G Model
PGEOLA 812 No. of Pages 17

ARTICLE IN PRESS

Proceedings of the Geologists' Association xxx (2019) xxx–xxx

Contents lists available at ScienceDirect

Proceedings of the Geologists Association

journal homepage: www.elsevier.com/locate/pgeola

# Pleistocene landscape evolution in the Avon valley, southern Britain: Optical dating of terrace formation and Palaeolithic archaeology

Ella Egberts[a,*], Laura S. Basell[b], Kate Welham[a], Antony G. Brown[c], Phillip S. Toms[d]

[a] Faculty of Science and Technology, Bournemouth University, Talbot Campus, Fern Barrow, Poole BH12 5BB, United Kingdom
[b] School of Archaeology and Ancient History, University of Leicester, University Road, Leicester, LE1 7RH, United Kingdom
[c] Palaeoenvironmental Laboratory University of Southampton (PLUS), Geography and Environment, University of Southampton, Highfields Campus, Southampton SO17 1BJ, United Kingdom
[d] Luminescence Dating Laboratory, School of Natural and Social Sciences, University of Gloucestershire, Swindon Road, Cheltenham GL50 4AZ, United Kingdom

ARTICLE INFO

*Article history:*
Received 8 August 2019
Received in revised form 3 February 2020
Accepted 5 February 2020
Available online xxx

*Keywords:*
Pleistocene
Palaeogeography
Europe
River terraces
Optical methods
Palaeolithic
Landscape evolution
Hominin behaviour

ABSTRACT

This paper presents the first comprehensive Optically Stimulated Luminescence dating programme from a sequence of Pleistocene river terraces in the Avon valley (Wiltshire-Hampshire-Dorset), southern Britain. These results offer the most complete chronometric framework for Pleistocene landscape evolution and Palaeolithic occupation in the Avon valley, allowing for the first time: (1) an assessment of the timing of terrace formation and landscape evolution, (2) the dating of hominin presence in the area, and (3) an investigation of the relationship between terrace formation and Quaternary climatic change. Analysis of 25 samples collected from terraces 10 and 7 to 4 show that the middle Avon terraces formed in response to the main Pleistocene climatic oscillations (Marine Isotope Stages (MIS) 10, 8, 6) and that fluvial mechanisms changed through time, resulting in three different types of terrace architecture. The highest and oldest deposits are compound terraces deposited during the Early Pleistocene before the Mid Pleistocene Transition. The middle reach of the valley is characterised by well-developed strath terraces overlain with thick fluvial deposits, reflecting the greater degree of incision in response to the increased amplitude of climate cycles in the Middle Pleistocene. The youngest deposits in the confined modern floodplain represent cut-and-fill terraces deposited after MIS5e. The results indicate that the two main Palaeolithic sites in the area, Milford Hill and Woodgreen, date to between at least MIS 10 and 8 with a pre-MIS 10 human occupation at a third main site at Bemerton. This is significant because the sites date to a period previously associated with a decline in hominin presence in Britain. The dating of the Avon valley terrace sequence highlights the complex nature of terrace formation during the Pleistocene and the need to critically reassess the chronological understanding of these fluvial archives in southern Britain. This research demonstrates that with a detailed and multidisciplinary approach shifts in hominin landscape use can be discovered, providing new information on hominin behavioural change during the Pleistocene.


## 1. Introduction

In the Avon valley, southern Britain, 14 aggradational terraces, recognised and mapped by the British Geological Survey (BGS, 1991, 2004, 2005), represent past cyclic changes in fluvial system dynamics related to climate oscillations and uplift throughout the Quaternary (Blum and Törnqvist, 2000; Bridgland and Westaway, 2008a,b). The Avon is part of the ancient Solent River System (Fig. 1), the largest fluvial system draining southern Britain and the Channel Region during the Pleistocene (Allen and Gibbard, 1993; Antoine et al., 2003a). The terraces of the Avon are unusually well preserved and laterally extensive, especially across the Palaeogene deposits of the New Forest which extend to the sea.

As the principal northern tributary of the Solent system, the Avon valley provides a corridor reaching over 80 km inland from the present shoreline. It dissects the northern terraces of the Solent, which has hampered correlation between the western and eastern terrace sequences of the Solent (Briant et al., 2012b). Correlation, dating, and integration of the Avon and Solent fluvial deposits is essential for understanding the geomorphological history of the region, which preserves the richest Palaeolithic record of Britain (Wymer, 1999). The ages of these river terraces

* Corresponding author.
*E-mail address:* ella.egberts@bournemouth.ac.uk (E. Egberts).

https://doi.org/10.1016/j.pgeola.2020.02.002

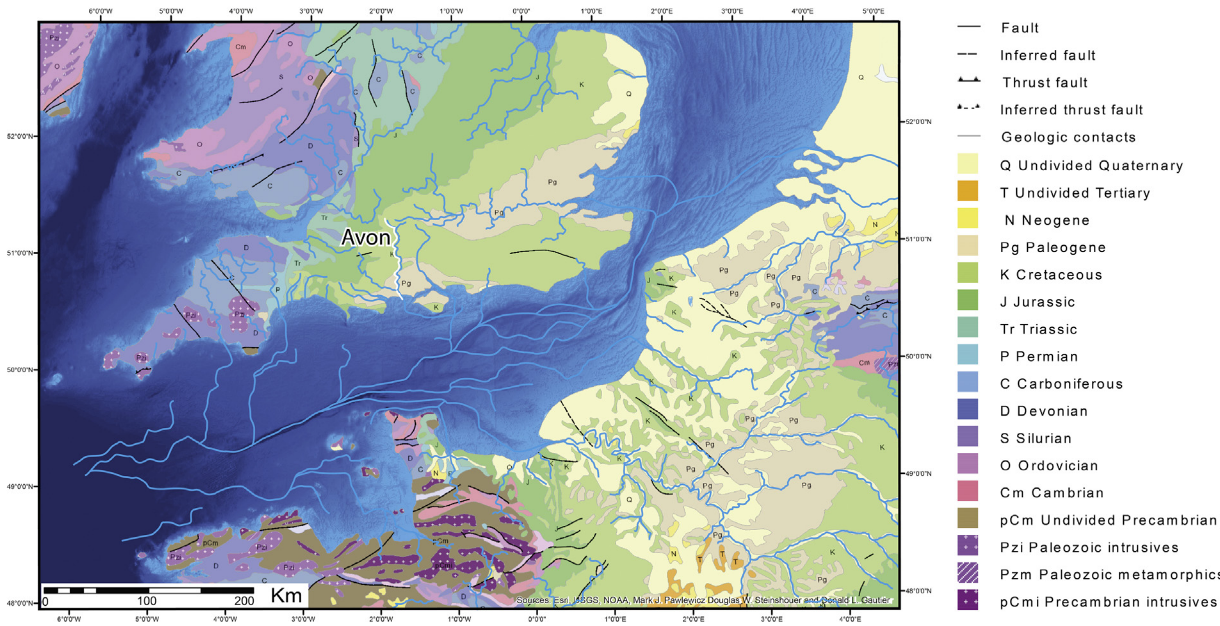


**Fig. 1.** Map showing the bedrock geology and Pleistocene rivers of southern Britain and northwest Europe (Sources: Esri, USGS, NOAA, M. J. Pawlewicz, D.W. Steinhouer and D. L. Gautier. Bathymethric data: GEBCO_2014 Grid, version 20141103, http://www.gebco.net) (Data in the map were modelled by LB in ArcGIS 10.5 under licence to Queen's University Belfast).

and their formation has been of interest to Quaternary researchers for over 150 years (Blackmore, 1864, 1865, 1867; Bristow et al., 1991; Clarke, 1981; Clarke and Green, 1987; Green, 1946; Kubala, 1980; Reid, 1898, 1902, 1903; Sealy, 1955; Westlake, 1889, 1902). Recently they have been the subject of several studies investigating the relationship between river terrace formation and climate change (*e.g.*, Bridgland, 2000); regional uplift (*e.g.*, Westaway et al., 2006); and the nature and age of the Palaeolithic record derived from the fluvial terrace deposits in the Solent region (Ashton and Hosfield, 2010; Davis, 2013; Wessex Archaeology, 1993). However, the Avon valley terrace sequence remained poorly dated and integrated. The principal aims of this study were dating the fluvial deposits to reconstruct Pleistocene landscape evolution and providing a chrono-stratigraphic framework for the Palaeolithic archaeology.

Establishing the age of river terraces in southern England has in the past been approached by means of relative dating based on terrace correlations (Briant et al., 2012a) and regional uplift rates (Maddy et al., 2000; Westaway et al., 2006). The rarity of fossiliferous deposits in the Solent river terraces precludes biostratigraphic dating, and chronometric dating is restricted to inorganic methods which have focussed primarily on optically stimulated luminescence (OSL) from sedimentary quartz (Briant et al., 2006, 2009).

In this research we use quartz OSL to date fluvial sediments from a sequence of five 'differentiated terraces' (terrace 10 and 7 to 4 (T10, T7-T4)) and one 'undifferentiated terrace' (UT) deposit to establish the timing of terrace formation and landscape evolution in the Avon valley alongside detailed and site specific stratigraphic information of the Pleistocene terraces in the area.

### *1.1. Geological and geographical setting*

The study area is located in the Hampshire Basin, a Palaeogene structural depression in southern Britain (Edwards and Freshney, 1987; Hopson et al., 2006). The bedrock geology comprises Late Cretaceous chalk, forming the higher contours of the basin, in-filled with unconsolidated Palaeogene sediments (Barton et al., 2003; Hopson et al., 2006, 2007) (Fig. 1). The River Avon flows north to south through the Hampshire Basin, rising in the Vale of Pewsey and draining into the English Channel at Christchurch and is located south of the maximal extent of the Pleistocene glaciations (Clark et al., 2004). Fluvial incision has resulted in a steep-sided valley on the chalk substrate in the Avon's northern reaches around Salisbury. The softer Palaeogene bedrock south of Downton allowed the floodplain to widen. Here staircase terraces developed which are unusually well-preserved. These comprise six draped 'Older River Gravels' (numbered O5, O4b, O4a-O1, T10) and nine main terraces (T9 to T1) which, like the 'Older River Gravels', decrease in age with terrace number (Kubala, 1980; Clarke, 1981; Allen and Gibbard, 1993; Clarke and Green, 1987). Downstream towards the confluence with the Solent a different numbering system is used in which fourteen terraces are recognised (Bristow et al., 1991). The highest terraces (O5-O1), up to 100 m above the modern Avon River, spread a maximum of 12 km wide either side of the current day river axis. The lower terraces in the Avon catchment are 6 to 3 km wide and are found alongside and below the present day river (BGS 1991, 2004, 2005) (Fig. 2).

### *1.2. Previous work*

The Quaternary deposits of the Avon have generated interest for decades partly due to the rich Palaeolithic record they contain, particularly at Woodgreen. Geological research over the last 150 years has resulted in a variety of terrace schemes (Blackmore, 1864, 1865, 1867; Bristow et al., 1991; Clarke, 1981; Clarke and Green, 1987; Green, 1946; Kubala, 1980; Reid, 1898, 1902, 1903; Sealy, 1955; Westlake, 1889, 1902) (Table 1). The current terrace numbering as used on BGS maps is presented in Table 2 and based on the work of Kubala (1980); Clarke (1981) and Bristow et al. (1991) for the Fordingbridge area, the area north of Bournemouth and the Bournemouth area respectively.

The highest gravel deposits in the Avon valley, found on the Avon-Test interfluve, are the oldest Pleistocene fluvial deposits in the catchment. They represent the early confluence zone between the Avon and Solent River and probably date to the Pliocene or early Pleistocene (Allen and Gibbard, 1993; Westaway et al., 2006) (Fig. 2). Further evidence for the timing of terrace formation in the

Please cite this article in press as: E. Egberts, et al., Pleistocene landscape evolution in the Avon valley, southern Britain: Optical dating of terrace formation and Palaeolithic archaeology, Proc. Geol. Assoc. (2020), https://doi.org/10.1016/j.pgeola.2020.02.002

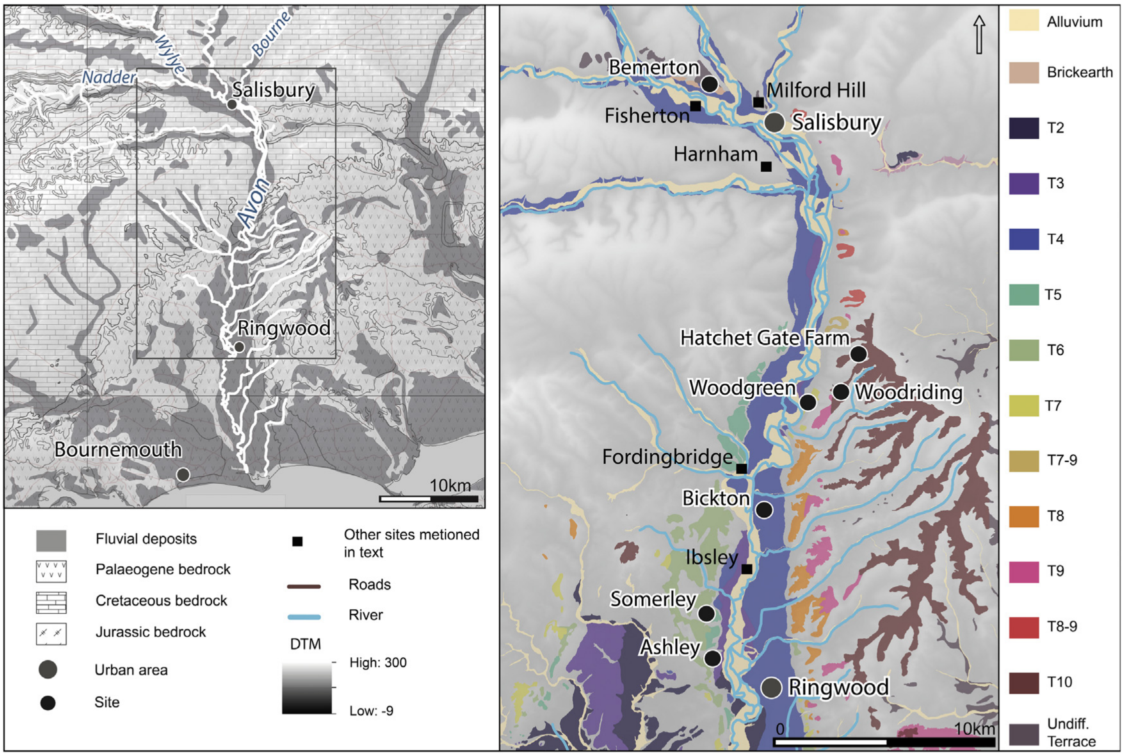


**Fig. 2.** Map showing the Avon valley and distribution of the field sites, in relation to superficial fluvial deposits and bedrock, draped over a DTM derivation 2.5 of the area based upon 1:625000 scale geology data, with permission of the British Geological Survey and 1:10000 scale OS VectorMap Local [shape files water line; main roads], Digimap Licence.

Avon valley is limited and currently based on fossiliferous sediments in the altitudinally-lowest terraces, tentative correlations with dated terrace deposits elsewhere in the Solent system, and the use of Palaeolithic artefacts from the terrace deposits as 'index fossils' (Barber and Brown, 1987; Bates et al., 2014; Delair and Shackley, 1978; Westaway et al., 2006; White et al., 2018).

Fossiliferous deposits are known from three localities in the Avon valley; Fisherton, Iblsey and Harnham. The Fisherton brickearths are located northwest of Salisbury in the Nadder valley and overly T4 deposits. The brickearth contains a rich fossil assemblage that has been related to the end of Marine Isotope Stage (MIS) 5 (Delair and Shackley, 1978) or early middle Devensian (MIS 4-3) (Green et al., 1983) (marine oxygen isotope stages discussed in this paper are based on the boundaries as defined in the LR04 stack (Lisiecki and Raymo, 2005)). Secondly, at Ibsley peat from beneath T3 has been dated to the Ipswichian IIb (MIS 5e) based on its pollen spectra which is dominated by herbaceous plants of temperate affinity (Barber and Brown, 1987; Allen et al., 1996). More recently, at Harnham, just down-stream of Salisbury, Palaeolithic artefacts and faunal material were found preserved beneath a solifluction deposit (Bates et al., 2014). The researchers recognised four depositional phases. The small faunal assemblage associated with phase II and IV indicates a pre-Ipswichian/post-Hoxnian date for sediment deposition. Quartz OSL dating of phase

**Table 1**
Overview of historic terrace schemes in the Avon Valley. O= 'Older river gravels' and T = Terrrace. The BGS scheme is added to aid comparison with the currently used schemes (Clarke, 1981; Green, 1946; Reid, 1902; Sealy, 1955; Westlake, 1889).

| HISTORIC TERRACE SCHEMES | | | | | BGS SCHEME |
|---|---|---|---|---|---|
| Westlake, 1889 | | Reid, 1902 | Green, 1946 | Sealy, 1995 | Clarke, 1981 |
| 175 ft Terrace | ? | High Plateau/Higher terraces | | Higher surfaces | O5 |
| | | | | | O4 a + b |
| | | | | | O3 |
| | | | | | O2 |
| | | | | | O1 |
| | | | Upper Ambersham | VIII | T10 |
| | | | Ambersham | VII | T9 |
| 150 ft Terrace | – | Eolith Terrace | Sleight Terrace | VI | T8 |
| 100 ft Terrace | – | Palaeolithic Terrace | Boyn Hill | V | T7 |
| 50 ft Terrace | – | | Upper Taplow | IV | T6 |
| | | | 1st Lower Taplow | III | T5 |
| | | Valley Gravels | 2nd Lower Taplow | II | T4 |
| | | | Mustcliff Terrace | I | |
| | | | Christchurch Terrace | | |
| | | | | | T3 |
| | | | | | T2 |
| | | | | | T1 |

**Table 2**
Overview of different terrace schemes currently used for the Avon valley and their correlations as proposed in Hopson et al. (2007); Barton et al. (2003) and based on current BGS maps (2004; 1991). O = 'Older river gravel's, T = terrace.

| BGS TERRACE SCHEMES IN THE AVON VALLEY | | | | | |
|---|---|---|---|---|---|
| Middle Valley | | | | Lower Valley | |
| Fordingbridge (Kubala, 1980) | BGS map 2004 | | North of Bournemouth (Clarke, 1981) | BGS map 1991 | Bournemouth (Bristow et al., 1991) |
| O5 | T10 | | O5 | | |
| O 4 a + b | | | O4 a + b | | |
| O3 | | | O3 | | |
| O2 | | | O2 | | |
| O1 | | | O1 | | |
| T10 | T9-T10 | | T10 | T14 | T14 |
| | | | T9 | T10-T13 | T10-T13 |
| T8-T9 | T9 | | T8 | T9 | T9 |
| | T8 | T8 | T7 | | |
| T7 | T7 | | | | |
| T6 | T5 | | T6 | T8 | T8 |
| T5 | T3-T4 | | T5 | | T7 |
| T4 | | T1-T4 | T4 | | T6 |
| T3 | | | T3 | T5 | T5 |
| T2 | | | T2 | | T1-T4 |
| T1 | | | T1 | | |

II deposits and amino acid racemisation on two *Bithynia tentaculata* opercula from the same sediments, suggest a MIS 8 or early MIS 7 date for sediment deposition (Bates et al., 2014). Relating this gravel deposit with certainty to the numbered terrace scheme is challenging but based on comparable height above the floodplain Bates et al. (2014) tentatively suggest that the Harnham deposits could be correlated with undifferentiated terrace deposits upstream, located at Milford Hill (Fig. 2).

### 1.3. Proposed relative chronologies

The chronology of the Avon terraces has previously been based on correlations with dated terrace deposits elsewhere in the Solent River system and the use of Palaeolithic technologies as 'index fossils' (Westaway et al., 2006). The main aims have been to date the Palaeolithic record and model terrace formation and regional uplift. For example, a comparison of the rich Palaeolithic deposits in the Avon valley with the better dated terraces in the Thames, led Maddy et al. (2000) to suggest a late Middle Pleistocene age for the Avon Palaeolithic record associated with T7. Similarly the chronological framework for the Avon valley proposed by Westaway et al. (2006) was based on the assumed age for the first appearance of Levallois technology and *bout-coupé* bifaces. This has subsequently been used to integrate the Avon 'super sites' (associated with T7 and UT deposits) into the wider pattern of the British Palaeolithic (Ashton and Hosfield, 2010; Hosfield, 2011). Hosfield (2011) used the chronology given by Westaway et al. (2006) to propose an MIS 13 date for the first arrival of hominins in the Avon valley based on a limited number of artefacts found in T8, and the association of T8 with MIS 13b. In this chronology of the Avon Palaeolithic record, the large concentration of artefacts from Bemerton (UT), Milford Hill (UT) and Woodgreen (T7) were related to the "peak" in biface densities seen in the rest of Britain (Ashton and Hosfield, 2010).

## 2. Materials and methods

Site selection was focussed on altitudinally separated terrace deposits preserving sand layers interbedded in the gravels, and the location of known Palaeolithic sites. This resulted in the selection of six sites: two exposures in T10 (at Woodriding and Hatchet Gate Farm), and one in T7 (Woodgreen), T6 (Somerley), T5 (Ashley Pit) and T4 (Bickton). The dating of loess overlying an UT deposit at a seventh location, Bemerton, provides a minimum age for this deposit (Fig. 2). All sections were recorded using traditional sedimentological logging techniques and photographic archive, Leica GS15 Viva differential global positioning system (DGPS) and terrestrial laser scanning (Leica C10 Scan Station).

All geospatial data were combined within ERSI ArcGIS version 10.1. The geomorphology of the Avon valley was analysed using LiDAR (New Forest National Park Authority, for the Hampshire region; Geomatics Group, Environment Agency 2013). The subsurface geology was modelled based on the digitisation of 1035 borehole records obtained through BGS GeoRecords+ (http://mapapps.bgs.ac.uk/GeoRecords/GeoRecords.html), and analysis in RockWorks 16. Methods and results of the extensive analysis of artefacts from the key Palaeolithic sites in the Avon valley (Bemerton, Milford Hilll and Woodgreen), which was carried out as part of this research, are discussed in a separate paper (Egberts et al., 2020) but overall support the arguments put forward here. Where present, fine-grained sediments with the potential for pollen preservation were samples for palynological analysis, following standard sampling and sample preparation methods. Identification of pollen and spores was assisted by the used of the identification key in Fægri and Iversen (1989) and reference to modern counterpart (Birks and Birks, 1980). The description of the textural, structural and lithological properties of the exposed stratigraphic sections followed guidelines discussed by Jones et al. (1999). OSL samples were taken following standard sample procedures (Duller, 2008). In this research we use quartz OSL to date fluvial sediments obtained from five terraces, at six different sites. Sample preparation was conducted under controlled laboratory illumination provided by Encapsulite RB-10 (red) filters. Depending on the grain size distribution of the sample, quartz within the silt (5–15 μm) or fine sand fraction (125–180 μm or 180–250 μm) was extracted using conventional luminescence sample preparation techniques; 10 % HCl carbonate digestion, 15 % $H_2O_2$ organic digestion, 2 weeks 35 % $H_2SiF_6$ (fine silt) or 60 min

40 % HF (fine sand) etching, density separation (fine sand). Grains were mounted on 12 aluminium discs as 10 mm, c. 1.5 mg (fine silt) or 8 mm, c. 4 mg (fine sand) multi-grain aliquots for acquisition of the equivalent dose ($D_e$). $D_e$ values were quantified from blue stimulated OSL using the Single-Aliquot Regenerative-Dose (SAR) protocol (Murray and Wintle, 2000; Murray and Wintle, 2003) within a Risø TL-DA-15 irradiation-stimulation-detection system (Botter-Jensen et al., 1999; Markey et al., 1997). Dose rate ($D_r$) values were assessed through in situ NaI gamma spectrometry for gamma dose and *ex situ* $G_e$ gamma spectrometry for alpha and beta dose. At Bemerton and Bickton, gamma dose was evaluated by *ex situ* gamma spectrometry. Estimates of radionuclide concentration were converted into $D_r$ values (Adamiec and Aitken, 1998), accounting for $D_r$ modulation forced by grain size (Mejdahl, 1979), moisture content (Zimmerman, 1971) and, where $D_e$ values were generated from fine silt quartz, reduced signal sensitivity to $\alpha$ radiation (a-value $0.050 \pm 0.002$). Cosmogenic $D_r$ values were calculated on the basis of sample depth, geographical position and matrix density (Prescott and Hutton, 1994). See research data for the laboratory procedures per sample.

## 3. Results

Site location and altitude, terrace number, depositional context and number of samples per site are given in Table 3. Figs. 3–8 present the OSL sample locations by site, while the results of sedimentological recording at each dated field site is described below and in appendix A.

### 3.1. Undifferentiated terrace (UT) at Bemerton (Fig. 3)

At Bemerton (E 412610 N 130945, SU 12610 30945) 1.9 m of thick, massively bedded sandy silt was found overlying undifferentiated terrace deposits. The section shows 1.5 m of loess which consists of yellow brown silt (BP3), with increasing clay towards the bottom of the pit (BP4), with a honeycomb fabric throughout typical of loess or possibly redeposited loess. The depth of the boundary with the underlying gravel, which provides the height OD of the fluvial terrace deposits at 75.9 m OD, was established through coring, but unfortunately could not be investigated by section exposure. The underlying terrace deposits were however, investigated in a separate section which lay 6.75 m to the southeast and showed 4 sediment units unconformably overlying weathered chalk bedrock. The latter consists of weathered autochthonous chalk and chalk rubble the top of which varied considerably in elevation between 76 and 73 m OD. A thin layer of very dark, stiff clay was observed between the fluvial gravel and chalk surface. This weathering interface possibly indicates the occurrence of solution processes during the Quaternary like those recorded to the west at Shapwick Grange quarry in Dorset (Chartres and Whalley, 1975; Basell and Brown, 2011). The sediment units directly overlying the chalk consisted of very poorly-sorted gravel, including large flint nodules (up to 20 cm), which showed limited abrasion or weathering. The overlying sediment unit also included large flint nodules that formed a crude band, possibly indicating a reactivation event. The inclusion of large flint nodules in this unit (BEM2.3) and underlying unit (BEM2.4) is probably the result of locally occurring solution and erosion of the chalk bedrock. Generally, the fluvial deposit fines upwards and the top sediment unit (BEM2.2) includes clast-supported medium gravel that is crudely bedded with bands of framework gravel.

### 3.2. T10 at Hatchet Gate Farm and Woodriding (Fig. 4)

At Hatchet Gate Farm (E 419310 N 119280, SU 19310 19280) 2.75 m of fluvial sediments were found unconformably overlying fine sandy bedrock of the Poole Formation. The bedrock surface dips west to east from 103.16 m O.D. to 102 m O.D. The presence of residual lag-cobbles deposited directly at the erosional boundary with the bedrock indicates a phase of bedrock erosion and bedload transport of gravel and subsequent decrease of water velocity causing the largest clasts to settle and imbricate (Bridge, 2005). This was followed by further sediment deposition. The deposition of unit HA1.5 (Fig. 4a) indicates the infilling of a depression or channel in the gravelly floodplain of the braided river. This deposit is overlain by another gravel unit. A period of erosion occurred between the deposition of HA1.3 and HA1.2. This suggests at least

**Table 3**
Summary of OSL sample locations. Terrace attributions are based on Kubala (1980) and Clarke (1981). Easting and Northing are based on BNG OSGB 1936. Latitude and Longitude are based on WGS 84 (SRID4326) and elevation is in metres above ordnance datum.

| SITE | Terrace | CONTEXT | Field Code | Lab Code | Easting | Northing | Latitude | Longitude | Elevation |
|---|---|---|---|---|---|---|---|---|---|
| BEMERTON | undiff.T | Loess overlying | BP02 | GL14038 | 412,872.43 | 131,240.93 | 51.08035 | −1.81762 | 76.6 |
| | | undifferentiated | BP04 | GL14039 | 412,872.43 | 131,240.93 | 51.08035 | −1.81762 | 77.1 |
| | | terrace deposit | BP01 | GL14040 | 412,872.43 | 131,240.93 | 51.08035 | −1.81762 | 76.6 |
| | | | BP03 | GL14041 | 412,872.43 | 131,240.93 | 51.08035 | −1.81762 | 77.1 |
| HGF | 10 | Fine sediment | HALE02 | GL14045 | 419,298.40 | 119,113.04 | 50.97111 | −1.72653 | 102.4 |
| | | within T10 | HALE01 | GL14046 | 419,298.40 | 119,113.04 | 50.97111 | −1.72653 | 102.5 |
| WOODRIDING | 10 | Two fine sediment | HALE03 | GL14047 | 418,634.96 | 117,751.94 | 50.9589 | −1.73604 | 99.6 |
| | | deposits within T10 | HALE04 | GL14048 | 418,634.96 | 117,751.94 | 50.9589 | −1.73604 | 99.8 |
| WOODGREEN | 7 | Fine sediment | WGRE01 | GL14042 | 417,198.39 | 117,004.06 | 50.95222 | −1.75653 | 58.8 |
| | | deposit within T7 | WGRE02 | GL14043 | 417,198.39 | 117,004.06 | 50.95222 | −1.75653 | 58.8 |
| | | | WGRE03 | GL14044 | 417,198.39 | 117,004.06 | 50.95222 | −1.75653 | 58.8 |
| SOMERLEY | 6 | 3 fin. sediment | SOM01 | GL15038 | 412,836.55 | 107,841.91 | 50.86994 | −1.81895 | 40 |
| | | deposits within T6 | SOM02 | GL15039 | 412,836.55 | 107,841.91 | 50.86994 | −1.81895 | 43.2 |
| | | | SOM03 | GL15040 | 412,836.55 | 107,841.91 | 50.86994 | −1.81895 | 43.2 |
| | | | SOM04 | GL15041 | 412,836.55 | 107,841.91 | 50.86994 | −1.81895 | 43.2 |
| | | | SOM05 | GL15042 | 412,836.55 | 107,841.91 | 50.86994 | −1.81895 | 41 |
| ASHLEY | 5 | Fine sediment | ASH01 | GL15033 | 413,315.34 | 106,149.27 | 50.85471 | −1.81221 | 33.1 |
| | | deposit overlying | ASH02 | GL15034 | 413,315.34 | 106,149.27 | 50.85471 | −1.81221 | 32 |
| | | T5; 3 fin. sediment | ASH03 | GL15035 | 413,315.34 | 106,149.27 | 50.85471 | −1.81221 | 30.6 |
| | | deposits within T5 | ASH05 | GL15036 | 413,315.34 | 106,149.27 | 50.85471 | −1.81221 | 30.4 |
| | | | ASH04 | GL15037 | 413,315.34 | 106,149.27 | 50.85471 | −1.81221 | 33.5 |
| BICKTON | 4 | 4 fine sediment | BICK01 | GL15075 | 414,982.43 | 112,414.54 | 50.91101 | −1.78827 | 26.8 |
| | | deposits within T4 | BICK02 | GL15076 | 414,982.43 | 112,414.54 | 50.91101 | −1.78827 | 26.9 |
| | | | BICK03 | GL15077 | 414,982.43 | 112,414.54 | 50.91101 | −1.78827 | 27.2 |
| | | | BICK04 | GL15078 | 414,982.43 | 112,414.54 | 50.91101 | −1.78827 | 27.3 |

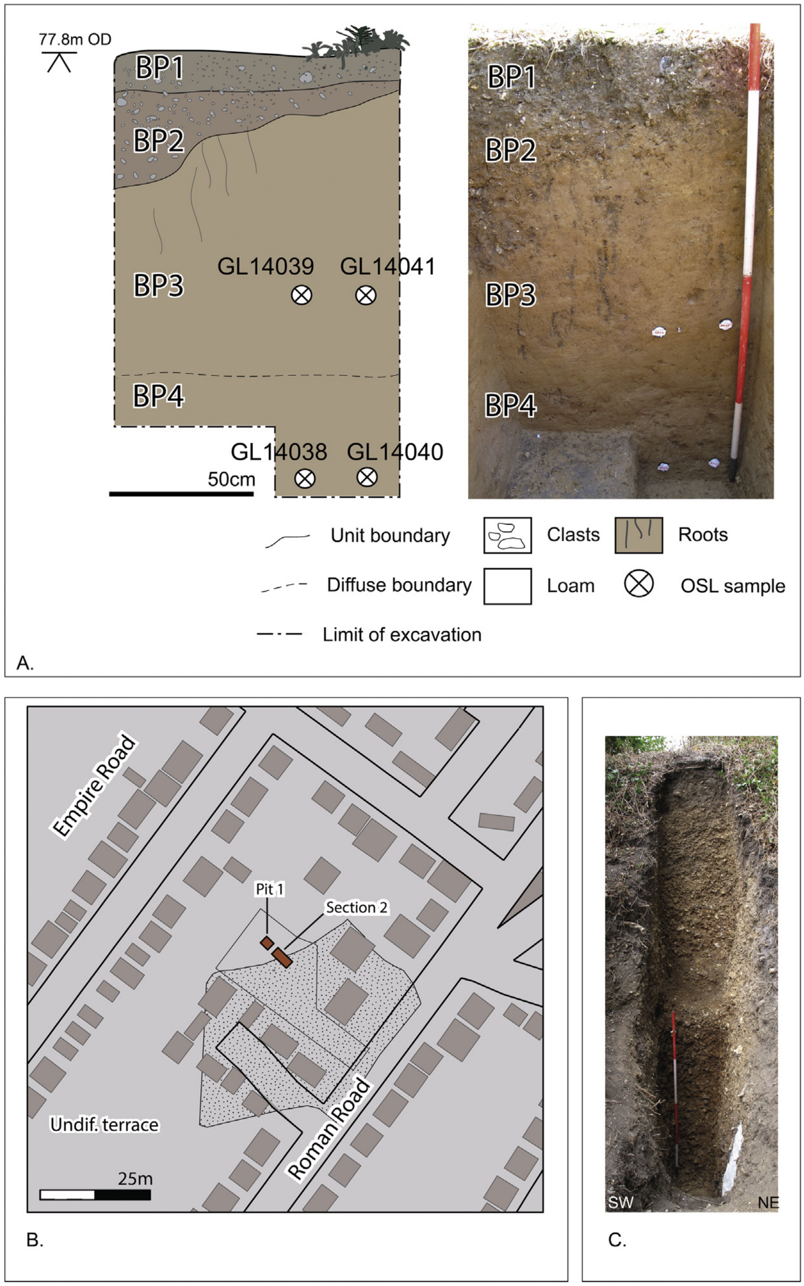


**Fig. 3.** A. South east section of pit 1 at Bemerton showing the massive loess found overlying the river gravels and the four OSL sample locations. B. OS map of Bemerton visualising the location of Pit1, on top of the terrace and behind Section 2. C. Photograph of Section 2 1:10000 scale OS VectorMap Local [shape file], Digimap Licence.

two, possibly three periods of gravel deposition and two phases of erosion. A first erosional event cut the bedrock, the second period removed part of the gravel deposited during the formation of HA1.3 and HA1.2.

At Woodriding (E 418634 N 117807, SU 18634 17807) three main gravel units were identified Fig. 4b). HB1.9 is a coarse, very poorly sorted gravel deposit that contains relatively high percentage of medium sand which derives from erosion of the Palaeogene bedrock (Poole Formation). HB1.9 is overlain by silty, very poorly sorted, medium gravel (HB1.2). This unit contains a relatively high percentage of fine material which may indicate a period of slope erosion and inclusion of fines in the gravel body. The particle-size analysis of the <63 μm fraction shows that it includes coarse to fine silt and clay. This poorly sorted particle-size distribution is characteristic of fluvially transported fines (Kovacs, 2008; Vandenberghe, 2013). A seam of large cobbles at the boundary between HB1.1 and HB1.2 indicates a reactivation surface overlain with bedded, coarser, sandier gravel (HB1.1), interspersed with horizontally bedded, crudely graded silty, clayey sand layers. The presence of multiple and large sand layers in HB1.1 suggests that during deposition of these sediments this area lay in the active region of the main channel of a braided river. The presence of Palaeogene flint at both sites indicates the erosion and incorporation of chalk-derived bedrock sediments.

### 3.3. T7 at Woodgreen (Fig. 5)

At Woodgreen (E 417200 N 117025, SU 17200 17025) ca. 4.5 m of fluvial sediments were found unconformably overlying the bedrock surface Palaeogene sands. The bedrock showed

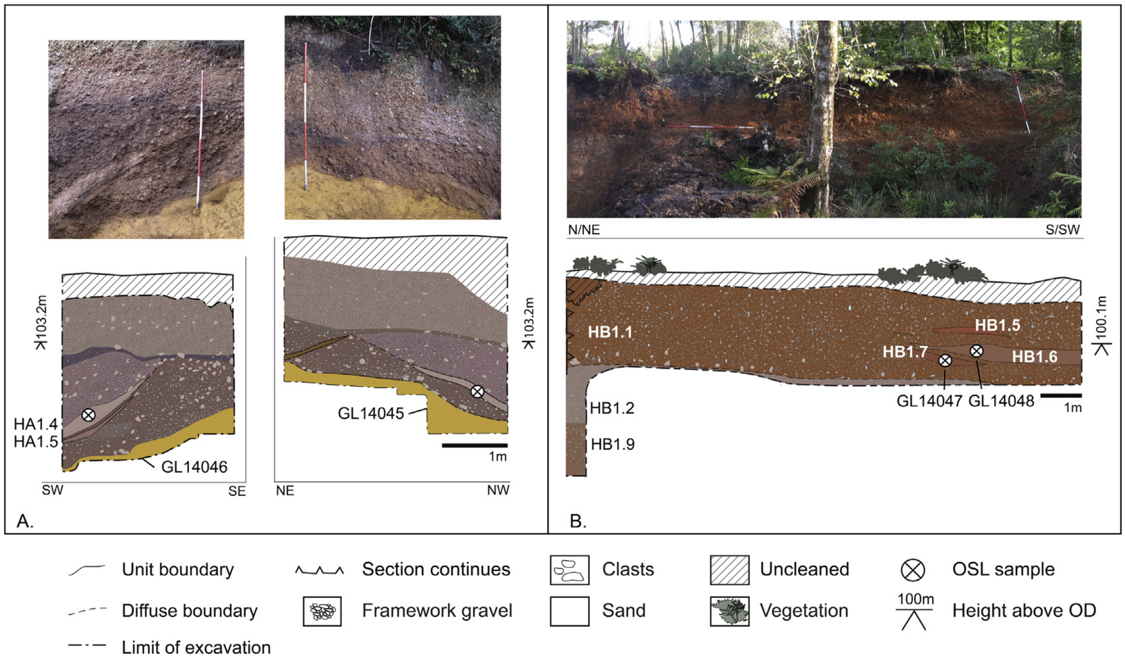


**Fig. 4.** A. South and north section of Hatchet Gate Farm gravel pit. B. West section of Woodriding gravel pit.

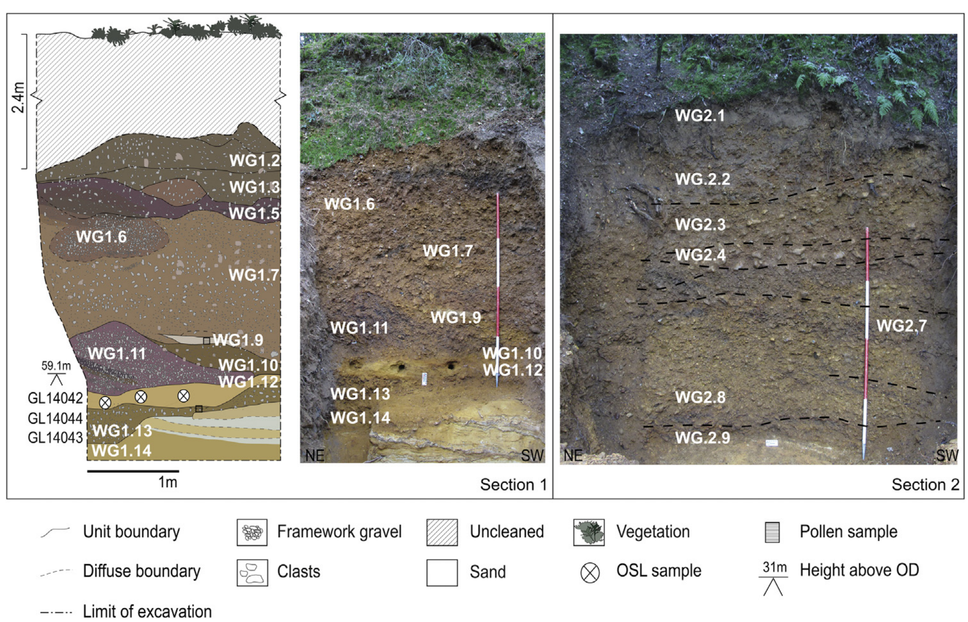


**Fig. 5.** Drawing of section 1 and annotated photographs of Sections 1 and 2 at Woodgreen. The sections were cleaned in the southeast section of the disused gravel pit.

small-scale scour features indicating bedrock erosion prior to gravel deposition. Sediments exposed in Section 2 consisted of 2.5 m of cross-bedded, moderately to poorly sorted, coarse to medium, matrix-supported flint gravel. The presence of lag-cobbles in WG2.3 indicates a reactivation phase between the deposition of this layer and WG2.4. Unit WG1.12 is a channel infill, covered by framework gravel from which the majority of fine sediments have been removed. WG1.9 is a small drape of silt and clay, interbedded in the gravel and possibly represents the deposits from a standing pool of water during lowered water stands (Miall, 1996). The presence of Palaeogene flint indicates the erosion and incorporation of bedrock sediments.

### 3.4. T6 at Somerley (Fig. 6)

At Somerley (E 412845 N 107825, SU 12845 07825) pit 5.6 m of fluvial deposits were found overlying Palaeogene sand. In section 2, 0.8 m of gravel, deposited on the bedrock, was overlain by a 1.4 m of cross-bedded sand and gravelly sand. These sediments, with low angles and multiple stacked cross-bedding, probably represent the deposits of a main channel in the braided river system. This was overlain by horizontally bedded gravel interbedded with cross-bedded sand layers. The gravel shows a set of graded layers that alternate between matrix-supported and clast-supported gravel. These cross-strata demonstrate the migration of channel bars and

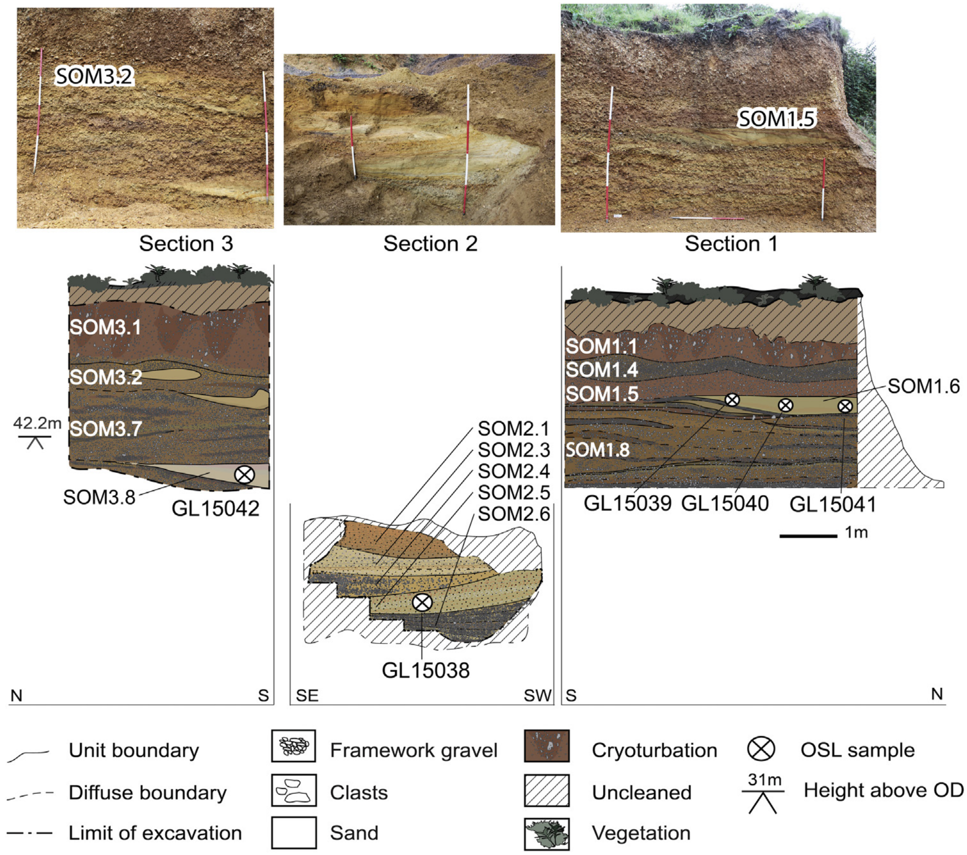


**Fig. 6.** Three sections in Somerley gravel pit showing OSL sample locations.

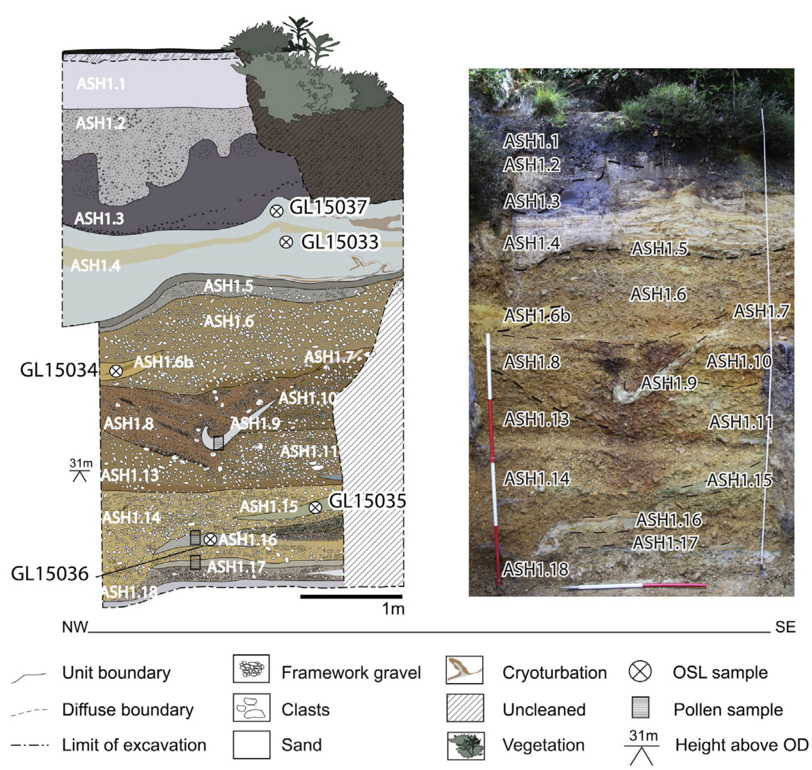


**Fig. 7.** West section of Ashley gravel pit.

sediment deposition under cyclically changing fluvial regimes (Bridge, 2005; Miall, 1996). Throughout the gravel pit at ca. 1.5 m below the top of the gravel a unit can be identified that consists of gravel interbedded with cross-bedded and horizontally-bedded sand layers. The cross-bedded sand layers represent deposition on the lee-side of gravel bars. Horizontally bedded sand presents the deposition in channels. This unit indicates the presence of multiple active channels at this location during the time of deposition. The top of the fluvial deposits at Somerley show cryoturbation features indicating periglacial conditions subsequent to terrace formation. The inclusion of massive sand blocks in the top demonstrates the erosion and incorporation of frozen sediments in the floodplain. Gravel from units SOM1.5 and SOM3.2 in particular contain relatively large percentages of sand. These units are interbedded with sand layers. This indicates the contribution of sand to the system, through the erosion of bedrock or sand deposits elsewhere in the floodplain. The relatively high percentage of Palaeogene flint in the gravel also suggests bedrock erosion and its incorporation in the fluvial deposits. The presence of less resistant clasts e.g. sandstone and especially limestone, indicates that at least some of the material was locally derived and had not travelled far (Bridgland, 1986).

### 3.5. T5 at Ashley pit (Fig. 7)

At Ashley pit (E 413293 N106143, SU 13293 06143) 3.3 m of horizontally bedded fluvial gravels interbedded with fines were found unconformably overlying sand and clayey Palaeogene bedrock. The gravel includes alternating matrix-supported and clast-supported gravel indicative of migrating channel bars and cyclically changing fluvial regimes (Bridge, 2005; Miall, 1996). The fine sediments are horizontally bedded channel deposits. The clay in ASH1.9 was deposited in standing water conditions in a pool on the braided floodplain during low water stands (Fig. 7). Cryoturbation processes have subsequently deformed this deposit. ASH1.9 contained twenty-one pollen grains which were all indicative of cold and locally wet conditions though the very small pollen count inhibits statistical analysis but demonstrates that finer sediments within terrace deposits may preserve environmental indications. This phase was followed by the deposition of horizontally bedded gravel, a thick deposit of fluvial fines and is capped by topsoil. In ASH1.4 large clasts (pebbles) were observed in bedded, fine sediment (sand). These are interpreted as 'drop stones'. Drop stones pose a hydrodynamic inconsistency, which may be explained by the larger clasts having been introduced to the sediment through a process of ice rafting. This is where sediment (which can include larger clasts) are contained in, and occasionally released from ice blocks carried by the river. Such evidence suggests periglacial conditions during sediment deposition (Bennett et al., 1996; Leeder, 1982). Additionally, ASH1.4 shows signs of cryoturbation indicating periglacial conditions also occurred after sediment deposition. The sediments at Ashley contain relatively high percentages of sand and Palaeogene pebbles demonstrating the erosion of bedrock and incorporation of clasts in the floodplain.

### 3.6. T4 at Bickton (Fig. 8)

The sediments at Bickton (E 414981 N 112409, SU149124) comprised horizontally bedded, moderately sorted, silty gravel. Approximately 1–1.5 m below the top of the terrace, the gravel is interspersed with cross-bedded, silty sand deposits. The sand deposits are overlain by cross-stratified framework gravel alternating with matrix-supported gravel. Due to excavation restrictions the height of the underlying bedrock could not be established in Bickton pit. BGS borehole data show that Bagshot Beds are encountered at 24.9 m OD (BGS reference SU11SE5) <1 km east of the site and at 22.2 m OD (BGS reference SU11SE4) <1 km north of the site.

### 3.7. OSL dating

The total $D_r$, mean $D_e$ and age estimates for all samples are given in Table 4. Details on the underpinning measurements for $D_r$ and

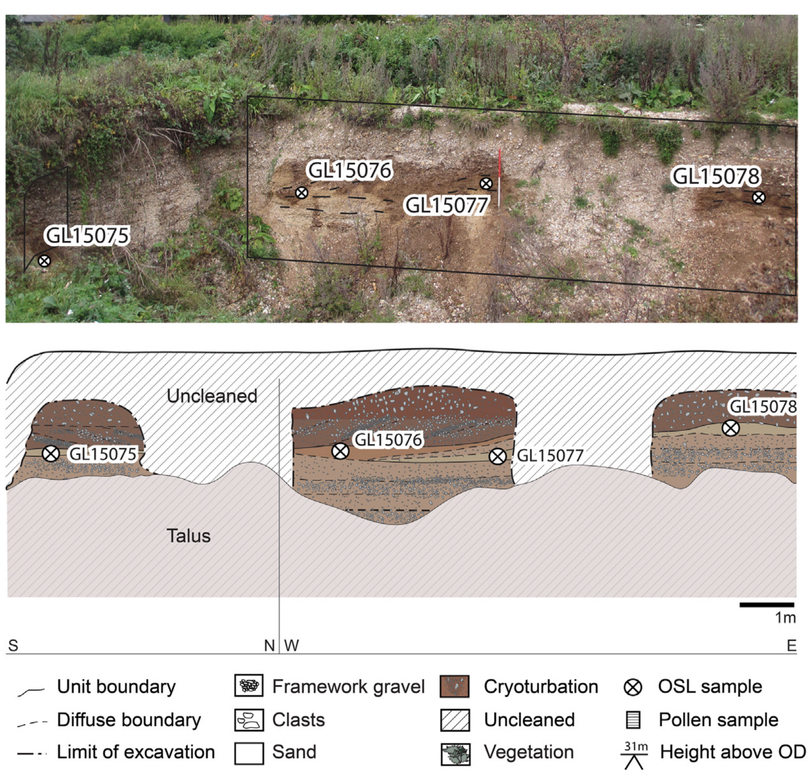


**Fig. 8.** West and north section of Bickton gravel pit.

Please cite this article in press as: E. Egberts, et al., Pleistocene landscape evolution in the Avon valley, southern Britain: Optical dating of terrace formation and Palaeolithic archaeology, Proc. Geol. Assoc. (2020), https://doi.org/10.1016/j.pgeola.2020.02.002

**Table 4**
$D_r$, $D_e$ and age data of the OSL samples. Ages are expressed relative to the year of sampling. Uncertainties in age are quoted at 1σ confidence, are based on analytical errors and reflect systematic and experimental variability and, in parantheses, experimental variability alone.

| TERRACE/SITE | Field Code | Lab Code | Total $D_r$ (Gy.ka$^{-1}$) | $D_e$ (Gy) | Age (ka) |
|---|---|---|---|---|---|
| Undiff.T | BP02 | GL14038 | 1.76 ± 0.08 | 150.8 ± 7.1 | 86 ± 6 (4) |
| BEMERTON | BP04 | GL14039 | 2.01 ± 0.14 | 141.0 ± 12.8 | 70 ± 8 (7) |
| | BP01 | GL14040 | 2.15 ± 0.10 | 150.8 ± 5.6 | 70 ± 4 (3) |
| | BP03 | GL14041 | 2.36 ± 0.12 | 138.0 ± 6.4 | 58 ± 4 (2) |
| T10 | HALE02 | GL14045 | 2.75 ± 0.14 | 613.5 ± 42.2 | 223 ± 19 (17) |
| HGF | HALE01 | GL14046 | 1.82 ± 0.09 | 481.0 ± 35.7 | 264 ± 23 (21) |
| T10 | HALE03 | GL14047 | 1.10 ± 0.07 | 287.2 ± 19.8 | 262 ± 25 (22) |
| WOODRIDING | HALE04 | GL14048 | 0.91 ± 0.06 | 340.4 ± 24.8 | 375 ± 38 (34) |
| T7 | WGRE01 | GL14042 | 0.65 ± 0.05 | 173.7 ± 11.7 | 269 ± 26 (23) |
| WOODGREEN | WGRE02 | GL14043 | 0.61 ± 0.04 | 214.6 ± 14.1 | 354 ± 35 (31) |
| | WGRE03 | GL14044 | 0.66 ± 0.05 | 207.0 ± 14.8 | 312 ± 31 (28) |
| T6 | SOM01 | GL15038 | 0.78 ± 0.07 | 193.5 ± 12.1 | 247 ± 27 (24) |
| SOMERLEY | SOM02 | GL15039 | 0.71 ± 0.06 | 238.6 ± 15.5 | 336 ± 34 (30) |
| | SOM03 | GL15040 | 0.89 ± 0.07 | 195.1 ± 14.3 | 219 ± 23 (20) |
| | SOM04 | GL15041 | 0.76 ± 0.06 | 218.0 ± 28.8 | 285 ± 44 (41) |
| | SOM05 | GL15042 | 0.67 ± 0.05 | 207.5 ± 11.5 | 310 ± 30 (26) |
| T5 | ASH01 | GL15033 | 1.89 ± 0.09 | 269.8 ± 19.3 | 143 ± 12 (11) |
| ASHLEY | ASH02 | GL15034 | 0.34 ± 0.04 | 66.8 ± 3.3 | 198 ± 23 (22) |
| | ASH03 | GL15035 | 0.60 ± 0.06 | 163.8 ± 7.6 | 271 ± 28 (25) |
| | ASH05 | GL15036 | 0.69 ± 0.05 | 77.8 ± 6.6 | 114 ± 12 (11) |
| | ASH04 | GL15037 | 0.35 ± 0.04 | 112.6 ± 4.2 | 323 ± 37 (34) |
| T4 | BICK01 | GL15075 | 0.66 ± 0.06 | 16.6 ± 0.9 | 25 ± 3 (2) |
| BICKTON | BICK02 | GL15076 | 0.16 ± 0.02 | 19.2 ± 0.8 | 14 ± 1 (1) |
| | BICK03 | GL15077 | 0.69 ± 0.05 | 13.6 ± 0.6 | 20 ± 2 (1) |
| | BICK04 | GL15078 | 0.91 ± 0.07 | 17.2 ± 0.7 | 19 ± 2 (1) |

diagnostics of SAR reliability for $D_e$ can be found in the research data section. Except for the four samples from Bickton (T4; GL15075-78), all had poor repeat ratios for high dose (c. 250 Gy), regenerated OSL suggesting limited correction of sensitivity change induced by laboratory measurement. This may have implications for accuracy of $D_e$ values recovered in the high-dose region. Twelve samples generated $D_e$ values >200 Gy, the typical characteristic saturation point ($D_0$) of quartz. Within those, two samples had $D_e$ values >2 $D_0$ (Hatchet Gate Farm, T10 samples GL14045, GL14046), the prudent datable limit suggested by Wintle and Murray (2006). Though few in number, there are sites in the UK where quartz OSL dates in these high $D_e$ ranges that have been verified, intrinsically or extrinsically. For example, Broom in Dorset (Toms, 2013) where a portion of samples exceeded 2 $D_0$ yet produced convergent age estimates from divergent dose rates, or Tyttenhanger in the Vale of St Albans where Pawley et al. (2010) produced age estimates from $D_e$ of 450 Gy consistent and that were consistent with the assignment of MIS 12 on the basis of lithostratigraphy.

Seven samples (GL14042, GL15038, GL15039, GL15041, GL15033, GL15035, and GL15037) displayed potentially significant U-disequilibria. All the samples from Bickton had good repeat regenerative dose ratios but three had potentially significant U-disequilibria (GL15075, GL15077, GL15078). Such disequilibrium can be caused by geochemical sorting that moves parent or daughter nuclides into or out of a system at a rate significant relative to the half-life of the daughter nuclides (Olley et al., 1996), changing the burial $D_r$. Although the impact of this phenomenon on age estimates is usually insignificant, the age estimates of samples where this effect is pronounced (>50 % U-disequilibrium between $^{238}U$ and $^{226}Ra$) should be accepted tentatively (Olley et al., 1996).

## 4. Discussion

### 4.1. Geochronology

Fig. 9 shows a model of the Avon terrace deposits built using Rockworks from the digitisation of 1035 BGS borehole records (Egberts, 2017). This displays the MIS attributions of the river's long-profile. The precise heights OD of the deposits dated are presented in Table 3. The diagram in Fig. 10 presents the OSL results per terrace and in relationship to the MIS stages. The schematic valley cross-section presented in Fig. 11 is also based on the 3D model of the superficial geology of the Avon valley, built in Rockworks based on BGS borehole data.

The OSL ages for T10-7 suggest deposition during or before MIS 10/9 (Fig. 10). They are broadly in agreement with, but potentially offer a refinement of, previously proposed relative chronologies used for dating the archaeological record of T7 and the calculation of regional uplift and incision rates. However, with a portion of $D_e$ values here exceeding 2 $D_0$ we are more circumspect on the reliability of the dates from Hatchet Gate Farm (T10). With a possible underestimation of the age of older deposits in the region due to age estimates approaching the upper limits of quartz OSL dating, it is likely that the period of deposition of the higher terraces is closer to, or exceeding the older OSL age estimates. The OSL age estimates from Somerley suggest T6 was deposited at some point between MIS 10 and 7. This is consistent with the formation of T6 after MIS 10, the age estimates for the preceding terrace deposits.

T5 is the lowest terrace of the staircase sequence along the Avon valley, and is separated from the floodplain by a steep bedrock bluff of ca. 14 m. Our OSL results suggest that terrace deposition at Ashley Pit can be dated to between MIS 10-5. The terrace clearly post-dates T6 (dated to MIS 10-7) suggesting deposition of T5 could be linked to the younger OSL age estimates obtained for this terrace. These results can further be compared to the dating of T4 and the Ibsley peat (Barber and Brown, 1987). Our OSL results from Bickton (T4) indicate deposition during MIS 2 (~20 ka). Close to Bickton, at Iblsey, organic deposits have been dated to MIS5e based on a distinct pollen assemblage (Ip IIb pollen zone) (Barber and Brown, 1987). The peat rests unconformably on Bagshot Beds, in a scour-hollow formed by fluvial erosion (Barber and Brown, 1987) and is overlain by river gravels (T3). The deposition of T4-T1 has been assigned to the Devensian (Clarke and Green, 1987), which is in agreement with the age estimation for T4 from Bickton and the

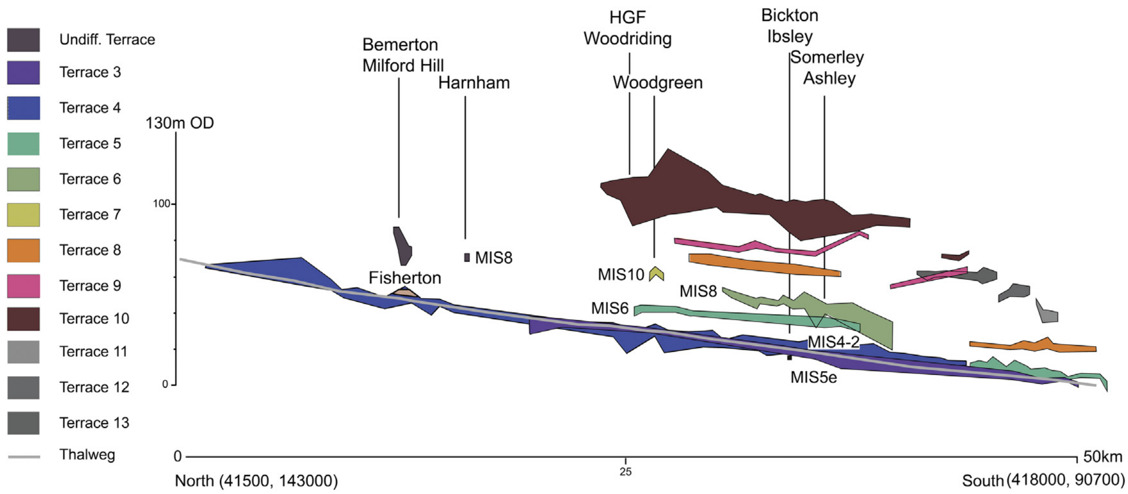


**Fig. 9.** Long profile projection of the river terraces in the Avon valley based on the BGS borehole data, digitised for this research, in Rockworks. Terrace numbering is based on BGS mapping (1991,2004, 2005). For comparison the proposed MISs for Harnham (Bates et al., 2014) and Iblsey (Barber and Brown, 1987) are added.

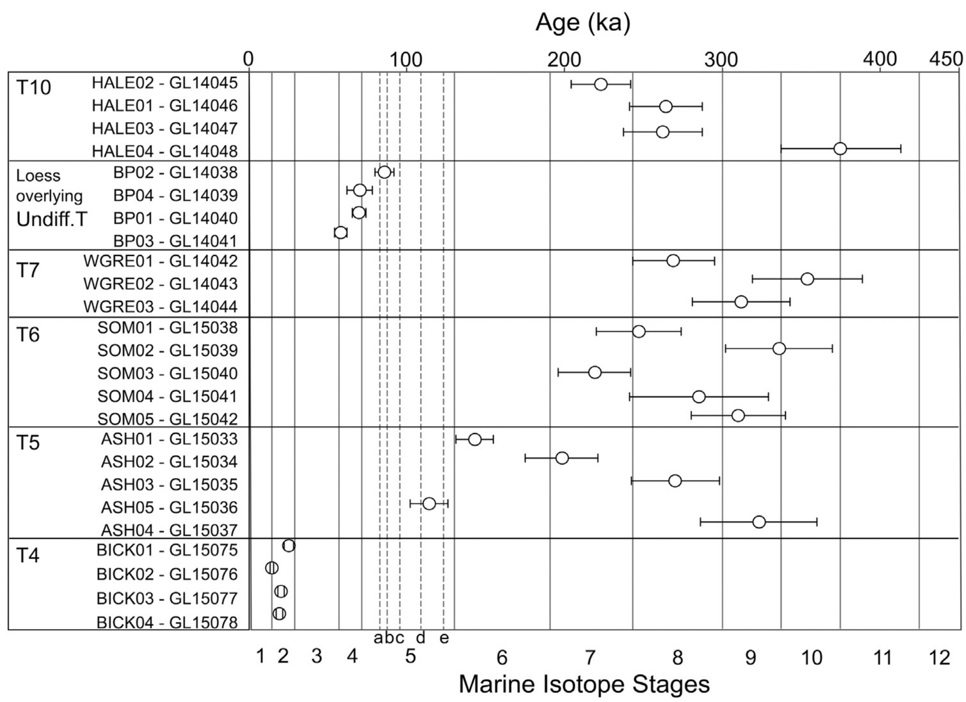


**Fig. 10.** Summary diagram showing OSL age estimates from the eastern Solent terraces in relation to the Marine Isotope stratigraphy, after LR04 (Lisiecki and Raymo, 2005).

dating of the Iblsey peat (Barber and Brown, 1987). However, because T4 lies stratigraphically below the Fisherton brickearth, it suggests it must pre-date MIS 3 (cf. Westaway et al., 2006) or MIS 4 (*cf.* Delair and Shackley, 1978; Green et al., 1983). Such an age for T4 is not supported by the here presented OSL results from Bickton. The apparently young age of T4 would put the deposition of subsequent terraces after the Last Glacial Maximum (LGM). This could indicate problems with the Bickton age estimates or is due to different aggradational histories in the tributaries (i.e. upstream of Salisbury) and the middle-lower valley. Assessment of the analytical reliability of these results suggest that the young age of the Bickton sediments is most likely representative of the age of these deposits. Therefore, more plausible explanations for this discrepancy between the age estimate of T4 at Fisherton and that at Bickton are either that T4 at Bickton includes sediments reworked during more recent fluvial processes or that T4 is a compound terrace exhibiting differing depositional behaviour in the upper and lower catchments. Such scenarios are possible as most valleys along the south coast like the Exe valley have their lower 2–3 terraces formed post LGM (Brown et al., 2010), and even the anomalous Axe valley has a lower terrace formed in the Lateglacial (Brown et al., 2015). It is worth pointing out that these floodplain terraces are formed by cut and fill processes.

The combined data from Bickton and Ibsley suggest that valley incision formed a scour in the Palaeogene bedrock during a cold period prior to MIS 5e. The valley formed a vegetated floodplain in

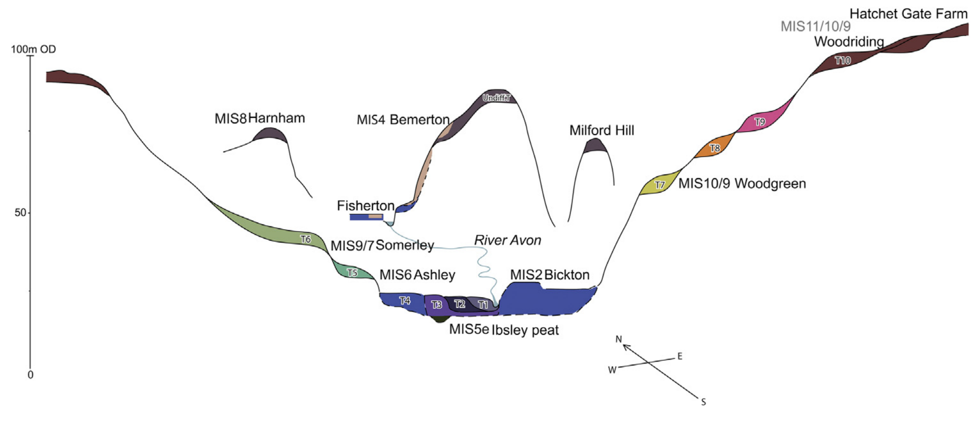


**Fig. 11.** Idealised oblique east-west cross-section of the river terraces in the Avon valley, with the here presented new MIS stages for terrace formation. Terrace deposits are based on the BGS borehole data, digitised for this research, in Rockworks. Terrace numbering is based on BGS mapping (1991, 2004, 2005). For comparison the proposed MISs for Harnham (Bates et al., 2014) and Iblsey (Barber and Brown, 1987) are added.

the subsequent warm stage and old bedrock scours were infilled with interglacial sediments such as those found at Ibsley (Barber and Brown, 1987). Climatic deterioration following the deposition of the peat resulted in an increase of water supply and erosion of the majority of the interglacial sediments (Barber and Brown, 1987), before covering the remnants with cold stage sand and gravel. Later erosion and deposition was not as pronounced as during proceeding periods, resulting in weakly distinguished terraces after MIS 5e. Rather than deep incision and terrace formation, considerable reworking of the terrace deposits occurred within the confined area of the valley. This scenario is compatible with the age of the higher terraces in the valley where we have dated T5, the first well-defined terrace of the staircase sequence, to MIS 10-5. T5 on the valley side, T4 and the Ibsley peat in the modern floodplain are separated by a bedrock bluff of *ca.*14 m indicating that a significant erosional event occurred between the deposition of T5 and the formation of the Ibsley peat. The significant valley incision could have been instigated by the substantial increase in water supply from the melting of the permafrost related to climatic warming towards the end of MIS 6. This has been widely observed in other fluvial systems and is also found reflected in the significant increase in discharge recorded for the Channel River at this time (Brown et al., 2010; Toucanne et al., 2009a, b). This is in agreement with the suggestion that T5 post-dates MIS 7 and pre-dates MIS 5e, based on the stratigraphic relationship of T5 with T6 and the Ibsley peat.

This assessment leads us to suggest the following chronology for the Avon terraces: T10-7 predate MIS10/9, T6 can be related to MIS 8, T5 to MIS 6 and T4-1 to MIS 5-1.

Although providing a minimum age for the underlying undifferentiated terrace, the OSL dates on the newly discovered loess deposits at Bemerton have most importantly repercussions on our understanding of the age of loess in the Avon valley. The OSL results provide an MIS 4 (70 ka) age for the loess at Bemerton. These observations are of interest for several reasons. Loess deposits are related to at least three depositional phases during the Late Pleistocene, before 170 ka, between 125 and 50 ka and 25 and 10 ka with the majority dated to the Late Devensian (Antoine et al., 2003b; Parks and Rendell, 1992). In the Hampshire Basin brickearth is generally found overlying river terrace deposits and has been subdivided into an Upper (younger) brickearth and a more extensive Lower Brickearth (Reynolds et al., 1996). The majority of such deposits in the region are dated to the Late Devensian (Parks and Rendell, 1992), which led Reynolds et al. (1996) to suggest that the Lower brickearth is of pre-Devensian age and the Upper brickearth of MIS 2 age. The MIS 4 age for the Bemerton loess is in agreement with the dating of brickearth deposits elsewhere in Britain (Bates et al., 2014; Rose et al., 2000; Wenban-Smith et al., 2010) and, considered in relation to other brickearths in the Avon catchment, could indicate that at least two of the three phases of loess deposition proposed by Parks and Rendell (1992) are present in the Hampshire Basin with for example Highcliffe just east of Christchurch dating to 20 ka (Parks and Rendell, 1992) and now Bemerton dating to 70 ka.

The presence of loess at Bemerton should also be briefly discussed in relationship to the famous fossiliferous Fisherton brickearths found just downslope from Bemerton, in the Nadder valley (Fig. 12). Apart from a distinct faunal assemblage, the Fisherton brickearths contained 2 *bout coupé* bifaces (Delair and Shackley, 1978; Lyell, 1827). Based on the faunal assemblage a final MIS5a (80 ka) or early middle Devensian age (70 ka – MIS 4) has been proposed for the deposition of the Fisherton brickearth (Delair and Shackley, 1978; Green et al., 1983). Westaway et al. (2006) tentatively proposed the Fisherton deposits to date to MIS 3 and the underlying gravels of T4 to MIS 4. Others have suggested that the Fisherton brickearth cannot be regarded as loess, as the deposit has quite a low silt content (12 %) and the laminae indicate a fluviatile origin (including fluvially redeposited aeolian sediments) (Delair and Shackley (1978).

Unlike the brickearth found at Fisherton (Delair and Shackley, 1978), the sediments revealed during our excavation at Bemerton, were massive suggesting aeolian depositional conditions. The chronological relationship between the sites depends on which interpretation for the age of the Fisherton sediments is followed (Delair and Shackley, 1978; Green et al., 1983; Westaway et al., 2006). Either way Bemerton and Fisherton are closely related in age and possibly contemporary. The Fisherton brickearth is derived from the erosion and redeposition of aeolian sediments present elsewhere in the landscape (Delair and Shackley, 1978), and Bemerton may represent the remnants of such a sediment source. The dating of the Bemerton loess demonstrates that early Devensian deposits are preserved in the area which may be associated with hominin presence as is evidenced by 2 *bout coupé* bifaces found at Fisherton. Investigating more deposits dated to MIS 6-4 for archaeological evidence may contribute to our understanding of hominin presence/absence from Britain during this period (Pettitt and White, 2012).

The integration of the dated Avon deposits with the Solent terraces has proved challenging due to the multitude of terrace schemes proposed for the area. The long profile projection (Fig. 9, Table 2) highlights the discrepancy between the different terrace numbering systems. In the lower Avon valley (Bournemouth area) more terraces are recognised as the lower terraces in these reaches are more clearly

Please cite this article in press as: E. Egberts, et al., Pleistocene landscape evolution in the Avon valley, southern Britain: Optical dating of terrace formation and Palaeolithic archaeology, Proc. Geol. Assoc. (2020), https://doi.org/10.1016/j.pgeola.2020.02.002

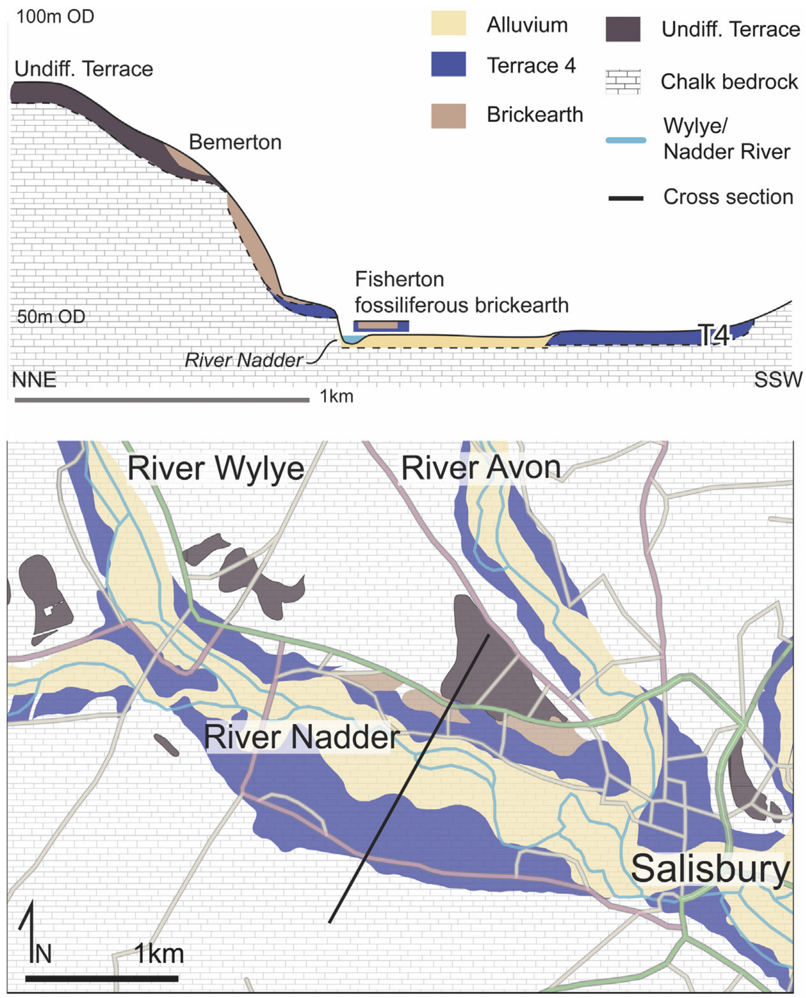


**Fig. 12.** Valley cross-section at Bemerton showing the stratigraphic position of undifferentiated terrace deposits, T4 and brickearth at Fiaherton geology based on 1:10000 scale geology data, with permission of the British Geological Survey and 1:10000 scale OS VectorMap Local [shape file], Digimap Licence.

differentiated. With the terrace mapping conducted per BGS sheet and the terrace numberings starting from the floodplain, this has resulted in discrepancies. It is possible that T5 in the lower valley may be related to T4 in the middle valley and T8 in the lower valley could be correlated with T6 in the middle valley. This should be taken into account when using the dating results presented in this paper to extrapolate age estimates to adjacent terrace deposits.

It is worth emphasising the dating and correlation of the Avon terraces with results from previous work (Bates et al., 2014; Briant et al., 2006, 2012a,b; Harding et al., 2012; Schwenninger et al., 2007), suggests a systematic under-estimation of quartz OSL ages on fluvial deposits in the western Solent and Test valley. The problems of quartz OSL dating in the Solent region have been highlighted in several publications (Briant et al., 2012a, b, 2009, 2006; Hatch, 2014; Schwenninger et al., 2007). The results from the altitudinally higher terraces presented here and the oldest age estimates elsewhere in the Solent might be close to the upper limit of quartz OSL dating in the area. However, even when the dates are near the limit of the method and demonstrate greater uncertainty, they still provide a minimum estimate of terrace age.

## 4.2. Implications for fluvial models

Although the OSL results show that the age estimates of T10 and possibly T7 could be reaching the upper limit of quartz OSL dating in the region, the dating of the middle terraces of the Avon suggests that these formed in response to the major 100 ka cyclic climatic changes of the Middle Pleistocene. Therefore, though not yet directly dated, it is possible that T8 and T9 formed during the MIS 12 and MIS 14 (respectively) cycles. This could suggest an MIS 16 age for T10. This is older than suggested by our OSL results, possibly showing that for these samples indeed the upper limit of quartz OSL dating is reached, as is also suggested by the high $D_e$ values. If this new chronology is accepted it would mean that the change in type of terrace formation between O5-1, T10 and T9-T5 from draped and compound terraces to altitudinally separated terraces (Fig. 10) happened more recently than proposed previously by Maddy et al. (2000) and Westway et al. (2006). These authors related this change in terrace form to a change in fluvial processes, instigated by the transition from the 41 ka to 100 ka cyclicity of Milankovitch forcing on global climate in the late Early Pleistocene 0.9 Ma (the Mid-Pleistocene Transition (MPT)) (Maddy et al., 2000; Westaway et al., 2006). This climatic change instigated an increase in valley incision which has also been coupled to positive feedback effects of globally accelerated uplift caused by crustal unloading and lower crustal forcing (Bridgland and Westaway, 2008a; Brown et al., 2009, 2010). Based on a time-averaged incision rate of ca. 0.007 m ka$^{-1}$ and the use of the Avon Palaeolithic record as age tie-point, Maddy (1997; Maddy et al., 2000) has suggested the O5-O1 (which directly precede T10) deposits to date between 1.4 Ma and 0.95 Ma 0.95. In this model T7 deposits, based on the artefact assemblage from Woodgreen, are assumed to date to MIS 12

(Maddy et al., 2000). Instead of a uniform uplift rate as proposed by Maddy et al. (2000); Westaway et al. (2006) suggested uplift rates in the Avon valley increased since 0.9 Ma as a result of lower-crustal flow forcing that is a consequence of cyclic surface unloading caused by intensified climatic change following the onset of the 100 ka cyclicity. There are obvious problems with uplift modelling based on relative altitudes of terrace deposits and the use of the Palaeolithic record as a chronological marker, and indeed the age proposed by Maddy et al. (2000) and Westaway et al. (2006) for T7 (Woodgreen Palaeolithic site) is not in agreement with our chronometric date of 389-243 ka. However, it is clear that Woodgreen covers several phases of gravel deposition, which could extend back to MIS 11. Together with the OSL results of the middle terraces and the suggestion of the formation of these in tune with the main climate cycles, the younger age for the transition between O5-O1, T10 draped terraces and T9-T5 strath terraces holds.

A transition from broad low-relief fluvial landscapes in the Early Pleistocene to the development of narrow deeply incised valleys in the Middle Pleistocene has been widely recognised in fluvial systems and related to the MPT (Bridgland and Westaway, 2008a, b, 2014). The onset of the MPT is dated to 0.9 Ma but the transition may span a considerable time from 1.2 Ma-0.5 Ma (Head et al., 2008).

The research presented here supports the change in terrace formation and shows a more pronounced physical manifestation of this change could have appeared around MIS 16 (676-621 ka), coinciding with the proposed intensification of the MPT between 750-600 ka (Head et al., 2008). Further research focussing on dating evidence of this transition is required to understand the impact of climate cycle transitions on the landscape.

### *4.3. Implications for the Palaeolithic archaeology in the Avon valley*

The archaeological analyses conducted as part of this research are summarised elsewhere (Egberts et al., 2019; Egberts, 2017; Egberts et al., 2020) but the new chronology presented in this paper raises some interesting general points of relevance. Firstly the dating provides the first direct age constraints for the Palaeolithic deposits at Woodgreen (T7) suggesting that hominins were present in the valley at least by MIS 10. This is significantly older than the MIS 8 Palaeolithic site of Harnham which lay in undifferentiated terrace deposits with dating estimates determined by OSL analysis, amino acid racemisation, and biostratigraphic information to ~250 ka (Bates et al., 2014). The comparable height above the floodplain of the undifferentiated Harnham terrace and the terrace at Milford Hill suggests these sites are of broadly similar age (Bates et al., 2014).

This raises the question of the relationship between the undifferentiated terrace at Bemerton from which 151 Palaeolithic artefacts were excavated during the second half of the 19th and the beginning of the 20th century (Read, 1885), and Milford Hill/Harnham. Bemerton is ca. 6 m higher above the floodplain than Milford Hill, suggesting that Bemerton predates Milford Hill. Long profile projections between Bemerton and Woodgreen show that Bemerton could also predate Woodgreen (Fig. 9). The OSL results from the Avon terrace sequence demonstrate that Woodgreen predates Milford Hill (if the correlation of Milford Hill with Harnham is accepted). As a result of the new dates from the terrace sequence presented here and those published for Harnham (Bates et al., 2014), it is possible to suggest a new relative chronology of Bemerton, Milford Hill and Woodgreen.

Based on height above the floodplain Bemerton is the oldest site (pre-MIS 10), followed by Woodgreen (at least MIS 10/9), with Harnham and Milford Hill dated to ~250 ka. The results from the Avon valley show that hominins were present in the area during various interglacials/interstadials prior to MIS 10 and until MIS 8. Bemerton and Milford Hill are both at the confluence zone of the Avon, Nadder and Bourne, but at different sides of the valley. Woodgreen, further down the valley, is situated at the junction of the Avon and a left bank tributary. Such confluence zones may have provided particularly favourable nutritional niches (Brown et al., 2013). Interestingly however, as the sites could be dated to different periods, is that the results from the Avon valley show that hominins focused on different locations during different interglacials/interstadials. This may be the result of landscape change and variations in flora and fauna between interglacials/interstadials (Ashton et al., 2006; Bridgland et al., 2013; Candy et al., 2015; Schreve, 2001) or may relate to shifts in the set of resources sought by (potentially different) hominins (Egberts et al., 2020).

## 5. Conclusions

Quartz OSL dating has been applied to a sequence of Pleistocene fluvial terraces in the Avon valley. The results presented to date have shown that the compound terraces of 'Older River Gravels' and T10 pre-date MIS 10 (Fig. 11).

Geomorphologically these upper level terraces are indicative of low-relief braided floodplain landscapes common across southern England during the Early Pleistocene. While there is a broad acceptance that the MPT affected fluvial systems resulting in more clearly defined and altitudinally separated terraces, and more deeply incised and tightly constrained channels, the Avon dates suggest further research needs to be conducted to understand the precise timing of such fluvial responses and what controls the manifestation of the MPT climatic regime change. This is evident from the dates achieved on the higher-level terraces of the Avon which are not concordant with previously modelled age estimates (Maddy et al., 2000). Since the OSL dating programme had variable results with more intrinsically reliable results for the lower terraces further research is underway by the authors to refine the dating of the higher-level terraces through targeted feldspar methods. As OSL signal saturation for feldspar lies around 2000 Gy (for quartz this is 200 Gy) (Wintle and Murray, 2006)), feldspar OSL dating has a much higher upper age limit (Thiel et al., 2011). It is anticipated that the application of this method will establish the degree to which the OSL dates achieved so far represent the limit of quartz OSL, and to determine more precisely terrace formation age (and therefore MPT-fluvial system response time estimates).

From at least MIS 10 to MIS 5e increased valley incision in the Avon valley led to well-developed strath terrace formation, overlain with thick fluvial deposits remnants of which were examined in this research (T9-T5). These altitudinally separated terraces reflect the increased amplitude of climate cycles in the Middle Pleistocene, a pattern seen elsewhere in many catchments across southern Britain (*e.g.*, Brown et al., 2010). The Avon deposits studied recorded a variety of environments typical for cold climate braided rivers such as coarse-grained migrating channels bars, multiple active channels and small pools of standing water on the braided floodplain. Overall the more constrained active channels of the Middle Pleistocene Avon laterally migrated west during the deposition of T9-7 (before MIS 10/9) and east during the formation of T6-5 (between MIS 8 and 5) (as demonstrated by the differential terrace preservation) (Figs. 2 and 11). This has implications for predictive modelling of the Palaeolithic resource (Egberts et al., 2020).

During this second phase of the Avon's evolution, the first strong evidence for repeated hominin occupation of the valley is evidenced by sites such as Woodgreen and Bemerton. The MIS 10/9 age of T7 provides the first direct chronometric age for the rich Palaeolithic record from Woodgreen. At Bemerton, Milford Hill and Woodgreen sediments covered the assemblages rapidly. This has led, combined with the steep downcutting of the Avon through the chalk bedrock near Salisbury and the westward migration of

Please cite this article in press as: E. Egberts, et al., Pleistocene landscape evolution in the Avon valley, southern Britain: Optical dating of terrace formation and Palaeolithic archaeology, Proc. Geol. Assoc. (2020), https://doi.org/10.1016/j.pgeola.2020.02.002

the channels near Woodgreen, to their long-term preservation with minimal reworking of these assemblages into the lower terraces (Figs. 2 and 11) (Egberts, 2017; Egberts et al., 2020).

Following climatic warming towards the end of MIS 6, significant valley incision occurred, probably instigated by a substantial increase in water supply from the melting of the permafrost. During the interglacial MIS 5e, vegetation re-established in the valley bottom and peat deposits formed in the scour holes which were preserved at Ibsley and dated to MIS 5e (Barber and Brown, 1987). After this, cut-and-fill terraces (T4-1) filled the spatially confined valley.

The reinvestigation of archaeological sites in the Avon valley shows that terrace deposits offer an opportunity to provide a valuable relative chronological framework but that in conjunction with chronometric age control and accurate height and deposit thickness modelling, a far better appreciation of the system's complexities and diachronic evolution can be achieved. The more detailed understandings of landscape evolution which can be realised have direct implications for our interpretations of hominin landscape use, behaviour and predictive modelling of Palaeolithic sites. The research highlights the challenges of temporal correlation of open-Palaeolithic sites even at the broadest (MIS) scale and demonstrates the danger of circular reasoning when the archaeological record is used as an 'index fossil' to confirm proposed relative chronologies. However, this research demonstrates that with a detailed and multidisciplinary approach, within a valley shifts in hominin landscape use can be discovered, providing exciting new opportunities for understanding hominin behavioural change.

## Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

## Acknowledgments

Funding: this work was supported by Bournemouth University and the Arts and Humanities Research Council (1869405, 2013); the Hampshire Field Club and Archaeological Society (2015); Lithic Studies Society (Conference Grant, 2015); Quaternary Research Association (New Research Workers' Award, 2016). The authors would like to thank the Forestry Commission, Natural England, The New Forest National Park Authorities, the Verderers, and landowners (names known by the corresponding author) for their consent to conduct research on their land.

## References

Adamiec, G., Aitken, M., 1998. Dose-rate conversion factors: update. Anc. TL 16. , pp. 37–50.
Allen, L.G., Gibbard, P.L., 1993. Pleistocene evolution of the Solent River of Southern England. Quaternary Science Reviews 12, 503–528.
Allen, L.G., Gibbard, P.L., Pettit, M.E., Preece, R.C., Robinson, J.E., 1996. Late pleistocene interglacial deposits at pennington marshes, Lymington, Hampshire, southern England. Proceedings of the Geologists' Association 107, 39–50. doi:http://dx.doi.org/10.1016/S0016-7878(96)80066-6.
Antoine, P.A., Coutard, J., Gibbard, P.L., Hallegouet, B., Lautridou, J., Ozouf, J., 2003a. The pleistocene rivers of the English Channel region. Journal of Quaternary Science 18, 227–243. doi:http://dx.doi.org/10.1002/jqs.762.
Antoine, P.A., Catt, J., Lautridou, J., Sommé, J., 2003b. The loess and coversands of northern France and southern England. Journal of Quaternary Science 18, 309–318.
Ashton, N., Hosfield, R., 2010. Mapping the human record in the British early Palaeolithic: evidence from the Solent River system. Journal of Quaternary Science 25, 737–753. doi:http://dx.doi.org/10.1002/jqs.1350.
Ashton, N., Lewis, S.G., Parfitt, S., White, M., 2006. Riparian landscapes and human habitat preferences during the Hoxnian (MIS 11) Interglacial. Journal of Quaternary Science 21, 497–505.
Barber, K.E., Brown, A.G., 1987. Ibsley organic deposits. In: Barber, K.E. (Ed.), Wessex and the Isle of Wight. Field Guide. Quaternary Research Association, Cambridge, pp. 65–74.
Barton, C.M., Hopson, P.M., Newell, A.J., Royse, K.R., 2003. Geology of the Ringwood District - a Brief Explanation of the Geological Map. Sheet Explanation of the British Geological Survey. 1:50 000 Sheet 314 Ringwood (England and Wales). Keyworth, Nottingham. .
Basell, L.S., Brown, A.G., 2011. The archaeological context of the Exe Valley and the adjoining areas. In: Basell, L.S., Brown, A.G., Toms, P.S. (Eds.), The Quaternary of the Exe Valley and Adjoining Areas: Field Guide. Quaternary Research Association, London, pp. 11–26.
Bates, M.R., Wenban-Smith, F.F., Bello, S.M., Bridgland, D.R., Buck, L.T., Collins, M.J., Keen, D.H., Leary, J., Parfitt, Sa., Penkman, K., Rhodes, E., Ryssaert, C., Whittaker, J. E., 2014. Late persistence of the Acheulian in southern Britain in an MIS 8 interstadial: evidence from Harnham, Wiltshire. Quaternary Science Reviews 101, 159–176. doi:http://dx.doi.org/10.1016/j.quascirev.2014.07.002.
Bennett, M.R., Doyle, P., Mather, A.E., 1996. Drop-stones: their origin and significance. Palaeogeography, Palaeoclimatology, Palaeoecology 121 (3-4), 331–339. doi:http://dx.doi.org/10.1016/0031-0182(95)00071-2.
Blackmore, 1864. Discovery of flint implements in the higher level gravel at Milford Hill, Salisbury. Journal of Archaeological Science 21, 243–245.
Blackmore, H.P., 1865. On the discovery of flint implements in the drift at Milford Hill, Salisbury. Quarterly Journal of the Geological Society of London 21, 250–252. doi:http://dx.doi.org/10.1144/GSL.JGS.1865.021.01-02.32.
Blackmore, H.P., 1867. On the recent discovery of flint implements in the drift of the Valley of the Avon. Wiltshire Archaeological and Natural History Magazine 10, 221–233.
Blum, M.D., Törnqvist, T.E., 2000. Fluvial responses to climate and sea-level change: a review and look forward. Sedimentology 47, 2–48. doi:http://dx.doi.org/10.1046/j.1365-3091.2000.00008.x.
Botter-Jensen, L., Mejdahl, V., Murray, A.S., 1999. New light on OSL. Quaternary Geochronology 18, 303–309.
Briant, R.M., Bates, M.R., Schwenninger, J.-L., Wenban-Smith, F., 2006. An optically stimulated luminescence dated Middle to Late Pleistocene fluvial sequence from the western Solent Basin, southern England. Journal of Quaternary Science 21, 507–523. doi:http://dx.doi.org/10.1002/jqs.1035.
Briant, R.M., Bates, M.R., Boreham, S., Cameron, N.G., Coope, G.R., Field, M.H., Keen, D.H., Simons, R.M.J., Schwenninger, J.L., Wenban-Smith, F.F., Whittaker, J.E., 2009. Gravels and interglacial sediments at Stone Point site of Special scientific interest, Lepe Country Park, Hampshire. In: Briant, R.M., Bates, M.R., Hosfield, R. T., Wenban-Smith, F.F. (Eds.), The Quaternary of the Solent Basin and West Sussex Raised Beaches. Field Guide. Quaternary Research Association, London, pp. 171–188.
Briant, R.M., Bates, M.R., Marshall, G.D., Schwenninger, J., Wenban-Smith, F.F., 2012a. Terrace reconstruction and long profile projection: A case study from the Solent river system near Southampton, England. Proceedings of the Geologists' Association 123, 438–449. doi:http://dx.doi.org/10.1016/j.pgeola.2012.01.006.
Briant, R.M., Kilfeather, A.A., Parfitt, S., Penkman, K.E.H., Preece, R.C., Roe, H.M., Schwenninger, J.L., Wenban-Smith, F.F., Whittaker, J.E., 2012b. Integrated chronological control on an archaeologically significant Pleistocene river terrace sequence: The Thames-Medway, eastern Essex, England. Proceedings of the Geologists' Association 123, 87–108. doi:http://dx.doi.org/10.1016/j.pgeola.2011.07.008.
Bridge, J.S., 2005. Rivers and Floodplains, second. ed. Blackwell Science Ltd, Oxford.
Bridgland, D.R. (Ed.), 1986. Clast Lithological Analysis. Technical Guide No. 3. Quaternary Research Association, Cambridge.
Bridgland, D.R., 2000. River terrace systems in north-west Europe: an archive of environmental change, uplift and early human occupation. Quaternary Science Reviews 19, 1293–1303. doi:http://dx.doi.org/10.1016/S0277-3791(99)00095-5.
Bridgland, D.R., Westaway, R., 2008a. Climatically controlled river terrace staircases: a worldwide Quaternary phenomenon. Geomorphology 98, 285–315. doi: http://dx.doi.org/10.1016/j.geomorph.2006.12.032.
Bridgland, D.R., Westaway, R., 2008b. Preservation patterns of Late Cenozoic fluvial deposits and their implications: Results from IGCP 449. Quaternary International 189, 5–38. doi:http://dx.doi.org/10.1016/j.quaint.2007.08.036.
Bridgland, D.R., Westaway, R., 2014. Quaternary fluvial archives and landscape evolution: a global synthesis. Proceedings of the Geologists' Association 125, 600–629. doi:http://dx.doi.org/10.1016/j.pgeola.2014.10.009.
Bridgland, D.R., Harding, P., Allen, P., Candy, I., Cherry, C., George, W., Horne, D.J., Keen, D.H., Penkman, K.E.H., Preece, R.C., Rhodes, E.J., Scaife, R., Schreve, D.C., Schwenninger, J.L., Slipper, I., Ward, G.R., White, M.J., White, T.S., Whittaker, J.E., 2013. An enhanced record of MIS 9 environments, Geochronology and geoarchaeology: data from construction of the High Speed 1 (London-Channel Tunnel) rail-link and other recent investigations at Purfleet, Essex, UK. Proceedings of the Geologists' Association 124, 417–476.
Bristow, C.R., Freshney, E.C., Penn, I.E., 1991. Geology of the Country around Bournemouth. Memoir for 1:50 000 Geological Sheet 329 (England and Wales). London. .
British Geological Survey, 1991. Bournemouth. England and Wales Sheet 329. Solid and Drift Edition. 1:50 000. .
British Geological Survey, 2004. Ringwood. England and Wales Sheet 314. Solid and Drift Geology. 1:50 000. .
British Geological Survey, 2005. Salisbury. England and Wales Sheet 298. Bedrock and Superficial Deposits. 1:50 000. .
Brown, A.G., Basell, L.S., Toms, P.S., Scrivener, R.C., 2009. Towards a budget approach to Pleistocene terraces: preliminary studies using the River Exe in South West

England, UK. Proceedings of the Geologists' Association 120, 275–281. doi: http://dx.doi.org/10.1016/j.pgeola.2009.08.012.

Brown, A.G., Basell, L.S., Toms, P.S., Bennett, J.A., Hosfield, R.T., Scrivener, R.C., 2010. Later Pleistocene evolution of the Exe valley: a chronstratigraphic model of terrace formation and its implications for Palaeolithic archaeology. Quaternary Science Reviews 29, 897–912. doi:http://dx.doi.org/10.1016/j.quascirev.2009.12.007.

Brown, A.G., Basell, L.S., Robinson, S., Burdge, G.C., 2013. Site distribution at the edge of the palaeolithic world: a nutritional niche approach. PLoS One 8, e81476 doi: http://dx.doi.org/10.1371/journal.pone.0081476.

Brown, A.G., Basell, L.S., Toms, P.S., 2015. A stacked late Quaternary fluvioperiglacial sequence from the Axe valley, southern England with implications for landscape evolution and Palaeolithic archaeology. Quaternary Science Reviews 116, 106–121.

Candy, I., Schreve, D., White, T.S., 2015. MIS 13-12 in Britain and the North Atlantic: understanding the palaeoclimatic context of the earliest Acheulean. Journal of Quaternary Science 30, 593–609.

Chartres, C.J., Whalley, W.B., 1975. Evidence of Late Quaternary solution of Chalk at Basingstoke, Hampshire. Proceedings of the Geologists' Association 86, 365–372.

Clark, C., Gibbard, P., Rose, J., 2004. Pleistocene glacial limits in England, Scotland and Wales. Developments in Quaternary Sciences 2, 47–82. doi:http://dx.doi.org/10.1016/S1571-0866(04)80056-3.

Clarke, M.R., 1981. The Sand and Gravel Resources of the Country North of Bournemouth, Dorset: Description of Parts of 1:25 000 Sheets SU00, 10, 20, SZ09, 19 and 29 NR051 Mineral Assessment Report IGS. .

Clarke, M.R., Green, C.P., 1987. The Pleistocene terraces of the Bournemouth - Fordingbridge area. In: Barber, K.E. (Ed.), Wessex and the Isle of Wight, Field Guide, , pp. 58–64.

Davis, R.J., 2013. Palaeolithic Archaeology of the Solent River : Human Settlement History and Technology. .

Delair, J.B., Shackley, M.L., 1978. The Fisherton brickpits; their stratigraphy and fossil contents. Wiltshire Archaeological and Natural History Magazine 73, 3–18.

Duller, G.A.T., 2008. Luminescence Dating: Guidelines on Using Luminescence Dating in Archaeology. English Heritage, Swindon doi:http://dx.doi.org/10.1016/j.apradiso.2007.07.020.

Edwards, R.A., Freshney, E.C., 1987. Geology of the Country Around Southampton. Memoir for 1:50.000 Geological Map Sheet 315 (England and Wales). HMSO, London.

Egberts, E., 2017. The Palaeolithic of the Avon Valley. A Geoarchaeological Approach to the Hominin Colonisation of Britain. Unpublished PhD thesis. Bournemouth University.

Egberts, E., Basell, L.S., Toms, P.S., 2019. Quaternary Landscape Change and Evidence of Hominin Presence in the Avon Valley. The Quaternary Fluvial Archives of the Major English Rivers. INQUA 2019 Field Guide Ed. (Accepted). QRA.

Egberts, E., Basell, L.S., Welham, K., Toms, P.S., 2020. A Local Perspective on Hominin Landscape Use During the Late Middle Pleistocene. Evidence From a Northwest European River Valley. (In press). .

Green, J.F.N., 1946. The terraces of Bournemouth Hants.. Proceedings of the Geologists' Association 57, , pp. 82–101.

Green, C.P., Keen, D.H., McGregor, D.F.M., Robinson, J.E., Williams, R.B.G., 1983. Stratigraphy and environmental significance of Pleistocene deposits at Fisherton, near Salisbury, Wiltshire. Proceedings of the Geologists' Association 94, , pp. 17–22.

Harding, P., Bridgland, D.R., Allen, P., Bradley, P., Grant, M.J., Peat, D., Schwenninger, J., Scott, R., Westaway, R., White, T.S., 2012. Chronology of the Lower and Middle Palaeolithic in NW Europe : developer-funded investigations at Dunbridge, Hampshire, southern England. Proceedings of the Geologists' Association 123, 584–607. doi:http://dx.doi.org/10.1016/j.pgeola.2012.03.003.

Hatch, M., 2014. The Pleistocene Solent River and Its Major Tributaries: Reinterpreting the Fluvial Terrace Stratigraphy As a Framework for the Palaeolithic Archaeology of the Solent Region. PhD thesis. University of London, Queen Mary College doi:http://dx.doi.org/10.1017/CBO9781107415324.004.

Head, M.J., Pillans, B., Farquhar, S.A., 2008. The Early – middle Pleistocene Transition : characterization and proposed guide for the defining boundary. Episodes 31, 255–259.

Hopson, P.M., Farrant, A.R., Newell, A.J., Marks, R.J., Booth, K.A., Bateson, L.B., Woods, M.A., Wilkinson, I.P., Brayson, J., Evans, D.J., 2006. Geology of the Salisbury sheet Area. British Geological Survey Internal Report IR/06/011, British Geological Survey Internal Report. Keyworth, Nottingham.

Hopson, P.M., Farrant, A.R., Newell, A.J., Marks, R.J., Booth, K.A., Bateson, L.B., Woods, M.A., Wilkinson, I.P., Brayson, J., Evans, D.J., 2007. Geology of the Salisbury district - a brief explanation of the geological map. Sheet Explanation of the British Geological Survey. 1:50 000 Sheet 298 Salisbury (England and Wales). Keyworth, Nottingham.

Hosfield, R., 2011. The british lower palaeolithic of the early middle pleistocene. Quaternary Science Reviews 30, 1486–1510. doi:http://dx.doi.org/10.1016/j.quascirev.2010.02.026.

Jones, A.P., Tucker, M.E., Hart, J.K. (Eds.), 1999. The Description and Analysis of Quaternary Stratigraphic Field Sections. Technical Guide No. 7. Quaternary Research Association, London.

Kovacs, J., 2008. Grain-size analysis of the Neogene red clay formation in the Pannonian Basin. International Journal of Earth Sciences 97, 171–178. doi:http://dx.doi.org/10.1007/s00531-006-0150-2.

Kubala, M., 1980. The Sand and Gravel Resources of the Country Around Fordingbridge, Hampshire: Description of 1:25 000 Resource Sheet SU11 and Parts of SU00, SU01, SU10, SU20 and SU21 NR050 Mineral Assessment Report IGS. .

Leeder, M.R., 1982. Sedimentology. Process and Product. George Allen & Unwin Ltd, London.

Lisiecki, L.E., Raymo, M.E., 2005. A Pliocene-Pleistocene stack of 57 globally distributed benthic $d^{18}O$ records. Paleoceanography 20, PA1003 doi:http://dx.doi.org/10.1029/2004PA001071.

Lyell, C., 1827. On some fossil bones of the elephant and other animals found near Salisbury. Proceedings of the Geological Society of London 1, 25–26.

Maddy, D., 1997. Uplift-driven valley incision and river terrace formation in southern England. Journal of Quaternary Science 12, 539–545. doi:http://dx.doi.org/10.1002/(SICI)1099-1417(199711/12)12:6<539::AID-JQS350>3.3.CO;2-K.

Maddy, D., Bridgland, D.R., Green, C.P., 2000. Crustal uplift in southern England: evidence from the river terrace records. Geomorphology 33, 167–181. doi: http://dx.doi.org/10.1016/S0169-555X(99)00120-8.

Markey, B.G., Botter-Jensen, L., Duller, G.A.T., 1997. A new flexible system for measuring thermally and optically stimulated luminescence. Radiation Measurements 27, 83–89.

Mejdahl, V., 1979. Thermoluminescence dating: beta-dose attenuation in quartz grains. Archaeometry 21, 61–72.

Miall, A.D., 1996. The Geology of Fluvial Deposits. Sedimentary Facies, Basin Analysis, and Petroleum Geology. Springer, Berlin.

Murray, A.S., Wintle, A.G., 2003. The single aliquot regenerative dose protocol: potential for improvements in reliability. Radiation Measurements 37, 377–381. doi:http://dx.doi.org/10.1016/S1350-4487(03)00053-2.

Olley, J.M., Murray, A.S., Roberts, R.G., 1996. The effects of disequilibria in the uranium and thorium decay chains on burial dose rates in fluvial sediments. Quaternary Science Reviews 15, 751–760. doi:http://dx.doi.org/10.1016/0277-3791(96)00026-1.

Parks, D.A., Rendell, H.M., 1992. Thermoluminescence dating and geochemistry of loessic deposits in Southeast England. Journal of Quaternary Science 7, 99–107. doi:http://dx.doi.org/10.1002/jqs.3390070203.

Pawley, S.M., Toms, P.S., Armitage, S.J., Rose, J., 2010. Quartz luminescence dating of Anglian Stage (MIS 12) fluvial sediments: comparison of SAR age estimates to the terrace chronology of the Middle Thames valley, UK. Quaternary Geochronology 5 (5), 569–582. doi:http://dx.doi.org/10.1016/j.quageo.2009.09.013.

Pettitt, P.B., White, M.J., 2012. The British Palaeolithic; Human Societies at the Edge of the Pleistocene World. Roetledge, Abingdon.

Prescott, J.R., Hutton, J.T., 1994. Cosmic ray contributions to dose rates for luminescence and ESR dating: large depths and long-term time variations. Radiation Measurements 23, 497–500.

Read, J.C., 1885. The flint implements of Bemerton and Milford Hill, near Salisbury. Wiltshire Archaeology and Natural History Magazine., , pp. 117–123.

Reid, C., 1898. The geology of the country around Bournemouth. Explanation of Sheet 329. Memoirs of the Geological Survey. Wyman and Sons Limited, London.

Reid, C., 1902. The geology of the country around Ringwood. Explanation of Sheet 314. Memoirs of the Geological Survey. Wyman and Sons Limited, London, England and Wales.

Reid, C., 1903. The geology of the counrty around Salisbury. Explanation of Sheet 298. Memoir of the Geological Survey. Wyman and Sons Limited, London, England and Wales doi:http://dx.doi.org/10.1007/s13398-014-0173-7.2.

Reynolds, P.J., Catt, J.A., Weir, A.H., Fisher, G.C., 1996. Stratigraphy and origin of new forest brickearths, England. Journal of Quaternary Science 11, 203–216.

Rose, J., Lee, J.A., Kemp, R.A., Harding, P.A., 2000. Palaeoclimate, sedimentation and soil development during the last glacial stage (Devensian), Heathrow Airport, London, UK. Quaternary Science Reviews 19, 827–847. doi:http://dx.doi.org/10.1016/S0277-3791(99)00094-3.

Schreve, D.C., 2001. Differentiation of the British late Middle Pleisto- cene interglacials: the evidence from mammalian biostratigraphy. Quaternary Science Reviews 20, 1693–1705.

Schwenninger, J., Bates, M.R., Briant, R.M., Wenban-Smith, F.F., 2007. Further Optically Stimulated Luminescence (OSL) Dates of Quaternary Deposits From the Sussex / Hampshire Coastal Corridor. English Heritage Research Department Report Series 55/2007. .

Sealy, K.R., 1955. The terraces of the salisbury avon. The Geographical Journal 121, 350–356.

Thiel, C., Buylaert, J.P., Murray, A., Terhorst, B., Hofer, I., Tsukamoto, S., Frechen, M., 2011. Luminescence dating of the Stratzing loess profile (Austria) - testing the potential of an elevated temperature post-IR IRSL protocol. Quaternary International 234 (1–2), 23–31.

Toms, P.S., 2013. Optical dating. Quaternary History and Palaeolithic Archaeology in the Axe Valley at Broom. Oxbow, South West England, pp. 157–164 ISBN 978-1-84217-520-0.

Toucanne, S., Zaragosi, S., Bourillet, J.F., Cremer, M., Eynaud, F., Van Vliet-Lanoë, B., Penaud, A., Fontanier, C., Turon, J.L., Cortijo, E., Gibbard, P.L., 2009a. Timing of massive “Fleuve Manche” discharges over the last 350 kyr: insights into the European ice-sheet oscillations and the European drainage network from MIS 10 to 2. Quaternary Science Reviews 28, 1238–1256. doi:http://dx.doi.org/10.1016/j.quascirev.2009.01.006.

Toucanne, S., Zaragosi, S., Bourillet, J.F., Gibbard, P.L., Eynaud, F., Giraudeau, J., Turon, J.L., Cremer, M., Cortijo, E., Martinez, P., Rossignol, L., 2009b. A 1.2 Ma record of glaciation and fluvial discharge from the West European Atlantic margin. Quaternary Science Reviews 28, 2974–2981. doi:http://dx.doi.org/10.1016/j.quascirev.2009.08.003.

Vandenberghe, J., 2013. Grain size of fine-grained windblown sediment: a powerful proxy for process identification. Earth-Science Reviews 121, 18–30. doi:http://dx.doi.org/10.1016/j.earscirev.2013.03.001.

Please cite this article in press as: E. Egberts, et al., Pleistocene landscape evolution in the Avon valley, southern Britain: Optical dating of terrace formation and Palaeolithic archaeology, Proc. Geol. Assoc. (2020), https://doi.org/10.1016/j.pgeola.2020.02.002

Wenban-Smith, F.F., Bates, M.R., Schwenninger, J.L., 2010. Early Devensian (MIS 5d-5b) occupation at Dartford, southeast England. Journal of Quaternary Science 25, 1193–1199. doi:http://dx.doi.org/10.1002/jqs.1447.

Wessex Archaeology, 1993. Southern Rivers Palaeolithic Project Report No. 1. 1991-1992. The Upper Thames Valley, the Kennet Valley and the Solent Drainage System, Salisbury.

Westaway, R.C., Bridgland, D.R., White, M.J., 2006. The Quaternary uplift history of central southern England: evidence from the terraces of the Solent River system and nearby raised beaches. Quaternary Science Reviews 25, 2212–2250. doi: http://dx.doi.org/10.1016/j.quascirev.2005.06.005.

Westlake, E., 1889. Outlines of the Geology of Fordingbridge and Neighbourhood, Including the Valley of the Avon. Titus Mitchell, Fordingbridge.

Westlake, E., 1902. Note on Recent Discoveries of Palaeolithic and Eolithic Implements in the Valley of the Avon. King's Fordingbridge Almanack, Fordingbridge.

White, M.J., Bridgland, D.R., Schreve, D.C., White, T.S., Penkman, K.E.H., 2018. Well-dated fluvial sequences as templates for patterns of handaxe distribution: understanding the record of Acheulean activity in the Thames and its correlatives. Quaternary International 480, 118–131. doi:http://dx.doi.org/10.1016/j.quaint.2017.03.049.

Wintle, A.G., Murray, A.S., 2006. A review of quartz optically stimulated luminescence characteristics and their relevance in single-aliquot regeneration dating protocols. Radiation Measurements 41, 369–391. doi:http://dx.doi.org/10.1016/j.radmeas.2005.11.001.

Wymer, J.J., 1999. The Lower Palaeolithic Occupation of Britain, Volume 1. Trust for Wessex Archaeology Ltd, Salisbury Text.

Zimmerman, D.W., 1971. Thermoluminescent dating using fine grains from pottery. Archaeometry 10, 26–28.

Please cite this article in press as: E. Egberts, et al., Pleistocene landscape evolution in the Avon valley, southern Britain: Optical dating of terrace formation and Palaeolithic archaeology, Proc. Geol. Assoc. (2020), https://doi.org/10.1016/j.pgeola.2020.02.002