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GRIME'S GRAVES, WEETING-WITH-BROOMHILL, NORFOLK
RADIOCARBON DATING AND CHRONOLOGICAL MODELLING

SCIENTIFIC DATING REPORT

Frances Healy, Peter Marshall, Alex Bayliss, Gordon Cook, Christopher Bronk Ramsey, Johannes van der Plicht and Elaine Dunbar

INTERVENTION
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SUMMARY

This report contains details of all the radiocarbon determinations obtained on samples dated from Grime's Graves up to the end of 2012. A series of chronological models is presented, providing a more precise chronology for the site.

CONTRIBUTORS

Frances Healy, Peter Marshall, Alex Bayliss, Gordon Cook, Christopher Bronk Ramsey, Johannes van der Plicht, and Elaine Dunbar

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Elsewhere, Fiona Brock of the Oxford Radiocarbon Accelerator Unit (ORAU) addressed sample pre-treatment concerns; John Davies and Alan West of the Norfolk Museums Service provided access to collections; Dana Challinor identified potential charcoal samples; Matthew Collins of the University of York identified a problematic sample to taxon by its collagen sequence; Ian Dennis and Kirsty Harding of Cardiff Univeristy expertly prepared illustrations for publication; and Ian Longworth, Roger Mercer, and Barry Bishop proved to be a fund of information and encouragement.

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Norfolk Historic Environment Service, Union House, Gressenhall, East Dereham, Norfolk, NR20 4DR

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CONTACT DETAILS

Frances Healy, 20 The Green, Charlbury, Oxon OX7 3QA. HealyFM@cardiff.ac.uk

Alex Bayliss and Peter Marshall, Scientific Dating Team, English Heritage, 1 Waterhouse Square, 138–42 Holborn, London EC1N 2ST. Tel 020 7973 3299, 020 7973 3287. alex.bayliss@english-heritage.org.uk, peter.marshall@english-heritage.org.uk

Christopher Bronk Ramsey, Oxford Radiocarbon Accelerator Unit, Research Laboratory for Archaeology, Dyson Perrins Building, South Parks Road, Oxford OX1 3QY. christopher.ramsey@rlaha.ox.ac.uk

Gordon Cook and Elaine Dunbar, Scottish Universities Environmental Research Centre Radiocarbon Laboratory, Scottish Enterprise Technology Park, Rankine Avenue, East Kilbride G75 1QF. gordon.cook@glasgow.ac.uk, elaine.dunbar@glasgow.ac.uk

Johannes van der Plicht, Centrum voor Isotopen Onderzoek, Rijkuniversiteit Groningen, Nijenborgh 4, 9747 AG Groningen, The Netherlands. j.van.der.plicht@rug.nl

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1.0 INTRODUCTION

1.1 Location, geology and topography

The Grime's Graves flint mines lie in Weeting-with-Broomhill parish, Breckland District, Norfolk, at latitude 52° 28' 50" N longitude 0° 40' 25" E, National Grid Reference TL 81758 89781 (Fig 1). The surviving earthworks lie between 25m and 30m OD, others discovered by geophysical survey and excavation in adjacent areas lie between 15m and 25m OD.

The Breckland is a distinctive area of south-west Norfolk and north-west Suffolk, characterised by light, sandy soils. While the Chalk is close to the surface, the gently rolling topography is unlike that of the Chalk downland of southern England because of the area's geological history. Long-term tectonic downwarping of an area centred on the southern North Sea basin has tilted the Cretaceous strata so that their surface consists of successive, relatively narrow, north-south bands, the oldest in the west and the most recent in the east (Peake and Hancock 1970, pl. 1). In the west of the region, where Grime's Graves lies, the Chalk is thus close to the present surface, while eastwards it is covered by increasing depths of later deposits and hence exposed only in valley sides or in sea cliffs. The Chalks exposed in the west of the region are of the Turonian stage. Within this, the Brandon Flint Series, worked at Grime's Graves, is the earliest stratum to contain appreciable quantities of flint, the older strata forming the surface of the Chalk to the west containing only sporadic amounts of low quality material. The Brandon Flint Series, at the base of the Upper Chalk, comprises up to 15m of relatively massively bedded Chalks with marl seams and widely separated courses of giant (0.2 to over 0.4m) tabular and nodular flint (Mortimore and Wood 1986; Bristow 1990, 16–29).

During the Pleistocene, while the southern English Chalk underwent periglacial, rather than glacial, modification, the East Anglian Chalk was planed off, at least by the Anglian (OIS 12) ice sheet, if not also by later ones. By the end of the Pleistocene, the Chalk, where it was still close to the surface, was covered by diverse sands, gravels, and tills. In the Breckland these were mainly sands, and where Coversand has remained subject to wind blows up to the present day. Ice-sheets stopped short of the region during the cold episodes of the last glaciation (OIS 4 and 2); it may have been at this time that cryoturbation mixed the top of the chalk and the lower part of the sands, forming a chalk-sand deposit (familiarly known as cryte) through which the Grime's Graves flint mines were sunk. This was described as Boulder Clay in early publications. Periglacial activity also gave rise to stripes and other forms of patterned ground, and to multifarious mixing and rafting of superficial deposits.

1.2 The site

The limits of the mined and quarried area remain unclear. It may extend beyond the area currently scheduled as an Ancient Monument (List Entry Number: 1003619), which corresponds to the 7.6ha covered by 433 pits still visible as earthworks together with areas to the west and north (Fig 2). Its southward extent is particularly uncertain because this area is now masked by windblown sands and forestry plantations. Slightly over 1km to the south is the Little Ouse river, one means of communication with the Fenland basin and the Great Ouse catchment to the west and the interior of East Anglia to the east. To the north the curve of a dry valley with a distinct palaeochannel recorded by ground penetrating radar more-or-less bounds the visible mined and quarried area (Fig 2). It is not known whether water flowed in it while the mines were worked, although peat has been identified in its bed. The highest part of the site forms a slight ovoid spur rising to 29m OD. Here, below the zone of cryoturbated sand and chalk, the chalk and its seams of flint are undisturbed. This is the area of the deeper, systematically worked, mine shafts.

Since the chalk strata, locally, gently shelve downward from north-west to south-east, the flint seams are deepest in the eastern part of the spur. To the north and west, on lower ground, the flint seams and the upper part of the Chalk are closer to the surface and underwent considerable disruption during the Pleistocene. The subsurface deposits here can be diverse, complex and, within the confines of excavation trenches, difficult to understand. These were areas of simpler, unstandardised, perhaps opportunistic quarrying in pits scattered around the periphery of the spur. The slight hollows and spoilheaps of most of the shallower workings have long been flattened. This is partly due to their having offered a less forbidding obstacle to probably intermittent cultivation, which was continued on part of the West Field into the twentieth century (Barber *et al* 2000, 5–6). The surviving earthworks of the higher part of the site (Fig 3) are dominated by Grimshoe, a flat-topped mound approximately 2.2m high and 20m in diameter apparently built on a subrectangular base. It may be contemporary with, or later than, the mining. A section cut slightly more than half-way across it in 1914, in the second of two exploratory excavations, showed that what may have been its second, later, part covered both a knapping floor and an unurned cremation and was capped with chalk rubble and knapping debris (Barber *et al* 1999, 71; 2000, 15–16, 29; Peake 1915, 106–11).

The flint mined at Grime's Graves occurs in three main seams, commonly known by the names given by the recent gunflint miners of Brandon, Suffolk, which lies 5km to the south-west. They are effectively described by Saville (1981, 1–2): the topstone, close to the surface of the Chalk, ranges from small pebbles to large nodules, often with convoluted extremities, with a thin grey cortex; the floorstone, which was favoured by the late Neolithic miners, is semi-tabular, occurring in large, smooth nodules with flat surfaces and convex undersides, covered with a thick, creamy cortex (Fig 4). The wallstone, stratified between the two, has some of the characteristics of both. Where the cortex and nodule form no longer survive, the black flint from all three seams is difficult to distinguish. Flint also occurs in the Chalk outside the seams, especially between the topstone and the floorstone, and, in derived form, in superficial deposits. The deeper mines were sunk only to the level of the floorstone, which was then pursued by means of galleries radiating from the base of the shaft (Fig 5; Longworth and Varndell 1996). In the area of the shallower workings to the west, flint was extracted and worked more indiscriminately, from both *in situ* and derived deposits (Lech 2012). Lower seams in the Brandon Flint Series, underlying the floorstone, do not seem to have been mined in prehistory, although they were exploited in more recent times both for gunflints and for building stone (Mortimore and Wood 1986).

Direct evidence for the prehistoric environment of Grime's Graves is confined to Mollusca indicative of deciduous woodland from the upper fills of the 1971 Pit, dating from long after its working and infilling. The inferred woodland is also evidenced by the charcoal from the same contexts, which is overwhelmingly from deciduous species. It was followed by undated clearance (Evans and Jones 1981). Hand-collected Mollusca from earlier excavations, described by Evans and Jones as of comparable composition, are predominantly from upper pit fills or from Bronze Age or undated superficial contexts (Kennard and Woodward 1915; 1919; Kennard 1934). Beyond the site, the more plausible of two chronologies for the relevant part of the pollen sequence from Hockham Mere, 13km to the north-east, indicates that the vegetation of the third and second millennia cal BC would have consisted predominantly of deciduous woodland, punctuated by small farmed areas but with no significant increase in herb pollen values until the late first millennium cal BC, when clearance and cultivation on a significant scale were a prelude to the formation of the heathland vegetation which characterised the area in historical times (Appendix 3; Bennett 1983a). If the localised catchment of a small mere (Bennett sees the pollen catchment as equivalent to a hydrological catchment of 380ha (1983a, 473), ie roughly a 1km radius around the mere) is representative of the wider region, then the Grime's Graves mines may have been worked in a clearing within a deciduous forest. The conifer plantations which now surround the site and at one-time covered it (Barber *et al* 1999, fig 12.1) are a development of the nineteenth and twentieth centuries.

1.3 Archaeological context

The Breckland, as a whole, was an area of flint procurement and working, principally from superficial sources, where it can occur in markedly larger nodules and fragments than in much of the rest of East Anglia. It was used extensively, giving rise to large flint scatters. Much, probably most, of this surface material dates from the Late Neolithic or Early Bronze Age, and often has an 'industrial' aspect, in the sense of high representation of the early stages of the reduction sequence and of axehead manufacture, as well as of miscellaneous heavy core tools (Bishop 2012; Healy 1998). Pits of all phases of the Neolithic and early Bronze Age are also present (Garrow 2006, fig 3.7). To the west, numerous Mesolithic to Bronze Age occupation sites progressively exposed by eroding peat on the edge of the Fenland basin show a lull in frequency in the early third millennium cal BC, corresponding to the local maximum of a marine transgression, which, while not extending to the occupied zone, would have had a substantial impact on it (Silvester 1991; Waller 1994; Bamford 1982, Healy 1996). In this zone, there is a higher frequency of polished, as distinct from flaked, flint axeheads, and of axeheads of non-local stone than in the Breckland (Healy 1984, fig 5.2; 1996, figs 40–1).

1.4 History of investigation

The distinctive earthworks of the site were recognised throughout their history, whether by middle Bronze Age occupants who dumped midden deposits into the tops of already infilled mine shafts and scavenged flint from the Neolithic spoilheaps (Peake 1915, 115–18; Armstrong 1924a, 192–93; 1927, 107–9; Mercer 1981, 36–8; Longworth *et al* 1988, 31–6); by an Iron Age population who buried successively a woman and a man in the top of another infilled shaft (Mercer 1981, 16–8); by a Romano-British population who deposited a 'black layer' over the top of a further infilled pit (Longworth and Varndell 1996, 45); or by Anglo-Saxons, who named both the site and the Grimshoe mound after the Nordic god Grim or Woden.

The history of the site's antiquarian recognition and subsequent investigation in the nineteenth and twentieth centuries is summarised by Mercer (1981, 1–7); Barber *et al* (1999, 4–16; 2000, 7–9); and Lech and Longworth (2000). Investigations go back to the mid-nineteenth century, when shaft tops were sectioned by the Reverend S.T. Pettigrew (1853) and the Reverend C.R. Manning (1872). Canon Greenwell excavated at the site in 1868–70, and was the first to reach the base of a shaft, concluding correctly that it was a Neolithic flint mine (Greenwell 1870a; 1870b; Rosehill 1871). It was the first prehistoric flint mine to be identified in Britain, its recognition being followed by excavations in the Sussex flint mines in the late nineteenth and early twentieth centuries. The period was also one of exciting developments and rising interest in Palaeolithic archaeology. Growing knowledge of Palaeolithic industries contributed to a groundswell of opinion to the effect that the flint mines were Palaeolithic rather than Neolithic, based on the similarity of the early, primary, 'industrial' stages of flint working at the site to some aspects of Palaeolithic industries. This gathered force, notwithstanding the presence in the already excavated flint mines of the remains of Holocene domesticates, pottery (in Sussex) and a ground stone axehead (in Canon Greenwell's Pit at Grime's Graves). It came to a head in a paper by Reginald Smith of the British Museum, which concluded that:

'*An examination of the types associated with Cissbury [in Sussex] and Grime's Graves has revealed various palaeolithic traits; and evidence from France, stratigraphical and otherwise, lends colour to the theory that the horizon is palaeolithic. Acceptance of the theory involves in the first place the recognition of palaeolithic flint mining, an achievement which, in itself and apart from prejudice, is just as credible in the early as in the later Stone Age*' (Smith 1912).

He particularly favoured the Aurignacian.

In this climate, the Prehistoric Society of East Anglia undertook excavations at Grime's Graves in 1914, their aims beginning with the chronological question:

'*The principal aim was to throw light on the date of the industry, and around this many points arose. Wide difference of opinion has been expressed, and they have been assigned by different authorities to the following periods: bronze, early or Late Neolithic, post Madelaine and Aurignac. This involves the question of whether mining took place in the Palaeolithic age or not*' (Clarke 1915).

Work was directed by A. E. Peake on behalf of a committee, many of whom, especially W.G. Clarke, took an active part in the investigation. A L (Leslie) Armstrong (Fig 6) was also a member of the team. They excavated Pits 1 and 2 and numerous small, exploratory trenches, some of them beyond the visible pits, especially on the West Field. They demonstrated for the first time that there was middle Bronze Age occupation, which subsequently proved to be rich and extensive. The results were published with exemplary speed in 1915 in a monograph edited by W.G. Clarke, which was state-of-the-art for its period. The chronological controversy rumbled on, different contributors expressing different opinions. It continued into the 1930s, especially as Armstrong, who had been a member of the 1914 team and was firmly in the Palaeolithic camp, undertook the principal excavations at the site in the interwar period. Resolution came in 1933 when Grahame Clark and Stuart Piggott reviewed the dating evidence (artefactual, faunal and stratigraphic) from the British flint mines and concluded that they must be Neolithic (Clark and Piggott 1933).

Between 1920 and 1939 Armstrong excavated Pits 3 to 15, together with numerous exploratory trenches to the north and west of the visible earthworks and the 'Black Hole', a middle Bronze Age occupation deposit in the top of an infilled mine shaft. His publications (1921a; 1921b; 1922; 1923; 1924a; 1924b; 1927; 1932; 1934) perpetuated Reginald Smith's arguments, while at the same time progressively acknowledging that some of the mining was Neolithic. He developed a sequence in which mining started in Mousterian times and continued into the Neolithic, finishing before the Bronze Age occupation took place. The first pits in this scenario were dubbed 'primitive pits' and were located on the south side of the dry valley to the north of the visible pits, where glacially-contorted floorstone was close to the surface (Armstrong 1927). He excavated at least five of these (Pits 3, 4, 5, 6, and 13). They were not more than 4m deep, characterised by the use of bone rather than antler picks; by undercuts rather than galleries at the base; and by additional undercuts about half way down, made to extract flint from the glacially contorted deposits that overlay the solid chalk (see Fig 52).

In 1971–2 a deep shaft and an adjoining area were excavated by Roger Mercer for the Department of the Environment, in anticipation of displaying the shaft to the public (Mercer 1981). This was immediately followed by a research programme by the British Museum, led by Ian Longworth and the late Gale Sieveking, which continued until 1976 (Clutton-Brock 1984; Legge 1992; Longworth *et al* 1988; 1991; Longworth and Varndell

1996; Longworth *et al* 2012). This included the re-excavation of Greenwell's Pit, Pit 2, Pit 3, and Pit 15, and the excavation '*de novo*' of knapping floors and of smaller, shallower pits, including two with the characteristics of Armstrong's 'primitive' pits, one (Pit 3A) next to Pit 3 (Longworth and Varndell 1996, 39–45), the other (F105) 360m away on the West Field (Longworth *et al* 2012, 72–6). For the first time, areas as well as trenches were opened on the West Field, one of *c* 940 sq m (950/820; Longworth *et al* 2012, fig 29) and one of *c* 900 sq m (940/940; Longworth *et al* 2012, fig 55); demonstrating the presence and character of small, simple pits in this part of the site. Both projects greatly enhanced understanding of extraction methods, flint working and the later-second/early first millennium cal BC occupation at the site. The British Museum programme has also elucidated the records and finds inherited from previous excavations. Together the 1971–2 and 1972–6 projects defined the main period of flint extraction at the site as the mid to late third millennium cal BC and the pottery of mining contexts, insofar as there was any, as Late Neolithic Grooved Ware. They also made it clear that axeheads were far from the only product of the industry (Saville 1981; Lech and Longworth 2000; Lech 2012). Both 1970s projects also excavated further middle Bronze Age deposits.

Investigation of Greenwell's Pit, Pit 15, and, to a less extent, Pit 2 by the Prehistoric Flintmines Working Group of the Dutch Geological Society, Limburg Section (PFWGDGSLS) in 1973–6 entailed the mechanical excavation of nineteenth or twentieth century backfill followed by the exploration of as yet unexcavated galleries of these and of adjacent pits. As a result, there are finds from, and detailed records of, the galleries of several previously uninvestigated pits at each location (Greenwell's Pits A, C, D, and E; Pits 15 A–K) but no information about the still unexcavated shafts from the bases of which they were driven. The same is true of Pits 11 A–H, where what had been intended as the re-excavation of Armstrong's Pit 11 proved to have been located some 50m from the actual pit (Longworth and Varndell 1996, 45).

In the 1990s Grime's Graves was surveyed as part of a national programme of research into flint mines in England by the former Royal Commission on the Historical Monuments of England (Barber *et al* 1999, fig 4.12; Barber *et al* 2000). The full extent of the complex remains unclear, although geophysical surveys in 2007 demonstrated that mining activity extended around the head of the dry valley to the north of the site, with the implication that it extended into the area of modern forestry. These surveys also suggested that mining in the West Field may not have been as intensive as elsewhere (Favard and Dabas 2007). A restricted ground-penetrating radar survey between the northernmost visible pits and 'primitive' pits 3–7 and 13, indicated that the more southerly part of this area was densely packed with pits 4–6m across and around 3m (in one case 4m) deep. They tailed off to the north, although it is not clear whether this represents their actual cessation or a greater depth of overburden farther down the slope of the dry valley (Linford *et al* 2009, 3–5, figs 3, 7–10). Their dimensions would tally with those of Pit 14, the nearest excavated pit (see Fig 31). A kilometre or so to the west of the scheduled area, ground-penetrating radar survey and test pitting following tree-felling have revealed probable extraction pits and dense areas of primary knapping debris, suggesting that the kind of extraction and flint working practised on the West Field may have extended this far (Bishop 2011; 2012).

1.5 History of absolute dating

One hundred and forty-five radiocarbon measurements had been made on samples from the site before the present project started (Table 1). In the 1960s a small number of samples from Grime's Graves and other flint mines was radiocarbon dated by the British Museum Research Laboratory. Within its limitations, the exercise indicated that, while the Sussex sites may have had their origins as early as the turn of the fifth and fourth millennia cal BC, Grime's Graves showed no sign of activity before the turn of the fourth and third millennia (Barker and Mackey 1961; 1963; Barker *et al* 1969b).

The two 1970s projects generated many more radiocarbon measurements (Ambers 1996; Ambers 2012; Ambers *et al* 1987; Burleigh 1976; Burleigh *et al* 1976; Burleigh *et al* 1979). On the basis of the 127 determinations available in the late 1970s, it was estimated that

'. . . *the evidence newly available from Grime's Graves suggests that the large-scale exploitation of flint by means of galleried mines dates to a relatively short period between ca 2100 to 1800 BC [c 2550 to 2250 cal BC], while open-cast quarrying continued until ca 1650 BC [c 1950 cal BC]. There is some evidence for intermittent occupation on the site, with tool manufacture, between this date and the intensive Bronze Age occupation, not related to flint extraction, beginning ca 1000 BC [c 1150 cal BC]. No evidence was found for an early mining period antedating the galleried mines*' (Burleigh *et al* 1979, 46).

These measurements were obtained over a long period by a succession of methods, summarised in Table 2. Janet Ambers spells out the problems of working with them (1996, 100; 1998, 591; 2012, 158), stemming from questions of the identification, suitability, and contexts of the samples, and of the accuracy and precision of the measurements. She began to redress these deficiencies by undertaking a selective programme of dating further material from the deep mines using only samples of high intrinsic and contextual integrity, modern measurement techniques, and high standard of quality control (Ambers 1998; 2012). This exercise yielded four new measurements from the Greenwell's Pit complex and three from the Pit 15 complex. In the first application of Bayesian analysis to any part of the Grime's Graves series, modelling of each group as a continuous phase of activity indicated a working period of *2580–2470 cal BC* to *2550–2400 cal BC* and a span of *0–120 years*, both at *68% probability*, for the interconnected pits of the Greenwell complex; and a working period of *2630–2490 cal BC* to *2555–2565 cal BC* and a span of *0–120 years*, again both at *68% probability*, for the interconnected pits of the Pit 15 complex. A similar exercise for the West Field, in which six measurements were obtained for five features, indicated a period of use starting at around the same time, *2610–2300 cal BC* at *68% probability*, but extending considerably later, to *2010–1670 cal BC* at *68% probability* (Ambers 2012). As explained below, italics are used to denote estimates generated by statistical modelling.

1.5.1 This Project

Renewed interest in Grime's Graves grew from the Royal Commision on Historical Monuments of England (RCHME) survey, finding expression in plans to understand the site more fully and present it more effectively. The increasingly frequent and successful application of Bayesian statistical analysis to series of radiocarbon dates on stringently selected samples (Bayliss 2009) offered a means of better defining the chronology of the site, and AMS (Accelerator Mass Spectroscopy) provided the means of dating smaller samples of a wider range of specimens than had been feasible during the British Museum's dating programme.

A project design was formulated (Healy 2009) and agreed by English Heritage. Its prime aim was to date flint extraction and working at Grimes Graves as precisely as possible, by applying radiocarbon dating and the Bayesian analysis of the results to the available archives. It would also provide an opportunity to train Frances Healy in Bayesian chronological modelling. The following questions were posed at the start of the project:

1. What was the timespan of flint mining at the site?

2. Was there, as the pre-existing dates suggested, a difference in periods of use between the area of deep mines and the West Field?

3. What was the probable labour input at any one time?

4. How did the emergence of the site relate to the introduction of metal-working?

5. Did the human remains recovered from shafts early in the twentieth century relate to the late Neolithic use of the site (at a time when formal burials were rare) or were they later insertions?

6. Could the chronology of the Bronze Age occupation be refined and extended to so far undated areas?

7. Could a horse skull found in the upcast surrounding one shaft be dated more precisely? While it was marginal to the chronology of the site, it was significant for the timing of the reintroduction of the horse into Britain.

8. Could the use of the site be related more precisely to the settlement of the surrounding area?

Answers to a number of subsidiary questions were seen as facilitating the investigation of these larger ones:

a. Could an unexpected discrepancy between dates on charcoal and on antler from the 1971 Pit (where measurements on unidentified bulk charcoal samples were consistently more recent than those on antler implements from comparable contexts) be elucidated?

b. Could antler/charcoal discrepancies be examined elsewhere?

c. Could the chronology of the northern area (where there were then only two radiocarbon determinations) be clarified?

d. Could the date of the 1972–4 knapping floor be clarified and better defined?

e. Was Pit 12, on the edge of the West Field, as old as the one of the pre-existing dates indicated (3270–2580 cal BC at 95% confidence — the weighted mean of BM-97 and BM-377)?

f. Could F6, F7, and F105 in the West Field be better dated?

2.0 METHODS

2.1 Pretreatment and measurement

The information is summarised in Table 2. In addition to the samples listed there, three measurements were made by the Oxford Radiocarbon Accelerator Unit on the humic acid fraction of charcoal samples for comparative purposes. Two of these succeeded (Appendix 1: OxA-X-2415-39, -2415-43). The duration of the British Museum's programme meant that methods varied greatly in the course of it (Ambers 1998, 592–5; 2012, 158–9). Significant points are discussed here.

2.1.1 Pretreatment

2.1.1.1 Charcoal

The records of the British Museum laboratory document that the charcoal and plant macrofossil samples for BM-775 to -780, from the 1971 Pit, were pretreated only by a hot acid wash, without an alkali wash, a procedure which could have trapped CO_2 from the atmosphere if the material was not properly acidified afterwards (Janet Ambers pers comm). Subsequently, charcoal samples with laboratory numbers between BM-811 and BM-1266 'were pretreated by prolonged boiling in dilute hydrochloric acid. The highly calcareous environment in which these materials had been buried precluded contamination by humic acids and no pretreatment with alkali was needed' (Burleigh *et al* 1979, 41). Relatively few of these charcoal measurements came from contexts that also yielded measurements on antler. Where they did, results for the charcoal samples tend to be more recent than those for antler.

This is clearest in the results for the 1971 Pit, where, if all the dates from the pit base and galleries are treated as contemporary with their contexts, the model has poor overall agreement (A_{model}:17) and the four bulk charcoal dates (BM-775 to -778) have low individual indices of agreement because they are too recent to be compatible with the other dates, whether for antler or for single charcoal fragments dated more recently (Fig 7). This is the opposite of what would normally be expected. The samples for BM-775 to -778 were bulked ones, capable of including material of various ages. They were not identified before dating, but, where charcoal from both mining contexts and middle Bronze Age middens on the site has been identified, the frequency of oak and other long-lived deciduous taxa (Keith 1915; Evans and Jones 1981, 106) strongly suggests that much of the charcoal in the samples would have been from mature wood. This is confirmed by further charcoal identifications obtained in the course of selecting samples for this project (Dana Challinor pers comm). In these circumstances, the Museum's charcoal samples might be expected to be older than their contexts and hence older than associated antler samples.

In the course of the recent dating project, the ORAU extracted high levels of humic acid from both the charcoal samples which it measured from the 1971 Pit, suggesting that an alkali (base) wash might not have removed all of the humic acid from previously dated samples (Fiona Brock pers comm). In an attempt to test this hypothesis, humic acid and humin samples from two charcoal fragments from primary contexts in the 1971 Pit were dated separately, and a further humic acid sample from the surviving part of a charcoal fragment that had already been the subject of four replicate measurements was also dated. The humic acid fraction in one of the pairs failed to date. The result for the humic acid fraction from the other pair (OxA-X-2415-43) was statistically consistent (T'=0.6; T'(5%)=3.8; **v**=1) with that for the humin (Table 5: OxA-24082). The result for the humic acid fraction from the remaining fragment (OxA-X-2145-39) was more recent than and statistically inconsistent with (T'=21.1; T'(5%)=9.5; **v**=4) the weighted mean of the statistically consistent dates for humin from the same sample (Table 5: sample 227). While this does not conclusively demonstrate that incomplete removal of humic acid was responsible for the anomalously recent dates of the British Museum charcoal samples, it leaves it as a distinct possibility.

Because of this uncertainty, almost all the British Museum bulk charcoal dates have been excluded from the following analyses on the grounds that they may be inaccurate. This is indicated by a question mark after the distribution name, eg Figure 17: BM-776?; excluded dates appear on the graphs but are not used in the calculations. The British Museum charcoal dates that are not excluded are BM-2377, -2379 and -3135, measured in the 1980s with improved pretreatment methods (Ambers *et al* 1987), and BM-1024, measured on charcoal from the same hearth as BM-3135 and statistically consistent with it (T'=0.5; T' (5%)=3.8; **v**=1).

2.1.1.2 Antler and bone

Polyvinyl acetate (PVA) was widely used as a consolidant in the second half of the twentieth century, both in the field and in museums. Being a petroleum derivative, it contains extremely ancient carbon. It was fairly widely applied to the Grime's Graves bone and antler, especially to that part of the collection which is held by the Natural History Museum. The British Museum laboratory was fully aware of the potential of this treatment for making measurements anomalously old, and avoided dating samples that had been so treated. For contextual reasons, 54 certain or possible PVA'd antler and bone samples and a further four treated with unidentified consolidants were dated in the course of this project. At ORAU routine pretreatment was preceded by solvent extraction where consolidants or other chemical contaminants are suspected, with water, acetone, and methanol for PVA, or with a series of solvents if the nature of the contaminant was uncertain (Table 2; Brock *et al* 2010, 106–7).

At the Scottish Universities Environmental Research Centre (SUERC), on the other hand, consolidants were removed from bone and antler samples by surface sanding (Table 2). A question remains as to whether this method removes all of the PVA, especially when it has been applied in fairly dilute form to a highly porous material like antler. In the four cases where such a sample has been replicated between ORAU and SUERC this does not seem to have occurred: three pairs are statistically consistent and, in the fourth, antler 304 from Pit 11 D, the SUERC result is more recent than the Oxford one. Out of caution, however, measurements made by SUERC on PVA-treated samples are modelled as *termini post quos* for their contexts, on the grounds that they may be older than the true age of the samples, unless there are independent grounds for considering them accurate. The exceptions are those which are statistically consistent with determinations for the same antler from other laboratories and those which are statistically consistent with determinations from other laboratories for antlers apparently laid down together in the same group.

Elaine Dunbar, of SUERC, has undertaken a series of experimental treatments, pre-treatments and radiocarbon measurements on samples of known-age bone to determine the efficacy of various pretreatments in removing PVA from the samples (Appendix 2).

2.1.2 Measurement

Measurement methods, including the successive procedures practised by the British Museum, are summarised in Table 2. None of the British Museum determinations was affected by the measurement problems experienced by that laboratory between 1980 and 1984 (Bowman *et al* 1990). There was, however, a significant change in the size of samples required for radiocarbon dating over the years since the first measurements were made. The British Museum Gas Proportional Counting (GPC) and Liquid Scintillation Counting (LSC) measurements called for substantial samples, sometimes all or most of a red deer antler or the '2 bags of good charcoal' noted as the sample for BM-1022. The Accelerator Mass Spectrometry (AMS) dates obtained in the course of this project called for far smaller samples, typically 2g or less of antler or bone, single fragments of charcoal weighing less than 2g, or less than 100mg of carbonised residue, thus greatly expanding the pool of potential samples.

2.2 Quality Assurance

Although the first radiocarbon determinations on samples from Grime's Graves were obtained before quality assurance programmes were undertaken between laboratories, known-age and absolute standards were used by the British Museum laboratory. Formal approaches to quality assurance started in the late 1970s when the first inter-comparison exercise between British laboratories was undertaken (Otlet *et al* 1980). The exercise demonstrated good agreement between the British laboratories and a large number of the Grime's Graves samples measured at the British Museum were processed during this period. The British Museum took part in subsequent international inter-comparison exercises (International Study Group 1982; Gulliksen and Scott 1995, Rozanski *et al* 1992;

Scott 2003; Scott *et al* 1990) when the remainder of samples from Grime's Graves were dated.

The laboratories involved in this current project maintain continual programmes of quality assurance procedures, in addition to participation in international inter-comparisons (Scott 2003; Scott *et al* 2007; 2010).

Further information about consistency in measurement is provided by replicate measurements on some of the Grime's Graves samples. Replicate determinations, sometimes multiple, have been obtained for 35 samples from the site (Table 3; Fig 8). Eleven samples were replicated during the British Museum's programme, one of these being replicated again during the current project, in the course of which 24 further samples were replicated, generally by sending subsamples to two different laboratories. Eleven of the 35 sets are statistically inconsistent, failing a χ^2 test (Ward and Wilson 1978) at the 95% confidence level shown in Table 3. They are unevenly distributed among sample materials. In descending order of frequency, they account for the one charcoal sample, two out of three animal bone samples, three out of seven carbonised residue samples, and five out of 27 antler samples.

Only five sets, however, fail at 99%. These call for closer inspection. The most spectacular are three measurements made on a horse skull from trench 3 (ARC 79 5017; T'=95; T'(5%)=6; ν=2), where the original determination (BM-1546) places the animal's death in the late third or earlier second millennium cal BC, while two statistically consistent AMS measurements (OxA-1635, -21193) place it in the first or second century cal AD. It is possible that the sample originally dated may have been contaminated by PVA despite efforts to the contrary, since the post-excavation treatment of the skull, which was friable and delicate when recovered, is described as follows: 'The large parts of the skull were immersed in a dilute emulsion of polyvinyl acetate; loose fragments, including this one [the sample for BM-1546], were kept untreated for dating' (Clutton-Brock and Burleigh 1991). BM-1546 is excluded from Figure 8.

Carbonised residue on a middle Bronze Age sherd from Armstrong's Black Hole, (Longworth cat. no. 73; T'=49.4; T'(5%)=3.8; ν=1) yielded one determination in the eighteenth to seventeenth centuries cal BC and another in the fourteenth to thirteenth. In this case it might be speculated that, since the material has been out of the ground since the 1920s, there was more scope for contamination here than for residue samples from other features.

The statistical inconsistency of five replicate measurements on an animal bone sample (GG71 119; T'=24.3; T'(5%)=9.5; ν=4) from a late, upper level in the 1971 Pit is attributable to one measurement (OxA-20760), which falls in the late second millennium cal BC while the other four, which are statistically consistent, fall in the early first millennium. The laboratory has concluded that OxA-20760 is inaccurate because a recombustion of the original pretreatment yielded a result comparable to the rest (email from Christopher Bronk Ramsey to John Meadows 26-10-09).

Two antlers from Pit 11 D yielded pairs of determinations which were statistically inconsistent to varying extents (304, T'=8.3; T'(5%)=3.8; v=1; 332a, T'=19.3; T'(5%)=3.8; v=1). In the case of 332a, the discrepancy is probably due to the inaccuracy of BM-983, since this has poor individual agreement when modelled with other dates from the pit (see Fig 28).

This is, however, exceptional for a British Museum measurement made on antler in the 1960s or 1970s and subsequently replicated, whether by the Museum or in the course of this project. There are 11 sets of these, nine of which are statistically consistent (Table 3). This mitigates Janet Ambers' caution as to the accuracy of measurements made during the 1970s (1998). Furthermore, when the British Museum's antler determinations from the 1960s and 1970s are modelled with subsequently obtained antler dates from the same features their individual indices of agreement are almost always good. For these reasons, the British Museum's antler determinations are treated as reliable, unless there are specific reasons to question an individual measurement.

2.3 Chronological Modelling

The chronological modelling in this report has been undertaken using the program OxCal v4.2 (Bronk Ramsey 2009a) and the IntCal13 dataset (Reimer *et al* 2013).

The principle behind the Bayesian approach to the interpretation of data is encapsulated by Bayes' theorem (Bayes 1763). It means that new data collected about a problem ('the standardised likelihoods') are analysed in the context of existing experience and knowledge of that problem ('prior beliefs'). The combination of the two permits a new understanding of the problem ('posterior beliefs') which can in turn become prior beliefs in a subsequent model.

In the modelling of archaeological chronologies calibrated radiocarbon dates form the 'standardised likelihoods' component of the model and archaeology provides the 'prior beliefs', so that the radiocarbon dates are reinterpreted in the light of the archaeological information to provide posterior beliefs about the dates. Such estimates will vary with the model(s) employed, and several different models may be constructed based on varying interpretations of the same data (Bayliss *et al* 2007). The purpose of modelling is to progress beyond the dates at which individual samples left the carbon cycle to the dates of the archaeological events associated with the samples.

Prior beliefs fall into two main groups: informative and uninformative. Informative prior beliefs employed in modelling dates from archaeological contexts often derive from the stratigraphic relations between the contexts of samples. In Figure 7, for example, the dates are constrained by the prior information that the phase 'galleries 1 and 3' was earlier than the phase 'gallery 2', since they are modelled as successive stages of the sequence 'galleries'. This will, of course, produce valid results only if the samples were contemporary with their contexts, rather than older than them.

An often employed uninformative prior belief is that the samples dated are representative of a continuous episode of activity, such as the working of the galleried shafts at Grime's Graves or the use of a particular pottery style, and are spread more-or-less uniformly through it, without necessarily including the earliest or the latest material generated by it (Buck *et al* 1992). This assumption is necessary to constrain the scatter inherent in radiocarbon ages, which would otherwise make episodes of activity appear to start earlier, continue longer, and end later than they actually did (Steier and Rom 2000).

The model is defined in OxCal, detailing the radiocarbon results and specifying the known relative ages of the samples. Once the probability distributions of individual calibrated results have been calculated, the program attempts to reconcile these distributions with the prior information by repeatedly sampling each distribution to build up a set of solutions consistent with the model structure. This is done using a random sampling technique (Markov Chain Monte Carlo or MCMC), which generates a representative set of possible combinations of dates. This process produces a highest posterior density interval for each sample's calendar age, which occupies only a part of the calibrated probability distribution. In this report these are shown in solid colour in the illustrations, the calibrated radiocarbon date from which they have been sampled being shown in a lighter tone.

Highest posterior density intervals are conventionally printed in italics, eg Fig 7: *BM-944.* Also printed in italics are other estimates which may vary from model to model, as well as from one run of a model to the next. These are calculated by the model for events which are not themselves directly dated. They include estimates for the starts and end of episodes of activity (eg Fig 7: *start 1971 pit*), for undated events within sequences of dated events (eg Fig 7: *abandon galleries 1 and 3*), for the durations of episodes (eg Fig 65: *work galleried shafts*) and for intervals between events (eg Fig 66: *start galleried/start simple*).

Statistics calculated by OxCal provide a guide to the reliability of a model. One is the individual index of agreement which expresses the consistency of the prior and posterior distributions (eg Fig 7: *SUERC-18821 [A: 117]*). If the posterior distribution is situated in a high-probability region of the prior distribution, the index of agreement is high (sometimes 100 or more). If the index of agreement falls below 60 (a threshold value analogous to the 95% significance level in a χ^2 test) the radiocarbon date is regarded as inconsistent with the sample's calendar age. Sometimes this merely indicates that the radiocarbon result is a statistical outlier (more than two standard deviations from the sample's true radiocarbon age), but a very low index of agreement may mean that the sample is redeposited or intrusive (ie that its calendar age is different to that implied by its stratigraphic position), or that it is contaminated with extraneous carbon. Another index of agreement, A_{model}, is calculated from the individual agreement indices, and indicates whether the model as a whole is likely, given the data. It too has a threshold value of 60. In Figure 7, for example, 'A_{model}: 17' indicates that the radiocarbon dates and the model are very far from fitting each other.

2.4 Sampling

There are 305 radiocarbon determinations (Table 1) for 256 samples, the difference being accounted for by replicate measurements, some of them multiple (Table 3). The composition of the samples by laboratory, material type and context type is shown in Figures 9 and 10.

2.4.1 Sample selection

The criteria by which samples were selected during this project are also those by which the pre-existing dates have been evaluated. Such criteria have been detailed elsewhere (eg Bayliss *et al* 2011, 38–42). Their purpose is to ensure that a sample is contemporary with its context, rather than already old when incorporated in it. The principal ones may be summarised as follows, in roughly descending order of reliability:

- Bones found in articulation. These samples would have been still connected by soft tissue when buried and hence from recently dead individuals.

- Bones identified as articulating during analysis, especially if a single individual is well represented. These may have been articulated in the ground or have only been slightly disturbed before burial.

- Bones with refitting unfused epiphyses identified during analysis, for the reasons given above.

- Antler tools left on, or near, the bases of features that they had been used to dig. The task of digging chalk calls for antlers to be springy and fresh; they should thus have been shed in or very close to the year in which they were used. Provided that an antler implement was recovered from where it was originally discarded, it should be very close in age to its context.

- Carbonised residues adhering to the interior of groups of sherds from a single pot. These are probably the remains of charred food (rather than firewood) and a well-represented pot has a good chance of being in the place where it was originally discarded. The survival of carbonised residues, which are relatively fragile, also suggests that the sherds have suffered little disturbance.

- Single fragments of short-lived charred plant remains functionally related to the context from which they were recovered (eg charcoal from a hearth or cremation pyre), or forming parts of structures (eg the outer sapwood rings of charred posts). The single fragments eliminate the risk of combining material of different ages in the same sample, and the dating of more than one sample from the same context make it possible to check against the inclusion of stray fragments of older material (Ashmore 1999).

- Single fragments of short-lived charred plant remains from coherent dumps of charred material: inferred on the basis of their coherence and fragility to be primary disposal events (eg charred grain from a substantial deposit in a pit).

At Grime's Graves, antler implements formed the overwhelming majority of suitable samples. These are ideal samples in that each antler is one year's growth, since they are shed annually by red deer stags (now in late February/early March, Legge 1981, 100), and because they have a direct functional relation to the working of the pits. The large numbers recovered here (as in the ditches of Neolithic earthworks) indicate that they were rapidly exhausted and discarded.

Once a pool of available samples was defined, simulations were run to determine which features were capable of more precise dating and how many samples would be necessary to achieve this in each case. Several pits yielding only one or two suitable samples were eliminated.

2.4.2 The possibility of dietary offsets

Diet-induced radiocarbon offsets can occur if a dated individual has taken up carbon from a reservoir not in equilibrium with the terrestrial biosphere (Lanting and van der Plicht 1998). If one of the reservoir sources has an inherent radiocarbon offset - for example, if the dated individual consumed marine fish or freshwater fish from a depleted source - then the bone will take on some proportion of radiocarbon that is not in equilibrium with the atmosphere. This makes the radiocarbon age older than they would be if the individual had consumed a diet consisting of purely terrestrial resources. Such ages, if erroneously calibrated using a purely terrestrial calibration curve will produce anomalously early radiocarbon dates (Bayliss *et al* 2004a).

On the face of it, the risk of marine offsets seems low, since Grime's Graves lies at least 50km from the coast to the north and at least 70km to the east, and as most of the samples derive from terrestrial herbivores, especially red deer. Marine offsets are not, however, out of the question, since the distances which people travelled to the site and the distances from which antler was collected are equally unknown, and deer in marine locations do eat marine resources such as seaweed.

There is also the possibility of freshwater offsets. Since the solid geology is chalk, which is calcareous and soluble, it is possible that carbonates of Cretaceous age leached into water courses and groundwater, making it depleted in ^{14}C (Lanting and van der Plicht 1998; Keaveney and Reimer 2012).

Figure 11 and Table 4 summarise the $\delta^{13}C$ and $\delta^{15}N$ values from the bone and antler radiocarbon samples. The $\delta^{13}C$ value of −22.2‰ and the $\delta^{15}N$ value of +6.0‰ for the single pig sample (SUERC-24128) are within the range of the herbivore samples from the site. The $\delta^{13}C$ values of −19.6‰ and −20.9‰ and the $\delta^{15}N$ values of +9.3‰ and +9.1‰ for the humans (OxA-22533, SUERC-28753) similarly show little signs of the isotopic enrichment that might indicate an appreciable freshwater fish component in the diet (Cook *et al* 2001; Wood *et al* 2013). The herbivores themselves have completely terrestrial $\delta^{13}C$ and $\delta^{15}N$ values. The one anomalous cattle bone result, a $\delta^{15}N$ value of +8.4‰ (OxA-20761), is for the only cattle bone sample dating from the first rather than the second millennium cal BC.

There is thus no indication of marine or freshwater offsets in the current project. The radiocarbon results are therefore simply calibrated using the terrestrial calibration curve (Reimer *et al* 2013).

3.0 RESULTS

The results are listed by laboratory number in Appendix 1 and by feature in the relevant tables. The overall composition of the samples is shown in Figures 9 and 10.

4.0 ANALYSIS

4.1 Local circumstances

The site and collection present several problems. The calibration curve for the mid third millennium cal BC, the main period of mining, is unfriendly (Fig 12); excavation has been unevenly distributed over the site (Fig 2); and pre-existing dates and available samples are heavily weighted towards deeper pits in the east and centre, with far fewer dates and far fewer potential samples from shallower pits in the west (Fig 10). Furthermore, the deep pits themselves were most recently investigated by reopening previously excavated shafts and exploring the still unexcavated galleries radiating from their bases and connecting with others, which were also explored, driven from unexcavated pits, thus recording very little vertical stratigraphy. On the West Field, many of the smaller pits investigated in the 1970s were not bottomed (Longworth *et al* 2012, table 2), so that, even if samples relating to their original excavation and working existed, they would not have been recovered. Antler and bone were less well preserved in the acid, sandy superficial deposits of the West Field than in the chalk of the east and centre. There is the further possibility, reinforced by some of the results, that when pits were backfilled in antiquity from adjacent spoilheaps, the backfill could include antler picks that had been abandoned some time before.

4.2 Structure and rationale of the models

There was a need to accommodate both features with series of dates large enough to be modelled separately and other features from which there are only one or two dates. This could only sometimes be overcome by dating further samples from the under-dated ones because in many cases suitable samples were simply not available, or not available in adequate numbers. Four principal models were adopted, based on the main spatial, functional, and chronological divisions of the site: one for galleried pits; one for simpler pits and other features on the West Field; one for second millennium cal BC pits - which had proved in the course of the dating programme to be chronologically and morphologically distinct; and one for the middens.

Following the conclusions of §2.1.1.1 above, almost all measurements on bulk charcoal samples are treated as outliers, because they may be more recent than the true age of the samples on which they were measured. The exceptions are BM-2377, -2379, and -3135, all measured in the 1980s or 1990s with improved pretreatment, and BM-1024, measured on charcoal from the same hearth as BM-3135 and statistically consistent with it. Most SUERC dates on PVA'd bone or antler are modelled as *termini post quos* because they may be more ancient than the true age of the samples. The exceptions are those which are statistically consistent with determinations for the same antler from other laboratories and those which are statistically consistent with determinations from other laboratories for antlers apparently laid down together in the same group.

4.3 Pre-mining activity

A ninth to seventh millennium cal BC date and a seventh millennium cal BC date were obtained in the 1970s for unidentified bulk charcoal samples, both from small trenches outside of the main excavated areas on the West Field. They are shown as simple calibrations (Fig 13). While both may be inaccurate, as outlined above, their samples must have included Mesolithic or earlier material.

The sample for BM-989 (8320–6770 cal BC; 95% confidence) came from 900/870 F5, a small pit containing hearth material and sand without associated artefacts, and dug into a trough-like structure (Longworth *et al* 2012, 47–9). The plan (ibid fig 28) suggests that the trough-like feature may have been a periglacial stripe. The sample for BM-990 (6610–6360 cal BC; 95% confidence) came from 880/910 F1, a hearth partly overlying a larger and deeper feature, 880/910 F2, which contained 54 Neolithic Bowl sherds, three Bronze Age sherds, and two leaf arrowheads (Longworth *et al* 2012, 46–7). The roughly crescentic plan and irregular fills of F2 (ibid fig 26) may suggest that it was a treethrow hole. At least some of the charcoal in the hearth must have been disturbed and redeposited, otherwise it would not have been associated with Neolithic and Bronze Age pottery.

Mesolithic activity elsewhere on the site is evidenced by a few redeposited or unstratified artefacts (eg Saville 1981, fig 91: F499–500).

4.4 Galleried pits

The galleried pits stand out not only by their depth and technical sophistication, but also by their rich antler assemblages (eg Fig 14), which have yielded numerous dates. Although there were many intersections between the galleries radiating from the pit bases, voids generally made sequences hard to determine. The overall structure of the model for these features is shown in Figure 15. Its component parts are shown in Figures 17–19, 21, 23, 26, 28, 30, 32, and 36–38. It places the galleried pits in a single bounded phase; incorporates any stratigraphic relationships between samples; and, where a feature has yielded four or more effective likelihoods at least three of which are not *termini post quos*, calculates first and last dated events using the First and Last functions in OxCal and durations using the Span function. In this way it is possible to compare individual estimates for the better-dated features, while all the dates contribute to the overall estimates. The choice of four effective likelihoods as a threshold for calculating estimates for individual features is a pragmatic one. Those features may be pits complete with their galleries, like Pit 12; single galleries, which are sometimes all that was excavated and/or dated of a pit, like Greenwell's Pit C; or occasionally smaller elements, separated on stratigraphic and chronological grounds, like gallery 15C1 above the Pit 15 C fill collapse. The model has good overall agreement (A_{model}: 87). Other ways of modelling the dates from the galleried pits are explored in §4.4.15 below.

4.4.1 The Mercer Pit complex

A deep shaft (the 1971 Pit) and an adjoining surface area at the east edge of the visible workings were excavated by Roger Mercer on behalf of the Department of the Environment with the main aims of providing a new shaft for display to the public, and elucidating the use, natural environment, and dating of this part of the site (Mercer 1981). A second pit, invisible from the surface (the 1972 Pit) was discovered during the course of the area excavation. The middle Bronze Age material in its topmost fills is described in 'Middens', §4.7 below. The 1971 Pit measured 11m across and 11.8m deep. Its undercuts and galleries were little developed compared with those of some other pits. The basal deposits indicated that gallery 1 was cut first, since it was backfilled with fresh chalk blocks and antler picks (Mercer 1981, 28, fig 15), presumably derived from the excavation of one or both of the other galleries. A pile of chalk blocks occupying most of the shaft floor would thus have come from the last gallery to be excavated. While galleries 2 and 3 had a common entrance (Fig 16), gallery 3 was filled, like gallery 1, with chalk and antler picks (Mercer 1981, fig 16 lower), suggesting that it too contained the spoil from another gallery, presumably gallery 2. The infilling of gallery 2 was different: antler was scarce and it had not been backfilled, but contained successive deposits of chalk from the walls, ceiling and adjacent shaft fill, interleaved with lenses of sand derived from the surface above (Mercer 1981, 28, fig 16 upper). This was a continuation of the natural silting of the lower part of the shaft itself which, exceptionally, had not been backfilled (Mercer 1981, figs 17, 18). Gallery 2 was thus the last one to be worked. The floor of the pit, and to some extent of the galleries, was covered by concreted, trampled chalk. In gallery 2, this surface underlay the lowest silt layers.

Gallery 1 intersected with another gallery driven from an unexcavated pit to the north-east. No stratigraphic sequence was discernible and it is not clear whether the entire length of this other gallery was excavated.

The only part of the paper archive which could be found, when the collection was examined and the samples selected, was the finds books. Plans, sections, and site notebooks remain elusive. Samples were therefore selected on the basis of information recorded in the finds books and on labels and bags. This is a full and thorough log and can usually be related directly to the published report. There are, however, some lacunae.

4.4.1.1 The 1971 Pit

Figure 17 shows a chronological model for the 1971 pit, differing from the version shown in Figure 7 in that the four bulk charcoal dates (BM-775 to -778) are excluded, for the reasons explained in §2.1.1.1 above. The dates and their contexts are listed in Table 5. Two measurements on the humic acid fractions of charcoal samples made in the course of trying to understand the discrepancy between dates on bulk charcoal and those on other materials from the pit (Table 5 and Appendix 1: OxA-X-2415-39, OxA-X-2415-

43) are not used in the model because they are not comparable with the other single-entity charcoal dates.

Determinations for five antler picks from the pit base, including two statistically consistent pairs of replicates, (Fig 17: *A598*, *A611*) are all statistically consistent (T'=7.2; T' (5%)=9.5; **v**=4) and, since the pit base would have seen activity throughout the final stages of extraction, are simply modelled as part of that phase. Galleries 1 and 3 are modelled as part of the same extraction phase and as pre-dating gallery 2, as described above. Measurements for nine antler implements from both of them, including a further statistically consistent pair of replicates (Fig 17: *A619*), are themselves statistically consistent (T'=11.8; T' (5%)=15.5; **v**=8) and are also consistent at 99% confidence with the dates for antlers from the pit base (T'=23.9; T'(1%)=29.1; **v**=14).

In Gallery 2 the unavailability of plans and sections poses problems. No antler samples could be located, corresponding to their original scarcity in this gallery (Fig 16). Dates were obtained for four individual fragments of *Corylus* or Maloideae charcoal from charcoal concentrations, two from the '5th section charcoal patch C', and one each from the '3rd sect charcoal patch (A)' and 'gal 2 4th section'. Multiple replicates were obtained on one charcoal fragment (Fig 17: *sample 227*) because of discrepancies between two original replicates. These section numbers refer not only to the plane of each drawn section, but to the block of fill between that section and the next (Fig 16; Mercer 1981, 11–12). The samples came from charcoal patches in the gallery and should hence postdate the samples from galleries 1 and 3. Without access to the original plans and sections, however, it is not clear whether these patches were on the floor of the gallery, where such deposits were recorded (Fig 16; Mercer 1981, 28), or in the lenses of silted sand in its mouth, where charcoal patches were also present (Mercer 1981, fig 16). In the first case, they were generated towards the end of the working of the pit. In the second they date from soon after its abandonment.

No suitable samples could be found from the lighting of a small fire and the placing of flint-working debris and parts of two Grooved Ware bowls on the surface of the chalk heap on the pit floor, which must have postdated the working of gallery 2 and marked the abandonment of the pit (Mercer 1981, 23, fig 11, figs 22–3). This remains represented only by an excluded date (Fig 17: BM-778?).

To cover both possibilities for the origin of the charcoal samples from gallery 2, two estimates for the abandonment of the pit are made. One (Fig 17: *abandon 1971 pit*), includes them in the overall phase of floorstone extraction; the other (Fig 17: *abandon galleries 1 and 3*) equates the final working of the pit with the abandonment of galleries 1 and 3 and places it before the generation of the gallery 2 charcoal samples. There are two corresponding estimates for duration, the second, shorter one arrived at by calculating the difference between start 1971 pit and abandon galleries 1 and 3.

The dates are in good agreement with this interpretation of the stratigraphy. The model estimates that the pit was initiated in *2655–2600 cal BC* (*95% probability*), probably in *2645–2610 cal BC* (*68% probability*, Fig 17: *start 1971 pit*) and abandoned either in *2485–2395 cal BC* (*95% probability*), probably *2480–2435 cal BC* (*57% probability*, Fig 17: *abandon 1971 pit*), or alternatively in *2555–2480 cal BC* (*95% probability*), probably *2530–2490 cal BC* (*68% probability*, Fig 17: *abandon galleries 1 and 3*). The pit would have been worked over *135–240 years* (*95% probability*), probably over *150–210 years* (*68% probability*, *work 1971 pit*, distribution not shown), alternatively over *70–155 years* (*95% probability*), probably over *95–140 years* (*68% probability*, Fig 44: *work 1971 pit galleries 1 and 3*).

Even the shorter of the two spans is vastly more than Mercer's total resource estimate of around two months, starting with a workforce of 20 or more and ending, once the shaft was sunk, with a spell of 14 days for the digging of galleries and the lifting of floorstone by a workforce of as little as four or five (Mercer 1981, 30–3), especially as all the samples, perhaps excluding the gallery 2 charcoal, should date from the last 14 days. The most plausible explanation for this is the shape of the calibration curve (Fig 12), which makes many of the distributions bimodal, although not fragmented (Fig 17).

The only possible archaeological evidence for intermittent working consists of weathering horizons within the chalk dumps surrounding the pit (Mercer 1981, 13–4). This, however, could have occurred in the course of a single season. Arguments against this interpretation include very limited weathering on the pit floor (Mercer 1981, 31), the lack of any evidence for re-entry in the form of truncated older fills, and the minimal extent of the galleries (Fig 16). Intermittent working would furthermore entail a great deal of re-excavation, as attested by re-examination of Pit 1 in 1920, six years after its excavation in 1914, which necessitated the removal of 7ft 6in (2.3m) to 10ft (3m) of material introduced by the action of rainwash and frost (Armstrong 1921a, 442–3).

4.4.1.2 Pit to the north-east of the 1971 Pit

Figure 18 shows the dates for eight whole or fragmentary antler picks from the single excavated gallery (Fig 16), all of them statistically consistent ($T'=13.9$; T' ($5\%=14.1$; $\nu=7$), and hence capable of having been shed in the same season. The model provides an estimated start date of *2655–2595 cal BC* (*95% probability*), probably *2640–2605 cal BC* (*68% probability*, Fig 18: *start pit NE of 1971 pit*); and an estimated abandonment date of *2550–2460 cal BC* (*95% probability*), probably *2515–2475 cal BC* (*68% probability*, Fig 18: *abandon pit NE of 1971 pit*). The gallery would have been worked over *75–175 years* (*95% probability*), probably *105–155 years* (*68% probability*, Fig 18: *work pit to NE of 1971 pit*). This is grossly disproportionate for a gallery 5.5m long, 2m wide and at most 1.5m high (Fig 16; Mercer 1981, fig 15: sections 5–10). Here again, the reason may lie in the shape of the calibration curve, which produces bimodal distributions (Fig 18). The consistency of the dates is compatible with a single season of working.

4.4.2 The 1972–74 knapping floor

This is included among the galleried pits because it lay in the south-east of the field (Fig 2), where the floorstone is deep and all the excavated pits are galleried, and because it was overlain by upcast from unexcavated Pit Y, indicating that its use falls within the period during which galleried pits were sunk. Dates from it are listed in Table 6.

The floor covered at least 70sq m with knapping debris amounting to an estimated 250,000 pieces at densities of up to 12,945 pieces per sq m. There were at least three hearths within the floor, and Grooved Ware bowls were present. A number of antler tines within the floor were almost certainly knapping hammers. The accumulation was clearly the result of numerous knapping episodes over a period of time (Longworth *et al* 1991, figs 3–4; Lech and Longworth 2000; Longworth *et al* 2012, 86–9, pls 5–6). Analysis of a sample of 39,735 pieces indicates that roughouts for a variety of forms, including axeheads and discoidal knives, were produced, mainly from floorstone - a further link between the floor and the galleried pits in addition to the stratigraphy (Lech 2012).

Four dates were obtained for unidentified bulk charcoal samples from hearths within the floor (Fig 19: BM-988?, -995?, -1013?, -1014?). No further charcoal from the hearths could be located in the course of this project. Dates were, however, obtained for four of the probable knapping hammers (Fig 19: OxA-20718, -20719; SUERC-24118, -24119). All were from locations overlain by upcast from Pit Y, so that, even if the interpretation that the tines were used in knapping is mistaken, the dates remain *termini post quos* for the working of that pit. Their statistical inconsistency (T'=26.3; T' (5%)=7.8; ν=3) accords with the inferred long use of the area as a knapping site. They provide an estimated start date of *2635–2505 cal BC* (*95% probability*), probably of *2630–2560 cal BC* (*68% probability*, Fig 19: *start 1972–74 knapping floor*) and an estimated end date of *2465–2385 cal BC* (*95% probability*), probably *2455–2405 cal BC* (*68% probability*, Fig 19: *tpq pit Y*). The floor would have accumulated over a period of *70–235 years* (*95% probability*), probably *125–205 years* (*68% probability*, *use 1972–74 knapping floor*, distribution not shown).

4.4.3 The Greenwell's Pit complex

Greenwell's Pit lies towards the south-east edge of the visible workings (Fig 2) and is 8.5m across and almost 12m deep. Following Canon Greenwell's excavation of most of the shaft fill and exploration of some of the galleries in 1868–70 (Greenwell 1870a; 1870b), the 1970s investigations of the Prehistoric Flintmines Working Group of the Dutch Geological Society, Limburg Section (PFWGDGSLS), started from the base of the mechanically re-excavated pit, tracing and defining more of its galleries (eg Fig 22) and the shaft bases of four further pits (Greenwell's Pits A, C, D, and E), and establishing the methods and sequence of working (Longworth and Varndell 1996, 9–33). This last exercise emphasised the extent to which spoil was moved from place to place underground as mining progressed, a practice facilitated by far more extensive interconnecting galleries than in the Mercer complex. This means that single antler implements in spoil, rather than deposited in groups or on surfaces, may have been redeposited. Single galleries were explored from Greenwell Pits A, C, and D and two from Greenwell's Pit E (Fig 20). There was at least one substantially represented plain Grooved Ware bowl in niche V of Greenwell's Pit and at least one other in the adjoining gallery of Greenwell's Pit C (Longworth *et al* 1988, 16–17, fig 5: N35, N36). Similar vessels has otherwise been found in only a handful of mining period contexts, notably Pits 1 and 2 and the 1972–4 knapping floor.

The sections of the model which cover the complex are shown in Figures 21 and 23 and the dates shown there are listed in Table 8. The galleries driven from the unexcavated pits are discussed first because they have a bearing on some questions arising from Greenwell's Pit itself.

4.4.3.1 Galleries driven from Greenwell's Pits A, C, D and E

The 9.5m gallery driven from Greenwell's Pit A, joining gallery II of Greenwell's Pit, was completely excavated (Fig 20). Greenwell had removed much of the fill of gallery II (Longworth and Varndell 1996, figs 5, 7) but, as far as it was preserved, this appeared continuous with that of this gallery (ibid, fig 7). The fill of the gallery of Greenwell's Pit A was undisturbed, a compacted 'crawling floor' of redeposited chalk being overlain by further chalk rubble and lumps. There were antler picks and charcoal patches at this level and on the actual gallery floor (ibid, fig 17). Three statistically consistent replicate measurements were made on an antler pick from the floor of the gallery (Fig 21: *923*; Table 8: BM-1050, OxA-23104, SUERC-30932). This pick provides a *terminus post quem* for the deposition of a dog, the complete articulated skeleton of which was found on the 'crawling floor' against the gallery side, 2m away from the dated antler (Burleigh *et al* 1977; Longworth and Varndell 1996, 23, figs 7, 8, 17, pl. 4). Antler 923 was also stratified below other antler samples, one from approximately 1.5m to the north-east (Fig 21: *BM-1068*) and a pair of antler picks crossed over each other at the entrance from Greenwell's Pit A (Fig 21: *OxA-23104*, *SUERC-30932*). These last two are statistically consistent (T'=0.4; T' (5%)=3.8; ν=1), and their placement may have been a final act on leaving the gallery. SUERC-30932 is therefore taken as contemporary with its context, although its treatment with PVA would otherwise lead to its being modelled as a *terminus post quem*. The gallery would have begun to be worked in *2570–2525 cal BC* (*52% probability*) or *2500–2460 cal BC* (*43% probability*), probably in *2560–2535 cal BC* (*37% probability*) or *2490–2470 cal BC* (*31% probability*, Fig 21: *start Greenwell's pit A*). It was abandoned in *2465–2380 cal BC* (*95% probability*), probably in *2445–2400 cal BC* (*68% probability*, Fig 21: *abandon Greenwell's pit A*).

There were no usable stratigraphic relationships in the galleries driven from Greenwell's Pits C and D, so that the dates from each are modelled in single phases. The Pit C gallery provided a pair of statistically consistent replicate measurements on a single antler (Fig 21: *647*) and dates on four other antler samples, one of which is modelled as a *terminus post* *quem* for the reasons noted in §2.1.1.2 above, since the antler had been treated with PVA (Fig 21: *SUERC-30924*). The fifth sample was a carbonised residue from the interior of sherds of a plain Grooved Ware bowl placed near the buttend of the gallery (Fig 21: *OxA-22577*; Longworth *et al* 1988, fig 5: N36). The estimated start and end dates for the Pit C gallery indicate that it began to be worked in *2585–2460 cal BC* (*95% probability*), probably in *2575–2525 cal BC* (*61% probability*); Fig 21: *start Greenwell's pit C*). The gallery was abandoned in *2465–2375 cal BC* (*95% probability*), probably in *2445–2400 cal BC* (*68% probability*; Fig 21: *abandon Greenwell's pit C*).

An antler pick from the gallery driven from Greenwell's Pit D provided two statistically consistent measurements (Fig 21: *720*), this is complemented by three further dates on antler implements, one of them forming part of the same group of six antlers as 720. All four dates are statistically consistent (T'=6.7; T' (5%)=7.8; ν=3). Two, however, were both treated with PVA and dated by SUERC, and are therefore modelled as *termini post quos*.

The samples relating to Greenwell's Pit E were all antler picks from the more westerly of the two galleries attributed to the Pit (Fig 20) and were all found within less than 1m of each other, close to the sill dividing this gallery from gallery III2b of Greenwell's Pit (Felder 1976a, VI-II-30). Given these circumstances, the results are surprisingly mixed. SUERC-30927 and OxA-23101, measured on the upper and lower of two superimposed antlers, are statistically consistent (T'=3.8; T' (5%)=3.8; ν=1). For this reason SUERC-30932 is taken as contemporary with its context, although its treatment with PVA would otherwise lead to its being modelled as a *terminus post quem*. SUERC-30931, also treated with PVA, is, however, is modelled as a *terminus post quem* for the reasons noted in §2.1.1.2. The four dates provide an estimated start of *2650–2575 cal BC* (*95% probability*), probably *2635–2585 cal BC* (*68% probability*; Fig 21: *start Greenwell's pit E*) and an estimated end date of *2500–2370 cal BC* (*94% probability*), probably of *2475–2430 cal BC* (*55% probability*) or *2425–2405 cal BC* (*13% probability*; Fig 21: *abandon Greenwell's pit E*).

4.4.3.2 Greenwell's Pit itself

Greenwell's original excavation removed all deposits on the pit floor except for the fill of niche V, an undercut on the north-west side, backfilled from the direction of the pit (Longworth and Varndell 1996, 13, figs 5, 6). His exploration of the galleries was less complete, encompassing gallery I, most of gallery II, and one lobe of gallery III (later known as gallery III3), which his workmen entered via gallery II, so that deposits in the mouth of gallery III and in its remaining two lobes remained intact, as did all the deposits in gallery IV (ibid, fig 5). BM-291, measured in the 1960s on an antler recovered by Greenwell from gallery III must thus have come from gallery III3. From the 1970s PFWGDGSLS investigations samples were available from niche V and from galleries II, III, and IV. These were far more extensive than the galleries of the 1971 Pit.

There is a single sequence near the mouth of gallery III, where an antler pick (Fig 23: *OxA-23096*) lay a little above the floor in spoil probably moved from further into the gallery, overlain by more rubble from gallery III2 (the southern lobe of the gallery) in which were four further antler picks (ibid, 13, fig 11: section 2), two of which were dated (Fig 23: *OxA-23095*, *SUERC-30923*). SUERC-30923 is modelled as a *terminus post quem* for the reasons noted in §2.1.1.2 above, since the antler had been treated with PVA. The remaining samples included replicate measurements on carbonised residue from the interior of sherds from a plain Grooved Ware bowl (Longworth *et al* 1988, fig 5: N35) found in niche V (Fig 23: *502*). The others were all antler implements, including three pairs of statistically consistent replicates (Fig 23: *900*, *578*, *705*). The outcome is an estimated start date of *2645–2575 cal BC* (*95% probability*), probably *2635–2600 cal BC* (*68% probability*, Fig 23: *start Greenwell's pit*); an estimated end date of *2450–2370 cal BC* (*95% probability*), probably *2435–2395 cal BC* (*68% probability*, Fig 23: *abandon Greenwell's pit*); and an estimated duration of *155–280 years* (*95% probability*), probably *175–230 years* (*68% probability*, Fig 44: *work Greenwell's pit*).

The same questions arise as for the 1971 Pit, as this timescale is vastly disproportionate to Felder's total resource estimate of around three months, starting with a workforce of roughly 20 and ending with a spell of 15 days in which all four galleries and niche V were initially worked in parallel, some abandoned before others, by a team of 5–14, once the shaft was sunk (Felder 1981; Longworth and Varndell 1996, 82–5, fig 64). As in the 1971 Pit, all the dated samples should relate to the final stage, in this case 15 days.

The disparity prompted an attempt to model the dates in Felder's sequence (Fig 24, Table 7), the precise locations of the samples being determined from the archive reports. There are no dates from his stage 3 or from some of the deposits related to the other stages. Furthermore, the dates attributed to stage 1 in the mouths of galleries III and IV may belong to stage 2, the samples being contained in spoil from farther into the gallery (Longworth and Varndell 1996, 13, fig 6). The sequence, however, would remain valid even with these samples shifted by one stage. The dates and the sequence are in good agreement (A_{model}: 159). The model shown in Figure 25, however, extends the time period, since it spreads the dates through more stages than that shown in Figure 23. It gives an estimated start date of *2740–2570 cal BC* (*78% probability*) or *2560–2500 cal BC* (*18% probability*), probably *2680–2590 cal BC* (*60% probability*, Fig 25 : *start Greenwell's pit*); an estimated end date of *2460–2185 cal BC* (*95% probability*), probably *2400–2255 cal BC* (*64% probability*, Fig 25: *abandon Greenwell's pit*); and an estimated use-life of up to *505 years* (*95% probability*), probably *225–430 years* (*66% probability*, distribution not shown).

Factors which may be relevant here, in addition to the shape of the calibration curve, are the location of the pit in an intensely worked area, surrounded by other pits of various dates, their galleries sometimes connected by breaches, and the location of Felder's later phases of working within the pit. The Felder scheme entails the piling up, in the early stages, of spoil and picks in the mouths of galleries III and IV (Longworth and Varndell

1996, figs 5, 6: a–b; 14, 15: a–b). This is described as 'not to the point where access was impeded' (ibid, 13), but access would at the very least have been severely restricted. It may be significant that some of the areas that fall in later extraction stages would have been accessible, via breaches, from the galleries of other pits: niche IIa, gallery III3 and niche III3a all from Greenwell's Pit A; niches III2a and b and the two buttends of gallery IV; all from Greenwell's Pit E, and, via an unexcavated west-to-east gallery, from Greenwell's Pit C (Fig 20). Could some or all of the later stages of working have involved entry into the galleries when their mouths were already blocked, from more recent pits, whether for further extraction or for the disposal of spoil and spent implements? It is noteworthy that an admittedly schematic longitudinal section shows continuous fills through gallery II and the excavated gallery of Greenwell's pit A (ibid, fig 7). Some of the later dates from Greenwell's Pit might relate to the working of Greenwell's Pits A and C, both initiated in the 26th century, rather than to the pit itself, initiated in the twenty-seventh century. The five measurements attributed to Felder's stage 1 (Fig 25) are statistically consistent (T'=1.5; $T'(5\%)$=9.5; ν=4) and may provide the best indication of the age of the pit. In this case, the estimated start date would be *2675–2565 cal BC* (*78% probability*) or *2540–2500 cal BC* (*17% probability*), probably *2635–2580 cal BC* (*59% probability*. Fig 25: *start stage 1*); the estimated end date would be *2580–2470 cal BC* (*95% probability*), probably *2525–2480 cal BC* (*68% probability*, Fig 25: *end stage 1*), and the estimated duration *10–160 years* (*95% probability*), probably *15–35 years* (*14% probability*) or *70–130 years* (*54% probability*, *duration stage 1*, distribution not shown).

4.4.4 Pit 2

This pit was one of the pair excavated by the Prehistoric Society of East Anglia in 1914, when the shaft and a considerable extent of the galleries were explored (Clarke 1915). Two additional galleries were found in 1915. Further investigation by the PFWGDGSLS in 1975 was confined to a resurvey; and to the removal of remaining deposits in the galleries, because deposits were too disturbed (partly as a result of long-term accessibility to the public) to permit reconstruction of the mining sequence (Longworth and Varndell 1996, 35, figs 26–9). The pit lies in the west-centre of the area of visible workings (Fig 2), and measures *c* 13m across and 9.4m deep. It yielded over 100 sherds of Grooved Ware, the largest single collection from the site (Longworth *et al* 1988, 16–8). The section suggests that the lower part was backfilled (Peake 1915, fig 7). A charcoal-rich 'black band' in the upper part is of uncertain date, as is a disarticulated but very substantially represented skeleton (Keith 1915, 134–5, 138–41) below it. Permission to sample the skeleton, now held in the palaeontology department of the Natural History Museum, was refused. This is unfortunate, since it may be a very rare third-millennium burial, or given the history of the site, it could be second or first millennium cal BC in date. There were few suitable samples to complement the existing dates (Fig 26: *BM-1020*, *-1069*, Table 9) and no further dating was undertaken.

4.4.5 Pits 3, 3A, 4, 6 and 8

These are dealt with in §4.6 below.

4.4.6 Pits 8, 9 and 10

These are dealt with in section §4.5 below.

4.4.7 Pit 11

This pit in the West Field was excavated by Armstrong in 1930. It was irregular in plan, with a maximum dimension near the base of *c* 15.5m, and *c* 4m deep, connected by 'creep holes' to other pits. There was a dark layer with Romano-British pottery in the upper fill (Armstrong 1932, 60; Longworth and Varndell 1996, 45–47, fig 2). There is only one date (Fig 26: *BM-103*; Table 9); the context of the antler on which it was measured is unknown.

4.4.8 Pits 11 A, 11 B, and 11 D to 11 H

Armstrong, who had surveyed the general plan of Grime's Graves published in the 1915 monograph (Clarke 1915), produced an updated version in 1935. In the process he misplaced Pit 11, which he had excavated in 1930, to a location some 50m south-south-west of its true location. In 1973, an attempt at the mechanical re-excavation of Pit 11 at this erroneous location sectioned two Pits (11 A and 11 B) connected by short galleries to five others (11 D to 11 H) which were not exposed (Fig 27). These pits lay at the western limit of the galleried shafts, and were only *c* 3m deep, sunk through sand for most of their depth, with the lowest *c* 1m cut through chalk to *in situ* floorstone (Felder 1973; Longworth and Varndell 1996, 45–50). Investigation by the PFWGDGSLS recorded the surviving parts of the two exposed shafts and the galleries driven from them and from the others.

No stratigraphic sequences between pits or between potential samples could be determined. Despite their proximity, they were probably not worked in a single season, since a number of antlers from them have common features which suggest that they had been shed by a single stag over a number of years (Clutton-Brock 1984, 38–9). Their find numbers and precise contexts of these specimens are not noted in Clutton-Brock's publication, but the markings legible in a photograph of three of them (ibid, pl. 6) show that they include, in ascending order of size, antlers 313 from Pit 11 A, 305 from Pit 11 D, and 304, also from Pit 11 D. It is as if a single group of people, gathering antler from a single area, returned in successive years to the same small area of Grime's Graves. The presence of more mature antlers in Pit 11 D suggests that it was worked after Pit 11 A.

It was possible to obtain measurements on 11 antler implements from Pits 11 A, 11 D, 11 E, and 11 F to supplement the dates already obtained (Fig 28, Table 10). Two further antler samples failed: one was not dated because a poor C:N ratio suggested that collagen survival was not sufficiently good for accurate dating, and another because an unidentified material used in conservation could not be removed. This second sample was one of a pair of replicates from an antler which had been treated with PVA. Its counterpart was dated (SUERC-30917); this result is treated as a *terminus post quem* because of the probability of contamination. Also treated as *termini post quos* are SUERC-30914, -30915, and -30916, because not all PVA may have been removed from them. A further date measured on a PVA'd antler (SUERC-28751) that falls in the fifth millennium cal BC, is clearly anomalous, and is excluded. Also excluded are a bulk charcoal date (Fig 28: BM-987?), which is more recent than the dates on antler, and an antler date (Fig 28: BM-983?) which is statistically inconsistent with its more recently measured replicate (Fig 28: *OxA-23109*; T'=19.3; T' (5%)=3.8; ν=1).

Three sets of samples (Fig 28: *304* and *OxA-22532*; *BM-984*, *OxA-23108* and *SUERC-30914*; *SUERC-28751*, *-30915*) were from groups of antlers which had apparently been deposited together, suggesting that they were deliberately placed rather than accidentally included in backfill.

No estimates have been made for individual pits because none has produced four effective likelihoods, three of which are not *termini post quos*. The dates from the complex are in good agreement with those from the larger galleried pits.

The antler implements from these pits stand out in some respects. As well as including examples perhaps cast by a single stag in successive years, they are less markedly regular in composition and treatment than those from the deeper shafts (ibid, 38–9). Furthermore, the implements from the complex include roe deer antlers, two of which are dated (Fig 28: *OxA-23107*, *OxA-23110*). Roe deer antlers are relatively rare at Grime's Graves. The dates for these two examples are in good agreement with those for red deer antler picks.

4.4.9 Pit 12

Pit 12 lay at the east edge of the West Field, some 180m north-east of Pits 11 A–H (Fig 2). It measured roughly 10m across at the top and 5.5m deep, and was sunk down to *in situ* floorstone. Excavations in 1928, 1930, 1932, and 1933 by Armstrong and Favell entailed the preservation of a vertical section of fill on the east side (Fig 29). Where the pit floor was excavated, galleries extended outwards at floorstone level, with at least one of them (gallery 1) connecting with another pit. Galleries 2 and 4 may have been the last to be extracted, since they were only partly infilled, while the others were packed with chalk. Successive knapping horizons in the fill (from A, the highest, to G, the lowest) suggest intermittent backfilling. Finds included small numbers of bone and roe deer antler picks as well as far more numerous red deer antler picks (Armstrong 1932, 59–61; 1934, 382–94; Longworth and Varndell 1996, 73–5). Peterborough Ware sherds from the upper levels, mainly from Floor C (Longworth *et al* 1988, 15, fig 3: N2–N9), must have been redeposited, since Floor C also contained sherds of bucket-shaped middle Bronze Age vessels (ibid, 27).

There were two pre-existing dates, both for antler from unknown contexts. Statistically consistent replicates on benzene from one antler yielded a date of 3270–2580 cal BC (95% confidence; Fig 30: *BM-97 & BM-377*), which would be exceptionally early for mining on the site. The other was exceptionally late, at 2300–1510 cal BC (95% confidence; Fig 30: BM-276?).

In addition to these, it was possible to sample six implements from the pit floor and galleries, the contexts of which were recorded on their original labels (Table 11). The results for these six implements are statistically consistent (T'=4.3; T' (5%)=11.1; ν=5). A seventh, from 'S side in chalk at 6ft [1.80m]' would, judging by the vertical scales beside Armstrong's published sections, have come from quite high in the fill, not far from the level of Floor C with its Bronze Age pottery. It is, however, statistically consistent with the samples from the pit base and galleries (T'=9.9; T' (5%)=12.6; ν=6) and is therefore modelled as redeposited and a *terminus post quem* for its context above them (Fig 30: *SUERC-24096*).

The two pre-existing dates are in poor agreement with the newly obtained ones. BM-276, which is much later, is excluded from the model. BM-97 and -377, which had originally raised the possibility that the working of Pit 12 might go back to the late-fourth or early-third millennium (§1.5.1), make the antler on which they were measured older than any of the statistically consistent dates on antlers from primary contexts; their weighted mean is therefore modelled as a *terminus post quem* for the pit. Both pre-existing dates could be accurate; BM-97 and BM-377 perhaps relating to the redeposited Peterborough Ware sherds in the upper levels, BM-97, to Bronze Age activity in the area.

The model provides an estimated start date of *2635–2535 cal BC* (*95% probability*), probably *2620–2560 cal BC* (*68% probability*, Fig 30: *start pit 12*) and an estimated end date of *2540–2450 cal BC* (*93% probability*), probably *2500–2465 cal BC* (*68% probability*, Fig 30: *abandon pit 12*).

4.4.10 Pit 14

Pit 14 lies to the north of the visible earthworks, some 250m north-east of Pit 12 (Fig 2). Excavation in 1934 by Favell and in 1935 and 1936 by Armstrong showed it to be ovoid in plan, measuring *c* 5m x 2m at the surface and 3.2m deep. It was sunk down to *in situ* floorstone, with incompletely excavated undercuts at the base which may have connected with other shafts. The irregularity of the fills in the sketched section (Fig 31) suggests backfilling. Four knapping horizons (from A, the highest, to D, the lowest), were noted in the fill. Bone picks were found in niche 3, antler ones elsewhere (Longworth and Varndell 1996, 73).

The one existing measurement has a large error (Fig 32: *BM-99*) and is from an unknown context. It was possible to sample eight further antler implements which, like those from Pit 12, retained their original labels, complete with contextual information (Table 12). All of these came from the undercuts or from near the base of the shaft, and all, together with BM-99, are statistically consistent (T'=5.6; T'(5%)=15.5; **v**=8). The model provides an estimated start date of *2640–2555 cal BC* (*95% probability*), probably *2625–2590 cal BC* (*55% probability*, Fig 32: *start pit 14*); and an estimated end date of *2520–2400 cal BC* (*95% probability*), probably *2510–2455 cal BC* (*68% probability*, Fig 32: *abandon pit 14*).

4.4.11 The Pit 15 complex

Pit 15 lies at the north edge of the visible workings (Fig 2), where the floorstone lies at a depth of *c* 5.8m. It was excavated by Armstrong in 1937–9, although never published by him. Its galleries were explored to some extent in the 1930s, and to a far greater extent by the PFWGDGSLS in the 1970s, when the bases of 10 further Pits (15 A to H, 15 J, and 15 K) were identified, together with their galleries (Fig 33; Longworth and Varndell 1996, 51–9). These explorations also revealed that Armstrong had excavated down to 'the crawling floor' level only in the galleries which he had explored, so that some *in situ* fill remained over the solid chalk floors. During much of the interval between the two investigations, Pit 15 was open to the public and informal exploration beyond the galleries cleared in the 1930s had caused damage to the chalk walls and the deposits (Longworth and Varndell 1996, fig 43). There was evidence for stratigraphic relationships (not always clearly defined) between the working of at least some galleries of Pits 15 A, 15 B, and 15 C. An antler pick lay on the natural chalk floor across the junction of galleries 15D2 and 15J1, indicating that they were open together (Longworth and Varndell 1996, fig 44). None of the other pits could be linked in any way.

While the Pit 15 complex and the Greenwell complex are comparable in the extent of their interconnections and their exploration, there are important differences between them, springing form their location. The Greenwell complex lies in the south-east of the area of visible earthworks, where the floorstone is *c* 12m deep. The Pit 15 complex lies at the north edge of the area, where the floorstone is only half as deep. Excavation to *c* 12m entailed not only deeper pits, but larger, more widely-spaced ones and consequently longer galleries than excavated to *c* 6m. The scale of the workings explored from Pit 15 is roughly half that of those explored from Greenwell's pit, not only in depth, but in pit diameter and gallery length. As a result, the tally of antlers is lower. 184 antlers and antler fragments were recorded from the Pit 15 complex in 1972–6, compared to 274 from the Greenwell complex in the same period (Longworth and Varndell 1996, 96–8), furthermore several individual galleries in the Pit 15 complex yielded only a couple of finds. There was thus a poorer pool of potential samples on which to draw.

4.4.11.1 Pit 15

The pit measured 4 x 5m across and *c* 5.8m deep. It was sunk down to *in situ* floorstone, like the other pits in the complex, although niches up to 1m deep had also been cut into the shaft wall to extract nodules of wallstone (Longworth and Varndell 1996, 51). Armstrong reported a chalk figure, chalk phallus and flint nodules at a gallery entrance as well as a platform of mined flint supporting antler picks, with a chalk vessel at its foot and a hearth at the mouth of another gallery. The authenticity of at least some of these placements and their components is questionable (Varndell 1991). Knapping floors and hearths occurred at various levels in the fill. It was not possible to find any suitable samples from primary contexts rather than backfill to supplement the two existing dates (Fig 36: BM-87?, *BM-88*), the former being a bulk charcoal date which has been excluded from the model for the reasons given in §2.1.1.1 above. There is still the potential to date charcoal from some of the apparent hearths in the infilling.

4.4.11.2 Pits 15 A, B, and C

It was not possible to find enough samples from the floors, rather than higher in the fill, in the three galleries of Pit 15 A to supplement the existing date, itself also from above the floor (Fig 36: *BM-973*). Galleries 15B3 and 15C1 ran into each other, together connecting Pits 15 B and 15 C (Figs 33–4). 'Crawling floors' in their fills and wear-marks on their roof show that they were used for movement, presumably during the working of adjacent galleries, in the case of the higher 'crawling floors', after the floorstone at the base of the galleries had been extracted and some spoil had been introduced (Fig 34; Felder 1975a, 18; Longworth and Varndell 1996, fig 45). It was not clear whether the lower fills of galleries 15B3 and 15C1 had been introduced from Pit 15 A or from Pit 15 B, although the topmost fill clearly came from Pit 15 B (Felder 1975a, 18). All this indicates that galleries 15A2, 15B3 and 15C1 were being used by miners at the same time, although they may have been worked at different times initially, providing more than one option for the sources of their fills and therefore redistrubuted antlers. At the south end of gallery 15C1, a roof collapse may have been the trigger for the slumping of shaft fill into the gallery mouth, covering a small depth of fill (Fig 34). The longitudinal section (Fig 34: bottom) and the account of the investigation (Felder 1975a, 18–9, 81; Longworth and Varndell 1996, 59) are in agreement that the fill and finds (antlers 58 and 59) beneath the slumped shaft fill belong to gallery 15C1 and related to the working of Pit 15 C, while the fills and finds post-dating the slumped shaft fill, including antlers 56 and 57 (Fig 34: section 7) related to gallery 15B3. Yet antlers 56 and 57, as well as 10 others forming a concentration in this area (Longworth and Varndell 1996, fig 44), are recorded as originating from gallery 15C1 (Longworth and Varndell 1996, 97), although found in layers which should post-date it and hence would have been deposited after Pit 15 C had ceased to be worked. The obvious explanation is that their attribution to this gallery was spatial rather than stratigraphic, since they lay within gallery 15C1 although in fills post-dating the working of Pit 15 C. If this was the case, these antlers and those attributed to gallery 15B3 would belong to a single phase of activity.

Two of the relevant dates, for antlers 59 and 57, are modelled as *termini post quos* because not all PVA may have been removed from the samples (Figs 35 and 36: *SUERC-30905*, *-30906*).

Figure 35 shows a model for Pits 15 B and C which follows the published interpretation: that the working of Pit C preceded that of Pit B; that the fills of gallery 15C1 above the collapse were continuous with those of gallery 15B3; and that antlers 58 and 59 were successively overlain by antlers 56 and 57 (Fig 34). The model has extremely poor overall agreement (A_{model}: 15). The dates from gallery 15C2 (Fig 35: *60*, *BM-1054*) fall into poor individual agreement when constrained to be earlier than those from contexts overlying the Pit 15 C collapse; and the statistically consistent replicate measurements for antler 56 (Fig 35: *56*) fall into poor individual agreement when constrained to be later than the date for antler 58, apparently stratified below it (Fig 35: *OxA-23144*). Furthermore, even when SUERC-30905 is modelled as a *terminus post quem*, the measurements from the apparently continuous fills of gallery 15C1 above the Pit 15 C fill collapse of gallery 15B3 (Fig 35: *SUERC-28752*, *OxA-23111*, *47*, *56*, *BM-1053*; *30*) are statistically inconsistent (T'=36.8; T' (5%)=11.1; ν=5). Taken separately, however, the 15C1 and 15B3 groups are each statistically consistent (T'=2.2; T' (5%)=7.8; ν=3 for those from gallery 15C1 above the Pit 15 C fill collapse (Fig 35: *SUERC-28752*, *OxA-23111*, *47*, *56*), and T'=2.0; T' (5%)=3.8; ν=1 from those from gallery 15B3 (Fig 35: *30*, *BM-1053*).

The stratigraphy may call for reinterpretation. To take a simple point first, the section drawn through the junction of galleries 15C1 and 15C2 shows the basal fill of gallery 15C2 overlying the collapsed shaft fill of Pit 15 C (Fig 34: section 8; Longworth and Varndell 1996, fig 46: h). In other words, the gallery was filled after Pit 15 C had gone out of use, even if it was originally worked from that pit, so that the antlers from it relate to another pit. The gallery 15C2 antlers were indeed, however, stratified above antlers 58 and 59 which were sealed below the slumped shaft fill.

For galleries 15C1 and 15B3, interpretation is complicated by the fact that the longitudinal section through both (Fig 34: bottom) was constructed retrospectively from the transverse sections (Felder 1975a, 18). This may mean that the stratigraphy was less continuous than it appears. Furthermore, a transverse section across the west edge of gallery 15C2, the south end of gallery 15C1 and the east edge of gallery 15A2 (Fig 34: section 7) was published with reversed orientation (Longworth and Varndell 1996, fig 46: g), since the PFWGDGSLS plan of the antlers shown in the section places antlers 56 and 57 to the west of antlers 58 and 59 (Felder 1975c, 21), rather than to the east of them as in the published version. The relation between antlers 58 and 59, beneath the collapsed shaft fill, and 56 and 57, to the west of them, is unclear because there was a pillar of *in situ* chalk against which the layers containing 56 and 57 were butted. The transverse section showing all four antlers (Fig 34: section 7) compresses them into a single plane, and the longitudinal section achieves a schematic compromise between the east part of the gallery mouth, where there was slumped shaft fill overlying antlers 58 and 59, and the west part, where gallery fills containing antlers 56 and 57 butted against the *in situ* chalk.

Bearing in mind that antlers 56 and 57 (and, by chance, the other dated antlers attributed to gallery 15C1), lay in the western part of its fill, their relation to antlers 58 and 59 may not have been as direct as section 7 suggests.

The disparity between dates for antlers attributed to gallery 15C1 above the collapsed fill of Pit 15 C and for antlers attributed to gallery 15B3 (Fig 33), despite the apparent continuity of their fills, may reflect the introduction into 15C1, (mooted by PFWGDGSLS) of fills and antlers from gallery 15A2, which had a more direct connection to 15C1 than to 15B3 (Fig 29). Whatever their source, they represent a distinct, relatively early phase of mining in the area of the complex.

There are other problems, which may not affect the model. Antler 57 is drawn stratified above antler 56 (Fig 34: section 7) but is recorded as in layer III, 0.35m above floor while antler 56 is recorded as in layer IV, 0.8m above the floor. The heights may reflect measurement from different 'crawling floors'; and it is unclear how layers were counted. This remains an uncertain issue. Antler 59 was planned as a pick with one remaining tine (Felder 1975c, 21). But the implement labelled '59' which was sampled, was an antler crown with three points and a tine lower down the beam. It may be that the object was fully disengaged only after planning; it may also be that, in the course of the 30+ years which elapsed between excavation and sampling, the label had become attached to an object other than the original one. If this happened, it must have done soon after excavation, since a catalogue in the archive entitled 'Grime's Graves 1973 Antler Small Finds Pits 15 & 11', apparently compiled soon after the excavation, describes it as 'the upper part of the handle shaft, including the Trez tine, and two crown points, a third which probably bifurcated exists but was broken off in antiquity'. On balance, the implement sampled seems indeed to have been antler 59.

The relevant section of the main model (Fig 36) therefore incorporates the following premises:

- Antler 58 was earlier than the two dated antlers from gallery 15C2, which cannot relate to Pit 15C and are therefore disengaged from it.

- Antlers attributed to gallery 15C1 are modelled as part of a single phase, despite their attribution to numbered layers (Table 13). This is because of uncertainty as to whether layer numbers were maintained consistently from one transverse section to another. Since all the measurements are statistically consistent, as noted above, the single phase seems justified.

- No relationship is assumed between galleries 15C1 and 15B3, leading to uncertainty as to the continuity or otherwise and the source(s) of their fills.

All the dates are in good agreement with this interpretation. All the dates from samples attributed to the galleries of Pit 15 B are in agreement with their having been worked as part of a single phase of activity. The dated antlers from gallery 15B2 (Fig 36: *BM-1003*,

23) were two of five stacked together on the floor of the gallery near its mouth (ibid, 19–*23*) and must thus have been deliberately placed rather than incorporated in re-located rubble. The two measurements are statistically consistent (T'=2.5; T' (5%)=3.8; **v**=1), so that the stack may indeed have derived from a single episode of working.

This provides an estimated start date for the filling, possibly from gallery 15A2, of gallery 15C1 above the collapsed fill of Pit 15 C of *2650–2580 cal BC* (*95% probability*), probably *2635–2600 cal BC* (*68% probability*, Fig 36: *start gallery 15C1*). The estimated start date for the galleries of Pit 15 B is *2625–2495 cal BC* (*95% probability*), probably *2585–2525 cal BC* (*68% probability*, Fig 36: *start pit 15 B*).

4.4.11.3 Pits 15 D and 15 J

Five galleries were attributed to Pit 15 D (Fig 33). Toolmarks interpreted as those of a polished flint or stone axe were noted in gallery 15D2. Antlers were absent from gallery 15D3 and scarce in galleries 15D1 and 15D2 (Longworth and Varndell 1996, fig 44). This could be attributed to recent disturbance only in gallery 15D1, the others having been intact when entered in the 1970s. At least six bone picks were present, in galleries 15D1, 15D3, and 15D5. The two dated examples proved to be of mid-second millennium cal BC age, as other dated bone picks from the site (Fig 37: OxA-20759?, SUERC-24108?). It seems that this pit was re-opened and some of its galleries explored almost a millennium after its original excavation, raising the question of whether the 'axe' marks were in fact bone-pick marks. A second millennium cal BC date for charcoal from gallery 15D3 (Fig 37: BM-272?) must relate to this episode. Reopening a pit in this part of the field would be a less laborious undertaking than in the south-west of the area. These dates are excluded from the current model and the reuse of the pit is discussed in §4.6 below.

An antler pick (Fig 37: BM-1057) lying on the chalk floor across the boundary between galleries 15D2 and 15J1 (Felder 1975c, 45, V-V-II-3: 238; Longworth and Varndell 1996, fig 44) indicates that these two galleries were open together and presumably filled together, although it is uncertain from which pit. The four measurements on antlers from them are statistically consistent (T'=2.5; T' (5%)=7.8; **v**=3). BM-986, measured on a bulk charcoal sample, is excluded. The estimated start date for their working is *2570–2515 cal BC* (*21% probability*) or *2505–2420 cal BC* (*74% probability*), probably *2490–2435 cal BC* (*65% probability*, Fig 37: *start galleries 15D2 and 15 J1*).

Since it is unclear from which pit galleries 15D2 and 15J1 were filled, the dates from the two remaining galleries attributed to Pit 15 D (Fig 37: 15D1, 15D4) are modelled separately. In 15D4, BM-1262 is excluded because it was measured on a bulk charcoal sample and may be inaccurate for the reasons noted in §2.1.1.1 above. The remaining two dates, both on antler picks (Fig 37: *BM-1011*, *-1260*) fall in the twenty-sixth to twenty-fifth centuries cal BC and are statistically consistent with those from galleries 15D2 and 15J1 (T'=10.6; T' (5%)=11.1; **v**=5). Those from gallery 15D1, however, fall in the late-third millennium cal BC (Fig 37: 110?, BM-980?) and have very low individual indices of agreement when included in the model. They are therefore excluded from it. These two antlers were indeed *in situ*, since they were recorded as lying within undisturbed fill beneath a recently disturbed area and were arranged compactly and symmetrically with a third antler against a wall of the gallery, close to its junction with gallery 9 of Pit 15 (Felder 1975c, 45, fig V-V-11-3: 108, 109, 110; Longworth and Varndell 1996, fig 44). Their radiocarbon ages are also statistically consistent (T'=0.8; T' (5%)=3.8; **v**=1). This seems to have been an original placement made in the course of a late-third millennium mining episode. This is feasible because gallery 15D1 connected with a gallery driven from Pit 15 itself (Fig 33) and Pit 15 remains effectively undated (Fig 36).

4.4.12 ?Pit 15 K

The only remaining element of the complex for which a separate estimate can be made is the single gallery tentatively attributed to Pit 15 K (Fig 33), although possibly driven from Pit 15 C (Longworth and Varndell 1996, 59). Here, statistically consistent (T'=8.0; T' (5%)=9.5; **v**=4) measurements were made on five antlers, three of which were piled together with two at right-angles to the third (Felder 1976c, 14; Longworth and Varndell 1996, fig 44). These provide an estimated start date for the working of the gallery of *2580–2475 cal BC* (*95% probability*), probably *2575–2525 cal BC* (*68% probability*, Fig 37: *start pit 15 K*). The estimated end date is *2465–2380 cal BC* (*95% probability*), probably *2445–2400 cal BC* (*68% probability*, Fig 37: *abandon pit 15 K*). It remains possible that the gallery was driven from Pit 15 C, since the five determinations from it are statistically consistent with OxA-23144, the radiocarbon age of antler 58 and the only accurate date certainly related to Pit 15 C (T'=8.0; T' (5%)=11.1; **v**=5).

4.4.12.1 The remainder of the Pit 15 complex

A bulk charcoal date from the breach between galleries 15E1 and 15J1 is excluded (Fig 37: BM-971?). The remaining eight antler dates from the complex were measured on thinly scattered samples. Statistically consistent measurements for two antler picks on the floor of gallery 15F2 (T'=0.2; T' (5%)=3.8; **v**=1) combine with their location to suggest that they were used to extract flint from there (Fig 37: *BM-977*, *-1059*). Statistically consistent replicate measurements of *2630–2465 cal BC* (*95% probability*) on an antler from the edge of the fill of Pit 15 G 0.4m above its floor (Fig 37: *124*; Felder 1975c, 65, 80) are earlier than the date of *2470–2385 cal BC* (*95% probability*) for an antler pick on the floor of the butt end of gallery 15G1, which was clearly driven from the pit (Fig 37: BM-976; Felder 1975c, 65, 80). The earlier antler is unlikely to have been moved into the shaft base during the redistribution of spoil from previous workings, since it lay parallel to a second antler, as if the two had been deliberately placed (Felder 1975c, 65). The later antler in the gallery butt end may perhaps have been introduced into the gallery when a breach was made between it and gallery 15H3, the date of which is unknown (Fig 33).

4.4.13 Small cuttings through spoil heaps in the area of the galleried pits

The final component, 'extraction in area of deep shafts' (Fig 38) comprises five dates for samples from surfaces sealed beneath spoil heaps surrounding deep shafts which are thus *termini post quos* for their working. Trenches 2 and 3, two of six exploratory trenches dug in the 1970s through the inner edges of visible deep mines, located charcoal concentrations; in the case of trench 3 a hearth (Longworth *et al* 2012, 83–6). Both bulk charcoal dates (Fig 38: BM-1065?, -1066?) are excluded from the model for the reasons set out in §2.1.1.1 above. A horse skull stratified above the hearth in trench 3 is covered in §4.8.2 below. In the 1980s, three further dates were obtained from beneath spoil heaps in the area of Greenwell's Pit (Healy 1985). In retrospect, it is not possible to be sure from which of several nearby pits the spoil sealing them derived, so that they are modelled as *termini post quos* for mining in the area of the galleried pits. BM-2380, measured on an antler pick from beside a hearth where there was also a knapping floor, is probably contemporary with its context, while BM-2379 and -2377, on unidentified bulk samples of charcoal from this hearth and another, are probably older than their contexts although, given that they were measured in the 1980s, their accuracy is not questioned.

4.4.14 Overall results for the galleried pits

The preferred model indicates that the working of galleried pits began in *2665–2605 cal BC* (*95% probability*), probably in *2650–2620 cal BC* (*68% probability*, Figs 15 and 40: start galleried shafts) and ended in *2435–2360 cal BC* (*95% probability*), probably in *2420–2385 cal BC* (*68% probability*, Figs 15 and 40: *end galleried shafts*), having lasted *185–290 years* (*95% probability*), probably *205–255 years* (*68% probability*, Fig 41: *work galleried shafts*).

Some parts of the model are more satisfactory than others. The problems of reconciling dates and stratigraphy in the Greenwell's Pit and Pit 15 complexes reflect the movement of spoil into available spaces underground in densely mined areas where there are numerous connections between the galleries of different pits. Those pits which shared fewer and simpler connections with others are dated more satisfactorily, as the probability of spoil and implement redistribution during the working of other pits was lower. This applies, for example, to the 1971 Pit, the pit to the north-east of it, Pit 12 and Pit 14 (Figs 17, 18, 30, and 32).

The uniform bounded phase within which the dates from the galleried pits are modelled is in this case justified by the distribution of the dates. Figure 39 shows the sum of the probability distributions of all the dated events relating to the galleried pits which have been neither excluded nor modelled as *termini post quos*. There are very few dated events before the mid twenty-seventh century or after the turn of the twenty-fifth and twenty-fourth centuries cal BC. Within this period, dated events are distributed uniformly apart from a very slight peak in the first half of the twenty-fifth century cal BC.

A few dates may hint at working of the galleried pits before and/or after this period, either in unexplored parts of the site or on a smaller scale:

Statistically consistent measurements made in the 1960s (Barker and Makey 1963; Barker *et al* 1969b) for an antler from an unknown context in Pit 12 calibrate to 3270–2580 cal BC (95% confidence), which is exceptionally early for mining at the site. Statistically consistent determinations for implements from primary contexts show that, if the 1960s dates are accurate, the antler does not relate to the working of this pit, and the early date is modelled as a *terminus post quem* (Fig 30: BM-97 & -377). But, if the date is accurate, the antler may have been redeposited from earlier working in the vicinity. If so, it may relate to the Peterborough Ware redeposited in the upper fills of the pit.

At the other end of the spectrum, the two dated examples out of a group of three antlers apparently placed together at the junction of gallery 15D1 and gallery 9 of Pit 15 yielded statistically consistent measurements in the late third millennium cal BC. When these are modelled with other dates attributed to Pit 15D the model falls into poor agreement. They are therefore excluded from the model (Fig 37: BM-980?, 110?). The possibility remains, however, that gallery 15D1 was worked and/or filled later than the others, possibly from Pit 15 which remains undated.

Pit 12 and the Pit 15 complex both lie in areas where the floorstone is little more than 5m deep. Unexcavated Pit Y, on the other hand, lies in the south-east, only some 50m from Greenwell's Pit, where the floorstone was *c* 12m deep. A *terminus post quem* of *2465–2385 cal BC* (*95% probability*), is provided by the estimated end date for the 1972–74 knapping floor sealed by its upcast (Fig 19: *tpq pit Y*). In other words, the working of this deep shaft and, by implication, others, could have extended into the twenty-fourth century cal BC.

4.4.15 Alternative models for the galleried pits

There is unevenness in the current stock of dates for the galleried pits. Some of the most obvious are in spatial distribution; in intensity within particular complexes or single pits; in precision between those elements for which individual estimates have been made and those represented only by one or a couple of dates; and in precision between pre-existing measurements and those made in the course of this project. Uneven accuracy between these two groups is not a major problem where antler is concerned, on the evidence of replicate measurements (§2.2). The probable inaccuracy of pre-existing dates on bulk charcoal samples (§2.1.1.1) is dealt with by excluding them from the models.

The influence of some of these factors is explored in two alternative models, described in Table 15. Both retain, *mutatis mutandis*, the structure of the preferred model, shown in Figure 15, and, like it, exclude measurements made on bulk charcoal samples before the 1980s and treat SUERC dates on PVA'd bone or antler as *termini post quos* unless they are statistically consistent with determinations for the same antler from other laboratories or are statistically consistent with determinations from other laboratories for antlers apparently laid down together in the same group.

Alternative model 1 includes only those elements for which individual estimates have been made, that is those that have yielded four or more effective likelihoods at least three of which are not modelled as *termini post quos* (§4.2).

Alternative model 2 includes only measurements made during the current project, almost all of which have smaller errors than those obtained previously.

Although both alternatives comprise fewer effective likelihoods and fewer features than the preferred model, the results show increasing precision, most readily visible in the estimated durations (Table 15, Figs 40–1). This suggests that the estimates generated by the preferred model may be stretched by larger errors and scattered dates and that the true span is narrower.

This does not, however, account for the fact that the difference between the end dates estimated by the preferred model and by the model built solely of dates obtained during this project (Fig 40: *end galleried shafts, end galleried shafts this project*) is greater than that between the start dates. This asymmetry would not arise from the exclusion of less precise dates alone. It suggests that the wider spread of the total stock of dates for the galleried pits used in the preferred model may be more representative of these features as a whole.

4.4.16 The use-lives of individual elements

It has already been noted that the use-lives calculated by the preferred model for the 1971 pit and for Greenwell's Pit can be vastly greater than those indicated by resource estimates, the character of the archaeology and the scale of the features concerned, all of which point to a single season of working, even for the deepest shafts (§4.4.1.1; 4.4.3.2). Scale is significant here, since many of the elements for which durations have been estimated are single stretches of gallery of a few metres long. Estimated durations for these are even more disproportionately extended. This could be understandable where a gallery might have been used for access and/or spoil disposal during the successive working of adjacent pits, but it is implausible where a gallery lacked complex connections and where the radiocarbon measurements for antler implements from it are statistically consistent, as in the case of the excavated gallery of the Pit NE of the 1971 Pit (Fig 16).

Figure 44 and Table 16 summarise durations estimated by the preferred model for those elements for which individual estimates have been made, together with durations derived from modelling each element in an independent bounded phase (eg Fig 42), and from a model with the same structure as the preferred one in which dates for antlers from primary contexts in each element are simulated as identical, while retaining the errors of the original measurement (eg Fig 43).

Table 16 also summarises two indices of whether the dated antlers from an element could all derive from a single event, ie whether they could have been shed in the same year, and hence used and deposited in a single season. These are the results of χ^2 tests (Ward and Wilson 1978) on radiocarbon measurements for antlers from each element, where they have been neither excluded nor treated as *termini post quos* in the preferred model, and of the application to the corresponding highest posterior density intervals of the Combine function in OxCal. This combines posterior density functions which give independent information on a parameter, in this case the working of each element, and calculates a combination agreement index: A_{comb} which is used to test if distributions may indeed be combined, the acceptable threshold being $1/\sqrt{(2n)}$, so that the distributions may be combined if A_{comb} is equal to, or greater than, An.

In 10 cases out of 12 the antlers could all have been shed in the same year. The outstanding exception is formed by 11 antlers from Greenwell's Pit, where it is argued that some, or most, of the infilling of the galleries after Felder's stage 1, may have derived from adjacent pits (§4.3.2). Three antlers from Greenwell's Pit E are also clearly of different ages (Table 16).

These statistics are compatible with single-season working in almost every case. The durations estimated by the models are rarely so, although those derived from independent bounded phases are often the least long (Table 16, Fig 44). The shape of the calibration curve is a principal cause of this, compounded by the size of some of the errors. The breadth of the highest posterior density intervals, even when constrained in a bounded phase (Fig 42), or when the radiocarbon measurements are simulated as identical (Fig 43), is such as to preclude estimated spans of a few years, let alone a year.

4.5 Simple extraction pits and other activity on the West Field

Because relatively large areas, as distinct from individual features, were excavated on the West Field, traces of other activity in addition to quarrying were encountered. These took two main forms: knapping debris, mainly formed on flint from superficial deposits, and traces of occupation, however, brief, in the form of hearths and domestic debris. The structure of an overall model for the area is shown in Figure 45. Extraction pits and other activity not necessarily related to them are modelled independently, because it is by no means certain that they were coterminous. Both parts of the model have good overall agreement (A_{model} 99).

4.5.1 Simple extraction pits

Of the two large excavated areas, identified by their SW grid coordinates, 950/820 has provided almost all of the samples from extraction features (Figs 47 and 49). This imbalance reflects a dearth of potential samples from area 940/940 where some of the features were indeed extraction pits, certainly F101 and F141 and probably F122 and

F124 (Longworth *et al* 2012, 70–82), but even fewer were bottomed here (4 out of 46) than in 950/820 (13 out of 53; Longworth *et al* 2012, 44–6), so that the character of many of the features remains uncertain and suitable samples were not available.

Only two features, F6 and F7, yielded enough effective likelihoods to permit the calculation of individual estimates, employing the same criterion as for the galleried pits of four or more effective likelihoods, at least three of which are not *termini post quos*. The generally single pre-existing dates from individual features (Figs 47 and 49) contribute to the overall estimates for the start, end, and duration of quarrying here. There are totals of 32 dates for antler and four for charcoal (Table 17). Two of the bulk charcoal dates (Fig 49: BM-994? and -1023?) are excluded for the reasons discussed in §2.1.1.1 above, and BM-109, and -993 are excluded for reasons explained below. SUERC-25711 to -25713, and SUERC-25717 are modelled as *termini post quos* because not all PVA may have been extracted from them, as discussed in §2.1.1.2 above.

4.5.1.1 Pits excavated by Armstrong in 1924–1928

Armstrong's extensive trenching on the West Field led to the discovery of several simple, shallow pits, which had been invisible from the surface (Longworth *et al* 2012, 17–27), three of which were excavated.

Pit 8 lies some 45m north-west of cutting 950/820 (Fig 2). It was excavated by Armstrong in 1924 and 1928, proving to be of multilobate plan, 5.75m x 4m. It was sunk through superficial deposits to a depth of 2.1m, where niches were made to extract glacially disturbed floorstone which lay on the surface of the natural chalk. It did not extend to the *in situ* floorstone about 1m below and was connected by 'gangways' at floor level to two other, unexcavated, pits. Most of the retrieved picks were of antler, with several of bone (Armstrong 1924a, 191; 1932, 58–59, Longworth and Varndell 1996, 65–69).

A single date, spanning most of the second millennium cal BC, was measured in the 1960s on an unspecified antler sample from an unspecified context in the pit. When modelled with the rest of the dates from extraction contexts on the West Field it falls into extremely poor agreement and is excluded from the analysis (Fig 47: BM-109?). No other clearly contexted samples could be found from the pit. It is impossible to judge whether the late date of the sample reflects its post-dating the pit or the pit's belonging to the phase of second millennium cal BC mining discussed in §4.6 below.

Only one suitable sample could be found from Pit 9, a pit in many ways similar to Pit 8 excavated in 1927, and it was not considered enough to date the feature reliably. Here there were twice as many bone picks as antler ones, and the latter included roe deer antler (Armstrong 1932, 37; Longworth and Varndell 1996, 69–71).

Pit 10 lies between cuttings 950/820 and 940/940 (Fig 2). It was excavated by Armstrong in 1928 and was multilobate in plan, 4.5m x 5.2m across and 2.4m deep. Like Pit 8 it was sunk not into *in situ* chalk, but down to glacially disturbed floorstone, where niches had been cut. Towards the top were two successive 'floors' separated by sand, the upper of them immediately under topsoil. Two 'hearths' lay beneath the upper 'floor', in uncertain relation to the lower one. One bone pick was found, as well as several antler ones. Roe, as well as red deer antlers were used and one bone pick was recovered (Armstrong 1932, 58–9; Longworth and Varndell 1996, 69–73).

A single measurement was made on an antler sample in the 1960s (Fig 47: *BM-93*). Three further antler samples at or close to the base of the pit, were submitted to supplement this, but one unfortunately failed. The remaining two are in good agreement when modelled as part of a single phase with the original date (Fig 47: *SUERC-28749*, *-28750*) and place the working of the pit in the second half of the third millennium cal BC.

4.5.1.2 The area excavations of 1972–1976

Where they were bottomed, the extraction pits excavated in cuttings 950/820 and 940/940 were between 1.6m and 2.3m deep and were cut through superficial deposits rather than *in situ* chalk, the exceptions being F7, which may have been partly natural in origin, and F105, described in §4.6 below. Only F6 and F7, which yielded large enough suites of samples to permit individual estimates, are described in detail here. The contexts of the other dates are noted in Table 17. Five samples came from other than primary contexts in their features; this is denoted by '(upper fill)' or '(middle fill)' in Figures 47 and 49. They could, in other words, have entered the features some time after they had been worked, although in fact their exclusion (model not shown) makes no appreciable difference to the overall estimates.

F6 was an irregular pit *c* 7m across and 1.65m deep, of which the eastern half was excavated in 1973–4. Finds include flint axeheads, picks, and discoidal knives (Longworth *et al* 2012, 52–53). Layers were designated differently in the two seasons: by numbers in 1973 and simply LA or LB in 1974. The salient features were upper sandy deposits (LA in 1974, L1 and L2 in Fig 46) overlying a mass of variably compacted chalk lumps in a matrix composed of varying proportions of sand and chalk with flints (LB in 1974, L3 and L7 in Fig 46), within which were thin lenses of chalk and sand (L4–6 in Fig 46). The mass of the main fill suggests that it was tipped rather than silted (Fig 46) and correlation between the two notations is inexact. Furthermore, the numbered layers to which finds were attributed in 1973 do not equate to the numbered layers on the drawn section. L5 in the section is a fine sand lens some 50mm thick near the base of L3 (Fig 46). Yes finds recorded from L5 in 1973 included are seven antler picks, one antler crown, and three objects which could not have been accommodated by the thin sand lens drawn as L5. Furthermore the recorded depths of these finds vary by 0.7m, many times more than the depth of the lens. The discrepancy is confirmed by the 1973 finds book, in which all are recorded as from '5 chalk'. This indicates that they came from the main chalky fill, equivalent to L3 and L7 in Fig 46. The numbered layers to which finds were attributed in 1973 were those encountered as excavation proceeded and do not equate to the layers on the section which would have been distinguished as it was being drawn at the end of the 1974 season.

Dates for samples attributed to layers 4 and 5 in 1973 are therefore modelled as if those layers formed a descending sequence (Fig 47). The five measurements for antlers attributed to L5 are statistically consistent (T'=9.4; T' (5%)=9.5; **ν**=4), compatibly with their having been deposited in a single backfilling event, presumably immediately after the pit was worked, given that silts would soon have accumulated on its base in the unstable sands and tills through which it was cut. The one date for a sample attributed to LB in 1974 is kept outside the sequence because of uncertainty as to the precise correlation of the two layer notations, BM-3006 is also outside the sequence because its context within the pit is unknown. SUERC-25711 to -25713 are modelled as *termini post quos* because not all PVA may have been removed. The dates for antlers from apparently overlying layers are far more scattered (Fig 47); compatibly with these upper fills having accumulated more slowly and haphazardly. One date (Fig 47: BM-993?) is so recent as to be in poor agreement with the model and is excluded. The best estimate for the date of the infilling, and hence of the end of the working of the pit, is probably the latest date for the antlers in layer 5, *2550–2400 cal BC* (*89% probability*), probably *2530–2455 cal BC* (*68% probability*; Fig 47: end F6 L5).

F7 was oval in plan, measuring 2.3m x 3.2m at the top, tapering to 1m at its narrowest, then expanding at the base, and was 4.1m deep. Finds include flint axeheads, roughouts, and discoidal knives. F7 was unlike any other feature in the area, and has been seen as an exploratory shaft to test the presence or absence of useful flint, perhaps utilising a natural solution feature (Longworth *et al* 2012, 43, 52–3).

Only sketch sections were drawn (Fig 48). The stratigraphy recorded in 1974, when excavation resumed about halfway down the pit, consisted of LA, orange gravel with sand and a chalk lens (L8 in Fig 48); LB, fine chalk-sand fill with flints, including tip lines (L9 in Fig 48); and LC, 'compacted chalk fill, rotted, at base of pit' (L10 in Fig 48). The 1974 site note book makes it clear that LC indeed contained several antler implements, so that it may have been more substantial than it appears in the sketch. Alternatively, antlers on the base of the pit may have been attributed to the lowest layer even if they projected above it.

Radiocarbon determinations were obtained for six antlers from LC, of these, SUERC-25717 is modelled as a *terminus post quem* because not all PVA may have been removed from it. The remaining five are statistically inconsistent (T'=26.5; T'(5%)=9.5; **ν**=4), and have a span of *120–425 years* (*95% probability*), probably *200–360 years* (*68% probability*; *duration F7 LC*, distribution not shown). It is difficult to imagine that they were placed in the pit base over such a long period, since such a narrow feature would have infilled rapidly from the loose, unstable surface deposits surrounding it. The fills may have included implements derived from previous quarrying in the immediate area, if so, the best estimate for their placement, and hence for the end of the working of the pit, is probably the estimated date for the latest antler on the pit base, *2410–2190 cal BC* (*89% probability*), probably *2330–2200 cal BC* (*68% probability*, Fig 49: *end F7 LC*). From the dates for samples from LA (L8 in Fig 48), if a pair of statistically consistent replicates on an antler pick (Fig 49: *GG74 136*) is modelled as later than the LC dates it both falls into poor individual agreement (A: 2) and throws the model for the West Field into poor overall agreement (A_{model}: 20). The antler (*GG74 136)* is therefore modelled as a *terminus post quem* for its context, as it may derive from earlier working elsewhere, introduced during backfilling. A bulk charcoal date from the same context is excluded because it may be inaccurately recent (Fig 49: BM-994?).

F105 in cutting 940/940 is dealt with in §4.6 below.

BM-3135, measured in the 1990s with improved pretreatment methods on a sample of pine charcoal, which is short-lived, provides a reliable date for a hearth lit in the top of F124, in 940/940 (Longworth *et al* 2012, 81), after it was infilled. The same consideration extends to BM-1034, previously measured on charcoal from the same hearth, since the two measurements are statistically consistent. They are therefore modelled as *termini ante quos* for the working of the pit (Fig 49). They do not provide a *terminus post quem* for pit F101, which cut F124, since drawings in the archive show that the hearth was fsr from the intersection and could have been made and used after the cutting of F101.

Overall estimates for the working of simple pits on the West Field indicate a start date of *2670–2500 cal BC* (*95% probability*), probably *2615–2520 cal BC* (*68% probability*, Fig 50: *start simple pits on West Field*), an end date of *2185–1995 cal BC* (*95% probability*), probably *2155–2055 cal BC* (*68% probability*, Fig 50: *end simple pits on West Field*), with a duration of *335–570 years* (*95% probability*), probably *370–500 years* (*68% probability*, Fig 64: *work simple pits on West Field*). Further support for quarrying to the end of the third millennium cal BC may be provided by two antler implements dated to the turn of the third and second millennia which were found redeposited in a mid-second millennium feature F105 (Fig 51: *BM-1061*, *-3134*).

4.5.2 Activity on the West Field not necessarily associated with mining

4.5.2.1 Flint knapping

Knapping debris was often associated with extraction features or sealed beneath upcast from them and hence attributable to the period of their working. Such activity is represented by some of the dates in Figure 47 (BM-992 and -3119 from F5, BM-1017 from F16, BM-1023? from F18). Other knapping debris was not sealed by upcast from pits, and could thus reflect scavenging of pre-existing spoil heaps after the pits had ceased to be dug. Even antler picks could have been used for scavenging as well as for primary extraction. The relevant dates, all pre-existing, are shown in Figure 50. Most were measured on unidentified bulk charcoal samples, leaving only a few which can be interpreted with confidence.

On the slender basis of three antler samples from knapping deposits (Fig 50: *BM-812*, -*1012*, *-1018*), it is possible to suggest a start date of *2150–1975 cal BC* (*91% probability*), probably *2130–2030 cal BC* (*68% probability*, Fig 50: *start West Field knapping*) and an end date of *1915–1605 cal BC* (*95% probability*), probably *1885–1840 cal BC* (*28% probability*) or *1815–1805 cal BC* (*2% probability*) or *1770–1660 cal BC* (*38% probability*, Fig 50: end West Field knapping). In other words flint-working at the West Field extended into the second millennium cal BC.

4.5.2.2 Miscellaneous activity

Domestic-type deposits (Fig 50) yielded only three dates which are not excluded because of potential inaccuracy (Fig 50: *BM-1019*, *-1034*, *-3135*). The last two, from a hearth at the top of F124, are cross-referenced from the first element of the model, where they are used as *termini ante quos* for the pit. Here they are used as dates for the hearth and the occupation which generated it. On this exiguous foundation, it is possible to suggest a start date of *2240–2040 cal BC* (*90% probability*), probably *2205–2120 cal BC* (*50% probability*) or *2100–2060 cal BC* (*18% probability*, Fig 50: *start West Field miscellaneous*) and an end date of *2080–1865 cal BC* (*90% probability*), probably *1985–1890 cal BC* (*57% probability*); Fig 50: *end West Field miscellaneous*).

When all the dates, including the excluded ones, are considered, there is a contrast between the two main cuttings on the West Field. Of three dates from cutting 950/820, one falls in the mid third millennium cal BC and two span the last quarter of the third and the first quarter of the second (Fig. 50: BM-1005?, -*1019*, -1022?). Of five dates from cutting 940/940, only the two from the hearth in the top of F124 fall in the later third millennium cal BC (Fig. 50: *BM-1035*, *-3134*), the remaining three spanning the whole of the second millennium (Fig. 50: BM-1031?, -1032? -1033?). While all the dates apart from *BM-1019, -1035* and *-3134* may be too recent for the reasons noted in §2.1.1.1 above, the concentration of second millennium dates in 940/940 suggests that they may reflect second millennium activity. This impression is reinforced by the fact that most of the small total of Collared Urn sherds from the site come from this cutting: from the top of F105; from hollow F108, with occupation material, including the charcoal dated by BM-1031; from a knapping deposit in the top of F112 and in an underlying layer which contained the sample for BM-1032; and from a hollow successively overlain by chalk rubble and knapping debris in F114 (Longworth et al 1988, 23–4; Longworth *et al* 2012, 66–79). It is further reinforced by the mid second millennium date of flint extraction in F105 (§4.6.4 below).

4.6 'Primitive' pits and Pit 15 D

The 'primitive' Pits had yielded only three dates before the current project, all measured on antler samples. One, from Pit 3 A in the north of the site, fell in the second half of the third millennium cal BC (Fig 51: *BM-1060*). Two, from F105 on the West Field fell in the late third to early second millennium cal BC (Fig 51: *BM-1061* and *-3134*). F105 was consequently seen as part of the general working of simple pits on the West Field, although it was deeper and more elaborate than those around it, being identical to the previously identified 'primitive' pits in its form, size, and two-stage working.

An attempt to date the 'primitive' pits more fully showed that the bone picks, which characterise them (as described in §6.0) are of mid-second millennium cal BC date, like those from a gallery of Pit 15 D which had been reopened in the second millennium, as described in §4.4.11.3 above. The bone picks, are indubitably mining implements as chalk often remains in the medullary cavities at the working end which would have been driven into the walls of the pits, and many have split longitudinally under pressure. They were also indubitably used in the primary working of the pits, since, in Pit 3 A and F105, where precise contexts are recorded, some of them occurred in undercuts at the bases (Table 19). Chalk fragments from Pit 3A and F105 held in the British Museum carry tool marks noticeably broader and flatter than those made by antler picks.

Figure 51 defines the model for these features in which BM-1060, -1061 and -3134 are all modelled as *termini post quos*, as they are so much earlier than the bone picks that they must have been redeposited. The same applies to SUERC-25719 and OxA-21192, two additional dates on antler samples obtained in the course of this project. SUERC dates on PVA'd bone or antler samples are also modelled as *termini post quos* unless they are statistically consistent with replicates on the same samples by another laboratory or are statistically consistent with others from the same context, because, as discussed above, not all PVA may have been extracted from them. The model has good overall agreement (A_{model} 100).

Consolidants are particularly prevalent here, since the pits and their implements have long been seen as of particular interest and therefore overly conserved. Among the bone picks only those from Pit 15 D were totally untreated, because they had gone unrecognised. The bone picks from the pits excavated by Armstrong have been out of the ground since the 1920s so that, while it is possible to see that they have been consolidated, it is difficult to tell when or with what.

4.6.1 The Pit 3 complex

Pit 3, *c* 4.1m across and 5m deep, seemed, when excavated in 1923, to have had undercuts at the level of the floorstone and a platform left at a higher level to allow access (Armstrong 1923). When it was re-excavated in 1976 the 'step' proved to be part of a series of undercuts made at depth of *c* 2m into cryoturbated chalk which overlay the *in situ* chalk. From this level, half of the pit was taken down to floorstone, where the undercuts noted by Armstrong were made (Fig 52; Longworth and Varndell 1996, 35–6, figs 30–3). Pit 3 A, less than 2m from Pit 3, was worked in the same way. A trampled surface between Pit 3A and unexcavated Pit 3B at the top of the solid chalk showed that they were worked together (Fig 53). Pit 3 A was also conjoined with unexcavated Pit 3 C (Longworth and Varndell 1996, 39–45, figs 32–6).

A bone pick from Pit 3 (Fig 55: A96), two from the lower-level undercuts in Pit 3 A, and one from the upper-level undercuts in the same pit all date to the mid-second millennium cal BC (Fig 51: *OxA-22528*, *SUERC-28743*, *SUERC-24126*, *GG76 pit 3A sf 46*). A pre-existing date on an antler pick and a newly-obtained date on another, both from one of the upper-level undercuts, fall in the third millennium cal BC and are modelled as *termini post quos* for the working of the pit, since they must have been redeposited in backfill (Fig 51: *BM-1060*, *SUERC-25719*). Not all PVA may have been extracted from the sample for SUERC-25719 which is distinctly early for mining activity at the site.

4.6.2 Other 'primitive' pits excavated by Armstrong

The Pit 3 complex formed part of a group of similar features (Pits 4 to 7, excavated in 1923–4, and Pit 13, excavated in 1934), all worked with bone picks, lying within 30m of each other on the south side of the dry valley to the north of the visible pits (Armstrong 1923, 115–119; 1927, 101–103; Longworth and Varndell 1996, 63–5, 73).

Further bone picks from on or near the bases of Pits 4 (Fig 51: *OxA-22530*, *SUERC-28747*) and 6 (Fig 51: *OxA-22531*, *SUERC-28748*) also date to the mid second millennium cal BC, those from Pit 4 being statistically consistent (T'=0.1; T'(5%)=3.8; v=1).

4.6.3 Pit 15 D and its galleries

Two further mid second millennium cal BC dates were obtained for bone picks from gallery 15D3 of Pit 15 D (Fig 51: *OxA-20759*, *SUERC-24108*). These are two out of at least six bone picks recovered from the pit. BM-972, a bulk charcoal date from the same gallery spanning most of the second millennium cal BC and part of the first, is excluded because it may be too recent for reasons noted in §2.1.1.1 above. Its sample must, however, have included charcoal relating to this episode. In this case, there is no question of the pit's having been initiated in the second millennium cal BC, since antler picks from galleries 15D1, 15D2, and 15D4 are consistently of third millennium cal BC date (Fig 37), and the dated examples are only six among many (Longworth and Varndell 1996, fig 44). The distribution of the bone picks is informative. One (find 256) was on the shaft floor in the entrance to gallery 15D1; another (find 1502) was *c* 0.5m to the north, in the mouth of the gallery. A third (find 1503) was in the same gallery but not plotted; the consecutive find number suggests that it may have been close to 1502. In gallery 15D3, find 250, dated by OxA-20759, lay near the mouth and find 251, dated by SUERC-24108, *c* 1m farther south within the gallery. All but 1503 are among the finds plotted by Felder (1976c, 17). This pattern would be consistent with the reopening of the shaft a millennium after its original excavation, followed by at least partial exploration of its galleries. In these circumstances, marks in gallery 15D2, interpreted as those made by a polished flint or stone axe (Longworth and Varndell 1996, 59) may have been made by bone picks. The pit's depth of 5–6m would have made its reopening less of a challenge than the 12m deep pits at the other side of the field.

4.6.4 F105

This feature (Fig 54) in cutting 940/940 on the West Field had all the characteristics of the 'primitive' pits in the north of the site. It was 4.55m wide and 4.7m deep, with undercuts at two levels. The first (II, V, VI) bottoming on *in situ* chalk, the second (III, IV) at the level of the floorstone (Longworth *et al* 2012, 72–6). Four bone picks from the larger of the lower undercuts (III) yielded statistically consistent (T'=2.8; T' (5%)=7.8; ν=3) mid second millennium cal BC ages (Fig 51: *OxA-20720*, *OxA-20591*, *SUERC-24121*, *SUERC-24122*).

A mid third millennium cal BC antler crown (Fig 51: *OxA-21192*) stratified above these in the middle fill (Fig 54: layer 44) must have been incorporated during backfilling. The taphonomy of two late third/early second millennium cal BC antler samples (Fig 51: *BM-1061*, *-3134*) from layer 39 is more uncertain. A solid line dividing layers 38, 39 and 40, to the east from layers 18, 35, and 41 to the west on the original field drawing is reproduced in the published version (Fig 54). It seems, however, to run across natural silting lines, suggesting that it did not represent a cut. In this case, the antler samples from layer 39 would have been stratified above the later samples in the base of the feature and would have been redeposited in its upper fill. Alternatively, if the solid line did indeed represent a cut, then layer 39 would have been a fill of another feature, predating F105. In either case the antler samples would have predated F105 and are therefore, like the antler from layer 44, is modelled as *termini post quos* for it.

The model shown in Figure 51 estimates the start date for this episode of mining as *1625–1505 cal BC* (*95% probability*), probably *1580–1515 cal BC* (*68% probability*, Fig 51: *start 'primitive' pits and gallery 15D3*), its end date as *1515–1410 cal BC* (*95% probability*), probably *1495–1435 cal BC* (*68% probability*, Fig 51: *end 'primitive' pits and gallery 15D3*), and its duration as *5–160 years* (*95% probability*), probably *35–120 years* (*68% probability*, Fig 51: *work 'primitive' pits and gallery 15D3*).

The way in which these pits were mined to some extent recalls the working of Pit 8, which ended at a depth of 7ft (just over 2m) in a series of undercuts bottoming on the top of the *in situ* chalk, without penetrating into it, and was joined to two further, unexcavated pits by 'gangways' at this level (Longworth and Varndell 1996, 65, figs 54–5). This suggests that the single pre-existing date from this pit (Fig 47: BM-109?), which spans most of the second millennium cal BC and is so late as to be in poor agreement with the model for simple pits on the West Field, may reflect working of comparable age to the dated 'primitive' pits.

The sample for BM-109 was antler, although a minority of the picks found in Pit 8 were of bone (Armstrong 1932, 59; Longworth and Varndell 1996, 65). While bone picks characterised the second millennium cal BC pits - they were the only kind found in Pits 3, 4, 5, 6, 7, and 13 (Longworth and Varndell 1996, 39, 63–5, 73), and there is no reason other than cultural choice why antler should not also have been used. Furthermore, some bone picks seem to have come from earlier contexts. Among the more convincing examples are those from niche 3 at the base of Pit 14 (Longworth and Varndell 1996, 73), a pit where nine antler implements yielded statistically consistent measurements in the twenty-sixth or early twenty-fifth century cal BC (Fig 32). Similarly, there was one bone pick among the 15 antler examples from the galleries of Pit 12 (Longworth and Varndell 1996, 73), also of twenty-sixth or early twenty-fifth century cal BC date (Fig 30). The late exploration of earlier pits, as in Pit 15 D, cannot be excluded. The contexts of a further bone pick from the shaft of Pit 12, some examples from Pit 10, and from the undated Pit 9, remain unclear.

The connection of Pit 3 A to Pits 3 B and 3 C and of Pit 8 to two adjoining pits at the level of the top of the solid chalk is part of a more widespread practice. The 1995 RCHME survey recorded several instances of three or more relatively narrow shafts set in the base of a single continuous quarry (Barber *et al* 1999, 41; 2000, 12–5, 24, 26–7). This may reflect a method adopted at various times in areas where the floorstone was relatively close to the surface. It might alternatively be an index of the extent of mining in the second millennium cal BC.

4.7 Middens

Dark, midden-like deposits rich in middle Bronze Age material (eg Fig 56) have been found in the tops of several infilled galleried pits, always by accident, becuase they have no surface signature, due to the spoil heaps surrounding each of the pits in question having been flattened. They are concentrated in the east and south-east of the site, the most fully explored being Armstrong's 'Black Hole' (Armstrong 1924a; 1927), the 1972 Pit (Mercer 1981), and Pit X (Longworth *et al* 1988; 1991). The quantity of middle Bronze Age pottery from the site, over 8000 sherds, against approximately 500 sherds from all periods of the Neolithic and early Bronze Age, and just over 200 from the late Bronze/early Iron Age (Longworth 1981; Longworth *et al* 1988 12–25; Rigby 1988, 102; additions from the West Field noted by Longworth *et al* 2012, 184), emphasises the difference in character between this activity and any that took place on the site before or after. The quantities of animal bone from these contexts similarly dwarf any from previous periods (Legge 1981; 1992). Articulated or articulating samples were, however, difficult to find, perhaps because the carcases had been thoroughly reduced and consumed, or perhaps because the deposits had been redeposited from their original locations.

The 14 pre-existing dates for these deposits are all on bulk charcoal samples. As Longworth and Herne point out (1991), the samples for BM-1041 and -1263 must have included redeposited Neolithic charcoal, and the dates from Pit X do not conform to the upward stratigraphic sequence of midden group III, blown sand C1, and midden group II. This could partly reflect the fact that the material was tipped into the pit top (Longworth and Herne 1991, 17–8), presumably from pre-existing deposits, so that the sequence in which the material was finally buried may not reflect its age. As elsewhere on the site, there is the possibility that some bulk charcoal dates may be too recent. Needham's ascription to the later part of the Taunton phase or to the Penard phase of spearheads cast in moulds, of which fragments occurred in the Pit X deposits (1991, 158) would point to a date in the fourteenth to eleventh centuries cal BC (Needham *et al* 1997, 77–80), rather earlier than the latest of the bulk charcoal dates (Figs 58–9).

Ten further samples, nine of carbonised residue from sherds and one of articulating animal bone, were dated from midden deposits, and one, of articulating animal bone, from an immediately pre-midden deposit in the top of Pit X. Six of the carbonised residue samples were replicated, the results for each set being statistically consistent except for a pair from the Black Hole (T'=49.4; T'(5%)=3.8; **v**=1). In this case, the older date, which is in poor agreement with the model, is excluded (Fig 59: OxA-22434?) and the more recent one retained (Fig 59: *SUERC-28758*). Once OxA-22434 is dismissed, the results for all ten new samples from the middens are statistically consistent, irrespective of whether they came from the Black Hole, the 1972 Pit or Pit X, and irrespective of their stratigraphic position in the 1972 Pit and Pit X sequences (T'=15.3; T'(5%)=16.9; **v**=9). This accords with the homogeneity of the pottery assemblages and with evidence for effectively single-episode deposition in the dispersal of sherds of the same vessel through the depth of the Black Hole and the even distribution of morphological traits through the deposits in Pit X (Ellison 1988).

Figure 57 shows the overall structure of a model for these features. Because there is one effective likelihood from pre-midden contexts in the top of Pit X, the sequence for this pit is modelled separately (Fig 58), before the estimates for the start and end of the Pit X middens are cross-referenced into a phase which incorporates the other two features (Fig 59). The estimated dates relate to the generation of the material, when the pots were used and broken and when animals were slaughtered and butchered, rather than to its deposition. Based on 11 effective likelihoods and excluding all the bulk charcoal dates, the model indicates a start date of *1450–1320 cal BC* (*95% probability*), probably *1425-1380 cal BC* (*59% probability*, Fig: 59: *start middens*); and an end date of *1395–1260 cal BC* (*95% probability*), probably *1385–1345 cal BC* (*37% probability*) or *1335–1300 cal BC* (*31% probability*, Fig 59: *end middens*); with a period of a generation of *0–160 years* (*95% probability*), probably *0–70 years* (*68% probability*), with most of the probability at the shorter end of the span; Fig 65: generate middens). Some elements of the middens may have been deposited considerably later, given small quantities of late Bronze/early Iron Age pottery in shaft X and the Black Hole (Rigby 1988), although the restricted distribution of examples from the Black Hole suggests that they may have come from an unrecognised pit cut into the earlier deposits (Longworth *et al* 1988, 31). The dated middle Bronze Age sherds represent the overwhelming mass of material in the middens. The bimodality of the estimated start date reflects wiggles in the calibration curve for the fourteenth century cal BC (Fig 60).

4.8 Later activity

4.8.1 The upper levels of the 1971 Pit

The upper fills here were very different from the midden deposits in the 1972 Pit less than 25m away, consisting of a series of semi-concreted chalky silts collectively labelled layer 1B (compare Figures 56 and 61; Mercer 1981, 16–8). Since they contained middle Bronze Age sherds, like those from the midden deposits, two articulating animal bone samples from layer 1B were dated in the expectation that the results would refine the chronology of the occupation represented thinly at the surface to the east and substantially in the top of the 1972 Pit. Two replicate samples from a horse radius articulating with an ulna, however, yielded statistically inconsistent results, one in the late second millennium cal BC, the other in the early first millennium (OxA-20760, SUERC-24109; T'=13.5; T'(5%)=3.8; **ν**=1), OxA-20760 being the older. Three further replicates were measured (SUERC-25612, OxA-21156, and SUERC-25613). In addition, ORAU undertook a re-combustion of the original pretreatment for OxA-20760, obtaining an age of 2776±27 BP rather than the original 2911±28 BP, concluding that OxA-20760 could certainly be rejected as an erroneous measurement (email from Christopher Bronk Ramsey to John Meadows 26/10/09). Once OxA-20760 is excluded, the remaining four results are statistically consistent (T'=4.2; T'(5%)=7.8; **ν**=3). The date is *940–840 cal BC* (*89% probability*, (Fig 62: *GG71 119*). The second articulating bone sample also falls in the early first millennium cal BC (Fig 62: *OxA-20761*). The middle Bronze Age sherds seem to have been redeposited here, perhaps silting in from the adjacent surface.

Cut into the 1B deposits was the articulated skeleton of a young woman, her feet resting on an area of *in situ* burning which provided a bulk charcoal sample dated by BM-780 (Mercer 1981, 16–8). This date is excluded from the model because of potential inaccuracy, as explained in §2.1.1.1 above. The woman herself had died in or after *390–190 cal BC* (*95% probability*), probably *370–340 cal BC* (*13% probability*) or *330–270 cal BC* (*26% probability*) or *260–200 cal BC* (*29% probability*, Fig 62: *SUERC-28753*). This date, having been measured by SUERC on a sample treated with PVA, is modelled as a *terminus post quem*. Her upper body was cut away by the insertion of a second burial, that of a young man who had died in *210–50 cal BC* (*93% probability*), probably in *200–150 cal BC* (*49% probability*) or *140–110 cal BC* (*19% probability*, Fig 62: *OxA-22533*). An iron ring bead beneath his mandible and another beneath the base of his skull were the only certain grave goods; an incised chalk plaque by the hip of the earlier burial (Mercer 1981, pl. VII) may perhaps derive from a Neolithic context.

4.8.2 The trench 3 horse skull

A horse skull was found during the cutting of an exploratory trench through the upcast surrounding an unexcavated pit among the galleried shafts. It was almost certainly cut into the spoil, although the narrowness of the cutting in which it was found made certainty difficult (Longworth *et al* 2012, 84–6). The date of 2870–1610 cal BC (95% confidence; BM-1546; 3740±210 BP) initially obtained for the skull made it appear significant for the adoption of domesticated horse in Britain (Clutton-Brock and Burleigh 1991). However, a further sample submitted for AMS dating in the 1980s yielded a late Iron Age or Romano-British date of cal AD 30–380 (95% confidence; OxA-1635; 1820±70 BP 18; Higham *et al* 2007). In 2009, members of the present project were unaware that this second date had been obtained and the apparent inherent interest of the skull prompted the submission of a further sample. The result of 1930±29 BP (OxA-21193) is statistically consistent with the pre-existing AMS measurement (OxA-1635; T'=2.1; T'(5%)=3.8; ν=1), the weighted mean of the two calibrating to cal AD 30–130 (95% confidence; Fig 63: ARC 79 5017). A possible reason for the discrepancy is noted in §2.2 above. The inaccuracy of BM-1546 becomes all the more probable in that contextual scrutiny and radiocarbon dating increasingly suggest that there is little or no evidence for horse in Britain between the early Holocene and the second millennium cal BC (Bendrey 2010; 2012; Bendrey *et al* 2013).

4.8.3 Remaining radiocarbon determinations

A date of 810–540 cal BC (95% confidence; 2559±80 BP; BM-1067,) was obtained for an unidentified animal bone from the top of unexcavated feature F123 on the West Field (Longworth *et al* 2012, 81). A date of AD 1280–1955* (95% confidence; 313±200 BP; BM-779) was obtained for oak apples from beneath the upcast surrounding the 1971 Pit. Since the spoilheap was penetrated by animal and root holes, the oak apples may perhaps have been cached by a squirrel.

5.0 ANSWERING THE ORIGINAL QUESTIONS

What follows is written in full consciousness that the unexcavated majority of site undoubtedly holds surprises. Many of the questions posed at the start of the project have been answered, the results for the more limited and straightforward ones are summarised in Table 22. This leaves the major questions:

- What was the timespan of flint mining at the site?
- Was there, as the pre-existing dates suggested, a difference in periods of use between the area of deep mines and the West Field?
- Over what period was the northern area worked?
- What was the probable labour input at any one time?
- How did the emergence of the site relate to the introduction of metal-working?
- Could the chronology of the Bronze Age occupation be refined and extended to so far undated areas?
- Could the use of the site be related more precisely to the settlement of the surrounding area?

Figures 64–5 and Table 23 summarise the dating and duration of the main episodes of activity on the site. The alternative approach of MCMC analysis confirms that the sequence start galleried shafts < start simple pits on West Field < end galleried shafts < end simple pits on West Field < start primitive pits and gallery 15D3 < start middens is 84% probable.

5.1 The timespan of flint mining, including the use of the West Field and the northern area

5.1.1 The galleried pits

According to the preferred model, galleried pits began to be sunk to the floorstone in *2665–2605 cal BC* (*95% probability*), probably in *2650–2620 cal BC* (*68% probability*, Fig 64: *start galleried shafts*). This method of mining continued for *185–290 years* (*95% probability*, (Fig 65: *work galleried shafts*). It continued until *2435–2360 cal BC* (*95% probability*), probably *2420–2385 cal BC* (*68% probability*, Fig 64: *end galleried shafts*). It is significant that these estimates for the galleried pits are a refinement, rather than a revision, of pre-existing ones (Table 23). The inclusion of five previously undated pits (Pit to the north-east of the 1971 Pit, Greenwell's Pit D, Greenwell's Pit E, Pit 14 and Pit 15

K) has confirmed rather than expanded the chronology. Even Pit 12, potentially anomalous on the evidence of its two pre-existing dates, is now within the span of the rest (Fig 67). Pits 12 and 14, indeed, are both spatially well-removed from other dated galleried pits (Fig 2), suggesting that this time span might apply to all the deep mines. Pit 14 shows for the first time that there was mining in the north of the area contemporary with the working of the galleried pits elsewhere (Fig 67).

Figure 67 and Tables 25–6 show the order in which the pits for which individual estimates have been made were initiated. A point which was not apparent before is that the earliest galleried pits include some of the deepest. The 1971 Pit, the Pit to the north-east of it and Greenwell's Pit were all sunk in the twenty-seventh century cal BC. The 1971 Pit cannot have been the earliest because a dense, floorstone-based knapping deposit was sealed beneath the upcast at its west edge (Mercer 1981, 14; Saville 1981, 32–5). The position of Greenwell's Pit among the earlier features is secure because, although dates from it span an extended period (Fig 23, Table 8), those from stage 1 of Felder's scheme (Fig 24) are statistically consistent and place its inception in the twenty-seventh century (Fig 25).

It is also clear that choice of pit location did not reflect any simple progress across the area. While most of the early galleried pits were in the east, where the floorstone is up to 12m deep, the dated antlers from gallery 15C1, possibly derived from gallery 15A2, indicate coeval mining 200-odd metres away to the north where floorstone is less than a third as deep. Continued mining to the east and south is evidenced by the twenty-sixth century date of Greenwell's Pit C, the twenty-sixth or twenty-fifth century date of Greenwell's Pit A, the longevity of the 1972–4 knapping floor, and the late twenty-fifth century *terminus post quem* which it provides for Pit Y, only 50m from the Greenwell complex (Fig 67: *tpq pit Y*).

Locations also appear to have been revisited after substantial intervals. The estimated interval between the start dates for Greenwell's Pit and Greenwell's Pit A, for example, is *35–165 years* (*95% probability*, *start Greenwell/start Greenwell A*, distribution not shown), while that between the start dates for gallery 15C1 and conjoined galleries 15D2 and 15J1 is *45–205 years* (*95% probability*, *start 15C1/start 15D2 & J1*, distribution not shown). This could reflect the opportunistic selection of remaining spaces by successive generations as shafts proliferated. It could also reflect connections between particular social groups and particular parts of the site to which they returned periodically. There may also be a hint of this in the antlers from Pits 11A to H, which included a number possibly shed by a single stag over a number of years, so that they may have been collected in a single area (Clutton-Brock 1984, 38–9).

5.1.2 Simple pits on the West Field

Estimates for extraction from simple pits on the West Field, generally of flint from superficial deposits, are less precise because they are based on far fewer effective likelihoods. There is, however, no hint of a progression from the working of shallower, more accessible deposits to deeper, far less accessible ones. It is 88% probable (Table 23) that quarrying on the West Field began after the sinking of the first deep shafts to the east, the estimated interval between the two being *−40 to +140 years* (*95% probability*), probably *20–110 years* (*68% probability*, Fig 66: *start galleried/start simple*).

On the available evidence, it seems that the considerable expertise needed to work the deepest and most challenging deposits on the site was imported and applied from the onset. There is no hint of any progressive development from shallower, simpler workings to deeper and more complex ones.

Simple pits did, however, continue to be sunk much later, up to *2185–1995 cal BC* (*95% probability*), probably to *2155–2055 cal BC* (*68% probability*, Fig 64: *end simple pits on West Field*). They continued to be worked for *335–570 years* (*95% probability*), probably *370–500 years* (*68% probability*, Fig 65: *work simple pits on West Field*). This may even be an underestimate. The pre-existing dates document knapping and ephemeral settlement on the West Field well into the second millennium cal BC (Figs 50 and 64) and bulk charcoal dates, excluded for reasons discussed in §2.1.1.1, could take these activities later yet (Fig 50). Whether or not quarrying continued, squatting and scavenging may have persisted. With these reservations, the working of simple pits on the West Field outlasted that of the galleried pits by at least *105–415 years* (*95% probability*), probably *245–350 years* (*68% probability*, Fig 66: *end galleried/end simple*).

5.1.3 'Primitive' pits and Pit 15 D

With the same reservations, the working of simple pits on the West Field may have ended some time before the 'primitive' pits and parts of Pit 15 D began: *420–650 years* (*95% probability*), probably *490–610 years* (*68% probability*, Fig 66: *end simple/start 'primitive'*). This second millennium cal BC mining episode was unsuspected before this project began and encompasses distinctive pits in the north of the area, near Pit 14, and on the West Field as well as the re-opening of Pit 15 D in the north-west. The dating of these features places Armstrong's 'primitive pits' at the end of mining on the site rather than at the beginning. They started to be worked in *1625–1500 cal BC* (*95% probability*), probably in *1575–1515 cal BC* (*68% probability*, Fig 64: *start 'primitive' pits and gallery 15D3*), lasting for *5–160 years* (*95% probability*), probably *35–120 years* (*68% probability*, Fig 65: *work 'primitive' pits and gallery 15D3*), and ending in *1510–1405 cal BC* (*95% probability*), probably in *1490–1435 cal BC* (*68% probability*, Fig 64: *end 'primitive' pits and allery 15D3*).

Three of these pits, 3 A, 3 B, and 3 C were connected at the level of the solid chalk surface (Longworth and Varndell 1996, 45, figs 34, 36); and the possibly contemporary Pit 8, was similarly joined to two other pits (Armstrong 1924a, 191; 1932, 58–59, Longworth and Varndell 1996, 65–9). If this practice was chronologically specific, it might provide a clue to the extent of contemporary mining: the 1995 RCHME survey recorded several instances of three or more relatively small shafts set at the base of a single continuous quarry (Barber *et al* 1999, 41; 2000, 12–5, 24, 26–7, figs 3–4).

Contemporary habitation, however short-lived, is apparent around F105, in cutting 940/940, where early Bronze Age pottery is least infrequent (Longworth *et al* 1988, 23–4), the largest single quantity occurring in what seems to be an occupation deposit in a shallow hollow (F108), including animal bone, fired clay and struck flint (Longworth *et al* 2012, 78). Some bulk charcoal samples from this cutting, with all their attendant problems, have been dated to the second millennium cal BC (Fig 50).

5.2 Probable labour input at any one time

This estimate is possible, even tentatively, only for the area of the galleried pits. Very approximately, if the 400-odd visible pits recorded by earthwork survey (Barber *et al* 1999, fig 13) were mainly galleried, as their location indicates, then they could have been worked at a rate of one or two per year over 185–290 years. Following Felder's and Mercer's resource estimates, there could at the very most have been two teams of 20 people working on the site in a single summer season, provided that the pits were worked at a steady rate.

5.3 Relation to the introduction of metal-working

In Britain, metallurgy continues to appear to be one of the numerous innovations linked to the introduction of Beaker pottery (eg Needham 2012, 4, 19), so that the dating of the one is a convenient proxy for the dating of the other. Beaker pottery was current during the working of Grime's Graves. Figure 68 repeats the Neolithic and early Bronze Age estimates shown in Figure 64, together with estimates for the start and end of the use-life of Beaker pottery in England of *2490–2340 cal BC* and *1880–1740* (*95% probability*, Healy 2012, fig 10.5j, table 10.2: *start English Beakers 2*, *end English Beakers 2*). The galleried pits had begun to be worked before the ceramic was adopted, *150–300 years* earlier (*95% probability*, Fig 69: *start galleried/start Beakers*). Simple pits on the West Field had begun to be worked *55–285 years* earlier (*95% probability*, Fig 69: *start West Field/start Beakers*).

The end of galleried pits and the adoption of Beaker pottery could have coincided, the interval between them being *−70 to +95 years* (*95% probability*, Fig 69: *start Beakers/end galleried*). It is 40% probable that the galleried pits went out of use before the uptake of Beaker pottery, 60% probable that there was an overlap (Table 28). With the simple pits on the West Field there was substantial overlap, since they continued to be worked for a further *150–390 years* (*95% probability*, Fig 69: *start Beakers/end West Field*). The 'primitive' pits of the mid-second millennium cal BC were worked by members of a fully metal-using society. MCMC analysis delivers comparable results. The sequence start galleried shafts < start simple pits on West Field < start English Beakers 2 < end simple pits on West Field < end English Beakers 2 <start primitive pits and gallery 15D3 is 88% probable. The relative timing of the abandonment of the galleried pits and the uptake of Beaker pottery, however, remains unclear. The sequence end galleried shafts < start English Beakers 2 is 41% probable; the sequence start English Beakers 2 < end galleried shafts is 59% probable.

5.4 Middens

It is 95% probable (Table 24) that an interval separated the mid-second millennium cal BC 'primitive' pits from the middle Bronze Age midden deposits, which were formed on the opposite, south and east, side of the site. This interval lasted *−20 to +175 years* (95*% probability*), probably *25–115 years* (*68% probability*; Fig 68: *end 'primitive'/ start middens*). The middens began to be generated in *1450–1375 cal BC* (*72% probability*, Fig 64: *start middens*). The material accumulated over *0–160 years* (*95% probability*), probably *0–70 years* (*68% probability*), most of the probability lying at the brief end of the distribution (Fig 65: *generate middens*). They were formed by *1395–1260 cal BC* (*95% probability*, Fig 64: *end middens*).

The original location of this occupation seems to have been nearby, at least in the case of the deposits at the top of the 1972 Pit, since a skin of comparable occupation material occupied part of the surface between the 1971 and 1972 Pits, abutting the eroded rear slope of the chalk dump surrounding the 1971 Pit (Mercer 1981, 12–3, figs 2, 4). Disregarding sherds of middle Bronze Age pottery scattered across the site, midden-like deposits around the south and east of the area, not only those dated here but also including section VII (Peake 1915, 115–8; Smith 1915, 212–3), and adjacent cuttings in area C to the south-west of Grimshoe (Longworth *et al* 1988, 36, figs 14, 35, 39, 40; Needham 1991, 178, fig 91; Legge 1992, 44 and 47), extend over *c* 1.5ha. The stylistic homogeneity of the middle Bronze Age pottery and the statistical consistency of the recently obtained radiocarbon dates suggest that all derive from a single episode of activity. If that activity was continuous, the occupation and accumulation would have been massive. The late Tony Legge made the point that the quantities of chalk brought to the surface during mining would have made the area attractive by improving its sandy soils (1981, 96), providing improved pasture for the largely dairy-based economy reflected in the slaughter pattern of the cattle from the midden deposits (Legge 1981, 86–89; 1992, 25–31). He also found that the slaughter pattern of the sheep reflected year-round occupation (1981, 84–6; 1992, 28, 33–4).

Excavation and other forms of prospection have been sufficient to establish that there was no associated field system, like those surrounding settlements of the period in other areas. The nearby land divisions of Game Farm, Brandon, Suffolk, may be of late rather than middle Bronze Age date, since the middle Bronze Age radiocarbon dates were measured on bulk samples, probably, or certainly, including mature material, while the pottery is late Bronze Age (Gibson *et al* 2004, 36–41, 49–51).

5.5 Relation to local settlement and other activity

A correlation with associated occupation and other activities can be attempted to only a limited extent, because most of the added precision is on the Grime's Graves side. The exercise is confined to the surrounding Breckland and the adjacent south-eastern fens. The slight Mesolithic and early Neolithic activity evidenced on the site reflects a contemporary presence across the Breckland. Notably, several phases of the Mesolithic are well attested at Two Mile Bottom, Thetford, 4km to the south-east (Haward 1914; Jacobi 1984, 53–7; Robins 1998); while mid-fourth millennium cal BC settlement at Kilverstone, Thetford, 6km to the south-east, generated well over two hundred pits (Garrow *et al* 2006). These sites are, however, exceptional; both periods being more widely and generally represented in the area by stray finds and, in the case of the early Neolithic, isolated features (Healy 1998, 225). In millennia when progressive wetness had not yet transformed the Fenland basin, this pattern extended well to the west, into areas subsequently peat-covered (Hall and Coles 1994, 28–41).

Radiocarbon dates for local activity in the period covered by the main phases of activity at Grime's Graves are listed in Table 29 and shown in Figures 71–3, which represent parts of a model structure shown in Figure 70. The various components are modelled independently of each other.

The Breckland saw an intensification of activity in the late fourth and the third millennium cal BC. A concentration of Peterborough Ware and Grooved Ware, already apparent when Cleal's distribution maps were compiled (1984, figs 9.2–9.4), has increased since (Garrow 2006, fig 3.7). What distinguishes the area in this period, however, is its 'industrial' aspect. It seems to have been a zone of dispersed settlement in which flint nodules of large size and fairly high quality were collected and/or extracted from a variety of superficial sources, and a range of implements made, including those calling for large, relatively sound, blanks, some of them being finished by grinding elsewhere. This is seen in the frequently large size of the lithics, an emphasis on the early stages of the reduction sequence, the use of Levallois technique, and the production of a range of heavy core tools (Healy 1998, 226–31; Bishop 2012). Bishop sees Grime's Graves as the heart of a landscape of extraction, most of it superficial or comparable to the simple pits on the West Field. 'Domestic' sites like those found elsewhere, in the form of subsoil features yielding Grooved Ware, which would have fallen within the working span of the galleried pits and parts of the West Field at Grime's Graves, remain undated. This upsurge of activity coincided with a lull to the west corresponding to a progressive landward spread of marine and fen environments in the fenland basin (Waller 1994).

The later third and the second millennium saw continued activity in the Breckland. Finds of Beaker pottery, for example are abundant. Unlike the Grooved Ware settlements, some of these are dated. A measurement on charred hazelnut shells from a pit or posthole at Sapiston, Suffolk, places activity there in *2200–2010 cal BC* (*93% probability*, Fig 71: *SUERC-19597*; Craven 2009). Other recently published examples include Beaker hearths at Lynford Quarry, Norfolk, where the three radiocarbon measurements are for samples which, although single-entity, were of unidentified charred wood. This is unfortunate, since the excavation report states that the same hearths contained charred buds, twigs, tubers, and seeds of grassland plants, which would have made excellent short-life samples (Birks and Robertson 2005). The dates are therefore modelled as contemporary with the occupation (Fig 71: *Wk-9384* to *-9286*). A measurement on unspecified animal bone from a pit containing incised and rusticated Beaker sherds at Kilverstone, Norfolk, Garrow *et al* 2006) can similarly be treated only as a *terminus post quem* (Fig 71: *Beta-178143*).

To the west, a slightly lowered watertable, the end of marine conditions in the centre of the basin and the renewed growth of freshwater peat seem to have combined to make the south-eastern fen margin more attractive. The zone shows an unprecedented level of occupation from the late-third millennium cal BC, characteristically preserved on natural hillocks subsequently covered by peat. The pottery from these sites is predominantly Beaker and early Bronze Age (Food Vessel, Collared Urn, Biconical Urn), the majority of the Beaker being stylistically late, with features of Needham's (2005; 2012) Long-Necked group, for which a currency of *2310–2120 cal BC* (*94% probability*) to *1940–1790 cal BC* (*95% probability*) has been estimated (Healy 2012, fig 10.5j: *start_English_long-necked_2, end_English_long-necked_2*), although there are some typologically earlier sherds. There are effectively no radiocarbon dates for the predominantly Beaker settlement sites, an accident of the timing and manner of their excavation.

The dating of non-Beaker early-Bronze Age occupation here is tentative. *Termini post quos* are provided by two dates for disarticulated animal bone from pits at Prickwillow Road, Isleham, Cambridgeshire (Fig 71: *Beta-77751*, *-77752*; Gdaniec *et al* 2007, 32–41), and by three dates for unidentified bulk charcoal samples from a site with predominantly Collared Urn pottery in West Row Fen, Mildenhall (MNL-130; Jordan *et al* 1994; Fig 71: *HAR-2510*, *-2516*, and *-2517*). There is also a longer series from an extensively excavated site nearby, also with predominantly Collared Urn pottery (MNL-165; Martin and Murphy 1988; Bayliss *et al* 2012, 202–204; Bayliss *et al* 2013, 117–118; Fig 71: *HAR-4629*, *-5634* to *-5637*, *-5639*, *-9268* to *-9269*, and *-9272*). These are almost all on mature or unidentified charcoal or wood samples, but, in two cases the identification of remaining material has shown it to consist predominantly of short-lived taxa, of which alder is the most frequent (Bayliss *et al* 2012, 202–204). These two dates are modelled, cautiously, as contemporary with the occupation of the site (Fig 71: *HAR-4629*, *-5638*); the others, including two on soil, are modelled as *termini post quos*. The resulting estimate for the occupation is very imprecise: *3000–1490 cal BC* to *1600–230 cal BC* (*90% probability*), probably *2180–1530 cal BC* to *1560–1000 cal BC* (*68% probability*, Fig 71: *start fen edge EBA settlement, end fen edge EBA settlement*).

A proxy for the Beaker occupation sites is provided by a precisely dated burnt mound at High Fen Drove, Northwold, one of hundreds within the occupied zone (Silvester 1991, fig 49). This particular mound covered and contained over 100 sherds of Beaker pottery of similar late style to that dominant on the occupation sites, as well as one sherd possibly of Food Vessel Urn. The stratigraphic sequence, multiple short-lived samples and Bayesian modelling have determined a use-life of *35–165 years*, between *2265–2165* and *2140–2065 cal BC* (*95% probability*; Bayliss *et al* 2004b; Fig 72: *start Northwold burnt mound*, *end Northwold burnt mound*). Two dates for short-life charcoal from a burnt mound at Feltwell Anchor, farther out into the fen and overlying Beaker sherds as well as being cut by a burial, lack the same precision but also indicate a date in the last quarter of the third millennium (Bates and Wiltshire 2000; Fig 72: *GU-5573*, -*5574*). Radiocarbon measurements for bulk charcoal samples from three further burnt mounds in Mildenhall, Suffolk, can be taken only as *termini post quos* and thus suggest similar or later dates (Martin 1988; Bayliss *et al* 2013, 116–117; Fig 72: *HAR-1876*, *-2690*, *-9271*). On this slender basis of five mounds out of hundreds, these features in the south-eastern fens would have been accumulated between *2500–2065* and *2115–1700 cal BC* (*95% probability*), probably between *2305–2150* and *2030–1880 cal BC* (*68% probability*; Fig 72: *start Fenland burnt mounds*, *end Fenland burnt mounds*).

The burial inserted into the Feltwell Anchor burnt mound is one of several from the south-eastern fens, most of them unaccompanied by grave goods, some of which have been directly dated by measurements on human bone. In addition to a pair of statistically consistent replicates on the Feltwell Anchor burial (T'=2.8; T'(5%)=3.8; **v** =1; Fig 73: *Feltwell Anchor burial*), there is another pair on 'Shippea Hill man' (T'=0.1; T'(5%)=3.8; **v** =1); Roberts 1998; Fig 73: *'Shippea Hill man'*). There is also a series of dates for complete and semi-complete skeletons from four locations in Methwold (Healy and Housley 1992; Healy 1996, 30–42; Fig 73: *OxA-2860* to *-2868*). All 11 individuals died between *2325–1970* and *2035–1730 cal BC* (*95% probability*), probably between *2185–2015* and *2005–1870 cal BC* (*68% probability*; Fig 73: *start Fenland burials*, *end Fenland burials*). Dates for two among 30 individuals inserted into a natural hillock in Hill Close, Feltwell, are kept separate from the Fenland burials because the location is distinct: on a slight chalk spur projecting from the upland above the fen (Healy 1996, 30–5) and because they are later, extending into the seventeenth and thirteenth centuries cal BC (Fig 73: OxA-2885, -3069).

The working of the galleried pits had probably ended before the better-dated aspects of this upsurge in fen edge activity began. It is 90% probable that they were out of use before burnt mounds began to be used, and 98% probable that they were out of use before the fenland burials began (Fig 74, Table 30). The working of simple pits on the West Field, however, overlapped substantially with these developments. It is 96% probable that some of the West Field pits were still being worked when the burnt mounds began to accumulate and 58% probable that that some were still being worked when the fenland burials began. Imprecisely dated knapping and occupation on the West Field seem to extend even later (Fig 50), especially given the presence of Collared Urn pottery. The brief sixteenth to fifteenth century cal BC mining episode with its 'primitive' pits fell within with the final stages of dense occupation on the fen edge to the west, characterised by Food Vessel, Collared Urn and Biconical Urn pottery. It is 100% probable that the admittedly imprecise estimate for the start of this episode predated the 'primitive' pits, and 88% probable that they went out of use before it ended.

MCMC analysis indicates that it is 83% probable that the sequence *end galleried shafts* < *start fenland burnt mounds* < *end simple pits on West Field* < *end fenland burnt mounds* is correct; and 98% probable that the sequence start fen edge EBA settlement < *start primitive pits and gallery 15D3* < *end primitive pits and gallery 15D3* < *end fen edge EBA* settlement is correct.

While most chalk flint brought to the fen edge from the Breckland in the late third and the second millennium cal BC was from heterogeneous, often superficial, sources, a minority has the macroscopic characteristics of Grime's Graves floorstone and could have come from there (Healy 1998). Some of the settlements of this date yield fragments of flint saddle querns, sometimes reworked as knapping material. Such querns are a peculiarity of a region poor in suitably large slabs of abrasive stone, and are made by dressing the surface of a slab of flint with a hammerstone, as in a Biconical Urn-associated assemblage from Mildenhall Fen, Suffolk (Clark 1936, 44–5). Complete examples tend to occur as stray finds (Healy 1996, 62, 74, fig 43). Where fragments occur in surface or excavated collections, these tend to be of predominantly Bronze Age rather than Beaker technology (Healy 1991, 124). The form and size of floorstone nodules would be ideal for their manufacture, and this may have been one motivation for once again sinking pits to the floorstone. The mid-second millennium cal BC is also the period of the last finely made, even specialist-made?, flint artefacts, in the form of plano-convex knives, recurrently found in early Bronze Age burials (Saville 1985, 130), as well as in settlements; and of the last barbed and tanged arrowheads, some of which occur in the same series of burials (Green 1980, 247–52). The quality and appearance of floorstone would be an asset in their manufacture.

The late-second millennium cal BC midden deposits in the south-east of Grime's Graves also include fragments of flint saddle quern (Herne 1991, 74, figs 31–2). By this time the re-establishment of wetter conditions in the south-east of the basin in the third quarter of the second millennium cal BC (Waller 1994, 154) had corresponded to a decline in fen edge settlement and an increase in the already ongoing deposition of metalwork (Healy 1996, figs 23–5). The large, 'ceremonial' spearheads made at Grime's Graves are comparable with many of those recovered from the fens (Needham 1991, 158), suggesting a link between the Grime's Graves occupation and deposition in the fen. The later of the two dated skeletons in Hill Close, Feltwell (Fig 73: *OxA-3069*) would have died in this period and the burial could conceivably relate to a Penard phase cauldron and flesh hook found in the same field (Gerloff 1986, 88–92, fig 6ii), since Penard metalwork dates from the fourteenth to the eleventh century cal BC (Needham *et al* 1997, 77–80).

The first millennium cal BC deposits in the upper part of the 1971 Pit (Fig 61), notably two successive Iron Age burials, and the first or second century AD burial of a horse skull in the spoilheap of another Neolithic pit (Fig 63) are unsurprising, given that Thetford and its surrounding area, 7km upstream, was a focus of activity throughout the Iron Age (Davies 1996, 78–80), culminating in the construction of the Fison Way religious centre in the first century AD (Gregory 1991).

5.6 Beyond the original questions

5.6.1 Artefacts

The dating programme has helped to define the currency of certain artefact types. The durability of lithics combined with the progressively accumulating quantity of struck flint on the site means that any incorporated in feature fills or subsurface deposits may have been redeposited. The dated flintworking contexts with lowered risks of redeposition are the surface beneath the upcast surrounding the 1971 Pit and the 1972–4 knapping floor, sealed by upcast from Pit Y. Fresh, well-preserved material from both of these must have been generated within the period in which the galleried shafts were worked (Fig 64, Table 27). The most distinctive products of both were discoidal knives (Saville 1981, fig 50: F129, F130; Lech 2012, fig 81: b) and axeheads made on flakes, the most finished ones often of triangular plan (Saville 1981, fig 44: F113; Lech 2012, fig 84), forms that were widespread elsewhere on the site (Lech 2012, 121–43).

Grooved Ware bowls, present in mining period contexts in the galleried shafts, including the base of the 1971 Pit, Pit 2 and the 1972–74 knapping floor (Longworth 1981, 39; Longworth *et al* 1988, 15–8) fall in the same time bracket, and two from the Greenwell's Pit complex are dated directly, to *2570–2520 cal BC* (*18% probability*) or *2500–2395 cal BC* (*77% probability*, Fig 21: *OxA-22577*) and *2640–2560 cal BC* (*78% probability*) or *2535–2495 cal BC* (*17% probability*, Fig 23: *502*).

The middle Bronze Age pottery from the midden deposits is also directly dated, since all but two of the newly obtained measurements (Figs 58–9) were made on carbonised residues, some of them on morphologically diagnostic vessels (Longworth *et al* 1988, fig 25: 73, fig 31: 239, fig 41: 528). The span of *1450–1375 cal BC* (*72% probability*) to *1395–1260 cal BC* (*95% probability*), Figs 57, 58: *start middens*, *end middens*) also applies to the channel-bladed, basal-looped spearheads cast in the moulds of which fragments occurred in the Pit X deposits (Needham 1991, 155).

5.6.2 The first millennium cal BC

Unexpected early first millennium cal BC dates for the 1B deposits in the top of the 1971 Pit (Fig 62) are significant, because this deposit was part of the only substantial sequence of Mollusca to be analysed from the site. John Evans' and Hilary Jones' analysis of the Mollusca from layers 1 down to 1B indicates that 1B, the context of these early first millennium samples, accumulated in a hollow surrounded by woodland with dense leaf litter, with clearer conditions developing subsequently (1981, 106). This would be compatible with regeneration after the middle Bronze Age episode. There is slight, but only slight, evidence of an early first millennium presence on the site to accompany the 1B animal bone. Small amounts of late Bronze/early Iron Age pottery extend beyond the occurrences noted above, and have mainly been found in the south-east of the site (Rigby 1988). A socketed axe was found on the base of Pit 1 when it was re-excavated in 1920, having apparently fallen in from a superficial layer (Armstrong 1921a, 443; Needham 1991, 172, fig 91: B3). Activity of this period, or rather later, is also evidenced by a bone dated to 890–400 cal BC (95% confidence) from the surface of an unexcavated feature on the West Field (Appendix 1: BM-1097).

The fourth to second century cal BC dates of two successive burials, the first in the top of the 1B layers of the 1971 Pit, the second cut into them (Fig 62: SUERC-28753, OxA-22533) are probably close in time to the clearance and open ground phases which conclude Evans' and Jones' sequence (1981, fig 59), although it is not possible precisely to equate the depths of the molluscan samples with the deposits described in the excavation report.

6.0 WIDER CONTEXT

The shallow, haphazard working of largely non-floorstone flint on the West Field, merging into the overall character of flint exploitation in the Breckland, conforms to a recurrent pattern of later Neolithic flint procurement. This tended to take the form of an 'industrial' facies to occupation in the areas of more readily accessible deposits, with or without shallow quarries, whether on the Clay-with-Flints of Cranborne Chase or the South Downs (Gardiner 1991; 1990), the dry valleys of Salisbury Plain (Richards 1990, 158–71), or the tills of Flamborough Head (Durden 1995). The West Field fits in here perfectly well.

The working of the galleried shafts, however, does not fit well. There is nothing comparable at this date in Britain. The minutiae of the methods by which the deep shafts were worked (Longworth and Varndell 1996) matched those practiced on the South Downs (Barber *et al* 1999, 38–40), over a thousand years before (Whittle *et al* 2011, 255–6), and those standardised methods seem to have been introduced to the site fully developed, since, on currently available dating, the deepest shafts were among the first to be worked. Furthermore, they were unnecessary in practical terms, since local industries were, from the Palaeolithic onwards, predominantly made from surface flint of the surrounding Breckland (Healy 1998). Their role calls for examination. Lech emphasises the distinction between the galleried pits and the West Field quarries by interpreting the deep mines and extensive knapping floors like the 1972–4 one as worked by highly skilled specialists and forming part of a long-distance exchange system in which symbolic significance attached to the mines and their floorstone products, while the simpler, more superficial workings served to meet local needs (2012, 119–21).

The symbolic aspects of mining and quarrying have been well rehearsed (eg Barber *et al* 1999, 61–7, 73; Topping 1997; 2004; 2005; 2010; Topping and Lynott 2005; Edmonds 1995, 59–66). An extra-functional aspect to the working of the galleried shafts at Grime's Graves is strongly suggested by various formal placements, summarised by Varndell *et al* (forthcoming), not least by the large quantities of antler implements often purposefully placed in groups in galleries and on shaft bases (eg Mercer 1981, fig 13; Longworth and Varndell 1996, figs 5, 17, 18, 44). A mid-third millennium emphasis on fine flint and stone artefacts (Edmonds 1995, 100–114), and a locally weak local tradition of constructing large communal monuments may together have contributed to the development of a consciously archaising, symbolically-charged practice, conducted by skilled specialists, an equivalent to the great late Neolithic monuments of some other regions. Bishop sees the wider Breckland flint procurement zone as a focus to which people would travel, gathering and meeting each other like those who had made their way to a monument (Bishop 2012).

Once Grime's Graves was established, the working of simple pits on the West Field continued to the turn of the third and second millennia cal BC, while that of galleried pits ended untill the twenty-fifth or the twenty-fourth century (Fig 67). With the galleried pits ended the construction of formal placements, for which there is no equivalent in the more expedient and functional pits on the West Field, even where they have been fully excavated. The exercise of standardised, highly developed, mining skills also extended with the galleried pits. The 'monumental' aspects of the site seem to have diminished at this time. In Lech's terms, the work of highly skilled specialists attached to long-distance exchange networks ended, while simpler, less skilled extraction for local needs continued (Leech 2012).

There is also continuity. The material culture of Grime's Graves in the late-third millennium cal BC remained predominantly that of the insular late Neolithic. Lech concludes that, despite differences in raw material quality and knapping skill, a sample from the 1972–4 knapping floor and a much smaller knapping deposit from F112 on the West Field showed the same approach to flint working, with similar multiple products (2012, 116–118). Across the West Field, although no other deposits have been analysed in detail, discoidal knife and axehead production was widespread, as it was across the site as a whole (Lech 2012, 121–41), and forms often associated with Beaker pottery, such as barbed and tanged arrowheads or scale-flaked knives were universally rare (ibid, 143–44).

It is significant that Beaker pottery is virtually absent from Grime's Graves, despite its currency overlapping with flint mining at the site (§5.3) and its frequency in the local area . The total from Grime's Graves consists of two rusticated sherds, both from superficial contexts (Longworth *et al* 1988, 15–6, fig 3: N12, N13). This is despite the presence of a major concentration of domestic sites with Beaker pottery on the edge of the Fenland Basin, some 15km to the west of the site (Cleal 1984, figs 9.6–9.7; Garrow 2006, fig 3.7), the dating of which is discussed above (§5.5). Less well preserved, small-scale sites are also frequent in the surrounding Breckland. They include those at Lynford Quarry, 5km north of Grime's Graves, Kilverstone, 6km to the south-east and Sapiston, 17km to the south-east, noted above (§5.5). Other recent finds in the Norfolk Breckland include pits at Hall Farm Reservoir, Croxton, 6km to the south-east (Birks 2001); Fison Way, Thetford 7km to the north (Gregory 1991, 10); Snetterton, 18km to the east (Robertson 2004); and Shropham 17km to the north-east(Woolhouse and Barlow 2007). In the Suffolk Breckland, recent finds include hollows at Cavenham quarry, 20km to the south (Gibson and Gill 2013) and pits at Barnham, 12km to the south-east (Tester *et al* 1993). Barbed and tanged arrowheads are correspondingly frequent in the surrounding area (Green 1980, fig 47), although scarce on the site.

A possible interpretation of the Beaker-free character of the site lies in the association of the ceramic with the introduction to Britain of metallurgy and a gamut of other new practices originating on the continent. The end of the galleried pits, at around the time that Beaker pottey was taken up in England, could reflect the transformation of indigenous networks of exchange, communication, and influence. The continued use of Grime's Graves could have been the work of a population who asserted traditional ways and values, including the manufacture of fine objects in flint rather than in metal, in the face of innovations that may have been unwelcome and threatening.

The bone picks which characterise the mid-second millennium cal BC flint mining at the site are made from cattle long bones, generally radii, with the shaft cut obliquely to form the working end, and the distal articulation retained (Fig 55). They can be paralleled loosely by a few comparable pieces among the large and diverse assemblages of bone tools from the Middle Bronze Age occupation of the site (eg Mercer 1981, fig 40: B7, B8; Legge 1992, fig 20: BM1, A1) and far more closely and repeatedly among the bone artefacts from second millennium cal BC copper mines at Great Orme, Gwynnedd, and Ecton, Staffordshire, where similar implements are directly dated to the same period (eg Dutton 1990; Barnatt 2013; Timberlake and Barnatt 2013; Timberlake 2013, fig 16: 27, 44). Antler implements are also present in some of the second millennium copper mines (Timberlake 2013, 2, 6–7, 17). By this stage, flint and copper mining may have shared certain working practices.

The late-second millennium cal BC middle Bronze Age midden deposits remain as exceptional as the galleried pits, since the numerous middens investigated in the almost 40 years since the excavation of Pit X (eg Waddington 2008, fig 11.1) are overwhelmingly of late Bronze/early Iron Age, rather than middle Bronze Age date (Waddington 2009, ch. 4). A possible exception is the base of the sequence at Potterne, Wiltshire (Lawson 2000, 257–59), although it is difficult to judge whether the small amount of middle Bronze Age material (including bulk charcoal radiocarbon samples) which accompanied its predominantly late Bronze Age contents was contemporary with the accumulation or derived from preceding occupation.

APPENDIX 1: RADIOCARBON DATES IN LABORATORY NUMBER ORDER

Lab no	Radiocarbon age (BP)	Sample reference	Feature	Material	$\delta^{13}C$ (‰)	$\delta^{15}N$ (‰)	C:N	Replicate of	Date list	Sample and context description
BM-87	4270±150		Pit 15	Charcoal					Barker and Mackey 1961	Table 13
BM-88	4050±150		Pit 15	Antler					" "	" "
BM-93	3870±150	B	Pit 10	Antler					Barker and Mackey 1963	Table 17
BM-97	4290±150		Pit 12	Antler				Count of same benzine as BM-377	" "	Table 11
BM-99	3980±150		Pit 14	Antler					" "	Table 12
BM-103	3700±150		Pit 11	Antler					" "	Table 9
BM-109	3290±150		Pit 8	Antler					" "	Table 17
BM-276	3550±150		Pit 12	Antler					Barker *et al* 1969b	Table 11
BM-291	3810±130		Greenwell's Pit	Antler					" "	Table 8
BM-377	4250±130		Pit 12	Antler				Repeat by liquid scintillation of gas proportional counter measurement BM-97 (Barker *et al* 1969b)	" "	Table 11
BM-775	3815±60	sample 229	1971 Pit	Charcoal					Burleigh *et al* 1976	Table 5
BM-776	3789±60	sample 165	1971 Pit	Charcoal					" "	" "
BM-777	3764±60	sample 183	1971 Pit	Charcoal					" "	" "
BM-778	3781±67	sample 133	1971 Pit	Charcoal					" "	" "
BM-779	313±200	sample 55	1971 Pit	Plant macrofossil					" "	" "
BM-780	2465±230	sample 19	1971 Pit	Charcoal					" "	" "
BM-811	3607±300		cutting 1000/905	Charcoal	−27.2				Burleigh *et al* 1979	Table 18

Lab no	Radiocarbon age (BP)	Sample reference	Feature	Material	$\delta^{13}C$ (‰)	$\delta^{15}N$ (‰)	C:N	Replicate of	Date list	Sample and context description
BM-812	3380±55		cutting 1000/910	Antler	−26.6				" "	" "
BM-943	4104±55	A602	1971 Pit	Antler					Burleigh *et al* 1976	Table 5
BM-944	4153±64	A647	1971 Pit	Antler					" "	" "
BM-945	4034±88	A756	1971 Pit	Antler					" "	" "
BM-970	3767±57	GG73 sf 98	F3	Antler	−24.9				Burleigh *et al* 1979	Table 17
BM-971	3868±66	219	Pit 15 E /J	Charcoal	−25.8				" "	Table 13
BM-972	3071±209	253	Pit 15 D	Charcoal	−27.4				" "	Table 19
BM-973	3827±45	7	Pit 15 A	Antler	−24.2				" "	Table 13
BM-974	3887±47	60	Pit 15 C	Antler	−24.1			BM-3007	" "	" "
BM-975	3940±41	105	Pit 15 B	Antler	−24.1				" "	" "
BM-976	3849±44	128	Pit 15 G	Antler	−23.0				" "	" "
BM-977	4015±61	209	Pit 15 F	Antler	−24.5				" "	" "
BM-978	3865±44	228	Pit 15 D	Antler	−25.0				" "	" "
BM-979	3820±46	231	Pit 15 J	Antler	−25.0				" "	" "
BM-980	3736±58	109	Pit 15 D	Antler	−24.8				" "	" "
BM-981	3874±47	333	Pit 11 A	Antler	−22.8			Possibly, but not certainly, a replicate of BM-3008	" "	Table 10
BM-982	4090±58	322	Pit 11 B/E	Antler	−21.0				" "	" "
BM-983	3761±48	332a	Pit 11 D	Antler	−21.7			OxA-23109	" "	" "
BM-984	3902±58	316	Pit 11 E	Antler	−23.1				" "	" "
BM-985	4010±59	341	Pit 11 F	Antler	−23.0				" "	" "
BM-986	3845±44	236	Pit 15 J	Charcoal	−25.9				" "	Table 13
BM-987	3671±75	324	Pit 11 E	Charcoal	−26.0				" "	Table 10
BM-988	3755±259		1972-74 knapping floor	Charcoal	−25.0				" "	Table 6
BM-989	8519±309	S22	F5 in 900/870	Charcoal	−21.6				" "	4.3
BM-990	7614±80	S1	F1 in 880/910	Charcoal	−24.9				" "	" "

Lab no	Radiocarbon age (BP)	Sample reference	Feature	Material	δ^{13}C (‰)	δ^{15}N (‰)	C:N	Replicate of	Date list	Sample and context description
BM-991	3414±46	S6 and S7	F2 in 900/870	Charcoal	−24.1				" "	Table 18
BM-992	3727±57	GG73 130/S28	F5 in 950/820	Antler	−23.2				" "	Table 17
BM-993	3614±67	GG73 128/S27	F6	Antler	−23.5				" "	" "
BM-994	3535±90	S25	F7	Charcoal	−25.1				" "	" "
BM-995	3947±66		1972-74 knapping floor	Charcoal	−25.3				" "	Table 6
BM-996	3890±42	30	Pit 15 B	Antler	−23.6			BM-3090	" "	Table 13
BM-997	3960±56	47	Pit 15 C	Antler	−24.9			SUERC-30903	" "	" "
BM-998	3992±45	216	Pit 15 E	Antler	−23.0				" "	" "
BM-1000a	4051±109	124	Pit 15 G	Antler	−23.2			BM-1000b	" "	" "
BM-1000b	4022±57	124	Pit 15 G	Antler	−23.2			BM-1000a	" "	" "
BM-1001	3868±56	246	Pit 15 J	Antler	−23.3				" "	" "
BM-1002	3882±45	116	Pit 15 E	Antler	−21.2				" "	" "
BM-1003	3949±42	20	Pit 15 B	Antler	−22.5				" "	" "
BM-1005	3948±37		F12	Charcoal	−24.7				" "	Table 18
BM-1006	4017±60	GG74 1011?	F38	Charcoal	−25.1				" "	" "
BM-1007	3825±54	GG74 sf 102	F6	Antler	−23.3				" "	Table 17
BM-1008	3764±39	GG74 sf 232	F24	Antler	−23.1				" "	" "
BM-1009	3825±41	GG74 sf 184	F7	Antler	−20.6				" "	" "
BM-1010	3770±66	GG74 135	F14 (probably = F22)	Antler	−21.5				" "	Table 17
BM-1011	3952±44	261	Pit 15 D	Antler	−22.5				" "	Table 13
BM-1012	3695±33	GG74 sf 123	F19	Antler	−22.9				" "	Table 18
BM-1013	3929±49		1972-74 knapping floor	Charcoal	−27.0				" "	Table 6
BM-1014	3813±43		1972-74 knapping floor	Charcoal	−25.8				" "	" "
BM-1015	3851±34	GG74 sf 200	F51	Antler	−22.2				" "	Table 17

Lab no	Radiocarbon age (BP)	Sample reference	Feature	Material	δ^{13}C (‰)	δ^{15}N (‰)	C:N	Replicate of	Date list	Sample and context description
BM-1016	3797±49	GG74 141	F11 (probably = F26)	Antler	−20.6				" "	" "
BM-1017	3710±39	GG74 sf 268	F16	Antler	−23.1				" "	" "
BM-1018	3593±37	GG74 sf 124	F23	Antler	−21.7				" "	Table 18
BM-1019	3593±45	GG74 sf 212	F4	Antler	−23.2				" "	" "
BM-1020	3844±221	1005	Pit 2	Antler	−23.0				" "	Table 9
BM-1022	3559±39		F13	Charcoal	−24.9				" "	Table 18
BM-1023	4061±52		F18	Charcoal	−24.3				" "	Table 17
BM-1024	3904±38		F36	Charcoal	−18.6				" "	Table 18
BM-1027	3855±36	567	Greenwell's Pit	Antler	−23.0				" "	Table 8
BM-1028	3922±38	578	Greenwell's Pit	Antler	−19.5			BM-3009	" "	" "
BM-1029	3859±53	647	Greenwell's Pit C	Antler	−22.4			OxA-23097	" "	" "
BM-1030	2953±36		F106 (probably = F120)	Charcoal	−25.8				" "	Table 18
BM-1031	3386±41		F108	Charcoal	−24.9				" "	" "
BM-1032	3286±67		F112	Charcoal	−20.1				" "	" "
BM-1033	2881±49		F121	Charcoal	−25.6				" "	" "
BM-1034	3763±47		F124	Charcoal	−25.8				" "	" "
BM-1035	2994±40		Pit X	Charcoal	−25.5				" "	Table 20
BM-1036	2995±39		Pit X	Charcoal	−25.5				" "	" "
BM-1037	3003±49		Pit X	Charcoal	−21.4				" "	" "
BM-1038	2936±43		Pit X	Charcoal	−24.8				" "	" "
BM-1039	2806±54		Pit X	Charcoal	−25.0				" "	" "
BM-1040	2905±54		Pit X	Charcoal	−25.0				" "	" "
BM-1041	3573±57		Pit X	Charcoal	−25.2				" "	" "
BM-1042	2919±53		Pit X	Charcoal	−24.7				" "	" "
BM-1043	2838±53		Pit X	Charcoal	−24.8				" "	" "
BM-1044	3922±86	711	Greenwell's Pit	Antler	−22.3				" "	Table 8

Lab no	Radiocarbon age (BP)	Sample reference	Feature	Material	δ13C (‰)	δ15N (‰)	C:N	Replicate of	Date list	Sample and context description
BM-1045	3949±41	668	Greenwell's Pit C	Antler	−23.3				" "	" "
BM-1046	3797±52	679	Greenwell's Pit C	Antler	−20.3				" "	" "
BM-1047	3974±45	683	Greenwell's Pit C	Antler	−22.6				" "	" "
BM-1048	3880±38	705	Greenwell's Pit	Antler	−21.6			BM-3010	" "	" "
BM-1049	3884±43	900	Greenwell's Pit	Antler	−22.1			BM-3089	" "	" "
BM-1050	3893±44	923	Greenwell's Pit A	Antler	−21.7			BM-3088, OxA-23103	" "	" "
BM-1051	3887±56	103	Pit 15 B	Antler	−23.2			BM-3087	" "	Table 13
BM-1052a	4114±45	23	Pit 15 B	Antler	−22.9			Counted on the same sample benzine as BM-1052b	" "	" "
BM-1052b	3954±43	23	Pit 15 B	Antler	−22.9			Counted on the same sample benzine as BM-1052a	" "	" "
BM-1053	3834±50	31	Pit 15 B	Antler	−23.3				" "	" "
BM-1054	3904±36	61	Pit 15 C	Antler	−22.2				" "	" "
BM-1056a	3838±42	110	Pit 15 D	Antler	−23.0			Counted on the same sample benzine as BM-1056b	" "	" "
BM-1056b	3740±48	110	Pit 15 D	Antler	−23.8			Counted on the same sample benzine as BM-1056a	" "	" "
BM-1057	3924±47	238	Pit 15 D/J	Antler	−23.0				" "	" "
BM-1058	3876±48	119	Pit 15 E	Antler	−22.9				" "	" "
BM-1059	3977±47	207	Pit 15 F	Antler	−22.6				" "	" "

Lab no	Radiocarbon age (BP)	Sample reference	Feature	Material	δ^{13}C (‰)	δ^{15}N (‰)	C:N	Replicate of	Date list	Sample and context description
BM-1060	3863±86	GG76 Pit 3A sf 10	Pit 3 A	Antler	−23.5				" "	Table 19
BM-1060	3863±86	GG76 Pit 3A sf 10	Pit 3 A	Antler	−23.5				" "	" "
BM-1061	3666±55	GG76 1372	F105	Antler	−22.0				" "	" "
BM-1062	3695±49	GG76 sf 331	F34	Antler	−22.9				" "	Table 17
BM-1063	3874±55	GG76 sf 1225	F28	Antler	−22.1				" "	" "
BM-1064	3748±59	GG76 1224	F32	Antler	−22.8				" "	" "
BM-1065	3941±89	9976	trench 3 hearth 10 and/or 11	Charcoal	−24.6				" "	Table 14
BM-1066	4224±74		trench 2	Charcoal	−24.7				" "	" "
BM-1067	2559±80	GG75 sf 535	F123	Animal bone	−21.9				" "	4.8.3
BM-1068	3784±50	933	Greenwell's Pit A	Antler	−22.1				" "	Table 8
BM-1069	3896±141	1007	Pit 2	Antler	−22.0				" "	Table 9
BM-1097	3038±44	sample 26	1972 Pit	Charcoal	−25.0				Burleigh and Hewson 1976	Table 20
BM-1260	4037±62	1514	Pit 15 D	Antler	−22.5				Burleigh *et al* 1979	Table 13
BM-1261	3853±71	832	Greenwell's Pit	Antler	−21.4				" ".	Table 8
BM-1262	3900±54	1516+1523	Pit 15 D	Charcoal	−24.7				" "	Table 13
BM-1263	3443±53		Pit X	Charcoal	−24.8				" "	Table 20
BM-1264	3154±64		Pit X	Charcoal	−24.9				" "	" "
BM-1265	2800±79		Pit X	Charcoal	−24.2				" "	" "
BM-1266	2834±53		Pit X	Charcoal	−24.7				" "	" "
BM-1546	3740±210	ARC 79 5017	trench 3	Animal bone	−21.4			OxA-21193, OxA-1635	Burleigh *et al* 1982	Table 21
BM-2377	4060±90	5640G157	area of Greenwell's Pit	Charcoal	−23.9				Ambers *et al* 1987	" "

Lab no	Radiocarbon age (BP)	Sample reference	Feature	Material	$\delta^{13}C$ (‰)	$\delta^{15}N$ (‰)	C:N	Replicate of	Date list	Sample and context description
BM-2379	4150±90	5640G121, 122, 123, 124, 155, 105,103	area of Greenwell's Pit	Charcoal	−25.7				" "	" "
BM-2380	3810±60	5640G79	area of Greenwell's Pit	Antler	−23.0				" "	" "
BM-3006	3780±45	GG73 136	F6	Antler	−22.2				Ambers and Bowman 1999	Table 17
BM-3007	4060±90	60	Pit 15 C	Antler	−23.8			BM-974	" "	Table 13
BM-3008	3890±40	333?	Pit 11 A	Antler	−23.3			Possibly, but not certainly, a replicate of BM-981	" "	Table 10
BM-3009	4060±90	578	Greenwell's Pit	Antler	−21.4			BM-1028	" "	Table 8
BM-3010	3960±45	705	Greenwell's Pit	Antler	−22.7			BM-1048	" "	" "
BM-3087	4010±35	103	Pit 15 B	Antler	−23.4			BM-1051	" "	" "
BM-3088	3980±60	923	Greenwell's Pit A	Antler	−22.3			BM-1050, OxA-23103	" "	" "
BM-3089	3960±60	900	Greenwell's Pit	Antler	−21.7			BM-1049	" "	" "
BM-3090	4010±70	30	Pit 15 B	Antler	−20.4			BM-996	" "	Table 13
BM-3119	3800±30		F5 in 950/820	Antler	−22.7				Ambers and Bowman 2003	Table 17
BM-3120	3850±50		F6	Antler	−21.0				" "	" "
BM-3121	3900±50		F7	Antler	−21.6				" "	" "
BM-3134	3560±50		F105	Antler	−22.8				" "	Table 19
BM-3135	3720±40		F124	Charcoal	−25.0				" "	Table 17
GrA-38913	4060±35	A620	1971 Pit	Antler	−22.9					Table 5
GrA-38914	4070±35	A653	Pit to NE of 1971 Pit	Antler	−23.4	4.7	3.2			" "
GrA-38915	4035±35	A743	1971 Pit	Antler	−22.2	5.1	3.4			" "
GrA-38924	4065±35	A603	1971 Pit	Antler	−22.8	5.9	3.6			" "

Lab no	Radiocarbon age (BP)	Sample reference	Feature	Material	$\delta^{13}C$ (‰)	$\delta^{15}N$ (‰)	C:N	Replicate of	Date list	Sample and context description
GrA-39260	4100±35	A619a	1971 Pit	Antler	−22.9	6.4	3.2	SUERC-18820		" "
OxA-1635	1820±70	ARC 79 5017	trench 3	Animal bone	−21.0			BM-1546, OxA-21193	Higham *et al* 2007	Table 21
OxA-20591	3231±28	GG76 1581+1578	F105	Animal bone	−22.1	5.4	3.2			Table 19
OxA-20709	4007±33	A598a	1971 Pit	Antler	−22.1	5.7	3.2	SUERC-24110		Table 5
OxA-20710	3978±34	A601	1971 Pit	Antler	−23.8	5.3	3.2			" "
OxA-20711	4046±35	A611a	1971 Pit	Antler	−22.3	5	3.2	SUERC-24111		" "
OxA-20712	4081±35	A675	Pit to NE of 1971 Pit	Antler	−24.0	4.7	3.2			" "
OxA-20713	4054±37	A680	Pit to NE of 1971 Pit	Antler	−23.1	4.2	3.2			" "
OxA-20714	4025±34	A682	Pit to NE of 1971 Pit	Antler	−23.1	3	3.2			" "
OxA-20715	3995±34	A746	Pit to NE of 1971 Pit	Antler	−23.6	6	3.2			" "
OxA-20716	4065±45	GG73 161	F6	Antler	−23.0	5.9	3.2			Table 17
OxA-20717	4083±33	GG74 sf 182	F7	Antler	−23.5	4.7	3.3			" "
OxA-20718	4068±32	GG74 L506	1972-74 knapping floor	Antler	−22.7	3.9	3.2			Table 6
OxA-20719	4013±33	GG74 L586	1972-74 knapping floor	Antler	−22.5	4.7	3.3			" "
OxA-20720	3226±33	GG76 1548+1549	F105	Animal bone	−21.8	5.3	3.2			Table 19
OxA-20750	3973±31	'1933 gal 2' a	Pit 12	Antler	−20.3	6.9	3.3	SUERC-24098		Table 11
OxA-20751	4029±31	'1933 entrance to gal 2'	Pit 12	Antler	−21.9	6.5	3.3			" "
OxA-20752	4009±30	'1933 gal 2 centre'	Pit 12	Antler	−20.9	5.2	3.3			" "

Lab no	Radiocarbon age (BP)	Sample reference	Feature	Material	δ^{13}C (‰)	δ^{15}N (‰)	C:N	Replicate of	Date list	Sample and context description
OxA-20753	4056±31	'1933 gal 3 just inside'	Pit 12	Antler	−21.1	5.3	3.4			" "
OxA-20754	4004±31	'gal 3' a	Pit 12	Antler	−22.8	6	3.3	SUERC-24099		" "
OxA-20755	3998±32	1936 'filling of *** gal near wall'	Pit 14	Antler	−20.9	3.3	3.4			Table 12
OxA-20756	4031±31	'filling of gal 3' a	Pit 14	Antler	−20.1	6.6	3.4	SUERC-24102		" "
OxA-20757	4033±31	'8 ft in chalk'	Pit 14	Antler	−22.2	6.5	3.4	OxA-20758		" "
OxA-20758	4063±29	'8 ft in chalk'	Pit 14	Antler	−22.4	6.5	3.3	OxA-20757		" "
OxA-20759	3290±28	250	Pit 15 D	Animal bone	−20.4	4.7	3.3			Table 19
OxA-20760	2911±28	GG71 119a	1971 Pit	Animal bone	−21.5	5.1	3.4	SUERC-24109, SUERC-25612, SUERC-25613, OxA-21156		Table 21
OxA-20761	2586±29	GG71 333	1971 Pit	Animal bone	−21.0	8.4	3.3			Table 21
OxA-20804	3933±29	GG71 sample 216	1971 Pit	Charcoal	−24.7					Table 5
OxA-20983	3942±29	GG71 sample 227	1971 Pit	Charcoal	−25.3			OxA-21023, OxA-20984, OxA-21024, OxA-X-2415-39		" "
OxA-20984	4006±29	GG71 sample 227	1971 Pit	Charcoal	−25.8			OxA-21023, OxA-20983, OxA-21024, OxA-X-2415-39		" "
OxA-21023	3917±29	GG71 sample 227	1971 Pit	Charcoal	−26.0			OxA-20983, OxA-20984, OxA-21024, OxA-X-2415-39		" "
OxA-21024	4017±29	GG71 sample 227	1971 Pit	Charcoal	−26.1			OxA-21023, OxA-20983, OxA-20984, OxA-X-2415-39		" "

Lab no	Radiocarbon age (BP)	Sample reference	Feature	Material	$\delta^{13}C$ (‰)	$\delta^{15}N$ (‰)	C:N	Replicate of	Date list	Sample and context description
OxA-21156	2728±28	GG71 119c	1971 Pit	Animal bone	−21.9	4.5	3.5	SUERC-24109, OxA-20760, SUERC-25612, SUERC-25613		Table 21
OxA-21187	3960±31	GG73 159	F6	Antler	−21.9	6.6	3.3			Table 17
OxA-21188	3988±32	GG74 136 B	F7	Antler	−23.0	5.9	3.3	SUERC-25718		" "
OxA-21189	3946±31	GG74 168	F7	Antler	−22.4	4.4	3.3			" "
OxA-21190	3915±32	GG74 183	F7	Antler	−22.7	6	3.3	OxA-21191		" "
OxA-21191	4015±31	GG74 183	F7	Antler	−22.7	6	3.3	OxA-21190		" "
OxA-21192	3988±31	GG76 1408	F105	Antler	−22.4	3.3	3.3			Table 19
OxA-21193	1930±29	ARC 79 5017	trench 3	Animal bone	−21.7	5.2	3.4	BM-1546, OxA-1635		Table 21
OxA-22433	3034±29	Longworth cat. no. 238	Black Hole	Carbonised residue	−23.5	4.5	12.3			Table 20
OxA-22434	3375±30	Longworth cat. no. 73 a	Black Hole	Carbonised residue	−24.9	4.2	11.2	SUERC-28758		" "
OxA-22435	3071±29	GG72 274 a	1972 Pit	Carbonised residue	−25.5	5	11.6	SUERC-28759		" "
OxA-22436	3072±29	GG72 735 a	1972 Pit	Carbonised residue	−23.8	4.8	12.1	OxA-22437, SUERC-28760		" "
OxA-22437	3110±29	GG72 735 a	1972 Pit	Carbonised residue	−24.3	4.3	11.8	OxA-22436, SUERC-28760		" "
OxA-22438	3113±30	GG72 1246 a	1972 Pit	Carbonised residue	−25.2	4.8	12.4	SUERC-28761		" "
OxA-22439	4014±34	502 a (BM 1987 2-2 212)	Greenwell's Pit	Carbonised residue	−27.1	8.9	5.6	SUERC-28762		Table 8
OxA-22440	3080±28	GG76 L1576	Pit X	Carbonised residue	−24.7	3.6	11.3			Table 20
OxA-22441	3041±28	GG76 L1899a	Pit X	Carbonised residue	−25.1	4.7	12	SUERC-28767		" "

Lab no	Radiocarbon age (BP)	Sample reference	Feature	Material	$\delta^{13}C$ (‰)	$\delta^{15}N$ (‰)	C:N	Replicate of	Date list	Sample and context description
OxA-22528	3220±28	1929 5-8 1	Pit 3	Animal bone	−21.4	4.7	3.3			Table 19
OxA-22529	3318±27	GG76 Pit 3A sf 46 a	Pit 3 A	Animal bone	−20.7	5.7	3.2	SUERC-28742		" "
OxA-22530	3185±27	A90	Pit 4	Animal bone	−20.6	4.7	3.2			" "
OxA-22531	3194±26	'Pit VI 12-6'	Pit 6	Animal bone	−20.4	5.4	3.2			" "
OxA-22532	3954±29	306	Pit 11 D	Antler	−22.7	6.5	3.2			Table 10
OxA-22533	2127±25	Skeleton 1	1971 Pit	Human bone	−19.6	9.3	3.2			Table 21
OxA-22576	2997±29	Longworth cat. no. 239 a	Black Hole	Carbonised residue	−26.9	5	10	SUERC-28757		Table 20
OxA-22577	3943±31	611a (BM 1987 2-2 213)	Greenwell's Pit C	Carbonised residue	−27.2	7.1	6.2	611 b (BM 1987 2-2 213)		Table 8
OxA-23095	4054±27	530	Greenwell's Pit	Antler	−22.4	5.5	3.2			" "
OxA-23096	4083±28	538	Greenwell's Pit	Antler	−23.0	5.2	3.2			" "
OxA-23097	3969±27	647	Greenwell's Pit C	Antler	−22.7	5.8	3.2	BM-1029		" "
OxA-23098	4092±27	720	Greenwell's Pit D	Antler	−22.7	6.2	3.2	OxA-23099		" "
OxA-23099	4130±27	720	Greenwell's Pit D	Antler	−22.6	6.1	3.2	OxA-23098		" "
OxA-23100	4120±29	733	Greenwell's Pit D	Antler	−22.8	6.9	3.2			" "
OxA-23101	4048±28	843	Greenwell's Pit E	Antler	−23.4	6.1	3.2			" "
OxA-23102	3930±27	845	Greenwell's Pit E	Antler	−22.3	4.4	3.2			" "
OxA-23103	3978±27	923	Greenwell's Pit A	Antler	−21.7	6.5	3.2	BM-1050, BM-3088		" "
OxA-23104	3932±27	974b	Greenwell's Pit A	Antler	−22.7	5.3	3.2			" "

Lab no	Radiocarbon age (BP)	Sample reference	Feature	Material	$\delta^{13}C$ (‰)	$\delta^{15}N$ (‰)	C:N	Replicate of	Date list	Sample and context description
OxA-23105	4063±28	304 A	Pit 11 D	Antler	−21.2	6.3	3.2	SUERC-30912		Table 10
OxA-23106	4071±28	308	Pit 11 A	Antler	−23.0	4.8	3.2			" "
OxA-23107	4029±27	311	Pit 11 A	Antler	−22.7	4.9	3.2			" "
OxA-23108	4133±28	315	Pit 11 E	Antler	−22.1	4.2	3.3			" "
OxA-23109	4007±28	332a	Pit 11 D	Antler	−21.6	6.4	3.2	BM-983		" "
OxA-23110	4112±28	344	Pit 11 F	Antler	−23.9	4.6	3.3			" "
OxA-23111	4076±27	50	Pit 15 C	Antler	−22.8	6.8	3.2			Table 13
OxA-23112	4102±28	56 B	Pit 15 C	Antler	−22.9	6.1	3.2	SUERC-30904		" "
OxA-23144	3943±47	58	Pit 15 C	Antler	−22.4	4	3.3			" "
OxA-23145	3933±27	1546	Pit 15 C/K	Antler	−22.4	5.5	3.2			" "
OxA-23146	4003±29	1551 (1)	Pit 15 C/K	Antler	−22.2	6.3	3.3			" "
OxA-23147	3922±29	1557	Pit 15 C/K	Antler	−22.6	5.8	3.3			" "
OxA-24081	3979±30	GG71 sample 220	1971 Pit	Charcoal	−28.2					Table 5
OxA-24082	4004±29	GG71 sample 240	1971 Pit	Charcoal	−26.8			OxA-X-2415-43		" "
OxA-X-2415-39	3858±28	GG71 sample 227	1971 Pit	Charcoal	−25.8			OxA-21023, OxA-20983, OxA-20984, OxA-21024		" "
OxA-X-2415-43	3974±25	GG71 sample 240	1971 Pit	Charcoal	−26.5			OxA-24082		" "
SUERC-18816	4020±30	A612	1971 Pit	Antler	−22.9					" "
SUERC-18820	4125±30	A619b	1971 Pit	Antler	−22.1			GrA-39260		" "
SUERC-18821	4065±30	A624	1971 Pit	Antler	−22.3					" "
SUERC-18822	4120±30	A730	1971 Pit	Antler	−22.4					" "
SUERC-18823	4085±30	A751	1971 Pit	Antler	−20.8					" "
SUERC-24096	4090±30	'S side in chalk at 6 ft'	Pit 12	Antler	−22.0	6.2	3.4			Table 11

Lab no	Radiocarbon age (BP)	Sample reference	Feature	Material	$\delta^{13}C$ (‰)	$\delta^{15}N$ (‰)	C:N	Replicate of	Date list	Sample and context description
SUERC-24097	3975±35	'chalk of *** of gal 2'	Pit 12	Antler	−22.9	4.6	3.3			" "
SUERC-24098	4015±30	'1933 gal 2' b	Pit 12	Antler	−21.9	6.9	3.4	OxA-20750		" "
SUERC-24099	4040±30	'gal 3' b	Pit 12	Antler	−22.5	6.6	3.3	OxA-20754		" "
SUERC-24100	4015±30	'2ft from bottom, in filling'	Pit 14	Antler	−22.6	5.7	3.3			Table 12
SUERC-24101	4055±30	'Filling at back of S. Gal. Near floor'.	Pit 14	Antler	−22.9	5.8	3.3			" "
SUERC-24102	4030±30	'filling of gal 3' b	Pit 14	Antler	−21.2	6.1	3.3	OxA-20756		" "
SUERC-24106	4045±30	'NE sector at 7 ft'	Pit 14	Antler	−20.2	6.5	3.3			" "
SUERC-24107	3995±30	'S end close to mouth of cove'	Pit 14	Antler	−23.1	5.7	3.2			" "
SUERC-24108	3295±30	251	Pit 15 D	Animal bone	−21.3	6.2	3.3			Table 19
SUERC-24109	2760±30	GG71 119b	1971 Pit	Animal bone	−22.7	5.4	3.3	OxA-20760, SUERC-25612, SUERC-25613, OxA-21156		Table 21
SUERC-24110	4040±30	A598b	1971 Pit	Antler	−21.8	5.9	3.3	OxA-20709		Table 5
SUERC-24111	4085±30	A611b	1971 Pit	Antler	−21.7	5.8	3.2	OxA-20711		" "
SUERC-24112	4095±30	A688	Pit to NE of 1971 Pit	Antler	−23.3	5.4	3.3			" "
SUERC-24116	4155±35	A763	Pit to NE of 1971 Pit	Antler	−22.0	5.1	3.4			" "
SUERC-24117	4090±30	A771	Pit to NE of 1971 Pit	Antler	−22.7	5.8	3.3			" "
SUERC-24118	3855±30	GG73 L186	1972-74 knapping floor	Antler	−23.5	6.7	3.3			Table 6

Lab no	Radiocarbon age (BP)	Sample reference	Feature	Material	$\delta^{13}C$ (‰)	$\delta^{15}N$ (‰)	C:N	Replicate of	Date list	Sample and context description
SUERC-24119	3945±30	GG74 L403	1972-74 knapping floor	Antler	−22.4	6.2	3.3			" "
SUERC-24120	4010±35	GG73 160	F6	Antler	−22.6	6.3	3.3			Table 17
SUERC-24121	3245±30	GG76 1580	F105	Animal bone	−20.8	4.7	3.2			Table 19
SUERC-24122	3290±30	GG76 1582	F105	Animal bone	−21.2	4.6	3.3			" "
SUERC-24126	3370±35	GG76 Pit 3A sf 48	Pit 3 A	Animal bone	−21.0	6	3.4			" "
SUERC-24127	3090±30	GG76 102	Pit X	Animal bone	−21.0	6.5	3.4			Table 20
SUERC-24128	3095±30	GG76 221	Pit X	Animal bone	−22.2	6	3.3			" "
SUERC-24129	3995±30	'S side near wall at 9 ft'	Pit 14	Antler	−22.6	6.2	3.4			Table 12
SUERC-24130	4045±30	GG71 sample 224	1971 Pit	Charcoal	−28.0					Table 5
SUERC-25612	2795±40	GG71 119b	1971 Pit	Animal bone	−22.3	5.4	3.3	SUERC-24109, OxA-20760, SUERC-25613, OxA-21156		
SUERC-25613	2820±40	GG71 119d	1971 Pit	Animal bone	−22.3	5.2	3.2	SUERC-24109, OxA-20760, SUERC-25612, OxA-21156		" "
SUERC-25711	4010±40	GG73 152	F6	Antler	−20.1	5.2	3.3			Table 17
SUERC-25712	4095±40	GG73 154	F6	Antler	−22.0	5.4	3.3			" "
SUERC-25713	4065±40	GG73 158	F6	Antler	−22.8	6.7	3.3			" "
SUERC-25717	4220±40	GG74 165	F7	Antler	−21.5	6.4	3.3			" "
SUERC-25718	4065±40	GG74 136 A	F7	Antler	−22.9	6.7	3.3	OxA-21188		" "
SUERC-25719	4215±40	GG76 Pit 3A sf 23	Pit 3 A	Antler	−22.5	5.2	3.3			Table 19
SUERC-28742	3240±35	GG76 Pit 3A sf 46 b	Pit 3 A	Animal bone	−21.4	5.5	3.3	OxA-22529		" "

Lab no	Radiocarbon age (BP)	Sample reference	Feature	Material	δ^{13}C (‰)	δ^{15}N (‰)	C:N	Replicate of	Date list	Sample and context description
SUERC-28743	3400±35	GG76 Pit 3A sf 53	Pit 3 A	Animal bone	−21.0	5.6	3.4			" "
SUERC-28747	3200±35	A91	Pit 4	Animal bone	−21.0	6.5	3.3			" "
SUERC-28748	3295±35	'Pit VI Bottom'	Pit 6	Animal bone	−21.3	6	3.3			" "
SUERC-28749	3950±35	'Pit 10 under W wall in cove at 6 ft'	Pit 10	Antler	−22.3	4.5	3.3			Table 17
SUERC-28750	3830±35	'Pit 10. N side in rubble at 6 ft (1)'	Pit 10	Antler	−22.4	6.3	3.4			" "
SUERC-28751	5620±35	318	Pit 11 E	Antler	−23.8					Table 10
SUERC-28752	4055±35	54	Pit 15 C	Antler	−23.5	4.8	3.3			Table 13
SUERC-28753	2210±35	Skeleton 2	1971 Pit	Human bone	–20.9	9.1	3.3			Table 21
SUERC-28757	3090±35	Longworth cat. no. 239 b	Black Hole	Carbonised residue	−27.2			OxA-22576		Table 20
SUERC-28758	3050±35	Longworth cat. no. 73 b	Black Hole	Carbonised residue	−27.8			OxA-22434		" "
SUERC-28759	3060±35	GG72 274 b	1972 Pit	Carbonised residue	−26.1			OxA-22435		" "
SUERC-28760	3155±35	GG72 735 b	1972 Pit	Carbonised residue	−26.2			OxA-22436, -22437		" "
SUERC-28761	3095±35	GG72 1246 b	1972 Pit	Carbonised residue	−26.1			OxA-22438		" "
SUERC-28762	4130±35	502 b (BM 1987 2-2 212)	Greenwell's Pit	Carbonised residue	−27.5			OxA-22439		Table 8
SUERC-28763	3130±35	GG76 L2409, L2420	Pit X	Carbonised residue	−26.1					Table 20
SUERC-28767	3105±35	GG76 L1899b	Pit X	Carbonised residue	−25.4			OxA-22441		" "

Lab no	Radiocarbon age (BP)	Sample reference	Feature	Material	$\delta^{13}C$ (‰)	$\delta^{15}N$ (‰)	C:N	Replicate of	Date list	Sample and context description
SUERC-30903	4095±35	47	Pit 15 C	Antler	−22.9	5.5	3.3	BM-997		Table 13
SUERC-30904	4105±35	56 A	Pit 15 C	Antler	−23.1	5.8	3.5	OxA-23112		" "
SUERC-30905	4085±35	57	Pit 15 C	Antler	−22.3	7.2	3.3			" "
SUERC-30906	4250±30	59	Pit 15 C	Antler	−22.6	5.7	3.7			" "
SUERC-30907	3890±35	1550 (2)	Pit 15 C/K	Antler	−22.8	5.9	3.6			" "
SUERC-30911	3970±30	1552 (2)	Pit 15 C/K	Antler	−23.2	5.2	3.4			" "
SUERC-30912	3945±30	304 B	Pit 11 D	Antler	−21.5	6.5	3.4	OxA-23105		Table 10
SUERC-30914	4030±35	314	Pit 11 E	Antler	−22.2	6.5	3.3			" "
SUERC-30915	4000±35	320	Pit 11 E	Antler	−23.0	5.9	3.3			" "
SUERC-30916	3955±30	342	Pit 11 F	Antler	−23.0	4.1	3.3			" "
SUERC-30917	4240±35	343 A	Pit 11 F	Antler	−22.4	5	3.5			" "
SUERC-30921	4040±35	503	Greenwell's Pit	Antler	−22.6	6.7	3.3			Table 8
SUERC-30922	4055±35	523	Greenwell's Pit	Antler	−22.8	6.3	3.4			" "
SUERC-30923	4045±35	531	Greenwell's Pit	Antler	−22.3	5.8	3.4			" "
SUERC-30924	3865±35	627	Greenwell's Pit C	Antler	−22.7	4.6	3.4			" "
SUERC-30925	4030±35	719	Greenwell's Pit D	Antler	−22.5	6.1	3.3			" "
SUERC-30926	4045±35	736	Greenwell's Pit D	Antler	−22.3	6.2	3.3			" "
SUERC-30927	4135±35	844	Greenwell's Pit E	Antler	−23.1	4.6	3.3			" "
SUERC-30931	3955±35	846	Greenwell's Pit E	Antler	−23.0	5.9	3.3			" "
SUERC-30932	3960±35	974a	Greenwell's Pit A	Antler	−22.4	4.8	3.3			" "

APPENDIX 2: EXPERIMENTAL PRETREATMENT

Following a realisation that SUERC removed consolidants by mechanical rather than chemical means, questions arose as to the efficacity of this procedure (§2.1.1.2).

Elaine Dunbar of SUERC consequently undertook a series of experimental treatments, pretreatments and radiocarbon measurements on samples of bone with a known age of 2130±60 BP (380 cal BC–cal AD 10). The results are shown in Table 31 and Figure 75. Sixteen samples were taken from the laboratory bone standard. Ten of these were left unconsolidated and were pretreated and radiocarbon dated according to SUERC's standard procedures (Table 31). The weighted mean of these results provided a baseline of 2140±11 BP against which to compare the results for the other six samples.

These remaining samples were coated with polyvinyl acetate (PVA) before undergoing the various forms of pretreatment, with or without ultrafiltration, listed in Table 31 and then being radiocarbon dated. In every case, whatever pretreatment(s) were used, the measurements for the PVA'd samples were older than the weighted mean for the untreated ones. The offsets ranged from −6340±37 years for sample KAB41, which was cold-filtered without ultrafiltration or solvent extraction, to −590±37 years for sample KAB49, which underwent solvent extraction with ethanol and ultrafiltration. Even the lowest of these is unacceptable. It can only be concluded that none of the pretreatments used in this experiment was successful in removing all of the PVA.

APPENDIX 3: HOCKHAM MERE

History of research

Godwin and Tallantire

Hockham Mere, a now largely drained basin in the Breckland 13km east of Grime's Graves at NGR TL 933 937, is significant in the history of pollen analysis in the region. It has been the subject of three successive analyses by members of the Cambridge Botany School, attracted by the length of its sequence, from the Late Glacial to the Saxon period. In the original research, coring and pollen analysis undertaken in 1940 and 1941, Godwin and Tallantire (1951) defined a sequence from open birch-pine woodland through deciduous woodland to open conditions with relatively few trees. The transition between zones VIIa and VIIb was marked by the elm decline (its defining feature, seen as roughly corresponding to the beginning of the Neolithic) and was soon followed by a substantial decrease in the proportion of tree pollen to non-tree pollen, which consisted mainly of grasses but also included ferns and ericaceous species as well as Plantago. This was interpreted as reflecting Neolithic land clearance and cultivation, initiating the heathland vegetation which came to characterise the area in historical times. A further rise in non-tree pollen at the zone VIIb/VIII boundary was accompanied by a further rise in ericaceous species and tentatively attributed to the Iron Age or later.

The form and stratigraphy of the basin were determined by means of 29 borings, in three north-west transects and one east-west. These made it possible to define an irregular profile for the basin, across which deposits varied in character, especially towards the top of the sequence, and shelved from the sides to the centre (Godwin and Tallantire 1951, fig 5). The combination of pollen analysis and multiple borings showed that the sequence was continuous only in the deeper, central part of the basin. Closer to the edges, deposits of dried, reworked material, including the remains of dry-land plants, extended from the shore into undisturbed lake deposits. These were interpreted as resulting from the subsequent erosion of exposed lake muds which had dried out during a period of low water level, attributed to the late Boreal on the evidence of an hiatus in the pollen sequence where these deposits occurred (Godwin and Tallantire 1951, 290–1).

Dating depended almost entirely on the attribution of successive deposits to pollen zones already defined not only for Britain but for north-west Europe. A pioneering step was the measurement by Willard Libby, on 2kg of mud from zone III, of two radiocarbon dates with a mean of 6020–4850 cal BC at 95% confidence (6555±280 BP; C-349). This was considered 'too young by several thousand years' for deposits attributed to the Late Glacial (ibid, 302). A radiocarbon date of 2580–2040 cal BC (95% confidence; 3880±90 BP; Q-9) later obtained for mud from the zone VIIa/VIIb boundary was considered '2000 yr younger than would be expected from other W European determinations' (Godwin and Willis 1961, 74).

Sims

Two decades later, Sims (1973; 1978) applied the greatly developed techniques of the day, and the capacity to identify many more taxa, to two cores from the upper part of the sequence, approximately from Godwin's and Tallantire's zone VI upwards, sampling approximately 5m of deposit, as distinct from their 9m. Local pollen zones were defined, and chronology was provided by a series of 13 radiocarbon dates (Switsur and West 1973, 539–40) measured on samples of mud from the cores, at a coarser resolution than the pollen samples which were taken from 6mm sections of core (Sims 1973, 231). The sequence followed that of Godwin and Tallantire, but with far more detail. Radiocarbon samples were clustered at the levels which appeared to be of particular interest, and were only sometimes taken across zone boundaries (Table 32, Figure 76). While Sims states that radiocarbon measurements were made on 8cm samples of mud from the cores (1973, 231), the datelist (Switsur and West 1973) records that sample thickness was based on carbon content and records the variable thicknesses shown in Table 32, which range from 8cm to 16cm. Most radiocarbon samples came from a single core, with a further five (Q-1045 to -1049) coming from a separate core 3m away (Sims 1978, 58). It is not clear how the age (BP) of particular events was estimated. It may have been read from a plot of age against sediment depth. Sims sought to identify small-scale, short-lived variations and to interpret them, often in terms of human intervention; the close focus of this analysis is reflected in his definition of 13 local zonules in 5m depth of deposit.

Bennett

A decade later again, with still further developed techniques, Bennett (1983a) sampled the whole of the sequence of 11m of deposit in the deepest part of the basin (Bennett 1983a, 460; 1983b, fig 1). Chronology was provided by a series of 23 radiocarbon dates, measured on samples of mud from the cores. The age (BP) of particular events was read from a plot of age against sediment depth (Bennett 1983a, 463). As in the Sims sequence, radiocarbon samples were clustered at levels of interest, but they were in addition systematically taken across zone boundaries (Table 33, Figure 77). They ranged in thickness from 4–6cm. Most came from two complete series of overlapping cores from adjacent boreholes, together with additional samples from the upper part of the sequence. The interval between pollen samples is not stated. Bennett focussed on longer-term vegetation change, with less emphasis on anthropogenic effects and more emphasis on ecological processes than Sims, and with a particular interest in the earlier part of the sequence. It is telling that he indentified only eight local zones or subzones in 11m of deposit and that his subzone 5b corresponds to zonules Hr-5, Hr-6 and Hr-7 of Sims' scheme.

Chronological discrepancy

A major and surprising development was that, while Bennett's vegetation history could be equated with the two previous ones (Bennett 1983a, fig 8), the later stages of his chronology were at variance with Sims' dating, his pollen zones being significantly more recent than their equivalents in Sims' sequence. (ibid, fig 3). Bennett's preferred reason for the chronological discrepancy was that Sims' sampling site, the location of which is imprecisely known, may have been closer to the edge of the lake than his and hence more susceptible to the inwash of older material into the sediment (1983a, 464). Sims, however, describes his sampling site as 300m from the nearest shore (1973, 233), which, depending on which part of the shore was nearest, might place it beyond the extent of the inwashed sediments identified by Godwin and Tallantire (1951, fig 2). Bennett also discusses the possible effects of different methods of sample pre-treatment. Pretreatment of the Sims' samples included boiling in potassium hydroxide solution to remove alkali-soluble humic acids in order to guard against their moving down the profile and introducing younger carbon into old sediment. This was not, however, done for the Bennett samples because it was felt that such movement would not occur in permanently waterlogged limnic sediments (ibid, 463–4). The probable role of extraneous humic acid in the generation of inaccurately recent radiocarbon dates for charcoal from Grime's Graves measured in the 1970s (§2.1.1) suggests that this difference in pretreatment might be significant, the widening of the discrepancy towards the surface reflecting the input of humic acid in run-off and rainwater. But this must remain speculative. Sample depths cannot be compared between the Sims and Bennett analyses, since, quite apart form the cores' having been taken at different locations in the shelving sediments of the basin, the depths were not measured from a common datum. It is unclear from what Sims' depths were measured, while Bennett's were measured from the surface of the water, encountered at 0.4m below the surface of the ground when coring (ibid, 460).

Chronological Modelling

Separate models for the two sequences of radiocarbon dates are shown in Figures 76 and 77. Each is constructed following Bronk Ramsey and Lee (2013), using a P_Sequence deposition model in which deposition is assumed to be random giving approximate proportionality to depth, in these cases without calculating interpolated points between those entered in the model ('P_Sequence("variable",1,0,U(-2,2))'). In both cases, the depths ascribed to the samples are the midpoints of their thickness and, where a sample was taken across a boundary between two pollen zones, its midpoint is taken as the location of that boundary even if slightly different from the depth specified for that boundary. If a separate estimate were made for the boundary, the result would be two very similar distributions obscuring each other on the graph. In the Sims sequence, for example, the depth of the boundary between H-r4 and H-r5 can be read off the pollen diagram (Sims 1978, fig 2) as 306cm, while the midpoint of the sample for Q-1048, which straddles it, is 304cm. Where no sample was taken across a boundary, the age of that boundary is estimated using the Date function. Outliers were detected following Bronk Ramsey (2009b), by means of a general outlier model ('Outlier_Model ("general", T(5), U(0,4), t)'). This assigns each measurement a prior probability of 0.05 of being an outlier and, as it runs, averages over cases where each measurement is assumed to be contemporary with its context and cases where it is not calculating a posterior outlier probability which indicates how likely it is that the measurement is inconstant with its context (Bronk Ramsey *et al* 2010).

No outliers were detected in the model shown in Figure 76 for the Sims sequence, and it has good overall agreement (A_{model}: 115). The smooth, regular form of the curve suggests unbroken deposition through the sequence. It is possible to calculate an overall sediment accumulation rate of 0.5–0.6mm per annum (Table 34).

Two potential outliers were detected in the model shown in Figure 77 for the Bennett sequence (Q-2224 with a posterior outlier probability of 0.06 and Q-2203 with a posterior outlier probability of 0.11). The model has good overall agreement (A_{model}: 108). This model contrasts, however, with the first one in that there are two marked points of inflexion in the curve, both also visible in Bennett's plot of age against sediment depth (1983a, fig 2). The first, at the boundary of zones HM-1 and HM-2 at *9130–8980 cal BC* (*11% probability*) or *8940–8550 cal BC* (*84% probability*, Fig 77: *Q-2207*) corresponds to an increase in tree, especially Betula, pollen to almost 90% (Bennett 1983a, fig 6) which led to a change in sedimentation from predominantly inorganic sands and silts, to more rapidly accumulating lake muds, as the formation of closed woodland reduced the wind-blown and inwashed mineral input to the lake. There is a corresponding change in sediment accumulation rate from 0.1–0.2mm to 1.3–1.5mm per annum (Table 34). This change in sedimentation was complete by the boundary between HM-2 and HM-3 at *8830–8310 cal BC* (*95% probability*, Fig 77: *Q-2209*), when denser, Corylus-dominated woodland developed (Bennett 1983a, 465; 1983b, 494).

Above this, the curve is smooth, like that for the Sims sequence, until the boundary of zones HM-5a and HM-5b at *3390–2900 cal BC* (*91% probability*, Fig 77: *Q-2222*), where the curve becomes less abrupt, the estimate rate of sediment accumulation dropping to 0.5–0.6mm per annum. This corresponds to no change in sediment type, and, viewed alone, might simply reflect a reduced rate of sedimentation as the lake infilled. It is not matched in the Sims sequence, which suggests that the upper deposits in the two locations may have had different histories. They can have been, at most, 300m apart, this being the maximum distance between the location of Bennett's cores (Bennett 1983b, fig 1) and a line drawn 300m in from the approximate edge of the lake (Godwin and Tallantire 1951, fig 2), following Sims' statement that his cores were 300m from the nearest shore (1973, 233). Differences in sedimentation rate might be expected between the deepest and less deep parts of the basin, but this is not apparent: the corresponding upper zones of both have the same sedimentation rate (Table 34, final row). It is possible that Bennett's upper samples were more scattered than Sims', since he records taking additional samples to those from his two adjacent boreholes in this part of the sequence (1983a, 460).

By this stage the chronologies of corresponding pollen zones in the two sequences have already begun to diverge. Figure 78 shows dates for zone boundaries derived from the models shown in Figures 76 and 77, simply arranged in stratigraphic order without further constraint. Table 35 compares those parts of the Godwin and Tallantire, Sims, and Bennett sequences which relate to the use of Grime's Graves, employing Bennett's correlation between them (Bennett 1983a, fig 8), which is based on palynological events. Inspection of the three diagrams (Godwin and Tallantire 1951, figs 3, 4, 12, 13; Sims 1978, fig 2; Bennett 1983a, fig 6) confirms Bennett's correlation and suggests one addition: the later part of Bennett's zone HM-5b, starting at the level of Q-2223, seems to equate to Sims' zone H-r7.

Estimates for the first shared zone boundary (Sims' H-r1/H-r2 and Bennett's HM-3b/HM-4) are comparable, at *6330–5730 cal BC* (*95% probability*, Figs 76 and 78: *H-r1 H-r2 boundary*) and *6240–5990 cal BC* (*95% probability*, Figs 77 and 78: *Q-2219*). Application of the Combine function in OxCal (§4.4.16) indicates that they could indeed relate to the same event (n=2, A_{comb}=117.7%, A_n=50%). From the sixth millennium cal BC onwards, however, discrepancies widen (Fig 78). Sims' H-r3/H-r4 boundary falls at *5780–5360 cal BC* (95% *probability*, Figs 76 and 78: *Q-1087*); Bennett's equivalent HM-4/HM5a boundary falls at *5220–4690 cal BC* (*95% probability*, Figs 77 and 78: *Q-2221*), *305–985 years later* (*95% probability*, Fig 79: *start H-r4/start HM-5a*). Sims' H-r4/Hr-5 boundary falls at *3960–3630 cal BC* (*95% probability*, Figs 76 and 78: *Q-1048*) Bennett's equivalent HM-6a/HM-5b boundary falls at *3390–2900 cal BC* (*90% probability*, Figs 77 and 78: *Q-2222*), *240–960 years* later (*95% probability*, Fig 79: *start H-r5/start HM-5b*). Sims' H-r7/H-r8 boundary falls at *2500–2200 cal BC* (*94% probability*, Figs 76 and 78: *Q-1095*); Bennett's equivalent HM-5b/HM-5c boundary falls at *120 cal BC–cal AD 130* (*92% probability*, Figs 77 and 78: *Q-2224*), this time *2110–2590 years* later (*95% probability*, Fig 79: *start H-r8/start HM-5c*). These last are such vastly different estimates for a major opening up of the landscape that it is difficult to see them in as simply reflecting the vegetation histories of different parts of the catchment. The dating of the upper part of the Hockham Mere sequence is problematic.

The two pioneering radiocarbon dates from the site, C-349 and Q-9, are also shown in Figure 78. Both are considerably younger than any subsequently obtained from comparable horizons in either sequence, confirming the original opinion of those who commissioned them, that they were too recent.

Discussion

Comparanda?

It is difficult to resolve the chronological discrepancy by reference to other dated local pollen sequences. Some of these lie to the west, in the Fens (eg Waller 1994), where vegetation history is so heavily influenced by local fluctuations in wetness as to preclude comparison with other regions. To the east, other south Norfolk meres at Stow Bedon (Bennett 1986) and Quidenham (Peglar 1993), although physically close, lie on the Boulder Clay of central East Anglia, where vegetation and land use differ substantially from those of the Breckland even today and differed even more in historical times.

The Breckland heaths

Given the historical vegetation of the Breckland, a salient question is how and when its tracts of heathland developed. For Godwin and Tallantire things were simple, 'It seems beyond doubt that the present curves show an anthropogenic origin of the Breckland heaths in Neolithic time' (1951, 305), although these authors showed that the same developments continued and intensified into their zone VIII, when,

'*These features seem to point to a new type of forest clearance leading to the formation chiefly of grass-heath. Unfortunately, the difficulties of zoning the upper parts of the diagram allow us no means of dating this intensification of forest destruction: one might perhaps expect it to be an effect of the Iron Age cultivation . . . or it might equally relate to the early historic Saxon period* (1951, 305).

By this time, however, a two-page note published in Nature (Godwin 1944) had told a simpler story, focussing on a Neolithic origin for the heaths. This made a dramatic impact at the time, and became lodged in the archaeological and wider memory.

In the Sims sequence, heathland taxa are present at low levels from the first, increasing at the start of H-r7 (*3160–2450 cal BC* (*95% probability*, Fig 76: *H-r6/H-r7 boundary*)) and showing a more substantial, sustained and progressive increase, together with grassland taxa, from the start of H-r8 (*2500–2200 cal BC* (*94% probability*, Fig 76: *Q-1095*)) to at least the end of H-r12 (*cal AD 770–970* (*95% probability*, Fig 76: *Q-1090*)), the process being interpreted as anthropogenic. Sims saw a step change in the extent of clearance, cultivation and heathland development at the start of H-r9 (*1360–670 cal BC* (*95% probability*, Fig 76: *H-r8/H-r9 boundary*). In the Bennett sequence, heathland taxa are similarly present at low levels from early on, increasing, together with grasses and non-tree pollen in general, in the later part of HM-5b (starting *930–770 cal BC* (*95% probability*, Fig 77: *Q-2223*)), all continuing to increase through HM-5c (running from *120 cal BC–cal AD 130* (*92% probability*, Fig 77: *Q-2224*) to at least *cal AD 330–550* (*95% probability*, Fig 71: *Q-2225*)). Bennett saw minimal, short-lived Neolithic impact on the local vegetation, with widespread clearance and the development of heathland starting only in the late first millennium cal BC in HM-5c.

Other kinds of evidence for vegetation support the Bennett chronology. It is pertinent that Mollusca from the 1B deposits in the top of the 1971 Pit at Grime's Graves, dated to the early first millennium cal BC (Fig 62), show that these deposits accumulated in a hollow surrounded by deciduous woodland with dense leaf litter with more open conditions developing only subsequently, and that charcoal from the same contexts is overwhelmingly from deciduous species (Evans and Jones 1981). Farther afield in the Breckland, there were no heathland taxa among the charcoal from Beaker and middle Bronze Age contexts at Fison Way, Thetford, although they abounded among the charcoal and charred plant remains from late-first millennium cal BC to early first millennium cal AD contexts at the site (Murphy 1991), as well as in the early first millennium cal AD Gallows Hill turf stack nearby (Le Hegarat and Lawson 1986). At Game Farm, Brandon, charcoal from second millennium contexts is overwhelmingly deciduous, the single feature with a low proportion of heathland material being an unurned cremation burial (Gale 2004); heathland taxa were, on the other hand, well represented in a 0.36m pollen profile from the Little Ouse floodplain to the north of the site which partly, and probably wholly, postdated the Bronze Age occupation on the evidence of Roman pottery at 0.14m (Scaife 2004). Mollusca from the ditches of a late Iron Age enclosure at Barnham, Suffolk, 14km south-east of Grime's Graves, indicated that it stood in an open landscape of short grassland and unstable soils (Murphy 1993). Single pollen samples from a late Iron Age/early Roman pit and a Roman ditch at Lynford quarry indicated predominantly open grassland conditions and included some heathland taxa (Green 2005).

As far as these site-specific records go, they accord with the development of significant areas of heathland in the centuries around the turn of the first millennia cal BC and cal AD.

Furthermore, OSL dating, supplemented by a single radiocarbon date, of Breckland dunes at Wangford Warren and Santon Downham points to a period of stability from the late Mesolithic to the early historic period, since when intermittent Aeolian activity, with its connotations of bare ground, led to repeated dune formation which has continued almost to the present (Bateman and Goodby 2004).

Repercussions

Hockham Mere has a place in archaeological consciousness as well as in vegetation history. The results of the original analysis, although expressed in terms of an ongoing process of unknown duration by the authors, became condensed into a belief that Neolithic forest clearance gave rise to the Breckland heaths. This has become a fall-back for time-poor archaeologists, as in 'Pollen evidence from Hockham Mere suggests that the Early Neolithic, from *c* 3800 BC onwards, saw widespread woodland clearance in

Breckland' (Birks and Robertson 2005, 696). It has proliferated among ecologists and natural scientists, as in a recent publication by the Breckland Biodiversity Audit:

'*Breckland was settled and cleared by arriving farmers during the Neolithic, c 6,000 years ago, and still retains post-glacial species requiring open conditions that have disappeared from most of lowland Britain. Subsequent forest clearance, shifting cultivation and stock grazing created more open habitats. A pattern of cereal cultivation and grazing continued through the Bronze Age, Iron Age and Romano-British periods, and after Saxon Estates were subsumed and redistributed by the arriving Normans, continued in varying forms until the late nineteenth century. In general, cereal cultivation was more prevalent in river valleys, with grazed commons and heaths on the drier plateaus and interfluves. However, all aspects of the land use were dynamic, and there have been changes and upheavals through time*' (Dolman *et al* 2010, 12).

It has also taken hold in the wider imagination, generalised across East Anglia to the Suffolk Sandlings by the persuasive pen of W G Sebald:

'. . . *I climbed onto Dunwich Heath, which lies forlorn above the sea. The history of how that melancholy region came to be is closely connected not only with the nature of the soil and the influence of a maritime climate but also, far more decisively, with the steady and advancing destruction, over a period of many centuries and indeed millennia, of the dense forests that extended over the entire British Isles after the last Ice Age. In Norfolk and Suffolk, it was chiefly oaks and elms that grew on the flatlands, spreading in unbroken waves across the gently undulating country right down to the coast. This phase of evolution was halted when the first settlers burnt off the forests along those drier stretches of the eastern coast where the light soil could be tilled. Just as the woods had once colonised the earth in irregular patterns, gradually growing together, so ever more extensive fields of ash and cinders now ate their way into that green-leafed world in a similarly haphazard fashion*' (Sebald 1998, 169).

Palynologists have much to overcome in communicating a more complex story.

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TABLES

Table 1: Summary of radiocarbon measurements by context type and origin

	Pre-existing measurements	No of features	This project's measurements	No. of features
Premining activity	2	2	-	-
Galleried shafts	84	26	103	17
Simple pits on West Field	21	15	15	3
'Primitive' pits	3	2	15	5
Knapping on West Field	7	7	-	-
Other activity on West Field	9	8	-	-
Middens	14	2	18	3
Remaining contexts	5	3	9	2
Totals	145	65	160	30
Grand total 305 measurements from 70 features (the total of features is less than 65+30 because some features figure in both subtotals)				

Table 2: Pretreatment and measurement methods

Year(s) measured	Laboratory numbers	Material	Number of measurements	Pretreatment	Measurement and reporting
British Museum Research Laboratory					
up to 1968	BM-87I	charcoal	1	Acid/alkali/acid protocol	Gas Proportional Counting of acetylene (Barker 1953; Barker and Mackey 1959). Ages not corrected for fractionation, although reported error includes ±80 for fractionation and ±100 for the 'de Vries effect' in addition to the counting errors (Barker and Mackey 1961)
	Numbers between BM-88 and -276	antler	7	Organic fraction extracted using acid only (Barker and Mackey 1961)	
1968	BM-291, -377	antler	2	Organic fraction extracted using acid only (Barker and Mackey 1961)	Liquid Scintillation Counting of benzene (Barker *et al* 1969a; 1969b). Ages not corrected for fractionation, although reported error includes ±80 for fractionation without the ±100 for the 'de Vries effect' previously used in addition to the counting errors (Barker *et al* 1969b, 279)
1968–79	Numbers between BM-811 and -1266	charcoal	41	For numbers between BM-811 and -1266 it is explicitly stated that 'charcoal samples were pretreated by prolonged boiling in dilute hydrochloric acid. The highly calcareous environment in which these materials had been buried precluded contamination by humic acids and no pretreatment with alkali was needed' (Burleigh *et al* 1979, 41)	Liquid Scintillation Counting of benzene (Barker *et al* 1969a; 1969b). Ages corrected for fractionation (Barker *et al* 1971)
	Numbers between BM-291 and -1261	antler	71	Dilute hydrochloric acid and, where appropriate, dilute alkali. One and antler demineralized in low vacuum with 0.75N hydrochloric acid at ambient temperature, leaving only the protein fraction (collagen) which was washed and dried before combustion (Barker *et al* 1971; Burleigh *et al* 1976). For numbers between BM-812 and -1261 it is explicitly stated that 'Antler and bone samples were demineralized with 1N hydrochloric acid at about 20°C to provide pure collagen for ^{14}C age measurement. The highly calcareous environment in which these materials. had been buried precluded contamination by humic acids and no pretreatment with alkali was needed' (Burleigh *et al* 1979, 41)	
	BM-1067, -1546	bone	2		
1985–2000	Numbers between BM-2377 and -3135	charcoal	3	1M HCl followed by washing in water and, where considered necessary, dilute alkali for removal of humic acids (Ambers *et al* 1987)	Liquid scintillation counting of benzene in low potassium glass vials, specially selected for similar backgrounds (Ambers *et al* 1986) as described by Ambers *et al* (1987). Quality assurance as described by Ambers (1998). Ages corrected for fractionation errors include both counting error and an estimate of errors contributed by modern and background samples.
	Numbers between BM-2380 and -3134	antler	14	Treated with cold dilute acid (Ambers *et al* 1987)	
Centrum voor Isotopen Onderzoek, Rijksuniversiteit Groningen					
2008	Numbers between GrA-38913 and -39260	antler	5	Collagen extraction as described by Longin (1971), followed by an extra alkali step	Combusted to carbon dioxide and graphitised as described by Aerts-Bijma *et al* (1997; 2001) and dated by Accelerator Mass Spectrometry as described by van der Plicht *et al* (2000)
Scottish Universities Environmental Research Centre, East Kilbride					
2008–10	SUERC-24130	charcoal	1	Acid-base-acid	Combusted to carbon dioxide Vandeputte *et al* (1996), graphitised (Slota *et al* 1987); dated by Accelerator Mass Spectrometry as described by Xu *et al* (2004) and Freeman *et al* (2007).
	Numbers between SUERC-18816 and -30932	antler	53	Light mechanical cleaning or, if consolidant or other contaminant suspected, surface sanding followed by base wash if humic acid contamination suspected, followed by collagen extraction as described by Longin (1971)	
	Numbers between SUERC-24108 and -28753	bone	14		
	Numbers between SUERC-28757 and -28767	carbonised residue	8	Acid-base-acid	
Oxford Radiocarbon Accelerator Unit					

Year(s) measured	Laboratory numbers	Material	Number of measurements	Pretreatment	Measurement and reporting
1988	OxA-1635	bone	1	Extracted protein purified using ion exchange (Hedges and Law 1989; Law and Hedges 1989)	Combusted to carbon dioxide (Hedges *et al* 1992) and placed into the carbon dioxide ion source in the AMS (Gillespie *et al* 1983; Hedges 1981)
2009–11	Numbers between OxA-20804 and -24082	charcoal	7	Acid-base-acid (Brock *et al* 2010, 104, 107)	Combusted to carbon dioxide and graphitised as described by Brock *et al* (2010, 110) and dated by Accelerator Mass Spectrometry as described by Bronk Ramsey *et al* (2004)
	Numbers between OxA-20709 and -23147	antler	49	Acid-base-acid wash followed by gelatinisation (Longin 1971) and ultrafiltration (Brown *et al* 1988); preceded by solvent extraction where consolidants or other chemical contaminants are suspected, with water, acetone, and methanol for PVA, or with a series of solvents if nature of contaminant uncertain (Brock *et al* 2010, 106–7)	
	Numbers between OxA-20591 and -22533	bone	12		
	Numbers between OxA-22433 and -22577	carbonised residue	11	Sequence of demineralization with 1M HCl; ultrasonication in fresh 1M HCl; rinsing in ultrapure; ultrasonication in fresh ultrapure water; acidification in 1M HCl; rinsing in ultrapure water (Brock *et al* 2010, 108).	

Table 3: Replicate measurements

Those shown in **bold** are statistically inconsistent at 95% confidence. Experimental measurements (OxA-X numbers) are not included. GPC= Gas Proportional Counting, LSC= Liquid Scintillation Counting, AMS= Accelerator Mass Spectrometry. PVA denotes that an antler or bone sample was treated with polyvinyl acetate. British Museum dates with numbers in the 3000s were measured in the 1980s or 1990s.

Feature	Material	Sample reference	Laboratory number	Radiocarbon age (BP)	Method	Weighted mean (BP)
1971 pit	Animal bone	GG71 119	OxA-21156	2728±28	AMS	**2804±15T'=24.25; T'(5%)=9.5; v=4), if OxA-20760 (which lab. concluded is inaccurate) is included** 2765±17T'=4.2; T'(5%)=7.8; v=3, without OxA-20760
			OxA-20760	2911±28		
			SUERC-25613	2820±40		
			SUERC-25612	2795±40		
			SUERC-24109	2760±30		
1971 pit	Antler	A598	OxA-20709	4007±33	AMS	4025±23 T'=0.5; T'(5%)=3.8; v=1
			SUERC-24110	4040±30		
1971 pit	Antler	A611	OxA-20711	4046±35	AMS	4069±23 T'=0.7; T'(5%)=3.8; v=1
			SUERC-24111	4085±30		
1971 pit	Antler	A619	GrA-39260	4100±35	AMS	4114±23 T'=0.3; T'(5%)=3.8; v=1
			SUERC-18820	4125±30		
1971 pit	Single entity charcoal	GG71 sample 227	OxA-21024	4017±29	AMS	**3971±15 T'=8.43; T'(5%)=7.8; v=3**
			OxA-20984	4006±29		
			OxA-20983	3942±29		
			OxA-21023	3917±29		
Greenwell's pit	Antler	578	BM-1028	3922±38	LSC	3943±36 T'=2.0; T'(5%)=3.8; v=1
			BM-3009	4060±90		
Greenwell's pit	Antler	705	BM-3010	3960±45	LSC	3914±30 T'=1.8; T'(5%)=3.8; v=1
			BM-1048	3880±38		
Greenwell's pit	Antler	900	BM-3089	3960±60	LSC	3910±35 T'=1.1; T'(5%)=3.8; v=1
			BM-1049	3884±43		
Greenwell's pit	Carbonised residue	502 (BM 1987 2-2 212)	OxA-22439	4014±34	AMS	**4071±25 T'=5.7; T'(5%)=3.8; v=1)**
			SUERC-28762	4130±35		

Feature	Material	Sample reference	Laboratory number	Radiocarbon age (BP)	Method	Weighted mean (BP)
Greenwell's pit A	Antler	923	BM-3088	3980±60	LSC	3958±22 T'=2.8; T'(5%)=6; **v**=2
			BM-1050	3893±44		
			OxA-23103	3978±27	AMS	
Greenwell's pit C	Antler	647	BM-1029	3859±53	LSC	3947±25 T'=3.4; T'(5%)=3.8; **v**=1
			OxA-23097	3969±27	AMS	
Greenwell's pit D	Antler	720PVA	OxA-23099	4130±27	AMS	4111±20 T'=1.0; T'(5%)=3.8; **v**=1
			OxA-23098	4092±27		
pit 3A	Animal bone	GG76 pit 3A sf 46PVA	OxA-22529	3318±27	AMS	3289±22 T'=3.1; T'(5%)=3.8; **v**=1
			SUERC-28742	3240±35		
pit 11 A	Antler	333	BM-981	3874±47	LSC	3883±31 T'=0.1; T'(5%)=3.8; **v**=1. Possibly, but not certainly, replicates
			BM-3008	3890±40		
pit 11 D	Antler	304PVA	OxA-23105	4063±28	AMS	4009±21 T'=8.3; T'(5%)=3.8; **v**=1
			SUERC-30912	3945±30		
pit 11 D	Antler	332aPVA	BM-983	3761±48	LSC	3947±25 T'=19.3; T'(5%)=3.8; **v**=1
			OxA-23109	4007±28	AMS	
pit 12	Antler		BM-97	4290±150	GPC	4267±99 T'=0.0; T'(5%)=3.8; **v**=1. Count of same benzene
			BM-377	4250±130	LSC	
pit 12	Antler	'1933 gal 2'	OxA-20750	3973±31	AMS	3995±22 T'=0.9; T'(5%)=3.8; **v**=1
			SUERC-24098	4015±30		
pit 12	Antler	'gal 3'	OxA-20754	4004±31	AMS	4023±22 T'=0.7; T'(5%)=3.8; **v**=1
			SUERC-24099	4040±30		
pit 14	Antler	'8 ft in chalk'	OxA-20758	4063±29	AMS	4049±22 T'=0.5; T'(5%)=3.8; **v**=1
			OxA-20757	4033±31		
pit 14	Antler	'filling of gal 3'	OxA-20756	4031±31	AMS	4030±22 T'=0.0; T'(5%)=3.8; **v**=1
			SUERC-24102	4030±30		
pit 15 B	Antler	103	BM-1051	3887±56	AMS	3976±30 T'=3.4; T'(5%)=3.8; **v**=1
			BM-3087	4010±35		

Feature	Material	Sample reference	Laboratory number	Radiocarbon age (BP)	Method	Weighted mean (BP)
pit 15 B	Antler	23	BM-1052a	4114±45	LSC	4032±32 T'=6.6; T'(5%)=3.8; **v**=1. Count of same benzene
			BM-1052b	3954±43		
pit 15 B	Antler	30	BM-3090	4010±70	LSC	3922±37 T'=2.2; T'(5%)=3.8; **v**=1
			BM-996	3890±42		
pit 15 C	Antler	47	BM-997	3960±56	LSC	4058±30 T'=4.1; T'(5%)=3.8; **v**=1
			SUERC-30903	4095±35	AMS	
pit 15 C	Antler	56PVA	OxA-23112	4102±28	AMS	4103±22 T'=0.0; T'(5%)=3.8; **v**=1
			SUERC-30904	4105±35		
pit 15 C	Antler	60	BM-974	3887±47	LSC	3925±42 T'=2.9; T'(5%)=3.8; **v**=1
			BM-3007	4060±90		
pit 15 D	Antler	110	BM-1056b	3740±48	LSC	3796±32 T'=2.4; T'(5%)=3.8; **v**=1. Count of same benzene
			BM-1056a	3838±42		
pit 15 G	Antler	124	BM-1000b	4022±57	LSC	4028±51 T'=0.1; T'(5%)=3.8; **v**=1
			BM-1000a	4051±109		
F7	Antler	GG74 136PVA	OxA-21188	3988±32	AMS	4018±25 T'=2.3; T'(5%)=3.8; **v**=1
			SUERC-25718	4065±40		
F7	Antler	GG74 183PVA	OxA-21191	4015±31	AMS	3967±23 T'=5.0; T'(5%)=3.8; **v**=1
			OxA-21190	3915±32		
Black Hole	Carbonised residue	Longworth cat. no. 239	OxA-22576	2997±29	AMS	3035±23 T'=4.2; T'(5%)=3.8; **v**=1
			SUERC-28757	3090±35		
Black Hole	Carbonised residue	Longworth cat. no. 73	OxA-22434	3375±30	AMS	3242±23 T'=49.4; T'(5%)=3.8; **v**=1
			SUERC-28758	3050±35		
1972 pit	Carbonised residue	GG72 1246	OxA-22438	3113±30	AMS	3105±23 T'=0.2; T'(5%)=3.8; **v**=1
			SUERC-28761	3095±35		
1972 pit	Carbonised residue	GG72 274	OxA-22435	3071±29	AMS	3067±23 T'=0.1; T'(5%=3.8); **v**=1
			SUERC-28759	3060±35		

Feature	Material	Sample reference	Laboratory number	Radiocarbon age (BP)	Method	Weighted mean (BP)
1972 pit	Carbonised residue	GG72 735	OxA-22437	3110±29	AMS	3108±18 T'=3.4; T'(5%)=6; **v**=2
			OxA-22436	3072±29		
			SUERC-28760	3155±35		
pit X	Carbonised residue	GG76 L1899	OxA-22441	3041±28	AMS	3066±22 T'=2.0; T'(5%)=3.8; **v**=1
			SUERC-28767	3105±35		
trench 3	Animal bone	ARC 79 5017	BM-1546	3740±210	LSC	1955±27T'=95; T'(5%)=6; **v**=2 if BM-1546 included 1914±27 T'=2.1; T'(5%)=3.8; **v**=1 without BM-1546
			OxA-1635	1820±70	AMS	
			OxA-21193	1930±29		

Table 4: summary of δ^{13}C and δ^{15}N values and C:N ratios for bone and antler samples

Range	Mean	Range	Mean	Range	Mean	Range	Mean	Range	Mean	Range	Mean	Range	Mean	Range	Mean	Range	Mean
Third millennium cal BC						Second millennium cal BC						First millennium BC–first millennium AD					
δ^{13}C (‰)		δ^{15}N (‰)		C:N		δ^{13}C (‰)		δ^{15}N (‰)		C:N		δ^{13}C (‰)		δ^{15}N (‰)		C:N	
Antler																	
−25.0 to −20.1 (N=155)	−22.6±1	+3 to +7.2 (N=88)	+5.6±1	3.2 to 3.6 (N=88)	3.3±1	−26.6 to −21.7 (N=5)	−23.6±2	-	-	-	-	-	-		-	-	-
Cattle bone																	
-	-	-	-	-	-	-22.1 to -20.4 (N=13)	−21.1±0.5	4.6 to 6.5 (N=13)	5.3±1	3.2 to 3.4	3.3±1	−21.0 (N=1)	-	+8.4	-	3.3	-
Horse bone																	
-	-	-	-	-	-	−21.0 (N=1)	-	+6.5	-	3.4	-	−22.1 to −21.4 (N=2)	-	+5.1 to +5.2 (N=2)	-	3.3 to 3.4	-
Pig bone																	
-	-	-	-	-	-	−22.2 (N=1)	-	6	-	3.3	-	-	-	-	-	-	-
Human bone																	
-	-	-	-	-	-	-	-	-		-	-	−19.6 to −20.9 (N=2)		+9.3 to +9.1 (N=2)	-	3.3 to 3.2	-
Indeterminate animal bone																	
-	-	-	-	-	-	−21.0 (N=1)	-	+5.6 (N=1)	-	3.4	-	-−1.9 (N=1)	-	-	-	-	-

*Table 5: Radiocarbon dates from mining period contexts in the Mercer complex**

Laboratory number	Sample reference	Material	Context	Radiocarbon age (BP)	δ^{13}C (‰)	δ^{15}N (‰)	C:N	Weighted mean (BP)	Calibrated date BC (95% confidence)	*Highest posterior density interval cal BC (95% probability)*	Comment
1971 pit											
OxA-20709	A598a; replicate of SUERC-24110	*Cervus elaphus* antler pick	Label: 'quad 4 undercut 3 on drawing 44'. On or just above shaft floor (Mercer 1981, fig 13)	4007±33	−22.1	5.7	3.2	4025±23 (T'=0.5; T'(5%)=3.8; v=1)	2620–2475	*2585–2470*	
SUERC-24110	A598b; replicate of OxA-20709			4040±30	−21.8	5.9	3.3				
OxA-20710	A601	*Cervus elaphus* antler pick, crusted with chalk	Label: 'quad 3 7th section lying on hard floor. Depth 12m. Drawing 34'	3978±34	−23.8	5.3	3.2		2580–2450	*2580–2450*	
BM-943	A602	*Cervus elaphus* antler pick	On floor, close to hearth, under another antler implement (Mercer 1981, fig 13)	4104±55	-	-	-		2880–2480	*2650–2480*	
GrA-38924	A603	*Cervus elaphus* antler pick	On or just above floor of pit, close to central hearth (Mercer 1981, fig 13). Under chalk rubble in the seventh and final spit of fill to be excavated	4065±35	−22.8	5.9	3.6		2860–2480	*2640–2480*	
OxA-20711	A611a; replicate of SUERC-24111	*Cervus elaphus* antler pick	On or just above floor of shaft, near entrance to gallery 1, grouped with antlers 608 and 667 (Mercer 1981, fig 13)	4046±35	−22.3	5.0	3.2	4069±23 (T'=0.7; T'(5%)=3.8; v=1)	2835–2495	*2640–2560 (79%), 2530–2495 (16%)*	
SUERC-24111	A611b; replicate of OxA-20711			4085±30	−21.7	5.8	3.2				
BM-776	sample 165	Bulk sample of unidentified charcoal	Hearth on thin layer of trampled chalk covering shaft floor and sealed by chalk dump (Mercer 1981, 23, fig 13)	3789±60	-	-	-		2470–2030	-	Excluded because of potential inaccuracy
SUERC-18816	A612	*Cervus elaphus* antler pick	On or just above floor of pit, at entrance to gallery 1 (Mercer 1981, fig 13). In the seventh and final spit of fill to be excavated	4020±30	−22.9	-	-		2620–2470	*2620–2500*	
GrA-39260	A619a, replicate of SUERC-18820	*Cervus elaphus* antler pick	Grouped with antler implements A620, A639, A640, at entrance to gallery 1, underlying 620, in chalk blocks overlying smaller chalk fragments on floor from which floorstone had been removed (Mercer 1981, figs 13, 15)	4100±35	−22.9	6.4	3.2	4114±23 (T'=0.3; T'(5%)=3.8; v=1	2865–2575	*2650–2575*	
SUERC-18820	A619b, replicate of GrA-39260			4125±30	−22.1	-	-				
GrA-38913	A620	*Cervus elaphus* antler pick	As GrA-39260 and SUERC-18820	4060±35	−22.9	-	-		2840–2480	*2635–2500*	
SUERC-18821	A624	*Cervus elaphus* antler pick	Grouped with antler implements A618, A623, A625 at entrance to gallery 1. On or just above floor of pit (Mercer 1981, fig 13). In NW quadrant (tr 6), in the seventh and final spit of fill to be excavated	4065±30	−22.3	-	-		2840–2490	*2640–2550 (83%), 2540–2500 (12%)*	
BM-944	A647	*Cervus elaphus* antler pick	Overlying another antler implement on floor of gallery 1 (Mercer 1981, fig 13)	4153±64		-	-		2900–2490	*2650–2550 (89%), 2540–2500 (6%)*	
BM-777	sample 183	Bulk sample of unidentified charcoal	Entrance to gallery 1 in BM datelist VIII, simply gallery 1 in monograph (Mercer 1981, 28)	3764±60	-	-	-		2440–1980	-	Excluded because of potential inaccuracy
OxA-20804	GG71 sample 216	1 fragment Maloideae charcoal	Label: 'gallery (2) 3rd sect charcoal patch (A)'. One of charcoal patches shown by Mercer (1981, fig 13)	3933±29	−24.7	-	-		2550–2340	*2500–2390*	
SUERC-24130	GG71 sample 224	1 fragment *Corylus avellana* charcoal	Label: 'gal 2 4th section'. Probably one of charcoal patches shown by Mercer (1981, fig 13).	4045±30	−28.0	-	-		2840–2470	*2530–2470*	

Laboratory number	Sample reference	Material	Context	Radiocarbon age (BP)	$\delta^{13}C$ (‰)	$\delta^{15}N$ (‰)	C:N	Weighted mean (BP)	Calibrated date BC (95% confidence)	*Highest posterior density interval cal BC (95% probability)*	Comment
OxA-24081	GG71 sample 220	Humin fraction from single fragment *Corylus avellana* charcoal	Label: 'gallery 2 5th section charcoal from NE section of charcoal patch (C) drawing [57]'. One of charcoal patches planned by Mercer (1981, fig 13)	3979±30	−28.2	-	-	OxA-24082	2580–2460	*2550–2450 (94%), 2420–2410 (1%)*	Experimental date on humic acid fraction of same sample failed
OxA-20983	GG71 sample 227; replicate of OxA-21023, -20984, -21024	1 fragment *Corylus avellana* roundwood charcoal	Label: 'gallery (2) 5th section charcoal patch C NW portion drawing 57'. One of charcoal patches shown by Mercer (1981, fig 13)	3942±29	−25.3	-	-	3971±15 T'=8.43; T'(5%)=7.8; ν=3	2570–2340	*2545–2535 (1%), 2500–2460 (94%)*	
OxA-20984	GG71 sample 227; replicate of OxA-21023, -20983, -21024			4006±29	−25.7	-	-				
OxA-21023	GG71 sample 227; replicate of OxA-20983, -20984, -21024			3917±29	−26.0	-	-				
OxA-21024	GG71 sample 227; replicate of OxA-21023, -20983, -20984			4017±29	−26.1	-	-				
OxA-X-2415-39	GG71 sample 227	Humic acid fraction from *Corylus avellana* roundwood fragment dated by OxA-21023, OxA-20984, OxA-21024	As OxA-21023, OxA-20984, OxA-21024	3858±28	−25.8	-	-	3947±13 T'=21.13; T'(5%)=9.5; ν=4)	2470–2200	-	Measured in an attempt to determine why previously measured bulk charcoal dates were too recent. Not used in model
BM-775	sample 229	Bulk sample of unidentified charcoal	Gallery 3 in BM datelist VIII, gallery 2 in monograph. Patches of charcoal on floor of gallery (Mercer 1981, 28). Plan (Mercer 1981, fig 13) shows charcoal patches on floor of gallery 2, but not gallery 3.	3815±60	-	-	-		2470–2040	-	Excluded because of potential inaccuracy
SUERC-18822	A730	*Cervus elaphus* antler tine tip, split longitudinally	In gallery 3 (Mercer 1981, fig 13)	4120±30	−22.4	-	-		2880–2570	*2650–2574*	Probably from a pick
GrA-38915	A743	*Cervus elaphus* antler tine	In gallery 3. The original label confirms the provenance, the object looks more like A745 on the published plan (a tine) than like A473 (a pick) (Mercer 1981, fig 13)	4035±35	−22.2	5.1	3.4		2840–2470	*2630–2500*	Probably from a pick
SUERC-18823	A751	*Cervus elaphus* antler tine	Gallery 3 (Mercer 1981, fig 13)	4085±30	−20.8	-	-		2860–2490	*2650–2560 (91%), 2530–2500 (4%)*	Probably from a pick
BM-945	A756	*Cervus elaphus* antler pick	Overlying an antler crown on floor of gallery 3 (Mercer 1981, fig 13)	4034±88	-	-	-		2880–2290	*2640–2500*	

Laboratory number	Sample reference	Material	Context	Radiocarbon age (BP)	δ13C (‰)	δ15N (‰)	C:N	Weighted mean (BP)	Calibrated date BC (95% confidence)	*Highest posterior density interval cal BC (95% probability)*	Comment
OxA-24082	GG71 sample 240	Humin fraction from single fragment *Corylus avellana* roundwood charcoal	Label: 'gal 3 3rd sect S chamber', ie in the south lobe of the gallery.	4004±29	−26.8	-	-		2580–2460	*2590–2490*	Measured in an attempt to determine why previously measured bulk charcoal dates were too recent
OxA-X-2415-43	GG71 sample 240	Humic acid fraction from *Corylus avellana* roundwood fragment dated by OxA-24082	As OxA-24082	3974±25	−26.5	-	-		2570–2460	-	Not used in model
BM-778	sample 133	Bulk sample of unidentified charcoal	Small burnt area on surface of chalk dump on shaft floor, c. 1m away from sherds of 2 Grooved Ware bowls on surface of same dump (Mercer 1981, 21, fig 11)	3781±67	-	-	-		2470–2020	-	Excluded because of potential inaccuracy
Pit to NE of 1971 pit											
GrA-38914	A653	*Cervus elaphus* antler tine tip	Pit to NE of 1971 pit. In chalk fill of gallery, intersecting with gallery 1 of 1971 pit (Mercer 1981, fig 13).	4070±35	−23.4	4.7	3.2		2860–2480	*2640–2490*	Probably broken from a pick
OxA-20712	A675	*Cervus elaphus* antler pick	Pit to NE of 1971 pit. Label: 'gallery 1 6th section 10cm above floor drawing 51' . In gallery radiating from base of unexcavated chalk-cut shaft (Mercer 1981, 27–28, fig 13)	4081±35	−24.0	4.7	3.2		2860–2490	*2650–2550 (77%), 2540–2490 (18%)*	
OxA-20713	A680	*Cervus elaphus* antler pick	Pit to NE of 1971 pit. Label: 'gallery 1 6th section drawing 51'. In gallery radiating from base of unexcavated chalk-cut shaft (Mercer 1981, 27–8, fig 13)	4054±37	−23.1	4.2	3.2		2840–2470	*2640–2480*	
OxA-20714	A682	*Cervus elaphus* antler pick, crusted with chalk	Pit to NE of 1971 pit. Label: 'gallery 1 6th section drawing 51'. In gallery radiating from base of unexcavated chalk-cut shaft (Mercer 1981, 27–8, fig 13)	4025±34	−23.1	3.0	3.2		2830–2470	*2620–2470*	
SUERC-24112	A688	*Cervus elaphus* antler pick	Pit to NE of 1971 pit. Label 'gallery 1 rear chamber drawings 51, 55'. In gallery radiating from base of unexcavated chalk-cut shaft (Mercer 1981, 27–8, fig 13)	4095±30	−23.3	5.4	3.3		2870–2500	*2650–2560 (89%), 2520–2490 (6%)*	
OxA-20715	A746	*Cervus elaphus* antler tine freshly broken from beam	Pit to NE of 1971 pit. Label: 'gallery 1 section 8, 20cm above floor drawing 51'. In gallery radiating from base of unexcavated chalk-cut shaft (Mercer 1981, 27–8, fig 13)	3995±34	−23.6	6.0	3.2		2580–2460	*2590–2460*	
SUERC-24116	A763	*Cervus elaphus* antler pick	Pit to NE of 1971 pit. Label: 'gall 1 sect 6 drawing 51'. In gallery radiating from base of unexcavated chalk-cut shaft (Mercer 1981, 27–8, fig. 13)	4155±35	−22.0	5.1	3.4		2890–2580	*2650–2570*	
SUERC-24117	A771	*Cervus elaphus* antler pick	Pit to NE of 1971 pit. Label: gal 1 sect 10 drawing 51'. In gallery radiating from base of unexcavated chalk-cut shaft (Mercer 1981, 27–8, fig 13)	4090±30	−22.7	5.8	3.3		2860–2490	*2650–2560 (87%), 2530–2490 (8%)*	

*In the main body of the shaft, 'section' often refers to a horizontal slice of fill, since the contents were excavated approximately 2m at a time, the highest 2m being 'section 1' and the lowest 'section 7', this last was at most 0.6m deep, since it came down onto the floor of the pit (Mercer 1981, 10; figs 17–8). In the galleries, 'section' refers to vertical slices of fill, whether longitudinal or transverse (Mercer 1981, 11). A gallery driven from a pit to the north-east of the 1971 pit and intersecting with its gallery 1 was recorded as sections 5 to 10 of gallery 1 (Mercer 1981, fig 13)

Table 6: Radiocarbon dates from the 1972–74 knapping floor

Laboratory number	Sample reference	Identification	Stratigraphic details	Radiocarbon age (BP)	$\delta^{13}C$ (‰)	$\delta^{15}N$ (‰)	C:N	Calibrated date BC (95% confidence)	*Highest posterior density interval cal BC (95% probability)*	Comment
BM-988		Bulk sample of unidentified charcoal	Trench 1255.5/905.5 layer 4	3755±259	−25.0	-	-	2910–1510	-	Excluded because of potential inaccuracy
BM-995		Bulk sample of unidentified charcoal	Trench 1267.5/905.5 layer 11	3947±66	−25.3	-	-	2620–2210	-	Excluded because of potential inaccuracy
BM-1013		Bulk sample of unidentified charcoal	Trench 1255/905. L6, hearth in chipping floor, extending into baulk (cf Longworth *et al* 2012, fig 72)	3929±49	−27.0	-	-	2570–2280	-	Excluded because of potential inaccuracy
BM-1014		Bulk sample of unidentified charcoal	Trench 1266/900.5 layer 10.	3813±43	−25.8	-	-	2460–2130	-	Excluded because of potential inaccuracy
SUERC-24118	GG73 L186	*Cervus elaphus* antler tine, anciently broken from beam, tip recently broken	Label: 'GG73 1267.5/906.1. H d chipping floor I. Antler as on plan'. Plan is GG 1973 P27	3855±30	−23.5	6.7	3.3	2470–2200	*2470–2380*	The location of several tines in the floor strongly suggests that they were used as knapping hammers
SUERC-24119	GG74 L403	*Cervus elaphus* antler tine	Label: 'GG74 β39 (6) square a level I chipping floor 1265/915-987 1265/905-4.27 level -0717'	3945±30	−22.4	6.2	3.3	2570–2340	*2570–2520 (19%), 2500–2390 (76%)*	As SUERC-24118
OxA-20719	GG74 L586	*Cervus elaphus* antler tine	1972–74 knapping floor. Label: 'GG74 β15-(6) square C level II chipping floor 1255/905-5.81 1265/905-6 .03 level 1785 SD 1049 -0.736'	4013±33	−22.5	4.7	3.3	2620–2460	*2620–2600 (2%),, 2590–2460 (93%)*	As SUERC-24118
OxA-20718	GG74 L506	*Cervus elaphus* antler tine, anciently broken from beam, tip missing	1972–74 knapping floor. Label: 'GG74 P17 (6) square β17 level II chipping floor 1255/905-4.98 1265/915-9.66'	4068±32	−22.7	3.9	3.2	2850–2490	*2640–2550 (70%), 2540–2490 (25%)*	As SUERC-24118

Table 7: Felder's reconstruction of the extraction sequence for the base of Greenwell's pit (Fig 24; Longworth and Varndell 1996, 85)

Stage	Content
1	Galleries I-IV quarried to 2m; niche V excavated
2	Galleries I-IV extended to 4m
3	Gallery I stopped; galleries II, III1 and IV extended to 6m; side gallery III3 begun
4	Niche IIa dug in gallery II; galleries III and 4 extended to 8m; gallery III3 enlarged to NW
5	Niche IIb dug in gallery II; gallery III1 extended to 11m; gallery III3 further enlarged to NE; gallery IV enlarged at SE end
6	Niches III3a and III1a cut in gallery III; gallery III2 begun; niche IVa cut in gallery IV
7	Gallery III2 enlarged to W, S, SE; niche IVb cut in gallery 4

Table 8: Radiocarbon dates from the Greenwell's pit complex

Laboratory number	Sample reference	Material	Context	Radiocarbon age BP	δ^{13}C (‰)	δ^{15}N (‰)	C:N ratio	Weighted mean (BP)	Calibrated date BC (95% confidence)	*Highest posterior density interval cal BC (95% probability)*	Comment
Greenwell's pit											
OxA-22439	502a (BM 1987 2-2 212); replicate of SUERC-28762	Carbonised residue from interior of sherds of find 502, most of it in 2 polythene vials, labelled 'FN 502 Greenwell. Sediment from pot'. 502, together with 658, consisted of >30 sherds from 1 or more plain, flat-based Grooved Ware bowls, (Longworth *et al* 1988, 17, fig 5: cat. no. N35). Sample 502a taken from one vial, 502b from the other	Niche V. An undercut at the NW side of the shaft base, containing the last remaining vestige of shaft fill, backfilled from the centre (Longworth and Varndell 1996, 13, figs 5, 6). Archive report (Felder 1974b, 83) records sherds as at variable heights above floor	4014±34	−27.1	8.9	5.6	4071±25 T'=5.7; T'(5%)=3.8; ν=1	2840–2490	*2640–2560 (78%), 2540–2490 (17%)*	
SUERC-28762	502b (BM 1987 2-2 212); replicate of OxA-22439			4130±35	−27.5	-	-				
SUERC-30921	503	*Cervus elaphus* antler pick in fragments, complete when found	Niche V. An undercut at the NW side of the shaft base, containing the last remaining vestige of shaft fill, backfilled from the centre (Longworth and Varndell 1996, 13, figs 5, 6). Near shaft bottom 10cm above floor	4040±35	−22.6	6.7	3.3		2840–2470	*2625–2480*	
BM-1049	900; replicate of BM-3089	Sketches on label and plan in archive report suggest *Cervus elaphus* antler pick. Survives as fragments	Gallery IIa. In a butt end with numerous antlers and charcoal patches (Felder 1975b, VI-II-18; Longworth and Varndell 1996, fig 5).	3884±43	−22.1	-	-	3910±35	2480–2290	*2550–2540 (1%), 2490–2370 (94%)*	
BM-3089	900; replicate of BM-1049			3960±60	−21.7		-				
BM-291		Antler, unspecified	Gallery III, Greenwell's excavation. Given extent of Greenwell's excavation (Longworth and Varndelll 1996, fig 5), probably gallery III3	3810±130	-	-	-		2620–1890	*2620–2380*	
OxA-23095	530	*Cervus elaphus* antler pick	Gallery III1. Near centre of main part of gallery, *c* 1.5m from entrance, near-vertical with mid-point 41cm above floor. In prehistoric gallery fill, with antlers 531, 532, 534, stratified above antler 538 (Felder 1974a, 52, 57; Longworth and Varndell 1996, fig 11: section 2)	4054±27	−22.4	5.5	3.2		2840–2480	*2620–2480*	
OxA-23096	538	*Cervus elaphus* antler pick, crusted with puddled chalk, fingerprints	Gallery III1. Near centre of main part of gallery, *c* 1.5 m from entrance, 5cm above floor. In prehistoric gallery fill, stratified below antlers 530, 531, 532, 534 (Felder 1974a, 52, 57; Longworth and Varndell 1996, fig 11: section 2)	4083±28	−23.0	5.2	3.2		2860–2490	*2650–2560 (94%), 2520–2500 (1%)*	

Laboratory number	Sample reference	Material	Context	Radiocarbon age BP	δ¹³C (‰)	δ¹⁵N (‰)	C:N ratio	Weighted mean (BP)	Calibrated date BC (95% confidence)	*Highest posterior density interval cal BC (95% probability)*	Comment
SUERC-30923	531	*Cervus elaphus* antler pick	Gallery III1. Near centre of main part of gallery, *c* 1.5m from entrance, 51cm above floor. In prehistoric gallery fill, with antlers 530, 532, 534, stratified above antler 538 (Felder 1974a, 52, 57; Longworth and Varndell 1996, fig 11: section 2)	4045±35	−22.3	5.8	3.4		2840–2470	*2840–2810 (4%), 2670–2470 (91%)*	
BM-1027	567	*Cervus elaphus* antler pick	Gallery III2. horizontal on the floor next to 568 (Felder 1974a, 52)	3855±36	−23.0	-	-		2470–2200	*2470–2380*	
BM-1261	832	Sketches on label and in archive show whole *Cervus elaphus* antler pick	Gallery III3a. In butt end of gallery, 20cm above floor (Felder 1975a, 49.)	3853±71	−21.4	-	-		2550–2050	*2570–2520 (7%), 2500–2370 (88%)*	
SUERC-30922	523	*Cervus elaphus* antler pick	Gallery IV. Near centre of main part of gallery, about 1.25 m in from entrance. On floor. (Felder 1974a, 63)	4055±35	−22.8	6.3	3.4		2840–2470	*2640–2480*	
BM-1028	578; replicate of BM-3009	*Cervus elaphus* antler pick (photo in archive)	Gallery IV. Close to E wall, 25cm above floor, 3m from gallery mouth (Felder 1974a, 63)	3922±38	−19.5	-	-	3943±36 T'=2.0; T'(5%)=3.8; ν=1)	2570–2310	*2570–2390*	
BM-3009	578; replicate of BM-1028			4060±90	−21.4	-	-				
BM-1044	711	Antler pick	Gallery IV. Towards junction with gallery running from Greenwell's pit E, 10cm above floor, 7m from entrance (Felder 1975a, 65)	3922±86	−22.3	-	-		2830–2140	*2620–2380*	
BM-1048	705; replicate of BM-3010	*Cervus elaphus* antler pick (sketch in archive)	Gallery IVc. Near SW butt of gallery (Felder 1975a, 65)	3880±38	−21.6	-	-	3914±30 T'=1.8; T'(5%)=3.8; ν=1	2480–2200	*2490–2380*	
BM-3010	705; replicate of BM-1048			3960±45	−22.7	-	-				
Greenwell's pit A											
BM-1068	933	Antler pick	Horizontal on 2nd crawling floor, 29 cm above chalk floor stratified above samples for BM-1050, -3088 (Felder 1975a, VI-II-18).	3784±50	−22.1	-	-		2440–2030	*2470–2380*	
BM-1050	923; replicate of BM-3088, OxA-23103	*Cervus elaphus* antler pick (sketch in archive)	Horizontal on floor close to numerous antlers and charcoal patches (Felder 1975a, VI-II-18. Longworth and Varndell 1996, fig 40). Stratified beneath dog skeleton (Longworth and Varndell 1996, fig 7)	3893±44	−21.7	-	-	3958±22 T'=2.8; T'(5%)=6; ν=2	2570–2460	*2570–2525 (52%), 2500–2460 (43%)*	
BM-3088	923; replicate of BM-1050, OxA-23103			3980±60	−22.3	-	-				
OxA-23103	923; replicate of BM-1050, BM-3088			3978±27	−21.7	6.5	3.2				
OxA-23104	974b	*Cervus elaphus* antler pick. This is a separate antler from 974a	Crossed with antler 974a, 33cm above floor at entrance to gallery from Greenwell's pit A	3932±27	−22.7	5.3	3.2		2490–2340	*2500–2380*	
SUERC-30932	974a	*Cervus elaphus* antler pick. Looks more eroded and less fresh than 974b, which is a separate antler	Crossed with antler 974b, 33cm above floor at entrance to gallery from Greenwell's pit A	3960±35	−22.4	4.8	3.3		2570–2340	*2560–2390*	
Greenwell's pit C											

Laboratory number	Sample reference	Material	Context	Radiocarbon age BP	$\delta^{13}C$ (‰)	$\delta^{15}N$ (‰)	C:N ratio	Weighted mean (BP)	Calibrated date BC (95% confidence)	*Highest posterior density interval cal BC (95% probability)*	Comment
BM-1029	647; replicate of OxA-23097	*Cervus elaphus* antler pick, complete when found (photo in archive)	Horizontal, 40cm above floor (Felder 1974a, 74)	3859±53	−22.4	-	-	3947±25 T'=3.4; T'(5%)=3.8; **v**=1	2570–2350	*2570–2525 (17%), 2500–2400 (88%)*	
OxA-23097	647; replicate of BM-1029			3969±27	−22.7	5.8	3.2				
BM-1045	668	*Cervus elaphus* antler pick (sketch in archive)	Stacked with antlers 671 and 672, 50 cm above floor (Felder 1975a, 74)	3949±41	−23.3	-	-		2580–2300	*2580–2390*	
BM-1046	679	*Cervus elaphus* antler pick (sketch in archive)	At side of gallery, near Greenwell's pit C, 10cm above floor (Felder 1975a, 74)	3797±52	−20.3	-	-		2460–2040	*2470–2380*	
OxA-22577	611a (BM 1987 2-2 213)	Residue in polythene vial, labelled '611 Sediment from pot', bagged with sherds of 611 and 623, dark internal discolouration on sherds indicates that residue was internal. Together with sherds from finds 616, 633 and 654, those of 611 and 623 were among >60 sherds from 1 or more plain, flat-based Grooved Ware bowls (Longworth *et al* 1988, 17, fig 5: cat. no. N36)	Towards butt of gallery. 611 was one of 8 pottery finds from the same gallery, and was approx. 1.75m from 623 (Felder 1974a, 74; Longworth and Varndell 1996, 23, fig. 18). Archive report (Felder 1974b, 84–5) records location of 611 as 35cm above floor; location of 623 as 25 above floor	3943±31	−27.2	7.1	6.2		2570–2340	*2570–2520 (17%), 2500–2390 (78%)*	A second sample from the same residue failed to date
BM-1047	683	*Cervus elaphus* antler pick (sketch in archive)	Stacked with antlers 684 to 686, close to Greenwell's pit C, 75cm above floor (Felder 1975a, 74)	3974±45	−22.6	-	-		2580–2340	*2590–2400*	
SUERC-30924	627	*Cervus elaphus* antler pick, with some of skull attached	On floor, towards buttend of gallery intersecting with niche V of Greenwell's pit	3865±35	−22.7	4.6	3.4		2470–2200	*2470–2380*	
Greenwell's pit D											
OxA-23098	720; replicate of OxA-23099	*Cervus elaphus* antler pick	20cm above gallery floor, horizontal. Grouped with antlers 715, 716, 718, 719, 721, 723	4092±27	−22.7	6.2	3.2	4111±20 T'=1.0; T'(5%)=3.8; **v**=1)	2860–2575	*2650–2575*	
OxA-23099	720; replicate of OxA-23098			4130±27	−22.6	6.1	3.2				
OxA-23100	733	*Cervus elaphus* antler pick	15cm above gallery floor, horizontal	4120±29	−22.8	6.9	3.2		2880–2570	*2650–2570*	
SUERC-30925	719	*Cervus elaphus* antler crown	35cm above floor, horizontal. Grouped with antlers 715, 716, 718, 720, 721, 723	4030±35	−22.5	6.1	3.3		2840–2470	*2840–2820 (2%), 2640–2470 (93%)*	
SUERC-30926	736	*Cervus elaphus* antler pick	5cm above floor	4045±35	−22.3	6.2	3.3		2840–2470	*2840–2820 (4%), 2670–2470 (93%)*	
Greenwell's pit E											
OxA-23101	843	*Cervus elaphus* antler pick, complete when found, some skull attached	On gallery floor, under 844, in more westerly of 2 galleries attributed to Greenwell's pit E (Felder 1976a, 41–4)	4048±28	−23.4	6.1	3.2		2840–2480	*2630–2480*	
SUERC-30927	844	*Cervus elaphus* antler pick, with some skull remaining	On gallery floor, horizontal, overlying 843, in more westerly of 2 galleries attributed to Greenwell's pit E (Felder 1976a, 41–4)	4135±35	−23.1	4.6	3.3		2880–2570	*2660–2570*	
OxA-23102	845	*Cervus elaphus* antler pick	21cm above gallery floor, in more westerly of 2 galleries attributed to Greenwell's pit E (Felder 1976a, 41–4)	3930±27	−22.3	4.4	3.2		2490–2340	*2560–2530 (4%), 2500–2390 (91%)*	

Laboratory number	Sample reference	Material	Context	Radiocarbon age BP	δ[13]C (‰)	δ[15]N (‰)	C:N ratio	Weighted mean (BP)	Calibrated date BC (95% confidence)	*Highest posterior density interval cal BC (95% probability)*	Comment
SUERC-30931	846	*Cervus elaphus* antler pick	16cm above gallery floor, horizontal, in more westerly of 2 galleries attributed to Greenwell's pit E (Felder 1976a, 41–4)	3955±35	−23.0	5.9	3.3		2570–2340	*2580–2400*	

Table 9: Radiocarbon dates from pits 2 and 11

Laboratory number	Sample reference	Material	Context	Radiocarbon age (BP)	$\delta^{13}C$ (‰)	Calibrated date BC (95% confidence)	*Highest posterior density interval cal BC (95% probability)*	Comment
Pit 2								
BM-1020	1005	*Cervus elaphus* antler pick	Gallery 1, overlying antler 1006, 35cm above floor (Felder 1975a, 104)	3844±221	−23.0	2910–1690	*2630–2390*	
BM-1069	1007	*Cervus elaphus* antler pick	Gallery 180cm above floor (Felder 1975, 104)	3896±141	−22.0	2880–1960	*2630–2390*	
Pit 11								
BM-103		Antler, unspecified	Location unspecified	3700±150		2570–1690	*2620–2370*	Relation to working of pit unknown

Table 10: Radiocarbon dates from pits 11 A–F

Laboratory number	Sample reference	Material	Stratigraphic details	Radiocarbon age (BP)	$\delta^{13}C$ (‰)	$\delta^{15}N$ (‰)	C:N	Weighted mean (BP)	Calibrated date BC (95% confidence)	*Highest posterior density interval cal BC (95% probability)*	Comment
Pit 11A											
OxA-23106	308	*Cervus elaphus* antler pick	In fill of gallery running E towards pit 11 E. Grouped with antlers 309, 310 (Felder 1973, IX-1; fig VII-8)	4071±28	−23.0	4.8	3.2		2840–2490	*2640–2550 (75%), 2540–2490 (20%)*	
SUERC-failed	309	*Cervus elaphus* antler crown with 2 points	As OxA-23106		-	-	-		-	-	Not dated because of poor C:N ratio
OxA-23107	311	Roe deer antler with cut marks at base and some skull still attached. Tip ??modified	In gallery running E towards pit 11 E, 20cm above floor. (Felder 1973, IX-1; fig VII-10)	4029±27	−22.7	4.9	3.2		2630–2470	*2620–2470*	
BM-981	333; probably replicate of BM-3008	*Cervus elaphus* antler pick (photo and sketch in archive)	Crossed with antler pick 334 in entrance of gallery running from Pit 11 A to pit 11 G, 60cm above floor (Felder 1973, VII-25)	3874±47	−22.8	-	-	3883±31 T'=0.1; T'(5%)=3.8; ν=1	2470–2210	*2470–2380*	
BM-3008	333? ; probably replicate of BM-981			3890±40	−23.3	-	-				
Pit 11 B/E											
BM-982	322	*Cervus elaphus* antler pick (photo and sketch in archive)	Between pits 11 B and 11 E. In gallery fill 5cm above floor. (Felder 1973 Fig. VII-16)	4090±58	−21.0	-	-		2880–2470	*2650–2480*	
Pit 11 D											
OxA-23105	304 A; replicate of SUERC-30912	*Cervus elaphus* antler pick	Label: On gallery floor, horizontal in fill. Grouped with antlers 305, 306 (Felder 1973, fig VII-6)	4063±28	−21.2	6.3	3.2	4009±21 T'=8.3; T'(5%)=3.8; ν=1)	2580–2470	*2575–2475*	
SUERC-30912	304 B; replicate of OxA-23105			3945±30	−21.5	6.5	3.4				
OxA-22532	306	*Cervus elaphus* antler pick	Horizontal on gallery floor. Grouped with 304, 305 (Felder 1973, IX-4, fig VII-6)	3954±29	−22.7	6.5	3.2		2570–2340	*2570–2520 (29%), 2500–2400 (66%)*	
BM-983	332a; replicate of OxA-23109	*Cervus elaphus* antler pick (photo and sketch in archive)	In gallery fill 50cm above floor (Felder 1973, IX-4)	3761±48	−21.7	-	-	3947±25 T'=19.3; T'(5%)=3.8; ν=1)	2340–2030	-	Excluded because in poor agreement with replicate (OxA-23109)
OxA-23109	332a; replicate of BM-983			4007±28	−21.6	6.4	3.2		2580–2460	*2580–2470*	
Pit 11 E											
SUERC-30914	314	*Cervus elaphus* antler crown	On floor, in gallery, grouped with antlers 315, 316 (Felder 1973, IX-5, fig VII-12)	4030±35	−22.2	6.5	3.3		2840–2470	*2840–2820 (2%), 2640–2470 (93%)*	
OxA-23108	315	*Cervus elaphus* antler pick	In gallery, horizontal about 25cm above floor, grouped with antlers 314, 316 (Felder 1973 IX-5, fig VII-12)	4133±28	−22.1	4.2	3.3		2880–2580	*2650–2570*	
BM-984	316	*Cervus elaphus* antler pick (photo and sketch in archive)	In gallery fill 30cm above floor. Grouped with antlers 314, 315 Felder 1973, IX-5, fig VII-12)	3902±58	−23.1	-	-		2570–2200	*2570–2380*	

Laboratory number	Sample reference	Material	Stratigraphic details	Radiocarbon age (BP)	$\delta^{13}C$ (‰)	$\delta^{15}N$ (‰)	C:N	Weighted mean (BP)	Calibrated date BC (95% confidence)	*Highest posterior density interval cal BC (95% probability)*	Comment
SUERC-28751	318	Head of *Cervus elaphus* antler pick	50cm above floor. Grouped with antlers 319, 320 (Felder 1973, IX-5, fig VII-14)	5620±35	−23.8	-	-		4540–4360	-	$\delta^{15}N$ measurement failed 2013. Excluded because of extremely poor individual agreement. Not all PVA may have been removed
SUERC-30915	320	*Cervus elaphus* antler pick	135cm above floor, grouped with antlers 318, 319 (Felder 1973, fig VII-14)	4000±35	−23.0	5.9	3.3		2620–2460	*2620–2600 (1%), 2590–2460 (94%)*	
BM-987	324	'Charcoal fragments 3 bags' (^{14}C file in Blythe House)	In gallery fill 80cm above floor (Felder 1973, IX-5).	3671±75	−26.0				2290–1880	-	Excluded because of potential inaccuracy
Pit 11 F											
BM-985	341	*Cervus elaphus* antler pick with apparently unrelated loose, extra tine (sketch and photo in archive)	In gallery fill 40cm above floor (Felder 1973, IX-7),	4010±59	−23.0	-	-		2840–2340	*2640–2440 (94%), 2420–2410 (1%)*	
SUERC-30916	342	*Cervus elaphus* antler pick	25cm above gallery floor (Felder 1973, IX-7)	3955±30	−23.0	4.1	3.3		2570–2340	*2570–2400*	
SUERC-30917	343 A; replicate of 343 B	*Cervus elaphus* antler pick	15cm above gallery floor (Felder 1973, IX-7)	4240±35	−22.4	5	3.5		2910–2700	-	Excluded because of probable contamination
OxA-failed	343 B; replicate of SUERC-30917				-	-	-		-	-	OxA letter Sept 2010: 'Failed due to conservation - treated with something that could not be removed'
OxA-23110	344	Complete *Capreolus capreolus* antler. Cut marks at base where detached from skull	In gallery	4112±28	−23.9	4.6	3.3		2870–2570	*2660–2570 (94%), 2510–2500 (1%)*	

Table 11: Radiocarbon dates from pit 12

Laboratory number	Sample reference	Material	Context	Radiocarbon age (BP)	δ^{13}C (‰)	δ^{15}N (‰)	C:N	Weighted mean (BP)	Calibrated date BC (95% confidence)	*Highest posterior density interval cal BC (95% probability)*	Comment
BM-97	Count of same benzine as BM-377	Antler, unspecified	location unspecified	4290±150	-	-	-	4267±99 (with BM-377) T'=0.0; T'(5%)=3.8; **v**=1	3270–2580	*3330–3230 (4%), 3180–3160 (1%), 3120–2570 (90%)*	Relation to working of pit unknown. Modelled as *tpq* for working of pit because substantially older than dates from primary contexts
BM-377	Repeat by liquid scintillation of gas proportional counter measurement BM-97 (Barker *et al* 1969a)			4250±130	-	-	-				
BM-276		Antler, unspecified	location unspecified	3550±150	-	-	-		2300–1510	-	Relation to working of pit unknown, excluded because substantially more recent than dates from primary contexts
OxA-20751	'1933 entrance to gal 2'	*Cervus elaphus* antler pick	Label: 'pit XII. 1933. Entrance to gal. 2'. This places the implement at the base of the pit	4029±31	−21.9	6.5	3.3		2630–2470	*2620–2470*	
OxA-20750	'1933 gal 2' a; replicate of SUERC-24098	*Cervus elaphus* antler crown.	Label: 'Pit XII. 1933. Gal. 2'	3973±31	−20.3	6.9	3.3	3995±22 (T'=0.9; T'(5%)=3.8; **v**=1)	2575–2465	*2575–2510 (62%), 2505–2470 (33%)*	
SUERC-24098	'1933 gal 2' b; replicate of OxA-20750			4015±30	−21.9	6.9	3.4				
OxA-20752	'1933 gal 2 centre'	*Cervus elaphus* antler pick	Label: 'Pit XII. 1933. Gal 2. centre'	4009±30	−20.9	5.2	3.3		2620–2460	*2590–2460*	
OxA-20753	'1933 gal 3 just inside'	*Cervus elaphus* antler pick	Label: 'pit XII. 1933. Gal. 3 just inside'	4056±31	−21.1	5.3	3.4		2840–2480	*2640–2480*	
SUERC-24097	'chalk of *** of gal 2'	*Cervus elaphus* antler pick	Label: 'Pit XII. 1933. Chalk of *** of gal. 2'	3975±35	−22.9	4.6	3.3		2580–2410	*2580–2440 (94%), 2420–2400 (1%)*	
OxA-20754	'gal 3' a; replicate of SUERC-24099	*Cervus elaphus* antler pick	Label: 'pit XII. 1933. gal. 3'	4004±31	−22.8	6	3.3	4023±22 T'=0.7; T'(5%)=3.8; **v**=1)	2620–2470	*2585–2475*	
SUERC-24099	'gal 3' b; replicate of OxA-20754			4040±30	−22.5	6.6	3.3				

Laboratory number	Sample reference	Material	Context	Radiocarbon age (BP)	δ^{13}C (‰)	δ^{15}N (‰)	C:N	Weighted mean (BP)	Calibrated date BC (95% confidence)	*Highest posterior density interval cal BC (95% probability)*	Comment
SUERC-24096	'S side in chalk at 6 ft'	*Cervus elaphus* antler pick	Label: 'Pit XII. 1930. S side in chalk at 6ft'. This may place the pick between floors D and E (Armstrong 1934, 58), at a fairly late stage in the infilling	4090±30	−22.0	6.2	3.4		2860–2490	*2870–2800 (19%), 2760–2560 (73%), 2530–2490 (3%)*	Modelled as *terminus post quem* for context because date incompatible with high level in pit

Table 12: Radiocarbon dates from pit 14

Laboratory number	Sample reference	Material	Context	Radiocarbon age (BP)	$\delta^{13}C$ (‰)	$\delta^{15}N$ (‰)	C:N	Weighted mean (BP)	Calibrated date BC (95% confidence)	*Highest posterior density interval BC (95% probability)*	Comment
BM-99		Antler, unspecified	Context unspecified	3980±150	-	-	-		2910–2030	*2640–2400*	Relation to working of pit unknown
SUERC-24107	'S end close to mouth of cove'	*Cervus elaphus* antler pick	Label: 'Pit XIV. 1936. Filling at S end close to mouth of cove 1ft from floor'. This places the implement close to one of the undercuts at the base of the pit	3995±30	−23.1	5.7	3.2		2580–2460	*2580–2460*	
OxA-20755	1936 'filling of *** gal near wall'	*Cervus elaphus* antler crown	Label: 'pit XIV 1936 antler from filling of *** gal near wall *** from a similar **** chalk rubble'. This refers to one of the undercuts at the base of the pit	3998±32	−20.9	3.3	3.4		2580–2460	*2580–2460*	
SUERC-24100	'2ft from bottom, in filling'	Large *Cervus elaphus* antler beam, both ends freshly broken off, probably once a pick	Label: 'P.XIV 2ft from bottom, in filling'. This places the implement near the base of the pit, at the level of the undercuts	4015±30	−22.6	5.7	3.3		2620–2470	*2620–2610 (1%), 2590–2470 (94%)*	
OxA-20757	'8ft in chalk'; replicate of OxA-20758	*Cervus elaphus* antler crown	Label: 'Pit XIV. 1935. At 8ft in chalk. NW sector. One tine broken by pressure & marked (3)'. This would have been 2.5ft above the shaft base, at the level of the undercuts	4033±31	−22.2	6.5	3.4	4049±22 T'=0.5; T'(5%)=3.8; v=1)	2830–2490	*2625–2550 (53%), 2540–2490 (42%)*	
OxA-20758	'8 ft in chalk'; replicate of OxA-20757			4063±29	−22.4	6.5	3.3				

Laboratory number	Sample reference	Material	Context	Radiocarbon age (BP)	δ^{13}C (‰)	δ^{15}N (‰)	C:N	Weighted mean (BP)	Calibrated date BC (95% confidence)	*Highest posterior density interval BC (95% probability)*	Comment
SUERC-24101	'Filling at back of S. Gal. Near floor'	*Cervus elaphus* antler pick	Label: 'Pit XIV 1934. Filling at back of S. Gal. near floor'. This refers to one of the undercuts at the base of the pit	4055±30	−22.9	5.8	3.3		2840–2480	*2640–2480*	
OxA-20756	'filling of gal 3' a; replicate of SUERC-24102	*Cervus elaphus* antler crown	Label: 'Pit XIV. 1936. Filling of Gal (3) in chalk & just above floor'	4031±31	−20.1	6.6	3.4	4030±22 T'=0.0; T'(5%)=3.8; v=1	2620–2475	*2620–2605 (2%), 2540–2490 (93%)*	
SUERC-24102	'filling of gal 3' b; replicate of OxA-20756			4030±30	−21.2	6.1	3.3				
SUERC-24106	'NE sector at 7 ft'	*Cervus elaphus* antler pick	Label: 'Pit XIV. Wall. N.E. Sector at 7ft (A)'. This would have been 3.5ft above the base of pit	4045±30	−20.2	6.5	3.3		2840–2470	*2630–2480*	
SUERC-24129	'S side near wall at 9 ft'	*Cervus elaphus* antler pick	Label: 'Pit XIV. 1936. In boulder clay & chalk of filling. S side near the wall at 9ft'. This would have been 2ft above the base of the pit	3995±30	−22.6	6.2	3.4		2580–2460	*2580–2460*	

Table 13: Radiocarbon dates from the pit 15 complex

Laboratory number	Sample reference	Material	Stratigraphic details	Radiocarbon age (BP)	$\delta^{13}C$ (‰)	$\delta^{15}N$ (‰)	C:N	Weighted mean (BP)	Calibrated date cal BC (95% confidence)	*Highest posterior density interval cal BC (95% probability)*	Comment
Pit 15											
BM-87		Bulk sample of unidentified charcoal	14ft [4.25m] from surface (Barker and Makey 1961, 41). This would have been *c* 5ft [1.5m] above the shaft floor	4270±150	-	-	-		3360–2470	-	Possibly from one of the 'hearths' noted by Armstrong. Excluded because of potential inaccuracy
BM-88		Antler unspecified	'Fast fill' 11ft [3.35m] from surface (Barker and Makey 1961, 41). This would have lain in the middle fills of the pit	4050±150	-	-	-		2930–2140	*2640–2400*	
Pit 15 A											
BM-973	7	*Cervus elaphus* antler pick (sketch in archive)	Gallery 15A1, 15cm above floor (Felder 1975c, V-V-I-5)	3827±45	−24.2	-	-		2470–2130	*2470–2380*	
Pit 15 B											
BM-1051	103; replicate of BM-3087	*Cervus elaphus* antler beam with 2 broken-off ends and broken-off tine near centre. Could have been pick (photo and sketch in archive)	Gallery 15B1. In undisturbed prehistoric fill beneath recently disturbed area, 20cm above floor, close to sample for BM-975 (Felder 1975c, fig V-V-I-17)	3887±56	−23.2	-	-	3976±30 T'=3.4; T'(5%)=3.8; ν=1	2580–2460	*2580–2460*	
BM-3087	103; replicate of BM-1051			4010±35	−23.4	-	-				Measured on fresh antler from the same implement as BM-1051 (email from Janet Ambers 13/03/08)
BM-975	105	*Cervus elaphus* antler crown (photo and sketch in archive)	Gallery 15B1. In undisturbed prehistoric fill beneath recently disturbed area, 20cm above floor (Felder 1975c, figs V-V-I-17)	3940±41	−24.1	-	-		2570–2290	*2570–2390*	

Laboratory number	Sample reference	Material	Stratigraphic details	Radiocarbon age (BP)	δ^{13}C (‰)	δ^{15}N (‰)	C:N	Weighted mean (BP)	Calibrated date cal BC (95% confidence)	*Highest posterior density interval cal BC (95% probability)*	Comment
BM-1003	20	*Cervus elaphus* antler pick (photo and sketch in archive)	Gallery 15B2. 5cm above floor, grouped with antlers 19, 21, 22, 23 (Felder 1975c, fig V-V-I-5)	3949±42	−22.5	-	-		2580–2300	*2580–2390*	
BM-1052a	23; counted on same sample benzine as BM-1052b	*Cervus elaphus* antler pick. Remainder is length of beam including one anciently truncated post-brow tine	Gallery 15B2. On floor, grouped with antlers 19, 20, 21, 22 (Felder 1975c, fig V-V-I-5)	4114±45	−22.9	-	-	4032±32 T'=6.6; T'(5%)=3.8; ν=1	2830–2470	*2620–2470*	
BM-1052b	23; counted on same sample benzine as BM-1052a			3954±43	−22.9	-	-				
BM-996	30; replicate of BM-3090	*Cervus elaphus* antler pick (photo in archive)	Gallery 15B3. In gallery fill 35cm above floor, beside 31	3890±42	−23.6			3922±37 T'=2.2; T'(5%)=3.8; ν=1	2560–2290	*2570–2530 (7%), 2500–2380 (88%)*	
BM-3090	30; replicate of BM-996			4010±70	−20.4						
BM-1053	31	*Cervus elaphus* antler pick (sketch in archive)	Gallery 15B3, 30cm above floor, beside 30 (Felder 1975c, V-V-I-5)	3834±50	−23.3				2470–2130	*2480–2380*	
Pit 15 C											
OxA-23144	58	*Cervus elaphus* antler pick (photo and sketch in archive). Sketch notes charred and scorched areas where beam broken off	Gallery C1. In gallery fill, under shaft fill, 20cm above floor. In same context as 59 (Longworth and Varndell 1996, fig. 46: g; Felder 1975c, fig V-V-I-24)	3943±47	−22.4	4	3.3		2580–2290	*2580–2430*	See §4.4.11.2 for stratigraphic questions
SUERC-30906	59	*Cervus elaphus* antler crown with 3 points (1 broken) and 1 tine tip lower down beam	Gallery C1. In gallery fill under shaft fill 10cm above floor. (Felder 1975c, fig. V-V-1-24; Longworth and Varndell 1996, fig 46: g)	4250±30	−22.6	5.7	3.7		2910–2870	*2920–2860 (80%), 2810–2750 (14%), 2720–2710 (1%)*	Modelled as a *terminus post quem* because not all PVA may have been removed. See §4.4.11.2 for stratigraphic questions
Gallery '15 C1'											
BM-997	47; replicate of SUERC-30903	*Cervus elaphus* antler pick (photo in archive)	'Gallery 15C1', layer II, 5cm above floor	3960±56	−24.9			4058±30 T'=4.1; T'(5%)=3.8; ν=1	2840–2480	*2640–2480*	See §4.4.11.2 for stratigraphic questions

Laboratory number	Sample reference	Material	Stratigraphic details	Radiocarbon age (BP)	$\delta^{13}C$ (‰)	$\delta^{15}N$ (‰)	C:N	Weighted mean (BP)	Calibrated date cal BC (95% confidence)	*Highest posterior density interval cal BC (95% probability)*	Comment
SUERC-30903	47; replicate of BM-997		(Felder 1975c, fig V-V-I-24; Longworth and Varndell 1996, figs 45: a; 46: g, h; 47)	4095±35	−22.9	5.5	3.3				
OxA-23111	50	*Cervus elaphus* antler pick	'Gallery 15C1', in layer II, 15cm above floor, drawn in section at same horizon as antlers 46 and 49. (Felder 1975c, fig V-V-I-24; Longworth and Varndell 1996, figs 45: a; 46: g, h; 47)	4076±27	−22.8	6.8	3.2		2850–2490	*2640–2560 (81%), 2530–2490 (14%)*	See §4.4.11.2 for stratigraphic questions
SUERC-28752	54	*Cervus elaphus* antler pick	'Gallery 15C1', layer III, 20cm above floor (Felder 1975a, fig V-V-I-24; Longworth and Varndell 1996, figs 45: a; 46: g, h; 47)	4055±35	−23.5	4.8	3.3		2840–2470	*2640–2480*	See §4.4.11.2 for stratigraphic questions
SUERC-30904	56 A; replicate of OxA-23112	*Cervus elaphus* antler pick	'Gallery 15C1, layer IV. In layer 4 of prehistoric fill, 80cm above floor (Longworth and Varndell 1996, fig 46: g; Felder 1975a, fig. V-V-I-24).	4105±35	−23.1	5.8	3.5	4103±22 T'=0.0; T'(5%)=3.8; v=1	2860–2575	*2645–2570*	See §4.4.11.2 for stratigraphic questions
OxA-23112	56 B; replicate of SUERC-30904			4102±28	−22.9	6.1	3.2				
SUERC-30905	57	*Cervus elaphus* antler pick	'Gallery 15C1', layer III, 3cm above gallery floor 56 (Felder 1975c, fig V-V-I-24; Longworth and Varndell 1996, figs 45: a; 46: g, h; 47)	4085±35	−22.3	7.2	3.3		2870–2490	*2870–2800 (18%), 2760–2560 (70%), 2540–2490 (7%)*	See §4.4.11.2 for stratigraphic questions
Gallery '15C2'											
BM-974	60; replicate of BM-3007	*Cervus elaphus* antler pick (photo and sketch in archive)	'Gallery 15C2'. In prehistoric gallery fill on floor (Felder 1976d, 14, fig V-V-I-33).	3887±47	−24.1	-	-	3925±42 T'=2.9; T'(5%)=3.8; v=1	2570–2290	*2550–2530 (1%), 2500–2370 (94%)*	
BM-3007	60; replicate of BM-974			4060±90	−23.8	-	-				

Laboratory number	Sample reference	Material	Stratigraphic details	Radiocarbon age (BP)	δ^{13}C (‰)	δ^{15}N (‰)	C:N	Weighted mean (BP)	Calibrated date cal BC (95% confidence)	*Highest posterior density interval cal BC (95% probability)*	Comment
BM-1054	61	*Cervus elaphus* antler pick	'Gallery 15C2', 50cm above floor (Felder 1976d, 14, fig V-V-I-33).	3904±36	−22.2	-	-		2480–2280	*2480–2380*	See §4.4.11.2 for stratigraphic questions
Gallery '15D1'											
BM-980		*Cervus elaphus* antler pick (photo and sketch in archive)	Gallery '15D1'. 10cm above floor, in prehistoric gallery fill under recently disturbed area, grouped with 108, 110 (Felder 1975c, 45, fig.V-V-11-3; Longworth and Varndell 1996, figs 43, 44)	3736±58	−24.8	-	-		2300–1960	*2340–2320 (1%), 2310–1950 (94%)*	
BM-1056a	110; counted on the same sample benzine as BM-1056b	*Cervus elaphus* antler pick (photo and sketch in archive)	Gallery '15D1'. 10cm above floor, in prehistoric gallery fill under recently disturbed area, grouped with antlers 108, 109 (Felder 1975c, 45, fig.V-V-11-3; Longworth and Varndell 1996, figs 43, 44)	3838±42	−23.0	-	-	3796±32 T'=2.4; T'(5%)=3.8; v=1	2340–2130	*2350–2130*	
BM-1056b	110; counted on the same sample benzine as BM-1056a			3740±48	−23.8	-	-				
Pit 15 D											
BM-978	228	*Cervus elaphus* antler pick	Gallery 15D2, 40cm above floor, close to antler 238 and junction with gallery 15J1 (Felder 1975c, 45, V-V-II-3); 1976c, 17, V-V- II-10)	3865±44	−25.0	-	-		2480–2200	*2480–2380*	
BM-1260	1514	PFWGDGSLS plan shows antler beam with stumps of 2 broken-off lateral tines (Felder 1976c, 17, V-V-11-10)	Gallery 15D4 (Felder 1976c, 17, V-V-11-10). 43cm above floor, 86-503, 200-75	4037±62	−22.5	-	-		2870–2460	*2640–2460*	

Laboratory number	Sample reference	Material	Stratigraphic details	Radiocarbon age (BP)	δ^{13}C (‰)	δ^{15}N (‰)	C:N	Weighted mean (BP)	Calibrated date cal BC (95% confidence)	*Highest posterior density interval cal BC (95% probability)*	Comment
BM-1262	1516+1523	Charcoal samples 1516 and 1523 bulked, unidentified	Gallery 15D4, 2 charcoal patches approximately 1m apart (Felder 1976c, 17, V-V-11-10). 1516 10 cm above floor, 1523 on floor	3900±54	−24.7	-	-		2570–2200	-	Excluded on grounds of potential inaccuracy
BM-1011	261	*Cervus elaphus* antler pick	Gallery 15D4. Both PFWGDGSLS plans show antler 261 here (Felder 1975c, 45, V-V-11-3; 1976c, 17, V-V-11-10), though it is listed as from gallery 15D2 by Longworth and Varndell (1996, 103) and Ambers (1998, 593)	3952±44	−22.5	-	-		2580–2300	*2580–2400*	
Pit 15 D/J											
BM-1057	238	*Cervus elaphus* antler pick	Junction of galleries 15D2 and 15J1, on floor, close to antler 228 (Felder 1975c, 45, V-V-II-3; 1976c, 17, V-V-II-10)	3924±47	−23.0	-	-		2570–2280	*2570–2520 (15%), 2510–2380 (80%)*	
Pit 15 E											
BM-1002	116	*Cervus elaphus* antler pick (photo and sketch in archive)	Gallery 15E1, 20cm above floor (Felder 1976d, fig V-V-III-8)	3882±45	−21.2	-	-		2480–2200	*2490–2370*	
BM-1058	119	*Cervus elaphus* antler pick	Gallery 15E1, 20cm above floor (Felder 1976d, fig V-V-III-8)	3876±48	−22.9	-	-		2480–2200	*2490–2370*	
BM-998	216	*Cervus elaphus* antler pick (photo in archive)	Gallery 15E2, on floor (Felder 1976d, fig V-V-III-8)	3992±45	−23.0	-	-		2620–2400	*2630–2450 (94%), 2420–2410 (1%)*	
Pit 15 E/J											

Laboratory number	Sample reference	Material	Stratigraphic details	Radiocarbon age (BP)	δ13C (‰)	δ15N (‰)	C:N	Weighted mean (BP)	Calibrated date cal BC (95% confidence)	*Highest posterior density interval cal BC (95% probability)*	Comment
BM-971	219	Bulk sample of unidentified charcoal	In breach between galleries 15E1 and 15J1, at single spot (Felder 1975a, 45, V-V-III-3).	3868±66	−25.8	-	-		2570–2130	*2550–2540 (1%), 2500–2140 (94%)*	
Pit 15 F											
BM-1059	207	*Cervus elaphus* antler pick (photo and sketch in archive)	Gallery 15F2. On prehistoric floor in fill (Felder 1975c, 58, fig. V-V-IV-3)	3977±47	−22.6	-	-		2620–2340	*2620–2610 (1%), 2590–2400 (94%)*	
BM-977	209	*Cervus elaphus* antler pick (sketch and photo in archive)	Gallery 15F2. On floor (Felder 1975c, 58, fig. V-V-IV-3)	4015±61	−24.5	-	-		2860–2340	*2640–2440 (94%), 2420–2410 (1%)*	
Pit 15 G											
BM-1000a	124; replicate of BM-1000b	Almost complete *Cervus elaphus* antler, brow tine broken off, 3 other tines still in place (sketch and photo in archive)	Pit 15G. In edge of shaft fill 40cm above floor, near antler 123 and entrance to gallery 15G1 (Felder 1975c, 65).	4051±109	−23.2	-	-	4028±51 T'=0.1; T'(5%)=3.8; v=1	2840–2460	*2630–2460*	
BM-1000b	124; replicate of BM-1000a			4022±57	−23.2	-	-				
BM-976	128	*Cervus elaphus* antler pick (sketch and photo in archive)	Gallery 15G1. On floor, in butt end (Felder 1975c, 65)	3849±44	−23.0	-	-		2470–2140	*2470–2380*	
Pit 15 J											
BM-979	231	Fragmentary *Cervus elaphus* antler pick (photo and sketch in archive)	Gallery 15J1, 5cm above floor, lying under antler pick 223 (Felder 1975a, 35, V-V-III-3; 1976c, 35, fig V-V-VI-2)	3820±46	−25.0	-	-		2470–2130	*2470–2380*	
BM-986	236	Bulk sample of unidentified charcoal	Gallery 15J1, at single spot, in prehistoric gallery fill (Felder 1976c, 35, fig V-V-VI-2)	3845±44	−25.9	-	-		2470–2140	-	Excluded on grounds of potential inaccuracy
BM-1001	246	*Cervus elaphus* antler pick (photo in archive). Sketch in archive annotated 'left antler shed, shows charring where 1 tine broken off	Gallery 15J1, 30cm above floor	3868±56	−23.3	-	-		2480–2140	*2560–2530 (3%), 2500–2370 (92%)*	

Laboratory number	Sample reference	Material	Stratigraphic details	Radiocarbon age (BP)	δ^{13}C (‰)	δ^{15}N (‰)	C:N	Weighted mean (BP)	Calibrated date cal BC (95% confidence)	*Highest posterior density interval cal BC (95% probability)*	Comment
Pit 15 K?											
OxA-23146	1551 (1)	*Cervus elaphus* antler pick	Gallery 15K1. Piled together with antlers 1550, 1552, horizontal on 1st 'crawling floor' (Felder 1976c, 14, fig V-v-I-33)	4003±29	−22.2	6.3	3.3		2580–2460	*2580–2470*	Gallery possibly driven from pit 15 K, possibly from pit 15 C (Longworth and Varndell 1996, 59)
SUERC-30911	1552 (2)	*Cervus elaphus* antler pick	Pit 15 C/K, gallery 15K1. Piled together with antlers 1550, 1551, horizontal on 1st 'crawling floor' (Felder 1976c, 14, fig V-V-I-33)	3970±30	−23.2	5.2	3.4		2580–2450	*250–2450 (94%), 2420–2410 (1%)*	As OxA-23146
OxA-23147	1557	*Cervus elaphus* antler pick	Gallery 15K1. Horizontal on floor (Felder 1976c, 14)	3922±29	−22.6	5.8	3.3		2480–2300	*2550–2540 (1%), 2490–2380 (94%)*	As OxA-23146
OxA-23145	1546	*Cervus elaphus* antler pick with some skull attached	Gallery 15K1. On floor (Felder 1976c, 14)	3933±27	−22.4	5.5	3.2		2490–2340	*2570–2530 (5%), 2500–2390 (90%)*	As OxA-23146
SUERC-30907	1550(2)	*Cervus elaphus* antler pick	Gallery 15K1. Piled together with antlers 1551, 1552 horizontal on 1st 'crawling floor' (Felder 1976c, 14, fig V-V-I-33)	3890±35	−22.8	5.9	3.6		2480–2210	*2480–2380*	As OxA-23146

Table 14: Radiocarbon dates from small cuttings in the area of the galleried pits

Laboratory number	Sample reference	Material	Context	Radiocarbon age (BP)	δ^{13}C (‰)	Calibrated cal BC (95% confidence)	*Highest posterior density interval cal BC (95% probability)*	Comment
Trench 2								
BM-1066		Bulk sample of unidentified charcoal	Trench 2 layer 3. Under rubble on pit edge on sand, with circumscribed patch of knapping debris (Longworth *et al* 2012, 84)	4224±74	−24.7	3010–2580	-	Excluded because of potential inaccuracy
Trench 3 hearth 10 and/or 11								
BM-1065	9976	Bulk sample of unidentified charcoal	Trench 3. Hearth 10 and/or 11. On old land surface beneath spoil surrounding unexcavated pit, stratified below horse skull (Longworth *et al* 2012, 84–5)	3941±89	−24.6	2840–2150	-	Excluded because of potential inaccuracy
Area of Greenwell's pit								
BM-2379	5640G121, 122, 123, 124, 155, 105, 103	Unidentified bulk charcoal sample	Cutting 19. From *in situ* hearth in area of dense, fresh knapping debris on old land surface preserved under upcast from Greenwell's pit or from another to the N (Healy 1985)	4150±90	−25.7	2920–2470	*2910–2490*	*Terminus post quem* for knapping episode, overlying dump and excavation of pit from which it came
BM-2380	5640G79	*Cervus elaphus* antler pick	Context 79, cutting 19. *In situ* hearth on old land surface preserved under upcast from Greenwell's pit or from another to the N (Healy 1985)	3810±60	−23.0	2470–2040	*2480–2370*	*Terminus post quem* for overlying dump and excavation of pit from which it came. Probably contemporary with knapping episode
BM-2377	5640G157	Bulk sample of unidentified charcoal	Context 157. Commercial excavation 3m W of cutting 19. Hearth on old land surface preserved below upcast from Greenwell's pit or from another to the N (Healy 1985)	4060±90	−23.9	2890–2340	*2880–2460*	*Terminus post quem* for overlying dump and for excavation of pit from which it came

Table 15: Results of alternative models for the galleried pits (Figs 40–1)

Model	No. of effective likelihoods	No. of features	No. of individual estimates	No. of *tpq*s	*Start cal BC (95% probability)*	*End galleried shafts cal BC (95% probability*	*Work galleried shafts (95% probability)*	A_{model}
Preferred	136	26	13	11	*2665–2605*	*2435–2360*	*185–290*	87
1. As preferred, but including only those features for which individual estimates have been made	95	13	13	6	*2655–2595*	*2445–2380*	*165–255*	86
2. As preferred, but using only measurements made during the current project	87	16	9	9	*2670–2610*	*2465–2430*	*155–225*	144

Table 16: Results of χ^2 tests on radiocarbon measurements for antler from primary contexts in elements for which individual estimates have been made and of the Combine operation on the corresponding highest posterior density intervals derived from the preferred model, in each case excluding those excluded or modelled as tpqs. *Also listed are estimates for the working of the same elements derived from the preferred model, from the modelling of each of these elements in an independent bounded phase, and from a model which simulates identical dates for all the antlers in an element while retaining the errors of the original measurements (Fig 44)*

Element	Brief description	Radiocarbon determinations for antler implements from primary contexts statistically consistent or not?	May highest posterior density intervals for antler implements from primary contexts be combined?	Duration in *years* (*95% probability*) from preferred model	Duration in *years* (*95% probability*) when element modelled as independent bounded phase	Duration in *years* (*95% probability)* when dates for antler implements from primary contexts in a pit simulated as identical but retaining errors of actual radiocarbon measurements
1971 pit base and galleries	Shaft base *c* 14sq m, 11m of galleries	Yes, at 99%: T'=23.4; T'(5%)=22.4; **v**=13	Yes: n=14, Acomb= 43.9% (An= 18.9%)	*70–155* (Fig 44: *work 1971 pit (galleries 1 and 3)*)	*20–190* (Fig 44: *work 1971 pit (galleries 1 and 3)* bounded)	*150–270* (Fig 44: *work 1971 pit (galleries 1 and 3* simulated)
pit NE of 1971 pit	Single gallery, excavated for 5.15m	Yes: T'=13.9; T'(5%)=14.1; **v**=7	Yes: n=8, Acomb= 31.6% (An= 25.0%)	*70–175* (Fig 44: *work pit NE of 1971 pit*)	*0–265* (Fig 44: *work pit NE of 1971 pit* bounded)	*135–345* (Fig 44: *work pit NE of 1971 pit* simulated)
Greenwell's pit	Shaft base c 15sq m, *c* 57m of galleries	No: T'=55.5; T'(5%)=18.3; **v**=10	No: n=11, Acomb=0.2% (An=21.3%)	*155–260* (Fig 44: *work Greenwell's pit*)	*60–380* (Fig 44: *work Greenwell's pit* bounded)	*190–380* (Fig 44: *work Greenwell's pit* simulated)
Greenwell's pit A	Single gallery, 9.5m long	Yes, at 99%: T'=10.6; T'(5%)=7.8; **v**=3	Yes: n=4, Acomb= 67.6%(An= 35.4%)	*25–165* (Fig 44: *work Greenwell's pit A*)	*0–890* (Fig 44: *work Greenwell's pit A* bounded*)*	*20–125* (Fig 44: *work Greenwell's pit A* simulated)
Greenwell's pit C	Single gallery, 11.5m long	Yes: T'=5.0; T'(5%)=7.8; **v**=3	Yes: n=4, Acomb=226.5% (An= 35.4%)	*40–185* (Fig 44: *work Greenwell's pit C*)	*0–320* (Fig 44: *work Greenwell's pit C* bounded)	*35–230* (90%) (Fig 44: *work Greenwell's pit C* simulated)
Greenwell's pit E	Dated antlers all from single gallery excavated for 4m	No: T'=22.9; T'(5%)=6.0; **v**=2	No: n=3, Acomb=3.3% (An= 40.8%)	*70–245* (Fig 44: *work Greenwell's pit E*)	*100–480* (Fig 44: *work Greenwell's pit E* bounded)	*35–280* (84%) (Fig 44: *work Greenwell's pit E* simulated)
pit 12	Shaft base *c* 24sq m, *c* 14m of galleries explored	Yes: T'=9.9; T'(5%)=12.6; **v**=6	Yes: n=7, Acomb=46.3% (An= 26.7%)	*40–165* (Fig 44: *work pit 12*)	*0–95* (Fig 44: *work pit 12* bounded)	*75–280* (Fig 44: *work pit 12* simulated)
pit 14	Shaft base *c* 13sq m, *c* 11m of niches/galleries explored	Yes: T'=5.6; T'(5%)=15.5; **v**=8	Yes: n=9, Acomb=103.1% (An= 23.6%)	*70–210* (Fig 44: *work pit 14*)	*0–100* (Fig 44: *work pit 14* bounded)	*170–360* (Fig 44: *work pit 14* simulated)
pit 15 B	3 galleries excavated for total of 11.5m	Yes, at 99%: T'=12.9; T'(5%)=11.1; **v**=5	Yes: n=6, Acomb= 41.8% (An= 28.9%)	*70–215* (Fig 44: *work pit 15 B*)	*0–260* (Fig 44: *work pit 15 B* bounded)	*60–245* (81%) (Fig 44: *work pit 15 B* simulated)
gallery 15C1 above collapsed pit 15 C fill	Single gallery 2.2m long	Yes: T'=2.2; T'(5%)=7.8; **v**=3	Yes: n=4, Acomb=134.3% (An= 35.4%)	*20–145* (Fig 44: *work gallery 15C1*)	*0–180* (Fig 44: *work gallery 15C1* bounded)	*35–355* (Fig 44: *work gallery 15C1* simulated)
galleries 15D2 and 15J1	2 conjoined galleries, 5.5m long, filled together on the evidence of an antler pick lying across their junction	Yes: T'=2.5; T'(5%)=7.8; **v**=3	Yes: n=4, Acomb= 152.0% (An= 35.4%)	*10–155* (Fig 44: *work galleries 15D2 and 15J1*)	*0–225* (Fig 44: *work galleries 15D2 and 15J1* bounded)	*10–145* (Fig 44: *work galleries 15D2 and 15J1* simulated)
pit 15 K	Single gallery excavated for 1.9m	Yes:: T'=8.0; T'(5%)=9.5; **v**=4	Yes: n=5, Acomb= 61.6% (An= 31.6%)	50–190 (Fig 44: *work pit 15 K*)	*0–205* (Fig 44: *work pit 15 K* bounded)	*35–165* (Fig 44: *work pit 15 K* simulated)

Table 17: Radiocarbon dates from simple pits on the West Field

Laboratory number	Sample reference	Material	Context	Radiocarbon age (BP)	δ^{13}C (‰)	δ^{15}N (‰)	C:N	Weighted mean (BP)	Calibrated date cal BC (95% confidence)	*Highest posterior density interval cal BC (95% probability)*	Comment
Pit 8											
BM-109		Antler, unspecified	Pit 8, context unspecified (Armstrong 1924, 191; 1927, 103–5; 1932, 59; Longworth and Varndell 1996, 65–9)	3290±150	-	-	-		1950–1260	-	Excluded because model otherwise falls into poor overall agreement
Pit 10											
BM-93	B	Antler, unspecified	Pit 10. Described as from the 'fast fill', presumably the material filling most of the pit	3870±150	-	-	-		2870–1920	*2580-2100*	
OxA-failed	'Pit 10 floor SE at 6 ft 6 in'	*Cervus elaphus* antler pick fragment	Label: 'Pit 10 floor SE at 6ft 6in' [2m]. This places the antler on the base of the pit (Longworth and Varndell 1996, fig 57)	-	-	-	-		-	-	'Failed due to very low yield' ORAU letter 14.6.2010
SUERC-28749	'Pit 10 under W wall in cove at 6 ft'	*Cervus elaphus* antler pick	Label: 'Pit 10 under W wall in cove at 6ft'60- [1.8m]. This places the antler close to the base of the pit (Longworth and Varndell 1996, fig 57)	3950±35	−22.3	4.5	3.3		2570–2340	*2570–2340 (94%), 2320–2310 (1%)*	
SUERC-28750	'Pit 10 N side in rubble at 6 ft (1)'	*Cervus elaphus* antler pick	Label: 'Pit 10. N side in rubble at 6ft (1)' [1.8m]. This places the antler close to base of the pit (Longworth and Varndell 1996, fig 57)	3830±35	−22.4	6.3	3.4		2470–2140	*2460–2190 (93%), 2170–2150 (2%)*	
F3											
BM-970	GG73 sf 98	Head of large *Cervus elaphus* antler pick in 2 joining fragments	F3, at 2.15m in lower fill. F3 was an irregular oval pit 3.8m x 3m and at least 2.15m deep. Jumbled (back?)fill of sand, gravel rotten chalk (Longworth *et al* 2012, 49–51)	3767±57	−24.9	-	-		2430–2020	*2460–2420 (2%), 2410–2370 (2%), 2350–2050 (91%)*	Pit appears backfilled, sample could have been redeposited
F5 in 950/820											
BM-992	GG73 130/S28	*Cervus elaphus* antler pick (photo in archive)	F5 layer 24 or layer 6. F5 was an irregular pit which was not bottomed. L24 was a layer of knapping debris in the upper fill; L6 (the context of the sample) was a lens of charcoal within L24 (Longworth *et al* 2012, 50–2)	3727±57	−23.2	-	-		2300–1950	*2340–2320 (1%), 2310–2040 (94%)*	Provides *terminus post quem* for knapping. Relation to working of pit unknown because pit not bottomed
BM-3119		Antler, unspecified	F5 layer 6. See BM-992	3800±30	−22.7	-	-		2340–2130	*2340–2140*	As BM-992
F6											
OxA-20716	GG73 161	Head of *Cervus elaphus* antler pick	F6 layer 5, 1.92m deep.	4065±45	−23.0	5.9	3.2		2860–2470	*2620–2470*	
OxA-21187	GG73 159	*Cervus elaphus* antler pick	F6 layer 5, 1.89m deep	3960±31	−21.9	6.6	3.3		2570–2350	*2570–2400 (89%), 2390–2340 (6%)*	
SUERC-24120	GG73 160	*Cervus elaphus* antler tine with worn tip, probably broken from pick	F6 layer 5, 1.86m deep	4010±35	−22.6	6.3	3.3		2620–2460	*2580–2460*	

Laboratory number	Sample reference	Material	Context	Radiocarbon age (BP)	$\delta^{13}C$ (‰)	$\delta^{15}N$ (‰)	C:N	Weighted mean (BP)	Calibrated date cal BC (95% confidence)	*Highest posterior density interval cal BC (95% probability)*	Comment
SUERC-25712	GG73 154	*Cervus elaphus* antler pick	F6 layer 5, 1.6m deep	4095±40	−22.3	5.4	3.3		2880–2490	*2870–2800 (20%), 2780–2560 (70%), 2530–2490 (5%)*	
SUERC-25713	GG73 158	*Cervus elaphus* antler pick	F6 layer 5, 1.6m deep	4065±40	−22.3	5.2	3.2		2860–2470	*2860–2810 (12%), 2750–2720 (3%), 2700–2480 (80%)*	
BM-993	GG73 128/S27	*Cervus elaphus* antler	F6 layer 4, 1m deep	3614±67	−23.5	-	-		2200–1770	*2200–2170 (2%), 2150–1770 (93%)*	
BM-3120		*Cervus elaphus* antler, unspecified	F6 layer 4	3850±50	−21.0	-	-		2480–2140	*2470–2190 (93%), 2170–2150 (2%)*	
SUERC-25711	GG73 152	*Cervus elaphus* antler tine anciently broken from beam	F6 layer 4	4010±40	−20.1	5.2	3.3		2630–2460	*2840–2820 (1%), 2640–2460 (94%)*	
BM-1007	GG74 sf 102	Described as 'large antler shaft well preserved' (Nigel Meeks' notebook)	F6 layer B=3. Finds book confirms that it was from layer B, though listed as from L1 by Ambers (2012)	3825±54	−23.3	-	-		2470–2060	*2470–2140*	
BM-3006	GG73 136	Antler, unspecified	F6, context uncertain. Listed by Ambers and Bowman(1999)as 'F6 136' among dates from deep mines	3780±45	−22.2	-	-		2350–2040	*2440–2420 (1%), 2410–2370 (1%), 2350–2110 (91%), 2100–2060 (2%)*	
F7											
BM-1009	GG74 sf 184	*Cervus elaphus* antler crown (photo in archive)	F7 layer C=10	3825±41	−20.6	-	-		2470–2140	*2460–2190 (90%), 2180–2140 (5%)*	
BM-3121		*Cervus elaphus* antler, unspecified	F7 layer C=10	3900±50	−21.6	-	-		2570–2200	*2500–2270 (89%), 2260–2200 (6%)*	
OxA-20717	GG74 sf 182	*Cervus elaphus* antler pick	F7 layer C=10	4083±33	−23.5	4.7	3.3		2860–2490	*2630–2480*	
OxA-21189	GG74 168	*Cervus elaphus* antler pick	F7 layer C=10	3946±31	−22.4	4.4	3.3		2570–2340	*2570–2520 (12%), 2500–2330 (82%), 2320–2310 (1%)*	
OxA-21190	GG74 183; replicate of OxA-21191	*Cervus elaphus* antler pick	F7 layer C=10	3915±32	−22.7	6	3.3	3967±23T'=5.04; T'(5%)=3.8; v=1)	2570–2460	*2570–2450 (94%), 2420–2400 (1%)*	
OxA-21191	GG74 183; replicate of OxA-21190			4015±31	−22.7	6	3.3				

Laboratory number	Sample reference	Material	Context	Radiocarbon age (BP)	δ13C (‰)	δ15N (‰)	C:N	Weighted mean (BP)	Calibrated date cal BC (95% confidence)	*Highest posterior density interval cal BC (95% probability)*	Comment
SUERC-25717	GG74 165	*Cervus elaphus* antler pick	F7 layer C=10	4220±40	−21.5	-	-		2910–2670	*2910–2830 (37%), 2820–2670 (58%)*	
SUERC-25718	GG74 136 A; replicate of OxA-21188	*Cervus elaphus* antler pick	F7 layer A=8	4065±40	−22.9	6.7	3.3	4018±25(T'=2.3; T'(5%)=3.8; ν=1)	2620–2470	*2585–2470*	
OxA-21188	GG74 136 B; replicate of SUERC-25718			3988±32	−23.0	5.9	3.3				
BM-994	S25	Bulk sample of unidentified charcoal	F7 layer A=8	3535±90	−25.1				2140–1630	*2140–1640*	
F11											
BM-1016	GG74 141	'Broken large antler, well preserved' (Nigel Meeks' notebook)	F11 (probably = F26) layer 12. One of lower fills of part of a pit or series of pits >1.7 m deep (Longworth *et al* 2012, 54–6)	3797±49	−20.6	-	-		2460–2040	*2460–2130*	
F14											
BM-1010	GG74 135	'Good whole antler' (Nigel Meeks' notebook) Head of antler pick remains	F14 (probably = F22) interface of bottom layer (24) and overlying layer (25). Pit 2.25m across and 1.65m deep, expanded at base. Antler at (Longworth *et al* 2012, 58–60)	3770±66	−21.5	-	-		2470–1980	*2350–2050*	
F16											
BM-1017	GG74 sf 268	'Fragment of antler tine' (finds book)	F16 layer 7. Chipping floor either under or in base of chalk dump in sand hollows (Longworth *et al* 2012, 60)	3710±39	−23.1	-	-		2210–1970	*2280–2250 (4%), 2230–2220 (1%), 2210–2040 (90%)*	Must lie within period of extraction because within/under chalk dump
F18											
BM-1023		Bulk sample of unidentified charcoal	F18, layer 2. Knapping debris with large flint nodules in top of feature, overlain by dump of chalk rubble in brown sand (Longworth *et al* 2012, 61).	4061±52	−24.3	-	-		2870–2470	*2870–2800 (13%), 2760–2470 (82%)*	Must lie within period of extraction because under chalk dump
F24											
BM-1008	GG74 sf 232	Antler pick (finds book)	F24 layer 4, sample 2m deep. Pit 2.1m across and at least 2.2m deep, probably almost completely excavated. L4 was a mass of sand and chalk filling most of lower excavated part of pit (Longworth *et al* 2012, fig 45)	3764±39	−23.1	-	-		2300–2030	*2340–2320 (1%), 2310–2110 (91%), 2100–2050 (3%)*	Mass of L4 suggests purposeful backfill soon after excavation
F28											
BM-1063	GG76 sf 1225	Antler unspecified	F28 L15. Part of same pit or group of pits as F11 and F26. Nigel Meeks' notes say 'sealed in chalk rubble'. Section shows shallow (max. 0.1m) layer of chalk rubble at base, overlain by mass of apparently tipped sand (Longworth *et al* 2012, 57)	3874±55	−22.1	-	-		2490–2150	*2480–2190 (94%), 2160–2150 (1%)*	

Laboratory number	Sample reference	Material	Context	Radiocarbon age (BP)	δ^{13}C (‰)	δ^{15}N (‰)	C:N	Weighted mean (BP)	Calibrated date cal BC (95% confidence)	*Highest posterior density interval cal BC (95% probability)*	Comment
F32											
BM-1064	GG76 1224	Survives as *Cervus elaphus* antler tine with truncated, battered tip	F32 layer 4. F32 was pit >2.65m across and at least 1.7m deep, with some undercutting. L4 was a tip overlying mass of chalky infilling (Longworth *et al* 2012, 65–6).	3748±59	−22.8	-	-		2350–1970	*2410–2380 (1%), 2350–2040 (94%)*	
F34											
BM-1062	GG76 sf 331	*Cervus elaphus* antler pick	F34 layer 3. F34 was pit 3.5 x 2.4m, 1.83m deep, undercut at base. L3 was a middle fill (Longworth *et al* 2012, 66)	3695±49	−22.9	-	-		2270–1940	*2290–2040*	
F51											
BM-1015	GG74 sf 200	Antler pick (findsbook); 'antler from young deer' (Nigel Meeks' notebook)	F51 layer 3. F51 was a pit 0.82m across and 0.65m deep cut from the bottom of F14. Layer 3 was the lowest of its 3 fills (Longworth *et al* 2012, 58–60)	3851±34	−22.2	-	-		2470–2200	*2470–2270 (85%), 2260–2210 (10%)*	Should predate filling of F14
F124											
BM-1034		Bulk sample of unidentified charcoal	F124, layer 2, hearth in top of pit, overlying layer 4 (Longworth *et al* 2012, 81)	3763±47	−25.8	-	-		2340–2030	*2290–2020*	Modelled as contemporary with context because consistent with BM-3135 which was measured on short-life charcoal (T'=0.5; T'(5%)=3.8; ν=1)
BM-3135		*Pinus* sp. charcoal	As BM-1034	3720±40	−25.0	-	-		2280–1980	*2210–2010 (92%), 2000–1970 (3%)*	Modelled as contemporary with context because measured on short-life charcoal

Table 18: Radiocarbon dates from contexts on the on the West Field not necessarily associated with mining

Laboratory number	Sample reference	Material	Context	Radiocarbon age (BP)	$\delta^{13}C$ (‰)	Calibrated date cal BC (95% confidence)	*Highest posterior density interval cal BC (95% probability)*	Comment
Cutting 900/870								
BM-991	S6 and S7	Bulk sample of unidentified charcoal	Cutting 900/870 F2 layer 2. Hearth with 7 indeterminate early Bronze Age sherds (Longworth *et al* 2012, 46)	3414±46	−24.1	1880–1610	-	Excluded because of potential inaccuracy
Cutting 950/820								
BM-1019	GG74 sf 212	'Fragment of antler pick' (findsbook)	F4 layer 3. Irregular pit 4.76 m across, >1.76m deep (not bottomed). L3 was near the top and may have post-dated backfilling (Longworth *et al* 2012, 51)	3593±45	−23.2	2120–1780	*2130–2090 (4%), 2050–1870 (87%), 1850–1810 (3%), 1800–1770 (1%)*	Date or *terminus post quem* for late stage of infilling. Relation to working of pit unknown
BM-1005		Bulk sample of unidentified charcoal	F12 layer 11. Fire/charcoal spread in shallow depression in sand, among extraction pits. Base not defined (Longworth *et al* 2012, 57–8)	3948±37	−24.7	2570–2340	-	Excluded because of potential inaccuracy
BM-1022		'2 bags of good charcoal', unidentified	F13 layer 3. Layer of charcoal and sand in upper fills of pit 2.8 × 3.7m, 1.03m deep, probably part of incompletely excavated larger feature filled with successive layers of sand (Longworth *et al* 2012, 58)	3559±39	−24.9	2030–1770	-	Excluded because of potential inaccuracy
BM-1012	GG74 sf 123	'Large fragment broken antler' (Nigel Meeks' notebook)	F19 layer 1. Small area of dumped chalk rubble with antler and knapping debris (Longworth *et al* 2012, 61)	3695±33	−22.9	2200–1970	*2200–1970*	Chalk rubble and antler suggest relation to extraction or scavenging
BM-1018	GG74 sf 124	'Shaft of antler 12 in long from sandy soil. Rootlets penetration' (Nigel Meeks' notebook)	F23, layer 1. Surface of chalk dump associated with knapping debris, between F10 and F47, planned but not excavated (Longworth *et al* 2012, 63)	3593±37	−21.7	2040–1830	*2120–2090 (1%), 2040–1870 (93%), 1850–1820 (1%)*	Could fall within period of extraction or could relate to scavenging of already quarried material
BM-1024		Bulk sample of unidentified charcoal	F36 layer 7. One of lowest excavated layers of infill in what was probably the top of a deeper feature, either overlying or at same level as layer of knapping debris (Longworth *et al* 2012, 68, fig 51)	3904±38	−18.6	2480–2230	-	Excluded because of potential inaccuracy
BM-1006	GG74 1011?	Bulk sample of unidentified charcoal	F38. Small area of burning on edge of *in situ* knapping debris including rods and roughouts, truncated by plough (Longworth *et al* 2012, 68)	4017±60	−25.1	2860–2350	-	Excluded because of potential inaccuracy
Cutting 940/940								
BM-1030		Bulk sample of unidentified charcoal	F106 layer 8, chipping unit 2. Lower of two knapping deposits, with hearth material, in F106 (probably = F120), a circular pit the top 0.73m of which were excavated (Longworth *et al* 2012, 76, fig 61)	2953±36	−25.8	1310–1040	-	Excluded because of potential inaccuracy
BM-1031		Bulk sample of unidentified charcoal	F108 layer 1. Occupation material in shallow oval depression, 2.72m across, with predominantly early Bronze Age pottery including collared vessels (Longworth *et al* 1988, 24), fired clay objects, animal bone, struck flint (Longworth *et al* 2012, 78–9)	3386±41	−24.9	1770–1530	-	Excluded because of potential inaccuracy
BM-1032		Bulk sample of unidentified charcoal	F112 layer 3. Upper layer of pit, underlying knapping floor in layer 2. Sherds of collared vessels from layers 2 and 3 (Longworth *et al* 2012, 78–9, 109–118; Longworth *et al* 1988, 23). Pottery seen as intrusive; there were also 3 gunflints (Gill Varndell pers comm 2008)	3286±67	−20.1	1740–1420	-	Excluded because of potential inaccuracy
BM-1033		Bulk sample of unidentified charcoal	F121, layer 2. Hearth near top of pit excavated down to 0.84m (not bottomed) (Longworth *et al* 2012, 80)	2881±49	−25.6	1260–910	-	Excluded because of potential inaccuracy

Laboratory number	Sample reference	Material	Context	Radiocarbon age (BP)	δ^{13}C (‰)	Calibrated date cal BC (95% confidence)	*Highest posterior density interval cal BC (95% probability)*	Comment
BM-3135		Pinus sp. charcoal	F124, layer 2, hearth overlying layer 4. F124 was an unbottomed circular pit, 2.64 x 2.56m, >1.08m deep, cut by extraction pit F101. (Longworth *et al* 2012, 81). Archive plans GG75 P24a and P37 show hearth as black area against SE side of pit with 'area of burnt timber (dense charcoal)' *c* 0.5m x 0.08m against pit wall. Archive plan GG76 P5 shows hearth *c* 1.5m x 1m, with burnt and unburnt chalk and flint blocks	3720±40	−25.0	2280–1980	*2210–2010 (92%), 2000–1970 (2%)*	Modelled as contemporary with context because measured on short-life charcoal. Should date hearth and provide taq for F124. Since the hearth was near the top of the fills of F124 and clear of the intersection with F101, it could have been formed after the cutting of F101, so that the dates from it do not provide *termini post quos* for that event.
BM-1034		Bulk sample of unidentified charcoal	As BM-3135	3763±47	−25.8	2340–2030	*2290–2020*	Modelled as contemporary with context because consistent with BM-3135 which was measured on short-life charcoal (T'=0.5; T'(5%)=3.8; ν=1). Otherwise as BM-3135
Cuttings 1000/905 and 1000/910								
BM-811		Bulk sample of unidentified charcoal	Cutting 1000/905. 1 of 2 small trenches dug to test linear feature detected by resistivity survey revealed parts of tops of 3 pits (1 extending into cutting 1000/910), a charcoal spread and a knapping floor, a little below topsoil (Sieveking *et al* 1973, 207, figs 12, 13, pls XXI, XXII)	3607±300	−27.2	2890–1290	-	Excluded because of potential inaccuracy
BM-812		Antler pick (Sieveking *et al* 1973, 207, fig. 12, pl. XXII)	Cutting 1000/910. 1 of 2 small trenches dug to test linear feature detected by resistivity survey revealed parts of tops of 2 pits (1 extending into 1000/905), and a knapping floor with antler pick (Sieveking *et al* 1973, 207, figs 12, 13, pl. XXII).	3380±55	−26.6	1880–1520	*1920–1600*	Relation to extraction unknown

Table 19: Radiocarbon dates from 'primitive' pits and gallery 15D3

Laboratory number	Sample reference	Material	Context	Radiocarbon age (BP)	δ^{13}C (‰)	δ^{15}N (‰)	C:N	Weighted mean (BP)	Calibrated date cal BC (95% confidence)	*Highest posterior density interval cal BC (95% probability)*	Comment
Pit 3											
OxA-22528	1929 5-8 1	*Bos*, Distal L tibia. Articular end perforated, distal end battered and plugged with chalk (Legge 1992, 69, fig 33: A96)	Penciled onto bone: 'Pit 3. 10'.0 sand'. This would place the artefact *c* 3ft (0.9m) above the base of the pit (Longworth and Varndell 1996, fig 30)	3220±28	−21.4	4.7	3.3		1530–1430	*1535–1440*	
Pit 3 A											
BM-1060	GG76 pit 3A sf 10	*Cervus elaphus* antler pick	Layer 10. In chalk rubble on floor of niche V, one of a series of higher-level undercuts (Longworth and Varndell 1996, 39–45)	3863±86	−23.5	-	-		2580–2040	*2580–2120 (93%), 2090–2040 (2%)*	Must have been redeposited, given second millennium cal BC date of bone picks from this pit
OxA-22529	GG76 pit 3A sf 46 a; replicate of SUERC-28742	*Bos*, Distal R tibia, broken across shaft, split longitudinally, pointed (Boyd 1996, fig 69: 8).	Layer 16, lower level niche III. Niche at base of pit (Longworth and Varndell 1996, 39–45)	3318±27	−20.7	5.7	3.2	3289±22 T'=3.1; T'(5%)=3.8; v=1)	1625–1500	*1595–1495*	
SUERC-28742	GG76 pit 3A sf 46 b; replicate of OxA-22529			3240±35	−21.4	5.5	3.3				
SUERC-24126	GG76 pit 3A sf 48	*Bos*, L radius, proximal end, cut marks on lateral proximal side, midshaft cut obliquely to form pick, gnawed	Layer 17. Rubble fill of one of a series of higher-level undercuts (Longworth and Varndell 1996, 39–45, fig 36)	3370±35	−21.0	6	3.4		1750–1530	*1750–1600 (88%), 1590–1530 (7%)*	Modelled as *terminus post quem* because not all PVA may have been removed
SUERC-25719	GG76 pit 3A sf 23	*Cervus elaphus* antler pick	Layer 10. Chalk rubble occupying floor of niche V, one of a series of higher-level undercuts. ? antler shown in published section (Longworth and Varndell 1996, fig 35)	4215±40	−22.5	5.2	3.3		2910–2670	*2910–2830 (34%), 2820–2670 (61%)*	Must have been redeposited, given mid-second millennium cal BC dates of bone picks from this pit. Not all PVA may have been removed
SUERC-28743	GG76 pit 3A sf 53	Long bone split and made into implement with 1 spatulate and 1 pointed end. Tentatively identified as human by Boyd (1996, fig 69: 26). Identified as animal by Sharon Clough 2010	Layer 16. Lower fill of niche 1, at the base of the pit (Longworth and Varndell 1996, fig 35)	3400±35	−21.0	5.6	3.4		1870–1610	*1880–1840 (3%), 1810–1800 (1%), 1780–1610 (91%)*	Modelled as *terminus post quem* because not all PVA may have been removed
Pit 4											

Laboratory number	Sample reference	Material	Context	Radiocarbon age (BP)	$\delta^{13}C$ (‰)	$\delta^{15}N$ (‰)	C:N	Weighted mean (BP)	Calibrated date cal BC (95% confidence)	*Highest posterior density interval cal BC (95% probability)*	Comment
OxA-22530	A90	Bos. Proximal L metatarsal. Pit cut in surface of articulation, medullary cavity plugged with chalk (Legge 1992, 69, fig A90)	Penciled onto bone: 'P.4. 12'-6'. Label stuck onto bone reads 'Grime's Graves. Pit 4. 12 feet 4. 1923. In sand'. This would have been close to the base of the pit (Longworth and Varndell 1996, 63–4)	3185±27	−20.6	4.7	3.2		1510–1410	*1520–1430*	
SUERC-28747	A91	*Bos*. Proximal L radius. Articular surface perforated, moderate wear on broken end of shaft (Legge 1992, 69, fig 32:A91), some chalk in medullary cavity	Penciled onto bone: '10'6. P4' and '(4)' At a depth of 10ft 6in (3.2m) This would have lain in the lower fills of the pit (Longworth and Varndell 1996, fig 50). Listed as from pit 3 by Legge (1992)	3200±35	−21.0	6.5	3.3		1530–1410	*1530–1440*	Modelled as *terminus post quem* because not all PVA may have been removed
Pit 6											
OxA-22531	'Pit VI 12-6'	Bone pick, probably of *Bos* long bone, split longitudinally, chalk in medullary cavity	Pit 6. Marked in pencil 'Pit VI 12-6'. This places the implement very close to the pit bottom (Armstrong 1924a, 185; Longworth and Varndell 1996, 65)	3194±26	−20.4	5.4	3.2		1520–1410	*1530–1440*	
SUERC-28748	'Pit VI Bottom'	Bone pick, probably of *Bos* long bone, split longitudinally, some chalk remaining in medullary cavity at point	Marked 'Pit VI Bottom'	3295±35	−21.3	6	3.3		1690–1490	*1670–1490*	Modelled as *terminus post quem* because not all of consolidant may have been removed
Gallery 15D3											
BM-972	253	Bulk sample of unidentified charcoal. 2 bags	Single patch of charcoal on floor (Felder 1975c, 45, V-V-II-3; 1976c, 17, V-V- II-10).	3071±209	−27.4	-	-		1880–810	-	Excluded because of potential inaccuracy
OxA-20759	250	L *Bos* radius, proximal end, mid shaft cut obliquely to form pick	50cm above floor. Planned at S side of gallery 15D3, near mouth, against chalk pillar (Felder 1975c, 45; 1976c, 17)	3290±28	−20.4	4.7	3.3		1640–1490	*1600–1490*	
SUERC-24108	251	R *Bos* radius, proximal end, mid shaft cut obliquely to form pick	On floor in centre of gallery, on floor (Felder 1975c, 45; 1976c, 17)	3295±30	−21.2	6.1	3.3		1670–1490	*1600–1490*	
F105											
BM-1061	GG76 1372	Antler unspecified	F105, layer 39. (Longworth *et al* 2012, 72–6). This may have been either an upper fill of F105 or a fill of an earlier feature through which F105 was cut. Sherds of collared vessels in topmost layer (1), post-dating layer 39 (Longworth *et al* 1988, 23)	3666±55	−22.0	-	-		2210–1890	*2200–1900*	
BM-3134		Antler unspecified. If this was GG76 sf 1373 then it was an antler pick (described in ms list of 1976 antler small finds)	As BM-1061	3560±50	−22.8	-	-		2040–1750	*2030–1750*	

Laboratory number	Sample reference	Material	Context	Radiocarbon age (BP)	δ13C (‰)	δ15N (‰)	C:N	Weighted mean (BP)	Calibrated date cal BC (95% confidence)	*Highest posterior density interval cal BC (95% probability)*	Comment
OxA-20591	GG76 1581+1578	*Bos*, R radius, proxmal end, perforated in middle of proximal surface, mid shaft cut obliquely to form pick. Split longitudinally, two halves glued together. 1581 sampled	Gallery III layer 55. Undercut made at floorstone level at base of pit (Longworth *et al* 2012, fig 59).	3231±28	−22.1	5.4	3.2		1610–1430	*1540–1440*	
OxA-20720	GG76 1548+1549	?*Bos*, distal end of tibia, gnawed, mid shaft cut obliquely to form pick	Gallery III. Undercut made at floorstone level at base of pit (Longworth *et a*l 2012, fig 59).	3226±33	−21.8	5.3	3.2		1610–1420	*1550–1430*	
OxA-21192	GG76 1408	*Cervus elaphus* antler crown, 1 tine broken off in antiquity	Layer 44. In mid fill of pit corresponding to upper of two levels at which undercuts made. (Longworth *et al* 2012, fig 58). Sherds of collared vessels in topmost layer	3988±31	−22.4	3.3	3.3		2580–2460	*2580–2460*	Redeposited
SUERC-24121	GG76 1580	*Bos*, R radius, proximal end. Mid shaft cut obliquely to form pick. Split, ?in use, chalk in cavity at distal end	Layer 55. No mention of L55 in site description, though label describes it as 'primary fill' and it is described as fill of gallery III in labels on samples for SUERC-24122, OxA-20591	3245±30	−20.8	4.7	3.2		1610–1440	*1570–1440*	Modelled as *terminus post quem* because not all of PVA may have been removed
SUERC-24122	GG76 1582	*Bos*, R radius, proximal end, mid shaft cut obliquely to form pick, gnawed	As OxA-20591	3290±30	−21.2	4.6	3.3		1640–1490	*1600–1490*	Modelled as *terminus post quem* because not all of PVA may have been removed

Table 20: Radiocarbon dates from midden deposits

Laboratory number	Sample reference	Material	Context	Radiocarbon age (BP)	$\delta^{13}C$ (‰)	$\delta^{15}N$ (‰)	C:N	Weighted mean (BP)	Calibrated date cal BC (95% confidence)	*Highest posterior density interval cal BC (95% probability)*	Comment
1972 pit											
OxA-22435	GG72 274 a; replicate of SUERC-28759	Abundant residue on interior of middle Bronze Age base angle	Tr 8B, L4A, sq 18, midden group 1. (Mercer 1981, 36–8, figs 2, 20, 21)	3071±29	−25.5	5.0	11.6	3067±23 T'=0.1; T'(5%3.8)=; v=1)	1415–1265	*1400–1300*	
SUERC-28759	GG72 274 b; replicate of OxA-22435			3060±35	−26.1						
OxA-22436	GG72 735 a; replicate of OxA-22437, SUERC-28760	Abundant residue on interior of middle Bronze Age body sherd	Tr 8B, L4Biv (light brown/grey sandy/ashy with charcoal), sq 49, midden group 3 (Mercer 1981, 36–8, figs 2, 20, 21).	3072±29	−23.8	4.8	12.1	3108±18 (T'=3.4; T'(5%)=6; v=2)	1430–1315	*1420–1370 (69%), 1350–1315 (26%)*	
OxA-22437	GG72 735 a; replicate of OxA-22436, SUERC-28760			3110±29	−24.3	4.3	11.8				
SUERC-28760	GG72 735 b; replicate of OxA-22436, -22437			3155±35	−26.2						
OxA-22438	GG72 1246 a; replicate of SUERC-28761	Fresh-looking residue on interior of middle Bronze Age base sherd. Tempered with 'a little grit including shell' (Longworth 1981, cat. no. P237). 2 sherds	Baulk Tr 8B/11, L4Bv, sq 15, midden group 3 (Mercer 1981, 36–8, figs 2, 20, 21)	3113±30	−25.2	4.8	12.4	3105±23 T'=0.2; T'(5%)=3.8; v=1)	1435–1315	*1420–1365 (68%), 1360–1315 (27%)*	
SUERC-28761	GG72 1246 b; replicate of OxA-22438			3095±35	−26.1						
BM-1097	sample 26	Bulk sample of unidentified charcoal	Trench 10, layer 5, midden group 3 (Mercer 1981, 36–8, figs 2, 20, 21)	3038±44	−25.0	-	-		1420–1130	-	Excluded because of potential inaccuracy
Black Hole											
OxA-22433	Longworth cat. no. 238	Residue on interior of large middle Bronze Age base angle fragment forming part of same pot as 3 wall sherds with irregular fingernail impressions, fabric 2 M F; G; occasional Sh (Longworth *et al* 1988, 62, fig 81: cat. no. 238)	Armstrong's square 4F, depth 2ft	3034±29	−23.5	4.5	12.3		1400–1210	*1410–1290*	
OxA-22576	Longworth cat. no. 239 a; replicate of SUERC-28757	Residue on interior of substantially represented 10.5cm	Armstrong's square 5E, depth 2ft	2997±29	−26.9	5	10	3035±23 T'=4.2; T'(5%)=3.8; v=1)	1395–1215	*1400–1295*	

Laboratory number	Sample reference	Material	Context	Radiocarbon age (BP)	$\delta^{13}C$ (‰)	$\delta^{15}N$ (‰)	C:N	Weighted mean (BP)	Calibrated date cal BC (95% confidence)	*Highest posterior density interval cal BC (95% probability)*	Comment
SUERC-28757	Longworth cat. no. 239 b; replicate of OxA-22576	diameter middle Bronze Age pot (8 sherds inc. 2 joining pairs), fingernail decoration, fabric 2 M G (Longworth *et al* 1988, 62, fig 31: cat. no. 239)		3090±35	−27.2	-	-				
OxA-22434	Longworth cat. no. 73 a, replicate of SUERC-28758	Residue on interior of large rim sherd from 20cm diameter cordoned middle Bronze Age pot, finger tip decoration on cordon, fabric 3 M G (Longworth *et al* 1988, 54, fig 25: cat. no. 73)	Armstrong's square 5F, depth 3 ft	3375±30	−24.9	4.2	11.2	3242±23 T'=49.4; T'(5%)=3.8; ν=1)	1750–1610	-	Excluded because, of the two inconsistent replicates, SUERC-28758 is in agreement with the rest of the model
SUERC-28758	Longworth cat. no. 73 bReplicate of OxA-22434			3050±35	−27.8	-	-		1420–1210	*1410–1300*	
Pit X											
BM-1264		Bulk sample of unidentified charcoal	Trench 1270.5/900.5, layer 10. Upper silting of pit, underlying MBA occupation deposits. Phase III in scheme of Longworth and Herne (1991)	3154±64	−24.9	-	-		1600–1290	-	Excluded because of potential inaccuracy
BM-1035		Bulk sample of unidentified charcoal	Trench 1270/900, layer 14, square G. Phase II, stratigraphic unit A2, group ii, in scheme of Longworth and Herne (1991)	2994±40	−25.5	-	-		1390–1110	-	Excluded because of potential inaccuracy
BM-1036		Bulk sample of unidentified charcoal	Trench 1270/900, layer 19, square G. Phase II, stratigraphic unit A3, group ii in scheme of Longworth and Herne (1991)	2995±39	−25.5	-	-		1390–1110	-	Excluded because of potential inaccuracy
BM-1041		Bulk sample of unidentified charcoal	Trench 1270/900, layer 19a, square C. Phase II, stratigraphic unit A4, group iii in scheme of Longworth and Herne (1991)	3573±57	−25.2	-	-		2130–1750	-	Excluded because of potential inaccuracy
OxA-22441	GG76 L1899a; replicate of SUERC-28767	Residue on interior of middle Bronze Age base angle, fabric 1 L F (Longworth *et al* 1988, 77: cat no. 551)	Trench 1270/900, layer 19a, square H. Phase II, stratigraphic unit A4, group iii in scheme of Longworth and Herne (1991)	3041±28	−25.1	4.7	12	3066±22 T'=2.0; T'(5%)=3.8; ν=1)	1415–1265	*1410–1360 (65%), 1355–1315 (30%)*	
SUERC-28767	GG76 L1899b; replicate of OxA-22441			3105±35	−25.4	-	-				
BM-1042		Bulk sample of unidentified charcoal	Trench 1270/900, layer 19b, square H. Phase II, stratigraphic unit B6, group iii in scheme of Longworth and Herne (1991)	2919±53	−24.7	-	-		1300–930	-	Excluded because of potential inaccuracy
BM-1043		Bulk sample of unidentified charcoal	Trench 1270/900, layer 19c, square H. Phase II, stratigraphic unit A5, group iii in scheme of Longworth and Herne (1991)	2838±53	−24.8	-	-		1200–840	-	Excluded because of potential inaccuracy
BM-1039		Bulk sample of unidentified charcoal	Trench 1270/900, layer 20, square M. Phase II, stratigraphic unit C1 in scheme of Longworth and Herne (1991)	2806±54	−25.0	-	-		1130–830	-	Excluded because of potential inaccuracy

Laboratory number	Sample reference	Material	Context	Radiocarbon age (BP)	δ^{13}C (‰)	δ^{15}N (‰)	C:N	Weighted mean (BP)	Calibrated date cal BC (95% confidence)	*Highest posterior density interval cal BC (95% probability)*	Comment
BM-1040		Bulk sample of unidentified charcoal	Trench 1270/900, layer 20a, square D. Phase II, stratigraphic unit B5, group iii in scheme of Longworth and Herne (1991)	2905±54	−25.0	-	-		1290–920	-	Excluded because of potential inaccuracy
SUERC-24127	GG76 102	*Equus*, 1st phalanx, articulating with 2nd	Trench 1270/900, layer 20A, square J. Phase II, stratigraphic unit B5, group iii in scheme of Longworth and Herne (1991)	3090±30	−21.0	6.5	3.4		1430–1270	*1410–1310*	
SUERC-28763	GG76 L2409, L2420	Residue on interior of some among joining sherds from base and lower wall of middle Bronze Age pot, fabric G (Longworth *et al* 1988, 76, fig 41: cat. no. 528). BM P1987 2-2 473	Trench 1270/900, layer 20A, squares D, E. Phase II, stratigraphic unit B5, group iii in scheme of Longworth and Herne (1991)	3130±35	−26.1	-	-		1500–1310	*1420–1360 (65%), 1350–1310 (30%)*	
SUERC-24128	GG76 221	*Sus*, juvenile, ulna articulating with radius and ulna. Radius diaphysis GL: 52mm. Unfused proximally and distally	Trench 1270/900, layer 24, square E. In upper fill of mine shaft. Phase III, stratigraphic unit G in scheme of Longworth and Herne (1991), below 'midden' deposits	3095±30	−22.2	6	3.3		1440–1290	*1430–1370 (68%), 1360–1310 (27%)*	
BM-1263		Bulk sample of unidentified charcoal	Trench 1270.5/905.5, layer 4, square L. Phase II, stratigraphic units D1-D2 in scheme of Longworth and Herne (1991)	3443±53	−24.8	-	-		1900–1620	-	Excluded because of potential inaccuracy
BM-1265		Bulk sample of unidentified charcoal	Trench 1275.5/900.5, layer 4, squares B, D, F, H. Phase II, stratigraphic unit C1 in scheme of Longworth and Herne (1991)	2800±79	−24.2	-	-		1210–800	-	Excluded because of potential inaccuracy
OxA-22440	GG76 L1576	Residue on interior of MBA base angle, fabric 1 L F; 1 S Sh; G (Longworth *et al* 1988, 76: cat. no. 542)	Trench 1275.5/905.5, layer 4, square M. Phase II, stratigraphic unit B1, group i in scheme of Longworth and Herne (1991), at interface of 'midden' deposits and overlying layers	3080±28	−24.7	3.6	11.3		1430–1260	*1410–1310*	
BM-1038		Bulk sample of unidentified charcoal	Trench 1275.5/905.5, layer 5, square A. Phase II, stratigraphic unit A1 in scheme of Longworth and Herne (1991)	2936±43	−24.8	-	-		1300–1000	-	Excluded because of potential inaccuracy
BM-1266		Bulk sample of unidentified charcoal	Trench 1275.5/905.5, layer 6, square K. Phase II, context group D1 in scheme of Longworth and Herne (1991)	2834±53	−24.7	-	-		1190–840	-	Excluded because of potential inaccuracy
BM-1037		Bulk sample of unidentified charcoal	Trench 1270.5/905.5, layer 9, squares J, M, N. Phase II, stratigraphic unit A2, group ii in scheme of Longworth and Herne (1991)	3003±49	−21.4	-	-		1410–1050	-	Excluded because of potential inaccuracy

Table 21: Radiocarbon dates from 1st millennium cal BC and later contexts

Laboratory number	Sample reference	Material	Context	Radiocarbon age (BP)	δ^{13}C (‰)	δ^{15}N (‰)	C/N ratio	Weighted mean (BP)	Calibrated date cal BC/cal AD (95% confidence)	*Highest posterior density interval cal BC/cal AD (95% probability)*	Comment
Upper levels of 1971 pit											
BM-780	Sample 19	Bulk sample of unidentified charcoal	Area of *in situ* burning in upper fill of shaft, immediately underlying feet of Skeleton 2 (Mercer 1981, 16–8)	2465±230	-	-	-		1190–1 cal BC	-	Excluded because of potential inaccuracy
SUERC-28753	Skeleton 2	*Homo*. R femur from articulated lower skeleton of 20 to 25-year-old female (Kenward 1981)	Near top of silted mine shaft, truncated by insertion of skeleton 1, feet overlying area of in situ burning dated by BM-780 (Mercer 1981, 16–8)	2210±35	−20.9	9.1	3.3		390–170 cal BC	*390–190 cal BC*	Modelled as *terminus post quem* because not all PVA may have been removed
OxA-22533	Skeleton 1	*Homo*. R. femur from articulated skeleton of 20–30 year-old male (Kenward 1981)	In pit cut near top of silted mine shaft, truncating skeleton 2. Two iron ring beads near head (Mercer 1981, 16–8)	2127±25	−19.6	9.3	3.2		350–50 cal BC	*340–325 cal BC (2%), 210–50 cal BC (93%)*	
OxA-20760	GG71 119a, replicate of SUERC-24109,SUERC-25612, SUERC-25613, OxA-21156	*Equus*, radius articulating with ulna	Quadrant 3, layer 1B. Stratified below BM-780 and above samples from mining contexts in pit	2911±28	−21.5	5.1	3.4		1260–1000 cal BC	-	Excluded because statistically inconsistent with 4 replicate measurements on the same sample
SUERC-24109	GG71 119b, replicate of OxA-20760, SUERC-25612, SUERC-25613, OxA-21156			2760±30	−22.7	5.4	3.3	2765±17 T'=4.2; T'(5%)=7.8; ν=3)	975–840 1610 cal BC	*975–955 cal BC (7%), 940–840 cal BC (88%)*	
SUERC-25612	GG71 119b, replicate of SUERC-24109, OxA-20760, SUERC-25613, OxA-21156			2795±40	−22.3	5.4	3.3				
OxA-21156	GG71 119c, replicate of SUERC-24109, OxA-20760, SUERC-25612, SUERC-25613			2728±28	−21.9	4.5	3.5				
SUERC-25613	GG71 119d, replicate of SUERC-24109, OxA-20760, SUERC-25612, OxA-21156			2820±40	−22.3	5.2	3.2				

Laboratory number	Sample reference	Material	Context	Radiocarbon age (BP)	$\delta^{13}C$ (‰)	$\delta^{15}N$ (‰)	C/N ratio	Weighted mean (BP)	Calibrated date cal BC/cal AD (95% confidence)	*Highest posterior density interval cal BC/cal AD (95% probability)*	Comment
OxA-20761	GG71 333	*Bos*, atlas articulating with axis	1971 pit, quadrant 5, layer 1B. In the upper fills of the pit, associated with Middle Bronze Age artefacts (Mercer 1981, 16–8). Stratified below BM-780 and above samples from mining contexts in pit	2586±29	−21.0	8.4	3.3		810–670 cal BC	*820–750 cal BC (87%), 690–660 cal BC (6%), 620–590 cal BC (2%)*	
Surface area around 1971 pit											
BM-779	GG71 sample 55	*Quercus*, carbonised galls	On old land surface sealed by dump of spoil from pit	313±200	-	-	-		cal AD 1280–1955*	-	It is conceivable that these were not carbonised but simply blackened and cached by an animal (animal- and root-holes penetrated the dump)
Trench 3											
BM-1546	ARC 79 5017; replicate of OxA-1635, OxA-21193	*Equus*, from fragmentary skull of mare >35 years old	Trench 3. Found during excavation of 5m x 2m trench through spoil surrounding unexcavated pit in E of field. Horse cranium placed diagonally and inverted above small cutting dug through L7. Stratified above sample for BM-1065 (Clutton-Brock and Burleigh 1991; Longworth *et al* 2012, 84–6)	3740±210	−21.4	-	-		2870–1610 cal BC	-	Excluded because much older than two statistically consistent AMS measurements
OxA-1635	ARC 79 5017; replicate of BM-1546, OxA-21193			1820±70	−21.0	-	-	1914±27 T'=2.1; T'(5%)=3.8; ν=1	cal AD 30–130	*cal AD 10–140 (94%), 200–210 (1%)*	Higham *et al* 2007
OxA-21193	ARC 79 5017; replicate of BM-1546, OxA-1635			1930±29	−21.7	5.2	3.4				This sample was submitted in ignorance of the fact that OxA-1635 had already been measured
West Field cutting 940/940											
BM-1067	GG75 sf 535	Animal bone, unspecified	F123, layer 2. Top of feature recorded in 1975–76 but not excavated (Longworth *et al* 2012, 81)	2559±80	−21.9	-	-		890–400 cal BC	*840–400 cal BC*	

Table 22: Questions asked at the start of the project and the answers to them

Principal questions		
1	What was the timespan of flint mining at the site?	See §5.1
2	Was there, as the pre-existing dates suggested, a difference in periods if use between the area of deep mines and the West Field? Over what period was the northern area worked?	See §5.1
3	What was the probable labour input at any one time?	See §5.2
4	How did the emergence of the site relate to the introduction of metal-working?	See §5.3
5	Did the human remains recovered from shafts early in the twentieth century relate to the late Neolithic use of the site (at a time when formal burials were rare) or were they later insertions?	It was unfortunately not possible to gain permission to sample this material
6	Could the chronology of the Bronze Age occupation be refined and extended to so far undated areas?	See §5.4
7	Could a horse skull found in the upcast surrounding one shaft be dated more precisely? While it was marginal to the chronology of the site, it was significant for the timing of the reintroduction of the horse into Britain.	The horse died in the first or early second century cal AD and is irrelevant to the insular introduction of domesticated horse
8	Could the use of the site be related more precisely to the settlement of the surrounding area?	See §5.5
Subsidiary questions		
a	Could an unexpected discrepancy between charcoal and antler dates from the 1971 pit (where measurements on unidentified bulk charcoal samples were consistently more recent than those on antler implements from comparable contexts) be elucidated?	Yes. It seems that the pretreatment practised in the 1970s did not always remove all extraneous humic acid, resulting in anomalously recent dates
b	Could antler/charcoal discrepancies be examined elsewhere?	Up to a point. Elsewhere antler and charcoal samples tend to have been dated from different features or contexts. Where comparisons can be made, some, although not all, bulk charcoal dates are later than those for bone or antler form the same or comparable contexts, in, for example, the 1972–74 knapping floor (Fig 19), pit 11 E (Fig 28), F7 (Fig 49), gallery 15D3 (Fig 51) and the pit X middens (Fig 57)
c	Could the chronology of the northern area (where there were then only two dates) be clarified?	Yes. The dated pits there fall into two groups: pit 14, which belongs to the same mid-third millennium timespan as the other galleried pits, and 'primitive' pits 3

		3A, 4 and 6 (as well, almost certainly, as pits 5, 7, and 13, of similar type), which were worked in the mid-second millennium cal BC
d	Could the date of the 1972–74 knapping floor be clarified and better defined?	Up to a point. Dates for what were probably antler knapping hammers provide an estimate of *2635–2505 cal BC* to *2465–2385 cal BC* (*95% probability*) according to the preferred model. Charcoal from the hearths within the floor unfortunately could not be found
e	Was pit 12, on the edge of the West Field, as old as the one of the pre-existing dates indicated (3270–2580 cal BC at 95% confidence - the mean of BM-97 and -377)?	No. Its twenty-sixth–twenty-fifth century cal BC date conforms to that of the other dated galleried pits
f	Could F6, F7 and F105 in the West Field be better-dated?	Yes, and to different periods. F6 and F7 fall within the same mid-third millennium timespan as the galleried pits; F105 is a mid second millennium 'primitive' pit

Table 23: Selected highest posterior density intervals shown in Figures 64–66 compared with earlier estimates

Appears in	From model shown in	Parameter	*Highest posterior density interval cal BC (95% probability) or in years*	Burleigh *et al* 1979	Ambers 1998, 2012
Fig 64	Fig 15	*start galleried shafts*	*2665–2605*	*c* 2550 cal BC	*2580–2470 cal BC* (*68%*) for Greenwell complex; *2630–2490 cal BC* (*68%*) for pit 15 complex
Fig 64	Fig 15	*end galleried shafts*	*2435–2360 cal BC*	*c* 2250 cal BC	*2550–2400 cal BC* (*68%*) for Greenwell complex; *2555–2565 cal BC* (*68%*) for pit 15 complex
Fig 64	Fig 45	*start simple pits on West Field*	*2670–2500*	-	*2610–2300 cal BC* (*68%*)
Fig 64	Fig 45	*end simple pits on West Field*	*2185–1995*	*c* 1950 cal BC	*2010–1670 cal BC* (*68%*)
Fig 64	Fig 45	*start West Field knapping*	*2150–1975 (91%)*	-	-
Fig 64	Fig 45	*end West Field knapping*	*1915–1605*	-	-
Fig 64	Fig, 51	*start primitive pits and gallery 15D3*	*1625–1500*	-	-
Fig 64	Fig 51	*end primitive pits and gallery 15D3*	*1510–1405*	-	-
Fig 64	Fig 57	*start middens*	*1450–1370 (72%), 1370–1320 (23%)*	*c* 1150 cal BC	-
Fig 64	Fig 57	*end middens*	*1395–1260*	-	-
Fig 65	Fig 15	*work galleried shafts*	*185–290 years*	-	*0–120 years* (*68%*) for Greenwell complex *0–120 years* (*68%*) for pit 15 complex
Fig 65	Fig 45	*work simple pits on West Field*	*335–570 years*	-	-
Fig 65	Fig 51	*work primitive pits and gallery 15D3*	*5–160 years*	-	-
Fig 65	Fig 57	*generate_middens*	*0–160 years*	-	-
Fig 66	Fig 64	*start galleried/start simple*	*−40 to +140 years*	-	-
Fig 66	Fig 64	*end galleried/end simple*	*205 to 415 years*	-	-
Fig 66	Fig 64	*end simple/start 'primitive'*	*415 to 650 years*	-	-
Fig 66	Fig 64	*end 'primitive'/start middens*	*−20 to +175 years*	-	-

Table 24: An ordering of the start and end dates for some of the main episodes shown in Figure 64

Each cell expresses the % probability that the start of the pit in the first column is earlier than the starts of the pits in the subsequent columns. It is, for example, 88% probable that galleried shafts began to be sunk before simple pits on the West Field

	start galleried shafts	*start simple pits on West Field*	*end galleried shafts*	*end simple pits on West Field*	*start 'primitive' pits and gallery 15D3*	*end 'primitive' pits and gallery 15D3*	*start middens*
start galleried shafts		88	100	100	100	100	100
start simple pits on West Field	12		100	100	100	100	100
end galleried shafts	0	0		100	100	100	100
end simple pits on West Field	0	0	0		100	100	100
start 'primitive' pits and gallery 15D3	0	0	0	0		100	100
end primitive' pits and gallery 15D3	0	0	0	0	0		95
start middens	0	0	0	0	0	0	

Table 25: Selected highest posterior density intervals shown in Figure 67, based on the model shown in Figure 15

Parameter	*Highest posterior density interval cal BC (95% probability)*
start 1971 pit	*2655–2600*
start pit NE of 1971 pit	*2655–2595*
start gallery 15C1	*2650–2580*
start Greenwell's pit E	*2650–2575*
start Greenwell's pit	*2645–2580*
start pit 14	*2640–2555*
start 1972–74 knapping floor	*2635–2505*
start pit 12	*2635–2535*
start pit 15 B	*2625–2495*
start Greenwell's pit C	*2585–2460*
start pit 15 K	*2580–2475*
start Greenwell's pit A	*2570–2525 (52%), 2500–2460 (43%)*
start galleries 15D2 and 15 J1	*2570–2515 (20%), 2505–2420 (75%)*
tpq pit Y	*2465–2385*

Table 26: An ordering of the start dates for extraction pits for which individual estimates have been made and for the 1972–74 knapping floor (Fig 67)

Each cell expresses the % probability that the start of the pit in the first column is earlier than the starts of the pits in the subsequent columns. It is, for example, 86% probable that the 1971 pit began to be sunk before pit 14

	1971 pit	*pit NE of 1971 pit*	*gallery 15C1*	*Greenwell's pit*	*Greenwell's pit E*	*pit 14*	*1972–74 knapping floor*	*pit 12*	*pit 15 B*	*Greenwell's pit C*	*pit 15 K*	*Greenwell's pit A*	*galleries 15D2 and 15J1*	*tpq pit Y*
1971 pit		57	71	74	75	86	92	93	98	100	100	100	100	100
pit NE of 1971 pit	43		64	67	70	81	89	90	97	99	100	100	100	100
gallery 15C1	29	36		53	57	70	82	84	95	99	99	100	100	100
Greenwell's pit	26	33	47		55	68	81	83	95	99	99	100	100	100
Greenwell's pit E	25	30	43	44		62	75	77	92	98	98	99	100	100
pit 14	14	19	30	32	38		67	68	88	97	97	99	99	100
1972–74 knapping floor	8	12	18	19	24	34		49	72	84	83	91	96	100
pit 12	7	10	16	17	23	32	51		77	90	90	96	98	100
pit 15 B	2	3	5	5	8	12	28	23		68	66	81	92	100
Greenwell's pit C	1	1	1	1	2	3	16	10	32		47	65	86	100
pit 15 K	1	1	1	1	2	3	17	10	34	53		69	88	100
Greenwell's pit A	1	1	1	1	1	1	9	4	19	35	31		79	100
galleries 15D2 and 15J1	1	1	1	1	1	1	4	2	7	14	12	21		92
tpq pit Y	0	0	0	0	0	0	0	0	0	1	8	0	8	

Table 27: Selected highest posterior density intervals shown in Figures 68 and 69

Appears in	From model shown in	Parameter	*Highest posterior density interval cal BC (95% probability) or in years*
Fig 68	Fig 15	*start galleried shafts*	*2665–2605*
Fig 68	Fig 45	*start simple pits on West Field*	*2670–2500*
Fig 68	Healy 2012, fig 10.5j	*start English Beakers 2*	*2490–2340*
Fig 68	Fig 15	*end galleried shafts*	*2435–2360*
Fig 68	Fig 45	*end simple pits on West Field*	*2185–1995*
Fig 68	Healy 2012, fig 10.5j	*end English Beakers 2*	*1880–1740*
Fig 68	Fig 51	*start primitive pits and gallery 15D3*	*1625–1500*
Fig 68	Fig 51	*end primitive pits and gallery 15D3*	*1510–1405*
Fig 69	Fig 68	*Start galleried/start Beakers*	*145–300 years*
Fig. 69	Fig 68	*Start West Field/start Beakers*	*55–290 years*
Fig 69	Fig 68	*Start Beakers/end galleried*	*−70 to +95 years*
Fig 69	Fig 68	*Start Beakers/end West Field*	*200–440 years*
Fig 69	Fig 68	*End West Field/end Beakers*	*150–390 years*

Table 28: An ordering of selected start and end dates for major episodes together with estimated start and end dates for the currency of Beaker pottery in England (Fig 68)

Each cell expresses the % probability that the start of the pit in the first column is earlier than the starts of the pits in the subsequent columns. It is, for example, 60% probable that the Beaker pottery was current in England before the galleried pits ceased to be worked

	Start galleried shafts	*Start simple pits on West Field*	*Start English Beakers 2*	*End galleried shafts*	*End simple pits on West Field*	*End English Beakers 2*	*Start primitive pits and gallery 15D3*
Start galleried shafts		88	100	100	100	100	100
Start simple pits on West Field	12		99	100	100	100	100
Start English Beakers 2	0	1		60	100	100	100
End galleried shafts	0	0	40		100	100	100
End simple pits on West Field	0	0	0	0		100	100
End English Beakers 2	0	0	0	0	0		99
Start primitive pits and gallery 15D3	0	0	0	0	0	1	

Table 29: Radiocarbon dates employed in the model shown in Figures 70–73

Laboratory number	Sample reference	Material	Context	Radiocarbon age (BP)	δ^{13}C (‰)	Weighted mean (BP)	Calibrated date cal BC (95% confidence)	*Highest posterior density interval cal BC (95% probability)*	Comment/reference
Sapiston, Suffolk									
SUERC-19597	SAP012 0077	Charred hazelnuts	Pit or posthole 76, with 7 sherds Beaker pottery (at least some rusticated), 2 pieces struck flint, charcoal	3700±30	−23.9		2200–1980	*2200–2010 (93%), 2000–1980 (2%)*	Craven 2009
Lynford Quarry, Norfolk									
Wk-9384		'Short length of burnt and cut timber'	Hearth, 451, containing 58 sherds of a single rusticated Beaker, struck flint, and charcoal	3926±45			2570–2280	*2570–2510 (8%), 2500–2280 (87%)*	Modelled as *terminus post quem* for context because wood could have been mature when felled. Birks and Robertson 2005
Wk-9385		'Piece of wood'	Hearth containing struck flint, seeds and charcoal	3881±47			2480–2200	*2480–2200*	" "
Wk-9386		'Piece of uncut wood'	Hearth 453, containing struck flint and charcoal	3941±45			2580–2290	*2570–2290*	" "
Kilverstone, Norfolk									
Beta-178143		Animal bone unspecified. Bone from pit elsewhere described as 'teeth and fragments of a mature cow jaw'	Pit 10 context 128. The single fill of 1 of 4 intercutting pits. Containing incised and rusticated Beaker sherds (Garrow *et al* 2006, fig 3.2: P174, P177, P178), struck flint, burnt flint, charred hazelnut shell	3990±40			2620–2460	*2630–2440 (92%), 2420–2400 (1%), 2380–2350 (2%)*	Modelled as *terminus post quem* for context because bone disarticulated. Garrow *et al* 2006
Prickwillow Road, Isleham, Cambs									
Beta-77751		Unspecified animal bone	F58, on base, with miniature bow of red deer antler, Collared Urn and Beaker sherds in overlying fill	3390±70			1890–1510	*1890–1520*	Modelled as *terminus post quem* for context because bone disarticulated. Gdaniec *et al* 2007
Beta-77752		One of two superimposed cattle skulls	F72, on base of pit beneath deliberate backfill, other animal bone present	3360±70			1880–1490	*1880–1840 (4%), 1830–1500 (91%)*	" "
West Row Fen MNL-130, Suffolk									
HAR-2510	MNL 130-0481	*Quercus* sp. wood from large timber	Bronze Age occupation surface spreading into peat	3760±80	−25.9		2290–1820	*2300–1870 (93%), 1850–1810 (1%), 1790–1500 (1%)*	Modelled as *terminus post quem* for context because wood probably mature when felled. Jordan *et al* 1994
HAR-2516	MNL 130-0486	*Fraxinus* sp. wood from large timber	" "	3510±80	−26.9		2040–1630	*2040–1630*	" "
HAR-2517	MNL 130-0482	Wood comprising *Salix* sp. twigs, *Alnus* sp. and *Quercus* sp. large timbers, and bark, *c* 25% of wood identified	" "	3390±80	−28.5		1900–1490	*1890–1500*	Modelled as *terminus post quem* for context because some of wood probably mature when felled. Jordan *et al* 1994
West Row Fen MNL-165, Suffolk									

Laboratory number	Sample reference	Material	Context	Radiocarbon age (BP)	δ^{13}C (‰)	Weighted mean (BP)	Calibrated date cal BC (95% confidence)	*Highest posterior density interval cal BC (95% probability)*	Comment/reference
HAR-4629	MNL165	Unidentified bulk charcoal; identifiable part of undated remainder composed of 0.8% *Fraxinus*, 1.4% *Quercus* heartwood, 2.4% Pomoideae, 11.4% *Prunus spinosa*, 84% *Alnus*	Occupation layer found in trial trench	3190±70	−27.2		1630–1310	*1640–1370 (90%), 1360–1300 (5%)*	Modelled as contemporary with context because Alnus relatively short-lived. Martin and Murphy 1988; Bayliss *et al* 2012
HAR-5634	165 9115	Soil	Pit 091, layer 0911(5), from waterlogged fill of ?water-hole	3280±70	−28.7		1740–1410	*1740–1710 (2%), 1700–1420 (93%)*	Modelled as *terminus post quem* for context because source(s) of organic fraction unknown. Martin and Murphy 1988; Bayliss *et al* 2012
HAR-5635	165 915	Soil	From a feature similar to pit 091	3390±90	−28.7		1930–1460	*1930–1490*	" "
HAR-5636	165 967	Unidentified bulk charcoal; identifiable part of undated remainder entirely composed of *Quercus*, probably all heartwood	Feature 0934, layer 0967, long, shallow pit with high concentration of oak charcoal, ?charcoal clamp	4020±120	−26.1		2900–2200	*2900–2270 (93%), 2260–2210 (2%)*	Modelled as *terminus post quem* for context because wood probably mature when felled. Martin and Murphy 1988; Bayliss *et al* 2012
HAR-5637	165 942	Unidentified bulk charcoal; identifiable part of undated remainder composed of 15% *Quercus* heartwood, 40% *Fraxinus*, 44% *Alnus*, 1% *Prunus*	Interpreted as from felled oak tree burnt *in situ*	3650±100	−27.9		2300–1740	*2240–2320 (1%), 2310–1740 (94%)*	Modelled as *terminus post quem* for context because some of wood probably mature when felled. Martin and Murphy 1988; Bayliss *et al* 2012
HAR-5638	165 946	Unidentified bulk charcoal; identifiable part of undated remainder composed of 2% *Fraxinus*, 2% *Quercus*, 10% Salicaceae, 48% *Alnus*, 38% *Betula*	Context 0956, extensive spread of ash and charcoal	3420±80	−27.8		1940–1520	*1900–1490*	Modelled as contemporary with context because *Alnus* and *Betula* both relatively short-lived. Martin and Murphy 1988; Bayliss *et al* 2012
HAR-5639	165 4034	Unidentified bulk charcoal; identifiable part of undated remainder composed of 1 cereal grain, cereal, 29% Alnus, 57% Quercus	From pit with abundant charcoal and hazelnut shells	3420±80	−27.1		1940–1520	*1930–1520*	Modelled as *terminus post quem* for context because some of wood probably mature when felled. Martin and Murphy 1988; Bayliss *et al* 2012
HAR-9268	165 4284	Unidentified bulk charcoal	Pit 4284, layers 4284 and 4287, feature interpreted as used for soaking antler prior to working	3510±60	−26.2		2020–1680	*2020–1680*	Modelled as *terminus post quem* for context because some or all of wood could have been mature when felled. Martin and Murphy 1988; Bayliss *et al* 2013
HAR-9269	165 4379	Unidentified bulk charcoal	Pit 4377, top fill 4379, pit contained Neolithic pottery	3520±60	−27.1		2030–1690	*2020–1690*	" "
HAR-9272	165 4249	Waterlogged wood fragments	Pit 4226, layer 4249, feature interpreted as water pit	3530±80	−31.0		2130–1670	*2130–2090 (2%), 2050–1660 (93%)*	" "

Laboratory number	Sample reference	Material	Context	Radiocarbon age (BP)	δ13C (‰)	Weighted mean (BP)	Calibrated date cal BC (95% confidence)	*Highest posterior density interval cal BC (95% probability)*	Comment/reference
High Fen Drove, Northwold, Norfolk									
		Sequence of 18 short-life samples	From burnt mound below and in which were >100 sherds of Beaker pottery with FN, FP and incised decoration (an illustrated sherd has a fragment of Clarke's motif 34), as well as 1 sherd possibly of Food Vessel Urn					*start Northwold burnt mound 2265–2165; end Northwold burnt mound 2140–2065 cal BC (95% probability)*	Bayliss *et al* 2004b
Feltwell Anchor, Norfolk									
GU-5573		*Alnus* sp. charcoal	Context 6, from burnt mound, overlying a soil which contained 12 sherds of FN-rusticated Beaker pottery	3720±70			2410–1890	*2280–1980*	Modelled as contemporary with context because the charcoal is from wood burnt during the generation of the mound and because the alder in the mound was from relatively young stems. Bates and Wiltshire 2000
GU-5574		" "	" "	3650±70			2350–2030	*2280–2030*	" "
GU-5571		From articulated skeleton of female in mid to late 20s	Feature 67, buried in grave cut into burnt mound burnt mound In plank-built coffin with flint scraper	3540±60		3617±39 (T'=2.8; T'(5%)=3.8; ν=1)	2130–1880	*2130–2080 (10%), 2070–1920 (85%)*	Bates and Wiltshire 2000
GU-5572				3670±50					
MNL-124, Suffolk									
HAR-1876	MNL-124	*Quercus* and *Corylus* charcoal all from fairly large timbers, *c* 50% identified	From patch of burnt and crackled flints in field on the fen edge	3720±70	−25.8		2340–1920	*2340–1950*	Modelled as *terminus post quem* for context because some or all of wood could have been mature when felled. Martin and Murphy 1988; Jordan *et al* 1994
MNL-137, Suffolk									
HAR-2690	MNL-137	Charcoal from large timbers, identifiable part of undated remainder composed of 73% *Fraxinus*, 17% *Corylus*/*Alnus*, 6% *Tilia*, 3%, *Alnus*, *Corylus*, *Ulmus*, *Quercus* sapwood each <1%	Potboiler deposit	3650±70	−28.4		2210–1820	*2280–2250 (1%), 2210–1900 (94%)*	Modelled as *terminus post quem* for context because some or all of wood could have been mature when felled. Martin and Murphy 1988; Jordan *et al* 1994; Bayliss *et al* 2012, xxxii
Swale's Fen, Suffolk									
HAR-9271	2040005	Unidentified bulk charcoal	Pit 0001, layer 0005, base of wood-lined pit in potboiler spread	3760±60	−26.7		2410–1980	*2440–2420 (1%), 2410–2370 (1%), 2360–2010 (92%), 2000–1980 (1%)*	Modelled as *terminus post quem* for context because some or all of wood could have been mature when felled. Martin 1988; Bayliss *et al* 2013
'Shippea Hill man', Cambs									

Laboratory number	Sample reference	Material	Context	Radiocarbon age (BP)	δ[13]C (‰)	Weighted mean (BP)	Calibrated date cal BC (95% confidence)	*Highest posterior density interval cal BC (95% probability)*	Comment/reference
OxA-4290 replicate of OxA-4291	5/D33928	Femur of male found 'hunched up and crowded into a small space less than two feet square' during drain digging		3500±100	−20.2	3523±65 (T'=0.1; T'(5%)=3.8; v=1)	2030–1680	*2130–2080 (4%), 2060–1810 (91%)*	Clark 1933; Roberts 1998
OxA-4291 replicate of OxA-4290	6/D33928			3540±85	−20.2				
Hemplands Farm, Methwold, Norfolk									
OxA-2868	2550MTW	Femur of adult female	Found during cutting of drainage ditch, lying on regular setting of wood	3840±80	−22.1		2570–2030	*2250–1940*	Healy and Housley 1992; Healy 1996
Methwold Severalls 2542/c1, Norfolk									
OxA-2862	2542MTW1	Femur of adult female	Part of group of 3 adults, 2 children and 1 infant together with 1 Cu alloy awl found during ploughing in peat fen	3580±80	−20.9		2170–1690	*2140–1870*	Healy and Housley 1992; Healy 1996
OxA-2863	2542MTW12–3	Femur of adult		3670±80	−20.7		2290–1820	*2190–2170 (1%), 2160–1900 (94%)*	
OxA-2864	2542MTW5	Femur of juvenile *c* 11yr		3650±80	−21.5		2280–1770	*2160–1890*	
Methwold Severalls 2542/c2, Norfolk									
OxA-2865	2542MTW7	Femur of adult ?male	Part of group of adult and 2 children with 2 flint scrapers found during ploughing in peat fen, *c* 9m S and 45m E of 2542/c1	3760±80	−20.8		2470–1940	*2220–1930*	Healy and Housley 1992; Healy 1996
OxA-2866	2542MTW8	Femur of juvenile *c* 6–7yr		3600±80	−21.7		2200–1740	*2140–1870*	
OxA-2867	2542MTW9	Femur of juvenile *c* 5–6yr		3620±80	−21.5		2200–1750	*2140–1880*	
Methwold OS 1231									
OxA-2860	2585MTW1	Femur of adult ?female	Part of group of adult and 2 children with bone pin found immediately above Fen Clay	3760±80	−18.6		2470–1940	*2220–1930*	Healy and Housley 1992; Healy 1996
OxA-2861	2585MTW2	Femur of juvenile, *c* 8–10yr		3540±80	−21.8		2140–1680	*2140–1830*	
Hill Close, Feltwell									
OxA-3069	5188FWL1	Femur of adult ?female	Skeleton 1, one of 30 burials inserted into a natural chalk hillock, leaf arrowhead close to spine	3100±70	−20.9		1510–1130	*1510–1190 (93%), 1180–1170 (1%), 1150–1130 (1%)*	Healy 1996
OxA-2885	5188FWL19	Femur of subadult	Skeleton 19, one of 30 burials inserted into a natural chalk hillock, small incised Beaker sherd on pelvis	3380±70	−20.4		1890–1500	*1880–1510*	

Table 30: An ordering of selected start and end dates for major episodes together with estimated start and end dates for aspects of local settlement and other activity (Fig 74)

Each cell expresses the % probability that the event in the first column is earlier than the event in the subsequent columns. It is, for example, 96% probable that burnt mounds began be used in the fens before simple pits ceased to be sunk on the West Field

	start simple pits on West Field	*end galleried shafts*	*start Fenland burnt mounds*	*end simple pits on West Field*	*start Fenland burials*	*end Fenland burnt mounds*	*end Fenland burials*	*start fen edge EBA settlment*	*start primitive pits and gallery 15D3*	*end primitive pits and gallery 15D3*	*end fen edge EBA settlement*	*start middens*
start simple pits on West Field		100	97	100	100	100	100	83	100	100	100	100
end galleried shafts	0		90	100	98	100	100	78	100	100	100	100
start Fenland burnt mounds	3	10		96	83	100	100	73	100	100	100	100
end simple pits on West Field	0	1	4		42	96	98	65	100	100	100	100
start Fenland burials	1	1	17	58		96	98	66	100	100	100	100
end Fenland burnt mounds	0	0	1	4	4		6	50	98	99	99	99
end Fenland burials	0	0	1	2	2	42		49	100	100	100	100
start fen edge EBA settlement	17	22	27	35	34	50	51		96	100	100	100
start primitive pits and gallery 15D3	0	0	0	0	0	2	1	4		100	98	100
end primitive pits and gallery 15D3	0	0	0	0	0	1	1	1	1		86	95
end fen edge EBA settlement	0	0	0	0	0	1	1	1	2	14		29
start middens	0	0	0	0	0	1	1	1	1	5	71	

Table 31: Samples of known age bone

Sample	$\delta^{13}C$ (‰)	Radiocarbon age (BP)	PVA used	Filtration Type	Solvent used	Offset in radiocarbon years BP from 2140±11
KAB40	−21.6±0.5	8480±30	PVA	cold filtered	-	−6340±37
KAB41	−22.4±0.5	2485±35	PVA	warm filtered	-	−645±37
KAB42	−22.0±0.5	2105±30	-	-	-	-
KAB43	−21.9±0.5	2095±30	-	-	-	-
KAB44	−21.9±0.5	2130±30	-	-	-	-
KAB45	−22.0±0.5	2220±30	-	-	-	-
KAB46	−21.8±0.5	2170±35	-	-	-	-
KAB47	−21.9±0.5	2135±30	-	-	-	-
KAB48	−21.9±0.5	2185±35	-	ultrafiltered	-	-
KAB49	−21.9±0.5	2730±35	PVA	ultrafiltered	ethanol	−590±37
KAB50	−22.0±0.5	2760±35	PVA	-	ethanol	−620±37
KAB51	−22.7±0.5	3680±30	PVA	-	acetone	−1540±32
KAB52	−22.2±0.5	2795±30	PVA	ultrafiltered	acetone	−655±32
KAB53	−21.8±0.5	2230±30	-	-	-	-
KAB54	−21.9±0.5	2085±30	-	-	-	-
KAB55	−22.9±0.5	2090±30	-	-	-	-

Table 32: Radiocarbon dates and estimated parameters from the Sims sequence shown in Figure 76

Laboratory number or name of estimated parameter	Radiocarbon age (BP)	Calibrated date cal BC/cal AD (95% confidence)	*Highest posterior density interval cal BC/cal AD (95% probability)*	Base of sample (cm)	Top of sample (cm)	Thickness of sample (cm)	Depth of estimated parameter or of mid-point of sample (cm)
Q-1088	7447±125	6510–6050	*6570–6080*	448	432	16	440
H-r1/H-r2 boundary	-	-	*6330–5730 cal BC*	-	-	-	418
H-r2/H-r3 boundary	-	-	*6070–5510 cal BC*	-	-	-	400
Q-1087 ≈ H-r3/H-r4 boundary	6730±120	5880–5470 cal BC	*5780–5360 cal BC*	394	377	17	386
Q-1089	5830±90	4930–4460 cal BC	*4950–4520 cal BC*	364	352	12	358
Q-1049	5210±120	4340–3710 cal BC	*4260–3800 cal BC*	324	316	8	320
Q-1048 ≈ H-r4/H-r5 boundary	4986±115	4040–3530 cal BC	*3960–3630 cal BC*	308	300	8	304
Q-1047	4794±115	3800–3350 cal BC	*3790–3440 cal BC*	298	290	8	294
Q-1046 ≈ H-r5/H-r6 boundary	4750±115	3770–3140 cal BC	*3660–3350 cal BC*	289	281	8	285
Q-1045	4585±120	3640–2920 cal BC	*3520–3030 cal BC*	274	265	9	270
H-r6/H-r7 boundary	-	-	*3150–2450 cal BC*	-	-	-	241
Q-1095 ≈ H-r7/H-r8 boundary	3901±55	2570–2200 cal BC	*2550–2530 (1%), 2500–2200 cal BC (94%)*	220	210	10	215
Q-1094	3022±45	1410–1120 cal BC	*1410–1130 cal BC*	180	170	10	175
H-r8/H-r9 boundary	-	-	*1360–670 cal BC*	-	-	-	164
Q-1091 ≈ H-r9/ H-r10 boundary	1929±35	10 cal BC–cal AD 140	*40 cal BC–cal AD 170 (94%), cal AD 190–210 (1%)*	120	110	10	115
H-r10/Hr11 boundary	-	-	*cal AD 80–740*	-	-	-	103
H-r11/ H-r12 boundary	-	-	*cal AD 240–900*	-	-	-	96
Q-1090 ≈ H-r12/H-r13 boundary	1145±30	cal AD 770–990	*cal AD 770–970*	90	80	10	85
Q-1093	734±30	cal AD 1250–1300	*cal AD 1220–1300*	62	52	10	57

Table 33: Radiocarbon dates from the Bennett sequence shown in Figure 77

Laboratory number or name of estimated parameter	Radiocarbon age BP	Calibrated (95% confidence)	*Highest posterior density interval (95% probability)*	Base of sample (cm)	Top of sample (cm)	Thickness of sample (cm)	Depth of estimated parameter or of mid-point of sample (cm)
Q-2203	12620±85	13320–12660 cal BC	*13350–12250 cal BC (92%), 11270–10930 cal BC (2%), 10910–10880 cal BC (1%)*	1182.5	1177.5	5	1180
Q-2204	11160±190	11450–10690 cal BC	*11440–10760 cal BC*	1158.5	1153	5.5	1156
Q-2205	10820±900	13250–8340 cal BC	*11200–8780 cal BC*	1134.5	1129.5	5	1132
Q-2206	9560±95	9260–8630 cal BC	*9180–8630 cal BC*	1116.5	1111.5	5	1114
Q-2207 ≈ HM-1/HM-2 boundary	9460±100	9190–8480 cal BC	*9130–8980 cal BC (11%), 8940–8550 cal BC (84%)*	1108	1104	4	1106
Q-2208	9390±140	9220–9290 cal BC	*9120–9000 cal BC (6%), 8930–8460 cal BC (89%)*	1104	1100	4	1102
Q-2209 ≈ HM-2/HM-3a boundary	9270±150	9120–8230 cal BC	*8830–8310 cal BC*	1096.5	1091.5	5	1094
Q-2210	9130±600	10450–7040 cal BC	*8790–8270 cal BC*	1087.5	1081.5	6	1085
Q-2211	9110±115	8630–7980 cal BC	*8630–8230 cal BC*	1070.5	1063.5	7	1067
Q-2212	9040±110	8550–7950 cal BC	*8460–7990 cal BC*	1030.5	1025.5	5	1028
Q-2213 ≈ HM-3a/HM-3b boundary	8960±95	8310–7780 cal BC	*8280–7810 cal BC*	982.5	977.5	5	980
Q-2214	8675±60	7940–7580 cal BC	*7960–7600 cal BC*	942.5	937.5	5	940
Q-2215	8500±80	7610–7380 cal BC	*7610–7350 cal BC*	822.5	817.5	5	820
Q-2216	8250±80	7520–7060 cal BC	*7520–7130 cal BC*	774.5	769.5	5	772
Q-2217	8230±150	7590–6770 cal BC	*7320– 6680 cal BC*	678.5	673.5	5	676
Q-2218	7505±90	6510–6210 cal BC	*6570–6540 (1%), 6530–6220 cal BC (94%)*	614.5	609.5	5	612

Laboratory number or name of estimated parameter	Radiocarbon age BP	Calibrated (95% confidence)	*Highest posterior density interval (95% probability)*	Base of sample (cm)	Top of sample (cm)	Thickness of sample (cm)	Depth of estimated parameter or of mid-point of sample (cm)
Q-2219 ≈ HM-3b/HM-4 boundary	7280±75	6350–6000 cal BC	*6240–6000 cal BC*	534.5	529.5	5	532
Q-2220	7080±60	6070–5840 cal BC	*6070–5840 cal BC*	506.5	501.5	5	504
Q-2221 ≈ HM-4/HM-5a boundary	6010±100	5220–4690	*5220–4690 cal BC*	434.5	429.5	5	432
Q-2222 ≈ HM-5a/HM-5b boundary	4500±100	3520–2900 cal BC	*3510–3420 (4%), 3390–2900 cal BC (91%)*	346.5	341.5	5	344
Q-2223	2660±50	910–780 cal BC	*930–770 cal BC*	294.5	289.5	5	292
Q-2224 ≈ HM-5b/HM-5c boundary-	1980±50	100 cal BC–cal AD 130	*170 cal BC–cal AD 130*	262.5	257.5	5	260
Q-2225	1625±45	cal AD 330–550	*cal AD 330–550*	134.5	129.5	5	132

Table 34: Estimated rates of accumulation for the two sequences and selected parts of them

Equivalent parts of each sequence are shown in the same row

Sims	Depth (m)	*Duration (years)*	Accumulation per annum (mm)	Bennett	Depth (m)	*Duration (years)*	Accumulation per annum (mm)
Whole sequence	5	*8630–10375 (95%; duration of Sims sequence,* distribution not shown*)*	0.5–0.6				
				Whole sequence	11.45	*14170–15700 (91%; duration of Bennett sequence,* distribution not shown*)*	0.7–0.8
				Base to HM-1/HM-2 boundary	0.79	*3280–5025 (90%; base of Bennett sequence/Q2207,* distribution not shown*)*	0.1–0.2
				HM-1/HM-2 boundary to HM-5a/ HM-5b boundary	7.62	*5190–6040 (95%; Q-2207/Q-2222,* distribution not shown*)*	1.3–1.5
H-r4/H-r5 boundary to top	3.04	*5335–5905 (95%; Q-1048/end of Sims sequence,* distribution not shown*)*	0.5–0.6	HM-5a/ HM-5b boundary to top	3.04	*3650–5220 (95%; Q-2222/end of Bennett sequence,* distribution not shown*)*	0.5–0.6

Table 35: A comparison of those parts of the Godwin and Tallantire, Sims and Bennett sequences which relate to the use of Grime's Graves, following Bennett's correlation between them (1983a, fig. 8), except for the distinction between HM-5b and HM-5b (upper), which is made by the present author

Godwin and Tallantire zone	Summary	Sims zone	Summary	Start from model shown in Fig. 76 (*95% probability*)	Bennet zone	Summary	Start from model shown in Fig. 77 (*95% probability*)
VIc	Predominantly deciduous forest with pine declining	Hr-2	Deciduous forest dominated by oak and elm, gradual increase in lime	*6330–5720 cal BC* (Fig 76: *H-r1/H-r2 boundary*)	HM-4	Deciduous forest, oak dominant, increasing alder and lime, fluctuating hazel, fluctuating grasses and herbs. No sign of human intervention	*6240–6000 cal BC* (Fig 77: *Q-2219*)
VIIa	Deciduous forest with hazel declining	Hr-3		*6070–5510 cal BC* (Fig 76: *H-r2/H-r3 boundary*)			
		H-r4	Deciduous forest, dominated by oak and elm. Temporary elm decline at start of zone, followed by recovery of woodland taxa, then decrease through rest of zone, less hazel than in previous and subsequent zones, fluctuating water level	*5780–5360 cal BC* (Fig 76: *Q-1087*)	HM-5a	Deciduous forest. Elm decline at start of zone, followed by recovery. Oak dominant and increasing, alder, lime, beech increasing, hazel decreasing.	*5220–4690 cal BC* (Fig. 77: *Q-2221*)

Godwin and Tallantire zone	Summary	Sims zone	Summary	Start from model shown in Fig. 76 (*95% probability*)	Bennet zone	Summary	Start from model shown in Fig. 77 (*95% probability*)
VIIb	Permanent elm decline at start of zone, other tree taxa constant. Progressive overall rise in non-tree pollen, especially grasses, from c. 0.50 m above elm decline, soon joined by progressive rise in Ericoids, ferns and Sphagnum. Increases punctuated with short-term fluctuations	Hr-5	Permanent elm decline at start of zone, with temporary drop in other tree taxa, longer-lived increase in hazel, temporary increase in grasses, ruderals, etc., interpreted as anthropogenic clearance and cultivation, followed by forest regeneration	*3960–3630 cal BC* (Fig 76: *Q-1048*)	H-5b	Permanent elm decline at start of zone, increase in hazel, slight decrease in other tree taxa, followed by return to approx. previous levels, except for elm. Cereal pollen present. *Plantago* increases at start of subzone, with elm decline	*3390–2900 cal BC* (*91%*; Fig 77: *Q-2222*)
		Hr-6	All taxa but elm and hazel returned to their levels in H-r4. Little human intervention	*3660–3350 cal BC* (Fig 76: *Q-1046*)			
		Hr-7	Increased forest clearance, increase in non-tree pollen including ruderals, fluctuations suggest temporary clearances; increase in heathland taxa and bracken	*3150–2450 cal BC* (Fig 76: *H-r6/H-r7 boundary*)	HM-5b (upper)	Ericales, *Calluna* and Gramineae increase. *Plantago* increases again. Non-tree pollen >10% by end of zone compared to 3% in HM-5a.	*930–770 cal BC* (Fig 77: *Q-2223*)

Godwin and Tallantire zone	Summary	Sims zone	Summary	Start from model shown in Fig. 76 (*95% probability*)	Bennet zone	Summary	Start from model shown in Fig. 77 (*95% probability*)
		Hr-8	Marked increase in grasses and ruderals, further increase in heathland taxa and bracken, decrease in tree taxa. Fluctuations suggest variations in intensity of clearance	*2500–2200 cal BC* (*94%*, Fig 76: *Q-1095*)	HM-5c	Increase in sediment accumulation. Increase in non-tree pollen to 30%, increase in cereals, weeds of cultivation, heathland species. Widespread clearance seen as leading to development of heathland	*170 cal BC–cal AD 130* (Fig 77: *Q-2224*)
		Hr-9	Grasses continue to increase, reaching 20%, increase in ruderals and cereals, decrease in tree pollen, further increase in heathland species. Seen as forest clearance on larger scale than before with increasing dependence on cultivation	*1360–670 cal BC* (Fig 76: *H-r8/H-r9 boundary*)			

Godwin and Tallantire zone	Summary	Sims zone	Summary	Start from model shown in Fig. 76 (*95% probability*)	Bennet zone	Summary	Start from model shown in Fig. 77 (*95% probability*)
		Hr-10	Increase in cereals and associated weeds, decline in grasses and some other herbs. Seen as increase in cultivation at expense of pasture	*40 cal BC–cal AD 170* (*94%*; Fig 76: *Q-1091*)			

FIGURES

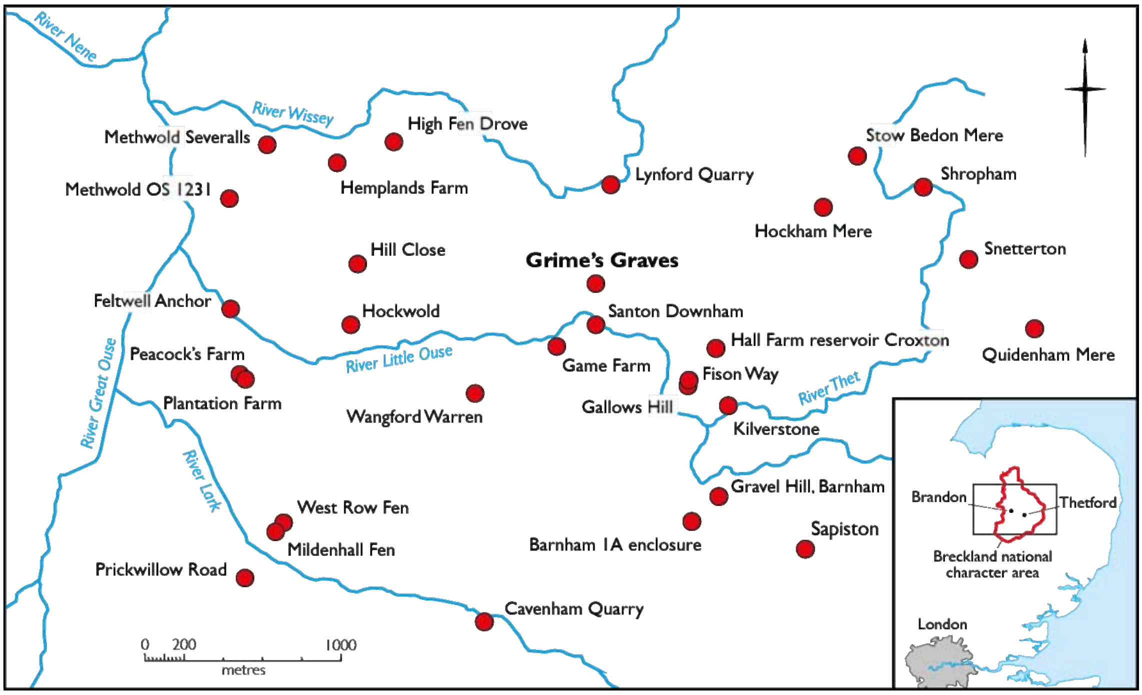


Figure 1: The location of Grime's Graves and of selected sites mentioned in the text

Figure 2: Plan of the site (Longworth et al *2012, fig 2). © British Museum*

Figure 3: The earthworks of largely infilled mineshafts in the eastern part of Grime's Graves © English Heritage

Figure 4: Floorstone in situ *in pit 1. Photo: Hallam Ashley. © English Heritage*

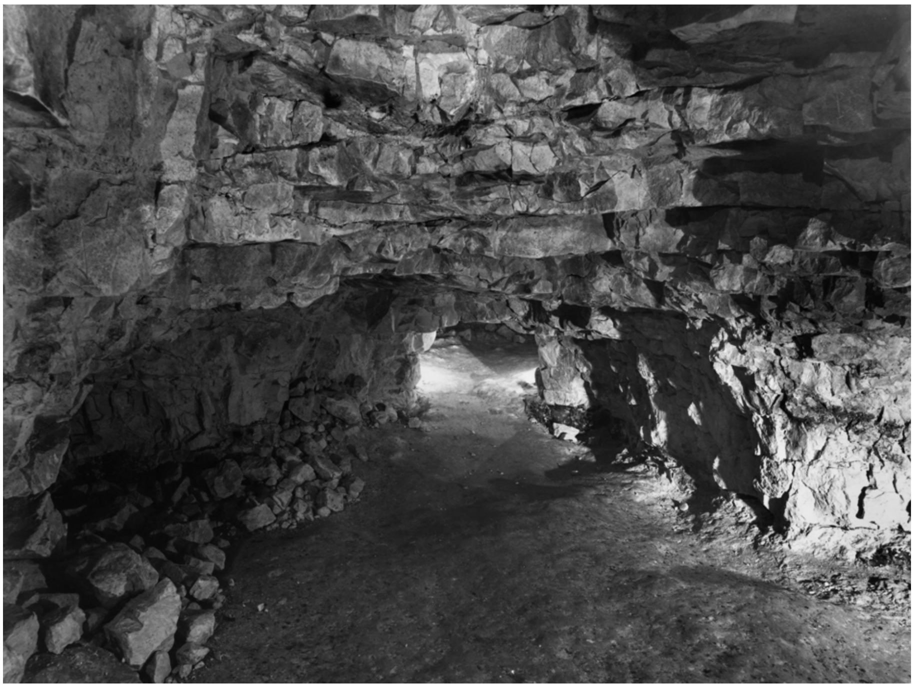


Figure 5: A gallery of pit 1, excavated by the Prehistoric Society of East Anglia in 1914. Photo: Hallam Ashley. © English Heritage

Figure 6: A L (Leslie) Armstrong and team at work in the interwar period © English Heritage

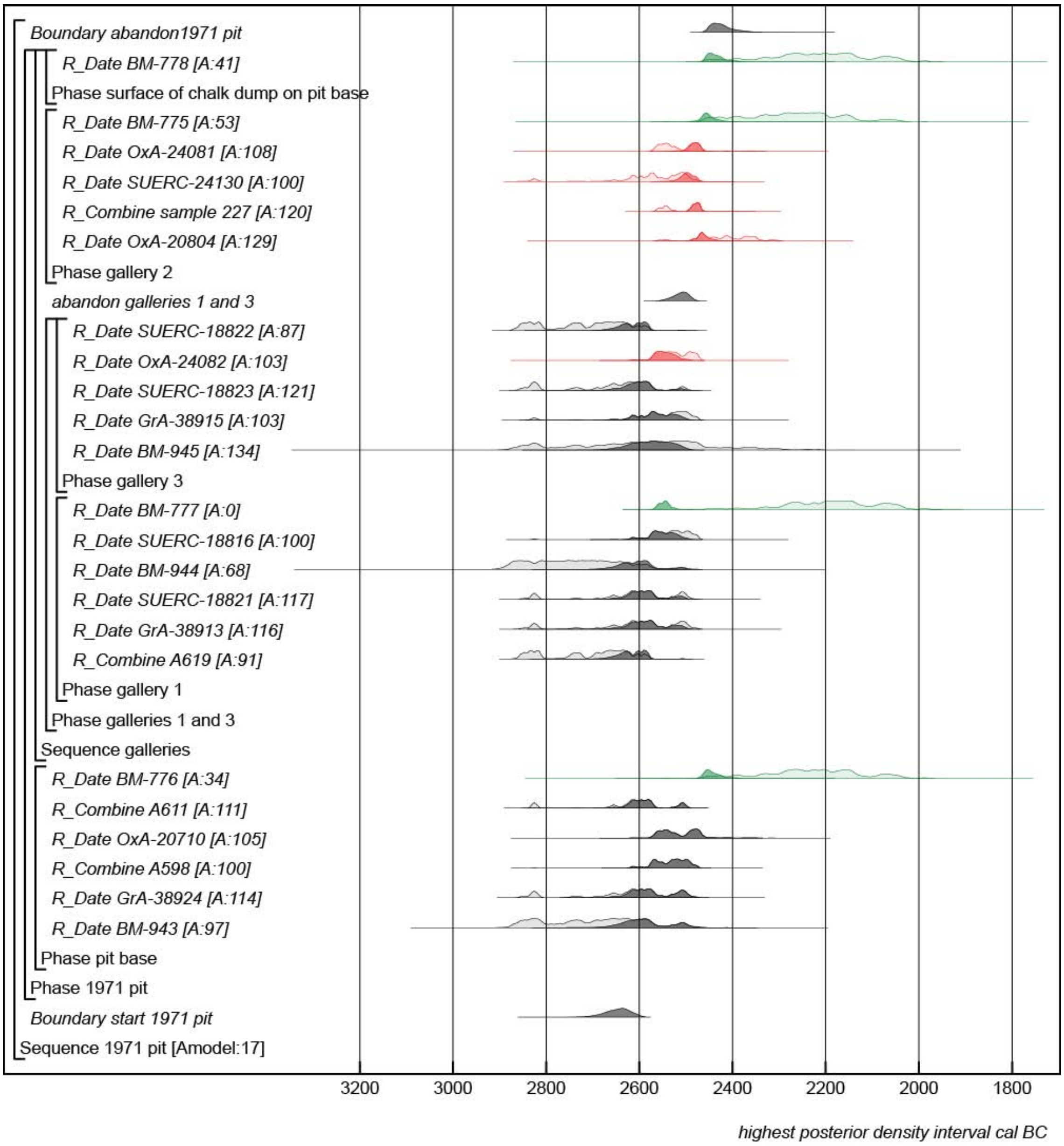


Figure 7: Dates from the 1971 pit (Table 5) modelled to incorporate stratigraphic information, with all dates treated as contemporary with their contexts. The four bulk charcoal dates (BM-775 to -778, shown in green) have low individual indices of agreement and, because they are too recent, push the model into poor overall agreement. Dates for single-entity charcoal samples are shown in red, and dates for antler samples in black

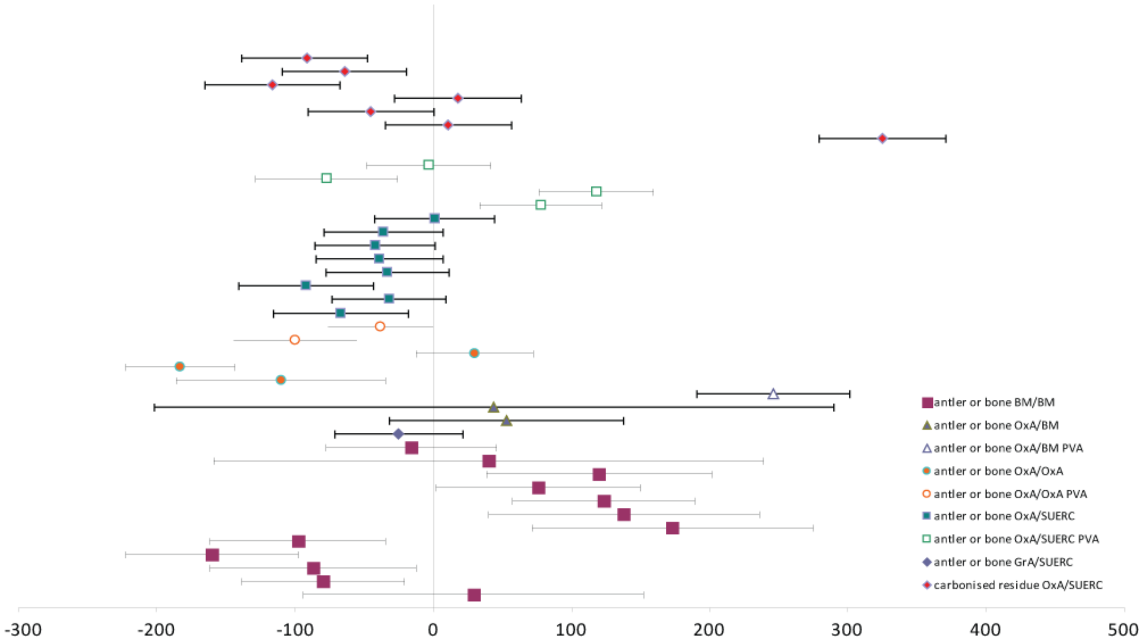


Figure 8: Offsets between replicate pairs of radiocarbon results on samples from Grime's Graves. Where there are more than two measurements the first measurement listed in Table 3 is compared with each succeeding measurement

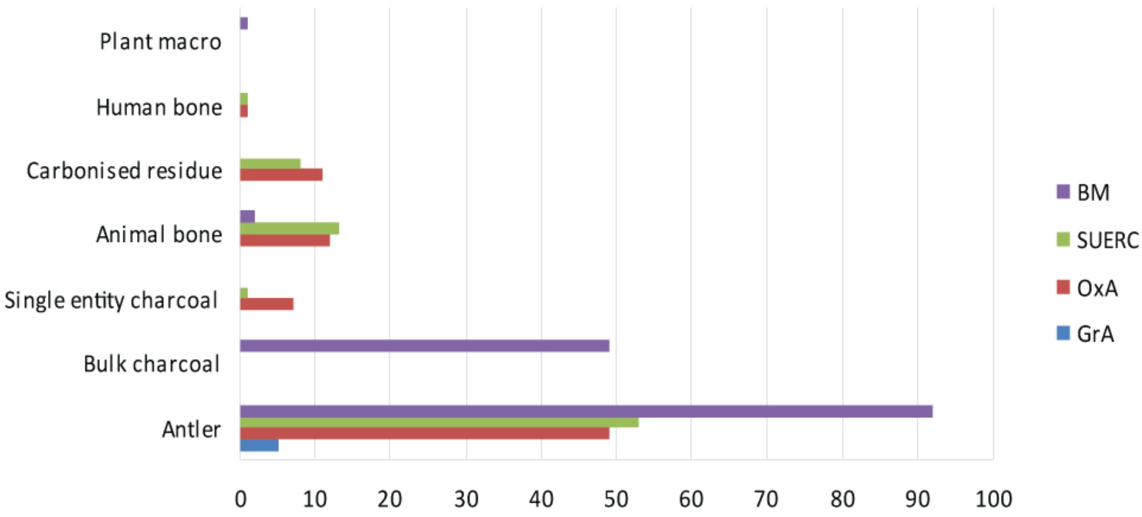


Figure 9: Incidence of radiocarbon measurements by material and laboratory

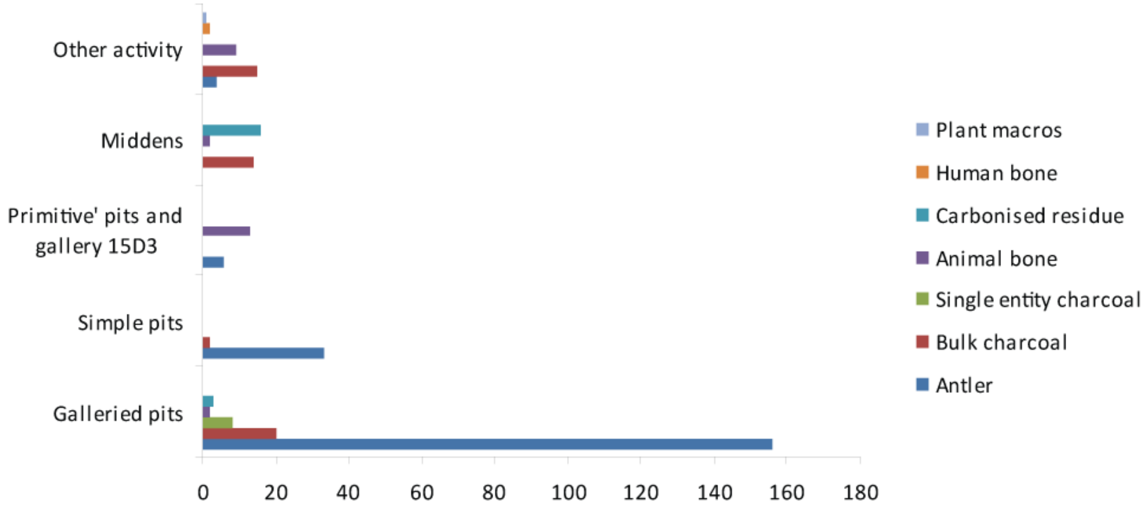


Figure 10: Incidence of radiocarbon measurements by context type and material

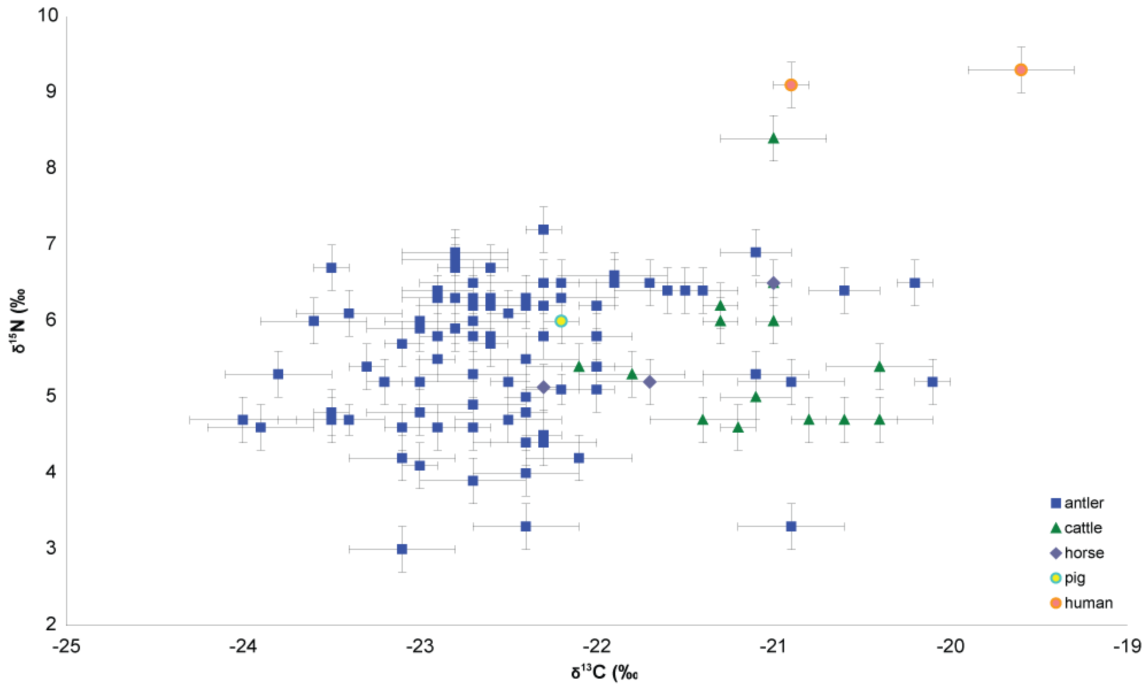


Figure 11: Plot of $\delta^{13}C$ and $\delta^{15}N$ values for bone and antler samples for which both are available

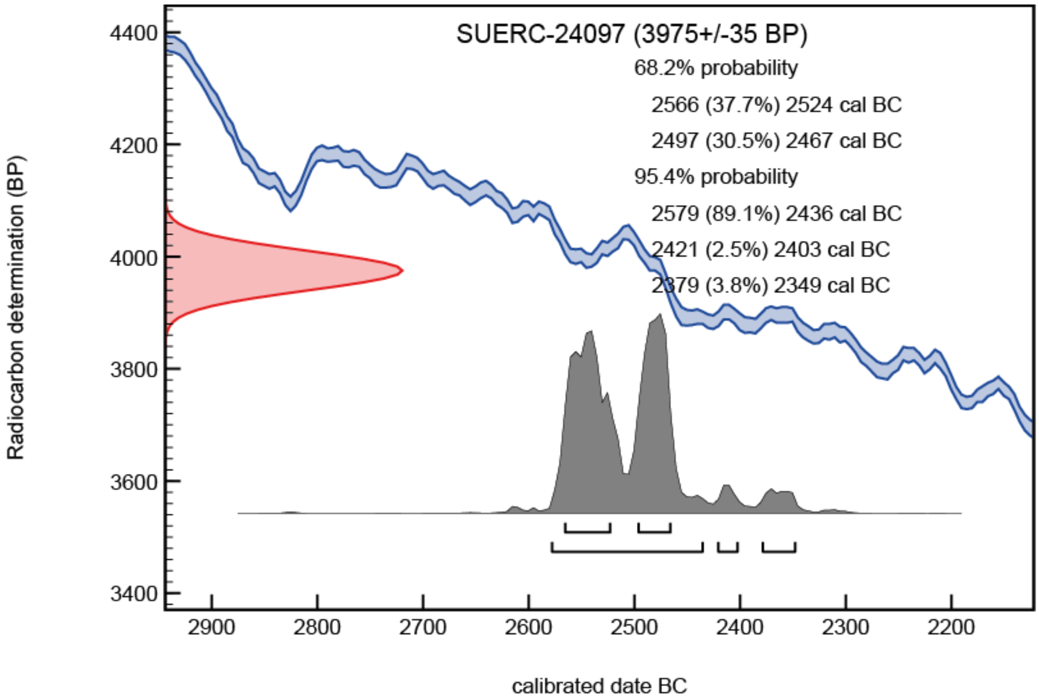


Figure 12: A calibrated radiocarbon date (probability method) of 3975±35 BP plotted on the calibration curve, showing how the shape of the curve in the mid-third millennium cal BC expands and in this case fragments the calibrated age range

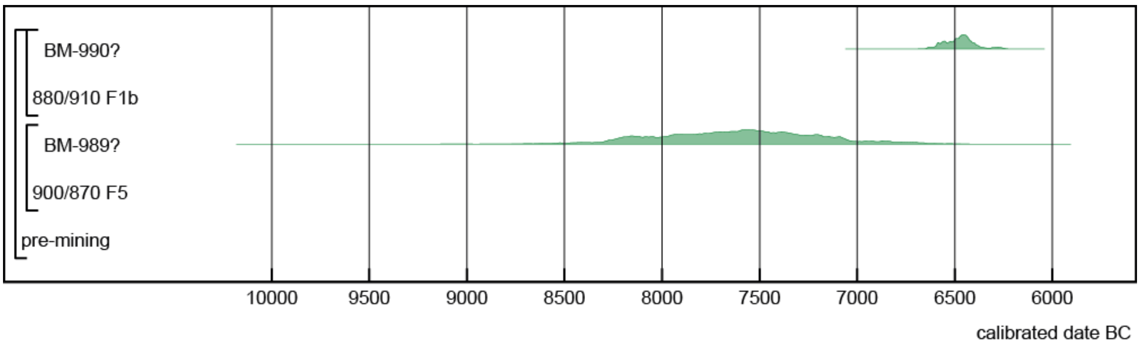


Figure 13: Simple calibrations of ninth to seventh millennium cal BC dates, both measured on bulk charcoal samples

Figure 14: A group of antler picks seen through a breach in a gallery wall in the Greenwell complex. © English Heritage

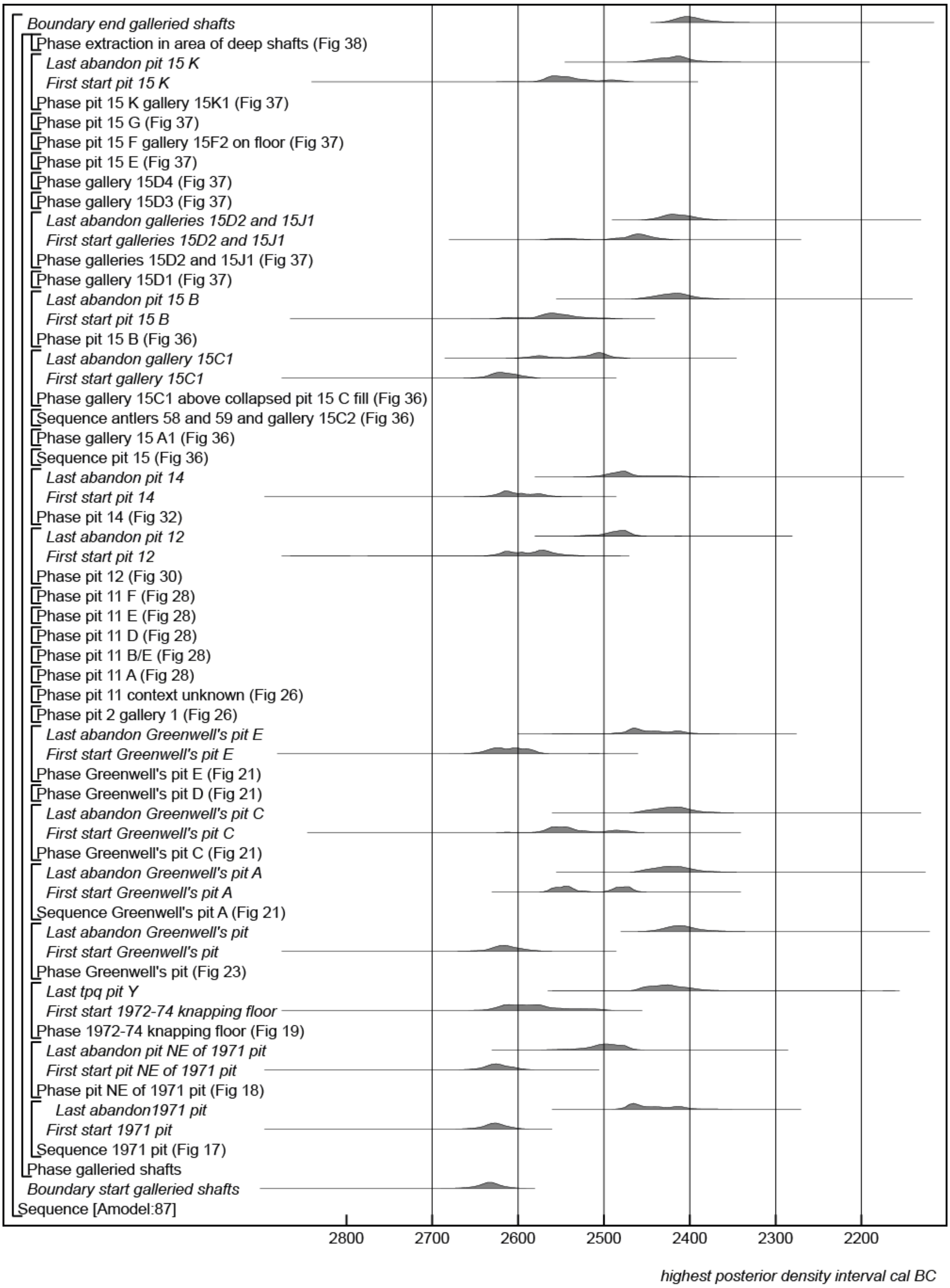


Figure 15: Overall structure of the main model for the galleried pits

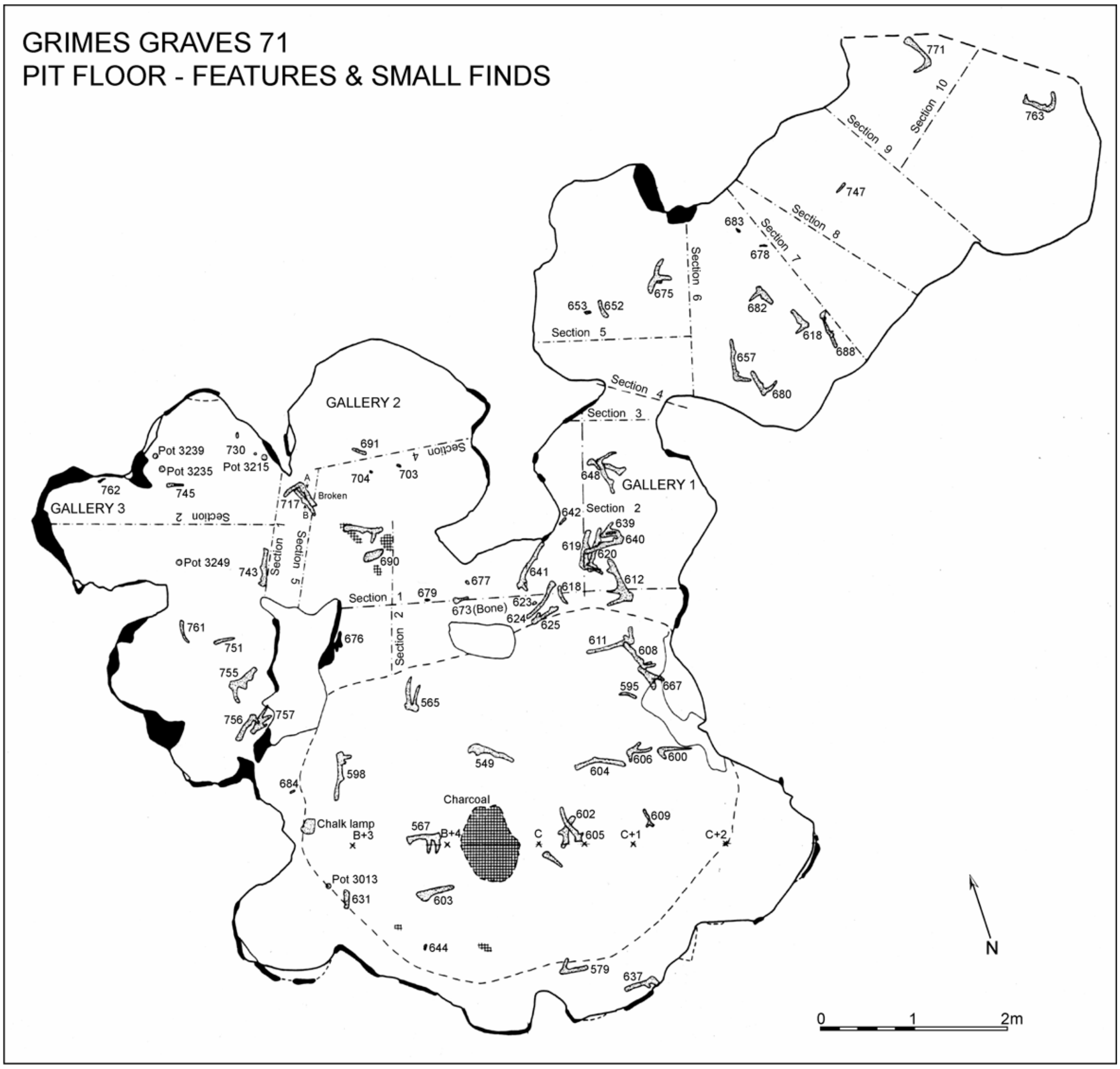


Figure16: The base of the 1971 pit and of the gallery of a second pit to the north-east, intersecting with gallery 1 at approximately to the line of section 4 in that gallery (Mercer 1981, fig 13). © English Heritage

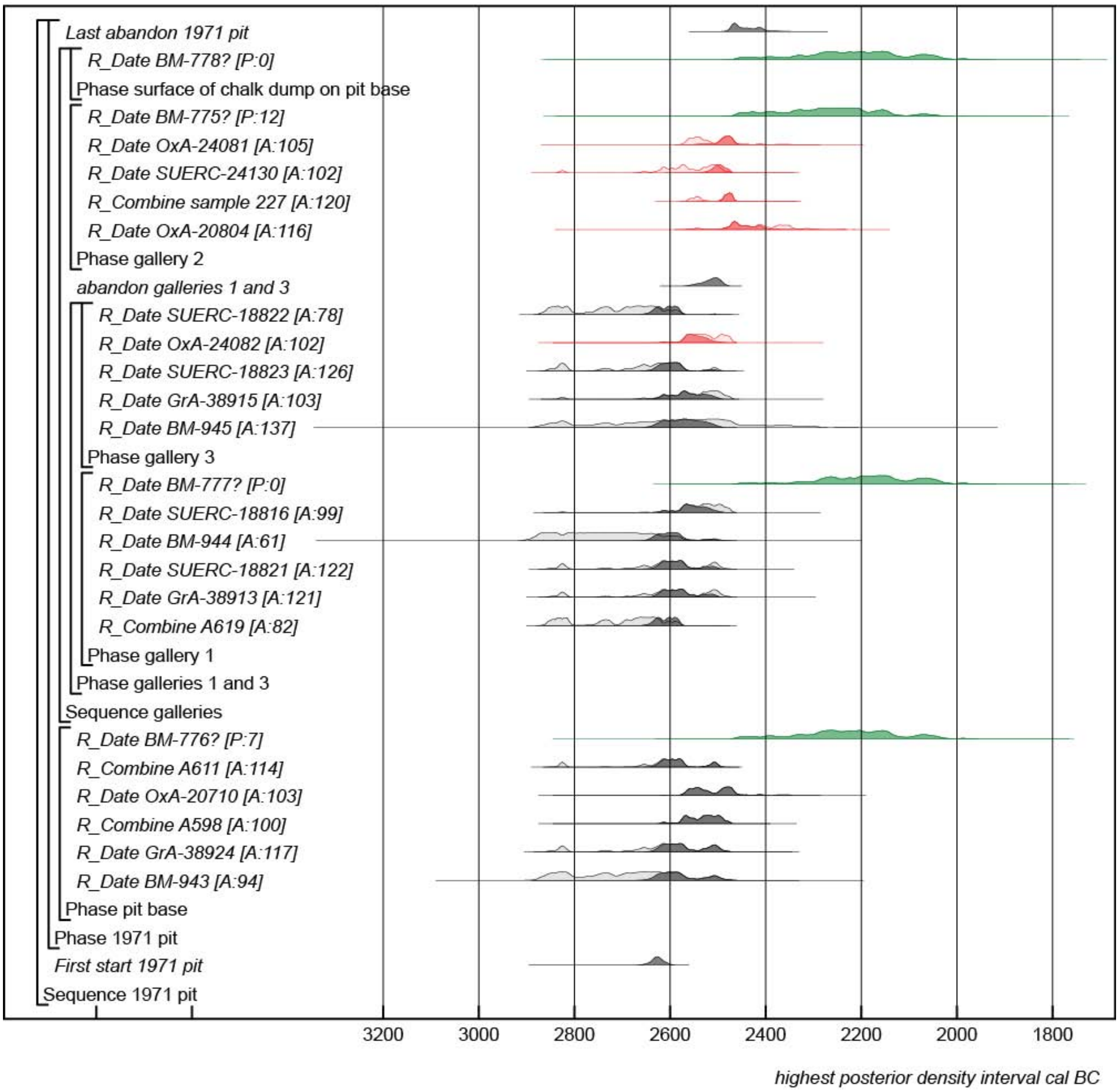


Figure 17: 1971 pit. Probability distributions of dates (Table 5). Part of the model the structure of which is shown in Figure 15. Each distribution represents the relative probability that an event occurred at a particular time. For each of the dates two distributions have been plotted, one shaded, which is the result produced by the scientific evidence alone, and a solid one which is based on the chronological model used. The other distributions correspond to aspects of the model. For example, the distribution 'start 1971 pit' is the estimated date when the pit began to be worked. Dates followed by a question mark have been calibrated, but excluded from the model for reasons explained in the text. The model is defined by the large square brackets down the left-hand side of the diagram and by the OxCal keywords. Dates measured on antler samples are shown in black; dates measured on bulk charcoal samples are shown in green; dates measured on single entity charcoal samples are shown in red

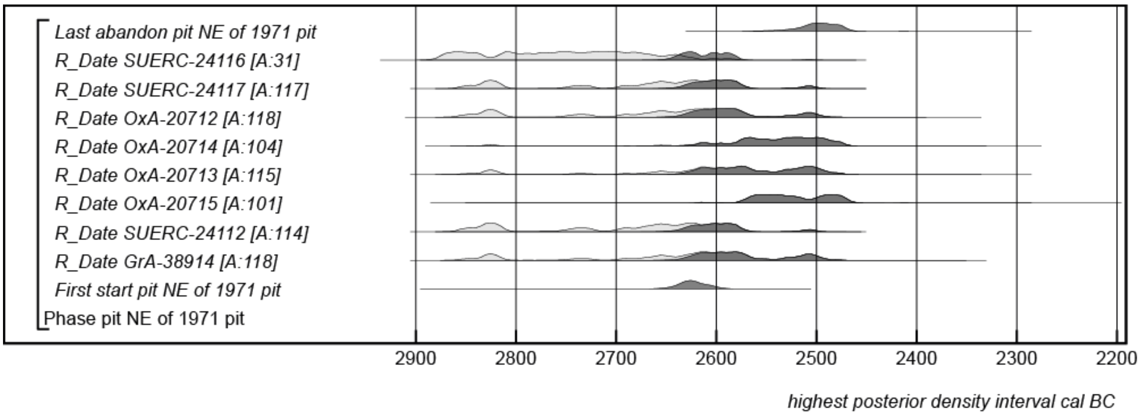


Figure 18: Pit to the north-east of the 1971 pit. Probability distributions of antler dates (Table 5). Part of the model the structure of which is shown in Figure 15. The format is identical to that of Figure 18

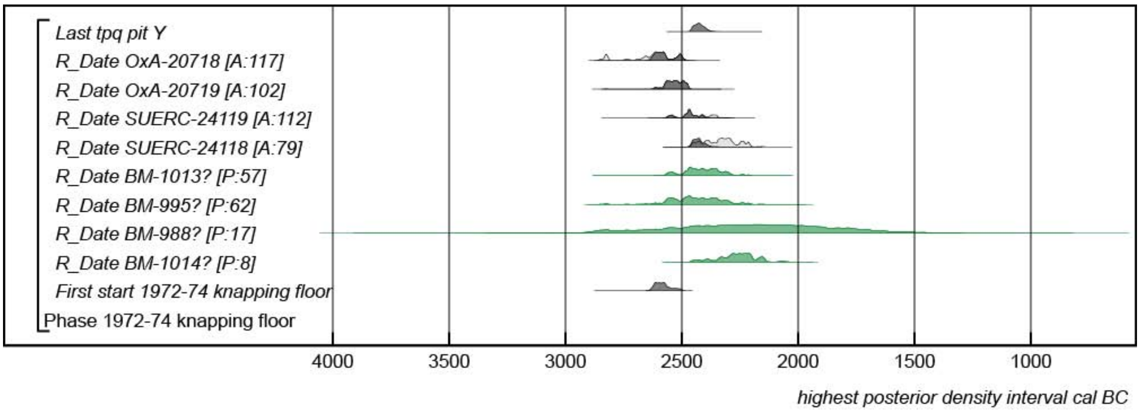


Figure19: Radiocarbon dates from the 1972–74 knapping floor (Table 6). Part of the model the structure of which is shown in Figure 15. The format is identical to that of Figure 17. Dates measured on antler samples are shown in black; dates measured on bulk charcoal samples are shown in green

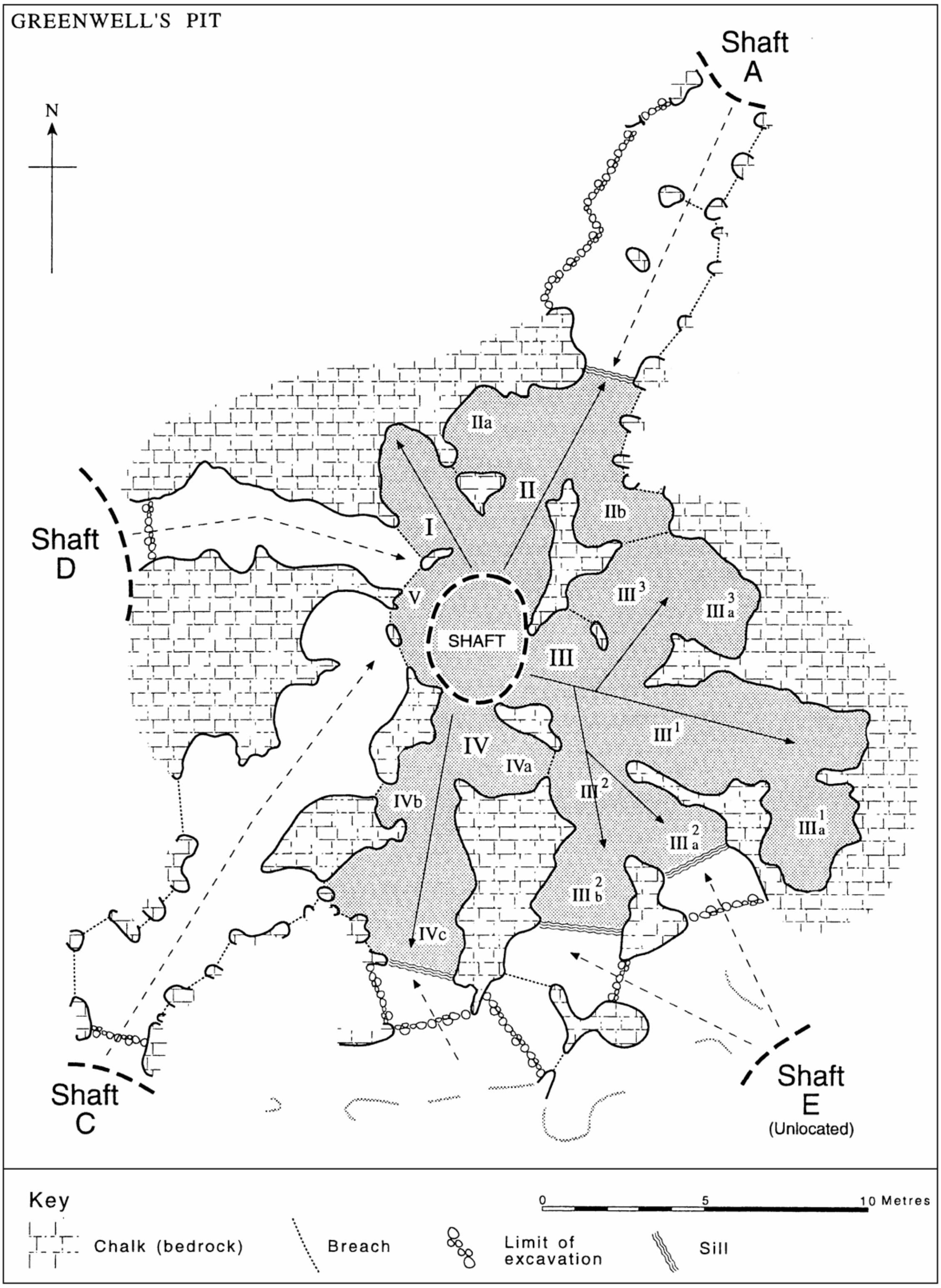


Figure 20: The Greenwell's pit complex. Greenwell's pit and its galleries are stippled (Longworth and Varndell 1996, fig 4). © British Museum

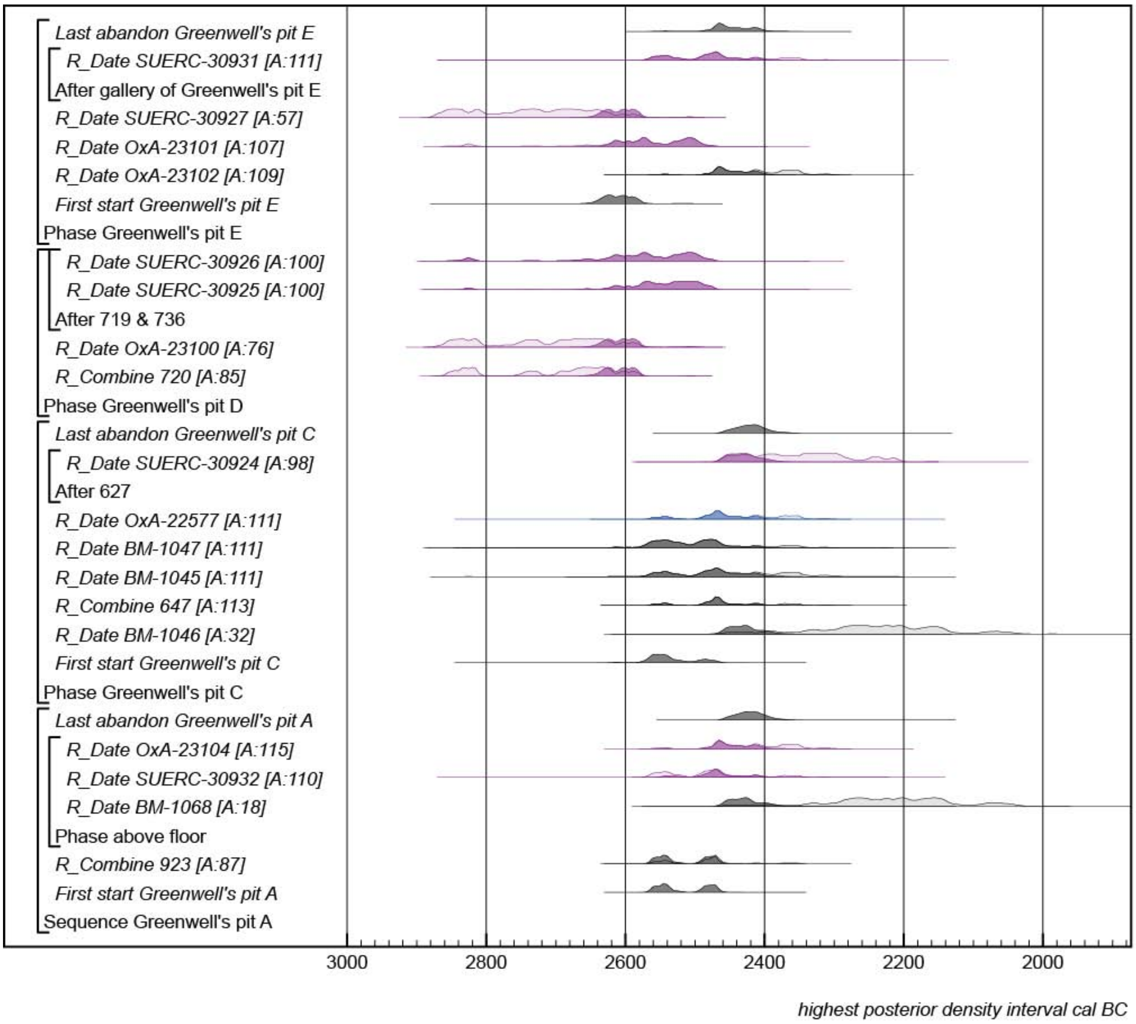


Figure 21: Radiocarbon dates for galleries driven from Greenwell's pits A, C, D, and E (Table 8). Part of the model the structure of which is shown in Figure 15.The format is identical to that of Figure 17. Dates measured on antler samples are shown in black, unless the samples have been treated with polyvinyl acetate (PVA), in which case they are shown in purple; dates measured on carbonised residue are shown in blue

Figure 22: Greenwell's pit gallery III2B. The pit props were inserted following investigations by the Prehistoric Flintmines Working Group of the Dutch Geological Society, Limburg Section © English Heritage

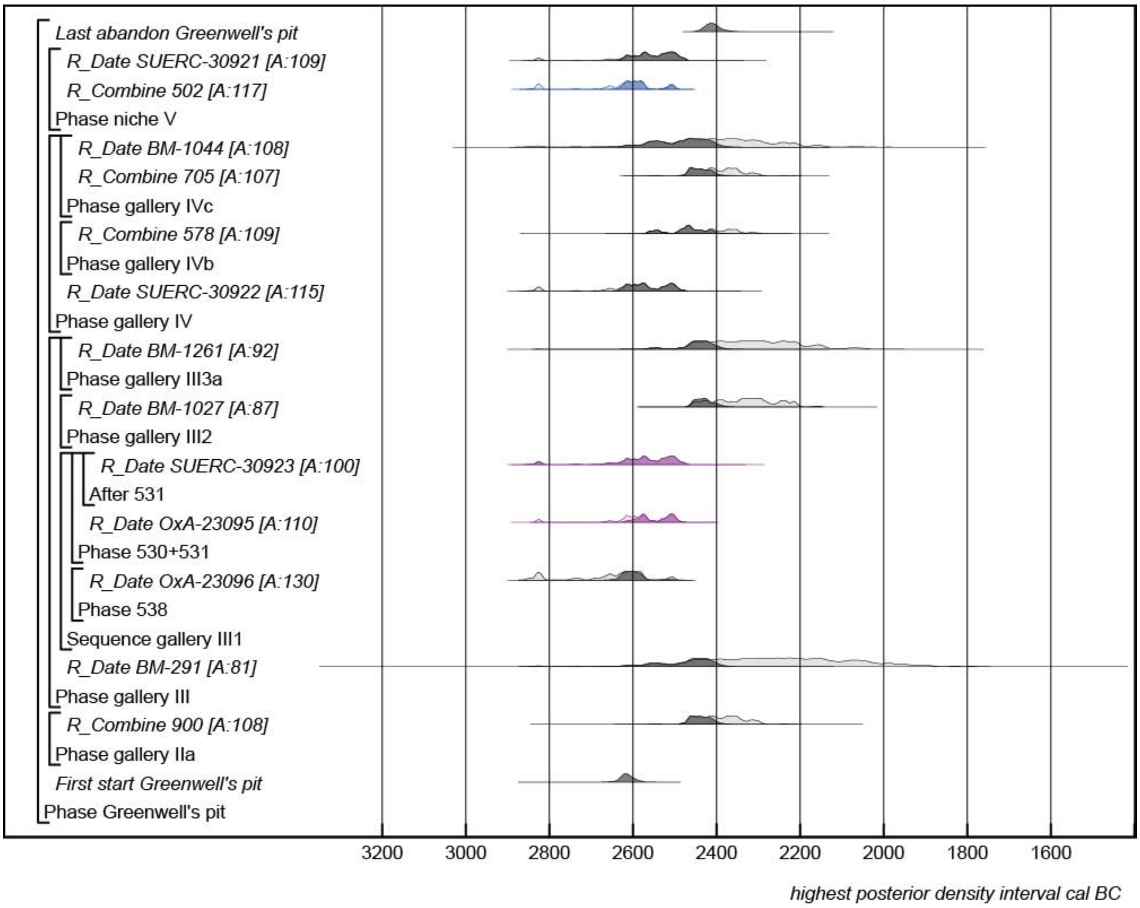


Figure 23: Radiocarbon dates from Greenwell's pit, modelled by gallery (Table 8). Part of the model the structure of which is shown in Figure 15. The format is identical to that of Figure 17. Dates measured on antler samples are shown in black, unless the samples have been treated with polyvinyl acetate (PVA), in which case they are shown in purple; dates measured on carbonised residue are shown in blue

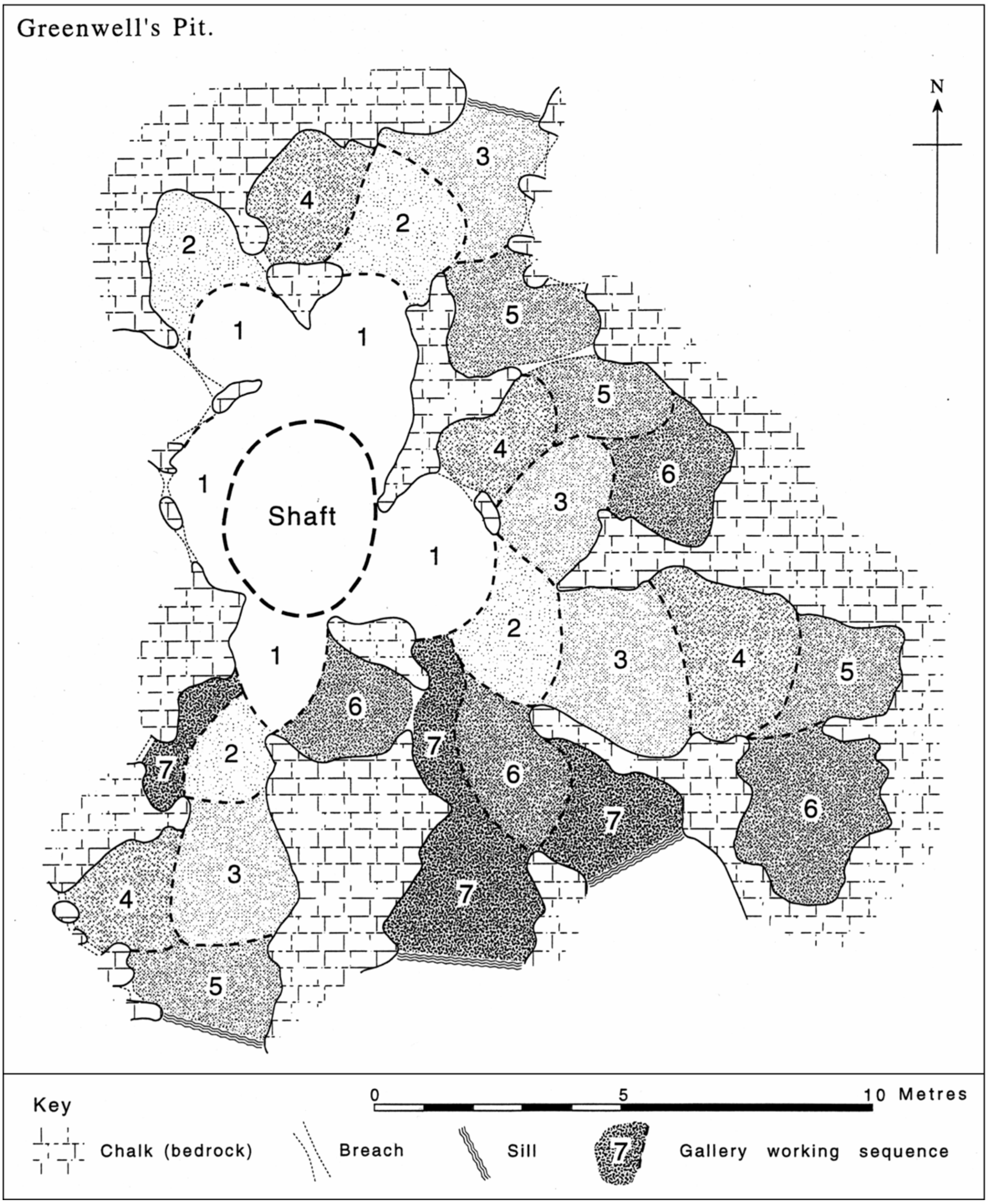


Figure 24: Felder's reconstruction of the extraction sequence for the floor and galleries of Greenwell's pit, summarised in Table 7 (Longworth and Varndell 1996, fig 64)

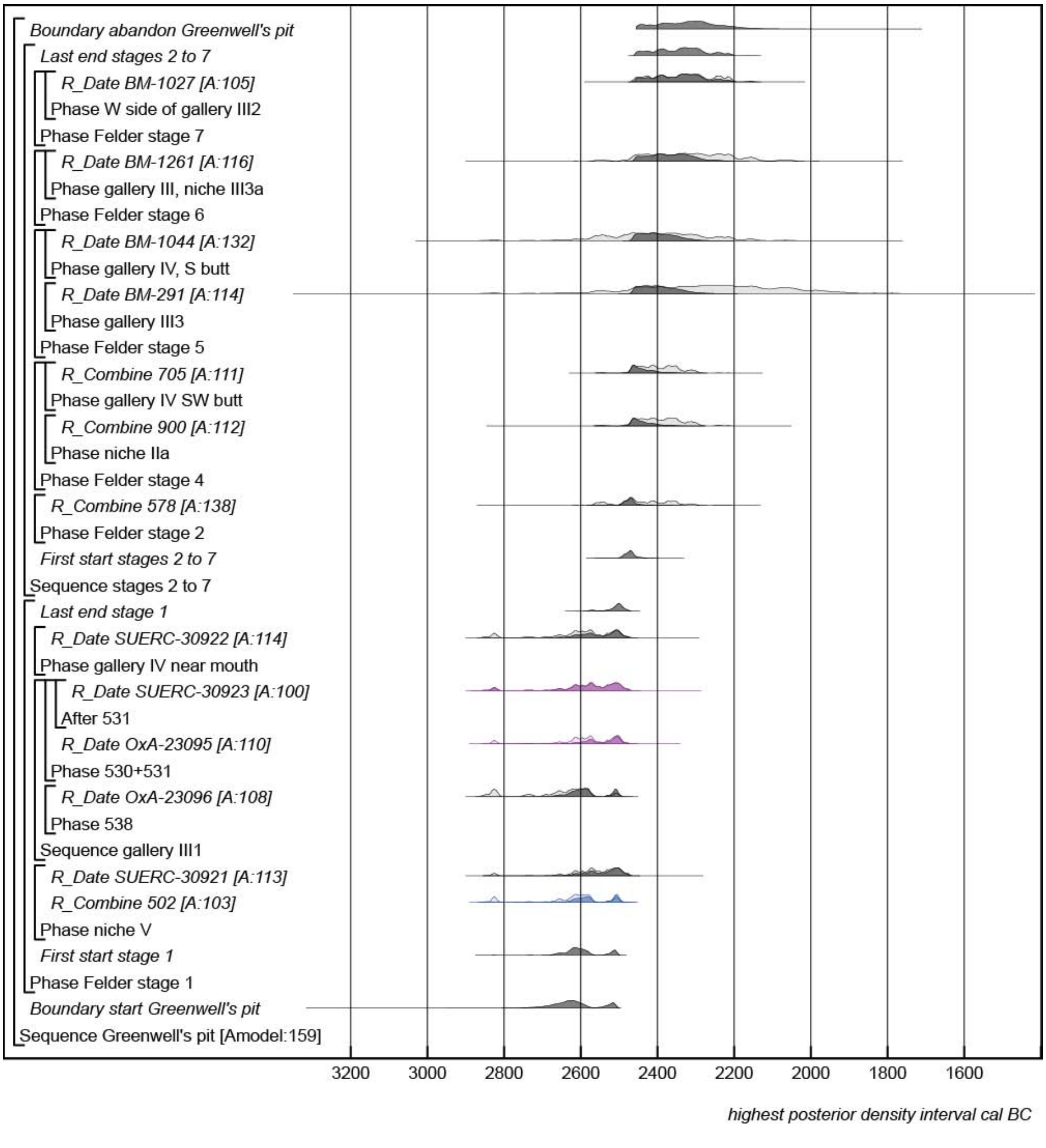


Figure 25: Radiocarbon dates from Greenwell's pit (Table 8), modelled according to Felder's reconstruction of the extraction sequence (Fig. 24, Table 7). Modelled independently. The format is identical to that of Figure 17. Dates measured on antler samples are shown in black, unless the samples have been treated with polyvinyl acetate (PVA), in which case they are shown in purple; dates measured on carbonised residue are shown in blue

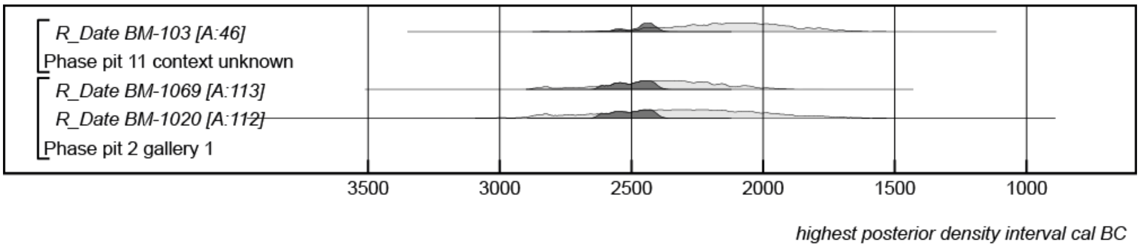


Figure 26: Radiocarbon dates from pit 2 and pit 11 (Table 9). Part of the model the structure of which is shown in Figure 15. The format is identical to that of Figure 17. Dates measured on antler samples are shown in black

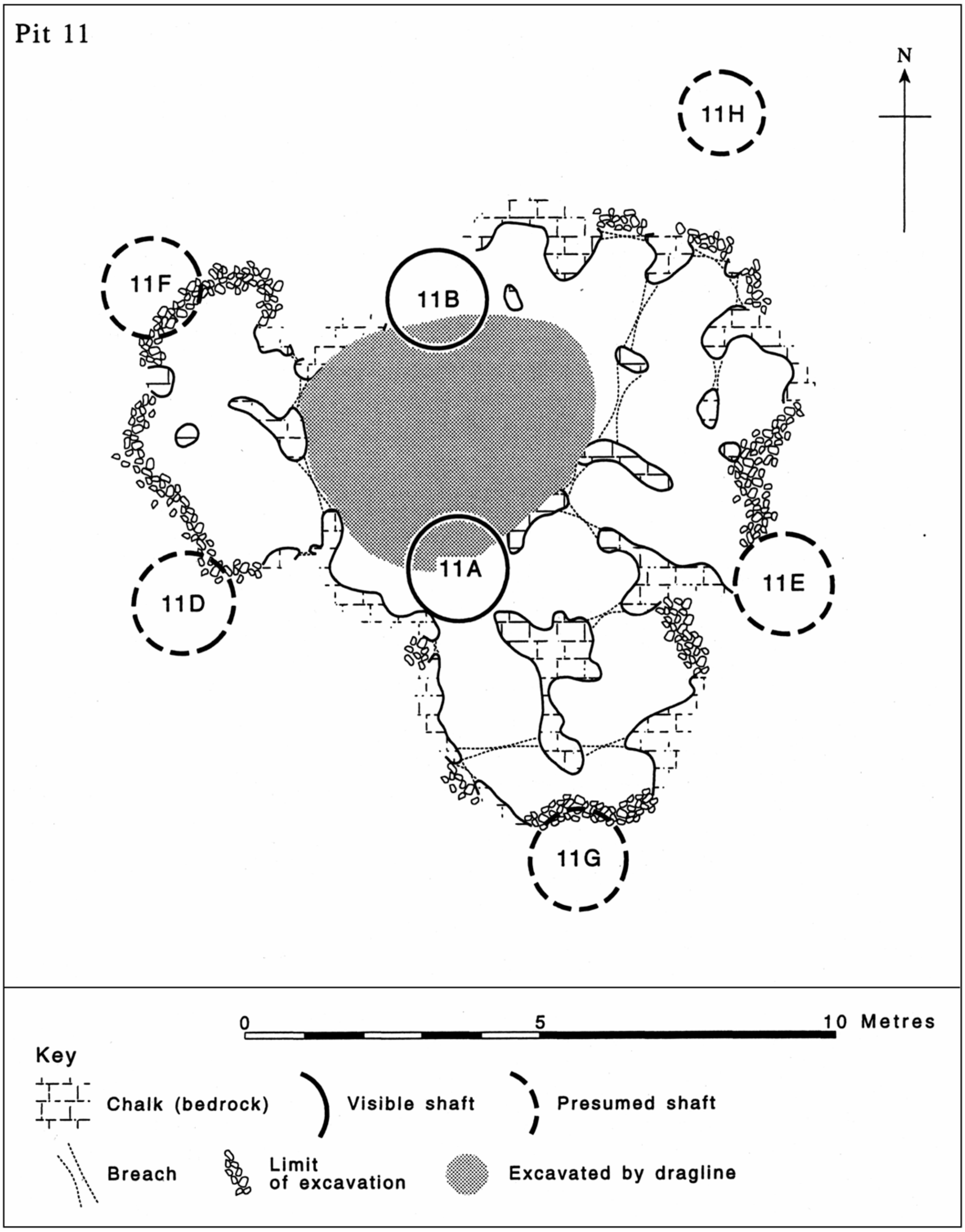


Figure 27: Pits 11 A to 11 H (Longworth and Varndell 1996, fig. 38). © British Museum

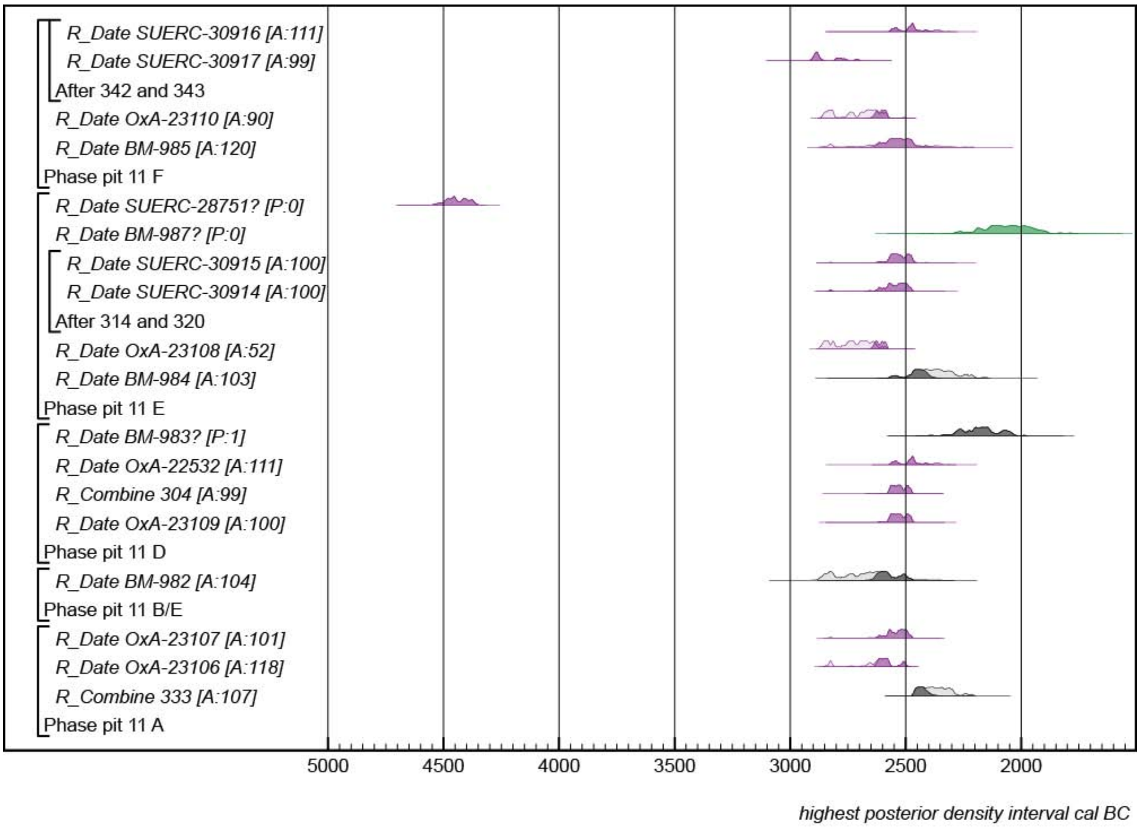


Figure 28: Radiocarbon dates from pits Pits 11 A to 11 F (Table 10). Part of the model the structure of which is shown in Figure 15. The format is identical to that of Figure 17. Dates measured on antler are shown in black, unless the samples have been treated with polyvinyl acetate (PVA), in which case they are shown in purple; dates measured on bulk charcoal samples are shown in green

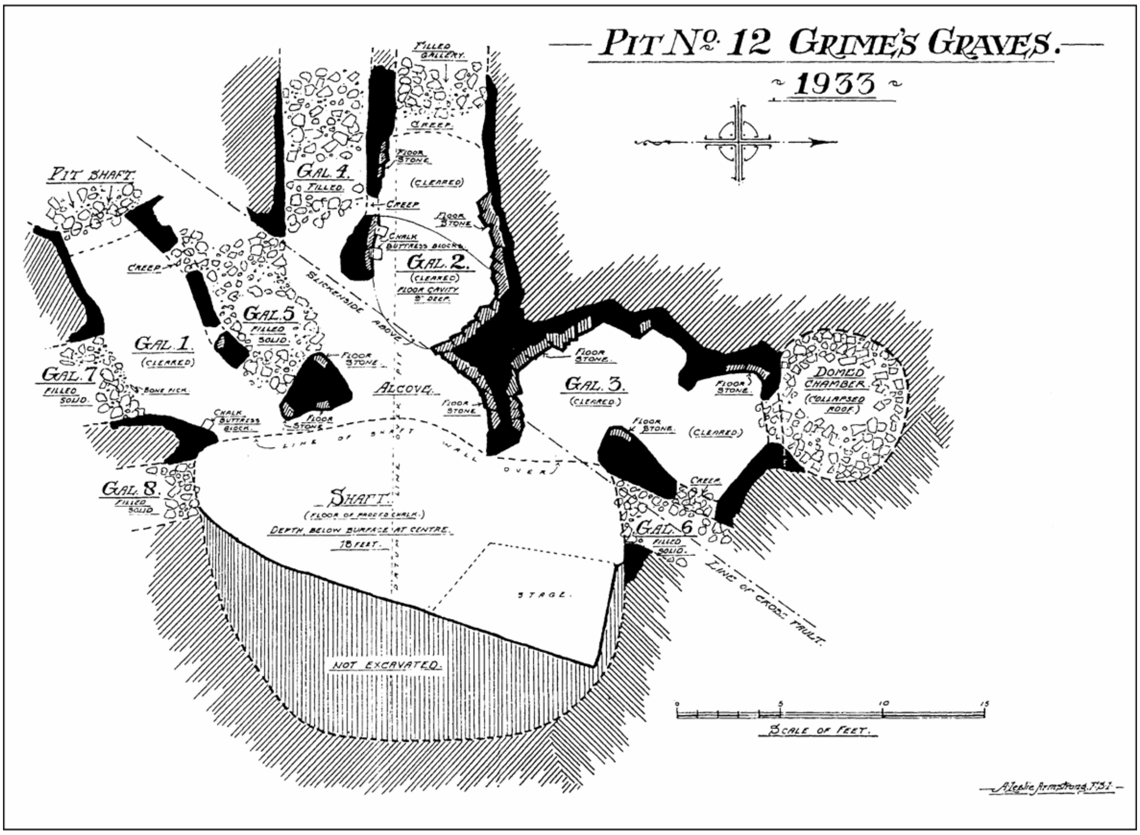


Figure 29: Armstrong's published plan of pit 12 (Armstrong 1934, fig 1)

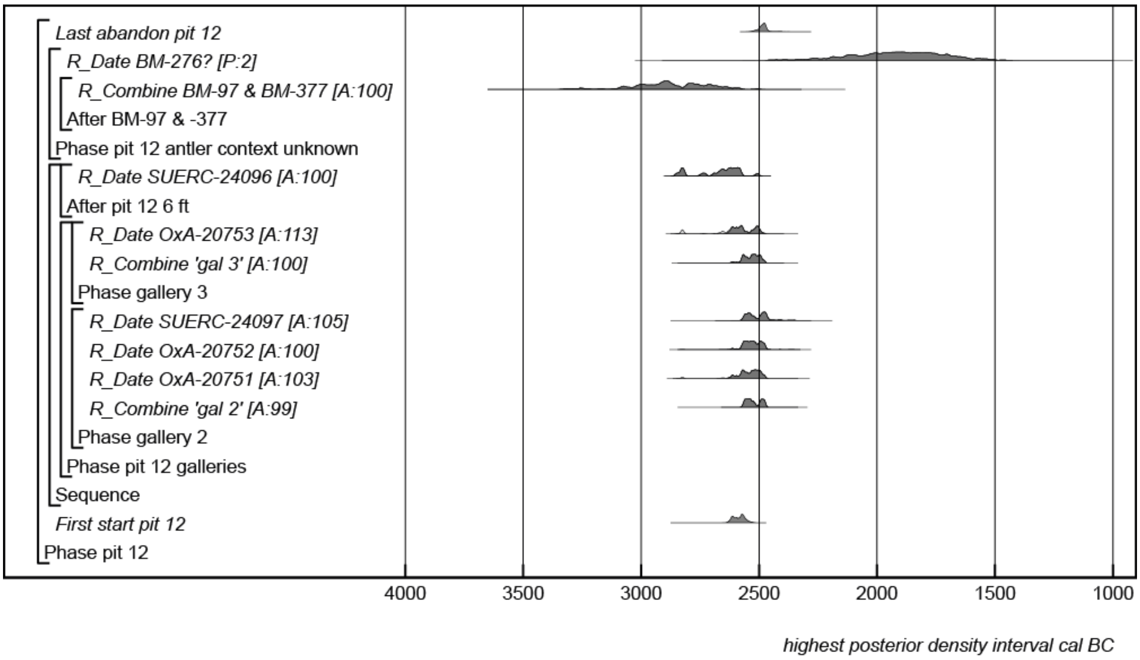


Figure 30: Radiocarbon dates from pit 12 (Table 11). Part of the model the structure of which is shown in Figure 15. The format is identical to that of Figure 17. Dates measured on antler or animal bone samples are shown in black

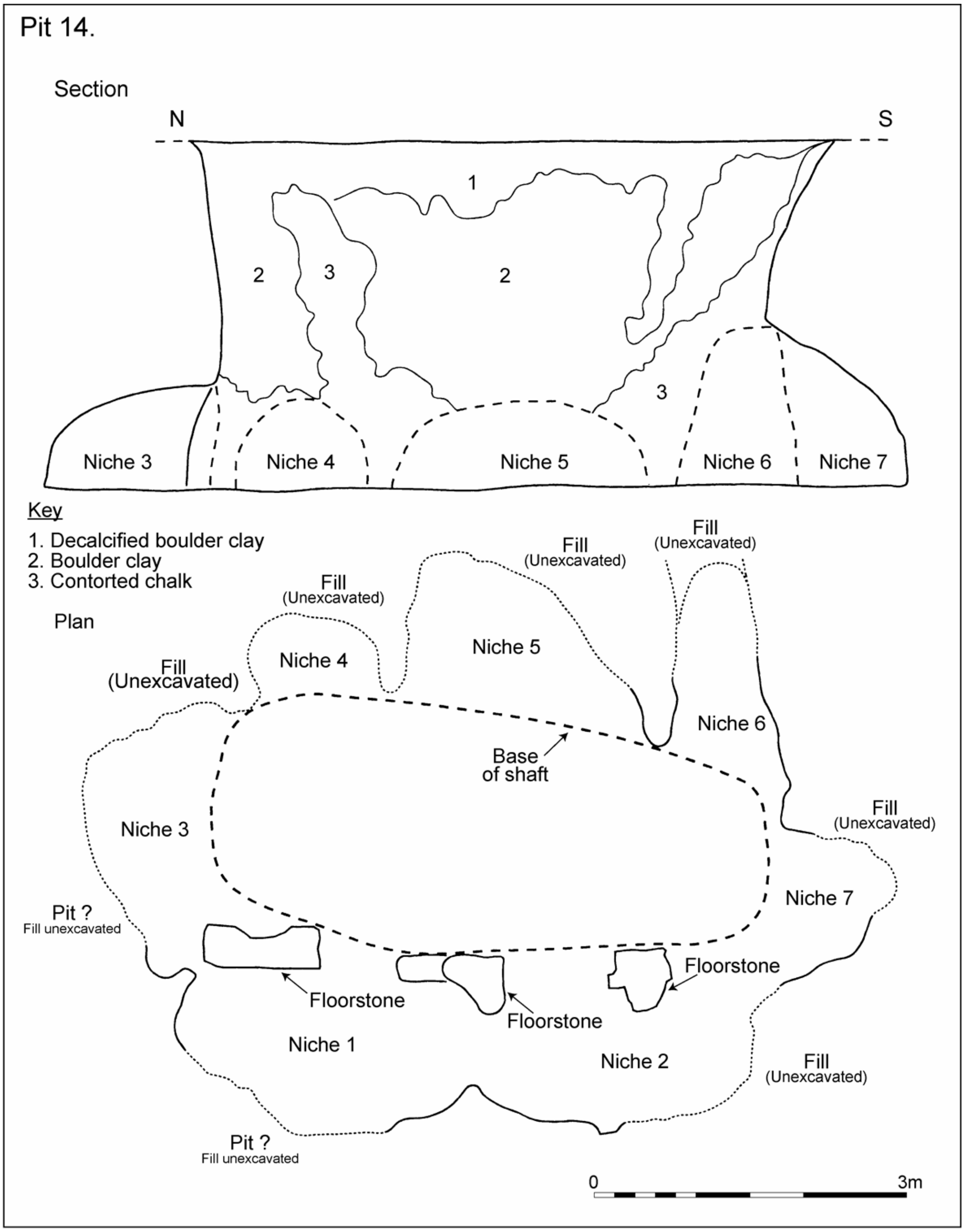


Figure 31: Pit 14 from Armstrong's field drawings (Longworth and Varndell 1996, fig 61)

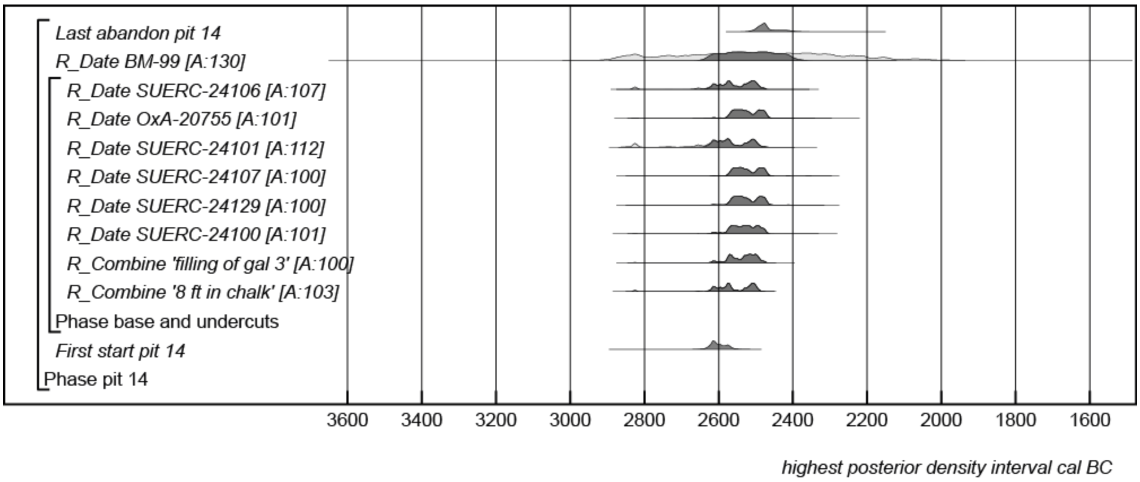


Figure 32: Radiocarbon dates from pit 14 (Table 12). Part of the model the structure of which is shown in Figure 15. The format is identical to that of Figure 17. Dates measured on antler samples are shown in black

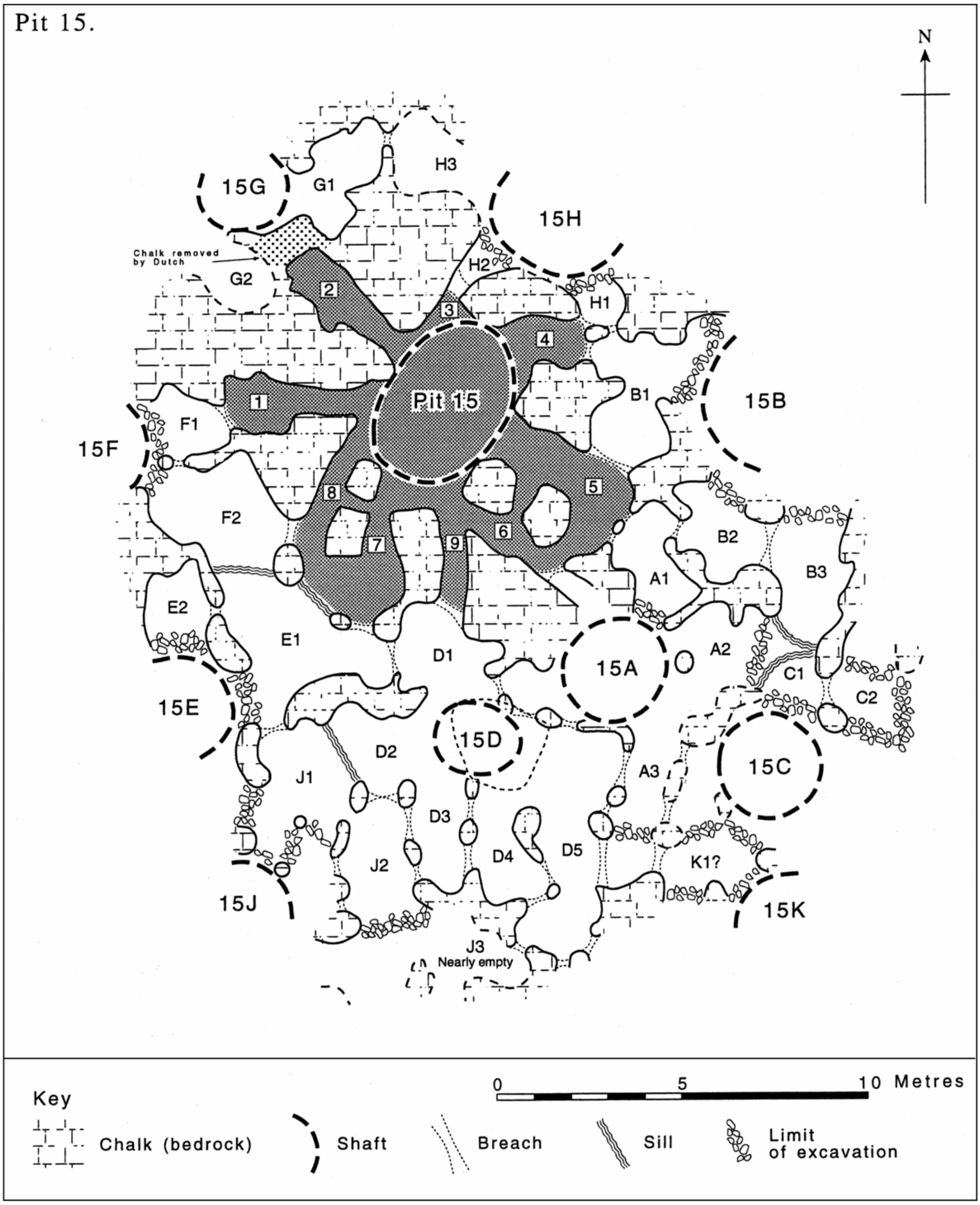


Figure 33: The pit 15 complex. Pit 15 itself and its galleries are stippled (Longworth and Varndell 1996, fig 41). © British Museum

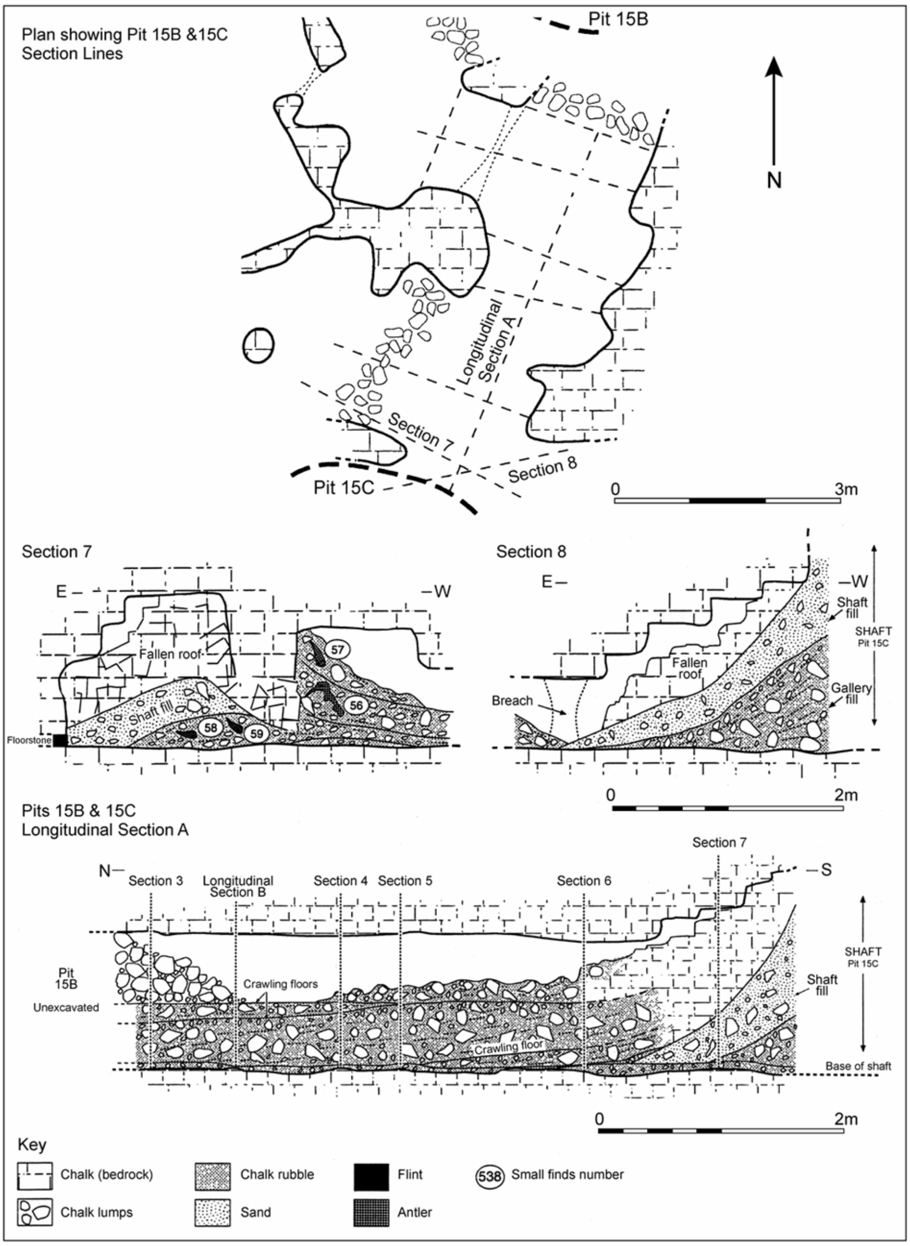


Figure 34: Location of sections across galleries in the east of complex (Longworth and Varndell 1996, fig 47); transverse section 7, across the west edge of gallery 15C2, the south end of gallery 15C1 and the east edge of gallery 15A2 (ibid, fig 46: g), with orientation amended; transverse section 8, across the west end of gallery 15C2, the south end of gallery 15C1, and the edge of the collapsed fill of pit 15 C. (ibid, fig 46: h); longitudinal section constructed retrospectively from the transverse sections (ibid, fig 45: a). © British Museum

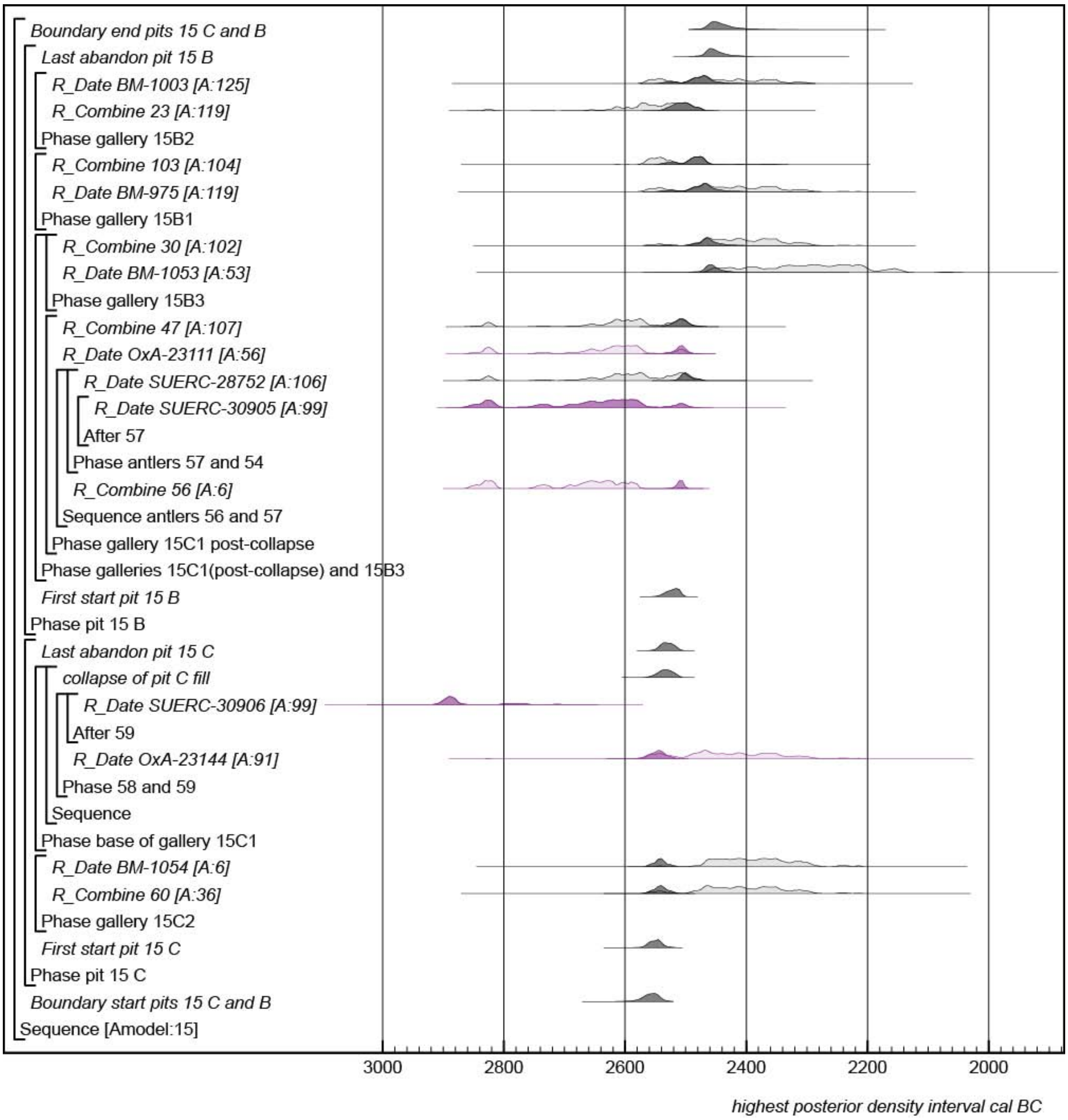


Figure 35: Radiocarbon dates for samples attributed to pits 15 B and 15 C (Table 13) modelled on the premises that the working of pit C preceded that of pit B; that the fills of gallery 15C1 above the collapse were continuous with those of gallery 15B3; and that antlers 58 and 59 were successively overlain by antlers 56 and 57. Modelled independently. The format is identical to that of Figure 17. Dates measured on antler samples are shown in black, unless the samples have been treated with polyvinyl acetate (PVA), in which case they are shown in purple

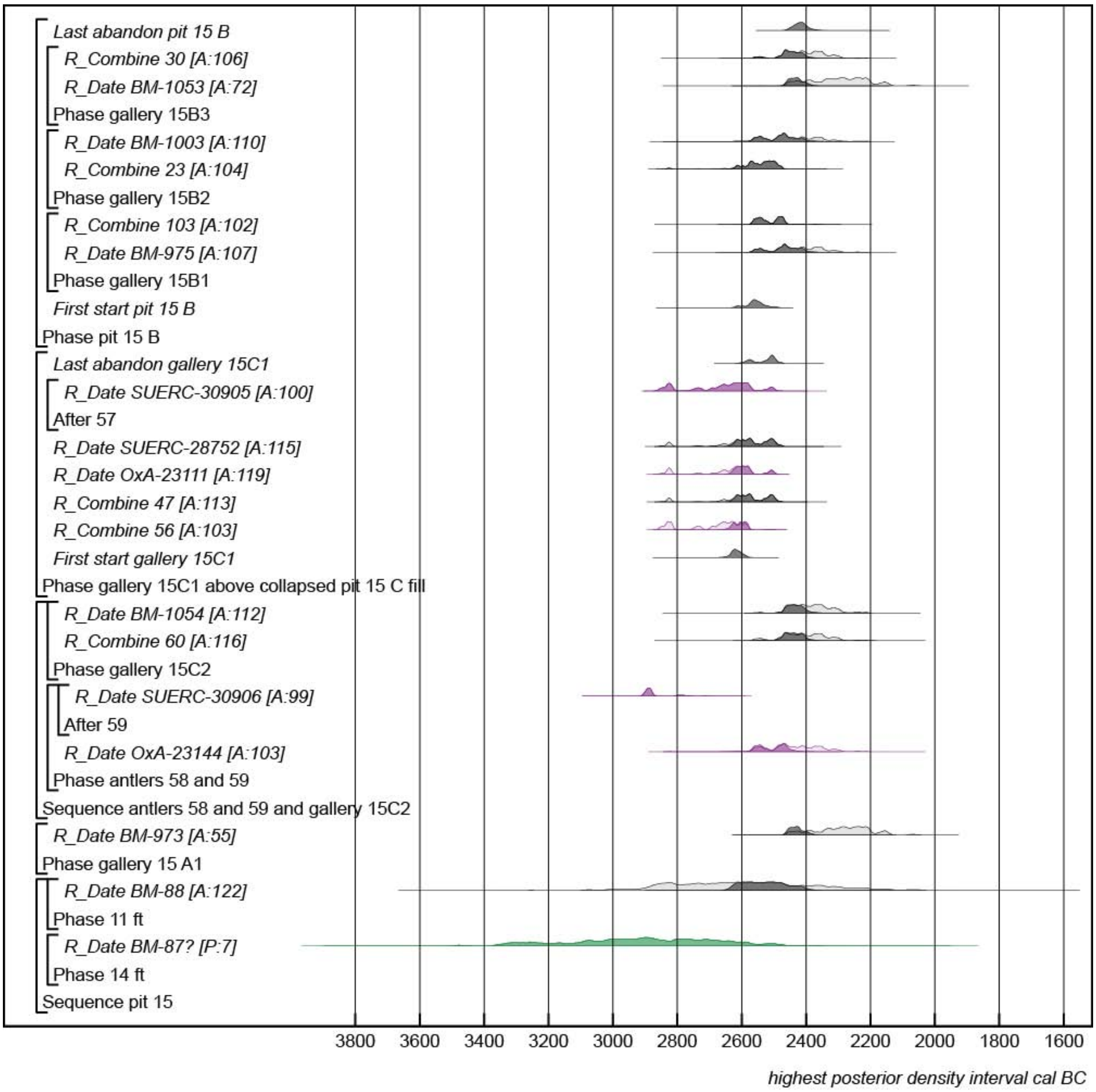


Figure 36: Radiocarbon dates from pits 15, 15 A, 15 C and 15 B (Table 13). Part of the model the structure of which is shown in Figure 15. The format is identical to that of Figure 17. Dates measured on antler samples are shown in black, unless the samples have been treated with polyvinyl acetate (PVA), in which case they are shown in purple; dates measured on bulk charcoal samples are shown in green

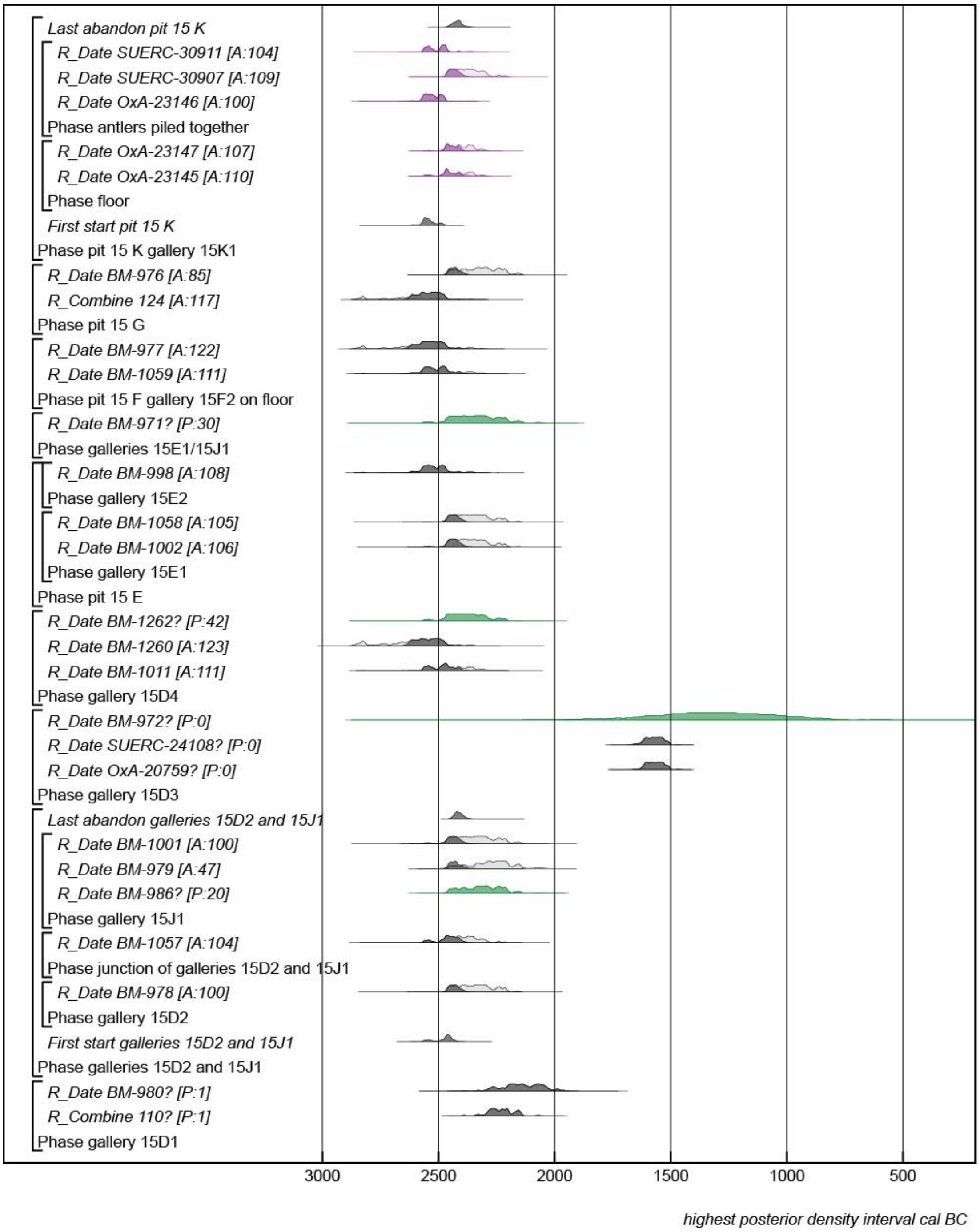


Figure 37: Radiocarbon dates from pits 15 D to 15 K (Tables 13 and 19). Part of the model the structure of which is shown in Figure 15. The format is identical to that of Figure 17. Dates measured on antler or animal bone samples are shown in black, unless the samples have been treated with polyvinyl acetate (PVA), in which case they are shown in purple; dates measured on bulk charcoal samples are shown in green

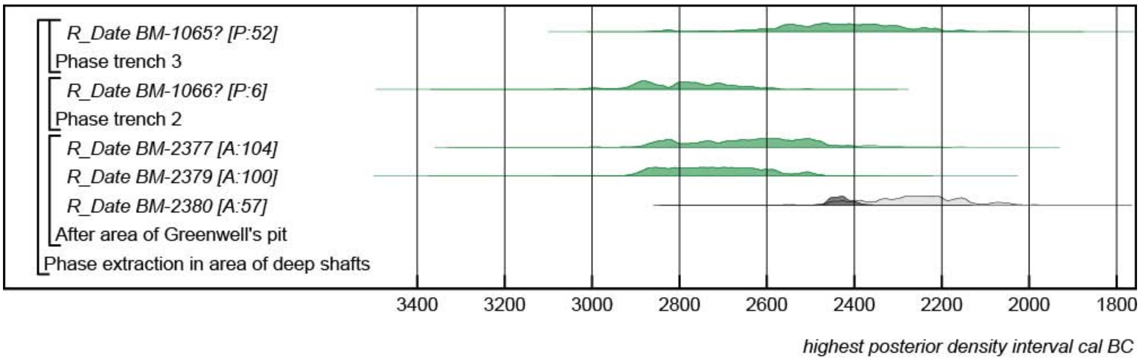


Figure 38: Radiocarbon dates for samples stratified beneath the spoilheaps surrounding pits in the area of the galleried shafts (Table 14). Part of the model the structure of which is shown in Figure 15.The format is identical to that of Figure 17. Dates measured on antler samples are shown in black; dates measured on bulk charcoal samples are shown in green

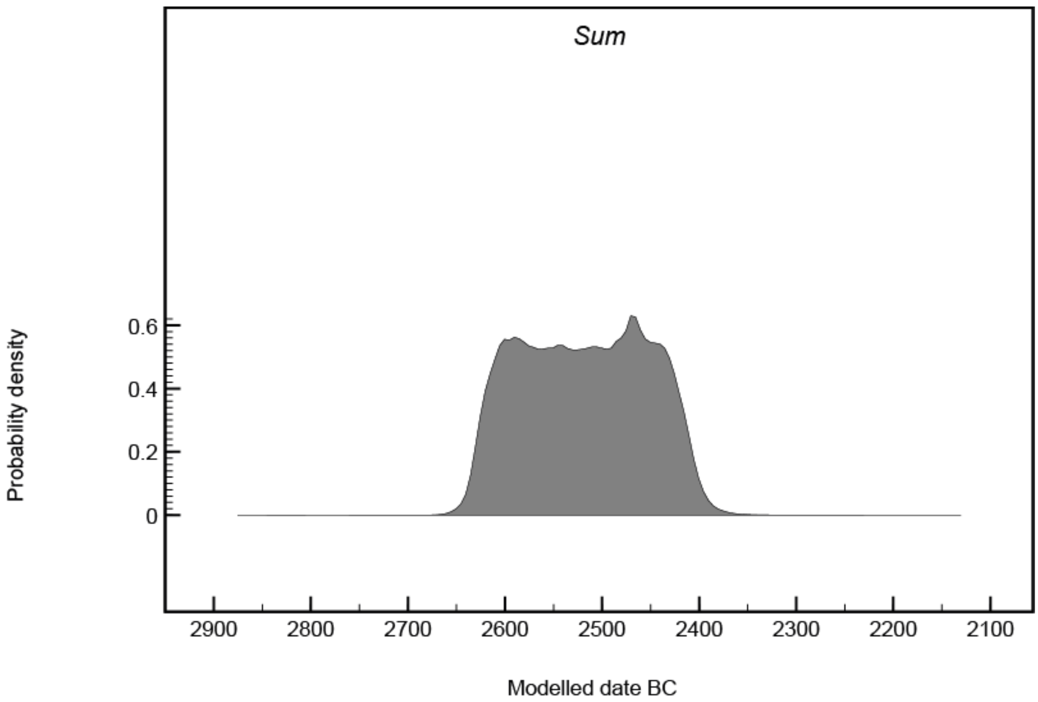


Figure 39: Sum of the probability distributions of all the dated events relating to the galleried pits which have been neither excluded not modelled as termini post quos

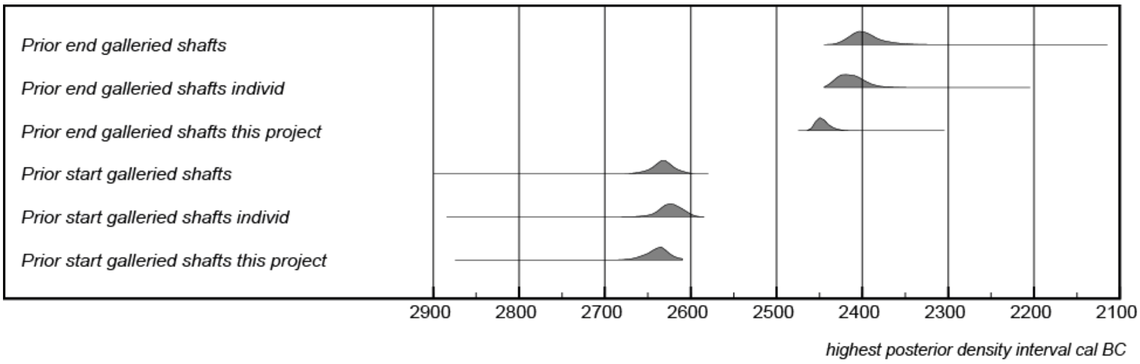


Figure 40: Estimated starts and ends for the galleried pits as a whole from the preferred model, alternative model 1 which is confined to those elements for which individual estimates have been made, and alternative model 2, which employs only dates obtained in the course of this project (Table 15)

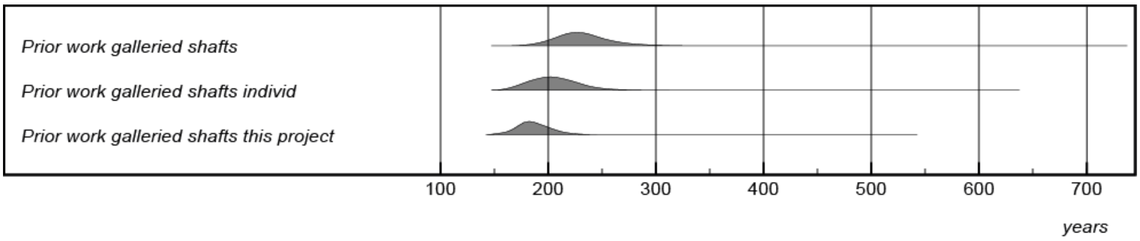


Figure 41: Estimated durations for the galleried pits as a whole from the preferred model , alternative model 1 which is confined to those elements for which individual estimates have been made, and alternative model 2, which employs only dates obtained in the course of this project (Table 15)

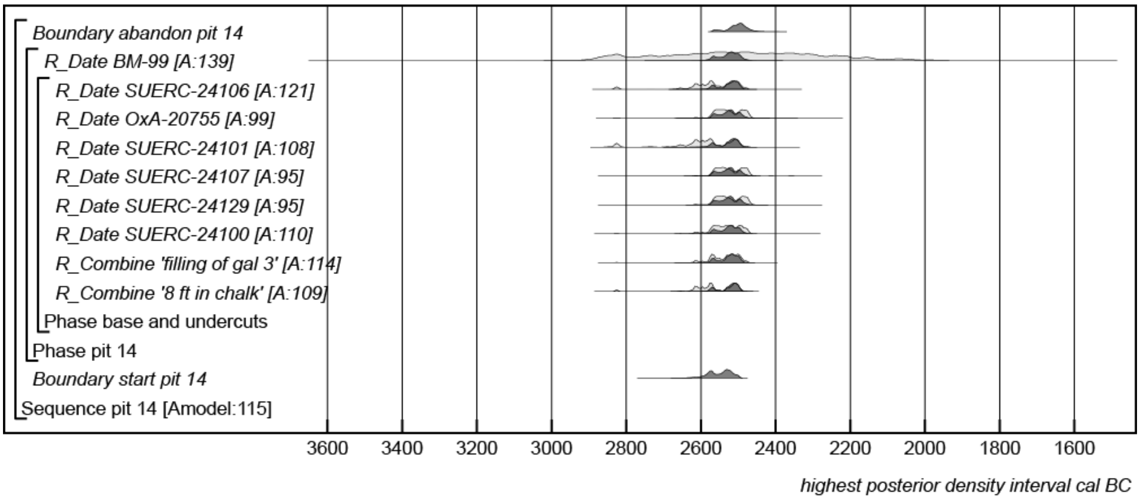


Figure 42: an example, in this case pit 14, of the modelling of an element for which an individual estimate has been made in an independent bounded phase

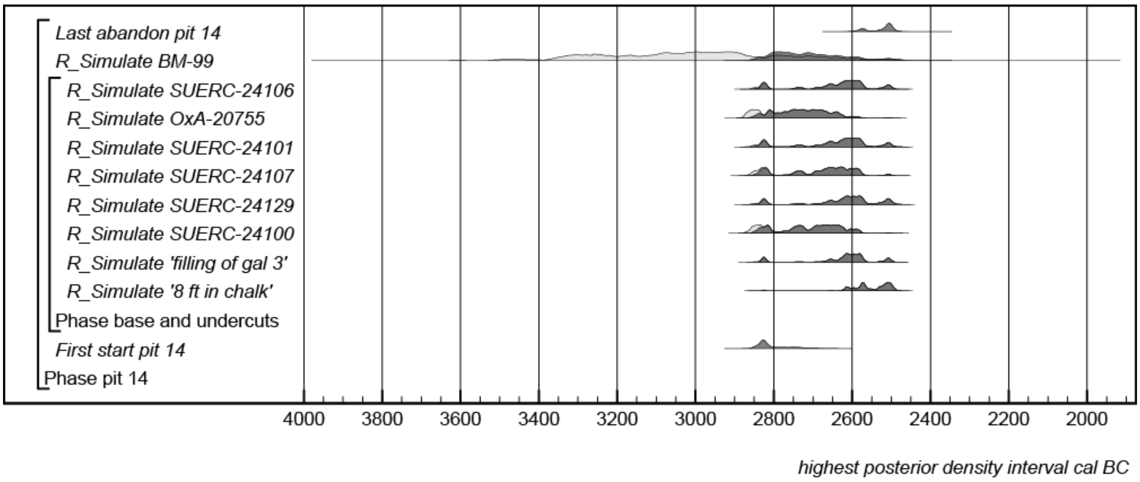


Figure 43: an example, in this case pit 14, of the replacement in the preferred model of all dates for antler (excluding those modelled as termini post quos *or excluded) with simulated dates which are identical within each element, but retain the errors of the actual dates used in the other models. OxA-20755, for instance, is simulated as 2610±32 cal BC and BM-99 as 2610±150 cal BC*

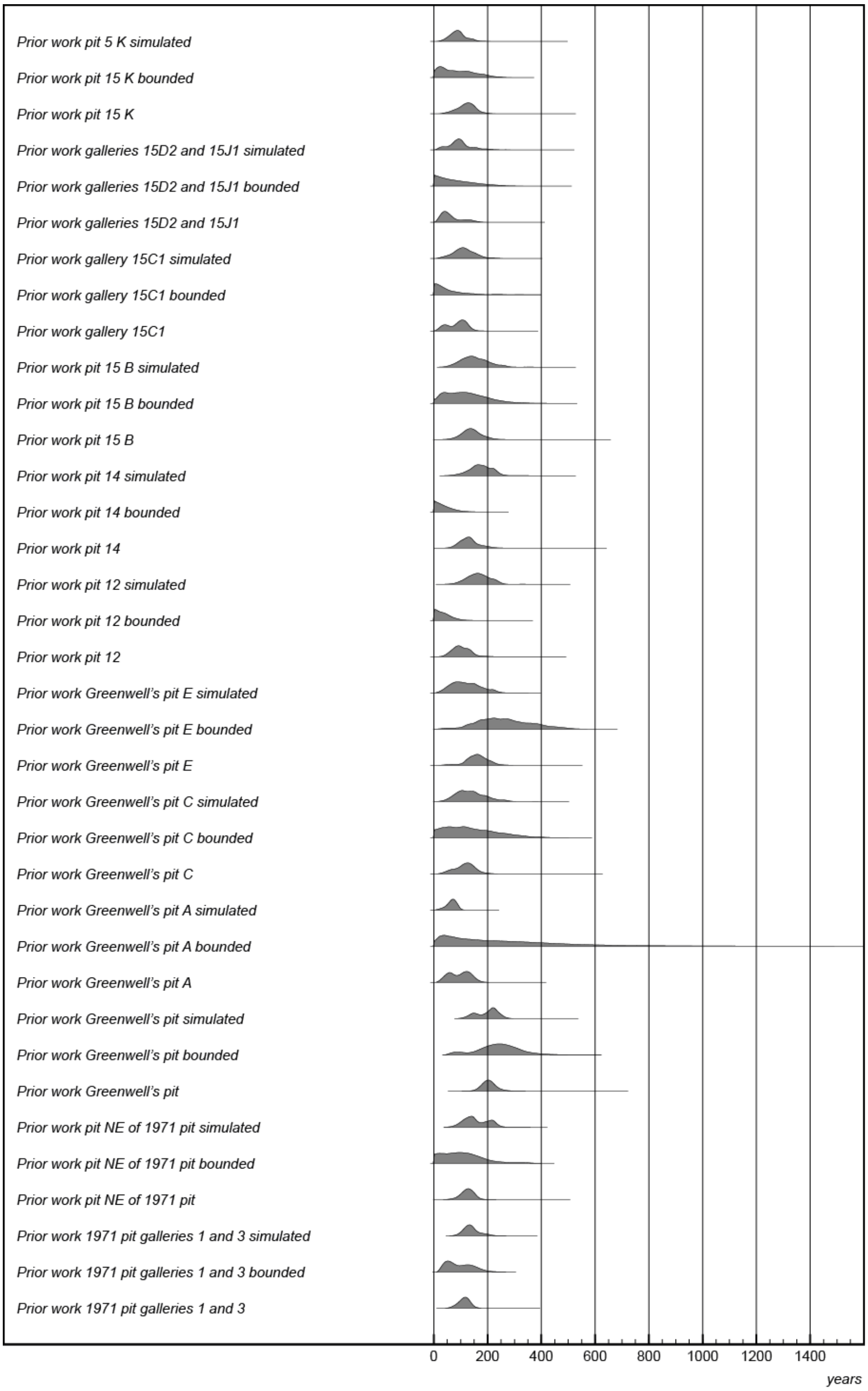


Figure 44: Estimated durations for individual elements among the galleried pits from the preferred model, from the modelling of each in an independent bounded phase, and from a model in which dates for antler implements from each element are simulated as identical (Table 16)

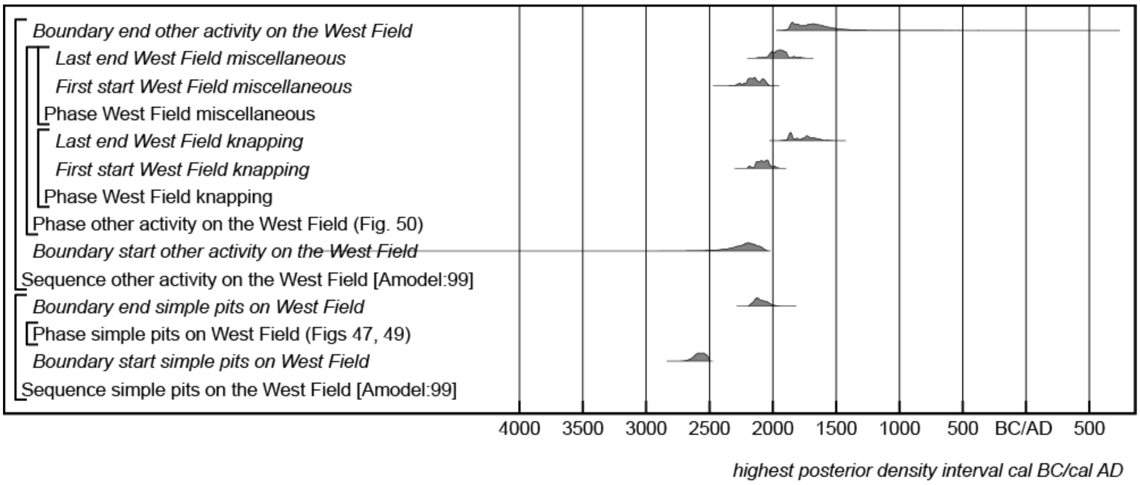


Figure 45: Overall structure of model for simple pits and other activity on the West Field

Figure 46: F6 in cutting 950/820 (Longworth et al *2012, fig 33). © British Museum*

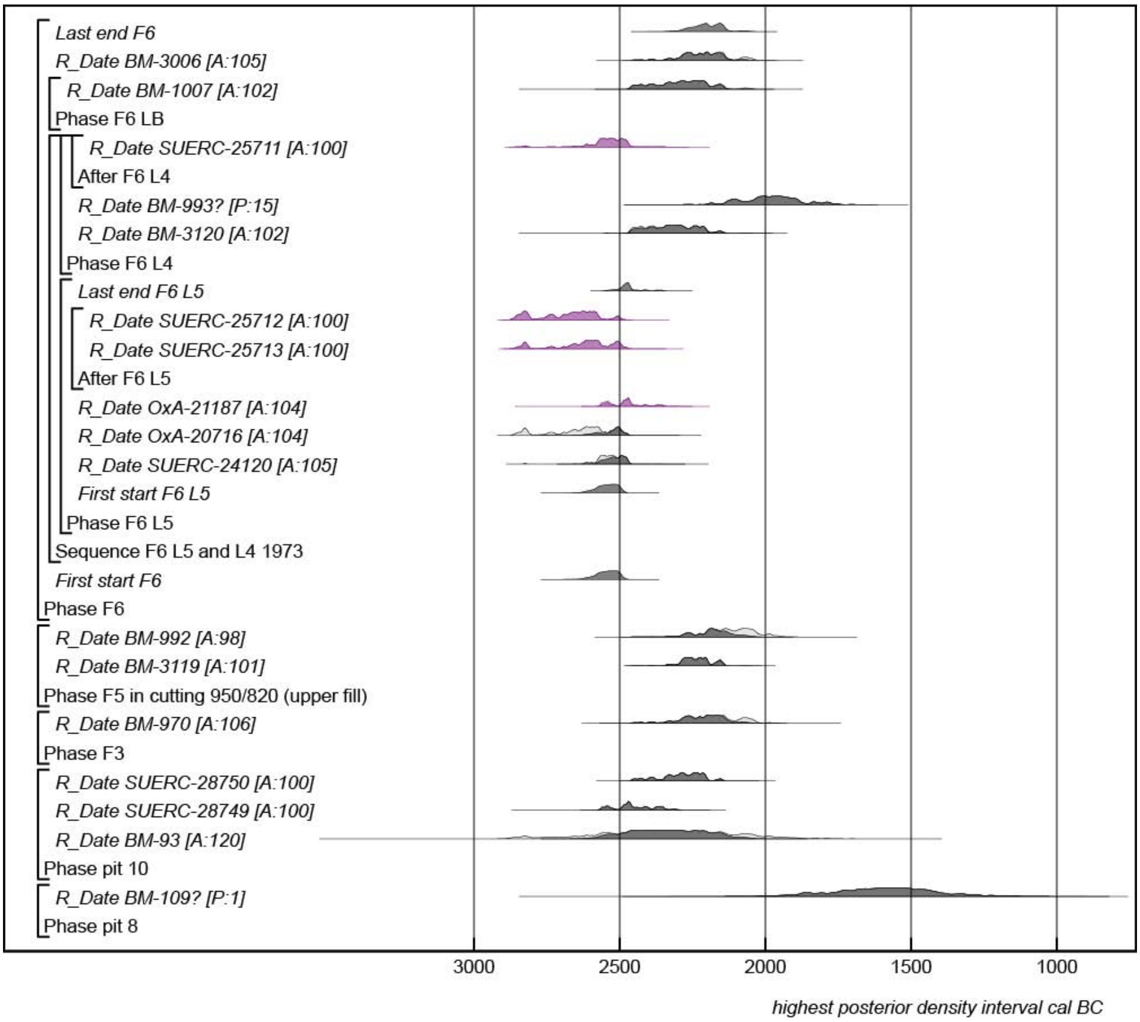


Figure 47: Radiocarbon dates from simple extraction pits, including F6, in the West Field (Table 17). Part of the model the structure of which is shown in Figure 45. The format is identical to that of Figure 17. Dates measured on antler samples are shown in black, unless the samples have been treated with polyvinyl acetate (PVA), in which case they are shown in purple

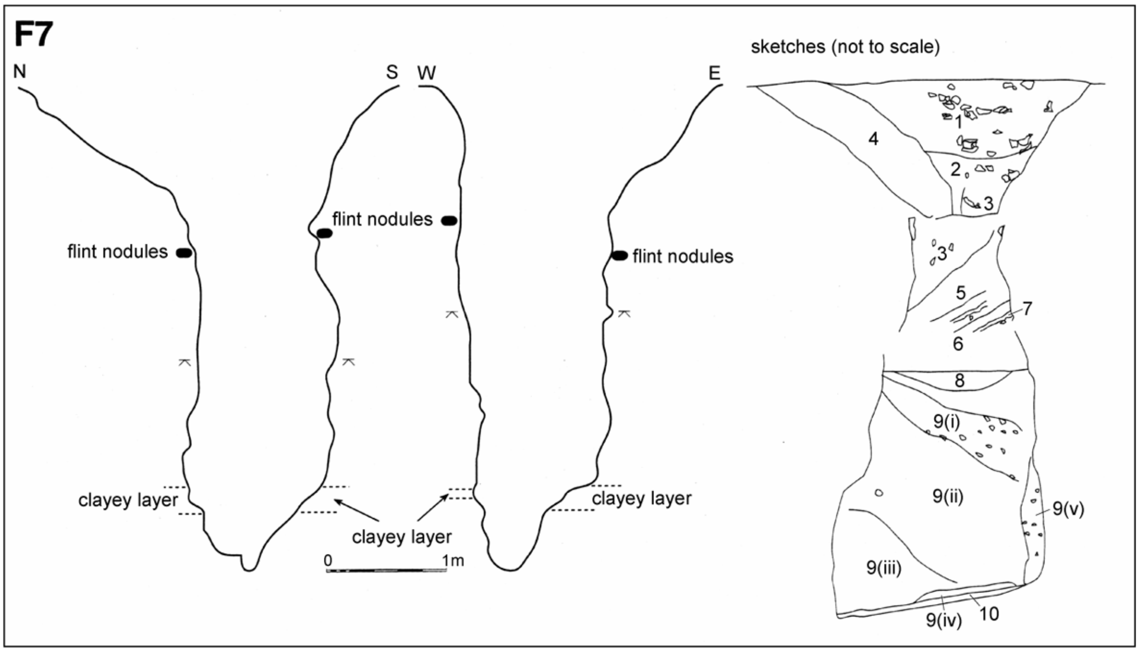


Figure 48: Profile and a montage of three separate sketch sections of F7 in cutting 950/820 (Longworth et al *2012, fig 34). © British Museum*

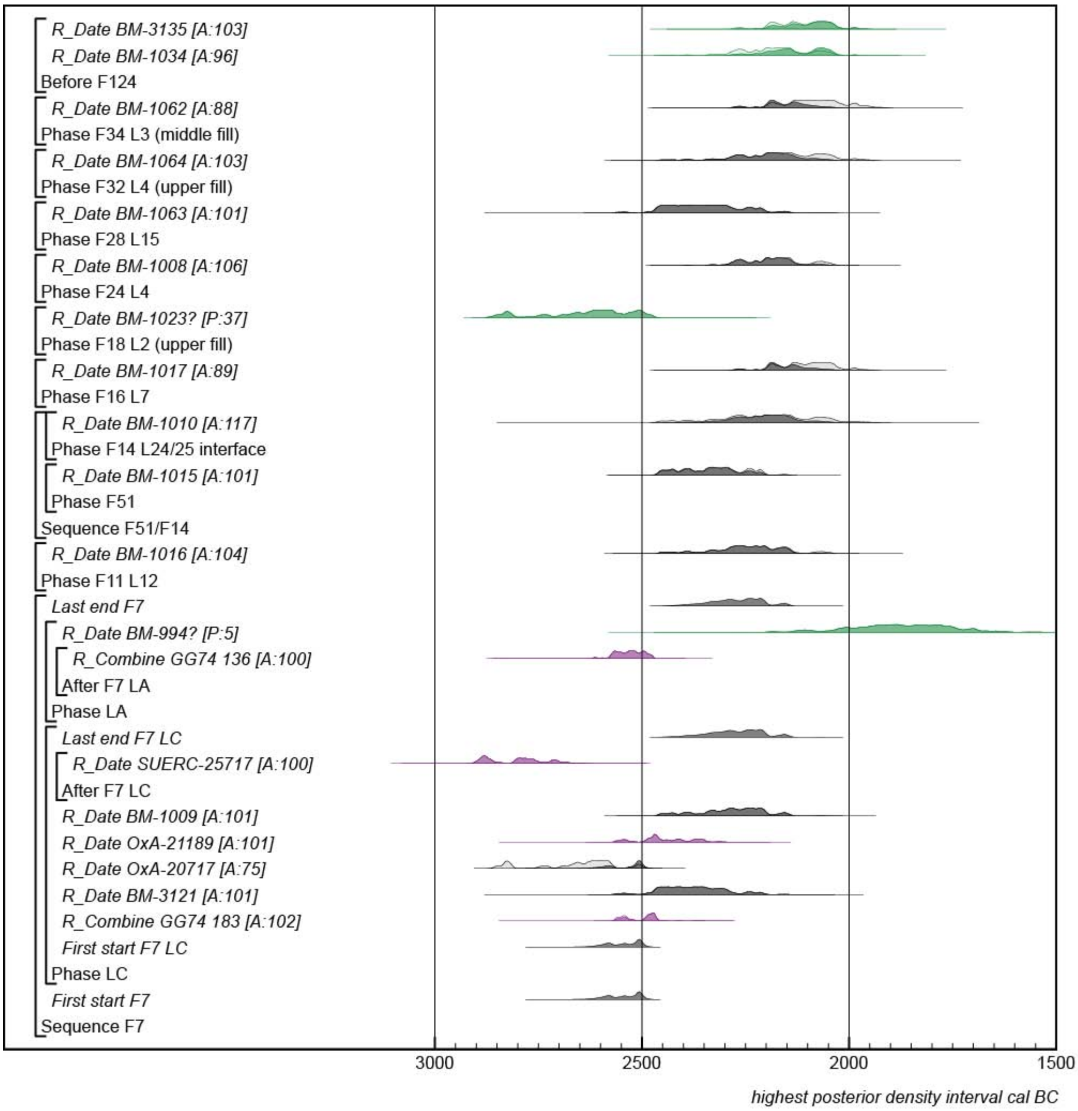


Figure 49: Radiocarbon dates from extraction pits, including F7, in the West Field (Table 17). Part of the model the structure of which is shown in Figure 45. The format is identical to that of Figure 17. Dates measured on antler samples are shown in black, unless the samples have been treated with polyvinyl acetate (PVA), in which case they are shown in purple; dates measured on bulk charcoal samples are shown in green

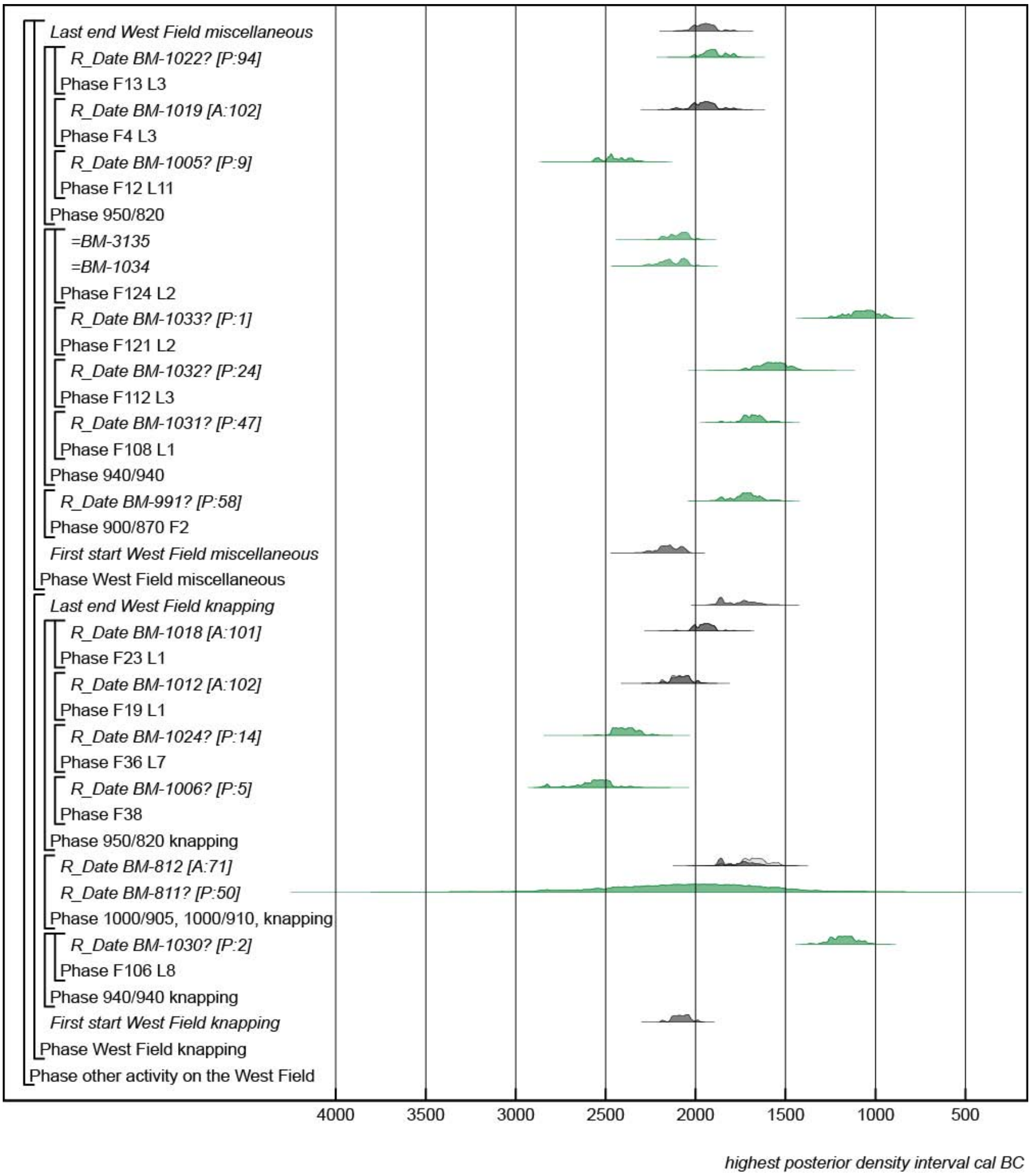


Figure 50: Radiocarbon dates from contexts on the West Field not necessarily associated with mining (Table 18). Part of the model the structure of which is shown in Figure 45. The format is identical to that of Figure 17. Dates measured on antler samples are shown in black; dates measured on bulk charcoal samples are shown in green

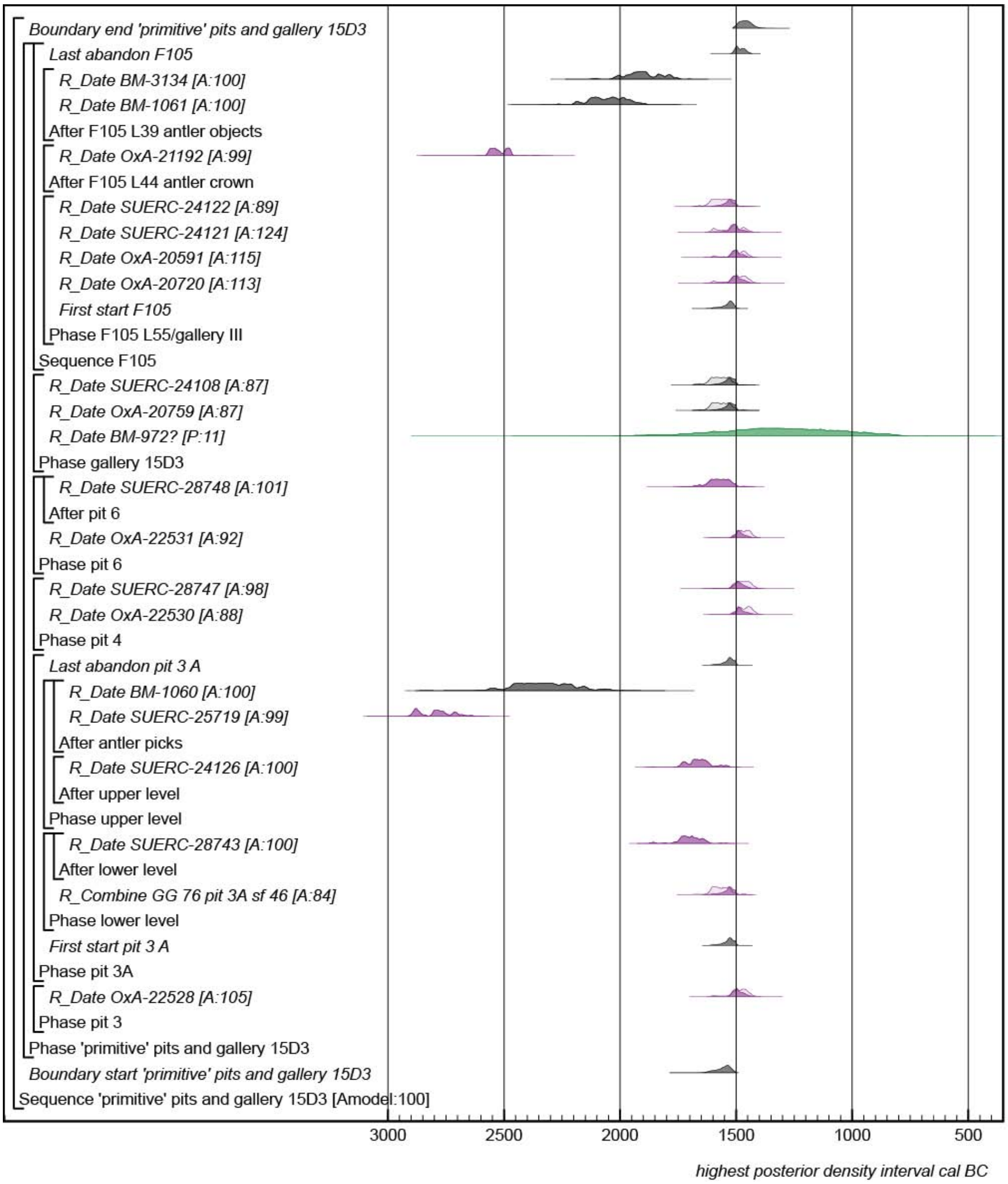


Figure 51: Radiocarbon dates from 'primitive' pits and gallery 15D3 (Table 19). Dates measured on antler or bone samples are shown in black, unless the samples have been treated with polyvinyl acetate (PVA), in which case they are shown in purple; dates measured on bulk charcoal samples are shown in green. The format is identical to that of Figure 17

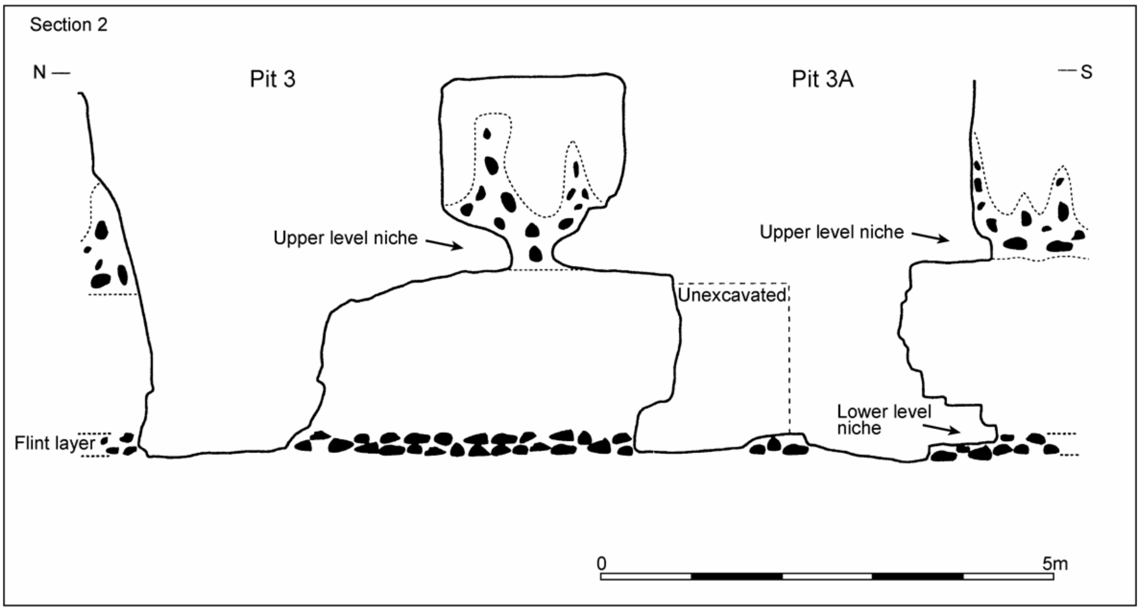


Figure 52: Profiles of 'primitive' pits 3 and 3 A, showing two tiers of niches, the first bottoming on the surface of the in situ *chalk, the second at floorstone level (Longworth and Varndell 1996, fig 32 (part). © British Museum*

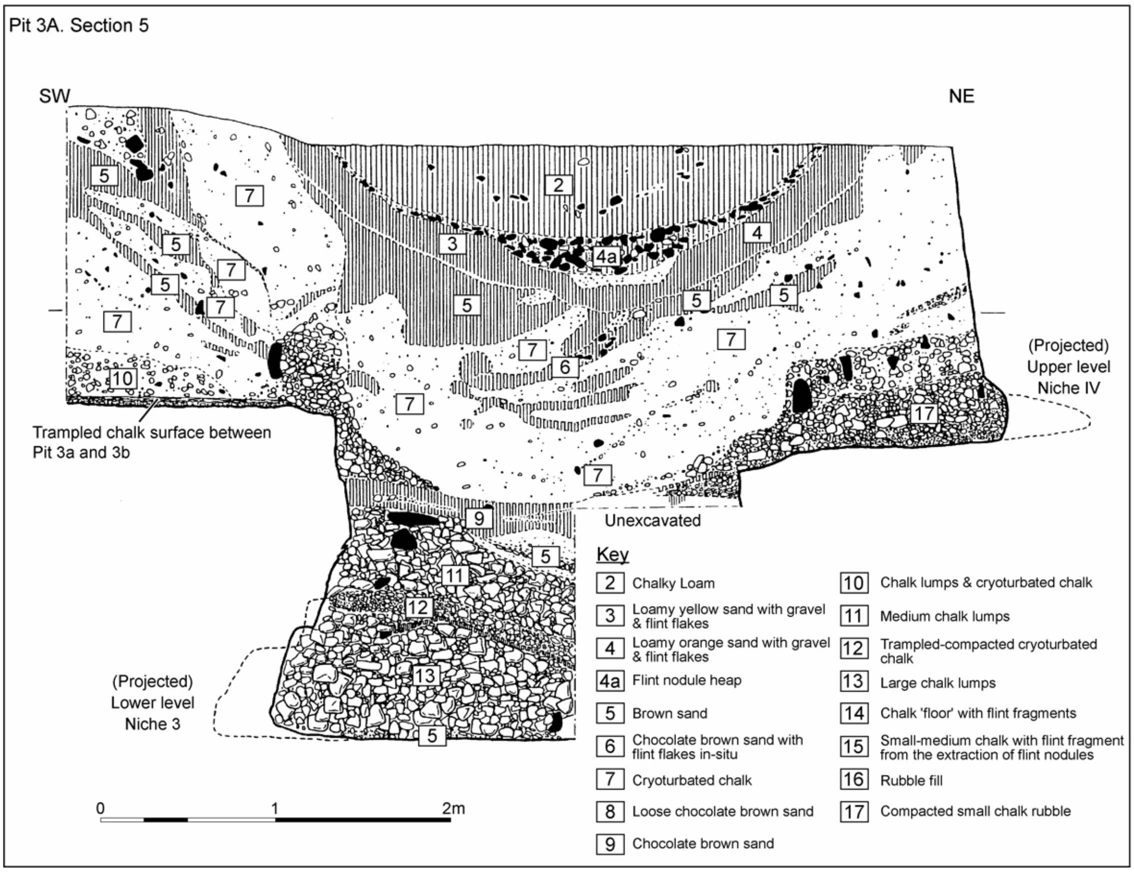


Figure 53: Section through pit 3A, showing 'gangway' linking it to unexcavated pit 3B (Longworth and Varndell 1996, fig 36). © British Museum

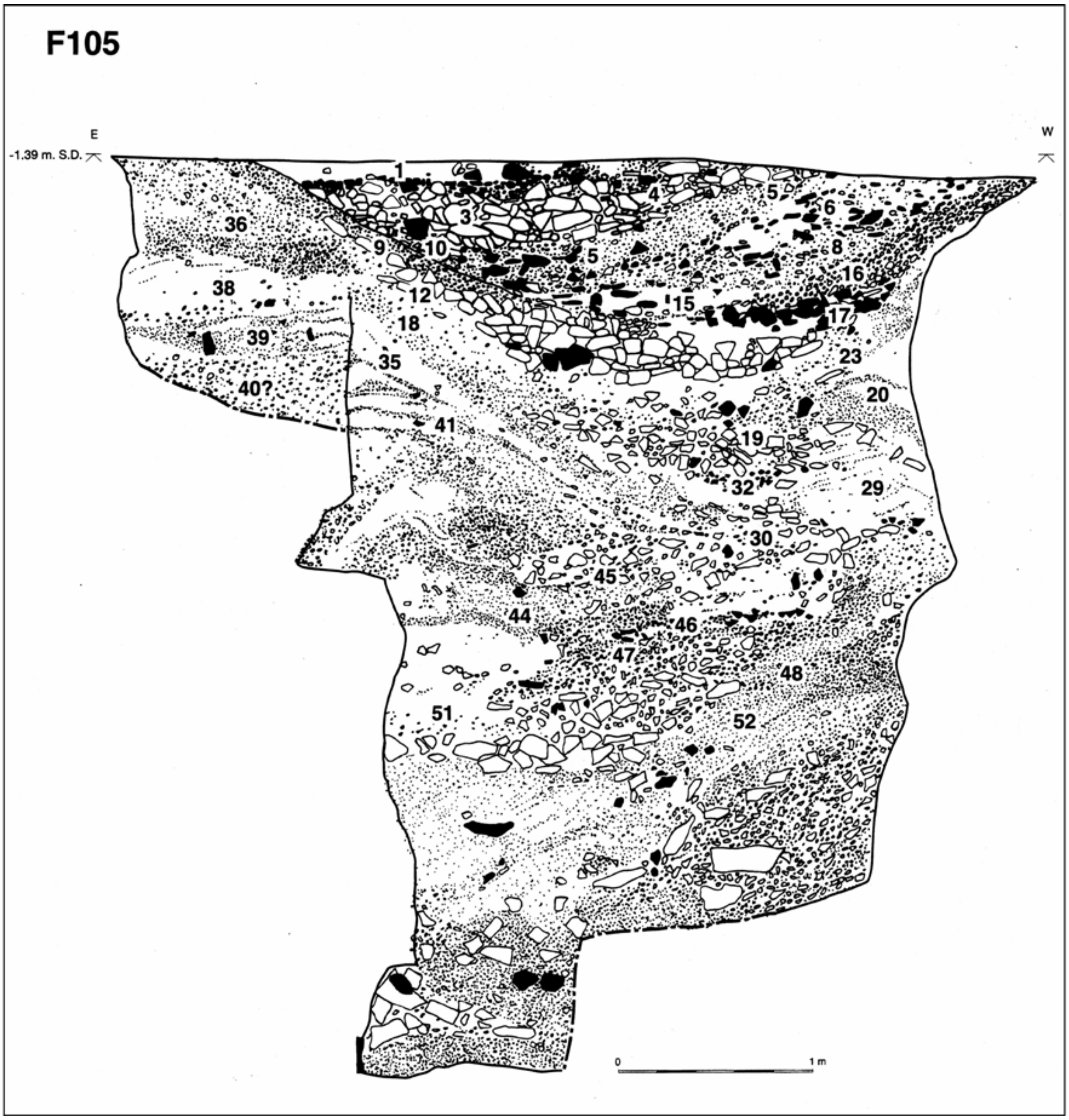


Figure 54: Section through F105 (Longworth et al *2012, fig 58). © British Museum*

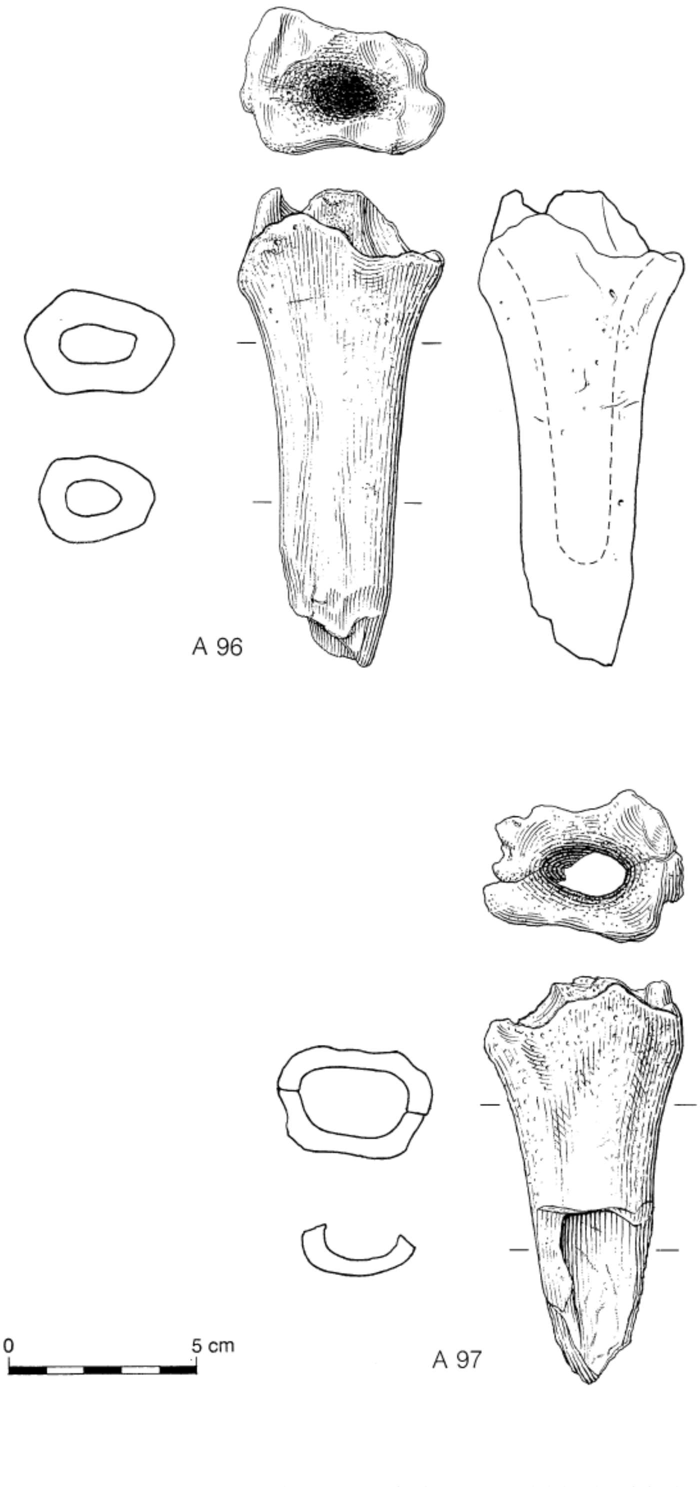


Figure 55: Bone picks from pit 3 (Legge 1992, fig 33 (part)). The upper example (A 96) is dated by OxA-22528 (Fig 51). © British Museum

Figure 56: The top of the 1972 pit, showing intercalated dark midden deposits and soil layers. © Roger Mercer

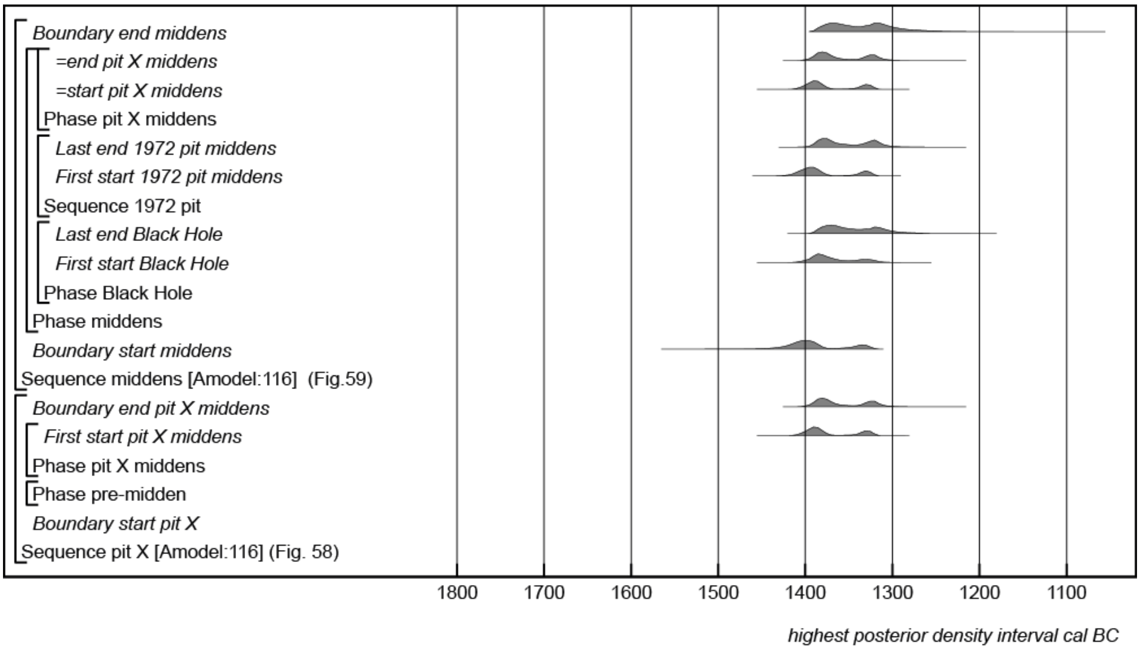


Figure 57: Overall structure of a model for midden deposits

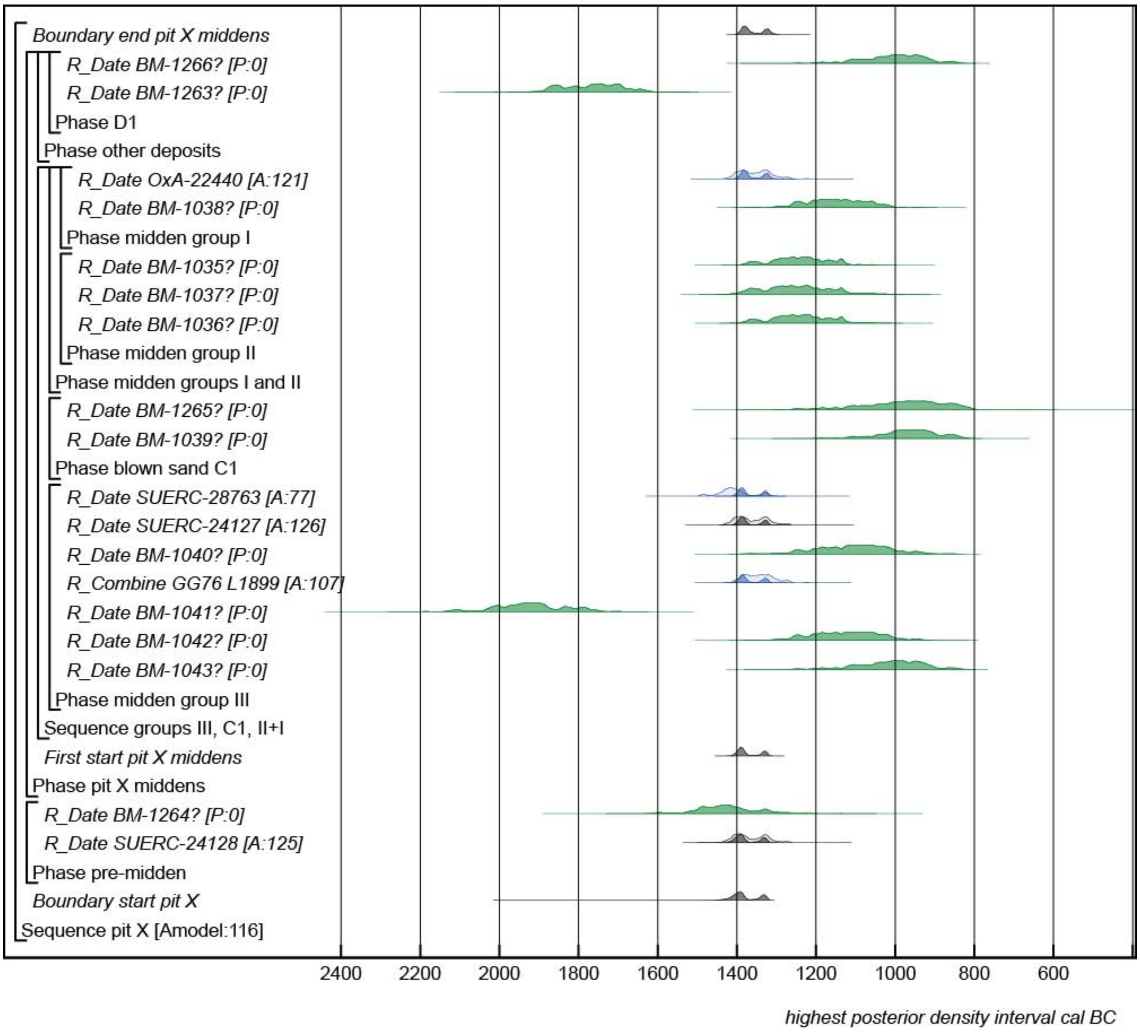


Figure 58: Radiocarbon dates from middle Bronze Age midden deposits and underlying layers in the top of pit X (Table 20). Part of the model the structure of which is shown in Figure 56. The format is identical to that of Figure 17. Dates measured on animal bone samples are shown in black; dates measured on carbonised residue are shown in blue; dates measured on bulk charcoal samples are shown in green

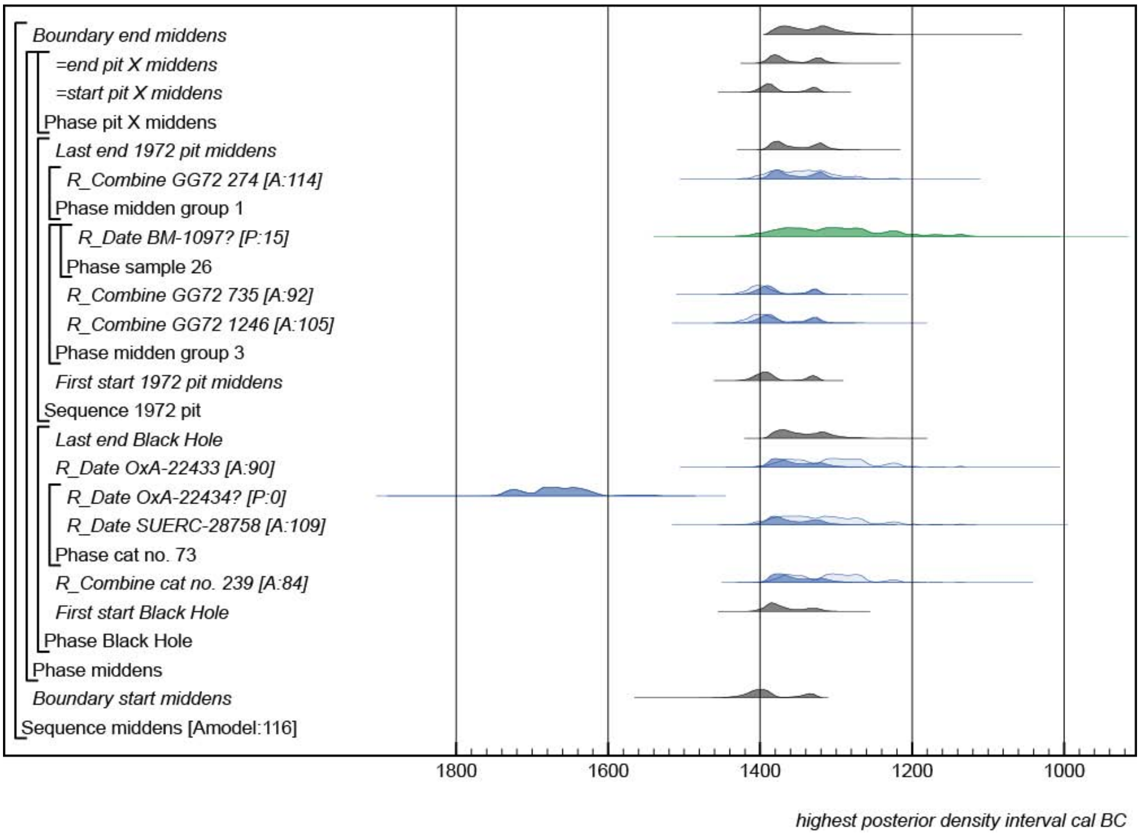


Figure 59: Radiocarbon dates from middle Bronze Age midden deposits in Armstrong's 'Black Hole' and in the top of the 1972 pit (Table 20), with start and end dates for the pit X middens cross-referenced from the part of the model shown in Figure 57. The format is identical to that of Figure 17. Dates measured on carbonised residue are shown in blue; dates measured on bulk charcoal samples are shown in green

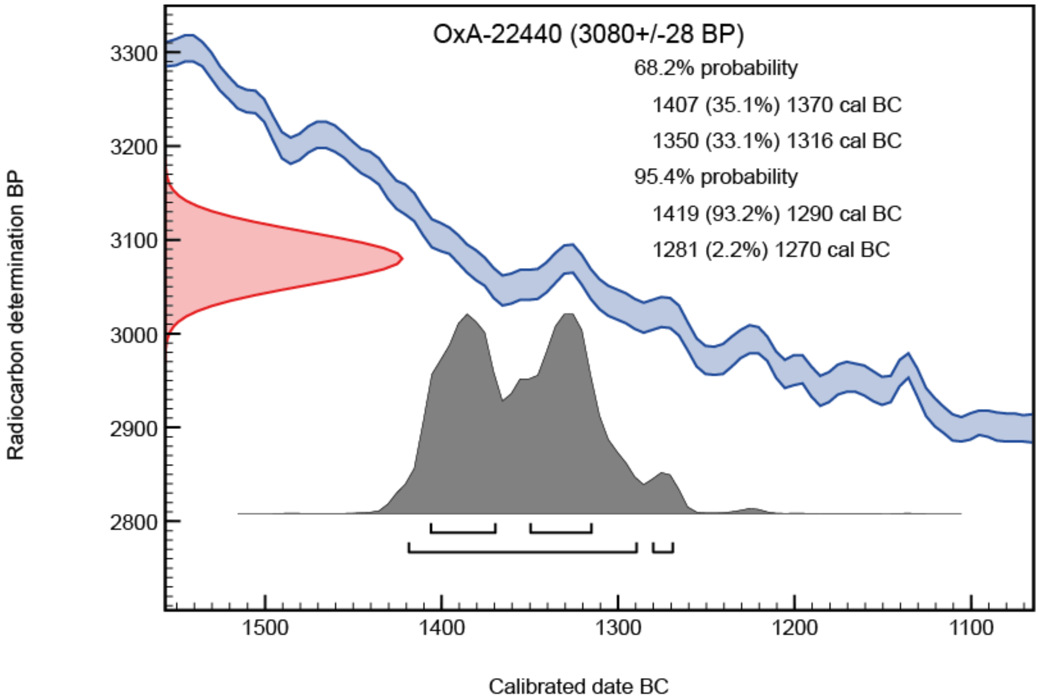


Figure 60: A radiocarbon measurement of 3080±28 BP plotted on the calibration curve, showing how the shape of the curve in the fourteenth century cal BC expands the calibrated age range (probability method) and in this case makes it bimodal

Figure 61: The upper fills of the 1971 pit under excavation. © Roger Mercer

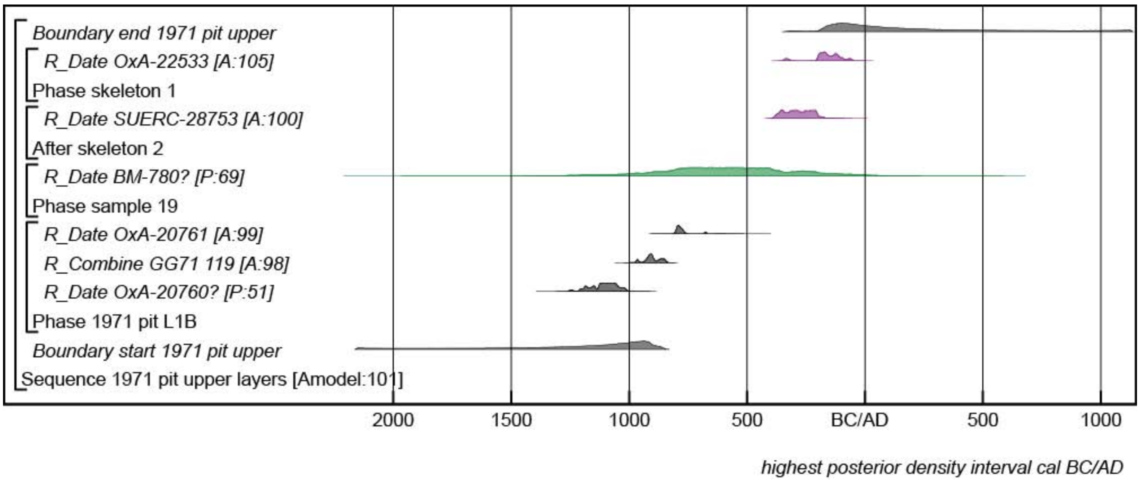


Figure 62: Radiocarbon dates from the upper levels of the 1971 pit (Table 21). The format is identical to that of Figure 17. Dates measured on human or animal bone samples are shown in black, unless the samples have been treated with polyvinyl acetate (PVA), in which case they are shown in purple; dates measured on bulk charcoal samples are shown in green

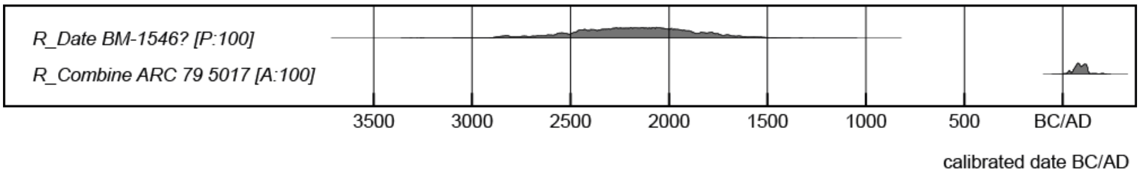


Figure 63: Radiocarbon dates for the horse skull from trench 3 (Table 21)

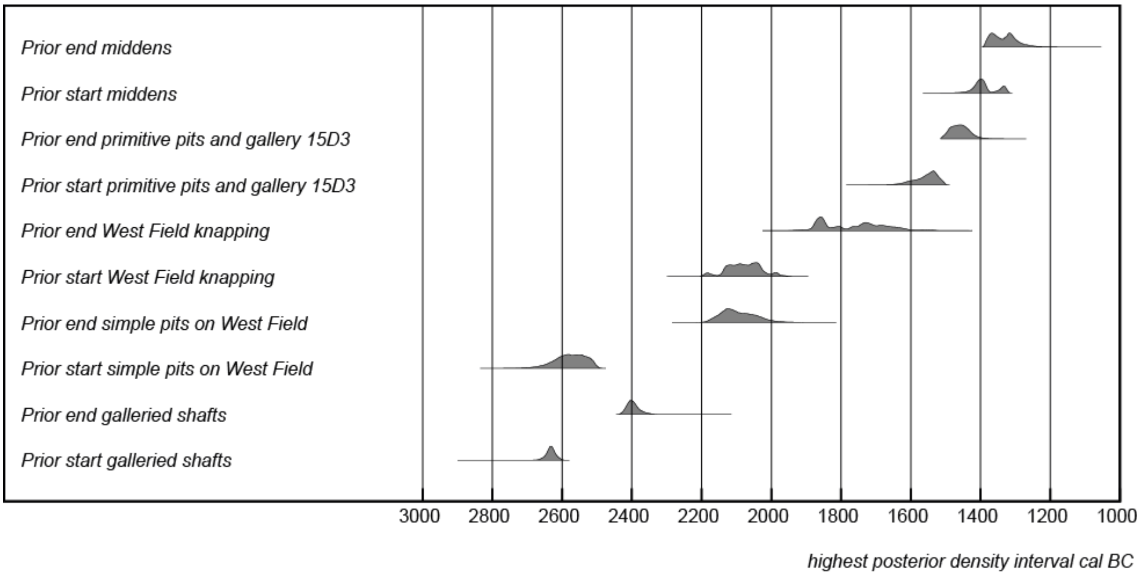


Figure 64: Start and end dates for major episodes, derived from the models shown in Figures 15, 45, 51, and 56 (Tables 23, 24)

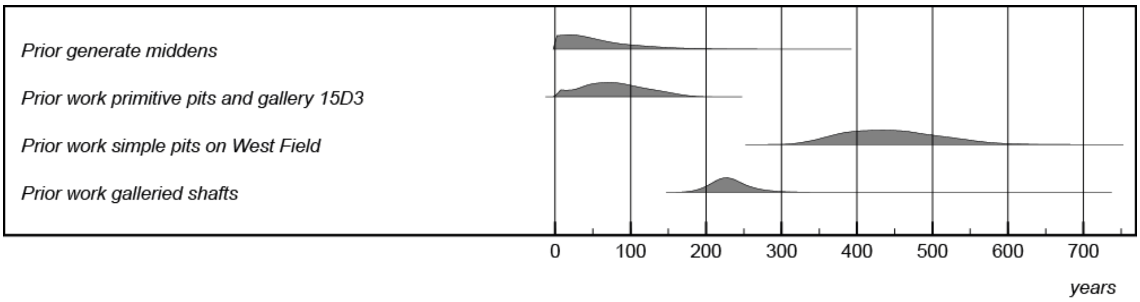


Figure 65: Durations of some of the major episodes summarised in Figure 64, derived from the models shown in Figures 15, 45, 51, and 57 (Table 23)

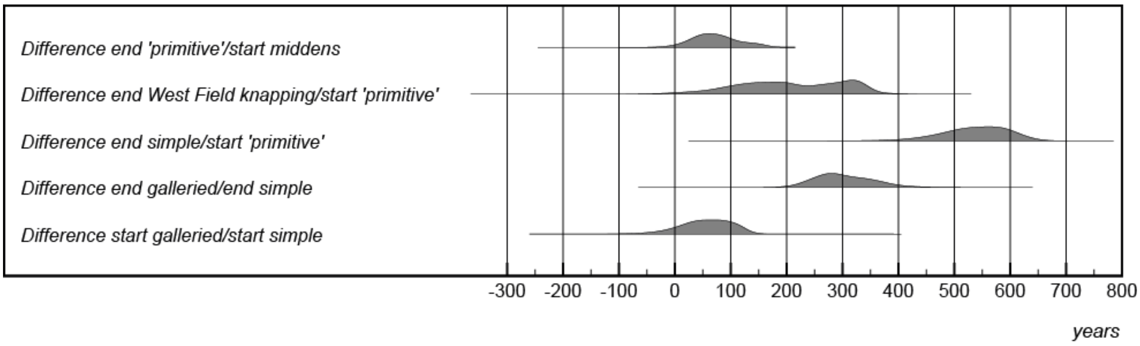


Figure 66: Intervals between some of the major episodes summarised in Figure 64, derived from the models shown in Figures 15, 45, 51, and 56 (Table 23)

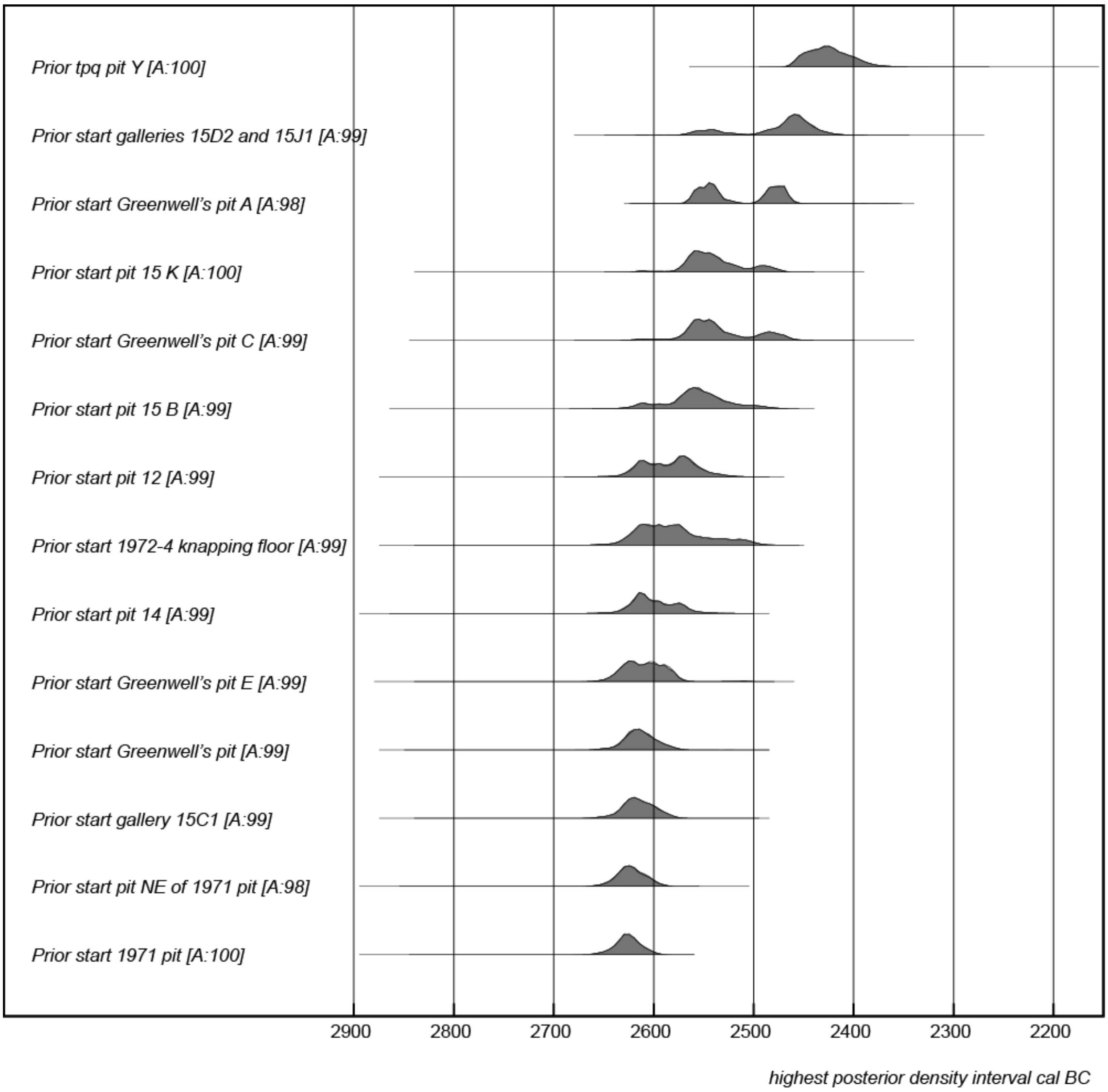


Figure 67: Dates for the initial working of those galleried pits for which individual estimates have been made derived from the model shown in Figure 15 (Tables 25–6)

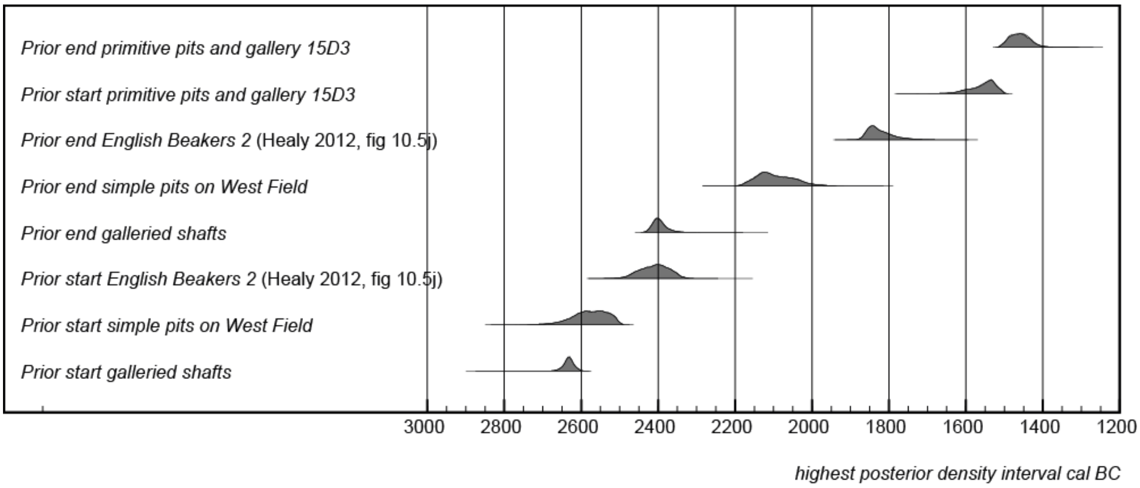


Figure 68: Estimated start and end dates for selected episodes (Tables 23, 27, and 28), derived from the models shown in Figures 15, 45, and 51, together with estimates for the start and end of the currency of Beaker pottery in England of 2490–2340 cal BC *and* 1880–1740 *(*95% probability*; Healy 2012, fig. 10.5j, table 10.2)*

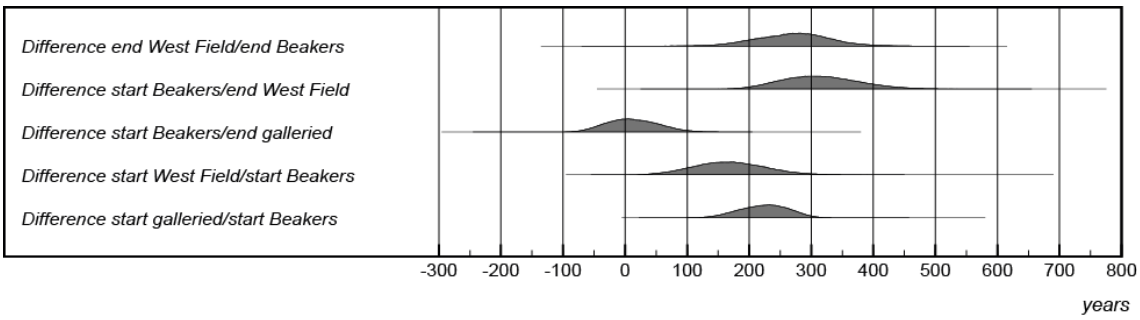


Figure 69: Intervals between some of the episodes shown in Figure 67 (Table 27)

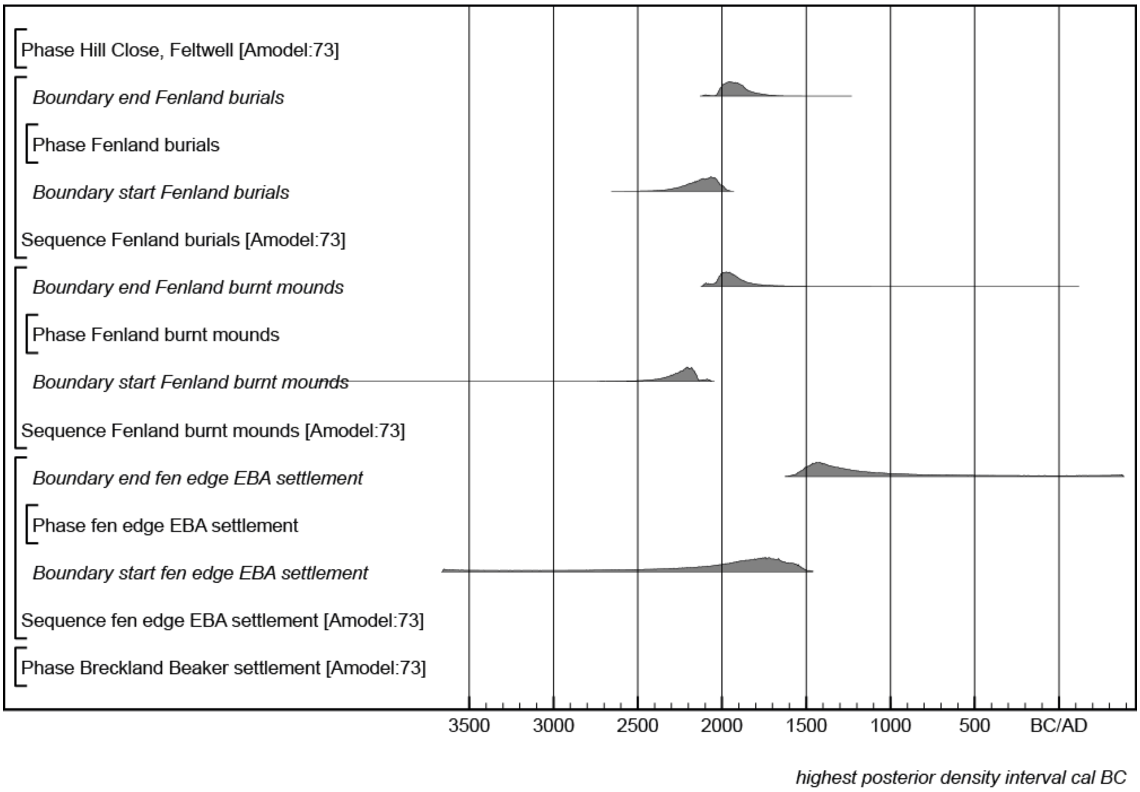


Figure 70: The overall structure of a model for radiocarbon dates for local settlement and other activity

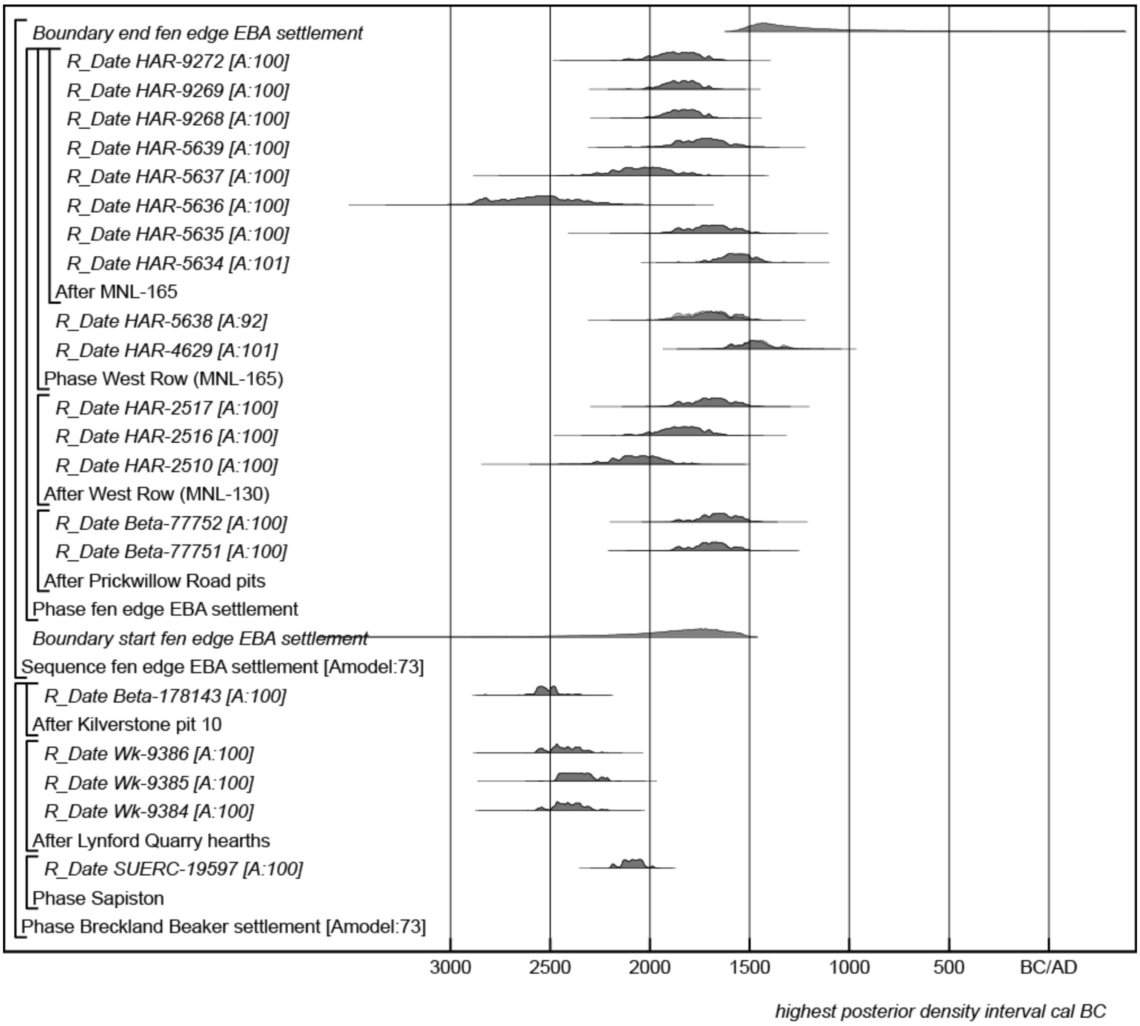


Figure 71: Available radiocarbon dates for later third and for second millennium local settlement. Part of the model the structure of which is shown in Figure 70

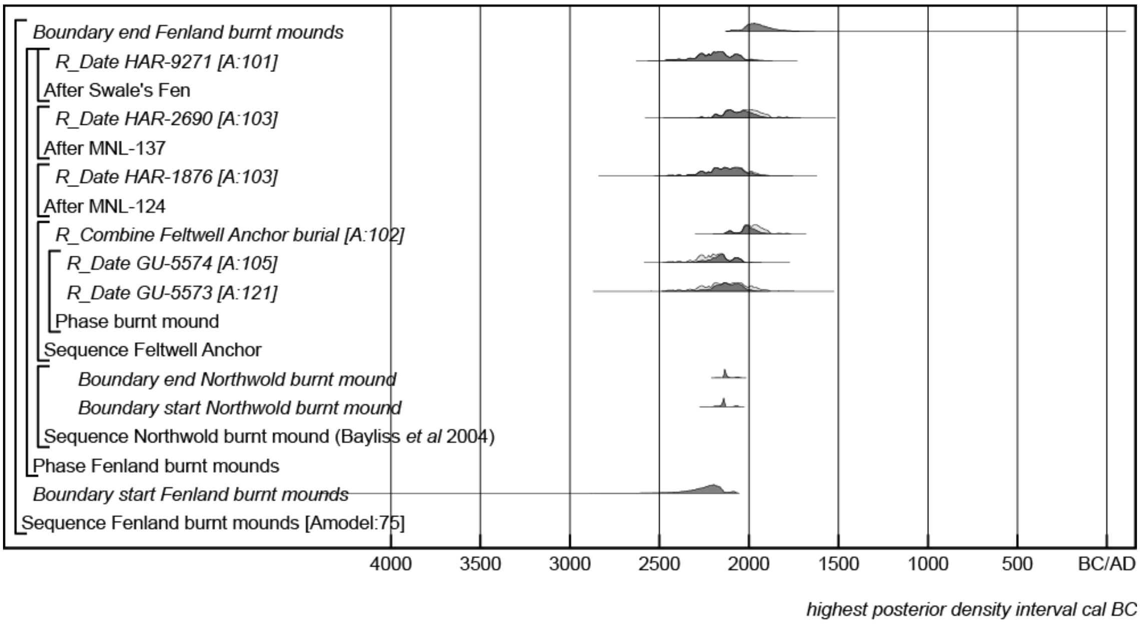


Figure 72: Available radiocarbon dates for local burnt mounds. Part of the model the structure of which is shown in Figure 70

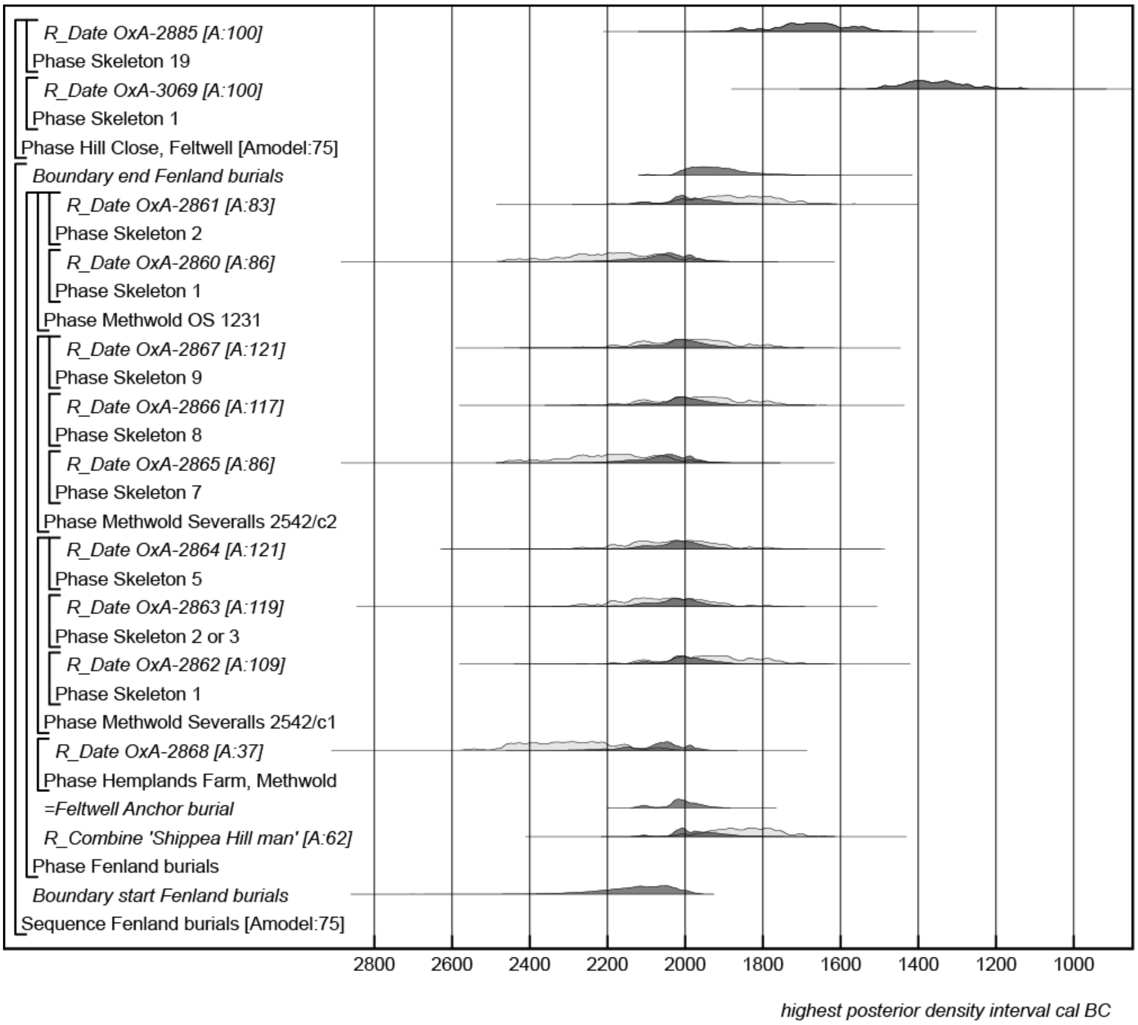


Figure 73: Available radiocarbon dates for inhumation burials in the south-eastern Fens. Part of the model the structure of which is shown in Figure 70

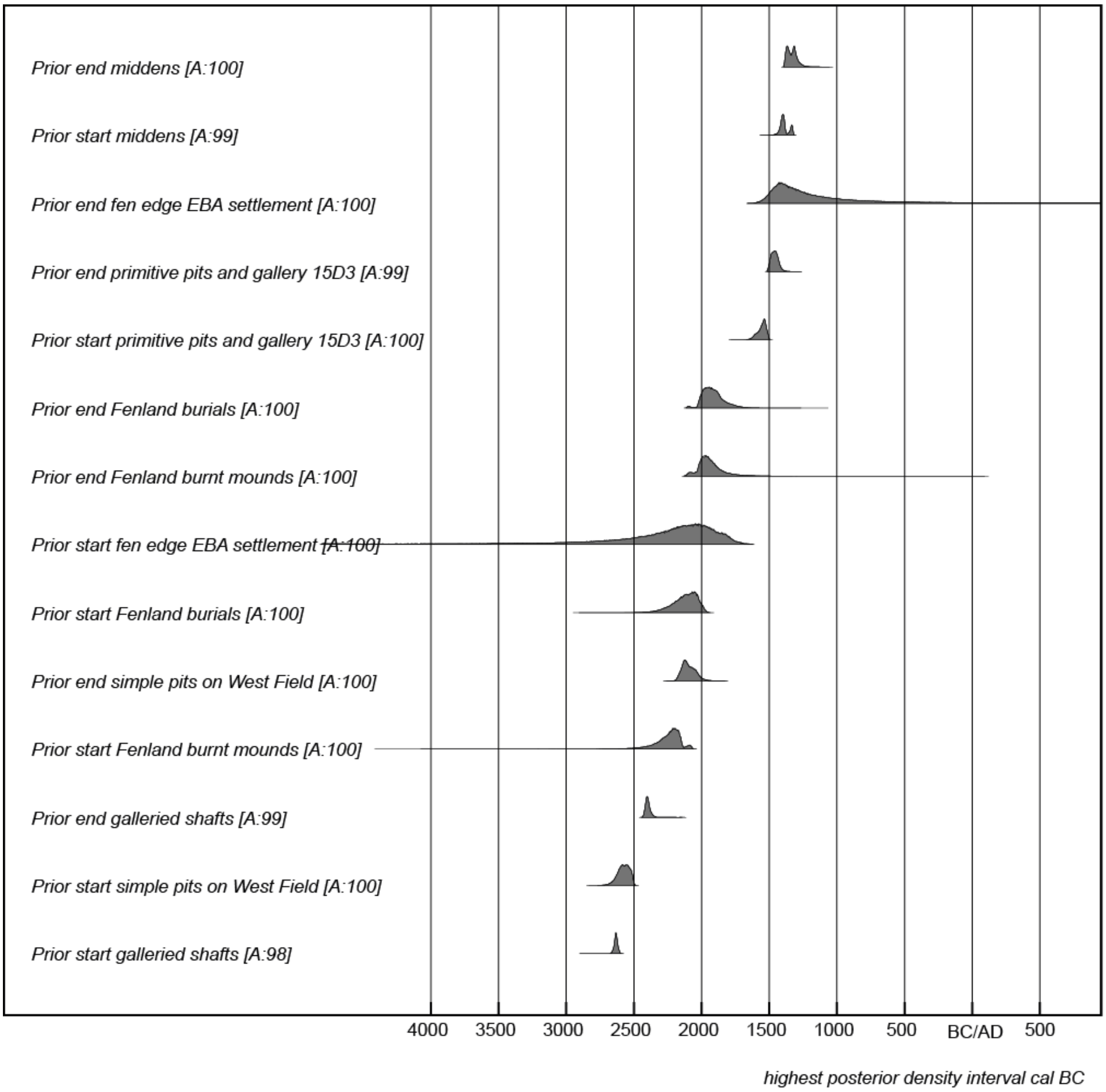


Figure 74: A summary of the results of the models shown in Figures 15, 45, 51, and 70

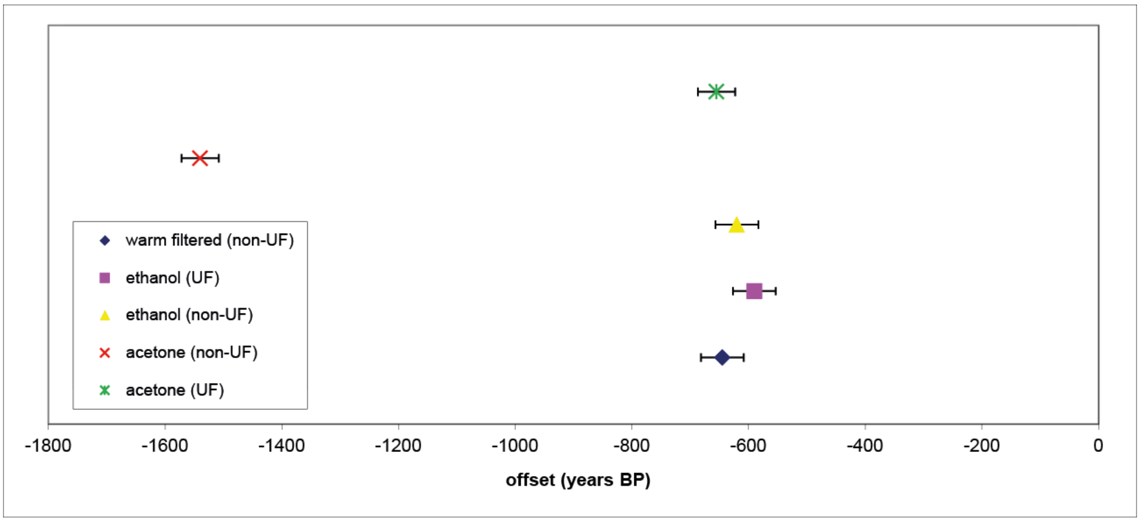


Figure 75: Offsets in radiocarbon years BP from the known age of the samples of radiocarbon dates measured on bone treated with PVA then subjected to the pretreatments listed in the key. An extreme offset of −6340±37 years for a cold-filtered sample is not shown

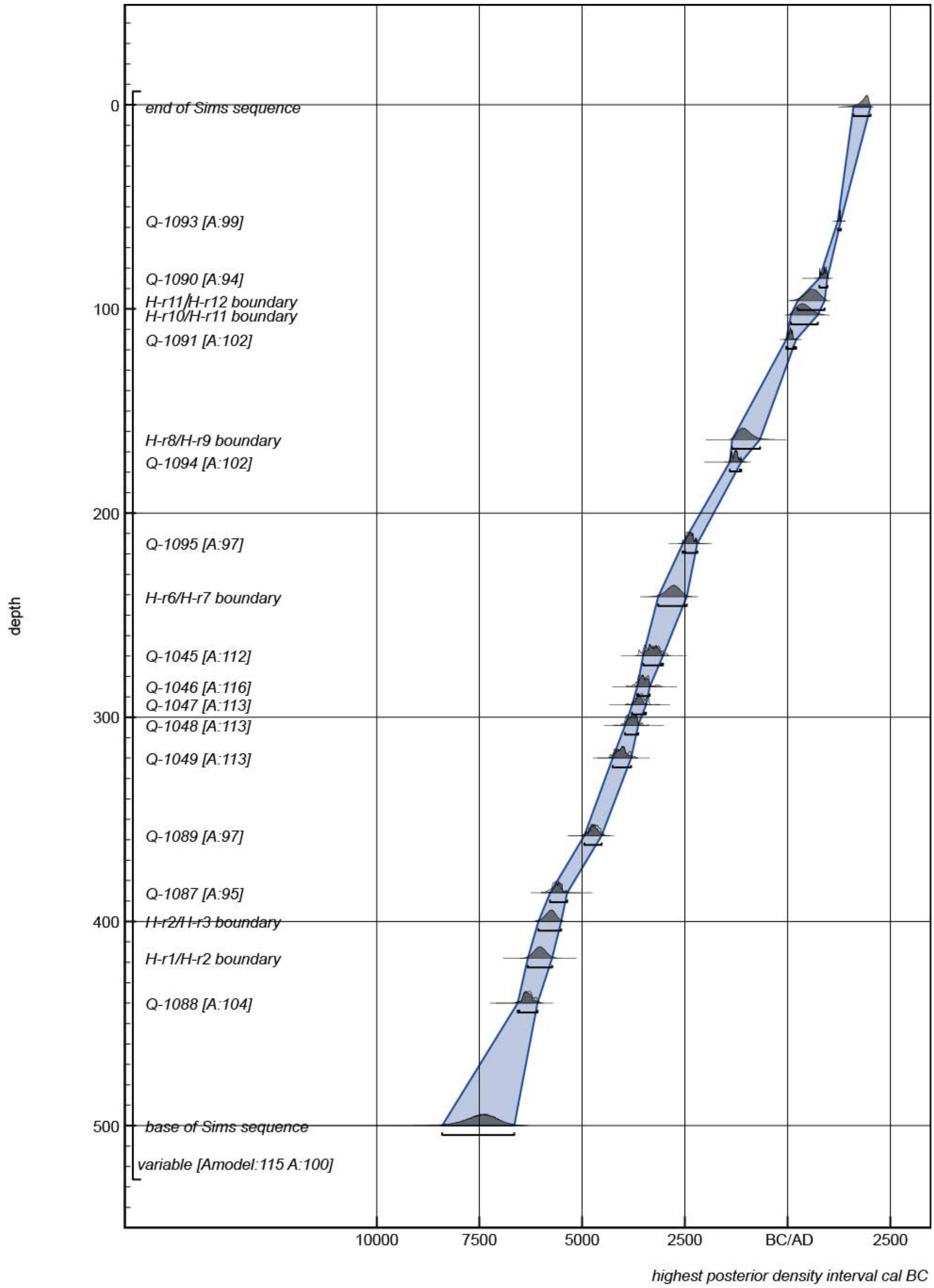


Figure 76: Bayesian age-depth model of the chronology of the Hockham Mere pollen sequence analysed by Sims (P_Sequence model (k=0.01–100); Bronk Ramsey 2008). The coloured band shows the estimated date of the sediment at the corresponding depth at 95% probability

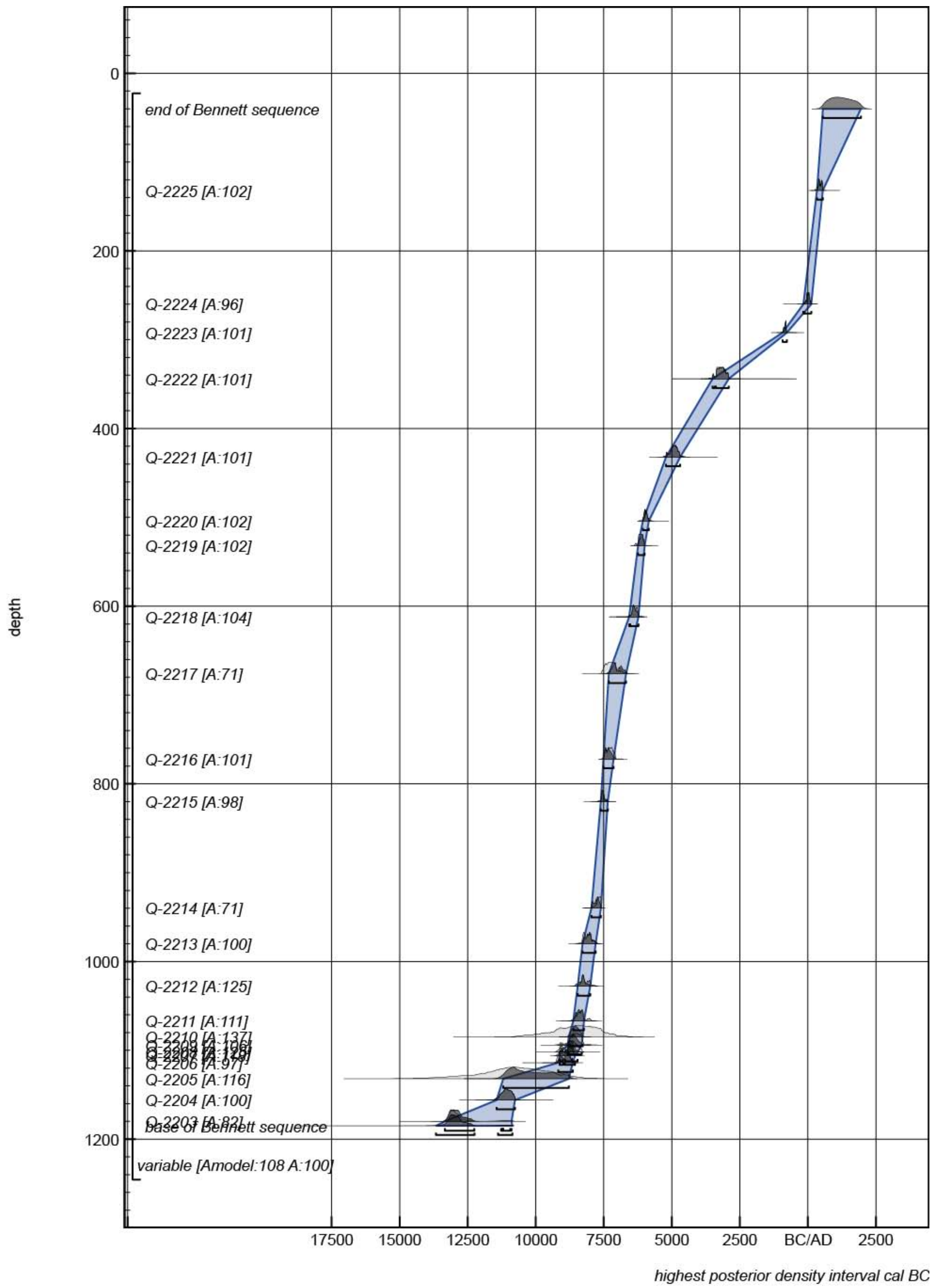


Figure 77: Bayesian age-depth model of the chronology of the Hockham Mere pollen sequence analysed by Bennett (P_Sequence model (k=0.01–100); Bronk Ramsey 2008). The coloured band shows the estimated date of the sediment at the corresponding depth at 95% probability

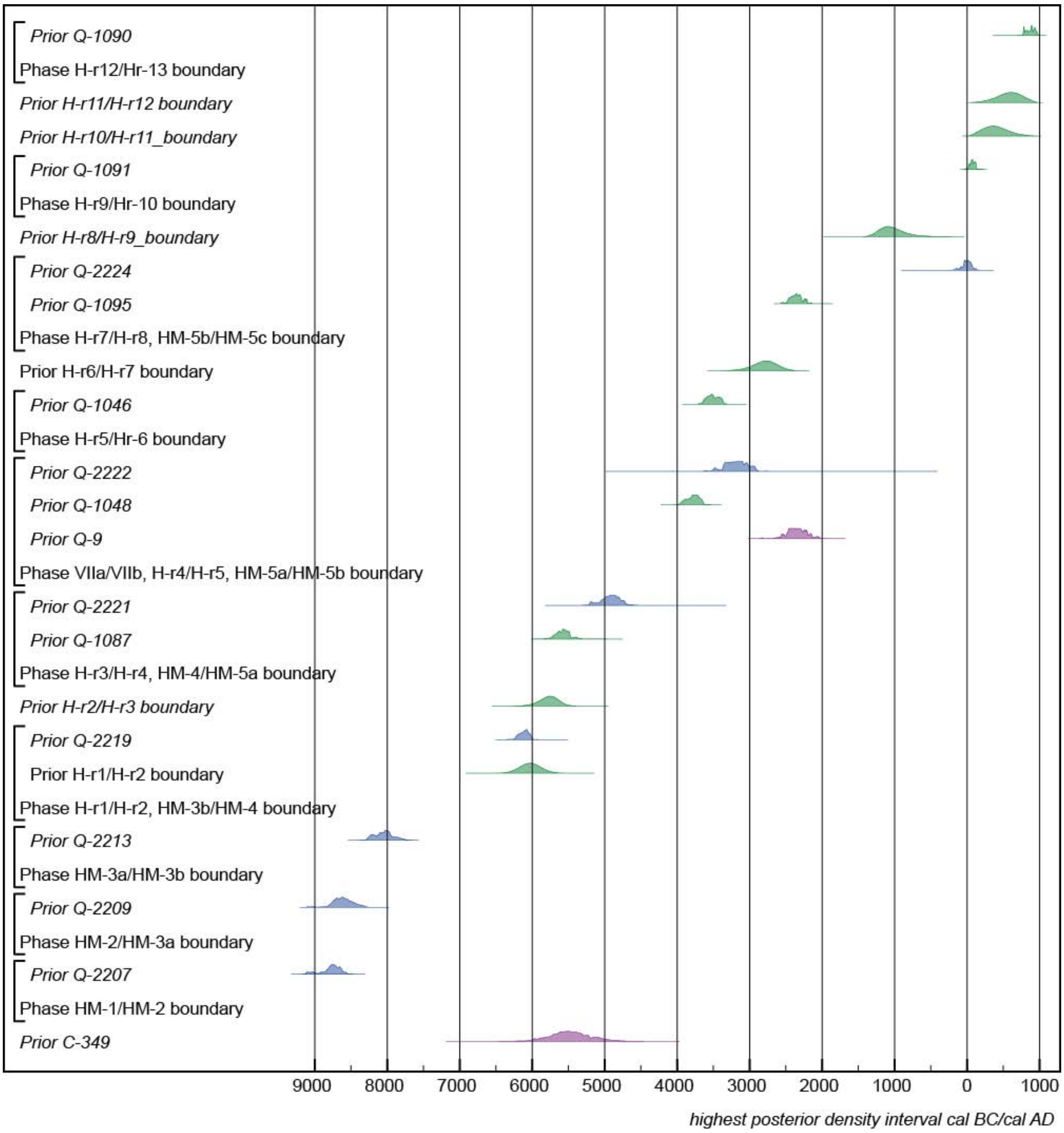


Figure 78: Summary of radiocarbon results from Hockham Mere. The two dates obtained in the 1950s are shown in purple. Results from the Sims model shown in Figure 76 are shown in green. Results from the Bennett model shown in Figure 77 are shown in blue

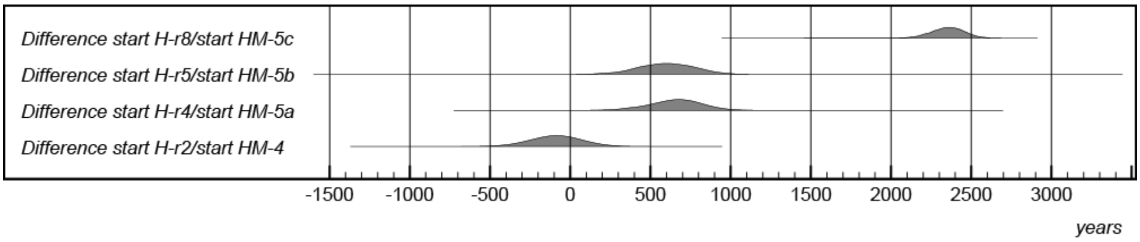
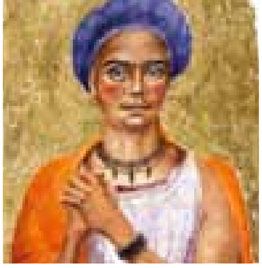
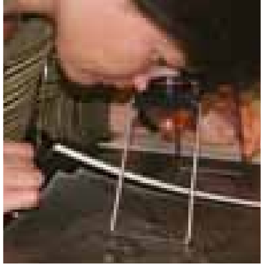


Figure 79: Intervals between estimated start dates for equivalent pollen zones in the sequences of Sims and Bennet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