting on the irregular chalk bedrock surface. According to these authors, the six units are separable into three main groups: the bedded sand and clayey sand (Unit 1 of Pit 1, Unit 5 of Pit 3), a 'periglacial deposit' (Unit 2 of Pit 1, Unit 4 of Pit 3) and a 'shallow surface drift with a podzolic soil profile' (Unit 3 of Pit 3, Unit 6 of Pit 3), a differentiation clearly seen in Pit 1 and confirmed by textural, mineralogical and palaeontological analyses. In addition, Units 2 and 3 of Pit 3 probably derive from the solution of the chalk bedrock. The bedded sand and clayey sand (Unit 1 of Pit 1, Unit 5 of Pit 3) are named the Headley Sand member of the Headley Formation, as defined by John (1980) and found at the base of all three high-level gravels at Upper Common, Mountain Wood and Upper Hale and a similar group of sediments from Lenham in Kent. Some of these sands have been attributed to fluvial deposition (Monkton, 1892; Salter, 1898, 1905), to deposition as a continental facies of the Reading Formation (Sherlock, 1924, 1929) or some of the material contained within them to glaciation (Sherlock, 1929). However, all other investigators concur on the marine origin of both the sediments and the fossils. Despite this, they remain enigmatic because they occur sporadically, the value of sand mineralogy analyses used to correlate them has been questioned (Sherlock, 1929), and fossils are rare and poorly preserved and not necessarily *in situ*. This is due, in part, to the structural and stratigraphical complexity of some of the deposits, such as here at Upper Common.

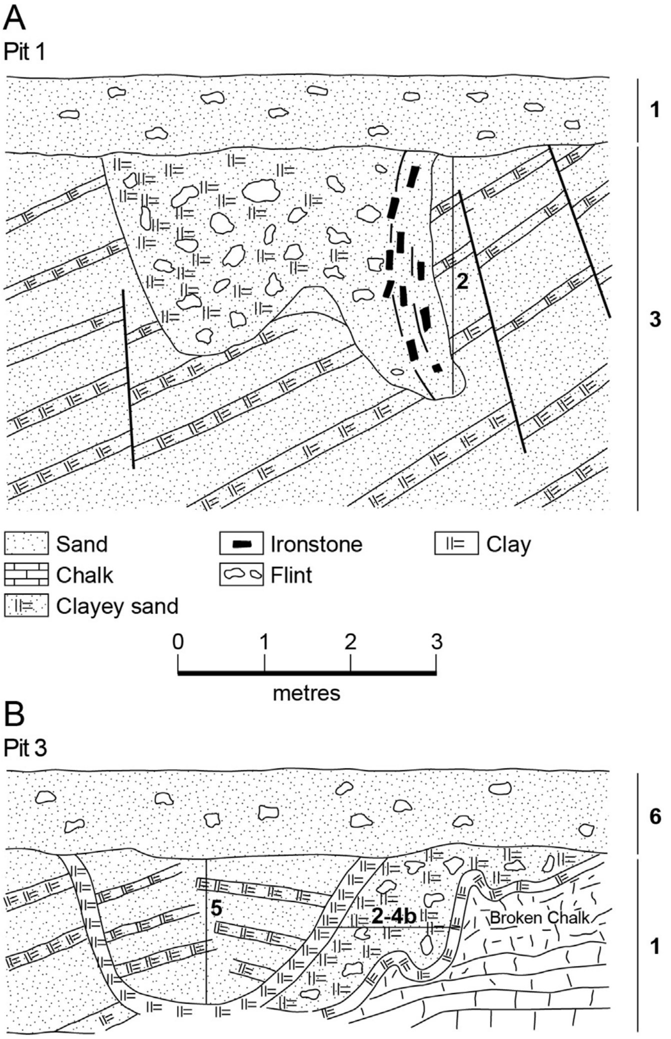

Fig. 44. Stylised section drawings of the north faces of Pit 1 (A) and Pit 3 (B) at Upper Common GCR site.
(Redrawn from John and Fisher (1984, their Fig. 3).)

Petrographic evidence from the Headley Sand has been gathered since the work of Wooldridge (1927). Groves (1931) suggested that heavy minerals from Upper Common (Netley Heath) were very different from the similar site at Lenham, Kent, with petrographic evidence indicating a southerly provenance, probably in the Lower Greensand of the Weald (Wooldridge, 1927; Rogers and Richardson, 1947; Wood, 1956 cited in John, 1980), rather than a provenance in Paleogene strata to the north. (The gravels at Mountain Wood also derive from the Lower Greensand.)

The stratigraphical complexity of the Headley Sand and overlying deposits has led to significant differences in interpreting their age. Stebbing (1902) found fragments of marine shell (referable to the genera *Modiola*, *Cyprina*, *Nassa*, *Trochus*, *Cardium*, *Pectunculus*, *Telliona* and *Thracia*) from a ferruginous sandy grit with occasional flint pebbles at the Upper Common site, tentatively linking them to the Lenham Formation. These latter had been assigned to the Coralline Crag by Prestwich (1854, 1858), Whitaker (1862) and Reid (1890), but later to the Eocene (Whitaker, 1872). However, after examining these fossils, and others

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found in the vicinity by Wright (quoted in Davies, 1917), Chatwin (1927) concluded that the assemblage at Upper Common was younger than that from Lenham and probably of Red Crag age. However, the issue remains of whether the fossils were deposited *in situ* within the Headley Sand. Chatwin (1927) believed that the separation of the boulders containing the fossils from the sands at Upper Common (Netley Heath), and the comminution of the shells indicated that the fossils were not *in situ*, a circumstance apparently proposed by Wood (Snr) (in White, 1928) with respect to the fossils at Lenham.

However, John and Fisher (1984, p. 245) have demonstrated conclusively that the ironstone containing the fossils within 'the periglacial deposit' (Unit 2 of Pit 1, Unit 4 of Pit 3) "is neither *in situ* nor incorporated into the Headley Sand at the time of its deposition" so the faunal assemblage 'cannot be used to furnish an absolute date for the underlying Headley Sand.' This conclusion was invoked by Jones (1999) as further conclusive proof of the untenability of the landscape evolution model proposed by Wooldridge and Linton (1955) which was dependent, in part, on the fossils assigning an age to the Headley Sands.

John and Fisher (1984) show that the 'periglacial deposit' (Unit 2 of Pit 1, Unit 4 of Pit 3) at Upper Common actually contains the fossiliferous material, thus showing conclusively that the latter is not part of the Headley Sand but a completely separate sediment. Whilst there is no reason to disagree with John and Fisher's (1984, p. 240) assumption that the "form and poor sorting" of heterogeneous mass of material in the structure in Pit 1 are "evidently due to geliturbation", no evidence of features exclusively associated with periglacial conditions is presented, though the sub-vertical orientation of the ironstone clasts and the mixed nature of the deposit is typical of frost-affected sediments (Ballantyne and Harris, 1994). The most likely explanation for the irregular chalk surface underlying Units 2 and 3 in Pit 3 (Fig. 44B) is solution, as indicated by the clay-with-flint-like material resting on it, rather than cryoturbation or differential erosion, for which there appears to be no evidence. Solutional lowering of the chalk surface was also probably responsible for the normal faulting in the Headley Sand in Pit 1 as the faults appear to be confined to this unit. Irrespective of the mode of formation of the 'periglacial deposit' (John and Fisher, 1984), it is mineralogically and texturally different from the Headley Sand. Furthermore, as the Red-Crag-like fauna occurs in the periglacial deposit it cannot be used to date the Headley Sand at Upper Common directly, nor the Lower Greensand gravel overlying the Headley Sand in Mountain Wood indirectly, and it follows that Wooldridge's (1927) view that initial excavation of the Vale of Holmesdale, and by implication the rest of the Weald, was related to post-Red Crag uplift, is unsound. This suggests a more recent age for the erosion of the Weald as Jones (1999) has argued. In view of these findings, it is unfortunate that the revised correlation of Quaternary deposits in the British Isles (Bowen, 1999, p. 53) defines a 'Netley Heath Member' of the 'Red Crag Formation' as 'gravel and sand with marine fossils between 152 and 204 m OD at Netley Heath', quoting Dines and Edmunds (1929) as the originators but failing to acknowledge the critical refinements of John and Fisher (1984). The thin, podzolised drift at the surface was not analysed by John and Fisher (1984), nor dated. It is likely to be of relatively recent age and of little, if any, relevance for interpreting the primary feature of this site.

John's (1974, 1980) and John and Fisher's (1984) work at Upper Common succeeded in clarifying the stratigraphical relationship of the 'marine Red Crag fossils' to the underlying 'Headley Sand' member, and therefore their temporal significance for landscape evolution of the Weald and the London Basin. This site remains of substantial importance not only as one of a very few known sources of fossiliferous material, but also for its potential contribution to understanding periglacial and other deformational processes which have affected surficial deposits beyond former glacial margins in southern Britain. A more extensive excavation of the site would be beneficial by providing clearer evidence of crucial structural relationships bearing upon the origin and relative age of the sediments. The location would also be an important location for application of age techniques that might be developed in future for dating older deposits.

6.1.4. Conclusions

These pits expose sandy deposits originally referred to as the Netley Heath Beds and thought to be Pliocene in age. Near the base of these sandy deposits numerous marine fossils occur. These are of considerable importance since they have Red Crag affinities. These have been variously reported as occurring in an iron pan formed *in situ*, or within detrital blocks of foreign material. John's (1974, 1980) and John and Fisher's (1984) work at Upper Common succeeded in clarifying the stratigraphical relationship of the 'marine Red Crag fossils' to the underlying 'Headley Sand' member. However, the lack of a robust age constraint for these deposits and their fragmentary nature makes an understanding of the relationship between these beds and the Red Crag from East Anglia difficult to unravel, decreasing our understanding of landscape evolution at this time. A more extensive excavation of the site would be beneficial by providing clearer evidence of crucial structural relationships bearing upon the origin and relative age of the sediments. The site would also be an important location for application of age techniques that might be developed in future for dating older deposits.

6.2. GCR Site 845 Mountain Wood (TQ093509) (CAW, RMB)

6.2.1. Introduction

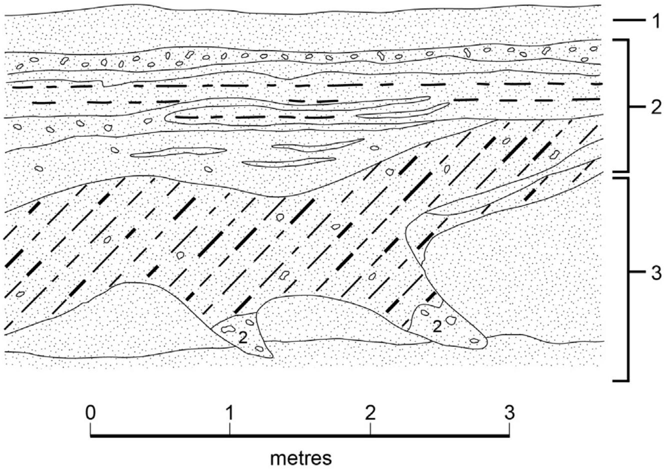
Mountain Wood, on the chalk dip slope of the North Downs (Fig. 42), is the location of a seemingly unique gravelly deposit almost entirely composed of Lower Greensand chert and sandstone. The distinctive lithological composition of this material implies that it was emplaced prior to the erosion of the Gault Clay vale to the south, the Vale of Holmesdale, as its likely provenance is the Lower Greensand escarpment on the southern side of this valley. The gravel overlies presumed Red Crag sand, which occurs also at Upper Common and a number of other sites scattered across the North Downs. The origin of the Red Crag sands has generated a great deal of controversy (see Upper Common — Section 6.1). The Mountain Wood GCR site, therefore, contains important evidence for the Quaternary, if not Paleogene, evolution of both the Weald and the London Basin. Until the work of John (1974, 1980; John and Fisher, 1984), only Bury (1910) and Wooldridge (1927) appear to have commented specifically on the Lower Greensand material overlying the sand in Mountain Wood. Surprisingly the site was not included in the *Revised Correlation of the Quaternary Deposits in the British Isles* (Bowen, 1999).

6.2.2. Description

Mountain Wood (TQ 093509) is located on the dip slope of the North Downs, some 9 km east of Guildford, Surrey and immediately south of the boundary of Sheepleas Site of Special Scientific Interest (Fig. 43). The main exposure of gravel at Mountain Wood is located in a separate rectangular area, about 60 m by 40 m, on the north-western side of a spur, on the northern side of the Heath. Within this area is a small artificial trackside exposure, presumably the one illustrated by John and Fisher (1984, their Figure 2) in a 'stylised section drawing' (Fig. 45) based on a similar figure in John (1974, his Figure 50). Data on particle size and morphology of the Mountain Wood Gravel is contained in John's unpublished PhD thesis (John, 1974, his Figs. 51 and 69 and Tables 10 and 11, 20 and 21). The samples from the Headley Sand had a modal particle size (60 % of sample) of medium sand (0.2–0.6 mm) and those from the overlying Mountain Wood Gravel a modal particle size of medium gravel (*c.* 30 % of sample, 6–20 mm). The Mountain Wood Gravel had a mean roundness varying between 0.41 for the smallest gravel and 0.50 for the largest, and sphericity between 0.64 and 0.66 ψp. John (1980, p. 122) reported "about 2 m of [the] deposit...exposed in a cutting for a Forestry Commission road (TQ 092508)" and commented briefly on clast lithology and structural relationships. The drawing (Fig. 45) shows a structurally complex series of at least 11 horizontal and inclined sandy gravelly beds which John and Fisher (1984, p. 238) separated into three units. Unit 1, immediately below the surface, is 25–30 cm of "sandy flinty podsolised drift", presumably the current soil. Beneath this are several more layers (Unit 2) comprising "variable mixes of [dominantly subangular to rounded, Lower Greensand] tabular chert and pitted sandstone [with a few clasts of flint and ironstone in a matrix of] presumably Red Crag sand" (Headley Sand), the latter described by John (1980) as reworked. The upper part of this second unit is described as horizontally stratified, though the drawing also shows wavy boundaries between strata, over-turning of strata and the inclusion of thin lenses of medium to fine sand within the Lower Greensand material. At a depth of about 0.8 m (1.3 m in John and Fisher, 1984) an unconformable boundary truncates the lower part of Unit 2 in which most of the stratification is inclined at about 30° towards the north–northeast, in the same direction as the interfluve spur on which the gravel is situated. Two tongues of this inclined material project diagonally downwards, "first through weathered, presumably Red Crag, sand and then into its unaltered, apparently in *situ*, counterpart" (John and Fisher, 1984, p. 238) that together constitute Unit 3. It should be noted that no fossils have been found here — the age and correlation of the Headley Sand are assumed by correlation with the sequence at Upper Common.

6.2.3. Interpretation

The views of Bury and Wooldridge have been summarised by John and Fisher (1984). Both Bury (1910) and Wooldridge (1927) accepted that the Lower Greensand material of the Mountain Wood area was probably transported to its present position by a 'consequent' river flowing northwards across the location of the present Gault Clay strike vale (the Vale of Holmesdale), immediately to the south of the chalk escarpment, some 3 km south of the GCR site. However, though Bury (1910) conceded that the gravel was fluvially transported, he believed that it was delivered to a Pliocene shoreline where it could have been more widely distributed, thereby explaining the continuity of chert-bearing formations on the North Downs as a whole. Wooldridge (1927), in contrast, implied that the gravel accumulated fluvially *after* the retreat of the sea, which had deposited the underlying Headley Sand. Wooldridge (1927) assumed that this happened immediately prior to glacial times, since, in his opinion, the excavation of the Vale of Holmesdale required a significant time-span. This timing conflicts with other suggestions that the Upper Common (Netley Heath) deposits, with which the Mountain Wood material is traditionally associated, had a glacial origin (Dines and Edmunds, 1929; Sherlock, 1929; Shepherd-Thorn, 1975), but these interpretations lack substantive evidence.



1) Sandy Flinty podzolised drift

2) Stratified medium, fine and loamy sands with much Lower Greensand detritus and few flints

3) Headley Sand

Fig. 45. Stylised section drawing of the exposure of Mountain Wood Gravel. (Redrawn from John and Fisher (1984, their Fig. 2).)

The early interpretations of Bury (1910) and Wooldridge (1927) appear to assume that the Lower Greensand material of Mountain Wood is *in situ*, remaining where it was originally deposited, either fluvially or by marine processes. John's (1980, p. 122) comment, that "a sprinkling of *the former gravel* which contributed the chert and sandstone [to the GCR site] is still very much in evidence on the surface of the Headley Sand in the higher parts of Mountain Wood", may seem to support this view. However, there are a number of sedimentological and structural reasons for concluding, with John and Fisher (1984, p. 239), that the Lower Greensand debris at the Mountain Wood GCR site is a "typical periglacial slope deposit". In particular, (a) it possesses a matrix of sand, apparently reworked from the subjacent Headley Sand, (b) individual beds are usually poorly sorted, (c) it is crudely bedded and apparently shows some evidence of disturbance, including folding, and (d) it occupies a position on the lower part of a steeply sloping spur. All of these characteristics are consistent with mass movement of sediment down a slope.

The composition of the dominantly-Lower Greensand gravel exposed in Mountain Wood on the dip slope of the North Downs implies initial emplacement, probably by fluvial processes, prior to the erosion of the Vale of Holmesdale. Its sedimentology, structure and current position suggest subsequent displacement due to periglacial slope processes. This complex evolution and its close association with sandy sediments similar to the controversial deposits at the Upper Common GCR site on Netley Heath ensure its importance to the development of ideas concerning the Quaternary history of the Weald and the evolution of the London Basin. Unfortunately, no evidence has so far been obtained from the site which could accurately date the initial fluvial or marine emplacement of this deposit, or its subsequent periglacial reworking. There is obviously scope for further analysis of this site in order to realise its full value to Quaternary science. As with Upper Common, the site could also be an important location for application of age techniques that might be developed in future for dating older deposits.

6.2.4. Conclusions

This trackside cutting exposes the Mountain Wood gravel, a unique deposit composed almost entirely of chert from the Lower Greensand, here resting on the chalk dip slope of the North Downs. The composition of this gravel implies that it was emplaced prior to the erosion of the Gault Clay Vale to the south, and it therefore has important implications for the Quaternary history of the Weald, as well as for evolution of the London Basin. There is currently no robust age estimate for this site, but it may prove possible to apply new techniques in future.

6.3. GCR Site 1172 Upper Hale (SU 823494) (CAW, RMB)

6.3.1. Introduction

The GCR site of Upper Hale, in northeast Hampshire, is a small group of abandoned pits in the western part of a high level gravelly deposit (Fig. 46), formally named the Caesar's Camp Gravel Formation after an Iron Age hill fort at the north-eastern edge of the deposit. The exceptional altitude of this gravel, around 180 m above O.D., places it well above the altitudinal range of adjacent, unequivocal river terrace deposits, such as those of the Blackwater–Loddon river system to the north and northwest. This exceptional altitude and the lack of convincing correlatives of this unusual gravel are reasons for both uncertainty and disagreement concerning its origin (*e.g.*, Dines and Edmunds, 1929): it has variously been interpreted as marine (Wood, 1880; Barrow, 1919; Bury, 1910, 1922; Wooldridge, 1927; Wooldridge and Linton, 1955), glacial (Montford, 1966) and fluvial (Prestwich, 1890;

Irving, 1890; Monkton, 1892; Clarke and Fisher, 1983). Early comments on the Caesar's Camp Gravel date to the second half of the nineteenth century. The fullest, most recent account of the sediments within and close to the GCR site, on which this report is substantially based, is by Clarke and Fisher (1983), who worked in the area between 1976 and 1980 when good exposures in the deposits were still available for study. In August 2014 CAW observed two heavily degraded and partially vegetated faces which revealed some coarse gravel and a small patch (*c.*, 40 × 40 cm) of rubified palaeosol. A small area of yellowish-orange sand is exposed in a track on the south-eastern side of the main pit (SU 8233 4932) but none of the sediments were sufficiently well exposed to give any indication of stratigraphy.

6.3.2. Description

The Upper Hale GCR site is within the Heath Brow geological SSSI and surrounded by the Bourley and Long Valley biological SSSI, about 3 km north-west of Farnham, Surrey (Fig. 46). The extent of the GCR site is *c.* 270 × 160 m, centred on national grid reference SU 823 494. It is located towards the western end of the small irregularly-shaped area of high ground, often referred to as the 'Hale Plateau'. The key feature of the site is the Caesar's Camp Gravel Formation defined by the British Geological Survey Lexicon, 2014 as "unbedded and thickly bedded cobble gravel with interbedded coarse sands up to 6 m thick. The gravels are dominantly nodular flint to 0.2 m diameter, with subordinate quartz and Greensand chert. The sand is subangular, dominantly quartz with some flint, and occurs as horizontal planar-bedded units, cross-bedded lenses, and channel-fill sands and silts". "The formation has a sharp, highly irregular lower contact with Paleogene sands, obscured by a veneer of solifluction deposits". According to BGS borehole records, both inside and outside the GCR site, the base of the Caesar's Camp Gravel Formation across the centre of the plateau is at 176.8 to 184.1 m O.D., but around the eastern and southern margins of the plateau, the Caesar's Camp Gravel Formation is recognised down to 168.6 and 152.8 m, respectively. The general surface of the plateau is about 40 m above the projected surface of the highest river terrace in the Blackwater catchment to the north and at least 30 m higher than the chalk forming the Hog's Back ridge, the western extremity of the North Downs, to the southeast.

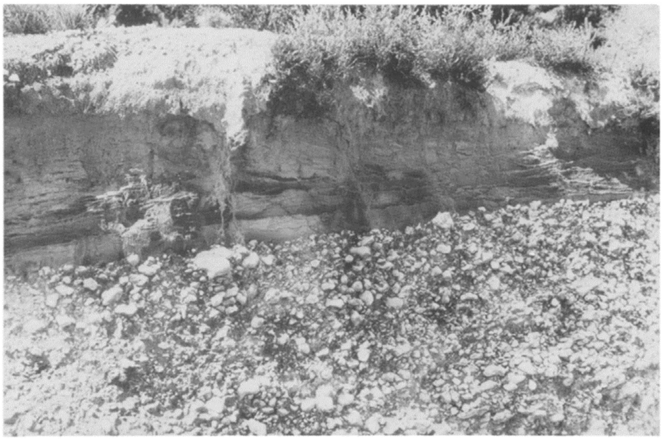


Fig. 47. Cobble gravel facies at Upper Hale.
(From Clarke and Fisher (1983, their Fig. 4), with permission.)

Clarke and Fisher (1983) recognised three main lithological units at Upper Hale from the base upwards: a) cobble–gravel facies, b) sand–clay facies and c) palaeosol and loam. The cobble gravel (Fig. 47), 0.8 to 1.5 m in thickness, is distinguished by the abundance (*c.*, 30 %) of its large (cobble size, + 64 mm), white-patinated, nodular flints derived from the chalk and greater than 95 % of smaller size fractions comprising flint. It is also poorly sorted. In addition, it contains typically rounded 'Paleogene' flint pebbles from local Paleogene pebble beds, a small quantity of chert from the Weald, and vein quartz, probably from pebble beds of Wealden Cretaceous strata. The small quantity of ironstone may be from this latter source or from iron pans within the Caesar's Camp Gravel itself. The matrix of the gravel is a yellow and orange fine to medium grained sand of subangular quartz with some coarse quartz and flint. The heavy mineralogy of the very fine sand fraction is dominated

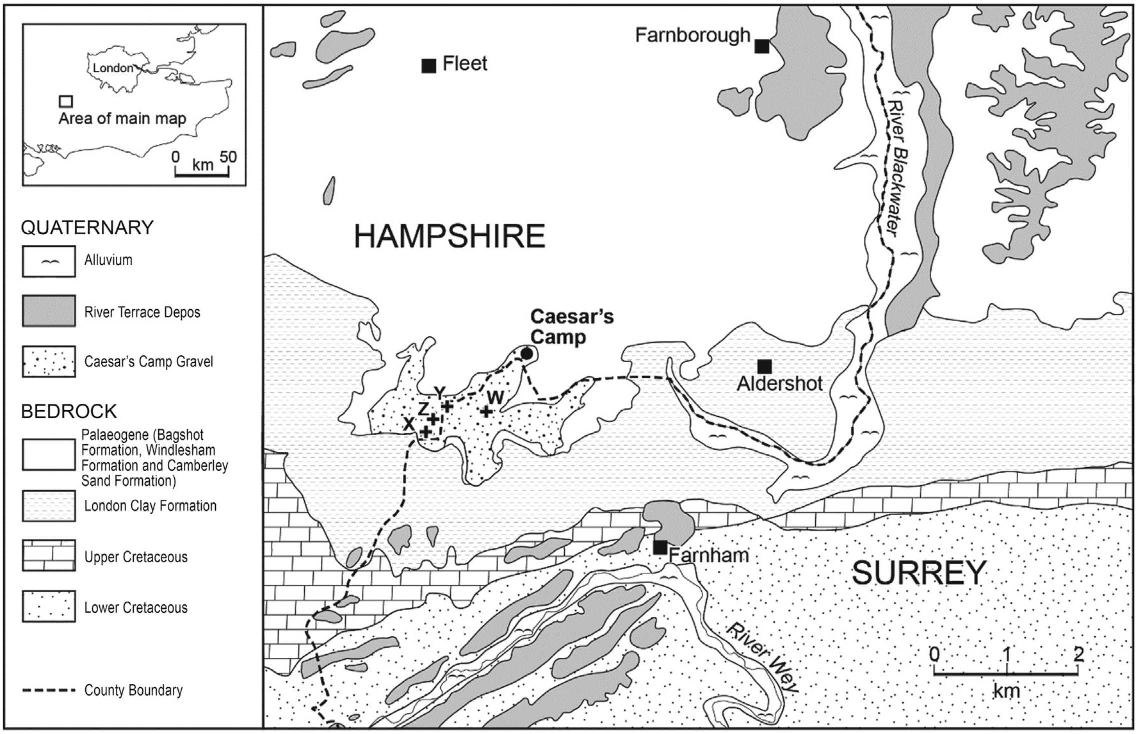


Fig. 46. Location and surrounding geology of the Upper Hale GCR site, showing samples taken by Clarke and Fisher (1983) from the Caesar's Camp Gravel.

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Fig. 48. Sand–clay facies at Upper Hale.
(from Clarke and Fisher (1983, their Fig. 7), with permission.)

by zircon and muscovite. Generally the gravel forms one unit but in places is separated by sharply-defined beds of fine to medium quartz sand, or thin silty-clay laminae that pass upwards into more massive clayey fine sand up to 0.5 m thick.

The sand–clay facies (Fig. 48) is differentiated into three sub-facies; horizontal, planar-bedded sands, cross-bedded sand lenses, and channel infill sands and silts. The planar-bedded sands, up to 1.5 m thick and sometimes showing thin textural banding, overlie and underlie the cobble gravel facies. At location Y overlying gravel occupies steep-sided channels up to 1.5 m deep and 1.0 m wide eroded into the top of the sands, interpreted as forming whilst the sands were frozen in periglacial conditions (Clarke and Fisher, 1983). Cross-bedded fine to medium sand lenses also occur within the gravel facies, especially in the western face of the pit at site Z (Fig. 46), varying in size from 1 to 10 m in length and 0.3 to 1 m in thickness. The fine-grained beds in the depression shown in Figure 48 exhibit concave bedding of fine to medium sand, passing upwards into laminated silts and clays parallel to the surface of the underlying gravel. Iron and manganese oxidation can be clearly seen at the base of the upper fine-grained unit.

The third of Clarke and Fisher's (1983) units is a rubified (10R4/6, 7.5YR6/8 and 10YR1/4 Munsell colours) palaeosol, in the upper part of the Caesar's Camp Gravels, which is overlain by up to 0.8 m of ‘freely draining very acid sandy and loamy soil’ in which a modern podzol of the Southampton series (Cranfield University, 2024) has developed.

6.3.3. Interpretation

The absence of fossils, confirmed *in situ* archaeological remains, and material suitable for absolute dating has made the determination of age, correlation with other sites, and accurate assessment of depositional processes relating to the Caesar's Camp Gravel at Upper Hale extremely difficult. Until the final decade of the nineteenth century high level gravels of southeast England, including the Caesar's Camp Gravel, were often assumed to be marine in origin, even in the absence of marine fossils, a traditional view typified by Wood (1880, p. 475) reference to “gravel of the great submergence…reaching elevations of about 600 feet” (*c.*, 183 m). In contrast, Prestwich (1890), in a wide-ranging summary of several decades of research, argued for a fluvial origin, supported a few months later by Irving (1890). Monkton (1892), in a review of gravels south of the Thames, concurred with this view. However, twenty years later, Bury (1910) reopened support for the marine hypothesis in a discussion of the development of the western area of the Weald. Later (Bury, 1922), in a description of high level gravels in north-east Hampshire, he maintained this viewpoint based on several, but actually inconclusive, lines of evidence. These are the large size of the flints, the loss of their extremities by battering, the apparent uniformity of height (560–620 ft, 170.7–189.0 m) of assumed equivalents along the length of the North Downs, and the acceptance of Barrow's (1919) view that deposits on the Chiltern Hills to the north of London, interpreted as marine, are equivalent to the so-called ‘Southern Drift’ which includes Upper Hale. Subsequently, Wooldridge (1927) argued for a widespread marine inundation across southeast England during the Paleogene and, later supported by Linton (Wooldridge and Linton, 1939, 1955), he maintained a strong advocacy of the marine process for the next four decades. However, although the marine interpretation still enjoyed some followers, it was receiving increasing opposition and by 1960 the pendulum had swung back firmly in favour of the importance of fluvial activity as the dominant process forming the late Paleogene and Quaternary landscape of southeast England. Although some of the earlier authors had inferred the presence of ice and snow as contributors to landscape development (Dines and Edmunds, 1929) in the region including at Upper Hale, most descriptions seem to equate to periglacial, rather than strictly glacial, processes (upright stones for example) and none were as forthright as Montford, who as late as 1966 advocated a glacial origin for the Caesar's Camp Gravel.

In contrast, the detailed descriptions of Clarke and Fisher (1983) strongly suggest that the Upper Hale deposits are waterlain, with significant variations in flow rates shown in the variation in particle sizes. The clast lithological assemblage suggests that the gravels and sand were deposited by a river or rivers flowing from the south or southeast across the North Downs. Post-depositional modification of the Caesar's Camp Gravel has involved pedogenesis and thermal and structural periglacial influences. In the absence of unequivocal evidence for a particular depositional process responsible for the dominant gravel component of the sediments at Upper Hale, it is inevitable that the site will remain controversial. Sedimentology suggests a fluvial origin, but it is situated significantly higher than the present-day River Blackwater. In view of the stratigraphic importance of this site and the unusual nature of the dominant sediment it is imperative that the extant faces, though degraded, should be protected, to facilitate additional research and educational access. There is no evidence as yet for the age of these deposits, nor anything to link them with the other ‘high-level’ GCR sites in the network.

6.3.4. Conclusions

Upper Hale Gravel Pits provide exposures in an Early Pleistocene aggradation of southern England known as the Caesar's Camp Gravel. The origin of this deposit has been widely disputed; marine, glacial and fluvial environments all being invoked at various times. Research at this site has described the sediments in some detail but failed as yet to yield a robust age estimate or clarity over potential correlative deposits nearby. The obvious antiquity of this accumulation, and its uncertain association with the fluvial system of the London Basin, makes the Caesar's Camp Gravel of great potential importance for palaeogeographical reconstructions of early Pleistocene times in Britain.

7. Tufa deposits

7.1. GCR Site 2249 Blashenwell Farm (SY 952805) (CAW, RMB)

7.1.1. Introduction

Blashenwell Farm, in Dorset, is the site of a large tufa (spring-fed calcium carbonate) deposit and associated Mesolithic settlement. Besides its value in terms of Holocene environmental reconstruction and molluscan biostratigraphy, it is of considerable archaeological importance. As the largest known tufa site in southern England, Blashenwell Farm has attracted the attention of researchers since at least the middle of the nineteenth century. Early workers, including Mansel (1857a, 1857b) and Austen (1857) and those who followed, such as Reid (1896) and Bury (1950), were able to study a large pit containing midden material as well as human artefacts. Molluscs and mammals from the ‘Romano-British layer’ at Blashenwell were published by Carreck and Davis (1955) as part of a paper mostly about a site at Bowleaze

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near Weymouth. However, this pit has been filled and the most recent palaeoecological investigation, reported by Preece in 1980, on which this account is substantially based, required the re-excavation of a small section at the eastern side of the pit. This new excavation facilitated detailed description of the stratigraphy and the collection of samples for the identification of the (mostly molluscan) fauna. No suitable material for radiocarbon dating was obtained from this excavation, but two dates were assayed from material in collections held at Dorset County Museum. Together with a comparative study of other molluscan sites in southern England, these two dates indicate that tufa deposition at the site occurred from the early to mid-Holocene.

7.1.2. Description

The Blashenwell tufa deposit (Fig. 49) is located in the upper catchment of the Corfe River, near the foot of the Cretaceous (formerly Jurassic) Purbeck Group scarp, 2 km south–southwest of Corfe Castle in the Isle of Purbeck region of Dorset. A calcareous spring, rising in Purbeck limestone, flowed intermittently across Cretaceous Wealden Group and the tufa into a Corfe River tributary. The tufa is up to about 4 m thick, east of the road at SY 9522 8045 (Preece, 1980; Figs. 49 and 50, site 1), and filled a shallow depression *c.* 600 × 280 m before being partially excavated for marling Purbeck clays. Prior to 1952, when the pit was filled and converted to arable land, researchers had access to a large area west of the road (Fig. 49). Preece (1980) was able to excavate, describe and sample Site 1 (Fig. 50) just east of the road at SY 952805. Two other small sections (Fig. 49, sites 2 and 3), were exposed during the 1970s. These latter sites are apparently unreported but, according to Preece (1980), site 2 differs only slightly from site 1 in lithology and faunal content, whilst the fauna of site 3 is similar to the upper levels of site 1.

The earliest site description was by Mansel (1857a, 1857b). He described four layers but, with the exception of the topsoil, they are

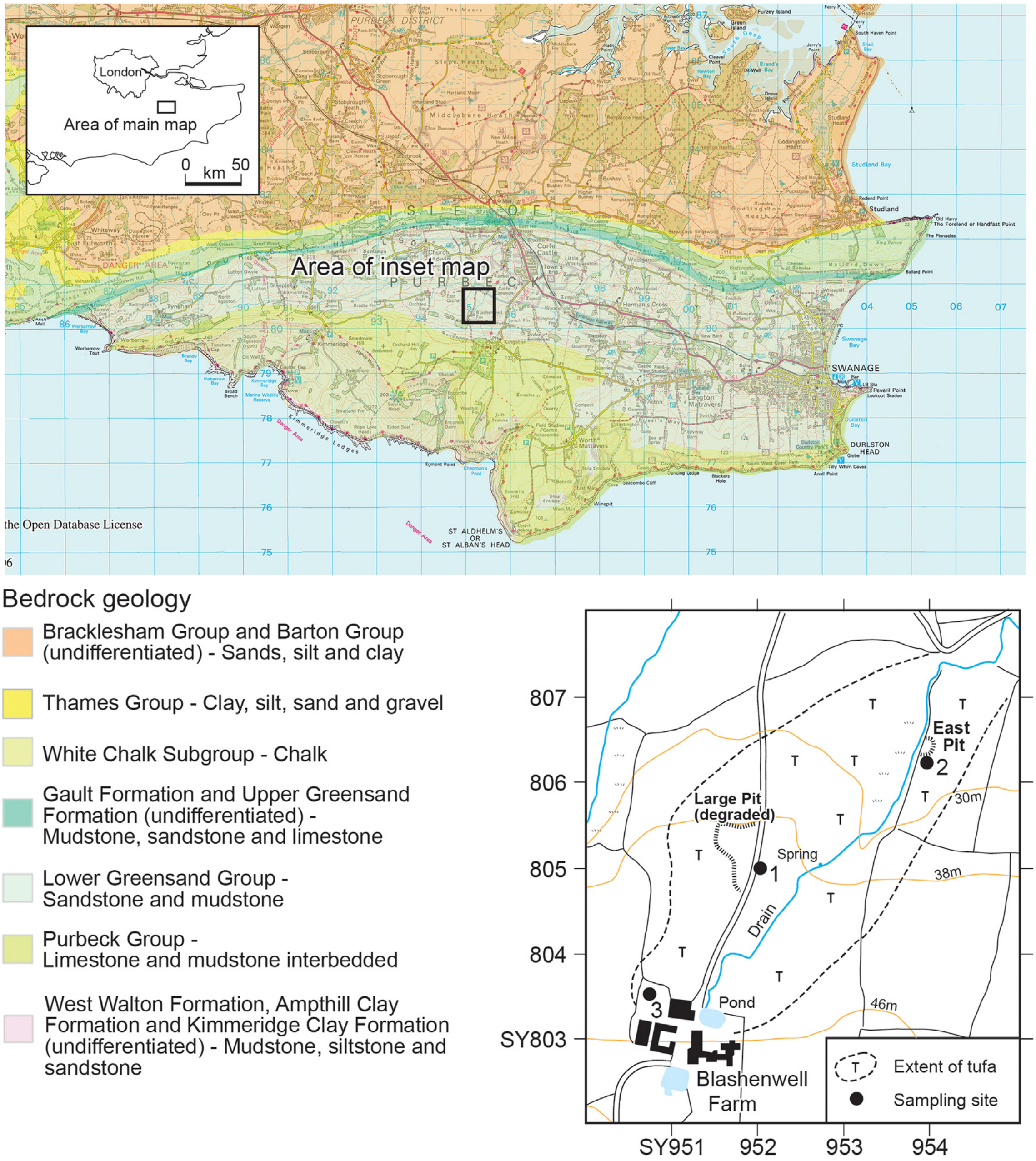

Fig. 49. Location of Blashenwell GCR site and surrounding geology, including extent of tufa and location of sampling points at Blashenwell GCR site (modified from Preece, 1980, his Fig. 2). Map contains geological data available under an Open Government licence from the British Geological Survey © UKRI [2024].

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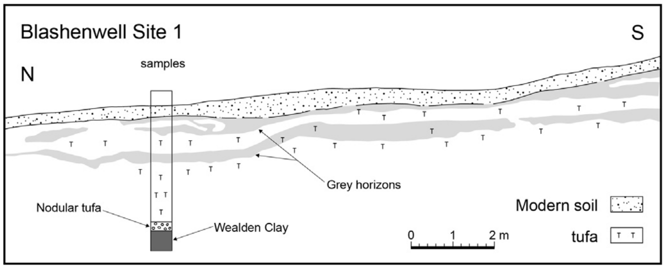

Fig. 50. Section through the tufa at Blashenwell Site 1, including the column sampled by Preece.
(After Preece (1980, his Fig. 3).)

difficult to recognise in the context of later work. His view, that the presence of marine, as well as non-marine, mollusca together at the site inferred a marine incursion, was quickly rejected by Austen (1857), who attributed the marine molluscs – limpets and winkles – to human activity. This interpretation was eventually conceded by Mansel-Pleydell (1886) and subsequently confirmed by the geological surveyor, Clement Reid (1896), who described a 'kitchen midden' with marine shells, animal bones, charcoal and microlithic flint chips, associated with tufa.

Reid (1896) was the first detailed work at the site. His section description, reproduced by Preece (1980) and set out below, includes a range of flora, fauna (including a list of Mollusca), charcoal and archaeological material, including flint flakes, pottery, and coins:

		Feet
Black soil	at its base roman coins, Romano-British pottery, shells of oyster, whelk, cockle, *Helix aspersa, H. ericetorum, H. virgata* etc.	1
Hard tufa	with leaves of hazel, elm and oak, land-shells, flint-flakes and charcoal.	8
Granular tufa	fairly soft, flint-flakes, bones of pig and deer, limpets and other marine shells, land snails, including *Clausilia 71ccurrin, Bulimus montanus,* etc., much charcoal	
Loamy and marly tufa	with small land-shells, occasional *Limnaea truncatula,* rare flint-flakes, and charcoal.	
Loam with stony base		

It illustrates the overlap between geology and archaeology in establishing the stratigraphical importance of the site.

Nothing of further interest emerged after Reid's (1896) work, until the site was given further stimulus by the construction of a road to Blashenwell farmhouse in 1936. However, with the exception of Bury (1950), who extended the faunal list, most interest subsequently focussed on archaeological finds and little was said about the depositional context. The geology of the site was not seriously considered again until the late 1970s when Preece (1980) exposed a small section (Fig. 49, Site 1) just east of the road at SY 952 805. This revealed the following stratigraphy (Fig. 50), with a modern soil above six different tufa layers and Weald Clay bedrock at the base.

Depth (cm)	Sediment description	Reid's (1896) terms
0–25	Modern rendzina soil	
25–40	Light brownish grey (Munsell colour when moist, 10YR 6/2) tufa, pisolitic in places	
40–50	Light grey (10YR 7/2) tufa	Granular tufa
50–70	Light brownish grey tufa	
70–112	Soft light grey tufa	–
112–142	Light brownish grey tufa	
142–300	Light grey tufa becoming nodular towards base	Loamy and marly tufa
300+	Weald Clay (Cretaceous) (7.5YR 5/4)	

Preece (1980) differentiated six tufa layers, largely on colour but also partly on texture. He compared his strata to those of Reid (1896) observing, as Reid had done, that the units above 112 cm were distinctly harder than those below, to the extent that extraction of shells was sometimes difficult. Preece did not find equivalent material to Reid's 'hard tufa' in his section, only fragments in the field on the west side of the road. The grey layers (Fig. 50) observed by both Reid (1896) and Preece (1980) are attributed by Preece to organic material accumulation due to subaerial exposure and drying during slow phases of tufa growth, rather than to the presence of excess charcoal as suggested by Reid (1896). Even though some charcoal flecks are present they are not considered by Preece to be the sole reason for the grey colouration.

The detailed molluscan analysis performed by Preece (1980; Fig. 51) enabled him to propose an environmental history of the Blashenwell tufa, based on three ecological phases, and to define three molluscan assemblage zones, facilitating correlation with other dated sequences in southern Britain (Kerney, 1977; Preece, 1978; Kerney et al., 1980). The three ecological phases are described as a) early marsh-ground (300–290 cm), b) development of a shaded environment (290–80 cm), and c) partial opening up of the habitat, possibly by human disturbance (80–25 cm), whilst boggy pools persisted throughout. The basis of the analysis is recognition of three ecological categories:

- Swamp species — obligatory hygrophiles: *Carychium minimum*, *Zonitoides nitidus*.
- Terrestrial A — wide ecological tolerance, occurring in open ground, marshes and coniferous and deciduous woods: *Cochlicopa*, *Columella*, *Punctum*, *Vitrina*, *Vitrea*, *Nesovitrea*, Limacidae, *Etuconulus*, *Cepaea*, *Arianta*.
- Terrestrial B — species more critical in their requirements than the Terrestrial A group and most frequent in deciduous woods and similar well shaded places: *Carychium tridentatum*, *Aegopinella*, *Acanthinula*, *Ena*, Clausiliidae. *Carychium tridentatum* (stippled in Fig. 51) and *Aegopinella* form numerically the largest part of this group.

Overall the mollusc assemblage suggests marshy ground but not a well-vegetated fen because several species of swamp *Vertigo* such as *V. antivertigo*, *V. moulinsiana* and *V. augustior* and Succineidae are absent. The only exception to this is the presence of *V. moulinsiana* at the top of East Pit (Fig. 49, Site 2). The presence of marsh is supported by the frequency of *Lymnaea truncatula* throughout the section except in the grey horizons where drier conditions inhibited its survival. Wet conditions near the base of the section are also indicated by *Vallonia pulchella*, *Zonitoides nitidus*, and *Carychium minimum*, and the nodular nature of the tufa.

Above 290 cm in zone b), the proportion of shade-demanding species of the Terrestrial B group, such as *Vertigo pusilla*, *Vertigo alpestris* and *Oxychilus alliarius*, increases at the expense of the marsh element. Between 190 and 145 cm the calcifuge, *Zonitoides excavates*, is present, suggesting a mosaic of different micro-habitats including somewhat acidic hollows on the tufa surface. At 135 cm, roughly corresponding to the change from Reid's 'loamy and marly tufa' and his 'granular tufa', the mollusc *Oxychilus cellarius* begins to replace *Oxychilus alliarius*, which prefers shade. Woodland species (Terrestrial B group) significantly decline whilst catholic species (Terrestrial A group) increase, marking an important ecological change. Well-drained soils and the substantial reduction of forest cover are indicated by the presence of *Pomatias elegans* and *Vertigo pygmaea*. In view of the evidence for human occupation at Blashenwell, this ecological change may have a human cause, although Preece suggests that the reason is not entirely clear. Near the top of the section, between 25 and 40 cm, *Lymnaea truncatula* is still present along with *Anisus leucostoma* and *Aplexa hypnorum*, which indicate the existence of boggy pools on the surface of the tufa towards the end of tufa formation.

The uppermost soil was not sampled by Preece but the molluscs were published by Carreck and Davis (1955). They found a molluscan

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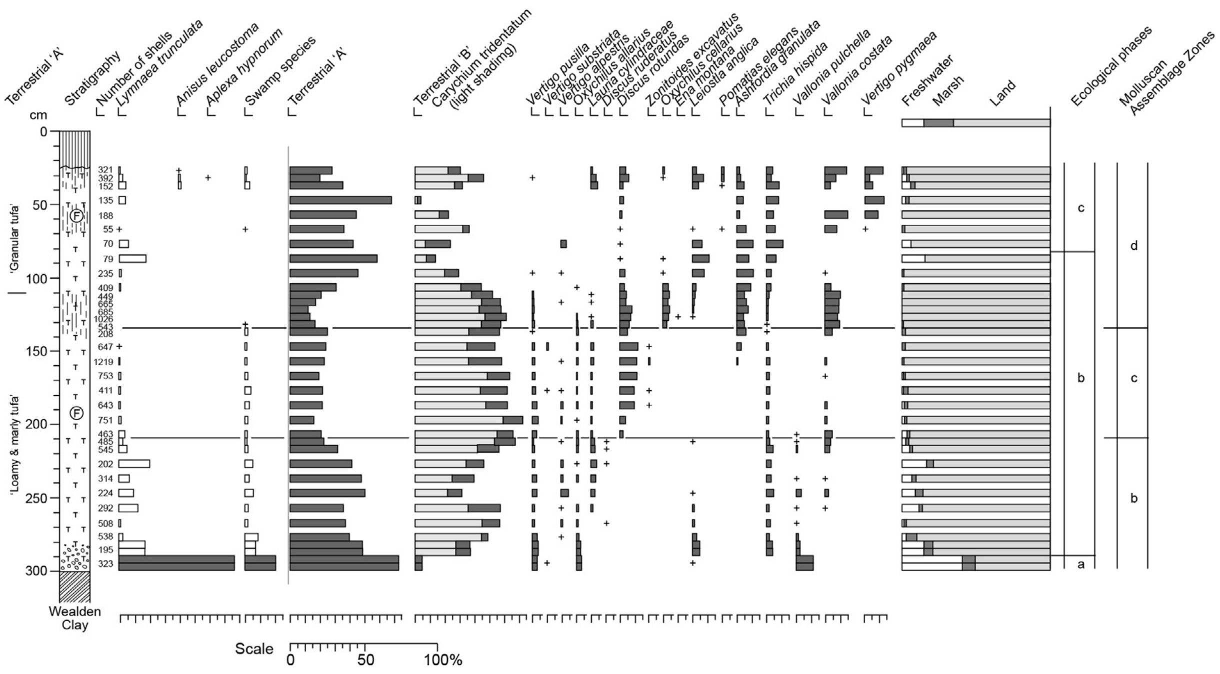

Fig. 51. Mollusc diagram summarising the analysis from the column sampled at Site 1. Percentages of freshwater and swamp species (open histograms) calculated as independent percentages of total land mollusca. F = flint flakes (after Preece, 1980, his Fig. 4). Key for sedimentary column as in Figure 45.

assemblage that was very similar to that shown in Figure 51. It is listed below:

Pomatias elegans (Müller) 300
Carychium minimum (Müller) 916
Lymnaea truncatula (Müller) 1
L. peregra (Müller) 3
Planorbis planorbis (Linné) 1
P. vortex (Linné) 2
P. crista (Linné) 1
Succinea sp. 1
Cochlicopa lubrica (Müller) 42
Vertigo pygmaea (Draparnaud) 63
Pupilla muscorum (Linné) 32
Lauria cylindracea (Curri) 1
Acanthinula aculeata (Müller) 34
Vallonia costata (Müller) 1
V. excentrica Sterki 440
Ena obscura (Müller) 9
Clausilia bidentata (Strom) 28
Cecilioides acicula (Müller) 176
Vortex lapicida (Linné) 5
Helix nemoralis (Linné) 15
H. aspersa (Müller) 43
Hygromia striolata (Pfeiffer) 114
H. hispida (Linné) 153
Helicella virgata (Curri) 94
Punctum pygmaeum (Drapamaud) 56
Discus rotundatus (Müller) 162
Vitrea crystallina (Müller) 29
Oxychilus cellarius (Müller) 8
Retinella radiatula (Alder) 1
R. nitidula (Drapamaud) 106
R. pura (Alder) 1
Vitrina pellucida (Müller) 1
Buccinum undatum (Linné) present
Ostrea edulis (Linné) present
Cardium edule (Linné) present

Preece (1980) also draws attention to several other mollusc species present as fossils within the tufa at Blashenwell: *Ena montana*, absent from Dorset today, may have been more tolerant of warmer summers during the Neolithic; unbanded morphs of *Cepaea nemoralis* may be climatically related, because some modern specimens show banding — possibly the fossil unbanded specimens indicate better summers than at present; *Pomatias elegans* fossils were larger than their modern equivalents on the site, as also at Wateringbury in Kent (Preece, 1978) but at the time of writing the reason for this difference was not clear.

Biostratigraphically, molluscan assemblage zones have been defined based on the presence, absence or appearance of certain indicator species (Fig. 51). These correspond with similar zones at other sites in southern England (see Wateringbury — Section 7.2). *Discus ruderatus*, a boreo-continental species, currently absent from Britain, is found at Blashenwell only in the lower samples below 210 cm, with a molluscan assemblage attributable to zone b. In contrast, *Discus rotundatus* first appears and expands at this level and defines the base of zone c. The base of zone d at 135 cm is recognised by the appearance and expansion of *Oxychilus cellarius*.

Using this biostratigraphy and on the assumption that there is broad zonal synchronism across southern Britain, Preece (1980) suggested that tufa deposition at Blashenwell began shortly before 9000 BP. Two radiocarbon dates, 5750 ± 140 ^{14}C BP and 5425 ± 150 ^{14}C BP, from bone containing zone d mollusca, give some indication of the timing of deposition of the upper part of the tufa, and are consistent with other zone d assemblage dates (Kerney, 1976; Preece, 1978). Preece (1980) discounts an older, bone-derived date of 6450 ± 150 ^{14}C BP (BM-89; Barker and Mackey, 1961), as it is only imprecisely described as from the middle zone of the tufa and unrelated to his detailed molluscan sequence.

Other types of fossils have also been recorded at the site – marine molluscs, plant remains, ostracods and several vertebrates – some of which support the environmental evidence of the non-marine molluscs. For instance, ostracod valves (*Eucypris pigra* (Fischer), *Herpetocypris reptans* (Baird) and *Cyclocypris* sp.) indicate the presence of boggy pools, whilst the two vertebrate species recovered by Preece, *Apodemus* sp. (wood mouse) and *Clethrionomys glareolus* (Schreber) (bank vole), suggest a shady environment. In addition, Carreck (1955) recorded

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Talpa europaea L. (mole), *Arvicola* sp. (water vole), *Sus scrofa* L. (pig), *Capreolus capreolus* (L.) (roe deer), *Cervus elephas* L. (red deer) and *Bos* sp. (ox) at the site and Carreck and Davis (1955) added *Ovis* or *Capra* (sheep or goat).

7.1.3. Interpretation

Preece (1980) states that faunal and stratigraphical evidence from other sites points to a cessation date for tufa formation broadly between 5000 and 4000 ^{14}C BP. The reason for this cessation is more difficult to ascertain and is probably not related simply to changes in temperature and/or the quantity of rainfall (Bury, 1950). Reid (1896) suggested tufa cessation was related to destruction of adjacent forests but did not elaborate the precise mechanism. Pedley et al. (2009) have demonstrated in flume experiments that tufa deposition depends on the presence of biofilm (extracellular polymeric substances), and that virtually no tufa-like precipitate was obtained from the flumes supplied with UV-treated river water. On this evidence, perhaps the opening up of the habitat, suggested in Preece's (1980) uppermost ecological phase, and by Reid over a century ago, is implicated in tufa cessation at Blashenwell because more UV radiation would reach the spring, leading to biofilm reduction.

The archaeological interest at Blashenwell Farm has been summarised by Dover (2005, p. 34), in a Bournemouth Archaeology Report, as “a Mesolithic Midden, at least three Bronze Age stone cist inhumations, other possible graves and isolated human remains, skulls and vertebrae, a herringbone ‘wall’, and at least one probable Building with Iron Age and Romano British phases, possibly associated with shale armlet production as well as other Iron Age and Romano British material discovered nearby”.

Whilst there is, presently, nothing to see of the geological or indeed the Mesolithic archaeological interest at Blashenwell Farm, the scale and complexity of the geology and archaeology are such that the site deserves its GCR citation. Blashenwell Farm remains the largest, and one of the most important, tufa sites in southern Britain, where a detailed environmental history of the early to middle Holocene has been reconstructed from the careful study of a molluscan assemblage supported by a number of radiocarbon dates. The geology of this GCR site is significantly enhanced by being closely associated with equally important Mesolithic material.

7.1.4. Conclusions

The tufa deposit at Blashenwell Farm is important for Quaternary studies, providing a detailed record of molluscan biostratigraphy and environmental history during the early- and mid-Holocene (mollusc assemblage zones b to d). It is particularly valuable for the length and continuity of the record and the dating potential provided by the presence of associated archaeological remains. Several radiocarbon dates are also available from the site.

7.2. GCR Site 2260 Wateringbury (TQ 688 534) (BAH, RMB)

7.2.1. Introduction

There are frequent occurrences of tufa in the Maidstone area, the source of carbonate being Kentish Ragstone within the Lower Cretaceous Hythe Formation. Tufa was extensively used by the Romans, Saxons and Normans as building stone (Archibald, 1934) and can be seen incorporated into the towers of local churches and St. Leonard's Tower, West Malling (Topley, 1875; Livett, 1904; Brown and Kennard, 1939; Worssam, 1963).

The tufa site at Wateringbury (Fig. 52) is the only one in the area to have been the subject of serious scientific study (Brown and Himus, 1938; Brown and Kennard, 1939; Kerney, 1956; Kerney et al., 1980; Preece, 1991; Garnett et al., 2004). It is also notified as a geological SSSI. The deposit contains an abundant, diverse and well-preserved early to mid-Holocene molluscan fauna spanning biozones a to d and can be compared to other Holocene mollusc successions, together with ostracods, mammals, plant macrofossils and pollen. Eight radiocarbon dates suggest a constant deposition rate of between 7 and 8 cm per century between 12,200 and 7100 cal BP. The reason why tufa deposition ceased at this time is not known but may be linked to Neolithic forest clearance which changed the hydrological regime. Recent work on the stable isotopes and trace elements of both ostracod and tufa calcite has provided important information on the early Holocene climate of the area (Garnett et al., 2004).

7.2.2. Description

The Wateringbury tufa was first described by Brown and Himus (1938), though the reporting of tufa in the vicinity had been known since Topley (1875) noted occurrences in the East Malling area. Livett (1904) also commented on the discovery of a tufa deposit close to the present site which was noticed after water scoured the bed of a stream near Wateringbury Lodge after a great storm in September 1902. A.S. Kennard was the first to work on the molluscs and reported 32 species, mostly terrestrial snails (Brown and Kennard, 1939). His work was extended by Kerney (1956) who collected new material and expanded the faunal list to 41 species of mollusc and three mammals.

The most detailed recent study on the contained micro- and macrofossils is by Kerney et al. (1980) and their work provides the basis for much of the following report. They stated that sections in the tufa were visible to a height of about 2.5 m for approximately 80 m along the eastern side of Love Lane, Wateringbury (Fig. 52) filling a channel in a small valley running north–south at its confluence with a larger east–west valley. Additional augering confirmed Brown and Kennard's view that the deposit occupies a roughly elliptical area 110 yards (101 m) long by 80 yards (73 m) wide resting on an erosion surface of unweathered Atherfield Clay. They suggested the tufa was probably deposited by water issuing from springs at the base of the Hythe Formation some 500 m to the northwest.

In 1975 a section was cleaned on the east side of the lane where the deposit was at its thickest (TQ 6876 5344, Fig. 53). Samples were taken from the open section, from the present soil surface to just beneath the level of the road, where the deposit became waterlogged. Augering showed that over a metre of further tufa existed beneath the water table and this was cored using a 10 cm diameter percussion corer (Kerney et al., 1980).

The stratigraphy at this location (Fig. 53) comprised:

0–20 cm	modern soil (10YR 4/2)
20–120	soft white (10YR 7/3, drying to 3/2) tufa, nodular in places; much disturbance by roots and animal burrows in upper part
120–124	grey (10YR 6/2) tufa
124–132	soft white tufa
132–138	grey (10YR 6/2) tufa
133–190	soft white tufa
190–194	grey (10YR 6/2) tufa
194–220	white tufa, lightly cemented and rather ‘biscuity’ in texture
220–230	iron-stained (7.5YR 5/6) layer of hard cellular tufa, containing occasional leaf impressions (*Salix*)
230–410	loose greyish brown (2.5YR 5/2) nodular tufa becoming coarser downwards; some macroscopic plant detritus towards base; waterlogged below 270 cm
410+	very dark grey (5Y 3/1) clay (Atherfield Clay Formation)

As a whole the deposit is fairly uniform though with coarser nodular tufa in the lower and upper parts of the succession, perhaps indicating stronger water flow. Between 220 and 230 cm is an iron pan probably marking the position of the former water table, whilst between 120 and 194 cm are three grey horizons possibly reflecting pauses in carbonate formation and incipient soil development. Recent work by Garnett et al. (2004) confirms the deposit has suffered minimal post-depositional diagenetic alteration.

A large piece of *Quercus* wood in the section between 255 and 260 cm (Fig. 54) was dated to 10,120–9000 cal BP (8470 ± 190 ^{14}C BP; Q-1425) by Kerney et al. (1980). Subsequently, Preece (1991) submitted six further samples of archived tufa for dating. The tufa dates

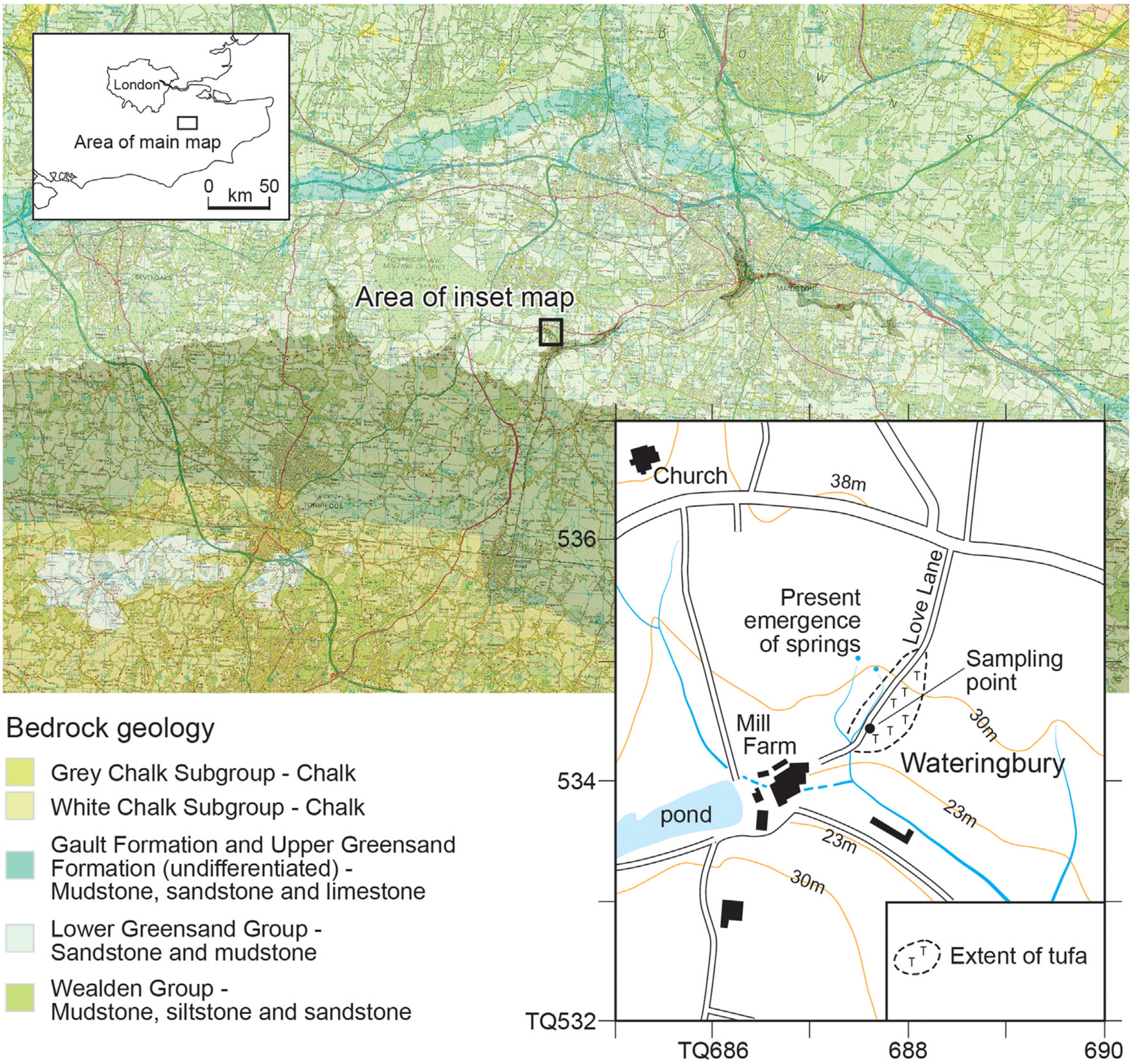

Fig. 52. Location and surrounding geology of the Wateringbury tufa site (from Kerney et al., 1980, their Fig. 7). Map contains ordnance survey data used under a Digimap licence to Birkbeck and geological data available under an Open Government licence from the British Geological Survey © UKRI [2024].

form a coherent series between 10,330 ± 80 (Gd-5542) and 6190 ± 70 ^{14}C BP (Gd-5539). However, they have not been corrected for the 'hard water' effect that terrestrial carbonate dates are prone to and therefore may be slightly older than their true age. This is illustrated by the date of 8470 ± 70 ^{14}C BP (Gd-5538) for tufa between 190 and 195 cm, the same age as the wood date Q-1425 but 65 cm higher in the stratigraphy. The dates are shown adjacent to the stratigraphic column in Figure 54 together with calibration to calendar ages (Garnett et al., 2004).

The tufa proved to be rich in molluscs of exceptionally good preservation; over 42,000 shells were extracted from 51 analysed samples (Kerney et al., 1980; Fig. 54). The general nature of the fauna throughout is that of a calcareous swamp with terrestrial forms dominating. There are a few aquatic species present, mainly *Lymnaea truncatula*, *Pisidium casertanum* and *Pisidium personatum*, which are typical of swampy ground or small pools. Only at one level, between 355 and 360 cm, do single individuals of *Bithynia tentaculata* and *Pisidium milium* suggest the presence of a larger, more permanent water body.

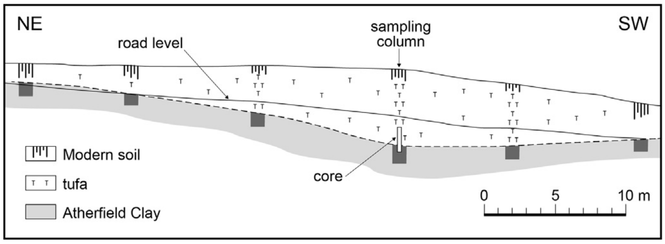

Fig. 53. Generalised stratigraphical section of the Wateringbury tufa site. (After Kerney et al. (1980, their Fig. 8).)

Kerney et al. (1980) divided the molluscan sequence into five zones based on the composition of dry-ground Mollusca.

Zone a between 410 and 365 cm (Fig. 54) contains high frequencies of terrestrial group 'A' species, catholic snails of wide ecological tolerance, *e.g.*, *Cochlicopa*, *Punctum*, *Vitrina*, *Vitrea*, *Nesovitrea*, *Euconulus*. *Vallonia excentrica* occurs uniquely in this zone; it is a shade-intolerant dry grassland species (Kerney, 1999) suggesting the environment was probably quite open.

Zones b and c between 365 and 195 cm (Fig. 54) show an increase in numbers of terrestrial group 'B' species, notably *Carychium tridentatum*; a species characteristic of relatively moist, sheltered, well-vegetated places (Kerney, 1999). The group rises rapidly to make up over 50 % of the land fauna and remains at about this level throughout the rest of the succession, probably reflecting the development of woodland at the expense of grassland. Above 345 cm the only *Vallonia* species to survive is *V. costata* which can tolerate light shading, which together with relatively high values for *Trichia*, suggests the canopy was probably light and open. The boundary between zones b and c is determined by

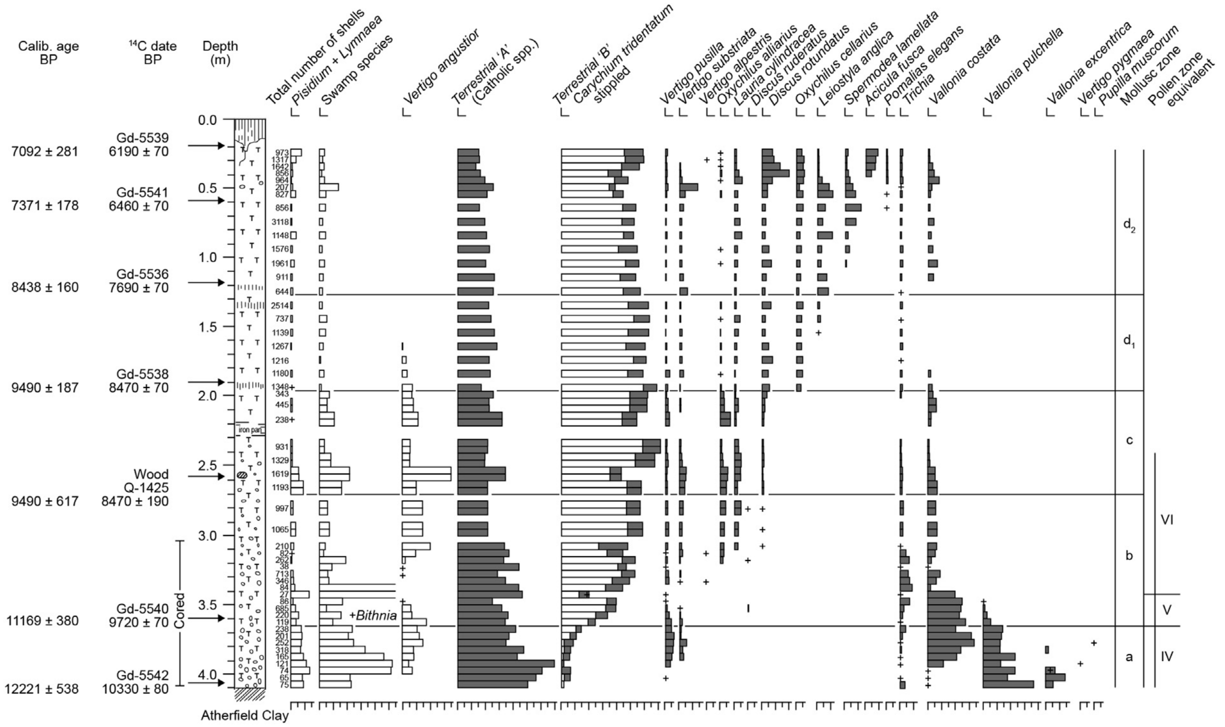

Fig. 54. Molluscan diagram from the Wateringbury tufa site. Key as in Figure 48. Strongly nodular tufa is shown by circles (after Kerney et al., 1980, their Fig. 9). Stratigraphical column and dates are from Garnett et al. (2004).

the appearance of *Discus rotundatus* at 270 cm, as at Blashenwell (Section 7.1).

Woodland elements remain dominant during zone d^1 between 195 and 125 cm (Fig. 54) with *Vallonia* disappearing, suggesting the presence of deep shade. The final disappearance of *Vertigo angustior* probably reflects the elimination of open grassy conditions within the swamp as woodland encroached around its margins.

In zone d^2 between 125 and 20 cm (Fig. 54) woodland elements continue to dominate. *Vallonia costata* returns, at values of about 5 % perhaps indicating some slight opening of the vegetation. *Leiostyla anglica* and *Spermodea lamellata* arrive and quickly reach combined values of about 15 % between 70 and 50 cm; they suggest humid, oceanic woodland. Kerney (1999) suggests both these species are good indicators of ancient woodland that has not been clear felled, implying the tufa succession reflects natural environmental change. They both decline above 50 cm and *Acicula fusca* appears in some numbers; it is another form that suggests the woodland was deciduous and undisturbed (Kerney, 1999).

Plant remains have been found only in the lower levels where they have been preserved through waterlogging. Pollen is also present throughout most parts of the section but a large proportion, often over 50 % of all palynomorphs, proved unidentifiable through corrosion or physical folding and breakage. The resulting pollen diagram (Fig. 55) which is from the lower part of the section only (Fig. 53), may therefore

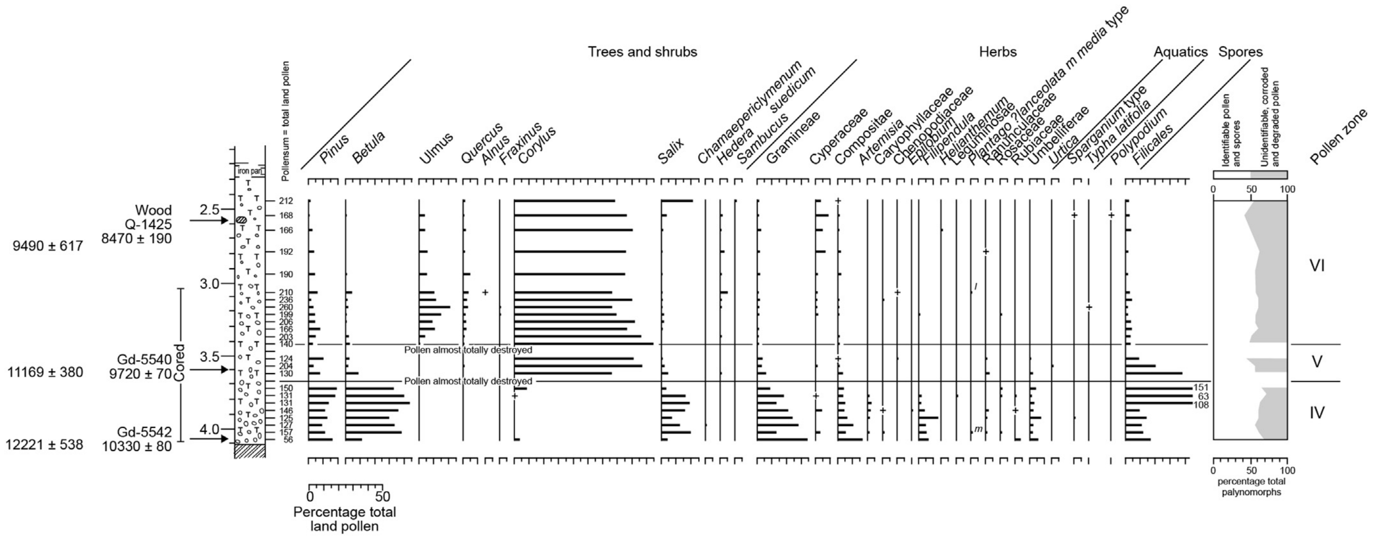

Fig. 55. Pollen diagram from the Wateringbury tufa site. Note that this diagram only covers the lowermost part of the sequence. (After Kerney et al. (1980).)

be biased towards more resistant and abundant taxa or those that have characteristic shapes that render identification possible (Kerney et al., 1980).

The lowest zone (IV — 365–410 cm) is dominated by *Betula* which has frequencies between 30 and 45 % total land pollen (TLP). *Pinus* and *Salix* are also worthy of note, the latter reaching up to 20 %. Poaceae, Asteraceae, Umbelliferae and *Filipendula* are the most abundant herbaceous taxa and fern spores are also present in large numbers. Kerney et al. (1980) interpreted this assemblage as representing an open birch woodland with pine in the vicinity; however the presence of *Salix*, a genus of moderate pollen production and dispersal, in such high percentages suggests willow carr existed in the wetter areas. Plant macrofossils from this zone include seeds of *Viola*, *Chenopodium* and *Chelidonium majus* together with fruits of *Eupatorium cannabium*.

The second zone (V — 345–365 cm) contains two horizons with virtually no pollen, presumably due to oxidation following temporary drying of the tufa surface. *Corylus* frequencies rise rapidly to over 85 % TLP and *Betula*, *Salix*, *Pinus* and Poaceae pollen are all greatly reduced. *Chelidonium majus* and *Eupatorium cannabium* are the most abundant plant macrofossils.

The uppermost zone (VI — 240–345 cm) contains pollen from more thermophilous taxa such as *Ulmus* and *Quercus*. However, *Corylus* pollen continues to dominate with high frequencies recorded. The uppermost pollen sample, 15 cm below the base of the iron-pan, contains high percentages of *Salix* pollen. Willow was probably growing on the site as proved by leaf impressions in the hard tufa of the iron-pan. Seeds of *Carex* also suggest a local presence which coincides with the rise in Cyperaceae pollen.

The pollen and plant macrofossil evidence together suggests therefore that in zone VI (mollusc zones b and c) the tufa was forming in an area of marsh, with *Salix* and Cyperaceae, within a temperate deciduous forest, also seen in the mollusc record, in which *Corylus*, *Ulmus*, and *Quercus* were abundant.

Mammalian remains were recovered from the mollusc samples and identified by A.J. Stuart. They included teeth of *Talpa europaea* (mole) and *Clethrionomys glareolus* (bank vole), together with a mandible and tooth of *Microtus agrestis* (field vole). Kerney (1956) reported the discovery of the mandibular ramus of *Neomys* cf. *fodiens* (water shrew).

Five species of ostracod were recovered by J.E. Robinson from various levels (Kerney et al., 1980). Between 180 and 300 cm *Psychrodromus* (*Ilyodromus*) *olivaceus* dominates, corresponding to the upper part of molluscan biozone b and all of c. It suggests a cool spring environment with very quiet, undisturbed sedimentation (>10 % of the specimens had articulated valves). Other species such as *Eucypris pigra*, *Candona compressa* and *Ilyocypris bradyii* indicate periods of flowing water above and below the peak in *Psychrodromus* (*Ilyodromus*) *olivaceus*.

Using Kerney's archived samples and some from a new basal core, Garnett et al. (2004) measured stable isotopes ($\delta^{18}O$ and $\delta^{13}C$) and trace elements (Mg, Sr and Ca) from both bulk tufa and ostracod calcite. They argued that the variation in $\delta^{18}O$ is caused principally by change in the isotopic composition of Holocene rainfall influencing aquifer recharge, caused itself mainly by changes in air temperature. The $\delta^{13}C$ variability through much of the deposit was suggested to reflect the increasing influence of soil-zone carbon dioxide due to progressive woodland soil development. The stable isotope records from ostracod shells showed evidence of vital effects, being markedly more 'spiky' and offset to more positive values by about 1 ‰ compared to the bulk tufa samples. Garnett et al. (2004) suggest the greater variability is probably because ostracods record snapshots of relatively short duration whereas the bulk tufa samples record averages of longer time periods, perhaps decades. They suggest that bulk tufa Mg/Ca and Sr/Ca ratios are controlled by their concentrations in water. First-order sympathetic relationships between $\delta^{13}C$ and the trace element ratios indicate they are controlled by aquifer processes such as residence time, CO_2 degassing and calcite dissolution/reprecipitation. For instance, dry periods of low recharge show increasing trace element ratios together with increases in $\delta^{13}C$. They propose that the trace element ratios might record former rainfall intensity.

The $\delta^{18}O$ record appears to show early Holocene warming of about 2.6 °C to a thermal maximum at about 8900 cal BP which was accompanied by decreasing rainfall intensity and decreasing spring flow (Fig. 56; Garnett et al., 2004). Although the general picture is one of increasing warmth, there may be evidence for two colder periods. Between 375 and 390 cm there is a 1 ‰ decrease in the $\delta^{18}O$ record which Garnett et al. (2004) suggest may be correlated with the Preboreal Oscillation dated to about 11,300 cal BP in the GRIP ice core (Dansgaard et al., 1993). The 8200 cal BP cold event (Barber et al., 1999) may also be detectable, centred at about 115 cm, representing a temperature drop of about 1.7 °C. The Mg/Ca ratios suggest this cold event was also dry in south-east England. The combined data suggest that warmer and wetter

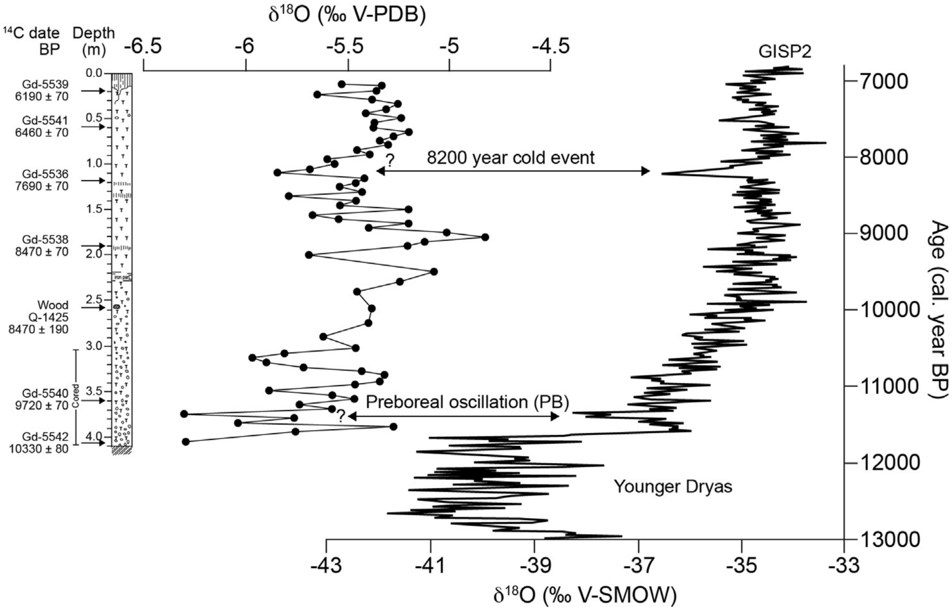

Fig. 56. Correlation of the Wateringbury and GISP2 $\delta^{18}O$ records after Garnett et al. (2004).

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conditions became established after the 8200 cal BP cold event and lasted until about 7100 cal BP when tufa accumulation ceased (Garnett et al., 2004).

7.2.3. Interpretation

The Wateringbury tufa formed in a calcareous swamp fed by springs issuing from the base of the Hythe Formation. The molluscs and ostracods indicate that there were no large bodies of standing water, rather small pools and shallow films of water trickling across wet ground. The nodular lithology and occurrence of aquatic molluscs in the lower part of the deposit suggest that there was a more vigorous discharge of water near the start of deposition. The ostracods also provide some evidence of a recurrence of stronger spring flow in the upper part of the deposit, especially above 100 cm. Conversely, very quiet conditions are indicated in the middle parts of the deposit where several grey horizons at 190, 132, and 120 cm probably reflect temporary pauses in tufa deposition (Kerney et al., 1980). This low energy mode of deposition enabled large numbers of dry-ground snails to be included, with much greater value for the interpretation of regional environmental changes than the freshwater and swamp elements (Kerney et al., 1980). The dry-ground molluscs reflect a change from open ground with grassy herbaceous vegetation to shaded forest, mirrored by pollen analysis that suggests a transition from birch woodland with willow carr in the wetter areas through hazel scrub, to a fairly dense temperate forest with elm, oak and hazel.

Approximate ages for each molluscan biozone at Wateringbury (Table 7) have been calculated using the central values of age and depth for the calibrated radiocarbon dates (Garnett et al., 2004) and linear regression. The Wateringbury ages have not been corrected for any hard water effect and are on average between 550 and 650 years older than the corresponding corrected ages from Holywell Coombe (Preece, 1991; Preece and Bridgland, 1998). This suggests that the hard water effect at Wateringbury is of *c.* 500 year magnitude. The earliest date (405–410 cm) of 11,680 to 12,760 cal BP also falls some 580 years before the age attributed to the start of the Holocene as recorded in Greenland ice (Alley et al., 1993), supporting this interpretation.

The date of about 7100 cal BP (Preece, 1991) for the uppermost 5 cm of tufa (which may be several centuries too old) would suggest a date near to the Mesolithic/Neolithic boundary for tufa cessation. The reason for this is unclear. Kerney et al. (1980) suggest a purely climatic cause is unlikely, suggesting instead that anthropogenic forest clearance during the Neolithic may have increased runoff and accentuated erosion.

The tufa deposit at Wateringbury is important because it provides an undisturbed record of natural environmental change from the earliest Holocene to about 7100 cal BP. It is probably one of the most studied tufa sequences from the British Isles. The calcareous swamp in which it formed was fed by shallow films of water trickling across wet ground though there may be evidence for more vigorous flow in the lower and upper parts of the sequence. A rich assemblage of terrestrial molluscs spanning biozones a to d has been recorded along with ostracods, mammals, plant macrofossils and pollen. The molluscan sequence is valuable for its length and completeness and fact that the low energy mode of deposition enabled large numbers of dry-ground snails to be included which are of greater value for interpretation of regional environmental changes. Together they document an increasing woodland cover as first birch then hazel, oak and elm returned to south-east England during the early Holocene.

Stable isotope and trace elements suggest the early Holocene warming of about 2.6 °C to a thermal maximum at about 8900 cal BP was interrupted by two colder events at 11300, and 8200 cal BP, the latter of which may also have been dry. Subsequently conditions became warmer and wetter until tufa deposition ceased, perhaps in response to anthropogenic forest clearance leading to changes in the hydrological regime.

Table 7
Approximate calendar ages of molluscan biozone boundaries at Wateringbury (data from Garnett et al., 2004 and Preece, 1991) and Holywell Coombe (data from Preece and Bridgland, 1998) in calendar years BP, based on interpolation between calibrated radiocarbon ages.

Molluscan biozone	Wateringbury		Holywell Coombe	
	Beginning	End	Beginning	End
a	11,950	11,375	11,180	10,980[a]
b	11,375	10,040	10,690[b]	9550
c	10,040	9210	9550	8410[c]
d^1	9210	8310	8410	
d^2	8310	6990		6400[a]

[a] Sometime before.
[b] Slightly before.
[c] Just before.

7.2.4. Conclusion

The site at Wateringbury contains a tufa deposit important for Quaternary studies. Tufa is a soft calcium carbonate commonly precipitated by springs which have flowed through chalk or limestone. Tufa is geologically important as it often provides a detailed and complete stratigraphy, preserving a rich and diverse fauna commonly *in situ* and therefore reflecting local and regional environmental changes. The Wateringbury tufa contains a detailed record of early Holocene (10,000 to 7500 years ago) mollusc biostratigraphy (mollusc assemblage zones a to d). It is particularly valuable in demonstrating the order of species recolonisation after the late Devensian cold stage, and for the length and completeness of the record. It is also notable for the small area of deposition which allowed large numbers of terrestrial snails to be incorporated in the tufa. These are of greater value for interpreting regional faunal changes than are autochthonous (*in situ*) freshwater and swamp species. Related pollen, ostracod and vertebrate records are also available from the site making this a key locality for understanding the changing environments of the early Holocene across southern England.

8. Mire deposits

Five mire sequences have been selected for GCR status within southern and south-central England, to provide between them a representative overview of vegetation development and climate during the Holocene. There are two sites from the New Forest that form a network, together providing the fullest picture of vegetation and climatic change in this region. These comprise the ombrotrophic bog sequence at Cranes Moor, the largest and deepest site, which has excellent detail of Early Holocene vegetation change, but is truncated by peat cutting at *c.* 4000 cal BP. The ombrotrophic nature of this sequence also allows for climatic reconstruction in relation to bog surface wetness (Grant et al., 2014). It is important because Early to Middle Holocene palaeoclimatic records from southern England are rare. At this time, most mires are controlled by groundwater, so a direct link with atmospheric conditions (precipitation–evaporation) can rarely be resolved. The valley mire sites developed at Church Moor and Barrow Moor within the GCR site of Mark Ash Wood complete this network of GCR sites. The earliest deposit at Church Moor dates from the Late Glacial Windermere Interstadial, with the overlying mire deposits recording the change in woodland dynamics through the early- to mid-Holocene. A mire-wide hiatus in the sequence, starting at *c.* 5000 cal BP, is present, with later sediment accumulation only covering the last one thousand years. Barrow Moor, located *c.* 500 m northwest of Church Moor, provides a continuous high-resolution pollen record from before 4000 cal BP to the present. Together, these two sites provide an almost continuous record of vegetation dynamics for this area of woodland since the Late Glacial period.

Elsewhere, the Cothill Fen site makes a valuable contribution to knowledge of the vegetation history in Oxfordshire, an area of south-central England where such sites are relatively uncommon. The site provides a detailed picture of both local and regional vegetation changes

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from the early to mid-Holocene. Finally, the Rimsmoor site in Dorset is an exceptional site, with an 18 m sequence through the entire Holocene in a subsiding doline setting. The high sediment accumulation rates at this site permit high-resolution sampling of this sequence, allowing the timing and length of key events, such as the mid-Holocene elm and lime declines, to be quantified at a sub-decadal resolution (see Grant and Waller, 2017).

8.1. GCR Site 1905 Cranes Moor (SU 194 028) (BAH, RMB, MJG)

8.1.1. Introduction

Cranes Moor is a large mire complex set in a shallow basin containing organic deposits dating back to the late Devensian. It is a key reference site for palynological and palaeoecological studies in southern England. The site is unusual for the rapid peat accumulation in the early Holocene and is therefore important in the study of the immigration and expansion of flora during this time period. Unfortunately, most of the mid- to late Holocene sediments have been removed through peat cutting, as shown in a significant discontinuity of radiocarbon ages (Grant et al., 2009a) and evidence of past-peat cutting still visible on the modern mire surface. Cranes Moor was investigated in 1951 by Newbould (1953, 1960), who described its present vegetation and water chemistry, and by Seagrief (1960) who studied its palaeoecology. In the 1980s the macrofossil succession of Sphagnum Bog, Cranes Moor, was studied in the unpublished PhD thesis of Clarke (1988) and reported along with pollen studies in condensed form by Barber and Clarke (1987). Further, more detailed, analysis was undertaken by Grant (2005) and Grant et al. (2009a, 2014), with a review of the change in the mire vegetation, since the 1951 study by Newbould, produced by Lovegrove et al. (2020).

8.1.2. Description

Cranes Moor is the most extensive mire complex in the New Forest located 1.5 km west of Burley (Fig. 52). The ridge on which Burley stands is capped by the Oligocene Headon Hill Formation and in places by plateau gravels. The mire itself is surrounded and underlain by Barton Group which is heavily podzolised over most of the area and supports heathland with stands of pine woodland. Unlike other mire systems in the area, Cranes Moor does not support alder carr.

Seagrief (1960) produced three undated pollen diagrams from the site: Little Bog core C12; Sphagnum Bog core I; and the unfortunately named Flush Bog core CY. He noted that changes in the surface vegetation at various parts of the bog complex were mirrored by changes in the type of peat sedimentation. Flush Bog receives the major portion of its drainage from Burley Ridge. The earliest organic sedimentation of the three sites began here, mainly comprising fen peats and muds, with a *Sphagnum* component developing in the mid-Holocene. Little Bog and the northern part of Sphagnum Bog receive a lesser supply from the Burley Ridge and are composed initially of fen peat, though again with *Sphagnum* peat developing in the mid-Holocene. Sphagnum Bog, the largest of the three, is shielded from water flow by two ridges of Barton Group and is almost entirely composed of *Sphagnum* remains. Sphagnum Bog has remained a largely oligotrophic, partially ombrotrophic, *Sphagnum*-dominated mire throughout the Holocene (Seagrief, 1960; Barber and Clarke, 1987; Grant et al., 2009a, 2014).

In the early 1980s, Sphagnum Bog (CM1) and Flush Bog (CM6) were resampled for pollen analysis (Barber and Clarke, 1987), with plant macrofossils analysed from CM1 (Clarke, 1988). These investigations included nine radiocarbon dates on bulk peat samples, with dates between 4550 ± 60 and 10,070 ± 60 ^{14}C BP (*c.*, 12,700 to *c.* 5200 cal BP), spanning the Late Glacial to mid-Holocene periods. In the early 2000s, the site was revisited to provide a more accurately dated record (Grant, 2005; Grant et al., 2009a, 2014), with a core taken from Sphagnum Bog to provide the longest possible sequence formed under ombrotrophic conditions. Analysis on this core included pollen, plant macrofossils and charcoal, with seven new radiocarbon dates obtained (Table 8).

The full sedimentary sequence at Sphagnum Bog is described from core CM1 from Sphagnum Bog (Barber and Clarke, 1987; Clarke, 1988). At the base (500–484 cm), was at least 16 cm of fine sand, containing some macrofossils. This is overlain by what has become known as the 'Nivea' layer (484–456 cm). Seagrief (1960, p. 73) described creamy-white Sphagnum mud containing macrofossils and "exactly like face-cream in texture". The sediment matrix was found to be an amorphous alumino-silicate, subsequently identified as proto-imogolite allophane a weathering product of podzolisation (Barber and Clarke, 1987). Barber and Clarke (1987) suggested the 'Nivea' layer is diachronous across the peat base, post-dating peat deposition. The 'Nivea' layer occurred between pollen peaks of *Betula* and *Pinus* in core CM1, but after the expansion of *Pinus* with rising *Cory1us*/*Myrica* in Seagrief's (1960) core. The proto-imogolite allophane is possibly derived from acidic weathering of muscovite which is a component of the underlying Barton Group. It suggests the movement of groundwater

Table 8

Radiocarbon dates from Cranes Moor: a) Conventional radiocarbon dates from Cranes Moor, reported in Barber and Clarke (1987), calibrated against IntCal20 (Reimer et al., 2020). SRR-1918 was excluded by the authors as an outlier; b) AMS radiocarbon dates from Cranes Moor, reported in Grant et al., 2009a and 2014, calibrated against IntCal20 (Reimer et al., 2020). SUERC-5246 was excluded by the authors as an outlier.

Lab no.	Coring site	Material dated	Depth (cm)	Radiocarbon age (BP)	Calibrated date range (95.4 % CI)
a) Barber and Clarke (1987)					
SRR-2126	Flush Bog CM6	Bulk peat	100–104	8630 ± 60	9880–9480
SRR-2127	Flush Bog CM6	Bulk peat	160–164	9110 ± 60	10,490–10,180
SRR-2128	Flush Bog CM6	Bulk peat	275–279	9570 ± 60	11,160–10,700
SRR-2129	Flush Bog CM6	Bulk peat	316–320	10,070 ± 60	11,840–11,320
SRR-1914	Sphagnum Bog CM1	Bulk peat	60–70	4550 ± 60	5450–4970
SRR-1915	Sphagnum Bog CM1	Bulk peat	148–158	5750 ± 60	6720–6400
SRR-1916	Sphagnum Bog CM1	Bulk peat	238–248	7000 ± 80	7970–7670
SRR-1917	Sphagnum Bog CM1	Bulk peat	362–372	8590 ± 90	9900–9430
SRR-1918	*Sphagnum Bog CM1*	*Bulk peat*	*435–445*	*8000 ± 110*	*9260–8550*
b) Grant et al. (2009)					
SUERC-6796		*Calluna vulgaris* leaves and monocote (undiff.) leaves	46	277 ± 30	450–150
SUERC-5243		Sphagnum leaves and stems	80	4972 ± 31	5850–5590
SUERC-5244		Sphagnum leaves and stems	140	6000 ± 37	6950–6740
SUERC-6802		Sphagnum leaves and stems	180	6585 ± 39	7570–7420
SUERC-5246		*Sphagnum leaves and stems*	*230*	*5790 ± 34*	*6670–6490*
SUERC-6803		Sphagnum leaves and stems	270	7909 ± 47	8990–8590
SUERC-5247		Sphagnum leaves and stems	328	8698 ± 53	9890–9540
SUERC-6805		Sphagnum leaves and stems	400	9204 ± 57	10,510–10,230

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containing proto-imogolite allophane along the basal peat–sand contact, some time after peat formation had begun, rather than *in situ* weathering (Barber and Clarke, 1987). Above the 'Nivea' layer (456–406 cm) is a *Sphagnum subnitens*-dominated peat which is initially granular in texture, with varying levels of humification. Humification particularly increases above 116 cm. At 15 cm the core is truncated by peat cutting, with the uppermost part of the sphagnum peat dated by Barber and Clarke (1987) to *c.* 4000 ^{14}C BP (5200 cal BP) (Table 8).

Seagrief (1960) and Barber and Clarke (1987) both reported peaks of *Betula* pollen at or shortly after the late Devensian/Holocene boundary, the date from Flush Bog being 10,070 ^{14}C BP (*c.*, 11,600 cal BP) (Fig. 58). Poaceae values are also high at this level, with herb taxa including *Artemisia*, *Rumex*, *Plantago* and Ericales, although *Juniperus* is absent despite its presence in the macrofossil record. *Betula* then declined as *Pinus* pollen rose in both diagrams around 9600 ^{14}C BP (*c.*, 10,900 cal BP) and dominated for *c.* 1300 years, during which time *Salix* carr developed over Flush Bog, and herbs of open ground diminished markedly. Following a decline in *Pinus* there was a rise in the frequencies of *Quercus*, *Ulmus* and *Corylus*/*Myrica* pollen. The subsequent deposits at Flush Bog have been removed by peat cutting and the top 50 cm or so comprised black oxidised recent surface peat. However, at borehole CM1 on Sphagnum Bog the peat was undisturbed to near the present surface and the expansion of *Tilia* was dated to *c.* 7100 ^{14}C BP (7800 cal BP). At *c.* 5750 ^{14}C BP (6550 cal BP). Also recorded was a prominent peak of herb pollen including *Artemisia*, *Rumex*, *Plantago* and Chenopodiaceae associated with a fall in *Quercus*, attributed by Barber and Clarke (1987) to late Mesolithic or earliest Neolithic clearances, though calibration of this date shows that it precedes the start of the Neolithic in Britain. A marked elm (*Ulmus*) decline was dated to *c.* 4550 ^{14}C BP (5200 cal BP), at the young end of the range of values identified by Parker et al. (2002) and Grant and Waller (2017), who found dates of the British elm decline spread over a period of about *c.* 1000 years, centred on *c.* 5800 cal BP.

Macrofossil analysis on core CM1 from Sphagnum Bog (Barber and Clarke, 1987; Clarke, 1988) yielded seven macrofossil zones, with macrofossils indicating a *Calluna*-dominated acid heathland community in the basal sand — Zone 1 (including *Calluna*, *Juniperus*, *Juncus acutiflorus* — type and several species of Sphagna) transitioning upwards through the 'Nivea' layer (Zone 2) to those indicating a *Sphagnum*-dominated mire. At *c.* 425 cm, within Zone 3, an increase in peat humification is marked also by the return of *Calluna*, *Polytrichum* sp. and *Sphagnum subnitens*, perhaps indicating a shift to drier surface conditions on the mire surface. Above this, between 406 and 340 cm, in Zone 4, *Molinia* and *Sphagnum tenellum* macrofossils suggest a fluctuating groundwater regime. Bog pool environments were interpreted from Zone 5 (340–116 cm) based on macrofossils of *Sphagnum subnitens*, *Sphagnum subsecunda sensu lato* and algal muds, with possible two dry shifts between 256–240 cm and 200–180 cm. Above this, and prior to the peat truncation, Zone 6 (116–15 cm) contains macrofossils that suggest a drier mire community dominated by *Molinia*, Sphagna and *Erica tetralix*. Barber and Clarke (1987, p. 42) stated that it was highly probable that the site exhibited ombrotrophic conditions in the past, and that for future studies on the palaeohydrology had great potential.

Grant et al. (2009a, 2014) cored 4 m on the eastern side of Sphagnum Bog at Cranes Moor (Fig. 57). The top 80 cm postdate peat cutting at the site (Grant et al., 2009a); radiocarbon dating above the hiatus provided a date of *c.* 350 cal BP, whilst immediately below it provided an age of *c.* 5700 cal BP. Eight new radiocarbon dates from the sequence (Table 8) were used to create an age depth model, from which SUERC-5246 was excluded as an outlier.

The pollen, plant macrofossils and charcoal analysed by Grant et al. (2014) are described below in relation to the five local pollen assemblage zones (LPAZ) and six local macrofossil assemblage zones (LMAZ) they identified and summarised in their Tables 2 and 3 (Fig. 59). At the base of the sequence (404–329 cm), CRMp-1 is dated to *c.* 10,400–9560 cal BP with *Pinus sylvestris* (15–50 %) and *Corylus avellana* (40–67 %) dominant, with *Ulmus* (1–10 %), *Quercus* (5–14 %) and *Betula* (1–6 %) also present. In macrofossil assemblage zone CRMm-1 (324–404 cm) the peat matrix alternates between *S. papillosum*/*S. s. acutifolia* and unidentifiable organic matter. Small quantities of *Juncus* species remains are present between 380 and 360 cm depths. Four fire events are recorded in the microscopic charcoal record (10,260, 10,180, 9930 and 9790 cal BP), with only one recorded in the macroscopic charcoal (10,230 cal BP).

In CRMp-2 (329–269 cm, 9650–8750 cal BP), *Corylus avellana* (46–61 %) and *Quercus* (14–23 %) dominate. *Pinus sylvestris* decreases from 14 % at the start of the zone to 5 % by the end. *Calluna vulgaris* (up to 3 %) increases throughout the zone. *Ulmus* (1–7 %), *Betula* (4–9 %) and *Pteridium aquilinum* (1–5 % TLP þ pteridophytes) are present throughout. In macrofossil assemblage zone CRMm-2 (268–324 cm) the lower zone boundary is defined by the appearance of *S. pulchrum* and *Phragmites*. *S. papillosum* and monolocotyledon remains dominate the rest of the zone. Two fire events are recorded in the microscopic charcoal record (9510 and 9030 cal BP) with two recorded in the macroscopic charcoal (9590 and 9530 cal BP).

In CRMp-3 (269–229 cm, 8750–8150 cal BP) *Corylus avellana* (34–54 %) and *Quercus* (20–30 %) dominate, along a high presence of *Calluna vulgaris* (2–14 %). *Pinus sylvestris* values fall from *c.* 7 % to between 2 and 3 % between 242 and 252 cm and above 234 cm. *Betula* (4–11 %) values are high, with a consistent presence of *Alnus glutinosa* (up to 7 %). Herb pollen increases to *c.* 5 % TLP, with peaks of *Melampyrum* at 262 cm (3 %) and 232 cm (9 %), coinciding with peaks in the charcoal record. In macrofossil assemblage zone CRMm-3 (236–268 cm) *S. papillosum* disappears from the core site to be replaced by *S. s. acutifolia*. Monocotyledon remains increase and *Calluna* wood is consistently present. Four fire events are recorded in the microscopic charcoal record (8720, 8639, 8300 and 8190 cal BP) with two recorded in the macroscopic charcoal (8750 and 8220 cal BP).

In CRMp-4 (229–129 cm, 8150–6650 cal BP) *Corylus avellana* (32–48 %) and *Quercus* (20–28 %) dominate, along with *Alnus glutinosa* (12–16 %). *Pinus sylvestris* values are <1 % TLP. *Calluna vulgaris* (1–4 %) values are low, with *Tilia cordata* (up to 2 %), *Fraxinus excelsior* (up to 2 %) and *Myrica gale* (up to 4 %) increasing above 190 cm. *Erica tetralix* is present at low values (up to 1.5 %). *Pteridium aquilinum* (up to 6 % TLP þ pteridophytes) decreases initially then increases in the latter half of the zone. In macrofossil assemblage zone CRMm-5 (124–180 cm) a mixed assemblage of *Sphagnum* species dominates the zone with alternations occurring between *acutifolia* and *subsecunda*/*cuspidata*. Unidentifiable organic matter declines to <10 % of the assemblage and charcoal is absent. In CRMm-4 (180–236 cm) the lower zone boundary is defined by a marked increase in unidentifiable organic matter to a peak of 80 %, accompanied by macroscopic charcoal. In the lower half of the zone total *Sphagnum* drops to <20 %. Later *S. s. acutifolia* increases to a peak of 90 % at the upper zone boundary. Ericaceae wood fragments are consistently present. Eight fire events are recorded from CRMm-4, in the microscopic charcoal record (7910, 7770, 7710, 7570, 7150, 6960, 6760 and 6680 cal BP) with six recorded in the macroscopic charcoal (8050, 7970, 7460, 7380, 6960 and 6850 cal BP).

In CRMp-5 (129–80 cm, 6650–5700 cal BP) *Corylus avellana* (20–34 %) and *Quercus* (22–37 %) dominate, along with *Alnus glutinosa* (13–20 %). *Corylus avellana* decreases at the beginning of the zone (34–20 %; 128–110 cm), coinciding with increases in *Betula* (up to 8 %), *Quercus* (24–39 %), *Tilia cordata* (1–4 %) and *Fraxinus excelsior* (1–3 %). There are increases in *Plantago lanceolata* (up to 1 %) and *Melampyrum* (up to 2 %). *Erica tetralix* (up to 2 % TLP) and *Calluna vulgaris* (1–5 %) also increase, with *Ulex* type (up to 1 %) also present throughout the zone. In macrofossil assemblage zone CRMm-6 (80–124 cm) *Sphagnum pulchrum* dominates, accompanied by small quantities of *S. tenellum*, *S. subnitens*, *S. s. cuspidate* and *S. s. subsecunda*. Five fire events are recorded in the microscopic charcoal record (6460, 6340, 6230, 6120 and 6040 cal BP) with three recorded in the macroscopic charcoal (6460, 6230 and 5810 cal BP).

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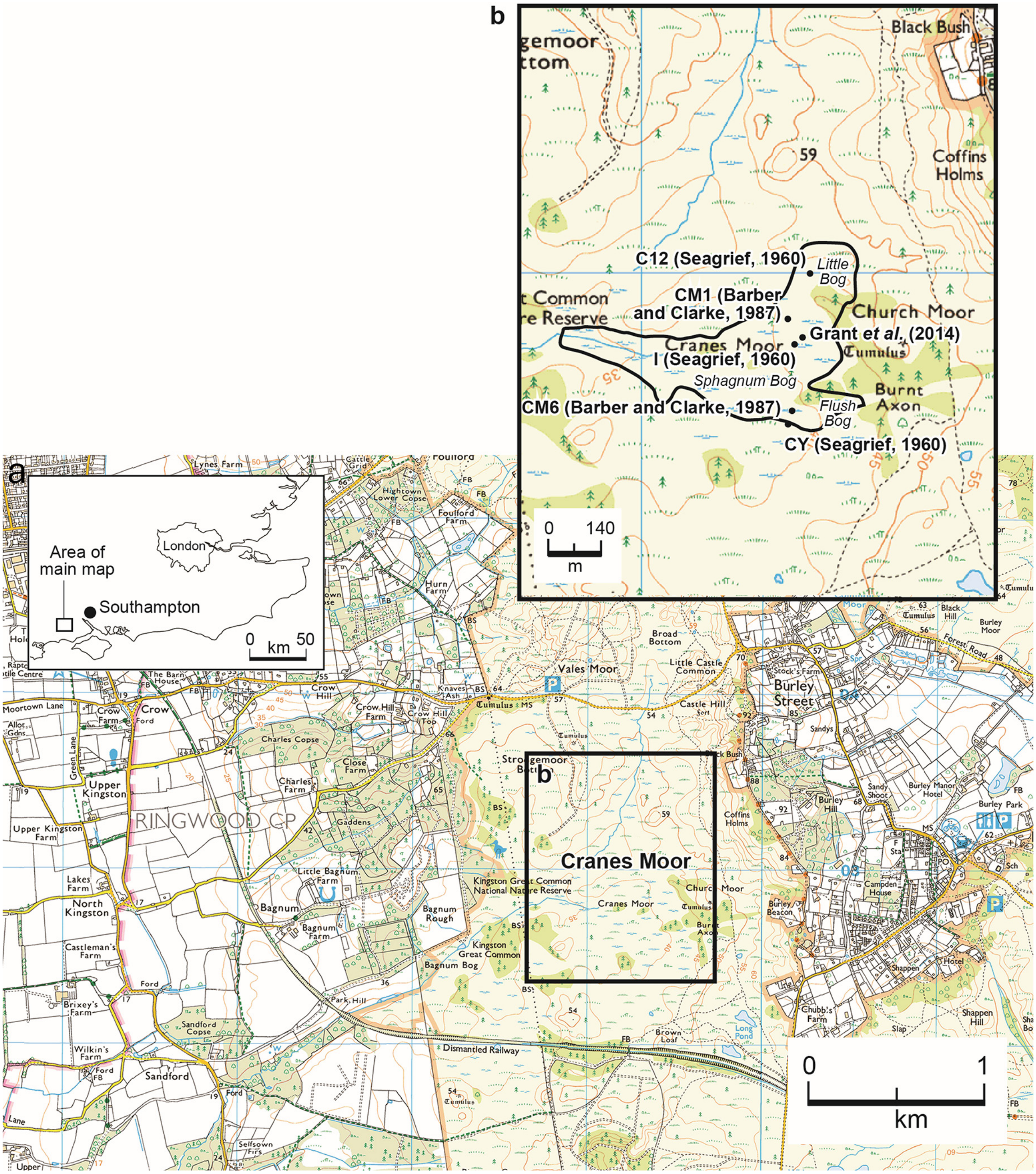

Fig. 57. a. Location of Cranes Moor GCR site. b. Detailed location of GCR boundary and previous work at Cranes Moor. Ordnance Survey map data used under Digimap licence to Birkbeck University of London.

8.1.3. Interpretation

The geomorphological setting of Cranes Moor (the ridge that protects Sphagnum Bog from flushing) is such that the bulk of the sequence was able to develop ombrotrophic conditions as it was shielded from flushing by groundwater. In these conditions, the water table is controlled by the length and severity of the summer water deficit (Charman et al., 2007) (*i.e.*, the balance between precipitation and evapotranspiration). Bog surface wetness (BSW), as reflected in plant macrofossil assemblages, can be used therefore to reconstruct past surface water balance conditions, which are closely related to the atmospheric water balance, in the absence of major human impacts to the bog or catchment (Grant et al., 2009a, 2014). It is suggested that ombrotrophic conditions establish above 320 cm depth, *c.* 9550 cal BP, as seen by the dominance of typical ombrotrophic bog taxa in the macrofossil record. Using this approach, Grant et al. (2014) detected phases of pool development starting at *c.* 9500, 7500 and 6400–5900 cal BP. They noted that these phases correspond to known humid episodes in other palaeoclimatic records such as continental lake level data (*e.g.*, Magny et al., 2003), suggesting that pool development was a response to increased regional moisture availability. The widely recognised North Atlantic cooling event at 8.2 ka BP is represented in the Cranes Moor record as a phase of dry bog surface conditions, in line with other records from England which show that the '8.2 ka event' was expressed as a cool, dry climate anomaly (*e.g.*, Rousseau et al., 1998; Lang et al., 2010).

The record from Cranes Moor published by Grant et al. (2009a, 2014) also enables the reconstruction of regional vegetation and fire

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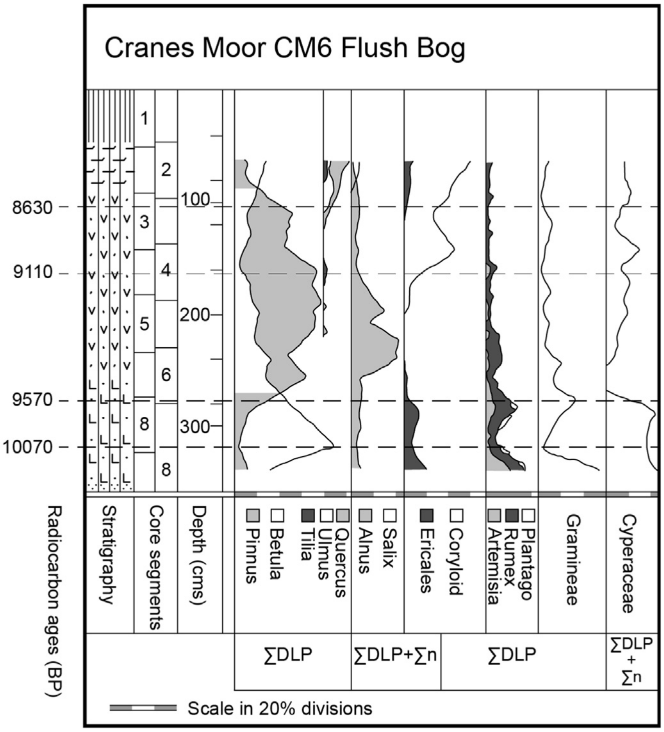

Fig. 58. Pollen recorded from Cranes Moor CM6 Flush Bog core (after Clarke and Barber, 1987). Radiocarbon ages are uncalibrated. See text for calibrated ages.

histories due to analysis of pollen and charcoal from the same core. In terms of vegetation, *Corylus avellana* (hazel) was dominant during the early- to mid-Holocene period recorded in the core (which terminates at 80 cm at *c.* 5700 cal BP), with a transition alongside this from *Pinus sylvestris* to *Quercus* (oak) and *Ulmus*, and then later with the additions of *Alnus glutinosa*, *Tilia cordata* (small-leaved lime) and *Fraxinus excelsior* (ash). Ongoing low levels of *Calluna vulgaris* (both pollen and macrofossils) show the presence of heathland-type vegetation on the mire surface throughout, meaning that the establishment of the current culturally important heathland environment in the wider region cannot be reliably determined from the pollen record (*sensu* Groves et al., 2012).

Charcoal analysis indicates that there is a relationship between the vegetation type expressed in the pollen assemblages and the occurrence of fire. Three main burning phases are identifiable in the record (Fig. 62): *c.* 9700 (330 cm), *c.* 8700 (270 cm) and 8200 cal BP (230 cm) (Fig. 59). Increased burning at *c.* 9700 cal BP coincides with a decline in *P. sylvestris* and expansion of *Quercus*. The Fire Return Interval (FRI) drops here from 180 to 340 years (Grant et al., 2014), suggesting a shift from regular low intensity fires to less frequent but possibly higher intensity fires. Grant et al. (2014) note that it is not clear whether this is the cause or a consequence of the *Pinus* decline. Burning peaks in Phases 2 and 3 coincide with a further reduction and then the final disappearance of *P. sylvestris* (Grant et al., 2014). Charcoal concentrations are strongly positively correlated with taxa known to be fire-responsive (*e.g., Melampyrum* and Cypercaeae) and negatively correlated with fire-sensitive species (such as *Tilia* and *Fraxinus*) (Grant et al., 2014). This is despite taphonomic processes that might be thought to blur such relationships.

The Cranes Moor macrofossil record also indicates a strong link between increased burning and drier conditions as recorded in the Bog Surface Wetness index. This implies that fire events were more frequent when summers were drier locally. Grant et al. (2014) note that fire events drop significantly after *c.* 7500 cal BP (Fig. 59), when other indicators suggest a shift to a more oceanic climate regime. Grant et al. (2009a; p. 210) state that 'the coincidental timing of vegetation changes, burning events and climatic shifts suggests that the changes observed are the result of natural rather than anthropogenic processes. This would indicate that the role of natural burning would have had a greater influence in the early to mid-Holocene than is currently acknowledged for the UK'. This trend has been identified from a number of other records in the British Isles (see Tsakiridou et al., 2020).

The Cranes Moor mire complex is the largest and arguably the most scientifically valuable site for tracing Holocene vegetation history in south-central England. During the early Holocene peat accumulation was rapid, up to 4 years/cm between 9600 and 9100 ^{14}C BP (*c.*, 10,900 and 10,300 cal BP) at Flush Bog. Because of its size and lack of tree cover both today and through the Holocene, Sphagnum Bog gives a detailed picture of regional vegetation change from the early to mid-Holocene whilst the smaller sites of Flush and Little Bog contain a more local record (Jacobson Jr. and Bradshaw, 1981). Detailed analysis of macrofossil and charcoal assemblages enables the relationship between climate, vegetation and natural fire to be examined in some detail.

8.1.4. Conclusion

Cranes Moor is a large mire complex, set in a shallow basin containing significant peat accumulations dating back to the Late Glacial times. It is a key reference site for palynological studies in southern England, particularly important in the study of the early immigration and expansion of flora in post-glacial times. The ombrotrophic nature of the mire, which began accumulating in the early Holocene, is rare for Northwest Europe, as many other mires, which would later become ombrotrophic mires, were often in an early successional swamp or sedge fen stage at this time (Hughes et al., 2000). This early to mid-Holocene palaeohydrological record means that it can be used to assess changes in summer water balance over this time period. Several studies of vegetational history have been carried out in the post-war period at a number of sub-sites within the basin including, most recently through an integrated investigation of macrofossils, pollen and charcoal, together with AMS radiocarbon dating of cores.

8.2. GCR Site 1900 Mark Ash Wood (Church Moor) (SU 247 069) with provisional extension to Mark Ash Wood (Barrow Moor) (SU 250 076) (BAH, RMB, MJG)

8.2.1. Mark Ash Wood (Church Moor)

8.2.1.1. Introduction. Church Moor is a small valley mire complex on the western side of Mark Ash Wood and located towards the head of the Black Water catchment, approximately 5 km west of Lyndhurst (Fig. 60). The site is of considerable importance for palynological and palaeoecological studies since it contains organic sediments dating back to the Late Glacial Windermere Interstadial. The site is also of importance in providing data on the early Holocene immigration and expansion of plant species, and it has been used as a reference site for correlation in southern England. The site was first investigated by Barber (1975) and the Mires Research Group in 1979 and again in the unpublished PhD thesis of Clarke (1988), further south in the mire, reported in abridged form by Clarke and Barber (1987). The sequence was recorded further north (Fig. 60) by Grant (2005) and Grant et al. (2009b), close to the location of the original Barber (1975) study, along with a sequence from the adjacent Barrow Moor to the east, to test questions about the continuity of woodland during the Holocene.

8.2.1.2. Description. The valley mire at Church Moor is a broadly linear feature, trending north-west to south-east in a shallow valley which forms the headwaters of a left bank tributary of the Black Water. The underlying solid geology comprises Eocene Chama Sand Formation with the earlier Barton Clay Formation outcropping some 400 m downvalley (Clarke, 1988). Its surface area is about 2.7 ha, of which alder carr presently occupies about 25 % towards the south-western edge of the mire along the main axis of water flow. The organic deposits are

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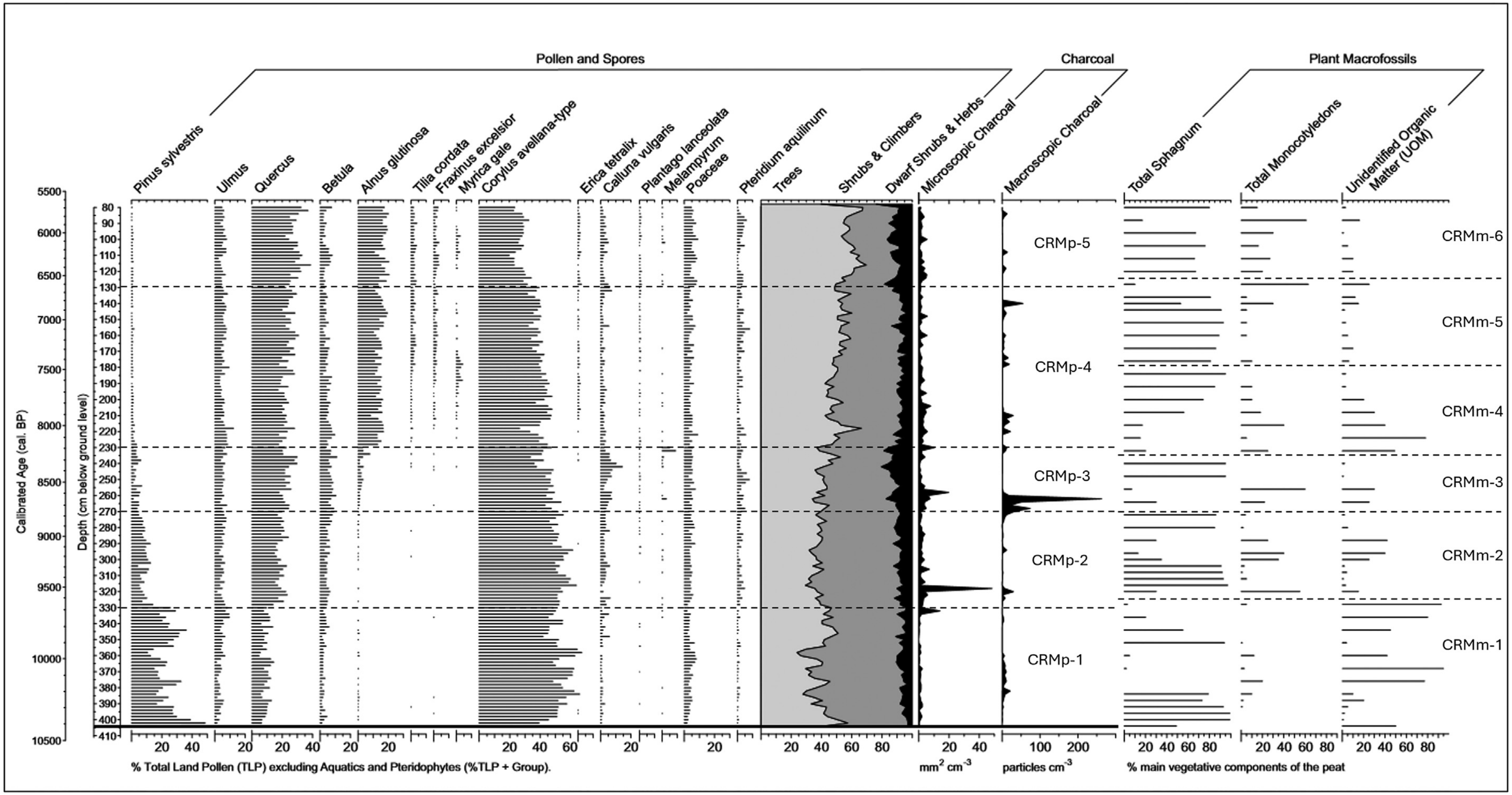

Fig. 59. Cranes Moor summary pollen, macrofossils and charcoal.
Redrawn after Grant et al. (2014) Figures 3 and 6.

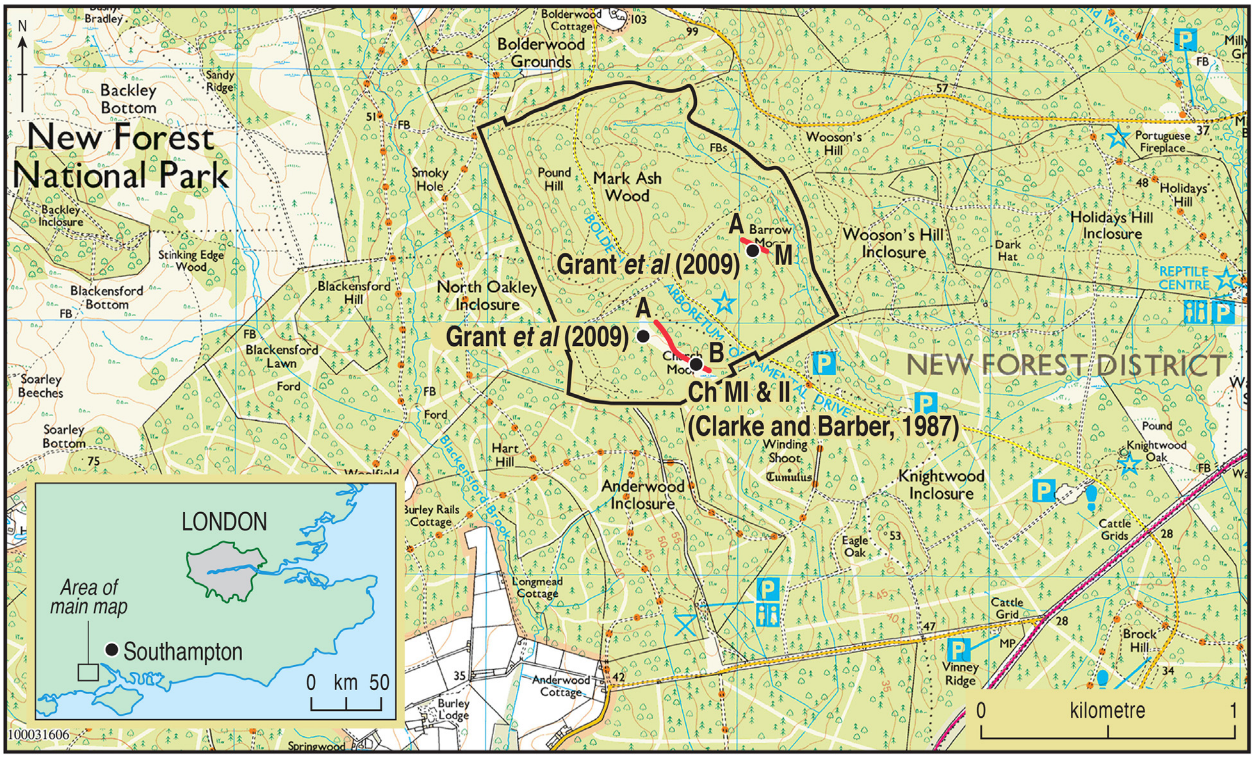

Fig. 60. Location of Mark Ash Wood. The Mark Ash Wood (Church Moor) (SU 247 069) and Mark Ash Wood (Barrow Moor) (SU 250 076) GCR sites fall within the area marked. Work undertaken at the sites is shown. Ordnance Survey data used under Digimap licence to Birkbeck University of London.

mainly 1–2 m or less in depth, with occasional depths of up to 4 m (Fig. 61). The site was first studied by Barber (1975), who described a core taken from within the alder carr towards the north of the site. Barber (1975), based upon a preliminary pollen diagram, suggested that organic accumulation began during the early Holocene, possibly more than 8000 years ago. A stratigraphic survey was undertaken by the Mires Research Group in 1979 and reported by Clarke (1988), as shown in Figure 61. This shows that above the basal colluvial deposit, a strongly gleyed silty clay with some fine gravel, the organic deposits thicken markedly after 90 m towards the south-east. In the lower part of the mire is up to 1.2 m of late Devensian deposits which include a more minerogenic layer attributable to the Loch Lomond Stadial (Clarke, 1988). Separate cores were taken using a 50 cm Russian sampler for pollen (ChMI) and macrofossils (ChMII; Clarke (1988). Grant (2005; Grant et al., 2009b) cored a shorter sequence further north, close to the original location cored by Barber (1975), along with an accompanying *c.* 2 m sequence from a similar valley mire in Barrow Moor *c.* 500 m to the north-east (Fig. 60).

The sequence cored by Clarke (1988) and Clarke and Barber (1987) was analysed for both pollen and plant macrofossils (Fig. 62), with a basal radiocarbon date from ChMI of 12,440 ± 60 ^{14}C BP; SRR 1921 (14,970–14,270 cal BP), comparable to the start of the Windermere

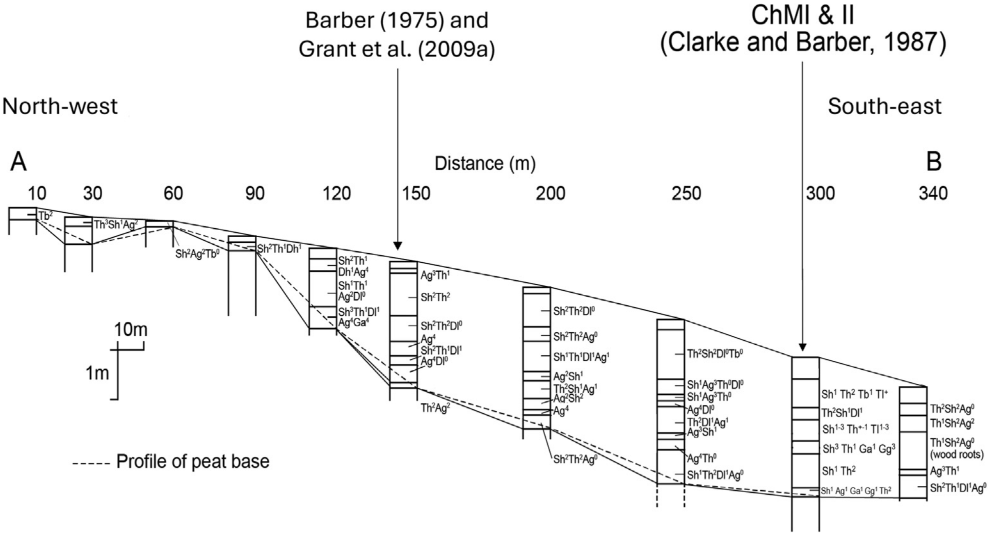

Fig. 61. Stratigraphical cross section of Church Moor after Clarke (1988), showing Troels-Smith sediment descriptions and location of cores reported by Clarke and Barber (1987) and Grant et al. (2009b).

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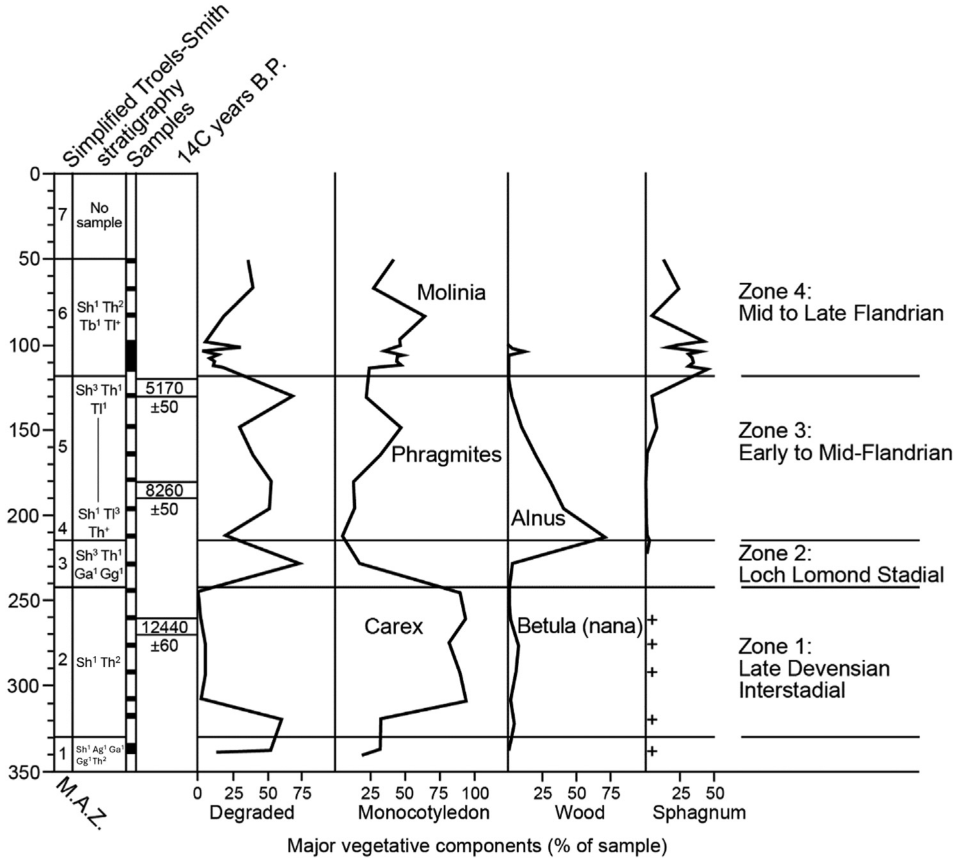

Fig. 62. Plant macrofossils from ChMII. After Clarke and Barber (1987).

Interstadial (Greenland Interstadial 1; commencing *c.* 14,640 cal BP (IntCal20); Rasmussen et al. (2014)). Within the basal colluvium they found a sparse macrofossil assemblage dominated by monocotyledon rootlets, including *Carex*, but also included well-preserved *Sphagnum* of various types. Above this, the late Devensian peat was characterised by abundant, well-preserved monocotyledon remains, derived mainly from *Carex*, particularly *C. rostrata* and *C. paniculata*-type. Fruits and cone-scales from *Betula pendula* and *B. nana* occur in this zone, with leaves of *B. nana* and rootlets resembling this species indicate that dwarf birch was actually growing on the mire between 293 and 243 cm (Clarke and Barber, 1987). This, along with the characteristics of the pollen record in zone 1 and the radiocarbon age, led Clarke and Barber (1987) to assign this lowest part of the sequence to the Late Glacial Windermere Interstadial. Together, the macrofossils and pollen suggested the mire to have been dominated by a tall sedge–dwarf birch community, with a moss ground layer (Clarke and Barber, 1987).

There is an abrupt change in the stratigraphy during zone 2 characterised by an increase in inorganic deposition, with silt, fine sand and abundant charcoal fragments, which Clarke and Barber (1987) attribute to deposition during the Loch Lomond Stadial (Fig. 62). This unit can be traced as a discrete layer across the entire area of late Devensian peat at the site (Fig. 61). A number of species disappear from the stratigraphy, including *Betula nana*, *Carex rostrata* (though other *Carex* species continue), *Scirpus tabernaemontani*, *Tomentypnum nitens* and *Campylium stellatum*. There is a marked decline of *Betula* pollen in the interval above the basal radiocarbon date BP and before deposition of the silty peat, which is non-polleniferous. The poor preservation of macrofossils, the absence of pollen and the presence of charcoal implying fire within the catchment, was interpreted by Clarke and Barber (1987) as indicative of a seasonally dry climate.

At the beginning of plant macrofossil zone 3, several taxa were recorded for the first time including *Alnus glutinosa* and *Juniperus communis.* High levels of decomposition continue throughout zone 3. *Phragmites australis* epidermal tissue was identified in several samples, as were *Myrica gale* rootlets (Clarke and Barber, 1987). Drier conditions, presumably promoting decomposition and poor macrofossil preservation, were indicated by the abundance of fungal sclerotia of *Coenococcum geophilum* between 197 and 129 cm, a species which has been associated with relatively dry mire surfaces (van Geel, 1978). At this time, there was also an increase in the frequencies of *Quercus*, *Ulmus* and *Coryloid* pollen, with a radiocarbon date of 9430–9020 cal BP (8260 ± 50 ^{14}C BP; SRR-1920), suggesting the development of a mixed oak–elm–hazel woodland during the Early to Mid-Flandrian [Holocene]. Clarke and Barber (1987) suggested that the presence of *Myrica gale* macrofossils cautions against acceptance of a purely *Corylus* origin for the Coryloid pollen (Clarke and Barber, 1987). *Alnus glutinosa* and *Molinia caerulea* (purple moor-grass), both dominant today at the site, were seen to expand through macrofossil zone 4 (Clarke and Barber, 1987), mirrored in the pollen record where an increase in *Alnus* pollen was dated to 6180–5740 cal BP (5170 ± 50 ^{14}C BP; SRR 1919). This date is now identified as being too young, following the subsequent work of Grant (2005; Grant et al., 2009b). This zone was thought to represent the beginning of a mire community which has persisted to the present-day, dominated by *Molinia caerulea* tussocks with *Erica tetralix*, *Myrica gale* and Sphagna (principally *Sphagnum palustre*) as important components. Other macrofossils in the assemblage include *Eriophorum angustifolium*, *Rhynchospora alba*, *Eleocharis multicaulis*, *Carexechinata*, *Carex viridula*, *Juncus acutiflorus*-type, *Potamogeton polygonifolius*, *Drosera rotundifolia* and *Calluna vulgaris* (Clarke and Barber, 1987). Clarke and Barber (1987) suggested the persistence of the mire community may be due to environmental stability, particularly in mire

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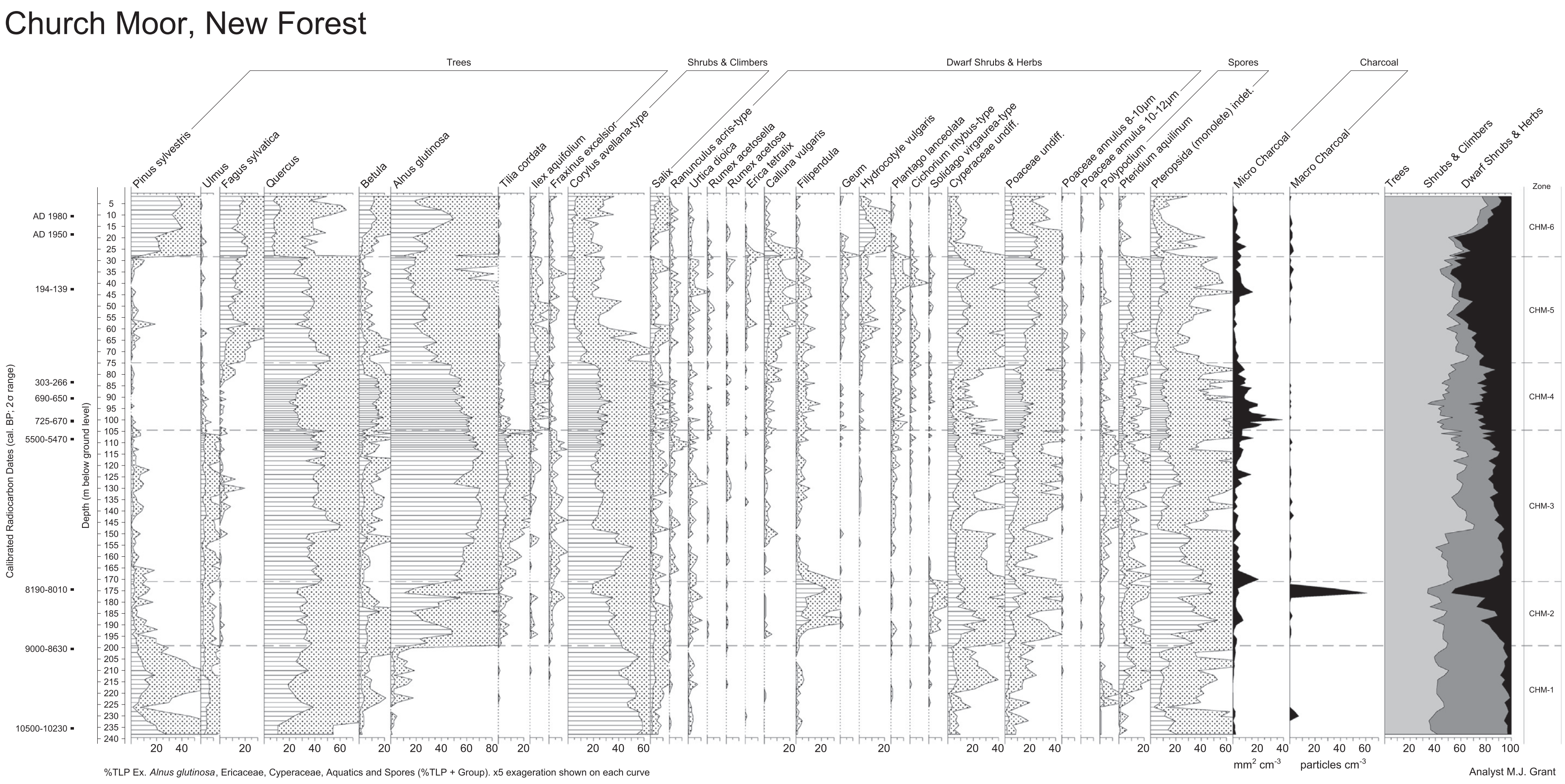

Fig. 63. Pollen and charcoal sequence from Church Moor. From Grant et al. (2009b) Figure 14.4.

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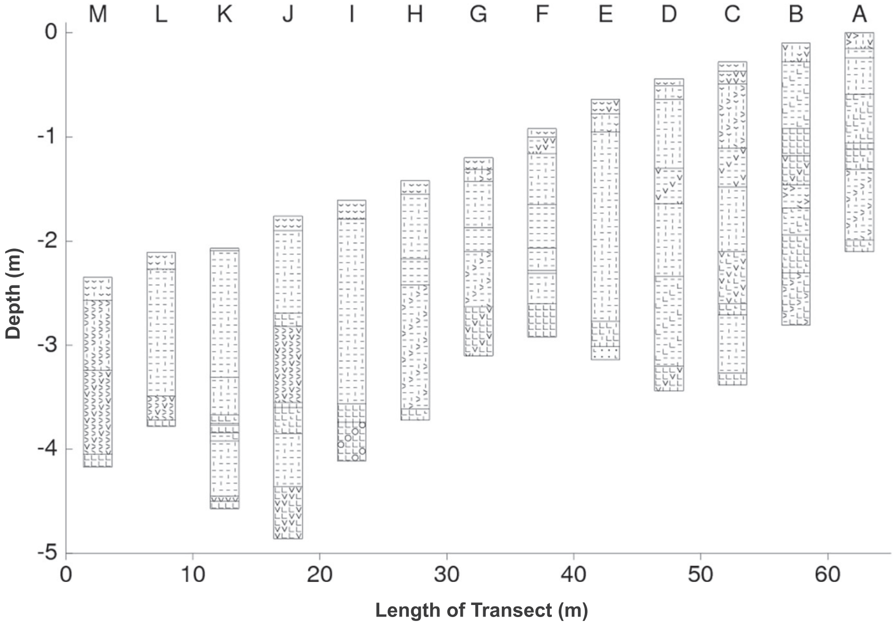

Fig. 64. Barrow Moor stratigraphic transect (Grant, 2005). Sedimentary sequence described after Troels-Smith (1955) — key shown in Figure 70. See Figure 60 for location. Core D was selected for pollen analysis and shown in Figure 65.

hydrology, since the stratigraphy of Church Moor shows the stream to have occupied its lateral position along the edge of the mire for much of the Holocene.

The sequence reported by Grant (2005; Grant et al., 2009b) is located further north than the study by Clarke and Barber (1987), in close proximity to the earlier study by Barber (1975) within the alder carr woodland, as shown in Figures 60 and 61. This sequence did not contain the high levels of decomposition seen within the ChM cores, likely due to its proximity closer to the axis of drainage within the mire. This has meant that pollen preservation was good throughout the sequence, permitting an intact record of the early to middle and late Holocene vegetation record to be obtained. Eight new radiocarbon dates were obtained (Table 9), allowing for an age-depth model to be developed based on these, two age-horizons obtained from analysis of spheroidal carbonaceous particles (SCPs) and the modern bog surface (Grant et al., 2009b). The base of the sequence dates from *c.* 10,350 cal BP (SUERC-6794), equivalent to Pollen Zone ChM-II of Clarke and Barber (1987). A hiatus within the sequence was observed between dates SUERC-4197 (*c.*, 5530 cal BP; 108 cm) and SUERC-6793 (*c.*, 700 cal BP; 100 cm).

The pollen sequence described by Grant et al. (2009b; Table 10, Fig. 63) postdates the Late Glacial Windermere Interstadial and Loch Lomond Stadial deposits previously described from the more southern sequence by Clarke and Barber (1987). The sequence below the stratigraphic break (zones CHMp-1 to CHMp-3) is radiocarbon dated to 10,500–10,230 cal BP (9170 ± 57 ^{14}C BP; SUERC-6794). Initially dominant are *Corylus avellana* and *Pinus sylvestris*, with *Ulmus* locally important (zone CHMp-1). *Quercus*, *Polypodium*, *Pteridium aquilinum* and charcoal then increase, corresponding with a decrease in *Pinus sylvestris*. Grant et al. (2009b) suggest that the changes indicate some partial opening up of the local canopy as a result of burning, allowing *Quercus* to expand and some scrub vegetation to form. *Pinus sylvestris* recovers at *c.* 9300 cal BP, at the expense of *Ulmus* and *Quercus*. *P. sylvestris* finally disappears at *c.* 8800 cal BP during the transition to CHMp-2, when *A. glutinosa* and *Betula* increase, indicating the initial formation of local alder carr woodland.

At *c.* 8100 cal BP (middle of zone CHMp-2) changes in the wetland and dryland vegetation coincide with a burning event. *Corylus avellana* type, *Betula*, *Tilia cordata* and *Fraxinus excelsior* decrease, whilst *Quercus* shows no significant change. *P. aquilinum* increases suggesting the creation of some open areas of woodland. Changes in the wetland flora are indicated by an increase in Poaceae, *Filipendula* (meadowsweet), *Solidago virgaurea*-type (aster) and Pteropsida monolete indet., and reductions in *Alnus glutinosa*. Grant et al. (2009b) suggest that these changes are due to the effects of burning and possible clearance, in addition to fluctuating ground water levels, leading to an opening up of the *Alnus glutinosa* canopy and promoting understorey vegetation development.

After this burning event, *Quercus*, *Tilia cordata*, *Fraxinus excelsior* and *Corylus avellana* type increase (zone CHMp-3), along with the permanent establishment of alder carr woodland and continued low levels of burning. *Alnus glutinosa* expands *c.* 7800 cal BP, coinciding with an increase in *Quercus* and *Betula*, with *Corylus avellana* type and Pteropsida monolete indet. decreasing, indicating both a change within, and expansion of, the carr woodland. Grant et al. (2009b) attribute this local suppression of *Corylus avellana* type to the expansion of *Quercus* and *Tilia cordata*. There is a second, less extensive, phase of disturbance of the alder carr between *c.* 6400 and *c.* 5850 cal BP.

Above the hiatus (zones CHMp-4 to CHMp-6, last *c.* 700 years), the assemblage records changes in the local woodland vegetation since the medieval period, with the most significant changes occurring in CHMp-5, with a reduction in *Corylus avellana* type and rise in *Fagus sylvatica*, which Grant et al. (2009b, p. 229) attribute to 'the change in demand from underwood (coppice) to timber production, and increased browsing and grazing', in common with many other New Forest sequences. There is also a reduction in *Alnus glutinosa*, which coincides with an increase in charcoal particles. It is probable that this reduction in *Alnus glutinosa* is a response to coppicing of the alder carr for use in charcoal production, which is known to have occurred in the area, particularly for use in the gunpowder industry (Grant et al., 2009b, p. 229). In CHMp-6, *Quercus* reduces significantly and there further increases in *Fagus sylvatica*, *Pinus sylvestris* and *Alnus glutinosa*. Grant et al. (2009b, p. 229) attribute the changes in *Quercus* and *Fagus sylvatica* to 'changes in woodland management and the selective removal of *Quercus* for construction, in addition to increased browsing and grazing pressure', whilst *Pinus sylvestris* increases due to "the introduction of softwood plantations in the area, with the earliest plantation adjacent to Church Moor dating from AD 1850."

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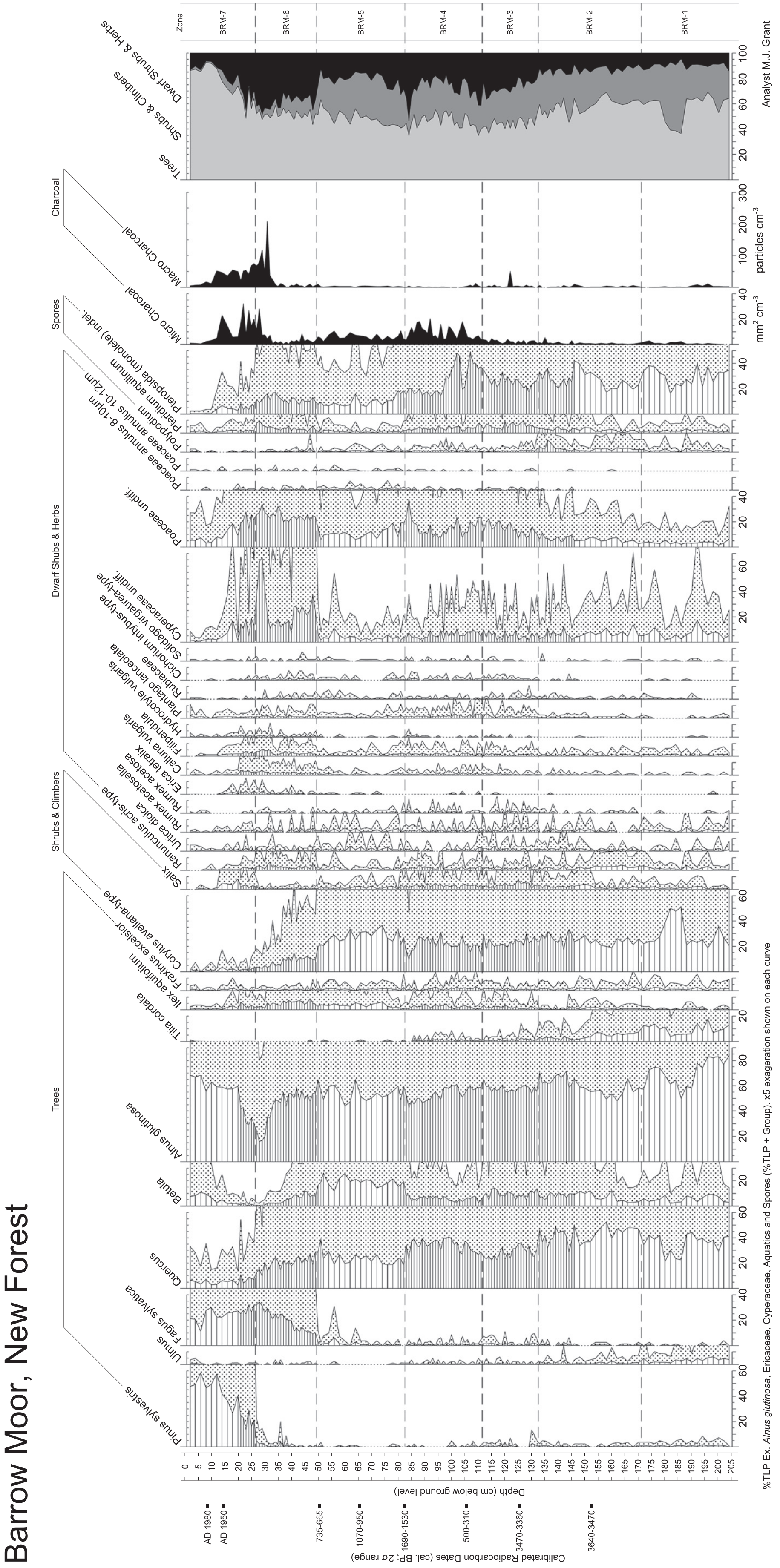

Fig. 65. Pollen sequence from Barrow Moor. From Grant et al. (2009b), their Figure 14.5.

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Fig. 66. Location of GCR site boundary and previous research at Cothill Fen. Ordnance Survey data used under Digimap licence to Birkbeck University of London.

8.2.1.3. Interpretation. The Church Moor sequence shows the early development of valley mires in the New Forest, dated to the Late Glacial Windermere Interstadial. This is a rare occurrence in extra-glacial southern England, especially as this deposit dates from the beginning of the Late Glacial Windermere Interstadial. Both pollen and macrofossil analyses suggest the coexistence during the late Devensian of plant species with different present-day ecological distributions, such as the cold-loving *Saxifraga nivalis* and *Betula nana* and more temperate indicators *Chrysosplenium* and *Filipendula*; Ericaceae and Sphagna are calcifuges whilst *Helianthemum* and *Hippocrepis* enjoy base-rich conditions. This may suggest that the ecological interactions governing community composition were different during the late Devensian compared to today (Clarke and Barber, 1987).

Barber and Clarke (1987) attempted to correlate the observed changes in site hydrology with the record from Cranes Moor (Barber and Clarke, 1987), such as the section of the Church Moor poor macrofossil preservation broadly correlating with the increase in *Calluna vulgaris* growth at Cranes Moor, to indicate drier conditions, and thus

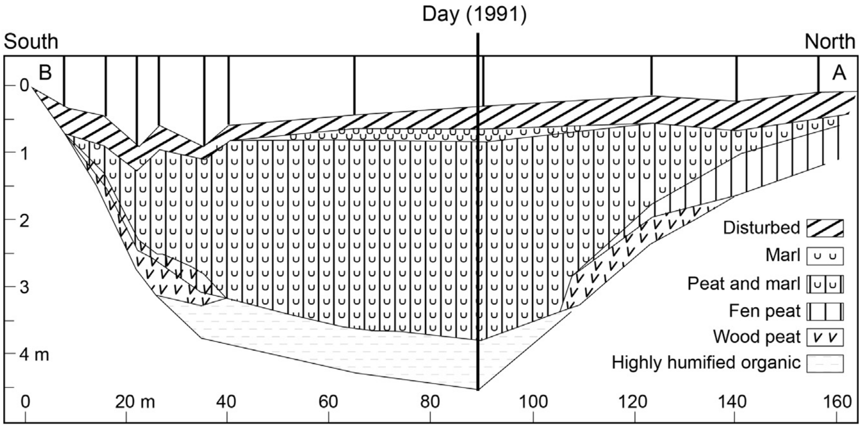

Fig. 67. Profile through the deposits at Cothill Fen along line AB in Figure 61.
Redrawn from Day (1991a), her Figure 3; itself modified from Clapham and Clapham (1939, their Figure 2).

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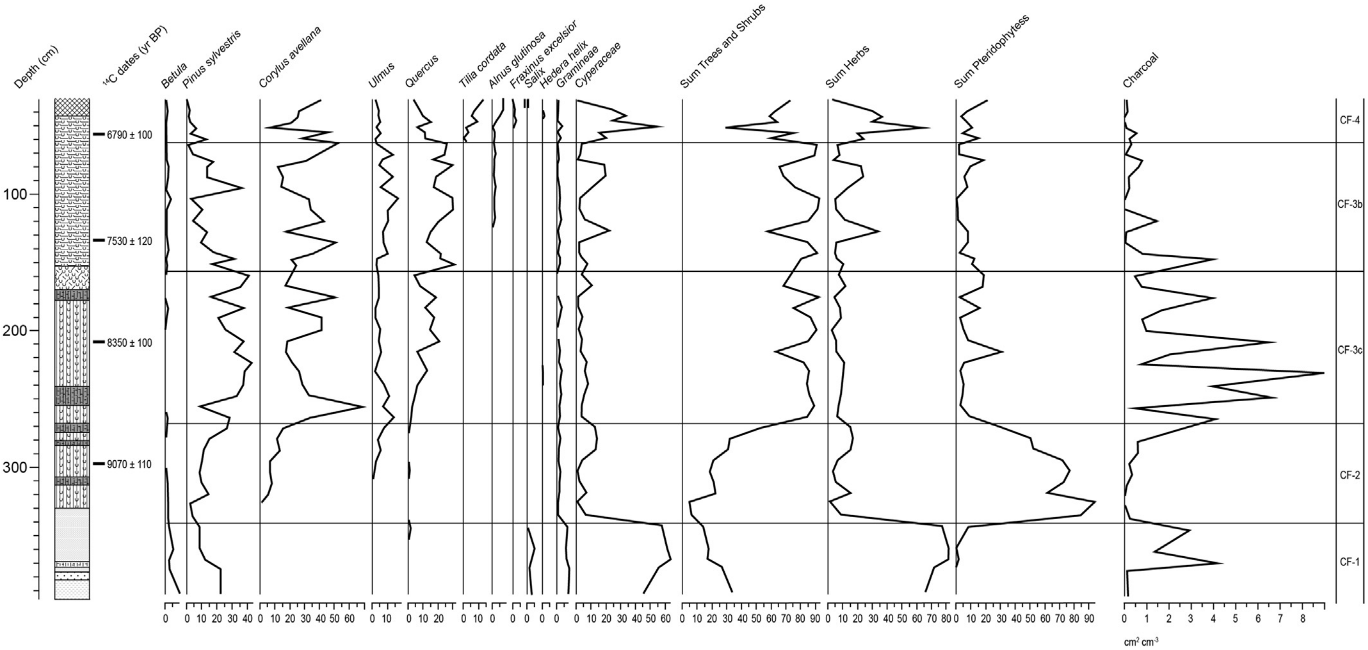

Fig. 68. Pollen percentage diagram from Cothill Fen and microscopic charcoal particle content of the deposits, after Day (1991a, 1991b), her Figures 10 and 11. Pollen sum is total or identifiable pollen and spores of vascular plants, excluding aquatics. Sum for aquatics, *Sphagnum* and indeterminable pollen types is main sum + sum of group.

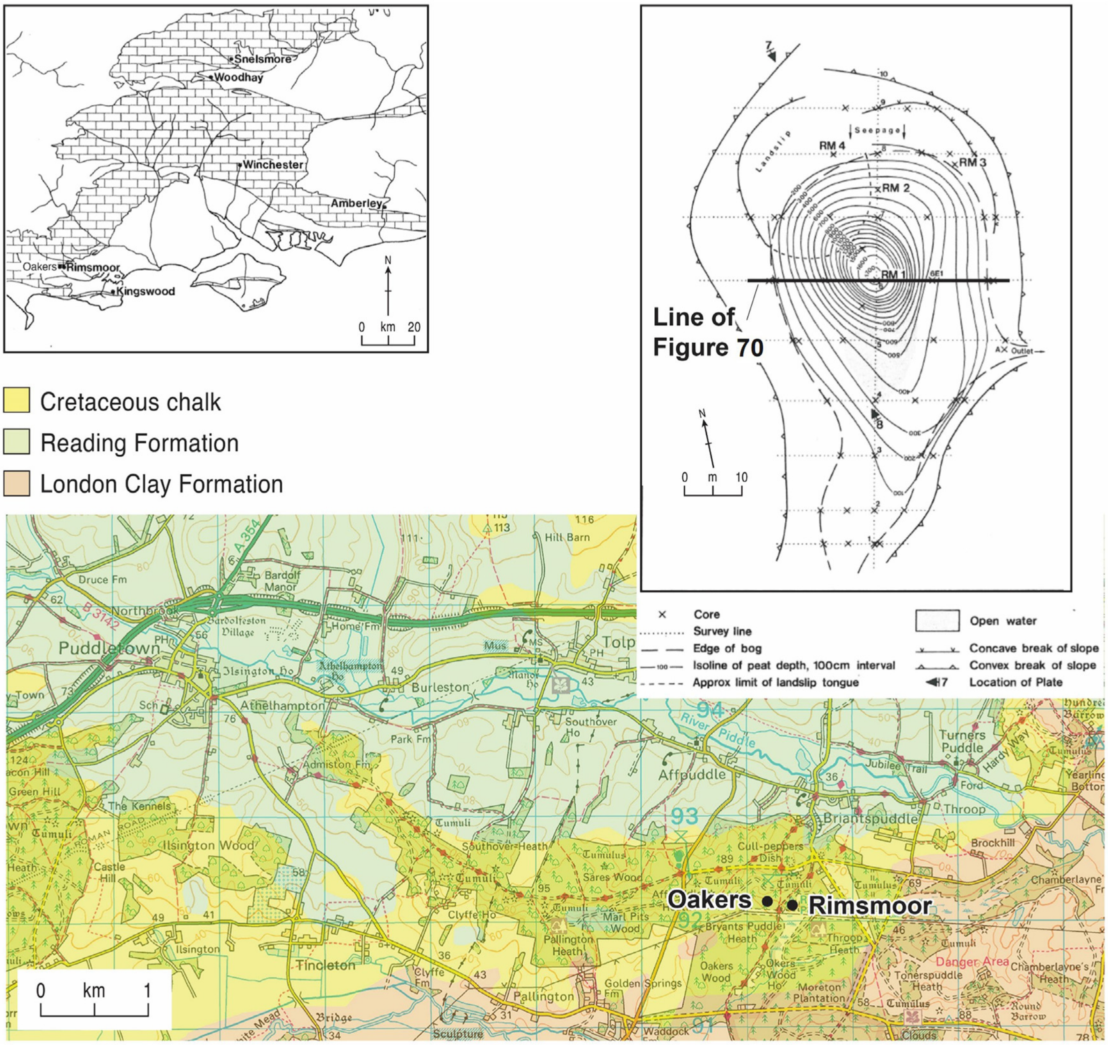

Fig. 69. Geology and location of Rimsmoor GCR site (SY 814 922), with depth of basin after Waton (1983), his Figure 4.21.

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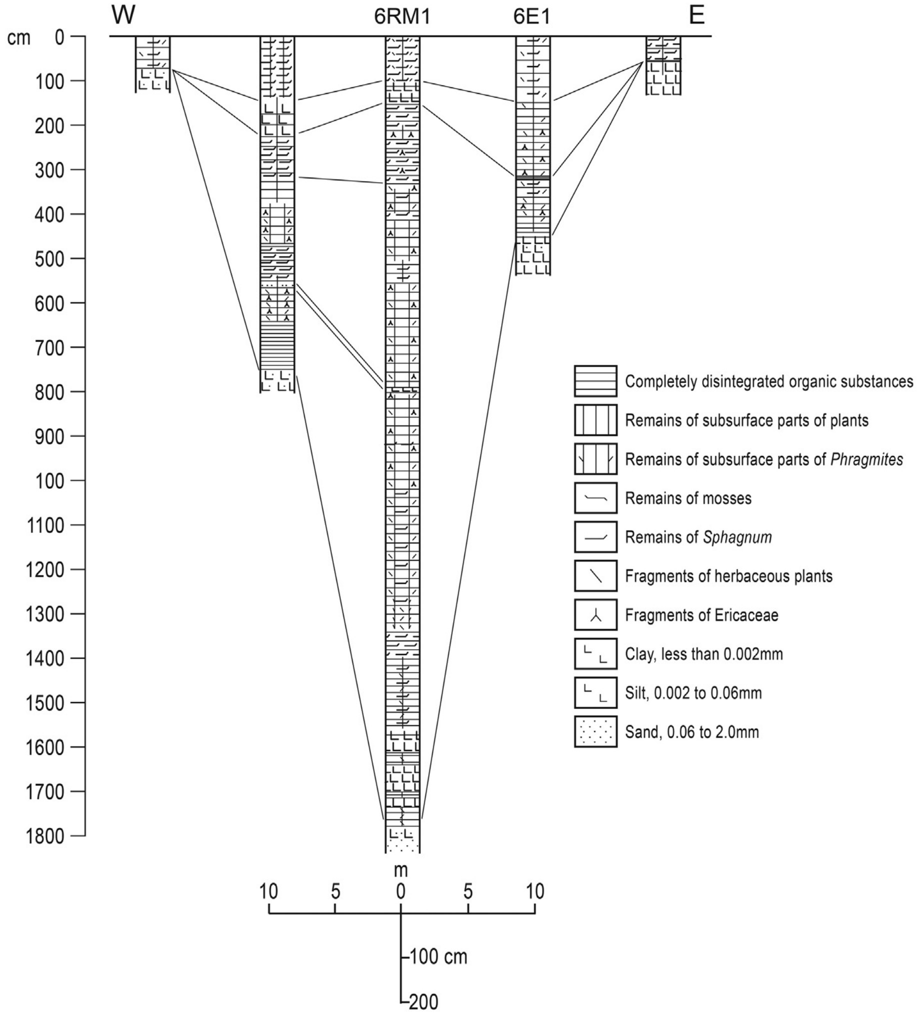

Fig. 70. Stratigraphical cross-section W–E across the Rimsmoor Basin (line shown in Fig. 69). Sedimentary key follows Troels-Smith (1955). Redrawn after Waton and Barber (1987).

a regional climatic signal. However, the work of Grant et al. (2014) has superseded these interpretations, with improved chronological control and higher resolution of the palaeoclimatic signal from Cranes Moor.

An important feature of the site is that it dates the establishment and lengthy period of stability of the alder carr woodland currently at the site. Clarke and Barber (1987) date this to *c.* 5930 cal BP (5170 ± 50 ^{14}C BP; SRR-1919), but Grant et al. (2009b) date it to *c.* 8800 cal BP (7945 ± 48 ^{14}C BP; SUERC-4199), which is broadly comparable with dates from Cranes Moor, 7 km to the south-west, where the alder rise is dated *c.* 8250 cal BP, and at Warwick Slade Bog, 2.75 km to the east the date is *c.* 8680 cal BP (7830 ± 100 ^{14}C BP; SRR-2250; Barber and Clarke, 1987). Clarke and Barber (1987) discuss that the late alder rise at Church Moor could reflect local factors at this site, for example due to a hiatus in deposition associated with a charcoal-rich layer, and

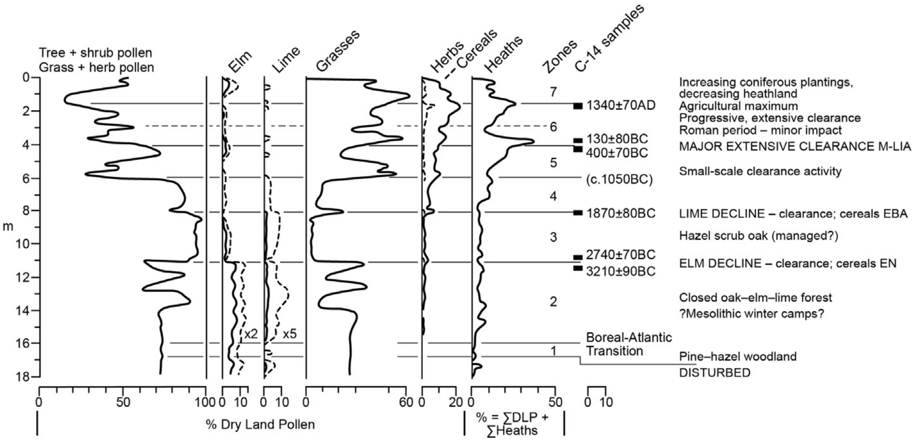

Fig. 71. Summary pollen diagram from core RM1 from Rimsmoor after Waton and Barber (1987).

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followed later by the resumption of peat accumulation at a later date. The charcoal-rich layer is not consistently found in all boreholes and Clarke and Barber (1987) suggest this may be a localised event caused either by natural or anthropogenic agency. The evidence for a hiatus in deposition in the sequence cored by Grant et al. (2014) strengthens this interpretation.

One of the remaining features of the pollen diagram is the arrival of *Fagus sylvatica* into the local area. Mark Ash Wood today is predominantly oak and beech, though Grant et al. (2014) note that *Fagus* pollen is present from as early as *c.* 8820 cal BP. Biogeographical interpretations by Birks (1989), Huntley and Birks (1983), Pott (1997, 2000) and Bradshaw and Mountford (2002) suggest that *F. sylvatica* did not become an important woodland constituent in England until *c.* 3000 cal BP (values above 2 % TLP). The values derived from the Church Moor sequence, although initially low (<1 %) reach up to 4 % TLP *c.* 6000 cal BP. Physical evidence for *Fagus* in England at this time is provided by radiocarbon dated charred wood from Ascott-under-Wychwood, dated to 6180–5920 cal BP (5246 ± 32 ^{14}C BP; OxA-12678; Bayliss et al., 2007) and Broxhead Common, dated to 5600–5320 cal BP (4790 ± 50 ^{14}C BP; Beta-218163; Graham and Graham, 2009). Grant et al. (2009b) note that the sustained low values for *Fagus sylvatica* imply that the mid-Holocene status of *Fagus* in southern Britain was probably only as isolated stands or individual trees, which were unable to compete effectively with the other woodland taxa present. For both Britain and Scandinavia, the main expansion of *Fagus* is coincidental with periods of intense human activity and disturbance within woodland, including increased clearance and adoption of woodland management (*e.g.*, Cowling et al., 2001; Bradshaw and Lindbladh, 2005; Grant and Dark, 2006).

In combination with the sequence from Mark Ash Wood (Barrow Moor), Grant et al. (2009b, p. 230) state that these sequences 'support the suggestion that woodland has been present on this site continuously since its early Holocene arrival'. However, the structure and composition of this woodland have been continuously modified over time due to both natural and anthropogenic activities, which has intensified until the present day, resulting in the current woodland composition and structure. The significance of this pollen record lies in the fact that Mark Ash Wood is classified as an Ancient and Ornamental Woodland, hosting important epiphytic lichens and bryophytes, as well as supporting many uncommon invertebrates, comprising some of the richest diversity in the UK (Rose, 1976), which are regarded as 'ancient woodland indicators' and taken, from a conservation perspective, as indicating antiquity of woodland at that site. Pollen analysis by Day (1991a, 1991b) at Sidlings Copse, another site hosting ancient woodland indicators, demonstrated that the current woodland there had only been present since the early medieval period. This makes Mark Ash Wood unique in Southern England by the fact that the current ancient woodland can be conclusively shown, through pollen analysis, to have never been clear-felled and has always been wooded since the first arrival of trees in the early Holocene.

The early appearance of *F. sylvatica* at Church Moor implies that although it has been present in Britain for a long time, its expansion is due to late Holocene human intervention rather than natural succession. Human activity is noticeable throughout the Holocene, though it has always been undertaken within a largely wooded environment without the large-scale clearance that has been common across much of lowland Britain. These records provide a clear indication of active woodland management within the pollen record, emphasised by the reduction of *Alnus glutinosa* values during the late post-medieval/modern period which matches those observed in modern coppiced *A. glutinosa* woodland (see Waller et al., 2012; Bunting et al., 2016).

8.2.2. Mark Ash Wood (Barrow Moor)

8.2.2.1. Introduction. Barrow Moor is a small valley mire located *c.* 500 m northwest of Church Moor, also within Mark Ash Wood. It is located towards the head of the catchment of an unnamed stream that drains into the Warwick Slade Cutting and then into the Black Water approximately 5 km west of Lyndhurst (Fig. 60). The site provides a high-resolution record of the last *c.* 5000 years of vegetation history in the New Forest, complementing the longer and earlier but incomplete sites at Cranes Moor and Mark Ash Wood (Church Moor). The site was first investigated by Barber (1981), who suggested that the timing of its formation was due to increased rainfall and clearance in the catchment during the Iron Age, though radiocarbon dating subsequently showed that this sequence was of greater antiquity (Grant, 2005; Grant et al., 2009b). The sequence was investigated (Fig. 60) by Grant (2005; Grant et al., 2009b) along with a sequence from the adjacent Church Moor to the west, to test questions about the continuity of woodland during the Holocene.

8.2.2.2. Description. Barrow Moor consists of a series of interconnecting valley fills forming the headwaters of a left bank tributary of the Black Water, *c.* 500 m northeast of the sequence at Mark Ash Wood (Church Moor) (Fig. 60). The underlying solid geology comprises Eocene Barton Group (Grant, 2005). The sampled site is one of the western tributary valleys draining into the main Barrow Moor complex to its east, and consists of a broadly linear feature trending north-west to south-east in a shallow valley. Wet alder carr presently occupies about 80 % of the ground surface, overlapping with the 95 % coverage of wet acidic woodland ground flora (Alcock, 1984). The organic deposits are up to 3 m in depth but vary locally (Fig. 64). The site was first studied by Barber (1981), who reported finding *Fagus* nuts within 0.1 m of the base of the bog sequence, which had a total depth of *c.* 2.5 m. A

Table 9
Radiocarbon dates obtained from Mark Ash Wood (Church Moor): a) Conventional radiocarbon dates from Church Moor, reported in Clarke and Barber (1987), calibrated against InCal20 (Reimer et al., 2020). SRR-1919 has been shown by Grant (2005) to be an outlier, but was originally accepted by Clarke and Barber (1987); b) Grant (2005; Grant et al., 2009b), recalibrated against IntCal20 (Reimer et al., 2020), using a Bayesian sequence to better constrain the dates.

Lab no.	Material dated	Depth (cm)	Radiocarbon age (BP)	Calibrated date range (95.4 % CI)
a) Clarke and Barber (1987)				
SRR-1919	Bulk peat	100–104	5170 ± 50	6170–5750
SRR-1920	Bulk peat	160–164	8260 ± 50	9430–9030
SRR-1921	Bulk peat	275–279	12,440 ± 60	14,970–14,270
b) Grant et al. (2009b)				
SUERC-4193	Seeds (*Rubus* type; *Carex* undiff.; *Potamogeton natans*; *Sambucus ebulus*), leaves, coleoptera	42	218 ± 24	290–0
SUERC-4194	Seeds (*Ranunculus* type; *Betula* undiff. fruits; *P. natans*; *S. ebulus*), leaves, coleoptera	83	196 ± 19	300–150
SUERC-5908	Seeds (*Ranunculus repens*; *Potomogeton natans*; *Sambucus ebulus*; *Carex* nutlets (undiff.; *Rubus fruticosus*)	90	712 ± 24	690–570
SUERC-6793	*Sphagnum* leaves, seeds (*Sambucus ebulus*, *Rubus* type, *Potomogeton natans*, *Carex* undiff.)	100	776 ± 25	730–670
SUERC-4197	Seeds (*Rubus* type, *Alnus glutinosa*),charcoal, *Sphagnum* leaves, monocote node	108	4815 ± 27	5600–5470
SUERC-4198	Seeds (*Carex* undiff.), charcoal, leaves, Sphagnum leaves	174	7319 ± 43	8280–8010
SUERC-4199	Seeds (*Carex* undiff.), charcoal	200	7945 ± 48	8990–8630
SUERC-6794	Charcoal and charred bud scales (undiff.)	235	9170 ± 57	10,500–10,230

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Table 10
Description of pollen zones recognised by Grant (2005; Grant et al., 2009b) from GCR site Mark Ash Wood (Church Moor).

Local pollen zone (cm BGL)	Description
CHMp-6 (28.5–2)	*Pinus sylvestris* and *Fagus sylvatica* dominate the zone, with increases in *Betula*, *Alnus glutinosa* and *Salix* towards the end of the zone. *Quercus* is present at low values throughout, with Poaceae decreasing mid-zone. *Erica tetralix*, *Calluna vulgaris* and *Plantago lanceolata* peak at the beginning of the zone before decreasing. *Hydrocotyle vulgaris* increases. *Polypodium* and *Pteridium aquilinum* are only present sporadically. Micro-charcoal decreases towards the end of the zone, with a low background of macro-charcoal.
CHMp-5 (75–28.5)	*Quercus* and Poaceae are dominant, with *F. sylvatica* increasing towards the end of the zone, and *Corylus avellana*-type and *Alnus glutinosa* decreasing. *C. vulgaris*, *P. lanceolata*, Poaceae and *Pteridium aquilinum* increase towards the end of the zone, with *Erica tetralix*, *Urtica dioica* and *Geum* at constant low values. Micro-charcoal peaks in the middle of the zone, with a low background of macro-charcoal throughout.
CHMp-4 (104.5–75)	*Quercus*, *C. avellana*-type, *Betula* and *Alnus glutinosa* are dominant, with *Calluna vulgaris* and *Ilex aquifolium* present throughout. *Tilia cordata* and *Ulmus* are present at low values, with the rare occurrence of *Fagus sylvatica*. *P. lanceolata* and *Filipendula* are present throughout, with *Rumex acetosella* present at the beginning of the zone. Poaceae is present at %, with a discontinuous presence of *Polypodium* and low values of *Pteridium aquilinum*. Micro-charcoal values are high at the beginning of the zone.
CHMp-3 (171–104.5)	*Quercus*, *Alnus glutinosa* and *Corylus avellana*-type dominate this zone, with *Ulmus*, *Tilia cordata*, *Fraxinus excelsior* and *Salix* consistent throughout. *Fagus sylvatica* peaks reaching 4 % TLP at 130 cm. *Ilex aquifolium*, *Hedera helix* and *C. vulgaris* increase, along with *Plantago lanceolata* and *Polypodium*. Cyperaceae, Poaceae and *Pteridium aquilinum* increase during the latter half of the zone. Pteropsida monolete indet. decreases from 52 % to 8 % (TLP + Spores). Micro-charcoal decreases at the beginning of the zone and remains low until an increase at the end. Macro-charcoal values are low throughout.
CHMp-2 (199–171)	*Alnus glutinosa* increases at the beginning of this zone. *Quercus* and *Corylus avellana*-type are dominant, with *Tilia cordata*, *Fraxinus excelsior* present throughout. *Betula* values increase, with low amounts of *Fagus sylvatica* also present. *Alnus glutinosa* (to 10 % TLP + *Alnus glutinosa*) and *Corylus avellana*-type (to 17 % TLP) values drop at 176 cm. *Pinus sylvestris* and *Ulmus* values are low throughout the zone. There is an increase in *Filipendula*, *Solidago virgaurea*-type, *P. aquilinum* and Pteropsida monolete indet. Poaceae and Cyperaceae are also increased during this zone. Micro-charcoal values increase towards the end of the zone, with macro-charcoal peaking at the end of the zone, with values up to 61 particles cm^{-3}.
CHMp-1 (238–199)	*P. sylvestris*, *C. avellana*-type and *Quercus* are the dominant taxa, with *Ulmus* and *Salix* also present. *Betula* and *Alnus glutinosa* appear at low levels during the middle of the zone. *P. sylvestris* decreases towards the end of the zone whereas *Quercus* increases. *U. dioica*, *Filipendula* and *Ranunculus acris*-type are present at low values throughout, with Cyperaceae and *P. aquilinum* increasing during the middle of the zone. Charcoal values are generally low.

radiocarbon age from wood remains from multiple cores at *c.* 1.4–1.6 m depth gave a date of 650–420 cal BP (495 ± 70 ^{14}C CE; UB-2214). The date of the base of the sequence was estimated by Barber (1981) to be *c.* 500 BCE. and the pollen is dominated by trees (*c.*, 70 % of total pollen on average), most notably *Fagus*, with *Ulmus* and *Tilia Corylus avellana* and *Fraxinus excelsior* present until very recent times.

The site was reinvestigated by Grant (2005), who undertook a stratigraphic survey through the Alder Carr area (Fig. 64). This was interpreted as crossing an abandoned channel meander within the valley, with cores F–H representing a point bar and cores B–E and I–L the abandoned channel itself. Grant (2005; Grant et al., 2009b) analysed pollen and charcoal from core D, whose Troels-Smith stratigraphy is shown below:

0–7 cm Tb^{3} Th^{1}
7–20 cm Tb^{1} Th^{2} Sh^{1} Tl^{+}
20–86 cm
Sh^{2} Th^{2} Tb^{+} Dh^{+}
86–120 cm Sh^{3} Th^{1} As^{+} Ag^{+}
120–186 cm Th^{2} Sh^{2} Dh^{+}
186–276 cm Sh^{3} As^{1} Ag^{+} Th^{+}
276–300 cm As^{3} Th^{1}

Six AMS radiocarbon dates (Table 11) were used by Grant (2005; Grant et al., 2009b), along with two age-horizons obtained from SCP analysis and the modern bog surface to create an age-depth model for Mark Ash Wood (Barrow Moor).The radiocarbon date at 105 cm (SUERC-6798) is much younger than the radiocarbon dates either side and was not used for the model. Grant et al. (2009b) suggested that it was the result of root penetration as the sample selected was poorly preserved.

Pollen and microcharcoal analysis from Mark Ash Wood (Barrow Moor) yielded seven local pollen zones, which are summarised in Table 12. The woodland composition at the base of the Barrow Moor sequence (zone BRMp-1) is very similar to that from the upper parts of the Church Moor sequence (pre-hiatus; zone CHMp-3), being dominated by *Quercus*, *Alnus glutinosa*, *Tilia cordata*, *Ulmus* and *Corylus avellana*. The base of the sequence is undated, but if the overlying radiocarbon dates are interpolated down-sequence, it would suggest a date of *c.* 4000 cal BP. However, the abundance of *Ulmus* matches that observed in the Church Moor (CHMII core of Clarke and Barber, 1987) and Cranes Moor (CM1 core of Barber and Clarke, 1987) pollen sequences prior to the mid-Holocene *Ulmus* decline, the latter dated *c.* 5200 cal BP. The end of zone CHMp-3 at Church Moor (Grant et al., 2009b) is dated *c.* 5500 cal BP, and shows that *Ulmus* was still present in the woodland at that time. It is therefore likely that the *Ulmus* decline at Barrow Moor occurred sometime between *c.* 5500 and 5200 cal BP, and therefore suggests that the base of the Barrow Moor sequence chronologically overlaps with the top of pollen zone CHMp-3 in the Church Moor sequence of Grant et al. (2009b).

The decline in *Ulmus* coincides with a reduction in *Quercus*, but an increase in *Corylus avellana*-type, which may be a response to reduced woodland canopy permitting understorey shrubs and herbs to respond to increased light conditions. Further up the sequence, in zone BRMp-2, there is a decline in *T. cordata* values occurring over a period of *c.* 200 years during the early Bronze Age *c.* 3500 cal BP (3346 ± 23 ^{14}C BP; SUERC-4202) and coinciding with an opening of the local woodland allowing taxa such as *Fagus sylvatica*, *Ilex aquifolium* and *Betula* to increase. *T. cordata* does remain locally present at much reduced values for a further 2000 years through zone BRMp-3, until it finally disappears during the late Roman/early Anglo-Saxon period (end of zone BRMp-4). Also low during these zones are *Ulmus* and *Alnus glutinosa*, whilst *Quercus* and *Corylus avellana* remain dominant. At the beginning of the Iron Age (in zone BRMp-4) there is an increase in charcoal values, coupled with a decrease in taxa indicative of open ground, and an increase in other woodland taxa such as *I. aquifolium* and *Quercus*. There is a close interaction between values of *Quercus* and *C. avellana*, with a reduction in one mirrored by an expansion in the other. *I. aquifolium* also increases when *Quercus* decreases, and these probably represent an interplay of changing woodland canopy, light availability and subsequent variations in local structure of the woodland mosaic vegetation.

During the late Anglo-Saxon and early medieval period (zone BRMp-5) there is no noticeable change in the pollen assemblage. Consistent low values for Ericaceae taxa remain, as do the dominant tree species, with the addition of *Betula*. Low levels of *Fagus sylvatica* are recorded in zone BRMp-5, followed by a significant expansion *c.* 1250 cal CE (zone BRMp-6). This expansion of *F. sylvatica* coincides with an opening up of the woodland indicated by an increase in Poaceae and *Pteridium aquilinum* and the reduction of *Corylus avellana* type, *Betula* and gradual decreases in the amount of *Quercus*. *Alnus glutinosa* also reduces in zones BRMp-6/7, coinciding with an increase in charcoal particles. Zone BRMp-7 is marked by a dominance of *Pinus sylvestris* and *Fagus*

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sylvatica, with *Alnus glutinosa* and *Betula* also present and increasing towards the end of the zone.

8.2.2.3. Interpretation. Grant et al. (2009b) suggested that the similarity in woodland composition between BRMp-1 and the upper zones from Church Moor (CHMp-3) meant there had been little change in the local area and that woodland was continuously present, although they noted that the initiation date at Barrow Moor was unknown. If the reduction in *Ulmus* in zone BRMp-1 isn't related to the mid-Holocene elm decline, then there might have been a time interval between the two sequences. During the Iron Age and Bronze Age, the main feature is the low levels of *Tilia cordata*. There is evidence of Bronze Age, Iron Age and Roman activity locally, much of which would have relied upon the need for fuel and possibly pastoral activity (*e.g.*, boiling mounds and pottery kilns). The timing of the decline of *Tilia cordata* at Barrow Moor coincides well with other British sites that occur mainly during the late Neolithic and Bronze Age (Grant et al., 2011). The associated increase in charcoal values within BRMp-3 may reflect activity at the Iron Age site adjacent to Church Moor, but its distance from Barrow Moor makes identifying the nature of its impact within the pollen sequence difficult. During the Roman period (BRMp-4), Grant et al. (2009b) note changes in the pollen assemblage, particularly for *Quercus*, *C. avellana*, *I. aquifolium* and Poaceae, and attribute these to selective clearance/management for fuel. Excavations of Roman pottery kiln sites in the north of the Forest have revealed, through charcoal assemblages, that *Quercus*, *Ilex aquifolium*, *Alnus glutinosa* and *Fraxinus excelsior* were used as fuel for these (Fulford, 1975), so it is likely that the charcoal composition used in the Mark Ash Wood pottery kilns would have had a similar composition. The reduction in *Corylus avellana* type is mirrored by a peak in Poaceae and may be a response to an opening up of the woodland through partial clearance and management, with an increase in grazing and browsing by animals associated with the potters restricting hazel regrowth. The final disappearance of *Tilia cordata* during this period may have also been the result of clearance and/or increased browsing/grazing pressure. The pottery production sites within Mark Ash Wood are small compared to those uncovered within the northern vicinity of the New Forest, although the level of human impact during this period is observable within the Barrow Moor sequence.

During the late Anglo-Saxon and early medieval period (zone BRMp-5), the lack of noticeable changes in the pollen assemblage from BRMp-4 suggests that the Norman introduction of Forest Law did not have a major impact on the local woodland at this location. Grant et al. (2009b) argue that the main changes occur during the late Roman/early Anglo-Saxon period, and that the systems established then may have continued more or less unchanged into the medieval period. The presence of consistent low values for Ericaceae taxa may indicate the presence of small areas of heath within the general woodland mosaic, although this pollen may have originated from taxa growing on-site. *Fagus sylvatica* was present around Barrow Moor as small stands throughout the medieval period, whereas at Church Moor it was probably only small, isolated stands or individual trees. Similarly, Grant et al. (2009b) show that the date of expansion of *F. sylvatica* varies considerably, with a date of *c.* 1250 cal CE for Barrow Moor (zone BRMp-6) and *c.* 1750 cal CE for Church Moor (zone CHMp-5). They note that this expansion is likely to be the result of changes in woodland management and the selective removal of *Quercus* for construction, in addition to increased browsing and grazing pressure and subsequent planting of hardwood and softwood plantations around the margins of Mark Ash Wood (Grant and Edwards, 2008). The disappearance of *C. avellana* in most areas of the New Forest was the result of the change in demand from underwood (coppice) to timber production, with increased browsing and grazing likely to have played an important role in its reduction (Tubbs, 2001). The reductions of *A. glutinosa* in zone BRMp-6/7 coincide with an increase in charcoal particles. It is probable that this reduction in *A. glutinosa* is a response to coppicing of the alder carr for use in charcoal production, which is known to have occurred in the area, particularly for use in the gunpowder industry (Pasmore, 1964). At the top of the pollen diagram is the expansion of *P. sylvestris*, resulting from the introduction of softwood plantations in the area, with the earliest plantation adjacent to Church Moor dating from 1850 CE.

The sequence from Mark Ash Wood (Barrow Moor) is a valuable addition to the network of GCR sites in the New Forest, providing a high-resolution record of changes in the structure and composition of the woodland over *c.* 5000 years. Particularly importantly, it documents the changing management strategies and woodland composition over the past 5000 years, leading to the current Ancient and Ornamental woodland that is of exceptionally high conservation value. The record also provides “a clear indication of active woodland management within the pollen record, emphasised by the reduction of *Alnus glutinosa* values as a response to coppice management during the late post-medieval/modern period” (Grant et al., 2009b, p. 230), matching those observed in the Church Moor sequence.

8.2.2.4. Conclusion. The GCR site at Mark Ash Wood comprises valley mire sequences at both Church Moor and Barrow Moor. Together, these provide an almost complete record of the last 14,000 years, with high-resolution data for the last 5000 years. The two sites together have considerable importance for palynological and palaeoecological studies and understanding the development of the New Forest Ancient and Ornamental woodlands. Sediment deposition at Church Moor dates from the Devensian Late Glacial Windermere Interstadial to the present day, covering a period of over 14,000 years, although both sequences that have been studied in detail appear to contain hiatuses. Late Glacial macrofossil and pollen analyses have yielded some of the earliest British post-glacial records of bryophytes. Church Moor is also of importance in tracing the early post-glacial immigration and expansion of plant species and has been used as a reference site for correlation in southern England. The peat at Barrow Moor has been accumulating since *c.* 5000 cal BP and provides a valuable high-resolution record of late Holocene woodland dynamics that is missing from other New Forest sequences. The oldest pollen spectra show a clear alder carr signal, suggesting significant local woodland stability. From the Medieval Period onwards, the record shows clear evidence of woodland management and the development of the wood–pasture system, today dominated by *Quercus* sp. and *Fagus sylvatica*, which is an iconic feature of the New Forest and the most extensive area of such active wood–pasture in north-west Europe.

8.3. GCR Site 2884 Cothill Fen (SU 463 999) (CAW, RMB)

8.3.1. Introduction

Cothill Fen (Fig. 66) is a calcareous valley fen set in an irregular basin containing organic deposits dating back to the early-Holocene. Old peat cuttings have been recognised at the site and partial drainage and ploughing occurred in 1957 but without significantly affecting the deposits. Cothill Fen is a key reference site for palynological and palaeoecological studies in southern England. It is also important historically to the development of palynology in Britain. According to Day (1991a), the early preliminary study of its pollen by Clapham and Clapham (1939) was used by Godwin (1940) as the foundation of his post-glacial pollen zonation scheme. Day's (1991a) more recent work, taking advantage of half a century of technical innovation, has been used as the basis for this report.

8.3.2. Description

Cothill Fen is located in the catchment of the Sandford Brook, between reaches of the River Thames, *c.* 8 km southwest of Oxford, on a ridge of Late Jurassic (Corallian) limestone and sandstone referred to as the Oxford Heights (Fig. 66). The sandstone, supporting brown earth and sandy soils, underlies the site; limestone, beneath rendzina soils, occurs on the eastern margin. Current vegetation is calcareous fen with oak and alder. Beneath the surface are the peat and marl deposits of palaeoecological interest extending across an area *c.* 600 m × 300 m, with a maximum thickness of *c.* 4 m towards the southeast of the site in the area known as Morland's Meadow.

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Table 11
AMS radiocarbon dates obtained from Mark Ash Wood (Barrow Moor) by Grant et al. (2009b), calibrated against IntCal20 (Reimer et al., 2020).

Lab. no.	Material dated	Depth below ground level (cm BGL)	^{14}C BP (uncal.)	δ^{13}C ± 0.1	Calibrated date range (95.4 % CI)
SUERC-4200	Seeds (*Ranunculus* type; *Rubus* type; *Carex* undiff.), charcoal, bud scales (undiff.), leaves, *Sphagnum* leaves, coleopteran	50	775 ± 24	−27.9	735–665
SUERC-6792	Leaf fragments (undiff.), seeds (*Alnus glutinosa*, *Betula* undiff.), bud scales (undiff.)	65	1102 ± 25	−27.9	1070–950
SUERC-4708	Seeds (*Betula* undiff., *Alnus glutinosa*, *Carex* undiff.), leaves, bud scale (undiff.), twig fragments, coleoptera	82	1688 ± 25	−27.3	1690–1530
SUERC-6798	Wood fragment (twig undiff.)	105	352 ± 20	−29.0	500–310
SUERC-4201	Seeds (*Carex* undiff.; *Betula* undiff. fruits), bud scales (undiff.), coleoptera	125	3203 ± 24	−26.4	3470–3360
SUERC-4202	Seeds (*Betula pendula* fruits; *Carex* undiff.), leaves, coleoptera	152	3346 ± 23	−27.8	3640–3470

Clapham and Clapham (1939) recognised four sedimentary horizons which they attributed to variations in lake depth broadly related to climate change. These units were reflected in their pollen analysis which revealed a base-upward sequence of a) Pre-boreal *Betula* and *Salix* with some *Pinus* at the base, followed by b) *Pinus*, c) boreal *Ulmus*, *Quercus* and *Corylus* with decreasing *Pinus* and finally d) *Tilia* and *Alnus* attributed to the Boreal–Atlantic Transition.

In the late 1980s Cothill Fen was resampled with the aid of modern techniques, and pollen analysis was supplemented by charcoal particle analysis, magnetic susceptibility scanning and radiocarbon dating by accelerator mass spectrometry (Day, 1991a). Day rejected the idea of a substantial lake at Cothill Fen based on the lack of an obvious mineral dam and the non-lacustrine nature of the sediments (Fig. 66). Broadly, the sequence comprises slightly less than 1 m of highly humified organics, overlain by *c.* 3 m of peat and marl, then overlain by a thin bed of pure marl and disturbed ground (Fig. 67). The detailed stratigraphy is however noticeably more variable (Table 13). This variability may account for the considerable variation in pollen concentration in the Cothill Fen deposits (not shown in Fig. 68 because the variation between samples is too great).

The calcareous nature of much of the deposits from Cothill Fen presented a potential problem in obtaining radiocarbon dates due to the possibility of hard water error (Day, 1991a). The deposits from Cothill Fen contained few identifiable plant remains, with the exception of mosses and seeds of *Menyanthes trifoliata*. Since both aquatic vascular plants and mosses may incorporate ^{14}C deficient carbon when growing in calcareous water, these two types of material were avoided. Samples for dating from the Cothill sequence comprised mixed plant detritus, including wood fragments. Interpolation of ages between these dated samples has allowed for estimation of ages at the base of each biozone and an accumulation rate of *c.* 0.11 cm/year or 9 years/cm.

Day (1991a) recognised 4 local pollen zones at Cothill Fen based on a numerical zonation analysis and shown in Figure 68:

> Zone CF1: 392–340 cm. The sediment is dominantly sandy with interbedded layers of highly humified organic material. It contains some charcoal. Cyperaceae dominate the pollen assemblage with some Gramineae, a range of other herbs, including *Artemisia*, *Carex* fruits and *Menyanthes trifoliata* seeds indicating an area with swampy vegetation. Arboreal pollen is represented mainly by *Betula*, and *Pinus sylvestris* with some *Salix*.
>
> Zone CF2: 340–268 cm. Sediment is humified herbaceous peat banded with layers and pockets of marly peat. Ferns, including *Thelypteris palustris*, indicated by common spores, were initially important in the local vegetation. An increasing amount of *Corylus* pollen and the start of the *Ulmus* curve, dated 10,570–9890 cal BP (9070 ± 110 ^{14}C BP; OxA-2114) are features of this zone. *Pinus sylvestris* reaches 28 % of the pollen count, *Quercus* appears occasionally whilst *Betula* is low at no more than 2 %. Pollen of herbaceous species is considerably less than in CF1.
>
> Zone CF3: 268–62 cm. Sediment is mostly humified herbaceous peat with a few layers and pockets of marly peat changing to heterogenous cream coloured marl in the upper 20 cm. Arboreal pollen is dominant in this zone, especially *Corylus*. *Pinus sylvestris*, *Ulmus* and *Quercus* achieve maximum frequency and there is a first appearance for *Tilia cordata*, *Alnus glutinosa*, *Fraxinus excelsior* and *Hedera*

Table 12
Description of pollen zones from Mark Ash Wood (Barrow Moor) from Grant et al. (2009b).

Local pollen zone (cm BGL)	Description
BRMp-7 (26.5–2)	*Pinus sylvestris* and *Fagus sylvatica* dominate, with *Alnus glutinosa* and *Betula* increasing towards the end of the zone. *Salix*, *Ilex aquifolium*, *Erica tetralix*, *Calluna vulgaris*, *Filipendula*, Poaceae, Cyperaceae and *Pteridium aquilinum* also decrease towards the end of the zone. Charcoal values are initially high but decrease.
BRMp-6 (49.5–26.5)	*Fagus sylvatica*, Cyperaceae and Poaceae dominate, with *Betula*, *Quercus*, *A. glutinosa* and *Corylus avellana*-type decreasing. *Ilex aquifolium*, *Ranunculus acris*-type, *Filipendula*, *Cichorium intybus*-type and *Pteridium aquilinum* increase. Charcoal values decrease throughout the zone before peaking at the end of the zone.
BRMp-5 (82.5–49.5)	*Quercus*, *Betula*, *A. glutinosa* and *C. avellana*-type dominate, with low values of *Fagus sylvatica* and *Fraxinus excelsior*. *Ilex aquifolium* increases, with increases in *Urtica dioica* and *Rumex acetosella*. Poaceae and Pteropsida monolete indet.. decrease. Cyperaceae, Poaceae and *P. aquilinum* are present at low values. Micro-charcoal is present throughout the zone.
BRMp-4 (111.5–82.5)	*Quercus*, *A. glutinosa* and *C. avellana*-type dominate, with *Betula*, *Salix*, *Ilex aquifolium* and *Fraxinus excelsior*. *Calluna vulgaris*, *Ranunculus acris*-type, *Filipendula* and *Plantago lanceolata* all increase during this zone. Poaceae and Pteropsida monolete indet. increase, with sustained values for *Pteridiumaquilinum*. Charcoal values are fairly constant throughout the zone.
BRMp-3 (132.5–111.5)	*Quercus* and *Corylus avellana*-type dominate, along with *Betula*, *Alnus glutinosa* and *Salix*. *Tilia cordata* decreases, with increases in *Ilex aquifolium*, *Filipendula*, *R. acetosella*, *P. lanceolata*, *C. intybus*-type and Poaceae. There is also an increase in *P. aquilinum*. Micro-charcoal values are constant, with a peak in macro-charcoal at 120 cm.
BRMp-2 (171–132.5)	*Quercus* and *Corylus avellana*-type dominate, with *Tilia cordata*, *Ulmus* and *Alnus glutinosa* declining to lower, sustained values by the end of the zone. *Betula* and *Salix* increase mid-zone. *Rumex acetosella* type increases towards the end of the zone, with little change in *Plantago lanceolata* and *Urtica dioica* values. Cyperaceae decreases towards the end of the zone, with Poaceae, *Polypodium* and *Pteridium aquilinum* increasing at the end of the zone. Charcoal values are low but fairly constant throughout the zone.
BRMp-1 (201–171)	Dominated by *Alnus glutinosa*, *Quercus* and *Corylus avellana*-type, with *Ulmus*, *Betula* and *Tilia cordata*. *Alnus glutinosa* decreases in the middle of the zone. Pteropsida monolete indet. are high, with low herb values, including *Rumex acetosella* type, *Urtica dioica* and *Plantago lanceolata*, and constant Poaceae values. Charcoal values are low and sporadic in occurrence.

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helix. After achieving 43 % frequency *Pinus sylvestris* declines to 1 % at the top of the zone. With the exception of Cyperaceae, herbaceous pollen frequencies are low.

Zone CF3 is subdivided into CF3a (268–156 cm) and CF3b (156–62 cm). In CF3a, dated 9540–9030 cal BP (8350 ± 100 ^{14}C BP; OxA-2081) in the centre of this sub-zone, *Quercus* rises and falls and *Pinus sylvestris* is generally above 20 %. The concentration of charcoal particles is variable but reaches its maximum in this sub-zone. The dominance of rush in the local vegetation is indicated by the abundance of aerenchyma cells from *Juncus* pith. In CF3b, dated 8390–7950 cal BP (7350 ± 120 ^{14}C BP; OxA-2080) towards the base of this sub-zone, *Pinus sylvestris* is generally below 20 %, *Quercus* shows relatively high frequencies peaking at 32 %, and *Tilia cordata* (<0.5 %) and *Alnus glutinosa* (<3 %) occur in very small quantities. Mosses now formed the main constituent of the peat. Bryophyte mat growth may explain the banding of the deposits in this sub-zone and the formation of marly peat.

Zone CF4: 62–30 cm. Cream coloured marl with bands of dark brown peat below 43 cm. The layer of pure marl may reflect deeper water. This uppermost zone shows a curve rising up to 9 % for *Alnus glutinosa* and to 15 % for *Tilia cordata*, although the percentage for *Tilia* may be inflated by the loss of less resistant pollen due to the effects of calcium carbonate. Other tree species represented in this zone are *Pinus sylvestris*, *Quercus*, *Ulmus*, and *Fraxinus excelsior*, all generally reduced in concentration compared to Zone CF3. One *Triticum* type pollen grain was recovered from this zone at 48 cm. A date of 7850–7430 cal BP (6790 ± 100 ^{14}C BP; OxA-2709) was obtained from towards the base of this zone.

8.3.3. Interpretation

The original interpretation by Day (1991a) provided a chronology based upon uncalibrated radiocarbon dates (^{14}C BP). In order to provide the chronology of recorded events as true ages, these require calibration against a radiocarbon calibration curve (*e.g.*, IntCal20; Reimer et al., 2020). The calibrated 'real' dates are therefore provided as calibrated ages BP (before 1950 CE) in parenthesis to assist the reader.

The results of the pollen analysis indicate that from *c.* 10,000 to 9500 ^{14}C BP (*c.*, 11,500 to 10,800 cal BP), the site in the valley bottom was a swampy area surrounded by a predominantly open landscape with herbs such as *Artemisia* indicative of disturbed ground. The occurrence of *Betula* and *Pinus sylvestris* with subsidiary *Salix* suggests only a light tree cover. There may have been some encroachment of woodland towards the swamp, indicated by the marginal layer of wood peat, illustrated by Clapham and Clapham (1939; Fig. 68), but the accumulation of marly peat, probably under fen conditions after *c.* 9500 ^{14}C BP (*c.*, 10,800 cal BP), seems to have reversed this trend.

Nevertheless, the increase of *Corylus avellana* (*c.*, 9400 ^{14}C BP; *c.* 10,600 cal BP), *Ulmus* (*c.*, 9100 ^{14}C BP; *c.* 10,300 cal BP) and *Quercus* (*c.*, 8800 ^{14}C BP; *c.* 9800 cal BP) during CF2, and the decline of *Betula* and herbaceous species, indicates sequential development of closed canopy woodland in the area surrounding the fen. *Pinus sylvestris* persisted in CF2 but its apparent increase into Zone CF3 from 8800 ^{14}C BP (*c.*, 9800 cal BP) may be an artefact of fern pollen abundance in the sequence from 9500 to 8800 ^{14}C BP (*c.*, 10,800–9800 cal BP).

From *c.* 8800 to 7700 ^{14}C BP (*c.*, 9800–8600 cal BP) (CF3a) woodland, with *Pinus sylvestris*, *Corylus avellana*, *Ulmus* and *Quercus*, apparently with no dominant species (although at Sidlings Copse (SP556096) on the north-east side of Oxford, *Corylus avallana* was the clear dominant; Day, 1991b), surrounded the open area now dominated by rush. The subsequent millennium (*c.*, 7700–6850 ^{14}C BP (*c.*, 8600–7800 cal BP) witnessed a further decline in *Pinus sylvestris*, probably to absence or isolated individuals. The woodland was dominated by oak at this time, but *Tilia cordata* and *Alnus glutinosa* began to appear at low frequency *c.* 7400 ^{14}C BP (*c.*, 8200 cal BP). Mosses with some bryophyte mats now occupied the low-lying open area. Around 6700 ^{14}C BP (*c.*, 7600 cal BP), *Tilia cordata* and *Alnus glutinosa* increased their contribution to the woodland assemblage, whilst *Pinus sylvestris*, *Quercus*, *Ulmus*, and *Fraxinus excelsior* all correspondingly decreased. On the basis of data from nearby Sidlings Copse *Tilia cordata* and *Alnus glutinosa* dominated the vegetation on well-drained and poorly-drained soils, respectively (Day, 1991a).

The presence of a single *Triticum* (cereal) type pollen grain equivalent to *c.* 6700 ^{14}C BP (*c.*, 7600 cal BP) is interesting as it predates the elm decline, traditionally associated with the introduction of agriculture, although Day (1991a) cautions against drawing conclusions from such sparse evidence. Nevertheless, this raises the possibility of a human impact on this landscape.

The persistence of *Pinus sylvestris* around Cothill Fen correlates with high charcoal counts from 8800 ^{14}C to 7700 ^{14}C BP (*c.*, 9800 to 8600 cal BP), which may indicate widespread natural burning. However, the absence of charcoal from the nearby Sidlings Copse sequence (Day, 1991b) suggests local, human-induced burning at Cothill Fen, rather than widespread natural burning, a conclusion supported by the proximity to Cothill Fen of Mesolithic archaeological evidence (pers. comm. from J. Wallis to S.P. Day). Whether the charcoal derived from the burning of woodland, fen vegetation or domestic fires is debatable. The persistence of *Pinus* around Cothill may be due to human disruption of the woodland canopy. The presence of *Pteridium aquilinum* and *Rumex acetosa* may also be related to such woodland openings.

There is no further evidence of vegetation development from this site after *c.* 5600 ^{14}C BP (*c.*, 6400 cal BP), but a similar fen-peat succession occurs *c.* 15 km to the north-east of Cothill Fen, beyond Oxford, at Sidlings Copse (SP 556 096), overlying up to 1.5 m of tufa and extending to the present day, as reported in Day (1991b). The base of the Sidlings Copse record records the disappearance of *Pinus sylvestris* and expansion of deciduous woodland, beginning with the rise in *Corylus avellana*, and is therefore complimentary with the Cothill Fen sequence, though the latter contains a higher resolution record of this early Holocene change in the local vegetation dynamics. Together, the Cothill Fen and Sidlings Copse sequence provide a full Holocene record of the vegetation history of Oxfordshire.

8.3.4. Conclusions

The Cothill Fen site makes a valuable contribution to knowledge of the vegetation history in an area of south-central England, supplementing the other similar GCR sites in a region where such sites are relatively uncommon. The site provides a detailed picture of both local and regional vegetation changes from the early to mid-Holocene, and when combined with the Sidlings Copse sequence, a full Holocene vegetation history for the Oxford region. Some indication, from both pollen and charcoal evidence, of human influence on vegetation during this time is also given.

8.4. GCR Site 1903 Rimsmoor (SY 814 922) (CAW, RMB)

8.4.1. Introduction

Rimsmoor (Fig. 69) is a deep peat bog occupying a doline, containing organic deposits dating back to the early Holocene. It is a key site for studies of palynology and doline formation in southern England, with evidence of vegetational change near the chalklands. The site is exceptional for both the presence and depth of peat, and an extremely rapid rate of organic accumulation, providing important evidence of the immigration and expansion of flora during this time. Dolines are particularly common on the heathlands between Dorchester and Bere Regis and in some areas they attain densities of a hundred or more per square kilometre (Waton, 1983). Dorset dolines were mentioned by Stevenson (1812), superficially described by Fisher (1858, 1859) and Reid (1899) later in the nineteenth century and studied more systematically in the twentieth century by Sperling et al. (1977). The sites of Rimsmoor and Oakers, however, are unusual in that most dolines in the area are free

Table 13
Description of the sediment core from Cothill Fen taken by Day (1991a), including information on plant macrofossils and radiocarbon dating, calibrated against IntCal20 (Reimer et al., 2020).

Depth (cm)	Sediment description	Plant macrofossil content	Radiocarbon dated material	Radiocarbon ages (^{14}C BP)	Calibrated date range (95.4 % CI)
30–43	Marl				
43–153	Heterogeneous marl with bands of humified moss peat	*Menyanthes trifoliata* seeds; mosses include *Homalethcium nitens*, *Hypnum cupressiforme*, *Drepanocladus* undiff., *Scorpidium scorpoides*	Mixed plant detritus, including wood, from 56–57 cm 133–135 cm	OxA-2709, 6790 ± 100 OxA-2080, 7350 ± 120	7850–7430 cal BP 8390–7950 cal BP
153–170	Heterogeneous marl with detritus and a little moss				
170–330	Humified herbaceous peat banded with layers/pockets of marly peat	*Carex* fruits, *Menyanthes trifoliata* seeds	Mixed plant detritus, including wood, from 208–209 cm 297–298 cm	OxA-2081, 8350 ± 100 OxA-2114, 9070 ± 110	9540–9030 cal BP 10,570–9890 cal BP
330–369	Highly humified organics				
369–373	Silty sand with detritus				
373–376	Highly humified organics	*Carex* fruit			
376–382	Sand				
382–397	Highly humified sandy organics	*Menyanthes trifoliata* seeds, *Carex* fruits, *Chara* ooospore			

from accumulations of organic remains and thus are free-draining (Waton, 1983).

However, the palynology of Rimsmoor, in particular, was not addressed in detail until 1982, when it was published by Paul Waton (1980; Waton, 1982) in a summary form, preceding the completion of his unpublished PhD thesis (Waton, 1983). A condensed report, focussed on the site, was subsequently published by Waton and Barber (1987). The original radiocarbon dating was reported in (uncalibrated) years BCE and CE. These dates have been calibrated for this paper for consistency with other sites (see below). Although not in the title of this GCR site, the GCR boundary includes within it the nearby Oakers doline. Thus, two dolines are included in the GCR site, both of which lie within the Oakers Bog SSSI. Whilst the Oakers doline was included 'for its palynological research *potential*', a palynological analysis was also carried out by Waton at Oakers/Okers (Waton, 1983, pp. 156–167 and 206–209), at the same time as his work on Rimsmoor itself, to assess spatial variability of vegetational changes. However this sequence was never radiocarbon dated and is only reported in his unpublished PhD thesis (Waton, 1983).

8.4.2. Description

The dolines containing the Rimsmoor (SY 8142 9218) and Oakers (SY 8127 9221) sequences are developed in Paleogene Reading Formation sediment. They are located in Bryants Puddle Heath, in west Dorset, 4 km south-west of Bere Regis and about 1 km south of the nearest Cretaceous chalk outcrop (Fig. 69).

The Rimsmoor doline consists of two parts: a northern basin *c.* 35 m in diameter and 20 m deep and a shallower, southern extension 20–30 m in diameter and only 4–5 m deep, the pair elongated downslope. Sudden collapse is often taken to be the mode of formation of dolines (*cf.*, Sperling et al., 1977), and there are evidence of land slips associated with the upper margin of the basin at Rimsmoor. Waton (1983) also pointed out that land slips could remove trees and that the exposed ground could then be colonised by plants taken to indicate human disturbance in pollen spectra, as in the Rimsmoor sequence. However, several lines of evidence at Rimsmoor suggest continuous slow solution aided by acidic groundwater. First, lacustrine sediments, which might be expected in a deep water-filled basin, are absent, as clay beds formed by transport from its steep margins are very rare, occurring only intermittently below 15.5 m and between 1.0 and 1.5 m. Second, the stratigraphy within the doline is gently concave (Fig. 69). Third, the nature of the telmatic peat infilling the doline indicates that the water level has always been similar to today, no more than a few centimetres below the *Sphagnum* surface. This infers a rate of solutional subsidence equivalent to the rate of peat accumulation, which can be quantified at a steady rate of 2.6 mm/year (3.84 years/cm), based on the lower five of six radiocarbon dates obtained from the peat (Table 14). The six dates, combined with palynological dating at *c.* 16.5 m indicate that most of the accumulation occurred in the last 8000 years. At the surface, a rich *Sphagnum*-dominated mat encircles a central pool. The adjacent sides of the depression are colonised by grasses, *Calluna vulgaris*, *Erica tetralix* and *Ulex europaeus* and surrounded by a 1950s heathland (*Calluna* and *Ulex*) based coniferous plantation with isolated groups of oaks, usually in dolines. The maximum depth of peat within the doline is 18 m (Fig. 70). White leached sand was reached at this depth but not penetrated (Waton, 1983).

Pollen diagrams were constructed for both Rimsmoor and Oakers (Waton, 1983). Waton and Barber's (1987) published summary diagram of Rimsmoor pollen and its zonation, illustrating the main trends related to landscape changes, is reproduced in Figure 71. Full pollen diagrams are contained within Waton (1983), including unpublished high-resolution pollen diagrams, at 1–2 cm sampling resolution, between 8.00 and 8.50 m and 10.40 and 10.90 m, focussing on the *Tilia* and *Ulmus* declines respectively.

The small size of the basin means that the source of most of the non-mire pollen deposited at Rimsmoor is within a few tens of metres of the mire edge (Jacobson Jr. and Bradshaw, 1981). Zonation begins at a depth of 16.55 m. The results of pollen analysis below this level, from 16.55 to 17.80 m, reveal distorted pollen spectra likely caused by slumping or the lateral displacement of the corer in markedly concave sediments. Above 16.55 m seven pollen zones are recognised. Charcoal is abundant but only in the lowest two zones. Waton (1983) discusses the significance of the charcoal, in terms of its sources, at some length but was inconclusive in attributing the presence of charcoal to natural or various human causes. The quoted ^{14}C dates are taken from the original interpretation by Waton (1982, 1983, pp. 201–206) who provided a chronology based upon uncalibrated radiocarbon dates (^{14}C BP). In order to provide the chronology of recorded events as true ages, these require calibration against a radiocarbon calibration curve (*e.g.*, IntCal20; Reimer et al., 2020). The calibrated 'real' dates are provided as calibrated ages BP (before 1950 CE) in parenthesis to assist the reader. In addition to the pollen diagram for the entire sequence (summarised in Fig. 71) in core RM1, supplementary cores were taken within 5 m of the RM1 sequence for radiocarbon dating samples, along with cores for high-resolution sampling over the *Ulmus* decline, covering the zone RM-2/3 transition between 10.90 and 10.40 m, and *Tilia* decline, covering the zone RM-3/4 transition between 8.50 and 8.00 m. This high-resolution analysis was conducted on consecutive 1 cm samples and is described as a series of subzones in Table 15.

For the upper section of the pollen sequence, above 4.15 m, Waton (1983) defined four pollen zones (RM-6 to 9), though in Waton and Barber (1987) these had been simplified to just two zones, zone 6

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subdivided within their summary Figure 6. The descriptions contained in Table 15 are based upon Waton (1983), with zones RM-6 and 7 the equivalent of zone 6 shown in Figure 71, and zones RM-8 and 9 the equivalent of zone 7 shown in Figure 71.

Waton (1983) also analysed the pollen at the much smaller Oakers bog in order to assess the spatial extent of the vegetational changes recorded at Rimsmoor. It too has a compound basin, with a floating *Sphagnum* mat and similar surrounding vegetation. Core OK1 was taken from the deepest peat which was accessible, located on the east edge of the pool. The Oakers pollen sequence was *c.* 4 m deep and not radiocarbon dated. It is equivalent to the top 3.6 m at Rimsmoor and shows good correspondence with zones RM-6 to 9 (zones 6 and 7 shown in Fig. 71) of the Rimsmoor pollen sequence. The sequence was divided by Waton (1983) into 6 zones. Zones OK-1 and OK-2 (3.95–3.65 m, 3.65–2.75 m) correspond to Rimsmoor zone RM-6 and show *Quercus* pollen rising to 65 % and then falling again. *Betula*, *Alnus* and *Corylus* all fall and then rise, as does Gramineae. Zones OK-3 and OK-4 correspond to Rimsmoor zone RM-7 (2.75–0.65 m, 1.65–0.95 m) and are marked by a fall in tree and shrub pollen and increases in Gramineae and herbs, although with a slight increase in tree pollen in zone OK-4. Cereal pollen grains are recorded sporadically, as is charcoal, insignificant in number. Zone OK-5 corresponds to Rimsmoor zone RM-8 (0.95–0.35 m) and shows an increase in herbs, particularly *Plantaqo lanceolata* and *Rumex*. Cereal pollen is present at 0.3 %. In zone OK-6, which corresponds to Rimsmoor zone RM-9 (0.35–0.00 m) tree and shrub pollen increases and cereal pollen is sporadic in occurrence.

The base of the Rimsmoor RM1 pollen sequence (zones RM-1 and 2), dating to the Mesolithic (6180–5720 cal BP (3210 ± 90 ^{14}C BCE; HAR-3919) shows the establishment of a mixed deciduous woodland around the site, with *Ulmus*, *Quercus* and *Tilia* as dominants over *Alnus*, *Corylus*, *Fraxinus* and *Betula*. However, changes in the relative amount of tree and grass pollen do occur possibly related to Mesolithic activity in the vicinity. The mire surface was colonised by *Phragmites* and other grasses resulting at times in grass pollen counts above 30 %. The upper boundary of zone RM-2 (subzone RMU-1/2) is marked by a brief but pronounced clearance indicated by the fall in *Ulmus* pollen. This is the Early Neolithic 'elm decline', confirmed by radiocarbon dates of 3210 ± 90 ^{14}C BCE (HAR-3919) and 2740 ± 70 ^{14}C BCE (HAR-3920) either side of the event.

Waton (1983, p. 308) discusses that transitory peaks of *Betula* and *Corylus* at the *Ulmus* decline are followed in the main core, RM I, by lower and fluctuating levels of *Betula*, reduced *Ulmus*, *Quercus*, *Tilia* and *Fraxinus* but very high *Corylus* at 55 to 70 %, with Gramineae and herbs low at 10 % or less. This suggests minimal open ground around the site, though the high *Corylus* may indicate unshaded conditions, with a reduction in shade-casting trees. Whilst this could conceivably indicate a period of woodland management, such as hazel coppice with oak standards (Waton, 1983, pp. 308–309), *Corylus* could also be present solely around the edge of the basin, maintained by the consistently unstable slopes of the depression preventing colonisation by, for example, *Quercus*; the crossing of a shade threshold with the increasing size of the basin, permitting the flowering of a hazel belt, in contrast to the period before the *Ulmus* decline (the event itself also assisting the establishment of the community; and human activity at a low level maintaining some parts of the basin sides free from woodland (Waton, 1983, p. 310).

From *c.* 4700 cal BP, at *c.* 9 m, some disturbance is detectable. *Quercus* pollen and *Ulmus* pollen are reduced, *Corylus* and *Alnus* are raised and *Sphagnum*, which tends to increase at Rimsmoor during clearance, is also higher. This may indicate some removal of oak and elm and replacement by hazel and alder and perhaps open ground, although herbs and Gramineae are unchanged. 1 m higher in the sequence, within subzone RMT-2, *Betula* rises at the expense of Corylus, with Gramineae and herbs increasing, especially *Melampyrum* and *Plantaqo lanceolata*, with *Pteridium*. Two cereal type pollen grains are recorded at the beginning of the zone with a peak of *Hydrocotyle*, and a clay bed for 3 cm immediately afterwards, which coincides with a *Ca1luna* maximum and is followed by elevated *Sphagnum*. Waton (1983, p. 311) suggests that removal of *Corylus* occurred, in particular with *Quercus Ulmus*, *Tilia* and *Fraxinus*, whilst *Betula* and *Pteridium* may have been colonising abandoned areas. The area cleared was again very limited in extent, affecting only a part of the pollen source area.

Pasture was predominant but some cultivation was underway initially, though could have been ceased because of soil erosion. The clay bed may also indicate that tillage was practised near to the site, perhaps around its edge, though it is conceivable that a surface stream carried the sediment in from a distance. A radiocarbon date immediately below this clay bed gave an Early Bronze Age date of *c.* 4200 cal BP (1870 ± 80 ^{14}C BCE; HAR-3921). The contemporary *Calluna* peak may represent colonisation of formerly arable areas, or surface water flow through *Calluna* vegetation around the depression slopes. The behaviour of *Tilia* during RMT-2 is unique as it fluctuates, then falls between samples at the centre of the zone and at the top of the clay bed. The position of this fall implies that its cause is related to the shift from arable to pasture (Waton, 1983, p. 311).

Within zone RMT-3, regeneration of woodland during the Early Bronze Age is recorded, including increases of *Quercus*, *Fraxinus* and Corylus pollen, with reductions in Gramineae and herbs. These indicate woodland regeneration, yet the persistence of the *Plantaqo lanceolata* and *Pteridium* indicates that some open areas remained. Waton (1983, p. 312) suggests that this regeneration lasted a minimum of about 40 years, prior to renewed activity recorded in RMT-4 with clearance of *Betula*, *Quercus*, *Alnus*, *Fraxinus* and *Corylus*, an expansion of Gramineae, *Plantaqo lanceolata*, *Artemisia* and *Pteridium*, with Sphagnum again is increased, and two cereal type pollen grains are recorded.

Within RM-4, whilst *Quercus* and *Corylus* attain their former abundance, Gramineae, various herbs, *Pteridium* and *Calluna* are greater than in RM-3. More open conditions are indicated, perhaps maintained by grazing as the absence of cereal pollen implies minimal cultivation, though it is unclear if this reflects open woodland or a mosaic of clearings and forest.

From the Middle to Late Bronze Age, notably at the RM-4/5 boundary, another clearance is apparent and considerably more extensive than recorded previously in this sequence. However, like the earlier episodes, changes are discernible in the pollen curves at the end of the preceding zone. These begin with falling *Corylus* and rising Gramineae and herbs at the end of RM-4, with *Corylus* further reduced and *Quercus* and *Alnus* pollen also falling and charcoal raised. Gramineae pollen rises dramatically and herbs, including *Rumex*, *Artemisia* and *Plantaqo lanceolata* are also increased. *Pteridium* is doubled in frequency and cereal pollen is recorded. This evidence suggests that the areas first cleared were those overgrown with *Corylus*, perhaps indicating initially a pushing back of woodland margins. Subsequently, activity was greatly increased and there was removal of dry oakwoods, areas of *Alnus* and further *Corylus*. A small reduction in *Calluna* may reflect heathland reclamation and the rise of grasses and herbs shows a marked expansion of pastoral farming with limited cereal cultivation, at least in the area around Rimsmoor.

At the start of RM-6, extensive clearance is recorded with notable reductions in *Corylus*, *Quercus* and *Alnus*. This decline is bracketed by two dates, *c.* 2420 cal BP (400 ± 70 ^{14}C BCE; HAR-3922) and *c.* 2050 cal BP (130 ± 80 ^{14}C BCE; HAR-3923), indicating an Iron Age date for this clearance. Woodland is progressively reduced throughout and the tree and shrub pollen total falls to below 40 % indicating the prevalence of open conditions around the site. Gramineae is doubled in frequency and increases are recorded in *Rumex*, *Artemisia*, *Plantago lanceolata*, *Spergularia* type and *Pteridium*. Further evidence for the extent of the clearance is provided by pronounced and temporary increases of Cyperaceae, *Hypericum* and *Sphagnum* which, with low aquatics, may suggest a eutrophication of the bog surface rather than simply flooding. The data from Oakers (zone OK-1) with their dominantly open pollen spectra indicate that the clearance affected an area at least up to a distance of 150 m around Rimsmoor and this is probably a minimum figure

Table 14
Details of radiocarbon dates and associated landscape change events recorded from core RM1 at Rimsmoor GCR site (Waton, 1983), calibrated against IntCal20 (Reimer et al., 2020).

Lab no.	Depth (cm)	Published age BCE–CE	Calibrated date range BP (95.4 % CI)	Event
HAR-3924	150–175	1340 ± 60 ^{14}C CE	670–520	Agricultural maximum
HAR-3923	355–380	130 ± 80 ^{14}C BCE	2310–1830	
				Major extensive clearance
HAR-3922	410–435	400 ± 70 ^{14}C BCE	2710–2150	
HAR-3921	790–815	1870 ± 80 ^{14}C BCE	4430–3980	*Tilia* decline – clearance; cereals
HAR-3920	1060–1085	2740 ± 70 ^{14}C BCE	5590–5300	
				Ulmus decline – clearance; cereals
HAR-3919	1125–1150	3210 ± 90 ^{14}C BCE	6180–5720	

in view of the likelihood of extensive chalkland clearance. The elevated Ericaceae pollen at Rimsmoor may attest to the later origin of the heath of the clay zone, in contrast to that of the sandy areas of the Poole Basin. Whilst the pollen may be a result of the colonisation of the bog surface, the proliferation of *Calluna* with its preference for drier soils indicates significant soil podzolisation at this time, presumably due to woodland clearance and, most notably, cultivation.

After the Iron Age clearance, there was some regeneration of *Betula*, *Quercus* and *Corylus* across areas of grassland and heathland, during the Late Iron Age to Early Roman period, along with a temporary phase of cultivation of rye and hemp, indicated by the presence of *Secale cereale* and *Cannabis* type pollen. This was of minor extent with little effect on any woodland regeneration or may have been at some distance from the site. Tree pollen and shrub pollen remain less than 50 %, indicating chiefly open conditions, though these increase to 70 % indicating more extensive woodland, notably of *Corylus*, *Quercus* and *Fraxinus*, with some *Fagus* and *Carpinus*, though indicators of grass and heathland nevertheless demonstrate continuing activity in the area. Finally, from 2.90 m to the start of RM-7, there was a major removal of *Corylus*, *Quercus* and *Fraxinus*, thought to date from the middle to late Roman period, with open conditions prevalent with grassland and arable cultivation, as indicated by cereal pollen reaching 2 % and increases in *Anthemis* type, *Rumex*, *Artemisia*, *Sinapsis* type, Chenopodiaceae, *Plantago lanceolata* and *Plantago media/major*. Some heathland expansion is also evident from the increase in *Calluna*, perhaps reflecting deteriorating soils.

The Oakers pollen data suggest that conditions around the site at this time were also fairly open, with local clearance of a presumably local copse of *Quercus*, thought to possibly be late Iron Age in date, and the end of zone OK-2 showing a recovery of *Quercus* and *Betula*, tentatively correlated with the RM-6/7 boundary. However, unlike the Rimsmoor sequence, there is no regeneration recorded at this time, which might be a reflection of the smaller pollen catchment area at Oakers.

At Rimsmoor, clearance continued through the late Roman period, meeting its maximum by the end of this period, followed by periods of temporary regeneration and clearance throughout the early medieval period, to the end of RM-7. When clearance occurred, it predominantly affected *Quercus* and *Corylus*, the most prevalent woodland species, but also *Alnus* and *Carpinus*. Over this period, woodland was progressively reduced, with tree and shrub pollen falling below 50 % indicating predominately open conditions around the site. Throughout this time, cultivation appears to have been fairly constant, but falling woodland and indicators of grassland, and rising *Calluna* and *Pteridium* imply progressive soil deterioration necessitating the clearance of more fertile woodland soils for agriculture. *Secale cereal* type pollen comprises about half of the total cultivar pollen, possibly due to its suitability for the local sandy soils. Hemp may have also been cultivated in the vicinity. At Oakers, this period is represented by OK-3, which opens with falling *Quercus*, *Betula* and *Corylus*, and the expansion of grassland, assumed to correlate with the mid to late Roman clearance at Rimsmoor. Some cereal pollen is recorded, with tree and shrub pollen below 30 % implying little woodland around the site.

Rimsmoor provides evidence for increased cultivation through the later early medieval and early medieval periods, with *Corylus* markedly reduced, along with falls in *Betula*, *Ulmus* and *Quercus* indicating general woodland clearance. This progressive clearance persists until near the end of RM-7, dated to *c.* 600 cal BP (1340 ± 60 ^{14}C CE; HAR-3924), when tree pollen and shrub pollen are only 25 %, implying that the area was extensively free from woodland. Cultivar pollen rises rapidly through RM-7, reaching 13.6 %, dominated by cereal type and *Cannabis* type, suggesting that hemp was being cultivated. The evidence from Rimsmoor is reinforced by the Oakers sequence, where OK-4 is characterised by cereal pollen up to 3 %. Rising *Betula* and *Corylus* and falling herbs, such as *Rumex* and *Plantago lanceolata*, show that at Oakers there was a local reduction in the intensity of land use later in this period. Falling *Calluna* may indicate some reduction of heathland, though this could also reflect local changes in the bog surface vegetation.

From the start of RM-8, there is a noticeable decline in both cereal and *Cannabis* types, coupled with an expansion of heath and grassland, presumably over former arable fields, which can probably be correlated with the late 14th Century recession (Waton and Barber, 1987). Within zone RM-9, an increase of woodland pollen taxa is present, due to the afforestation of the area in the last 200 years, with various species, particularly *Pinus*, well-represented.

8.4.3. Interpretation

Rimsmoor is an exceptional site, unique in Britain. It is only 35 m in diameter but has 18 m of Holocene peats. The chalk of the Dorset Downs outcrops within a kilometre to the north, and the bog has developed in a doline, a form of depression in the landscape caused by the slow solution of the chalk underlying the Paleogene strata that feather out over the chalk. These dolines are very common in the area, but whilst most are dry, Rimsmoor has a clay base which has subsided and infilled with peat at a rate of around 1 cm every 4 years for the last 8000 years. The peats are herbaceous with much *Phragmites* up to 13 m depth, after which they are dominated by *Sphagnum*. High resolution pollen analysis has revealed an interesting vegetational history with mid Holocene woodland of pine and hazel being replaced by oak–elm–lime woodland. The Elm Decline is dated at *c.* 5670 cal BP and there are signs of farming, with herbs and two occurrences of cereal grains, *c.* 400 years prior to this. Contiguous 1 cm counts across the Elm Decline horizon show that this event may have occurred very quickly, in only 4 to 7 years. Lime declines to virtual extinction during small scale clearances in the Early Bronze Age before major extensive clearances during the Late Bronze Age, *c.* 3000 cal BP, and the Iron Age *c.* 2450 cal BP. There are large increases in both grass pollen and heathland taxa, before a period of subdued impact during Roman/early medieval times, followed by the maximum expansion of agriculture by *c.* 600 cal BP, and the expansion of heathland for which this part of Dorset is famous today. The adjacent sequence at Oakers doline is much shorter, spanning only the last *c.* 400 years, but shows very similar development of local vegetation over this time period.

8.4.4. Conclusion

Rimsmoor is a key site both for studies of palynology and doline formation. It is exceptional for the depth of peat it contains; most dolines in the area (apart from Oakers doline) are free-draining and lack significant organic accumulation. Palynologically, Rimsmoor is

Table 15

Description of pollen zones from Rimsmoor, including subzones for the *Ulmus* and *Tilia* declines, from Waton (1983).

Local pollen zone (m BGL)	Description
Zone RM-9 1.05–0.00 m	The total for tree and shrub pollen increases from 20 % to 60 % throughout the zone. *Pinus* in particular rises from 1 to 40 % and *Betula* from 1 % to 10 %. Others, including *Ulmus*, *Quercus*, *Fraxinus*, *Fagus* and *Corylus* increase, then decline. Gramineae falls from 60 to 30 % with *Plantago lanceolata* from 12 to 1 % and herbs also falling. *Calluna* and *Pteridium* are similarly reduced. Cereal pollen is higher than in RM-8 at 1 to 2 %. Charcoal is absent
Zone RM-8 1.50–1.05 m	RM-8 is distinguished by the lowest total of tree and shrub pollen at only 20 %, comprising *Quercus* at 3 to 8 %, and *Corylus* at 8 to 12 % with Gramineae at 52 to 63 % and herbs at 20 to 30 %. *Plantaqo lanceolata* is at a maximum of 15 % with high Liguliflorae (5 %) and *Potentilla* type (5 %). *Calluna* varies between 15 and 20 %. Cultivar pollen is low, represented by Cereal type undiff at 0.5 %. Charcoal is absent.
Zone RM-7 2.85–1.50 m	In RM-7 there is overall a progressive decrease of tree and shrub pollen and increase of open country types, but with a temporary reversal of this trend in the centre of the zone. *Quercus* and *Corylus* are most reduced, from 25 to 10 % and 35 to 5 % respectively. The tree and shrub pollen total falls from about 70 to 20 % through the zone, Gramineae rises from 30 to 50 % and herbs from 10 to 25 %. *Plantaqo lanceolata* remains common with *Anthemis* type and *Rumex*. Calluna increases steadily from 5 % to in excess of 20 %. Cultivars are high at a minimum of 3 %, peaking at 15 % at about l.60 m. Secale and Cannabis types are frequent, in addition to Cereal type undiff. Charcoal is low. A radiocarbon date from the top of this zone, at 1.75 to 1.50 m, produced an age of 670–520 cal BP (1340 ± 60 ^{14}C CE; HAR-3924).
Zone RM-6 4.15–2.85 m	RM-6 is similar to RM-5 and opens with a decline in *Corylus* from 45 to 10 %, *Quercus* from 20 to 10 % and *Alnus* from 10 to 4 %. The tree and shrub pollen total falls from 75 to 20 %, Gramineae rises from 25 to 65 % and herbs from 5 to 20 %. *Plantago lanceolata* is especially common at 5 to 10 %, with *Rumex*, *Artemisia*, *Sperqularia* type and Liguiiflorae also prevalent at between 1 and 4 %. The latter half of the zone shows a recovery of trees and shrubs to 70 %, with Gramineae lower at 20 % and herbs at 10 %. *Calluna* exceeds 30 % in the first half of the zone, falling subsequently to 5 %. Cereal pollen is recorded in most samples. Charcoal is present in low quantities. The middle of this zone is radiocarbon dated, between 3.80 and 3.55 m, providing an age of 2310–1830 cal BP (130 ± 80 ^{14}C BCE; HAR-3923).
Zone RM-5 6.025–4.15 m	RM-5 opens with a major decline in woodland species and a dramatic increase in Gramineae. *Quercus* falls from 26 to 12 %, Corylus from 60 to 16 % and *Alnus* from 22 to 10 %. The tree and shrub total falls from 90 to 30 %, Gramineae climbs from 10 % to 55 % and herbs from 10 to 20 % with *Plantaqo lanceolata*, *Artemisia* and *Rumex* most abundant. *Pteridium* reaches 65 % and Calluna is depressed. From about 3.50 m there is a recovery of woodland pollen and *Calluna*, and a reduction of Gramineae and herbs. By the end of the zone tree, the shrub pollen total is 75 %. Cereal pollen is recorded at the beginning and end of RM-5. Charcoal is present in small amounts. The top of this zone is radiocarbon dated, between 4.35 and 4.15 m, providing an age of 2710–2150 cal BP (400 ± 70 ^{14}C BCE; HAR-3922)
Zone RM-4 0.815–6.025 m	Zone RM-4 opens with changes similar to those at the beginning of RM-3 but instead of *Ulmus*, *Tilia* is most drastically and permanently reduced from 2 to 0.3 % or less, *Quercus*, *Ulmus*, *Betula*, *Alnus* and *Corylus* are temporarily reduced whilst Gramineae peaks at 20 % and herbs at 5 % with cereal pollen recorded. The curves generally return to their former levels by about 7.50 m with *Quercus* fluctuating between 25 and 35 %, *Alnus* 15 to 20 %, *Corylus* at up to 65 % and Gramineae varying from 5 to 25 %. Herbs are at less than 10 %, but there is a continuous curve for *Plantago lanceolata* at 2 to 4 % and later for Chenopodiaceae at less than 1 %; *Calluna* steadily increases. Throughout the zone tree and shrub total between 80 and 90 %. Charcoal is present throughout with greater quantities recorded at the beginning of the zone. A clay horizon is present between 7.95 and 7.82 m, where pollen degradation was noted to be significant. A radiocarbon date, taken from the base of this clay horizon and underlying peat, at 8.15–7.90 m, produced a date of 4430–3980 cal BP (1870 ± 80 ^{14}C BCE; HAR-3921).
Subzone RMT-4 *8.05–8.00 m*	The final four counts of the core show *Betula* falling from 15 to 6 %, *Quercus* fluctuating between 50 and 58 %, *Alnus* falling from 20 to 11 %, *Fraxinus* falling from 4 to 0.5 % and Corylus at about 40 %. Tree and shrub pollen in total falls from 93 to 88 %, Gramineae is raised from 3 to 5 % and herbs from 2 to 6 %. *Plantaqo lanceolata* in particular rises from 0.5 to 4 % and *Pteridium* peaks at 18 %. Three cereal grains are recorded, but charcoal is absent.
Subzone RMT-3 *8.15–8.05 m*	In RMT-3 *Betula* stabilises at 14 %, *Quercus* increases from 15 to 32 %, *Fraxinus* rises from 2 to 5 % and *Corylus* after an initial peak falls to 43 %. Tree and shrub pollen climbs rapidly from 75 % to a constant 92 %, Gramineae falls from 20 % to 4 % and herbs to 1 to 3 %. *Pteridium* is generally less than in RMT-3 at 5 %. Cereal pollen is absent. Charcoal is not recorded.
Subzone RMT-2 *(start of RM-4)* *8.43–8.15 m*	The subzone is characterised by *Quercus* fluctuating between 15 and 30 %, *Corylus* falling from 60 to 40 %, *Betula* rising from 6 to 12 %, and *Ulmus* slightly increased to 1 to 2 %. *Tilia* remains at 1 to 2 % until the centre of the subzone, at 8.27 m, when it falls abruptly to 0.3 %. Tree and shrub pollen falls from 90 to 75 %, Gramineae rises from 6 % to a maximum of 24 % at the end of the subzone, herbs peak at nearly 5 % and two cereal pollen grains are recorded at 8.33 and 8.36 m. *Plantaqo lanceolata* dominates the herbs at 0.3 to 3 % with *Potentilla* type, *Melampyrum* and *Rumex* relatively common. *Calluna* sharply peaks between 8.31 and 8.25 cm. A clay horizon is present between 8.315 and 8.275 m, where pollen degradation was noted to be significant, and charcoal through most of the subzone is occasional to frequent.
Subzone RMT-1 *(end of RM-3)* *8.50–8.43 m*	*Corylus* pollen at 55 to 65 % dominates the zone with *Quercus* at 20 to 30 %, *Tilia* at 2 %, *Ulmus* at 1 to 1.5 % and *Fraxinus* at 1,5 to 2 %. Tree and shrub pollen total over 90 %, Gramineae 3 to 6 % and herbs 0 to 1 %. *Calluna* is initially at 4 %, increasing to 7 % and *Pteridium* fluctuates between 1 and 12 %. Charcoal is absent until the end of the subzone
Zone RM-3 11.025–0.815 m	The RM-2/RM-3 boundary is marked in particular by *Ulmus* falling from 7 to 0 %, Gramineae from a brief peak at 50 % to 7 %, *Alnus* also from a peak at 78 % to 10 %, *Corylus* rising from 20 to 50 % and temporary restrictions occurring in *Tilia*, *Quercus* and *Fraxinus*. *Plantago lanceolata* briefly peaks at 2 %, with *Pteridium* at 8 %, and two cereal pollen grains. A radiocarbon date centred on the decline in *Ulmus*, at 10.60 to 10.85 m, provided a date of 5590–5300 cal BP (2740 ± 70 ^{14}C BCE; HAR-3920). The remainder of the zone is characterised by *Corylus* and *Quercus* dominant, with *Ulmus* (which recovers to 4 %), *Tilia* and *Fraxinus* present throughout, and *Betula* fluctuating between 4 and 15 %. Tree and shrub pollen total 90 to 95 %, with Gramineae about 5 % and herbs 1 to 3 %. Charcoal is sporadically recorded.
Subzone RMU-2 *10.43–1040 m*	The final subzone is tentative and represented by only two counts. *Betula* is increased from 5 to 12 %, and *Alnus* from 12 to 15 %; *Corylus* is reduced from 60 to 52 %.
Subzone RMU-2 *(start of RM-3)* *10.785–10.43 m*	The subzone opens with *Ulmus* dropping from 8 % to 3 % between two contiguous 1 cm samples and thereafter declines to less than 1 %. Over the following two samples *Alnus* falls from 30 % to 14 % and also reduced are *Tilia*, *Quercus* and *Fraxinus*. Conversely, *Corylus* rises steadily from 33 % to 60 %, *Betula* from 3 to 6 % and herbs, notably *Plantaqo lanceolata*, from 1 to 3 % in total. The Gramineae curve is complex, initially peaking then falling. Two cereal pollen grains are recorded towards the end of the subzone. Charcoal is mostly rare or absent
Subzone RMU-1 *(end of RM-2)* *10.90–10.785 m*	*Ulmus* is at 7 to 9 %, *Quercus* 30 to 35 %, *Tilia* 2 %, *Fraxinus* 2 to 3 %, *Betula* 3 to 5 % with *Alnus* peaking at 40 %, then falling. Tree and shrub pollen total about 80 %, Gramineae 15–20 % and herbs 1 to 2 %, predominantly *Potentilla* type. Charcoal is occasional to frequent.
Zone RM-2 15.70–11.025 m	The rise in *Alnus* and only sporadic occurrences of *Pinus* distinguish zone RM2 from RM1. *Ulmus*, *Quercus* and *Corylus* are abundant throughout, with continuous curves for *Tilia* and *Fraxinus*. Tree and shrub pollen total 70 % initially, later fluctuating between 50 and 85 % with Gramineae 20 to 30 %, later 15 to 50 %, Herbs are less than 4 % with *Potentilla*-type and *Melampyrum* most significant. *Pteridium* fluctuates between 1 and 10 %. New herbs are recorded at the beginning and end of the zone, with two cereal pollen grains at 12.00 and 11.70 m. Charcoal is generally abundant, but absent in the centre of the zone. A radiocarbon date from the top of this zone, at 11.25–11.50 m, provided an age of 6180–5720 cal BP (3210 ± 90 ^{14}C BCE; HAR-3919).
Zone RM-1 16.55–15.70 m	This zone is characterised by declining *Betula* and *Pinus* values, with increases in *Ulmus*, *Quercus* and *Alnus*. Trees and shrubs rise, whilst Gramineae reduce, with the herb assemblage dominated by *Potentilla*-type. Charcoal was frequent to abundant.
Below 16.55 m	The base of the sequence, between 17.80 and 16.55 m, was regarded by Waton (1983, p. 200) as a combination of coring difficulties and likely subsidence within the doline had led to a distorted pollen assemblage, with fluctuations in *Pinus* and *Alnus* curves, elevated *Ulmus*, *Quercus* and *Fraxinus* frequencies, and depressed *Corylus* values. As a result of these taphonomic and sampling issues, Waton (1983, p. 200) omitted these samples from inclusion in any pollen zonation.

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important as one of few sites providing evidence of vegetational change near the chalklands since the middle Holocene to present. High temporal resolution is possible because of the apparently extremely rapid rate of organic accumulation. There is little precise evidence for the ages of the Dorset dolines and similar hollows elsewhere in England, but it is assumed, based upon correlation of the pollen sequence with other dated sites in the area (*e.g.*, Cranes Moor) that the base dates from approximately 8000 years BP. Stratigraphical evidence demonstrates gradual subsidence as the means of formation of Rimsmoor doline. The nearby Oakers doline is also included for its palynological research potential, though this sequence lacks any independent radiocarbon dating. When the work was originally conducted by Waton (1983), conventional radiocarbon dating on large bulk sediment samples was required to construct the chronology for Rimsmoor. Now, with the availability of AMS radiocarbon dating, Rimsmoor presents a significant opportunity to obtain a high-resolution chronology for key Holocene vegetation change events, such as the *Ulmus* and *Tilia* declines and timing of medieval agricultural expansion and contraction thanks to the high sedimentation rates present within the Rimsmoor sequence. As Grant and Waller (2017) point out, Rimsmoor has the potential of being one of the only sites in lowland England where sub-decadal resolution records of Holocene vegetation change could be achieved.

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