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Resolving the late Pleistocene (MIS3–1) sedimentary sequence from Doniford, UK: Implications for British-Irish ice sheet extent, megafaunal history and hominin occupation

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ABSTRACT

We present a new Optically Stimulated Luminescence (OSL) chronology, detailed sedimentological evidence, new palynological data and a new Palaeolithic artefact from a classic site known for over 100 years. The fluvioperiglacial sedimentary sequence and chronology irrevocably indicates that the BIIS did not reach the north shore of the SW peninsular of the British Isles in MIS 3–2. Both the sedimentology and palynology suggests cool–cold steppic conditions rather than polar desert. The discovery during this project of a new unrolled bout coupé biface is significant since it adds another westerly example of this characteristic Middle Palaeolithic form associated with Neanderthals, that is relatively common in Britain (compared to Europe). The chronology and sedimentology also confirm the likely reworking of the cold fauna and Acheulian artefacts from regional floodplains prior to MIS 3. The site highlights the archaeological potential of actively eroding cliffs for expanding knowledge of hominin occupations of south–western Britain, near to an 'edge' of the Middle Palaeolithic world.

1. Introduction

Doniford on the north Somerset coast near Watchet (Lat. 51.180464, Long. −3.307559/NGR 308701E, 143172N, Fig. 1) is one of the most westerly stratified sequences in Europe from which Palaeolithic archaeology has been recovered and was close to the maximum extent of the British-Irish Ice sheet (BIIS). Since 1827 CE the extensive exposures of stratified loams, sands, silts and gravel have yielded fragments of mammoth, woolly rhinoceros and lithic artefacts designated as Bronze Age/Neolithic, Mesolithic and Palaeolithic. The deposits from which the archaeology derives have been minimally studied and remained undated. Basic mapping in the 1940s followed by a more detailed study in the 1970s addressed whether the deposits were of glacial origin (Gilbertson and Mottershead, 1975). These authors concluded the deposits were periglacially reworked river gravels of the former Washford River, largely of Devensian age (Gilbertson and Mottershead, 1975).

Starting in 2006 the Palaeolithic Rivers of South West Britain (PRoSWeB) Project re–investigated these deposits, best exposed in a cliff section east of Watchet. The principal aim of this research was to understand the genesis of the gravels, and how and when the Lower–Middle Palaeolithic artefacts and Pleistocene fauna came to be incorporated within them. A freshly eroded 150 m section was recorded in detail with sedimentological logs and samples taken for pollen analysis and Optically Stimulated Luminescence (OSL) dating. Here we present these data and a revised interpretation for the formation of the deposits and their antiquity. The context of the artefacts is re–evaluated, alongside an analysis of a bout coupé biface which was discovered during a Quaternary Research Association fieldtrip to Doniford in 2011. This research has made it possible to establish the relationship of the deposits and artefacts to other fluvial deposits and Palaeolithic findspots

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in Somerset and consider their relevance to current debates about the glaciation of the Bristol channel and paraglacial processes (e.g. Rolfe et al., 2012, 2014; Carr et al., 2017; Gibbard et al., 2017; Murton and Ballantyne, 2017; Smedley et al., 2017). The geoarchaeological approach and interpretation has important taphonomic implications for many North West European Palaeolithic sites that contain mixed lithic and faunal assemblages.

2. Regional setting

2.1. Bedrock geology & topography

The Doniford valley lies between the Brendon Hills and Exmoor which rise to the south west and the Quantocks to the south east (Fig. 1).

The bedrock geology of the surrounding hills comprises Devonian Hangman Grits, grey sandstones, slates with some limestone (Edwards, 1999). There are also Permian pebble beds of quartzites, greywacke, vein quartz, and sandstones, and Triassic Mercia Mudstones which include red marls, grey and green siltstones, gypsum and calcite horizons, grey and black shales (Fig. 2).

Whilst Exmoor trends E–W, the Quantocks trend NW–SE and the two massifs have been faulted and uplifted creating a half rift (or graben) between them (Robinson, 2006) (Fig. 2). This lowland area has acted as a depo–centre accumulating sediments. During the Pleistocene, sediment was only derived from the erosion of the surrounding hills. This is because the Doniford valley is separated by a bedrock ridge from the Tone Valley to the south. At Doniford, Liassic (Lower Jurassic) blue clays with loose blocks of limestone outcrop on the beach and are important because they show evidence of periglacial plucking (Murton and Ballantyne, 2017). The Blue Lias can be seen directly beneath the Doniford gravels in the cliff exposure, where it forms an undulating wave–cut platform.

The Quantocks are dissected by incised minor combes, and near Watchet narrow valleys have been eroded into bedrock by water from the Exmoor–Brendon Hills. The hills, rounded by erosion, contrast with the low coastal plain of late Triassic Mercia Mudstones (Robinson, 2006). The areas underlain by Mercia Mudstones are marked by strong red soils, clearly visible around Doniford. Small streams drain into the structural valley formed by the half rift, which runs from Taunton to the coast. The low, flat, east–west interfluve between Tolland and West Bagborough divides drainage with the southern part of this tectonic valley flowing into the River Tone, and the northern part flowing into Doniford stream and Washford River. Both are "misfit" rivers far too small for the size of the valley and floodplains into which they are incised (Brown, 1997).

2.2. Previous interpretations of the superficial geology and its antiquity

During British Geological Survey (BGS) re–mapping of this area in 1994 designations of the superficial deposits were largely derived from the 1970s mapping. River terrace deposits were mapped in three areas within the catchment: an undifferentiated fragment at Lower Vexford

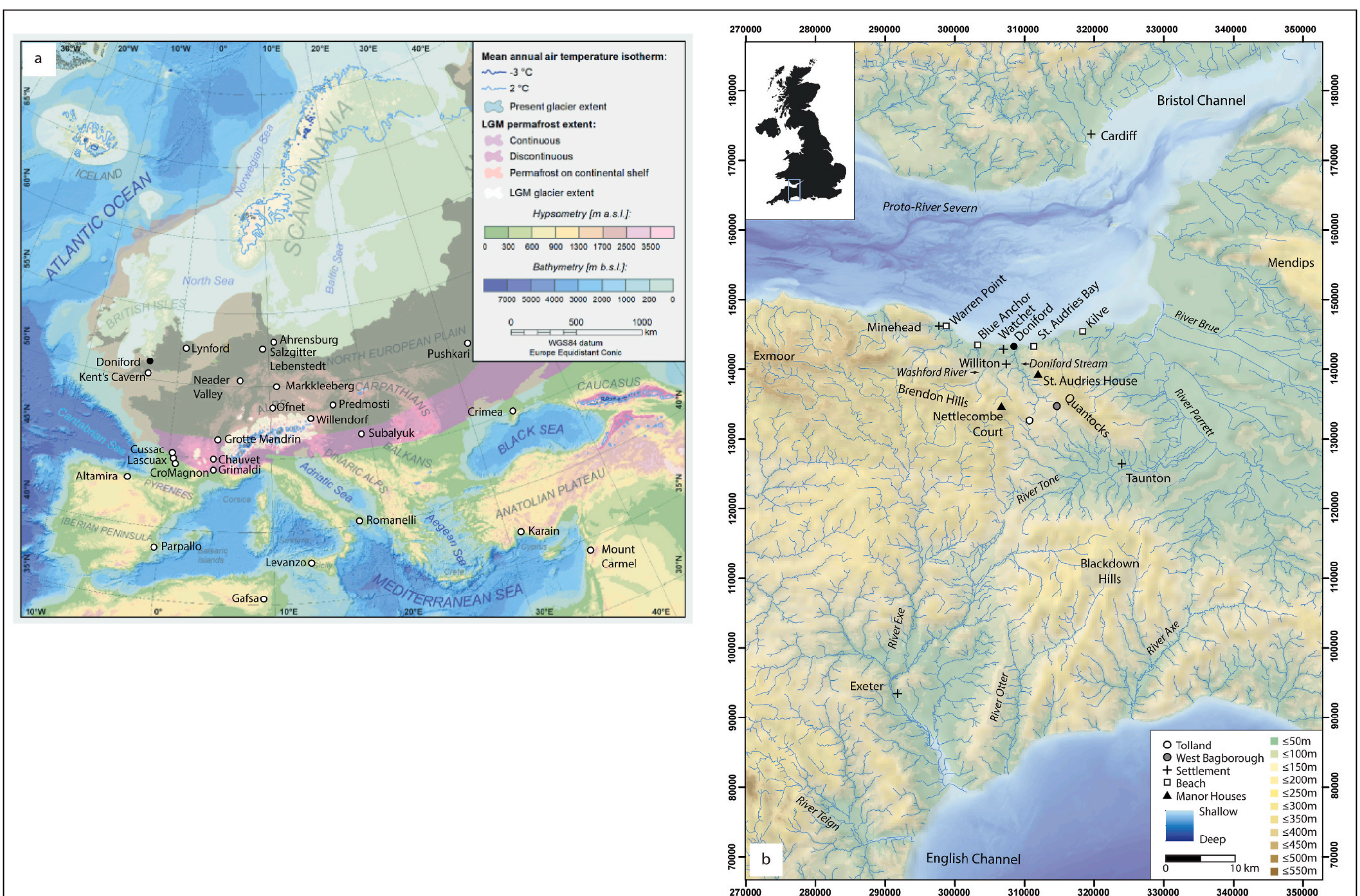


Fig. 1. a) Map of Europe at the LGM adapted from Oliva et al., (2023) to include selected key Upper Palaeolithic sites. Map shows the distribution of continuous, discontinuous permafrost, continental shelf permafrost and glaciers during the LGM versus current Mean annual air temperature isotherms of 2 °C (defining current periglacial realm) and −3 °C (defining current continuous permafrost) and current glacier extent. b) Map showing places mentioned in the text against current topography of the Doniford region including Bristol Channel bathymetry and current fluvial network. Modelled in ArcGISPro 3.3.0 using DEM and fluvial network derived from Digimap data licenced to the University of Leicester and EMODnet Digital Bathymetry (DTM, 2022).

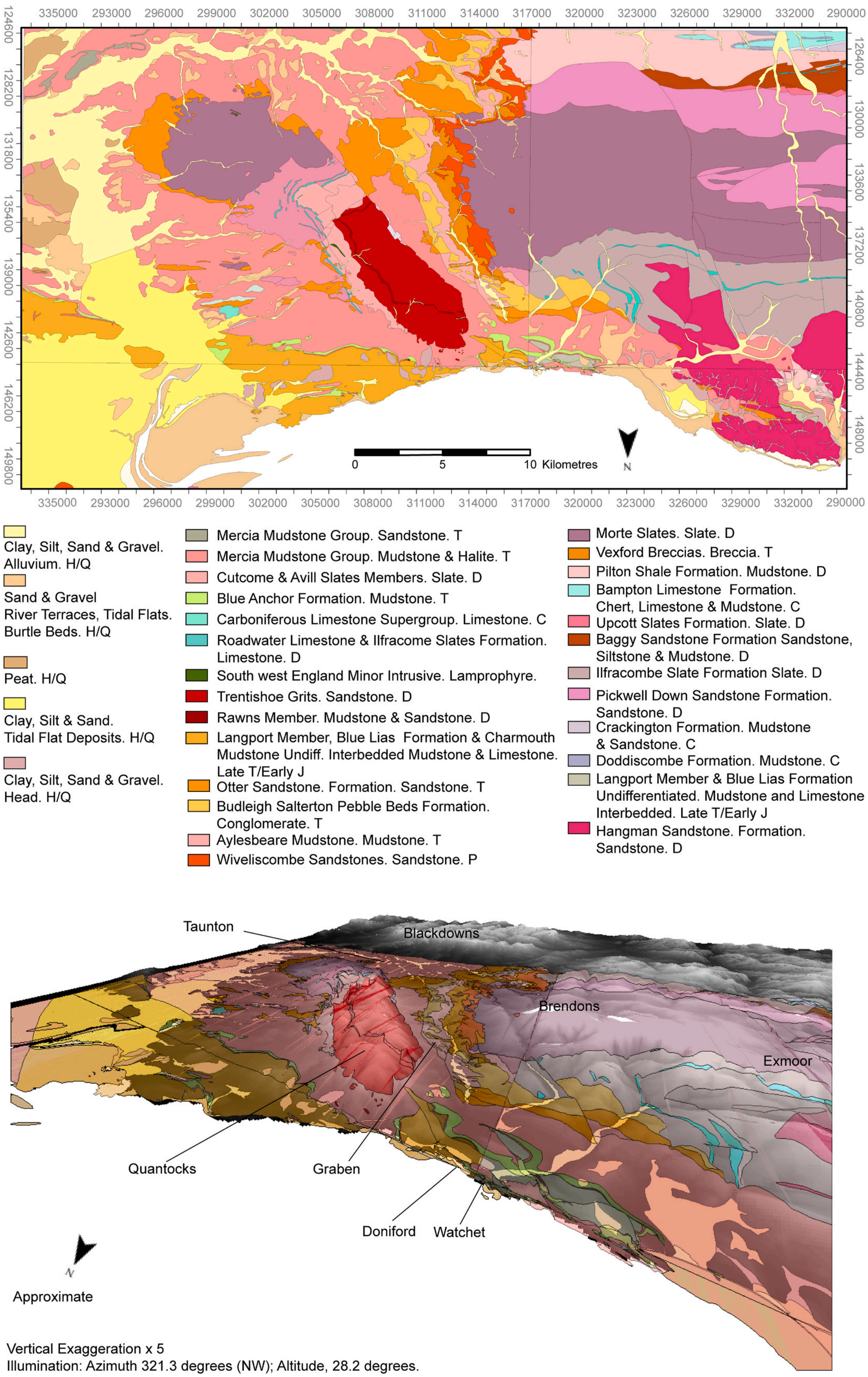
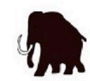
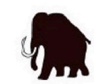
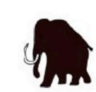


Fig. 2. Geology of the North Somerset area as mapped by the British Geological Survey 1:50,000 and drape of the geology over the vertically exaggerated, hillshaded DEM of the Doniford–Washford valleys looking south east. Modelled in ArcGIS using BGS data and DEM derived from Digimap data licenced to University of Leicester.

Farm, between 80 and 85m OD west of Doniford stream, and three adjacent deposits north of Lower Weacombe designated as River terrace deposit 2 at 80–100 m OD, and a fragment at Williton around 30 m OD (Fig. 4b shows the former two). Whittaker and Green (1983) classified the Doniford gravels as head deposits, but examination of Whittaker's 1:10,000 field slips shows more detailed descriptions of "*flat topped gravel spread*", and "*terrace like level in gravel spread*". He noted strong cryoturbation features in the gravels to the east of Doniford at Helwell Bay, discontinuous cross–bedding to the west of Doniford Farm, and "*purplish–red gravely loam*". His uncertainty over classification reflects

Table 1

Summary review of Pleistocene faunal remains from Doniford and immediate vicinity. Figs. 1 and 6 show photographs of Watchet museum mammoth remains. HER = Historic Environment Record database numbers, https://www.somersetheritage.org.uk/ References cited in Table 1 are: Trevelyan, 1839; Buckland, 1841; Page, 1895; Günther, 1904 Wedlake, 1950; Poole, 1864; Lant Carpenter, 1868; Boyd Dawkins, 1872; Nichols, 1891;Page, 1906;Ussher, 1908; Grinsell, 1970; Additions to the Museum from October 13th 1917 to October 11th (Council Day), 1918: VI. Natural History (2) Fossils, Botanical Specimens etc, 1918, Additions to the Museum: VI. Natural History (1) animals, etc. Notes of the Fifty-seventh annual meeting, 1905; McDonnell, 2001;Chadwick and Catchpole, 2013a, 2013b

Entry	Year of discovery	Finder	Place	Specific Discovery Location	Details	Sources	Estimated Minimum Number of Animals	
1	1801 or 1835	Sir John Trevelyan 4th or 5th. Possibly Mr (Rev'd E.) Webb.	Near Watchet	"*Bed of the Severn near Watchet...found 38 years ago*" (Buckland 1839, p.138). "*Bed of Bristol channel near Watchett* [sic]...*found 3 or 4 years ago*" (Buckland, 1841, p.163). Foreshore off the mouth of Doniford stream (Page 1895 citing Somerset County Gazette 1882)	Very large molar. In 1839 John Trevelyan (5th Baronet) from Nettlecombe Court owned it. By 1882 tooth posessed by his cousin "Mr Spencer G. Percival [sic] of Henbury Clifton". Spencer George Perceval presented the tooth either to the Trevelyan museum at Wallington or the British Museum in 1902. Page and Wedlake give dimensions as 13 inches x 6 inches. Weight 11 lb.	Trevelyan, 1839, p.138. Buckland 1841, p.163. Page 1895 citing Somerset County Gazette Sept 9 1882. Günther 1904. Wedlake 1950.	Due to varying accounts of discovery dates and locations, could potentially all be from the same mammoth.	
2	1827	Inmate at Williton Workhouse	Doniford	Within gravel being dug on the beach	Complete mammoth molar. 12lb in weight and 1 foot long.	Taunton Courier March 1827. Wedlake 1950		
3	1835	Reports vary. Teeth and possibly whole skull and tusks found by Mr Webb (possibly Rev. E. Webb?) and later obtained by Sir Alexander Fuller-Acland-Hood. Lant Carpenter (1866, p.47) reports Fuller-Acland-Hood found the tusks a few year's after Webb lifted the teeth.	St Audries below the cliff (Poole 1864) or foreshore off the mouth of Doniford Stream, (Page 1895).	From clay and gravel deposits between parrallel reefs of Lias with their northern edges tilted up at the cliff at St Audries. (Poole 1864, p.120). "The probability of these remains having been washed out of the seaward extension of the Doniford gravel must be admitted" Ussher (1908, p.78). See also entry number 13 below.	Mammoth (*Elephas primigenius*) skull with teeth and tusks. Deposited at St Audries House (Page 1895; Nichols 1891). St Audries House purchased by Sir Peregrine Acland in 1836 from Rev. Elias Webb. Inherited by Acland's daughter and her husband Sir Alexander Fuller-Acland-Hood (Nichols 1891; Historic England listing). Tusks 4 inches in diameter at small end and 8 inches at larger end. 4 feet 6 inches long. Very curved (Poole 1864).	Poole 1864; Lant Carpenter 1868; Boyd-Dawkins 1872; Nichols 1891; Page 1895; Ussher 1908; Wedlake 1950; Grinsell 1970.		
4	1861	Not specified.	Watchet	During Watchet harbour deepening.	Two mammoth tusks.	Wedlake 1950; Grinesll 1970.	1 mammoth.	
5	February 1899	Mr W.A. Rixon presented tusk to Taunton Museum.	Kilve	On Kilve shore, Somerset, near the mouth of the Pill Stream.	Mammoth tusk.	n.d. Additions to the Museum, 1904-1905, p.85. Wedlake 1950; Grinsall 1970.	Could be the same individual.	
6	1917	Rev. D.H. James.	Kilve	Shore	Mammoth molar tooth portion.	n.d. Additions to the Museum, 1917-1918, p.67. Wedlake 1950; Grinsall 1970.		
7	1947	Mr A.L.Wedlake.	Doniford	Shore	Mammoth molar tooth portion.	Wedlake 1950. Photographed by L. Basell in 2006 on display in Watchet Museum by label indicating they were found in the Doniford Gravels. Labelled AC2.1 and AC 2.2. HER 27209.	Could be the same individual.	
8	1949	Mr A.L.Wedlake.	Doniford	In situ embedded in the lower cliff gravels	Mammoth molar tooth portion identified as *Elephas primigenius*.			
9	1950	Mr A.L.Wedlake.	Doniford	In situ embedded in a patch of clayey gravel. These were the lower gravels which were exposed following scouring of the beach by strong tides. This removed the sand and pebbles and exposed the lower gravels. Grid reference 309400, 143400	Large mammoth tusk.	Wedlake 1950; HER 27208.		
10	Sping 1993	Mr Colin Nurton	Kilve Beach	Near low water on a Spring Tide	Mammoth tusk fragment. Dontated to Watchet museum by Chris Norman (co-author this paper) from North Petherton in 2007 and on display there.	Photographed by L. Basell in 2006 on display in Watchet Museum with label. See Fig 7.	Could be part of same tusk under entry 5. Very small.	
11	2001	Mr Paul Date and Mr Mike Martin. Identified by Dr Jay Weinstock (University of Southampton).	Off Warren point (caught while fishing)	Grid Reference 298502, 147795	Initially thought to be auroch *Bos primigenius*, pelvis was formally identified as Woolly Rhino, *Coelodonta antiquitatis*.	McDonnell, 2001, p.38. Site 85. HER 29281.	1 rhino.	
12	Not known but probably between 1940s and 2006 as finder born in 1938	Mr Anthony John Richards.	Foreshore at Blue Anchor	No more details known.	Mammoth molar on display in Watchet Museum labelled with details provided here. Photographed by L. Basell in 2006.	N/A	Probably 1 mammoth.	
13	29th October 2007 (HER 36861)	Mr Richard Brunning reported.	St Audrie's Bay	Grid Reference 310234,143738. Peat deposits. Only a few small lenses of peat were visible around the find spot, in a thin layer exposed amongst beach cobbles (Point No. 53). Peat was very organic and quite silty ~0.05m thick with grey clay lying on top of it, and blue-grey clay underneath. Unclear if this was an in situ peat bed, present as a thin layer interdigitated with Pleistocene gravel and cobble deposits, or if it was an eroded block derived from somewhere else further up the foreshore. Peat appeared contained within a possible palaeochannel ~1m wide, cutting through red marl on either side of it and with cobbles lying above.	Chadwick and Catchpole 2013, p.64 report a tooth. No faunal remains identified when find spot examined 10/08/2010 so it was unclear whether fauna comes from the reported palaeochannel or deposit it was cutting. However HER 37496 shows and records photograph of large bone. No dimensions provided. Presumably sent to Taunton museum.	Chadwick and Catchpole 2013, Vol. 1 p.64. Vol 3 p.74. HER 36861.	Potentially the same location and animal as that reported by Poole, 1864, now recorded as HER 37496. See entry 3 above.	
14	2008	Mr Steven Membury. Identified by Ms Lorrain Higbee of Wessex Archaeology.	Doniford	Doniford beach cliff face. Grid Reference 308515, 143041	Rhinocerous tooth.	HER 28376, 28375.	1 rhino.	

earlier accounts where the gravels are described as a “*kind of delta*” (Horner, 1816, 374). Others regarded them as anomalously thick river deposits or river terraces consisting of material derived from the Quantock Hills (Date, 1867; Thomas, 1940).

From the late 1940s, A.L. Wedlake who co–founded the Watchet Market House Museum, and his son, R. Wedlake, collected lithic artefacts and Pleistocene fauna eroding out of the sequence. They identified 3 divisions within the coastal exposure: an “Upper” deposit of post-glacial (Holocene) origin based on the presence of Mesolithic lithics; “Middle” gravels attributed to the last Interglacial; and “Lower” gravels they considered Hoxnian (MIS 11) which yielded “early to middle Acheulean” lithics (Wedlake and Wedlake, 1963) and mammoth remains (Wedlake, 1950). They viewed the whole valley as a former river–bed and tributary of the greater River Severn during the Palaeolithic (Wedlake and Welake, 1963).

In 1975 Gilbertson and Mottershead, undertook a geological study of the Doniford exposure partly in response to a suggestion that an ice sheet had travelled up the Bristol Channel and covered inland areas (Hawkins and Kellaway, 1971). In contrast to the Wedlakes’ interpretation, they argued that the gravels were neither river terraces, nor related directly to glacier ice; rather that the accumulation was re–worked, soliflucted and cryoturbated material. They reported some transport by running water, supported by analyses of clast roundedness, areas of weak bedding and channel–fill features, but were unable to determine convincing palaeoflow directions. However they postulated that the origin of the erosional concavity in the Lias on which the gravels rest, represented a long profile of a former river valley running W–E which had once flowed to a confluence with Doniford Stream (Gilbertson and Mottershead, 1975).

Gilbertson and Mottershead (1975) identified 5 major units from a typical section, attributing the sequence to a single cold, periglacial phase, with no major breaks in except for the uppermost loam, which they considered Flandrian (postglacial), forming under conditions of climatic amelioration and consistent with the Wedlakes’ interpretation. The deposits’ age was estimated using Wedlakes’ artefacts and sediment characteristics. They deemed mammoth remains unreliable for dating (due to the longevity of their presence in Britain) but the Acheulean bifaces led them to suggest the gravel sequence formed in the Wolstonian (MIS 10–6) or Devensian (MIS 5d–2) (Gilbertson and Mottershead, 1975).

2.3. Megafauna

Mammoth remains typically attributed to *Mammuthus primigenius* have been recovered from several locations along the West Somerset coast over the last 150 years (Wedlake, 1950). At Doniford, Wedlake’s mammoth tooth and tusk finds came directly from lower the gravels, which were also the source of the Acheulean bifaces (cf. Wedlake, 1950, 1973). More recently, rhinoceros (*Coelodonta antiquitas*) remains have also been found at, and near Doniford. A summary is provided in Table 1 with locations indicated in Fig. 1.

2.4. Lower and Middle Palaeolithic archaeology

C.W.K. Wallis found three handaxes at Doniford between 1913 and 1914 and corresponded with W. Boyd Dawkins about them (Wedlake and Wedlake, 1963; Wedlake, 1973). From 1948 onwards A.L. Wedlake collected and studied many more (Wedlake, 1950; Wedlake and Wedlake, 1963; R. Wedlake pers. comm. to LSB, 2006). A.L. Wedlake relocated one of Wallis’s artefacts with the assistance of Dr Mabel Tomlinson (Wedlake and Wedlake, 1963; Trowelblazers, 2016; **Supplementary Information (SI) 1** Table 1). Wedlake’s six–inch map record shows his finds were made over a distance of 2.5 km, extending eastwards from Doniford to the main beach in St Audrie’s Bay. Most were found to the east of the river between Doniford Holiday Camp and Swill Point (pers. comm. A.L. Wedlake to C.Norman (1975)).

Although A.L. Wedlake kept all the letters he received from many well–known archaeologists over a thirty–year period (copies are held at Somerset County Museum (SCM)), these contain no evidence that specialists examined his Palaeolithic discoveries. Wedlake’s approach to the British Museum in 1951 was politely declined and his 1945–1956 correspondence with A.D. Lacaille does not mention the examination of any Doniford finds. Roe’s 1968 gazetteer of Palaeolithic artefacts in Britain relies entirely on information supplied by A.L. Wedlake in a letter. Similarly, during fieldwork for the Southern Rivers Palaeolithic Project Survey in August 1993, J. Wymer and P. Harding saw only limited material on display in Watchet Museum and obtained other information from R. Wedlake. The result of this was that most of the claimed handaxes and Palaeolithic flakes had not been verified as artefacts.

On July 04, 2011 during a Quaternary Research Association fieldtrip to Doniford Dr Tom White found a bout–coupé handaxe lying on the top of the beach pebbles at the base of the eroding gravel section. The artefact is knapped on dark grey–black chert, and retains some white cortex. This find fits well within both the spatial and temporal distribution of bout–coupé handaxes in the British Isles (Jacobi and White, 2002; Wragg Sykes, 2010; White and Pettitt, 2011).

2.5. Upper Palaeolithic archaeology

There have been three claims that the exposure has yielded Upper Palaeolithic archaeology. A.L. Wedlake said he found Early Upper Palaeolithic artefacts on the foreshore, but these were never verified and their present location is unknown (Grinsell, 1970, 15). In 1972, two flint blades were found *in situ* in gravel exposed in the cliff face ~50m west of the stream (Norman, 1978). The cliff face drawn at the time (Fig. 3a) shows the larger blade (Fig. 3b) was found in a lens of fine, well–sorted gravel. This was overlain by up to a metre of coarser, poorly sorted material towards the base of which was found part of a second broken blade (Fig. 3b). Both artefacts are in an abraded, lustrous condition and display edge damage consistent with a small amount of movement within a gravel body.

Whilst the larger blade could date to the Early Upper Palaeolithic (~38–27 ka; see for example artefacts in Jacobi and Higham, 2011b), the closest parallels occur in the British Magdalenian (Late Upper Palaeolithic known locally as Creswellian) from assemblages such as Gough’s Cave, Cheddar. The Magdalenian (~23.5–13.5 ka; MIS 2) is one of several technocomplexes identified in Europe during the late Upper Palaeolithic (Marsh and Bello, 2023; Riede et al. 2024), although its appearance in Britain starts towards the end of this timespan in the form of the Final Magdalenian (Creswellian ~15.0–14.5 ka cal BP; Jacobi and Higham 2011a, 2011b). It is notable for complex lithic and bone technology as well as unusual artistic and ritualistic behaviours (Marsh and Bello, 2023). Recent research has highlighted similarities between the Cresswellian and the Classic Hamburgian, found in the northern Netherlands and lowlands of northern Germany and Poland (Grimm and Weber, 2008; Jacobi and Higham, 2011a). Although there is evidence of populations living in ice–marginal environments at the LGM in Europe (Terberger and Street, 2002; Reade et al., 2020), careful consideration of radiocarbon dates suggests that there is no evidence for the recolonization of southwestern Britain before 15,000 cal. BP (Jacobi, 2004; Jacobi and Higham, 2009, 2011a).

Finally, a small tanged point found by one of the authors (CN) in cliff–fall material just west of the stream is characteristic of Final Upper Palaeolithic (Ahrensburgian) industries in southeastern England, and the near continent, but in England similar artefacts also occur in Early Mesolithic assemblages. Although this artefact has been identified as an Ahrensburgian tanged point (Barton, 1997, 131), its fresh condition suggests it may originate from fine–grained deposits above the gravel, possibly indicating a Holocene date and Mesolithic attribution.

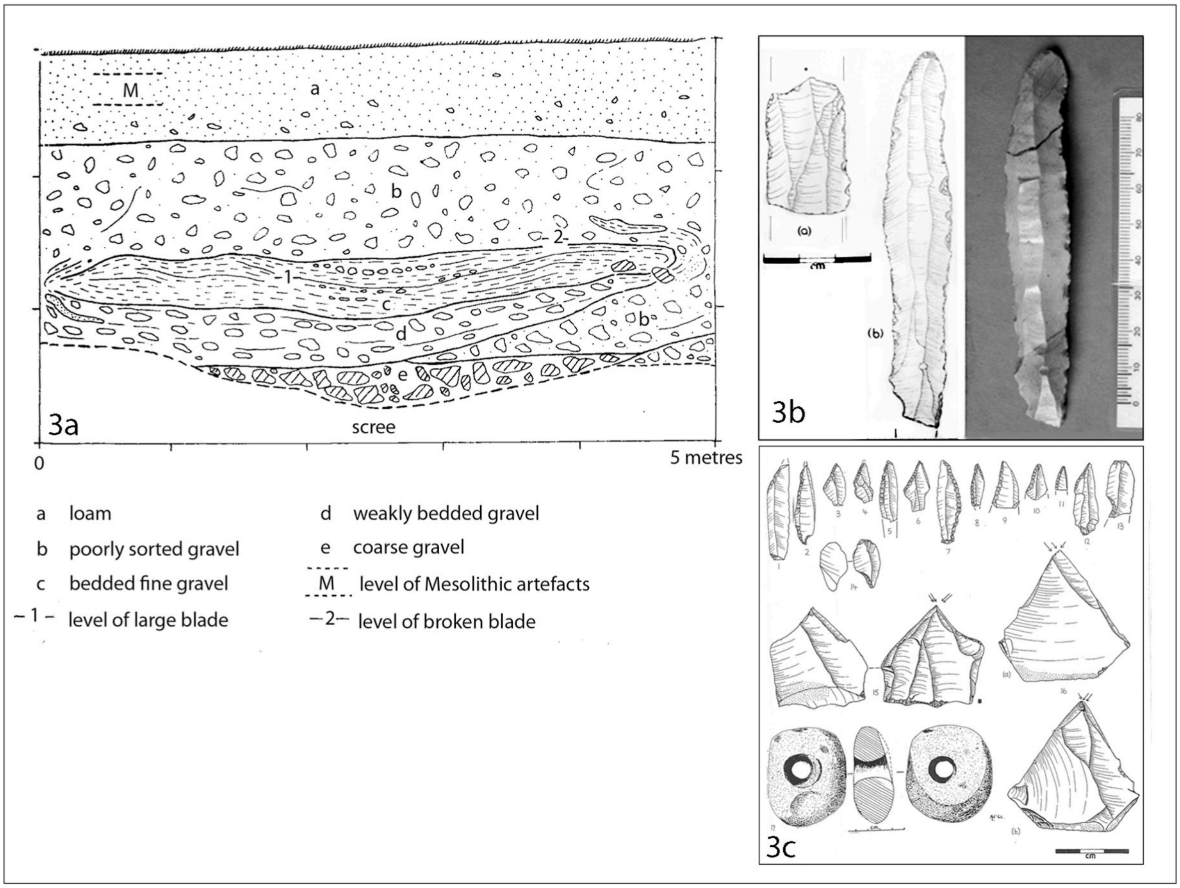


Fig. 3. (3a) Doniford gravels at 309030E 143240N, and artefacts derived from them: (3b) Upper Palaeolithic and (3c) Mesolithic artefacts after Norman (1975), 1978.

2.6. Mesolithic archaeology

A substantial quantity of Mesolithic material was collected by A. L. Wedlake from an area to the east of Doniford stream. Most artefacts appear to have come from the upper part of the loam exposed in a section of the low cliff centred on 309200E, 143300N, and from the adjacent shingle beach. By the early 1960s, this prolific findspot had been completely destroyed by coastal erosion (A.L. Wedlake pers. comm. to CN). Artefacts eroded from the site were published as an unmixed Early Mesolithic (Maglemosian) assemblage (Fig. 3c–Wedlake, 1973; Norman, 1975), but re–examination by CN leads us to consider that the assemblage may contain some later material and represent more than one phase of occupation. The bulk of the collection, including several large obliquely–backed microliths, end scrapers and two convincing burins remain likely to be of Early Mesolithic date and may be contemporary with material recorded from sites elsewhere in west Somerset and east Devon (Norman, 1975). Much of the Mesolithic material is on display in Watchet museum.

Given the generally accepted dates for the Early Mesolithic in England (*c.* 9600 BCE (Conneller et al., 2016)), it seems probable that this phase of occupation coincided with an early stage of the Holocene marine incursion into the Lower Severn valley, when Doniford would have lain some distance from the contemporary coastline. Finally, during the 1970s, Norman recorded a diffuse scatter of Mesolithic artefacts from the cliff face between the limekilns and the mouth of Doniford stream (Fig. 3) These artefacts occurred mainly in the uppermost 40–60 cm of loam and included an elongated triangular microlith of Late Mesolithic type found near the stream. None were found in the underlying gravels.

3. Methods

A general description of the geoarchaeological approach employed by PRoSWeB is summarised in Basell et al., 2011a. Only methodological information specific to the Doniford fieldwork is presented here.

3.1. Mapping, modelling and sedimentological logging

Geomorphological mapping was conducted in the area immediately surrounding the cliff exposure and upstream as far as Williton. British Geological Survey (BGS) maps were examined in detail and both the geomorphological and BGS 10" geological maps were georeferenced for manipulation within ArcGIS. Topographic analysis of digital elevation model (DEM) data from a variety of sources was conducted in ArcScene and ArcGISPro combining vertical exaggeration, drapes of geomorphological mapping, archaeological data, bedrock and superficial data (see Basell et al., 2011b and Fig. 4).

Historically, gravel exposures were recorded in the cliffs either side of Doniford Stream (Wedlake and Wedlake, 1963). In 2005 the cliff exposures to the east were obscured by large concrete sea defences, but significant gravel deposits remained visible to the west of the stream. From the stream's western edge to the edge of the limekiln path onto the beach (Fig. 4c), the gravel exposure was obscured by soil dumping and vegetation. West of the limekiln path, accessible and actively eroding exposures were recorded. Based on map regression, Wedlake's co–ordinates and our survey data of the exposure, the cliff section has eroded at ~1 m/year since 1940. Consequently, the 2006 exposure was "fresh" exposure of the same sedimentary sequence studied by Gilbertson and Mottershead (1975), located approximately 30 m further inland.

Detailed logging was completed to scale at 16 recorded locations.

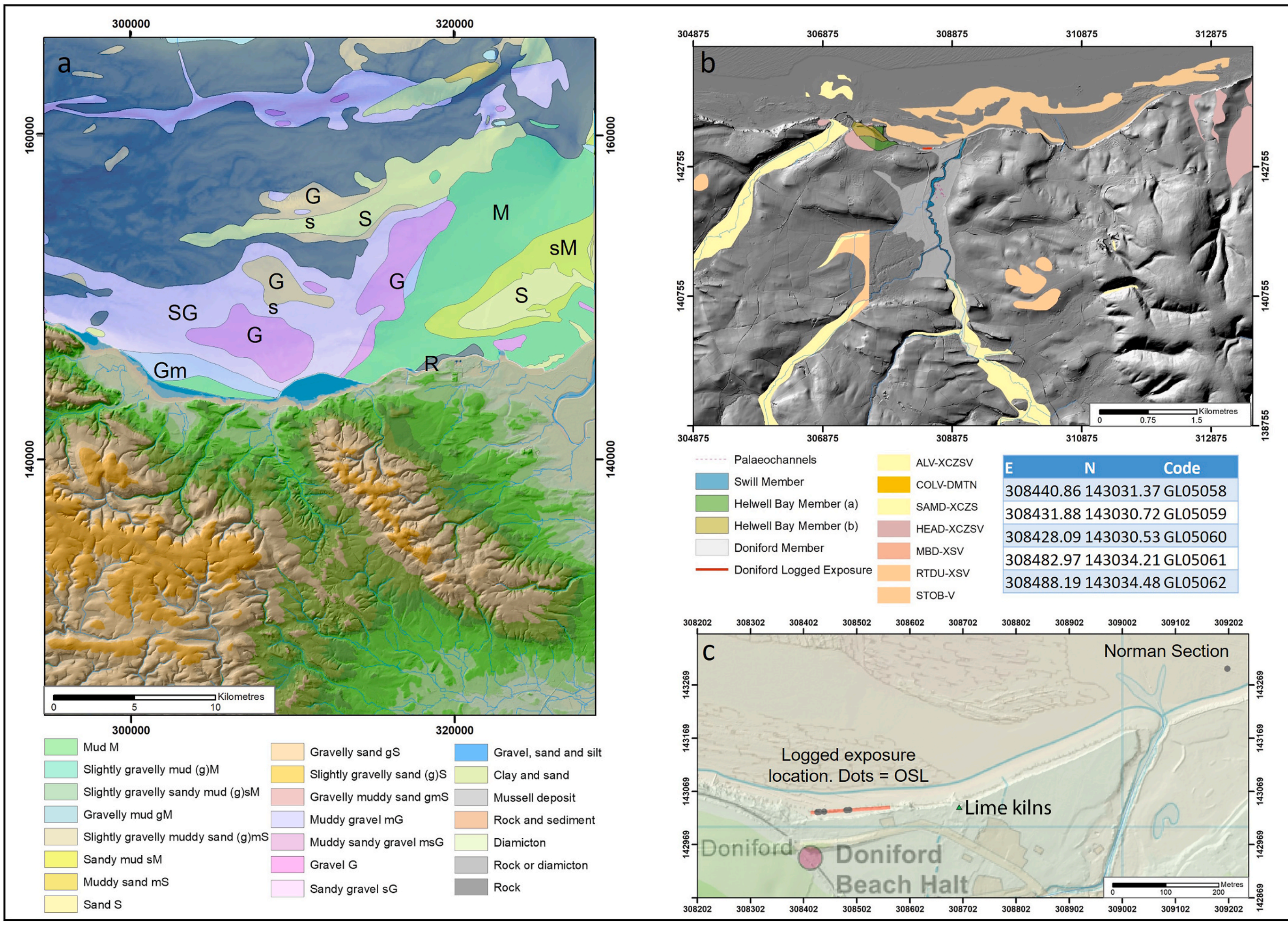


Fig. 4. a. Map showing sea-bed sediment types in the offshore geology adjacent to the Doniford coast as mapped by BGS DiGSBS250K (2011) under educational licence to University of Leicester via Digimap. Digital Elevation Model (DEM) of onshore area created from NASA Shuttle Radar Topography Mission (SRTM) (NASA Shuttle Radar Topography Mission, 2013). **b.** DEM modelled from LIDAR of the Doniford area draped with superficial geological data as mapped and classified by BGS 1:50,000 and geomorphological mapping. OSL sample co-ordinates are provided in the key. **c.** Detailed map showing location of logged exposure and Norman section (Fig. 3) in relation to the lime kilns. Graphics produced using ArcGIS Pro 3.3.0 and Adobe Suite licenced to the University of Leicester.

Deposits between the logs were photographed and major features were drawn and photographed (**SI2** Figs. 3–8). Clast roundedness and lithology were recorded during sediment logging, with occasional sampling for detailed lithological identification. At the westernmost end of the exposure, the Lias bedrock rises. A gravel deposit is still visible at the top of the section in the Helwell Bay area (**SI2** Fig. 7), but being inaccessible was impossible to study in detail or sample for dating. Sand and silt lenses suitable for OSL dating were identified within the gravel exposures.

3.2. OSL dating

Five OSL samples (GL05058 to GL05062; Table 1) were extracted from the section within opaque plastic tubing. Under red light conditions, provided by Encapsulaite RB-10 filters, fine sand (125–180 μm) or coarse silt (63–90 μm) quartz was isolated from each sample by means of dry sieving, alkali (15 % H_2O_2) and acid digestion (10 % HCl), acid etching (40 % HF, 60 min for fine sand, 15 min for coarse silt) and density separation, retaining <2.68 g cm^{-3}. Quartz grains were then mounted as 8 mm diameter, multi-grain aliquots on 10 mm diameter, 1 mm thick aluminium discs. Signal stimulation–detection and aliquot irradiation were conducted using a TL–DA–15 Risø system (Markey et al., 1997; Bøtter-Jensen et al., 1999). Equivalent dose (D_e) values were assessed using a single–aliquot regenerative–dose protocol (Murray and Wintle, 2000, 2003).

Optical stimulation was provided by an assembly of blue diodes (5 packs of 6 Nichia NSPB500S), filtered to 470 ± 80 nm conveying 15 mW cm^{-2} using a 3 mm Schott GG420 positioned in front of each diode pack. Infrared (IR) stimulation, provided by 6 IR diodes (Telefunken TSHA 6203) stimulating at 875 ± 80 nm delivering ~40 mW cm^{-2}, was used to indicate the presence of contaminant feldspars (Hütt et al., 1988). Stimulated photon emissions from quartz aliquots are in the ultraviolet (UV) range and were filtered from stimulating photons by 7.5 mm HOYA U-340 glass and detected by an EMI 9235QA photomultiplier fitted with a blue-green sensitive bialkali photocathode. Aliquot irradiation was conducted using a $^{90}Sr/^{90}Y$ β source calibrated for multi-grain aliquots of 63–90 μm (0.080 ± 0.003 Gy s^{-1}) and 125–180 μm (0.077 ± 0.003 Gy s^{-1}) quartz against the 'Hotspot 800' ^{60}Co γ source located at the National Physical Laboratory (NPL), UK. Optical stimulation occurred at 125 °C and test dosing to 5 Gy was followed by preheating at 220 °C for 10s. Measures of D_e preheat dependence and dose recovery were taken in order to evaluate the optimum thermal treatment following natural and laboratory irradiation (Table 2 and SI 3 Figs. 1–5). Dose recovery tests for GL05058 and GL05060 demonstrated significant underestimation (*c.* 10–15 %; Table 2 and SI 3 Figs. 1–5) of the applied laboratory doses, suggesting age estimates from these samples should be accepted tentatively. Recycling ratios (Murray and Wintle, 2000) of each aliquot in each sample were statistically consistent with unity, indicating

Table 2

Dr, De and Age data of quartz OSL samples extracted from Doniford, 51°N, 3°W, 7m. Age estimates expressed relative to year of sampling, 2005. Uncertainties in age are quoted at 1σ confidence, are based on analytical errors and reflect combined systematic and experimental variability and (in parenthesis) experimental variability alone. Blue indicates samples with accepted age estimates, red, age estimates that should be accepted tentatively owing to Dose Recovery test failure (SI 3 Figs. 1–5).

Field Code	Lab Code	Overburden (m)	Grain size (µm)	Moisture content (%)	NaI γ-spectrometry (*in situ*) γ D_r (Gy.ka^{-1})	Neutron Activation Analysis (*ex situ*)			β D_r (Gy.ka^{-1})	Cosmic D_r (Gy.ka^{-1})	Total D_r (Gy.ka^{-1})	Preheat (°C for 10s)	Recycling Ratio	Post-IR OSL Ratio	No. of Aliquots	CAM D_e (Gy)	Overdispersion (%)	Age (ka)
						K (%)	Th (ppm)	U (ppm)										
DON01	GL05058	6.3	125-180	15 ± 4	1.03 ± 0.04	1.75 ± 0.07	9.84 ± 0.42	3.34 ± 0.15	1.58 ± 0.14	0.08 ± 0.01	2.70 ± 0.14	260	1.04 ± 0.04	0.97 ± 0.03	13	136.7 ± 8.2	29 ± 6	50 ± 4 (3)
DON02	GL05059	6.3	63-90	17 ± 4	0.94 ± 0.03	1.77 ± 0.08	8.01 ± 0.35	2.30 ± 0.12	1.47 ± 0.14	0.08 ± 0.01	2.49 ± 0.15	240	1.00 ± 0.04	0.99 ± 0.04	12	162.5 ± 9.1	14 ± 3	65 ± 5 (4)
DON03	GL05060	6.6	125-180	18 ± 4	0.99 ± 0.03	2.96 ± 0.12	11.28 ± 0.48	3.07 ± 0.14	2.23 ± 0.22	0.08 ± 0.01	3.29 ± 0.22	240	1.04 ± 0.04	1.03 ± 0.03	11	148.4 ± 12.9	25 ± 6	45 ± 5 (4)
DON04	GL05061	5.0	125-180	18 ± 4	0.99 ± 0.03	2.51 ± 0.11	9.80 ± 0.42	2.48 ± 0.12	1.88 ± 0.19	0.09 ± 0.01	2.97 ± 0.19	260	1.02 ± 0.04	1.02 ± 0.04	7	145.7 ± 12.6	20 ± 6	49 ± 5 (5)
DON05	GL05062	4.0	125-180	16 ± 4	1.08 ± 0.04	3.17 ± 0.13	13.37 ± 0.56	2.97 ± 0.14	2.46 ± 0.23	0.11 ± 0.01	3.65 ± 0.23	260	1.01 ± 0.03	1.00 ± 0.04	9	89.8 ± 9.0	24 ± 6	25 ± 3 (3)

successful correction for OSL sensitivity change during regenerative-dose measurements.

The significance of feldspar contamination was assessed using the post–IR OSL depletion ratio (Duller, 2003) but was found to be negligible (Table 2 and SI 3 Figs. 1–5). D_e values based on 7 to 13 aliquots depending on the available datable material, were interpolated from an exponential plus linear fitted dose response using Analyst (Duller, 2015) and a central age model (Galbraith et al., 1999) was used to calculate geometric mean D_e values. Average Dose Model (Guérin et al., 2017) estimates of D_e centrality ranged from no difference to the CAM to 4 % higher, yet statistically indistinguishable from the CAM estimates. Overdispersion values range from 14 to 29 %, consistent with inter-grain D_e variation forced by variability in microdosimetry and experimental error alone, though insights from overdispersion between multi-grain aliquots will depend on the number of OSL-bearing grains per aliquot. Signal analysis (Bailey et al., 2003) did not reveal the presence of partial bleaching (SI 3 Figs. 1–5) and there were no *in situ*, visible indications of post–depositional turbation associated with the OSL sample positions. Terrestrial dose rate (D_r) was estimated through *in situ* NaI gamma spectrometry (for γ D_r) and Neutron Activation analysis (for β D_r), quantifying U, Th and K radionuclide concentrations and converting to D_r values (Adamiec and Aitken, 1998) incorporating the modulating effects of grain size (Mejdahl, 1979) and present moisture content (Zimmerman, 1971). Geographical and overburden–based calculations were adopted to evaluate Cosmic D_r (Prescott and Hutton, 1994). The quotient of D_e and D_r presented an estimate of burial age for each sample relative to the year of sampling (2005), with associated uncertainty premised upon propagated systematic and experimental errors.

3.3. Pollen analysis

The soft organic 'pebbles' recovered from Doniford Member–Unit 1 were sampled and analysed for pollen and spores (see Fig. 5 for sample locations). Due to the sandy nature of the pebbles 4 ml were processed using a standard chemical preparation but with a prolonged hydrofluoric acid stage and triple sieving. All counts were undertaken using a Nikon Optiphot microscope at a magnification of ×400, and ×1000 when needed. Identification of pollen grains and spores was aided with the use of standard keys and by comparison with modern pollen reference material (type slides) of the Department of Geography, University of Exeter and subsequently at the Palaeoenvironmental Laboratories University of Southampton (PLUS). Due to the low concentration (<100 grains ml^{-1}) only a low pollen sum was possible and so the inferences are limited; a problem common to glacial stage deposits, as discussed in the results section 4.3.

3.4. Archaeological analyses

The Palaeolithic artefacts, faunal remains, A.L. Wedlake's records and original artefact drawings held at Watchet Museum were examined

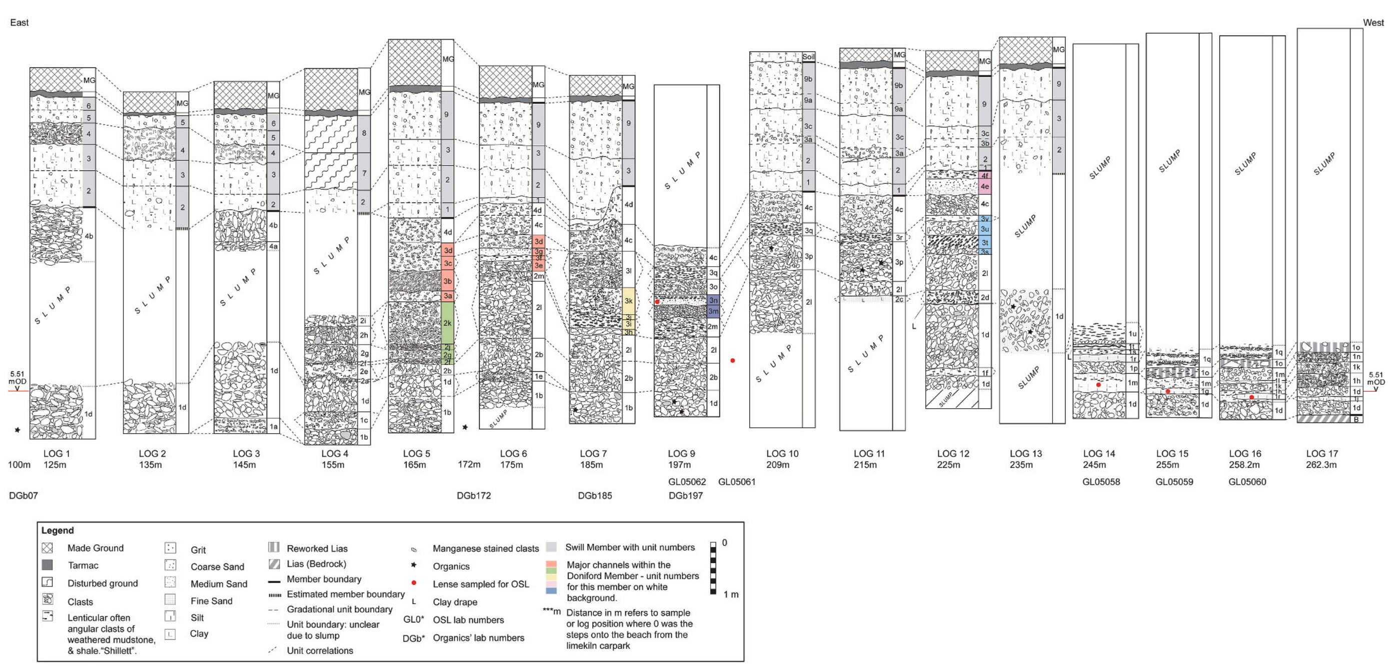


Fig. 5. Scaled logged sections at Doniford with inter-bed corelations based on field observations and sample location data. Level of 5.51m OD marked on E and W of logs.

(LSB); and another Wedlake assemblage from Doniford held at The Museum of Somerset, Taunton (CN). All Palaeolithic bifaces held in Somerset, Exeter and Chard Museums were also examined, basic morphometrics recorded and a photographic archive created. Devon and Somerset Historic Environment Record (HER) data were explored in ArcGIS to evaluate the regional distribution of Palaeolithic material and associate museum finds with HER records. In reassessing which lithics were Palaeolithic and from Doniford, A.L. Wedlake's written records and illustrations (Wedlake and Wedlake, 1963) were cross–checked with the museum records (**SI1**).

The bout coupé biface was high-resolution 3D laser–scanned to maximise morphometric data access and transparency for researchers worldwide. Scanning enables comparative and technological analyses, offers visually accessible outputs, and allows 3D printing for diverse users. Scanning was done using a LLP2 scanner attached to a Faro Platinum Arm (Tanner, 2013). The detailed methodology of the high–resolution method of scanning employed and modelling process is included in the **SI5** accompanied by a suite of downloadable 2D and 3D model outputs.

Megafaunal remains were contextualised via the HER and literature review. The mammoth teeth fragments held at Watchet Museum retrieved in 1947 and 1949 were examined and photographed but the location of the 1827 and 1852 tusks is no longer known. The tusk found by the Wedlakes in 1950 is described as embedded in Doniford cliff, so was presumably left *in situ*. The 2008 rhino tooth identified during review was in poor condition on discovery and disintegrated following examination (Membery, 2008; Somerset HER 28375).

4. Results

4.1. The sedimentary sequence

Sixteen detailed logs were recorded along a 138 m section (Fig. 5). Inter–log section drawings and photographs are shown in **SI 2** Figs. 1–5.

The section at Doniford exhibited considerable lateral variability but broad correlations are possible. At the simplest level from the base to the top these are: the Doniford Member Gravel (white and colours in Fig. 5 log units numbering), Swill Member silts, clays and fine gravels (grey in log numbering Fig. 5) and made ground at the top (MG in Fig. 5). A further Member, the Helwell Bay Member was also identified during geomorphological mapping and examination of the cliff section at the far west of the beach beyond the logged exposure, mapped by BGS as Head (**SI2** Fig. 7). Its inaccessibility prevented detailed logging but geomorphological mapping and examination of the exposure from the beach indicates this is 1–2m above the Doniford and Swill members with two units distinguished based on altitude (Fig. 4; Basell et al., 2011b). It is a gravel unit that underlies both made ground and a weakly developed palaeosol ~0.5–1m thick. It is altitudinally higher than the Doniford Member, its highest upper boundary being estimated at ~16–17m OD. It ranges from ~0.5 to 2m in thickness with well–developed cryoturbation features, and directly overlies an exposure of Lias bedrock of several metres. By contrast the top of the Doniford Member lies between ~9 and 10m OD.

4.1.1. The Doniford Member

The Doniford Member (DM) accounts for more than half the thickness of the section logged in detail and is visible across the entire exposure. There is significant lateral and vertical variability shown graphically in Fig. 5, with the principal generalised units described and key observations as discussed below. See **SI2** Figs. 1–7 for additional drawings and photographs illustrating key inter–log features. No major differences in clast lithologies were seen between the different units of the Doniford Formation and clast lithologies included quartz, quartz–rich sandstone, cleaved sandstone (which is possibly the Early Devonian Red Sandstone derived from the Hangman grits on Exmoor) and a fine–grained sandstone or siltstone. All lithologies are consistent with a local derivation, being known from Exmoor and local river terrace deposits (Edwards, 1999).

DM–Unit 1 (a–u) is the lowermost unit. Clast size is up to ~100 mm, and occasionally up to 200 mm. Deposits are clast–supported, or clast–rich matrix–supported units. The boundary between Unit 1 and Unit 2 is frequently cryoturbated which accords with the congelifracted clasts and cryoturbation features which are common in DM–Unit 2 (SI2 Fig. 6a–c). Despite this, it is possible to see imbrication and sub–horizontal bedding. Organic–rich sandy "pebbles" up to ~100 mm were occasionally found particularly in the basal deposits of DM–Unit 2, (e.g. logs 9, 7 and 13; SI2 Fig. 4). A series of laterally contiguous deposits are present at the end of the section (logs 14–17). These include clay drapes, fine silt and sand units and evidence of imbrication. Three OSL samples (GLO5058, GLO5059 and GLO5060) were taken from these finer grained deposits. The junction with bedrock was visible in log 17, and is a clear, sharp, erosional boundary. The lowermost gravels in Unit 1 (e.g. 1d, 1b), particularly visible in the west of the exposure comprise clast–supported, poorly sorted gravels with some cobbles, imbrication and bedding. Of particular interest are the beds and blocks of reworked Lias clay (4m) some of which contain bedded shillett, but occasionally large angular cobbles. Finer silts, clays and sands often separated by clast–rich bedded matrix supported deposits, overlie these (4f–i and 4l; see also SI2 Fig. 6 8d–f).

DM–Unit 1 represents high energy fluvial conditions which scoured into brecciated bedrock and transported some large clasts. After the initial scouring, deposition of cobbley basal–gravels began, which can be traced across the section. In the western part of the section, a bar began to develop represented by the finer deposits described above. Reworked Lias with bedded gravel lenses within it, indicates higher energy flows continued nearby, reworking the bedrock into bedded fluvial deposits. An angular block of Lias visible to the west of Log 17 suggests its possible transportation as a frozen block (Bennett et al., 1996; Leeder, 1982).

DM–Unit 2 (a–j) is visible in logs 4–12 (Fig. 5) and consists of poorly–sorted and frequently chaotic deposits with numerous large clasts of ~100 mm. The unit is weakly bedded and clast–rich although generally matrix–supported. There are occasional distinct but laterally discontinuous units (e.g. logs 4, (DM–Unit 2a, 2e) Log 5 (DM–Units 2f–2k), Log 12 (DM–Unit 2d)). Large areas are heavily affected by cryoturbation and there are frost–shattered clasts. Despite this it is possible to see deep channels, larger than those in Unit 1, often with a deposit of large clast–supported gravel at their base. One such channel was clearly visible between logs 9 and 10 (**SI2** Fig. 5). Other channel fills include lenses of framework gravel and diagonally bedded well–sorted clasts with manganese staining (e.g. logs 4 and 5). Although poorly–sorted and weakly–bedded, matrix–supported gravels dominate. The channels, upward fining within some channels, and framework gravel indicate fluvial processes and variable flow regimes. Post–depositionally DM–Unit 2 has been strongly affected by periglacial processes.

DM–Unit 3 (a–q) is visible in logs 4–12 and consists of clast rich, matrix supported deposits with some weak bedding. Clasts are generally sub–rounded, and although sorting is poor it is better than DM–Unit 2. Large shallow channels were clear across the section, some >5 m resulting in a clear boundary with the underlying DM–Unit 2 across much of the section. Channel examples are highlighted in Fig. 5 in logs 5, 6, 7, 9 and 12 by colours behind the Unit numbers. Some deposits are bedded, others show preferred clast orientation which is indicated graphically in Fig. 5, but there is also evidence of cryoturbation (e.g. Log 7, Units 3k and 3l). Two small soft-organic "pebbles" were noted in Log 11 DM–Unit 3p. The dominant formation process here is fluvial and interpreted as a braided stream environment.

The uppermost part of the Doniford Member, DM–Unit 4 (a–f) is a matrix supported gravel lying directly below the Swill Member across much of the section. The boundary between the Members is very clear due to colour and grain size differences, though sometimes disrupted by cryoturbation. DM–Unit 4 matrix varies laterally from yellow orange in the east to red in the west. The matrix consists of coarse sand, grit and shillett (brecciated mudstone), which is compact and indurated. Clasts are chaotically oriented, subrounded and occasionally exhibit weak bedding. No organics were observed in this deposit, which is interpreted as a solifluction deposit with cryoturbation. A small channel feature was seen in the west of the section (Log 12, 4e–4f).

4.1.2. The Swill Member

The Swill Member (SM) is *c*.2 m thick and occurs across the majority of the section. The laterally discontinuous SM–Unit 1 is only present in Log 5 to Log 12 and comprises an orange–brown clayey silt with some sand, grit and occasional stones. There is usually a gradational boundary with the overlying and continuous SM–Unit 2 which, in logs 1–4, is the first Unit overlying the Doniford Member. SM–Unit 2 is a yellow, clay–and carbonate–rich deposit with a gradational boundary to SM–Unit 3. Carbonate increases towards the western end of the section where creamy white involutions and nodules appear, and the boundary between the two units becomes increasingly disrupted (SI Figs. 4 and 5). Sedimentological pipe structures of material from SM–Units 9 and 3 (described below) penetrate Units 2 and 1 in this area.

Unit 3 is an argillic orange–red silt with occasional well rounded flat clasts and variable grit (1 mm–5mm). The well–rounded clasts are too weathered to determine rock type. A large block of SM–Unit 3 which had fallen from the section revealed it to be blocky, quite friable and to contain a shell fragment. Rootlet traces are present throughout. SM–Units 2 and 3 recur along the section, with some lateral variation in appearance and composition. SM–Unit 4 is a laterally discontinuous, platy, clast–supported gravel, with no clear bedding or structure, present in logs 1–3 and tapering out between logs 3 and 4. Its clasts are sub–angular and the matrix is an orange–brown silt. In the easternmost part of the section (logs 1–3), there is a sharp boundary between the platy gravel of SM–Unit 4 and SM–Unit 5. This is a yellow–brown silty clay which grades up into an orange, brown, silty clay, SM–Unit 6. Both units have rootlet traces and contain small clasts averaging 20 mm with a maximum size of 40 mm. The sequence is truncated by overlying road metalling and made ground. The upper units of the Swill Member were disrupted in log 4 due to drainage pipes seen in the section between logs 4 and 5. This makes it difficult to trace the uppermost units of the Swill Member westwards across the section. However from log 5 onwards, there is no subdivision of the upper clayey silt units and SM–Units 6 and 5 probably equate to SM–Unit 9 which is also an orange–brown clayey silt although the colour change seen between SM–Units 5 and 6 in logs 1–3 is not present in SM–Unit 9.

These clay–rich silt deposits with different horizons are interpreted as alluvial palaeosols (entisols) and it is possible they incorporate a loessic component. Soil horizons are apparent, but they are only weakly developed. Determining the presence and source of loess is an objective of our ongoing research (cf. Bell and Brown, 2008; Milodowski et al., 2015; Kenis et al., 2020; Stevens et al., 2020; Lehmkuhl et al., 2021; Bunce et al., 2022). The silt and clay–rich nature of the deposits, the topography, and the presence of fluvial gravels (Unit 4) at the same level as a small exposure to the west of the limekilns, suggest that these soils were formed on alluvial flats. The sedimentology indicates a low energy environment and possibly ponding. The field identification of rubefaction, mottling and carbonate concretions indicates the colour differences relate to iron and carbonate contents and soil formation processes (contra Gilbertson and Mottershead (1975) who attributed this to source rock only).

The Swill Member relates to the “loams” referred to by previous researchers. SM–Units 5, 6 and 9 probably correlate with Norman’s “a” (Fig. 3) which yielded Mesolithic artefacts. The presence of the matrix–supported, platy gravel SM–Unit 4 observed in logs 1 to 3, separates SM–Units 5 and 6 (which equate with SM–Unit 9 to the west) from SM–Units 1, 2 and 3. This is significant because SM–Unit 4 subdivides the palaeosol units, suggesting two separate episodes of palaeosol formation; and because SM–Unit 4 indicates different depositional processes occurring between the soil formation episodes. A similar but less extensive or defined gravel lens (SM–Unit 3a) is visible further west in logs 10–11.

SM–Unit 4 exhibited no bedding or preferred clast orientation and is interpreted as an overbank deposit disturbed by bioturbation or solifluction. SM–Unit 4 can be correlated with Norman’s “b”, “c” and “d” (Fig. 3a) from which the Upper Palaeolithic artefacts were recovered, with Norman’s “c” being a bedded fluvial deposit typical of a small, braided stream channel. The boundary between the different palaeosol units is uneven and gradational across the section. In the more westerly parts of the exposure the boundaries between the lower palaeosols (SM–Units 1, 2 and 3) are particularly disturbed by heaves and involutions. These probably indicate root disturbance/bioturbation.

4.2. OSL dating

Five OSL age estimates were determined from Doniford (Fig. 4, Table 2).

With no independent, absolute age control, the reliability of the OSL chronology is assessed intrinsically on the basis of analytical acceptability and inference. Samples GL05059 (65 ± 5 ka in DM-Unit 1), GL05061 (49 ± 5 ka in DM-Unit 2) and GL05062 (25 ± 3 ka in DM-Unit 3) proved analytically acceptable. Age estimates from samples GL05058 (50 ± 4 ka) and GL05060 (45 ± 5 ka), both extracted from DM-Unit 1 should be treated tentatively, owing to each ones failure of the Dose Recovery test. Inferred reliability in OSL dating is possible from the level of stratigraphic consistency and the convergence of age estimates from stratigraphically equivalent units of divergent dosimetry.

The estimated age of each unit is broadly consistent with their relative stratigraphic position in the sequence. However, owing to the limited number of OSL samples/age estimates and the lateral distance between samples, driven by the lack of homogenous fine grain deposits at Doniford, refinement of the OSL ages in Table 2 based on relative stratigraphic position through Bayesian modelling is not appropriate. However, it is apparent that the only DM–Unit 1 with multiple OSL samples generates distinct rather than coeval age estimates against modestly divergent D_r values. This implies some measure of inaccuracy within the OSL age estimates of the lowermost DM–Unit 1. Noting that this unit contains two samples (GL05058 and GL05060) with analytical defects, greater weighting here is given to the age from GL05059.

On the balance of present evidence, the DM is Devensian with DM–Unit 1 forming between 70 ka and 60 ka (MIS 5a–3) and DM–Unit 3 beginning to accumulate between 28 ka and 22 ka (MIS 2, Dimlington Stadial).

4.3. Environmental assessment of organic samples from DM–unit 1

The pollen and spore concentrations are all low, reflecting the sandy, highly humified black (Nig 4) nature of the soft-organic pebbles, which must have been derived from an oxidized humic–peaty hydromorphic floodplain river-bank and are analogous to flood-mud-balls. Typically these cohesive but soft sediments are the result of floods erosion of riverbanks but do not travel far. They are well-known from Holocene and Arctic floodplains and even lakes. Although they do predate the gravel they are normally from the same Interglacial or Interstadial (Brown, 1997; Wojcicki, 2022; Poliakova et al., 2023). Material from all 4 adjacent samples had to be combined due to the low concentrations and so limited inferences can be made (Table 3).

The assemblage has strong similarities with other cold stage fluvial and lacustrine deposits, which also have very low concentrations (<100 grains ml^{-1} or cm^3) and an assemblage comprising both local and long–distance transported grains (cf. Kelly et al., 2010; Egberts et al., 2020; Alsos et al., 2020; Poliakova et al., 2024). The highly damaged grains suggests that the *Pinus* and single *Picea* grains are long–distance transport. Other than these the assemblage is dominated by grasses, *Salix* and open–ground herbs several of which are known from open

Table 3
Pollen and spore counts (grains) and sample pollen and spore concentration for organic pebbles (DGb) at Doniford Unit DM-1. ()* degraded/corroded.[1] from Väliranta et al. (2015). H value in brackets hardiness number (Royal Horticultural Society, UK).

Pollen Spore Type	count	% TLP	Conc. gr ml^{-1}	Comments
Pinus	12 (7)*	10.8	22.2	Almost certainly long-distance transport as also suggested by damaged grains (body or bladder detached)
Picea	2 (1)	1.6	2.0	Almost certainly long distance transport
Coryloid	2	1.6	2.0	Possibly *Myrica gale*
Salix	9	7.3	4.0	Probably *Betula nana* following Karlsdóttir et al., 2007
Calluna	2	2.1	4.0	
Poaceae	44(5)	36.6	66.5	5 were both clumped and degraded
Cyperaceae	3(2)	2.5	6.1	
Anthemis t.	1(1)	+	2.0	Common in lateglacial pollen diagrams
Apiaceae *Anthriscus* t.	1	+	2.0	Common up to the Arctic today
Caryophyllaceae und.	4	4.2	16.1	
Caryophyllaceae *Arenaria* t.	1	+	2.0	Lateglacial presence (Birks and Dinter 2010)
Gypsophila repens	3	2.5	4.0	Lateglacial indicator from Denmark to Ireland (Mortensen et al. 2011; Andrieu et al. 1993) (H5)
Chenopodiaceae	2	1.6	4.0	Common in lateglacial pollen diagrams
Rubiaceaea, *Galium* t.	3	2.5	6.1	Common in lateglacial pollen diagrams
Helianthemum t.	5	4.1	6.1	Classic lateglacial indicator (prob. *nummularium*), not high Arctic
Plantago maritima	1	+	2.0	Common in lateglacial pollen diagrams
Plantago und.	7(3)	5.8	12.1	Common in lateglacial pollen diagrams
Polygonum viviparum	2	1.6	4.0	Lateglacial presence (Birks and Dinter 2010), Svalbard today
Veronica t.	3	3.1	6.1	Common in lateglacial diagrams
Aquatics				
Persicaria amphibia t.	7	7.3	4.0	Wide climatic range (H7) can tolerate temps. down to −25 °C
Typha latifolia	2	1.6	4.0	17 °C July temp.[1] (H6), poor condition could be long distance transport
Non-vascular				
Cryptograma crispa	3	3.1	6.1	Common Arctic-Alpine-Boreal-montane fern
Ustilago	5	5.2	10.1	Smut fungi on plants
Riccia	2	2.1	4.0	Genus of liverworts
Thermomyces (T26)	45	47.3	90.9	Decomposer fungal spores
Chrysomyxa	4	4.2	16.1	Rust fungi
Total Land Pollen	**120**	**100**	**164.0**	
Tot. Quat. pollen & spores	179	149.1	272	
Total Exotics counted	7828	–	–	
Unidentified	9	10.9	18.0	
Pre-Quaternary pollen	2	2.4	2.0	
Charcoal <50μ	159	–	313	
Charcoal >50μ	21	–	34	

interstadial–like environments (e.g. *Anthemis* t., Caryophyllaceae (including the alpine *Gypsophila repens*), Chenopodiaceae, *Helianthemum* t., *Plantago maritima* (Walker et al. 2005), and *Polygonum vivipara*. The assemblage is too small to produce an accurate temperature assessment but the presence of both Coryloid (probably *Myrica gale*), *Galium* type (probably *Galium aparine*) and Typa all suggest cold–temperate open steppic conditions rather than full tundra or polar desert (Alsos et al., 2020).

Three fungal spore types were recorded. *Ustilago* or Type 26 (van Geel, 1972; Blackford et al., 2025) are parasitic 'smuts' common on Poaceae (grasses) and *Polygonum* (Blackford et al., 2025) and *Chrysomyxa* which is a genus of rust fungi. The other, *Thermomyces* is also documented globally. This is a thermophilic found in decaying plant material. Strains have been reported in dry and waterlogged grassland, loamy garden soil and aquatic sediments (Singh et al., 2003). More specifically the fungus has been associated with organic substrates such as the culms, roots and leaves of grasses, composts of various plant materials and the dung of various birds and mammals (Singh et al., 2003). Overall, the assemblage supports any of the warmer oscillations (Greenland Interstadials (GI)) in MIS 3–5a but is probably MIS 5a (GI21–19) based on the OSL chronostratigraphy proposed here.

4.4. Palaeolithic artefact re–evaluation

Palaeolithic bifaces and flakes have been recovered from the Doniford foreshore since the early 1900s. Roe (1968) listed 24 hand axes, >50 flakes/flake implements (retouched and unretouched), 1 miscellaneous worked fragment and 10 Levallois flakes. Bifaces have also been recorded from gravel deposits on higher ground and further inland near Doniford, in or near Watchet, Williton and West Quantoxhead (Fig. 6). It is unclear whether Roe's 24 bifaces include bifaces recovered from the locations inland and Wymer (1999) added no further details to previous descriptions.

Of the fourteen putative Palaeolithic handaxes held in Watchet museum, our re–examination indicates 4 of these eroded out of the Doniford Member (Fig. 6a–d; **SI1** Table 1). Two that A.L. Wedlake classified as "bifaces" are a bifacially trimmed flake (Fig. 6h) and a core or small handaxe (Fig. 6i). These artefacts differ in knapping strategies, condition and overall appearance from more recent lithic finds reported from the Doniford, supporting a Palaeolithic attribution. There is no other sedimentary source near to this location from which they could be derived except the Doniford or Helwell Members. A further discoidal core was discovered digging foundations in Wedlake's garden on the Doniford Road (Fig. 6l - not relocated). Another handaxe from Williton (Fig. 6g) was relocated in Taunton Museum and likely derives from the Doniford or Helwell Member as it was found when digging foundations (Wedlake and Wedlake, 1963).

Other handaxes held in Watchet Museum and labelled as coming from Doniford are problematic. Three probable handaxes could come from Doniford but three are clearly not from the south–west region or even the UK based on the raw materials (R. Wedlake, pers. comm. to LSB; LSB pers. obs. 2006; **SI1,** Table 1). Four are not archaeological artefacts having no convincing evidence of key knapping features (SI1, Table 1). Wedlake noted his collection included artefacts from Cleeve Hill and their similarities to lithics from Paviland Cave (Wedlake, 1973, 7).

In 2001 CN conducted a rapid analysis of a large portion of a collection lent by the Wedlake family to SCM (Minnitt pers. comm. to LSB). This contained 133 lithics said to come from the Doniford foreshore. Of 6 potential handaxes, 2 were acceptable as heavily worn artefacts from Doniford (Fig. 6e and f); 1 was a possible handaxe but could not be correlated with the Wedlakes' 1963 illustrations; and the remaining 3 putative handaxes were not convincing as artefacts (SI2, Table 3). Text on an unpublished illustration (Fig. 6f) by A.L. Wedlake indicates the discovery location as St Audries, but the same artefact in Wedlake and Wedlake (1963, Fig. 6) indicates it came from Doniford so

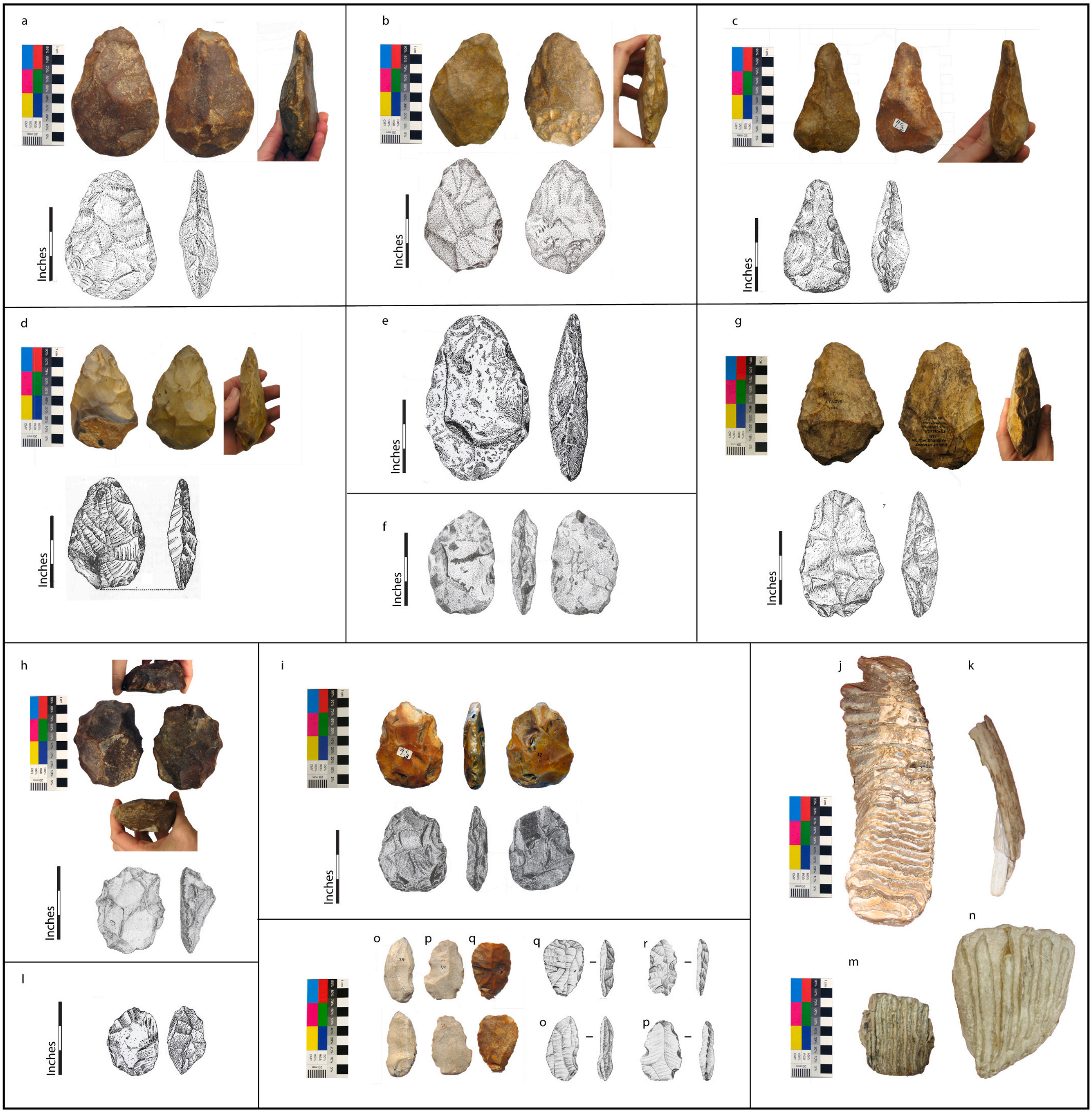


Fig. 6. Palaeolithic artefacts (verified by LSB or CN) and mammoth faunal remains from Doniford. **a**–**f** hand axes from Doniford. **a**–**d** Watchet museum **e** and **f** SCM. **g** A.T. Love hand axe from Willitonin 1950 when workmen were excavating old foundations in his garden (Wedlake and Wedlake, 1963), relocated in SCM. **h**–**i** originally classified by Wedlake as bifaces from Doniford now in Watchet museum. Redesignated as probable Middle Palaeolithic bifacially worked flake (h) and core or small rolled biface. **l.** Originally described as a hand axe this is a probable Middle Palaeolithic core (Wedlake and Wedlake, 1963, Fig.10). **j, k, m,** and **n** mammoth remains on display in Watchet museum and link to Table 1, entries 12, 10, 8 and 7 respectively. **o**–**r** flakes considered by Wedlake as "possible Levalloisian" **r** could not be relocated by LSB in Watchet museum. All photographs LSB. Illustrations A.L. Wedlake. **a, c, d, e, l** adapted from Wedlake (1950) and Wedlake and Wedlake (1963). **b, h, i, l, o**–**r** previously unpublished illustrations by A.L. Wedlake provided to LSB by R. Wedlake. Further artefact details in **SI1**.

was probably collected walking between the two. It is likely that Fig. 6e is the second biface recorded in HER Entry 33345 as coming from St Audries. The remaining lithics were primarily naturally fractured lumps of chert or flint, or post–Palaeolithic flakes and cores eroded from the cliff and abraded by the sea. Wedlake identified six possible Lower Palaeolithic flakes in this collection but CN only found one convincing example of a large, potentially Palaeolithic primary flake.

Unpublished illustrations of flakes from this collection and 6 putative Palaeolithic flakes still held at Watchet museum were also examined for this research. This included illustrations by A.L. Wedlake depicting 4 "Levalloisian?" artefacts (Fig. 6o–r). Three were relocated in Watchet Museum (Fig. 6o–q) and certainly came from Doniford foreshore (Wedlake, 1950). None had facetted platforms, and lateral and distal convexity was weak. Their rolled condition is comparable to the other

Lower Palaeolithic artefacts from Doniford. The Levallois method of reduction previously thought to be present as early as MIS 8 at Purfleet, is now considered as a technology that appears in Britain suddenly in MIS 7 as part of post-glacial recolonization and persists into the Upper Palaeolithic (Schreve et al. 2002, 2006; White et al., 2024). However, following White et al. (2024) who draw a distinction between Levallois, discoidal and hierarchically worked cores we would categorise Fig. 6o–p as products of hierarchical working (**SI1** Fig. 3). Previously unpublished illustrations of additional flake fragments deemed Palaeolithic by A.L. Wedlake are in **SI1**. Although some of Wedlake's "flakes" in Watchet museum are Palaeolithic (Fig. 6o–q**; SI1)** re-examination suggested many were natural.

Consideration of Wedlakes collections demonstrate that Roe's (1968) figures, repeated in later studies, are incorrect. While Palaeolithic handaxes exist, they are fewer than previously reported. Eight convincing handaxes made from chert and flint come from Doniford. Seven are include ovate and pointed bifaces (SI1 Fig. 2) typical of British Lower Palaeolithic variability in the later Middle Pleistocene (Roe, 1968; White, 2015). While there is evidence that Neanderthals made Acheulean bifaces in Europe and parts of Asia, in Britain these forms are generally associated with earlier hominins such as *Homo heidelbergensis*. Bout coupés are specifically associated with Neanderthals. The artefacts are generally slightly or very rolled (Ashton et al., 1998) and all artefacts exhibit patination (Fig. 6 and **SI1** Table 4). Wedlake and Wedlake (1963) observed that artefacts found further inland are typically fresher and less rolled, a pattern supported by our findings.

The closest source of chert is the Blackdown Hills (25 km SSE) but it is more likely that raw materials came from the higher terraces that once would have mantled the Doniford–Taunton Vale interfluve. Chert and flint in these ancient river gravels would ultimately have been derived from Cretaceous deposits, now eroded away, with the exception of remnant outcrops in the Blackdown and Haldon Hills. Carboniferous cherts exist to the west of the Brendons and the east of the Quantocks (Fig. 2), but local chert sources from eroded Cretaceous deposits are the most probable sources. Such cherts are well suited to the production of bifaces, and are better than some flint sources such as Beer (Newberry, 2017). Good quality flint is known from a variety of locations in east Devon, the Haldon Hills and at Orleigh Court near Bideford, and would also have been available on beaches (Newberry, 2002, 2017; Quinnell et al., 2018). The Doniford bifaces, recovered if not necessarily produced in southwest Britain show little evidence of being constrained in their production by the size/shape and/or quality of the available raw materials.

4.5. *The 2011 bout coupé biface*

Bout coupé bifaces are a particular biface form directly associated with Neanderthals. Neanderthal remains in Britain are rare, the earliest being from Swanscombe (~400 ka) (Stringer and Hublin, 1999). Later finds from Pontnewydd Cave in Wales date to ~225 ka (Compton and Stringer, 2015). Neanderthal presence is determined mainly through Mousterian lithic assemblages and Levallois technique though Britain seems to have a less intensive occupation and with significant gaps compared to Continental Europe (Wragg Sykes, 2010). Neanderthals inhabited north–western Europe during MIS 6 and 4, yet despite the land bridge between Europe and Britain, there is limited evidence for their early presence in Britain between with the exception of the Dartford Tunnel site dated to ~100,000 years ago (Wenban–Smith et al., 2010; White and Pettitt, 2011; Weiss et al., 2022).

After 60,000 years ago there is more evidence for Neanderthals associated with Mousterian tools as well as woolly mammoth, at sites such as Lynford (Boismier et al., 2003, 2012). Later Neanderthals' lithic assemblages are distinct from earlier ones and fit within the Mousterian of Acheulian Tradition (MTA). This is part of a wider resurgence of bifacial technologies across the late Middle Palaeolithic which appears to reflect a pattern of increasingly regionalised behaviour, and in Britain includes bout coupé or "flat butted cordate" forms of which there are ~190, particularly concentrated in the south and east of England (Wymer, 1968; Tyldesley, 1987; White and Jacobi, 2002; Wragg Sykes, 2010; Ruebens and Wragg Sykes, 2016). While caution should be exercised using artefacts as a temporal markers, a review of 23 well–contextualised and dated British sites and comparison with NW Europe demonstrate that the bout coupé in Britain is an MIS 3 phenomenon with other biface forms having wider chronological associations (White and Jacobi, 2002; Ruebens and Wragg–Sykes, 2016).

Definitions of key bout coupé characteristics vary, but the Doniford example conforms to all main criteria (Tyldesley, 1987; White and Jacobi, 2002; Wragg Sykes, 2010; Ruebens and Wragg Sykes, 2016). The maximum width of the biface lies just above the base breadth measurement (taken at 1/5th of the whole size of the artefact) (Fig. 7), and its proportions fall within the larger size range of metric variability for British Middle Palaeolithic bifaces (Ruebens and Wragg Sykes, 2016, Fig. 8). It has a flat, sharpened butt and a rounded tip and slightly straighter edges than many bout coupés which often exhibit slight lateral margin convexity. The straightness is similar to the classic bout coupé from Coygan cave (Fig. 8f). There are two clear margins at the intersection of the butt and the lateral margins and a cutting edge is present around the entire margin. The slight asymmetry does not appear to be the result of re–sharpening. Some cortex is apparent on both faces of the biface. The arêtes and edge are fresh exhibiting only very slight abrasion (i.e. not "mint' condition but 'fresh' (Ashton et al. 1998) with a recent flake removal on the tip possibly caused by its fall from the exposure onto the gravel beach. Made from dark grey–black chert with light patination, it contrasts with other Doniford bifaces all of which are heavily rolled and made on an orange–brown chert except for one of C.K. Wallis's finds (Fig. 6d). Bout coupés are known in Britain from both cave and open sites and are made on diverse raw materials. Given the location of the artefact within 2–3 m of the exposure, its fresh condition on a cobble beach and the tidal range at Doniford, this biface can only have come from the lower part of the cliff section. The basal date on the sequence provides a *terminus post quem* of 65 ± 5 ka for the find. **SI5** includes a suite of downloadable data for 3D viewing, measuring or printing this artefact at varying resolutions.

At least four further bout coupés known within 30 km of Doniford and held in Taunton Museum were examined and morphometrics recorded by LSB (Fig. 8; SI 1 Table 4). These are not from dated contexts but, if contemporary, would support the wider regional occupation by Neanderthals being within 1–2 days walk of Doniford (cf. Churchill et al. 2016). The artefacts come from: the West Quantoxhead above St Audries Bay (Fig. 8a); North Petherton, (which is remarkably similar in condition and style to the Doniford example, was donated to Taunton museum in 2005 and has not previously been published) (Fig. 8d); Cheddon Fitzpaine (Fig. 8b); a more controversial example from Bradford on Tone (Seaby, 1950; Tyldesley, 1987; Riley, 2006, Basell pers. obs. 2009) (Fig. 8c); and Pitminster (Fig. 8e). A wider regional presence is also supported by the closest examples of dated bout coupé bifaces. These come from the cave sites of Hyaena Den and Rhinoceros Hole ~50 km west; Kent's Cavern ~110 km south (e.g. Fig. 8g which, while very small, is similar to an undated example from Sherborne cemetery, Fig. 8h); and Coygan Cave (Fig. 8f) near Laugharne in Wales ~110 km north–west of Doniford. The most reliable radiocarbon dates suggest ages between ~55 and 40 ka (Ruebens and Wragg Sykes, 2016, Table 6) which corresponds well with the Doniford biface being derived from the basal gravels DM–Unit 2.

5. Interpretation and discussion

5.1. *The general environmental model*

The primary conclusions from the sedimentological research are summarised in Fig. 9.

At the base of the Doniford sequence is a smoothed bedrock head

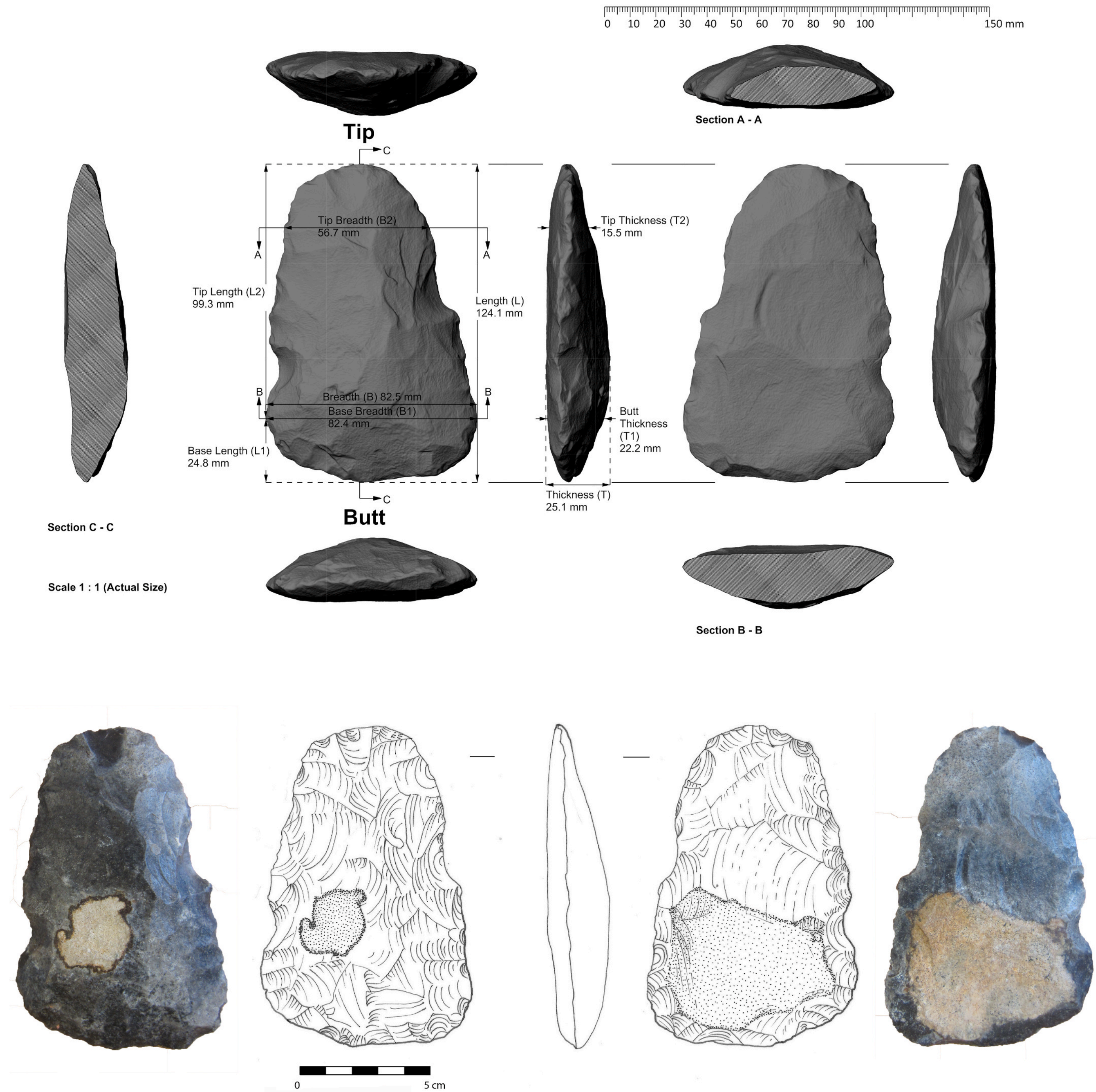


Fig. 7. The bout coupé biface found at Doniford in 2011, 3D laser scanned using an LLP2 scanner in a Faro Platinum Arm (PT). Photographs and illustration (LSB).

surface with evidence of periglacial processes (plucking) suggesting it was formed by periglacial scouring probably during MIS5b-4. The lower gravels (DM–Units 1, 2 and 3) are of fluvial origin and provide evidence of high-energy events and the removal of fines from gravel bar deposits. They extend over a floodplain width of at least 0.8 km, suggesting a large braid-plain taking discharges greatly in excess of those seen today. DM–Units 1, 2 and 3 all exhibit some evidence of cryoturbation and congelifraction. Despite this large channel and bar features can still be identified, not all deposits are affected, and there are multiple sand and silt lenses with bedding and cross-bedding (e.g. Fig. 5 Logs 15–17 also shown in SI2 6d). Studies in arctic environments have shown that river ice is an important cause of clast movement and sediment variability which could also be the case here (Lotsari et al. 2015).

Cryoturbation features across the complex stratigraphy include heaves and involutions. Such periglacial features in the UK are commonly associated with Devensian (MIS 3 and 2) and Younger Dryas deposits but evidence from earlier stages exists (Ballantyne and Harris, 1994; Murton and Ballantyne, 2017). However, sedimentology, environmental reconstruction from the peat balls and the dates suggest large fluvial discharges probably associated with rapid warming during the many and frequent interstadials of MIS3 (Fig. 9). DM-Unit 4 differs from DM-Unit 1–3 in being a solifluction deposit. This did not yield any material suitable for direct dating but we suggest it was deposited following the LGM.

At least two palaeosols are present in the Swill Member with the stratigraphically lowest being heavily affected by cryoturbation. Based

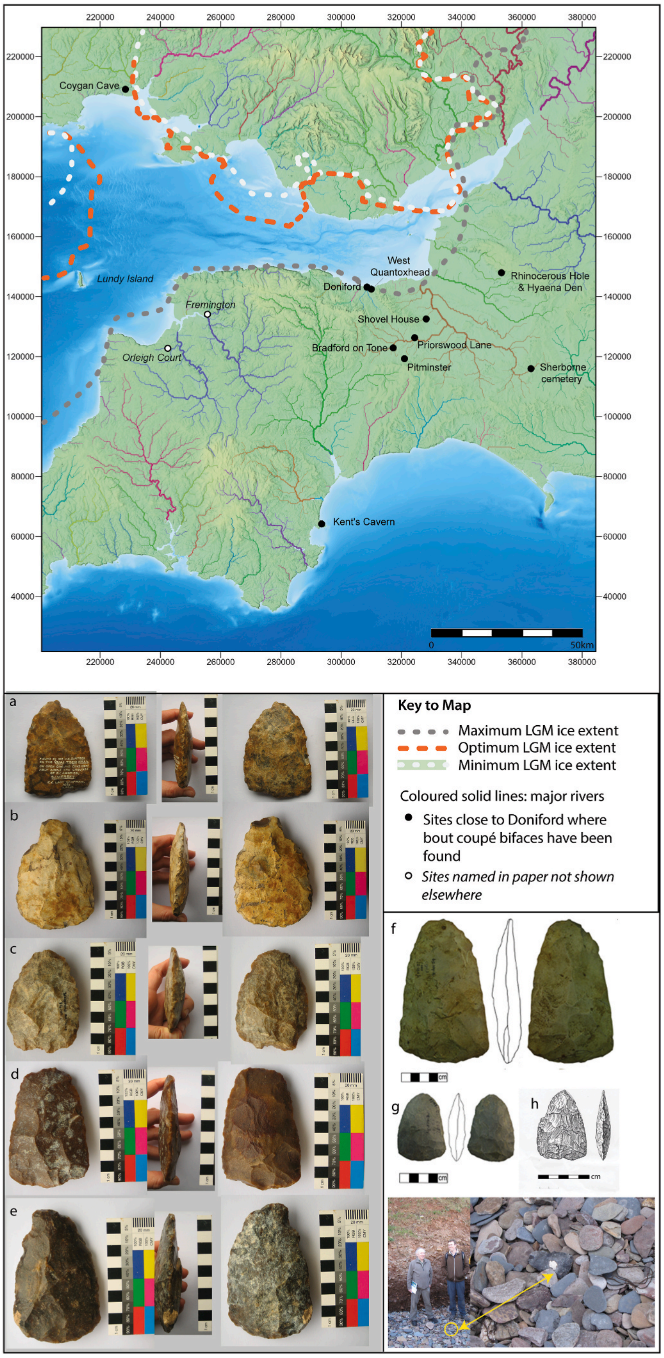


Fig. 8. Map of bout coupé findspots near Doniford, showing further places named in text and the modelled limits of the LGM based on Clark et al., 2022. See text for lithic details. Photo inset shows R. Wedlake and T. White next to the artefact on the day of discovery and location on the Doniford Bout coupé in relation to the exposure. All photographs LSB except **f–g** adapted from Ruebens and Wragg Sykes (2016). Illustration adapted from Arkell (1946).

on dates, sedimentology and archaeology, we propose that the lower palaeosol formed during the Windemere interstadial (Bølling–Allerod in Europe), that the cryoturbation features are Younger Dryas in age and affected the lower palaeosols after their formation (Murton and French, 1993; Murton and Ballantyne, 2017). However, it remains feasible that the cryoturbation features in the lower palaeosol relate to multiple phases from the Late Devensian (29–11.7 ka) onwards. Murton and Ballantyne argue that in lowland Britain, a widespread cryostratigraphic marker horizon, commonly attributed to the MIS 2 is frequently found within the upper 0.5–2.0 m of Pleistocene sedimentary sequences. The involutions in this marker horizon are usually Vandenberghe's sedimentary architecture types 2, 3, and 4 (Vandenberghe, 2025; , Murton and Ballantyne, 2017 Fig. 5.12 and 524). In both the Swill and Doniford Members involutions are dominated by types 2, 3 and 4.

The fine gravel in which CN found a blade (exposure has now eroded; Fig. 3), correlates with the Lower Swill Member (SM–Unit 4) based on the relative stratigraphy in the two exposures and sedimentology. The lack of significant coarse gravel deposition during the Late Glacial is uncommon. This is probably due to the small catchment area of the river and incision synchronous with uplift which was followed by coastal transgression over gravels within the estuary. Such gravels underlie the Holocene silt and peat sequences just to the east of Doniford at Hinkley Point (Griffiths et al., 2015). The upper palaeosol is likely Holocene in date. This multi–phase genesis of the Swill Member is consistent with CN's reinterpretation of the lithics. Further radiometric dating, sedimentological and mineralogical analyses of the palaeosols (which may contain loess) is required to verify this.

Our model has clear glacial implications as the latest modelling suggests the BIIS reached its maximum extent (LGM) at 26 ka (Hughes and Gibbard, 2015; Scourse et al. 2021; Clark et al., 2022). Interestingly, the maximum modelled LGM ice cover incorporates Lundy and reaches the north coast of Devon and Cornwall BP (Hughes and Gibbard, 2015; Clark et al., 2022, Fig. 8). GL05062 (25 ± 3 ka) which dates DM–Unit 3n, covers this period, but it is most likely that DM–Unit 3 was deposited either prior to the LGM and/or after this as the ice began to retreat and water flow reactivated. With the ice margins so close both to the west and the north of Doniford, at the LGM the landscape would have been frozen and inactive (as is seen in other UK fluvial systems e.g. Rivers Axe (Dorset/Somerset/Devon) and Trent)). The solifluction deposit DM–Unit 4 is consistent with post LGM climatic amelioration but being undated can only be said to be Late Devensian.

5.2. Sediment supply, permafrost, periglacial processes and relationship to fluvial terraces

The quantity of gravel at the Doniford contrasts with most terrace deposits in the south west raising questions regarding its source. The River Tone has two terraces at a low altitude above the river, which have not been chronometrically dated. The limited terrace development, unusual for catchments in the region, remains debated but may stem from faulting, river capture or complex geomorphological factors (cf. Gallois, 2006; Brown et al., 2015). However it is likely that during the Pleistocene, these areas were covered with significant gravel deposits resulting from erosion of the Quantocks and Exmoor. The Helwell Bay Member and high-level terrace fragments in the Tone and Doniford catchments may be remnants of these. The antiquity of the Helwell Bay Member is supported by its altitudinal separation from the Doniford Formation and evidence of severe, probably repeated post-depositional cryoturbation.

At some point prior to, or in the Early Devensian, at a time of lower sea level, there was clearly a dramatic increase in water supply eroding the headwaters and surrounding gravels. Swollen by snowmelt the palaeo–Doniford and palaeo–Washford rivers incised a channel, reworked the (inferred) large gravel spreads, and in places cut into the bedrock, causing the formation of a wide valley with narrow gorge sections which drained into the proto–River Severn. This interpretation is supported by present day geomorphology of the valley and the erosional boundary visible between the lowest gravels and the Lias in the Doniford cliff section.

The timing of the initial incision is uncertain. However, if the Helwell Member correlates with terrace 2 in the Tone Valley (Edmonds and Williams, 1985) incision may have occurred at the end of the Wolstonian (i.e. late MIS 6/early MIS 5). This hypothesis would accord well with a period of amelioration following glacial advance evidenced regionally by: 1) the proposed Wolstonian age of the Fremington Clay (Rolfe, 2014;

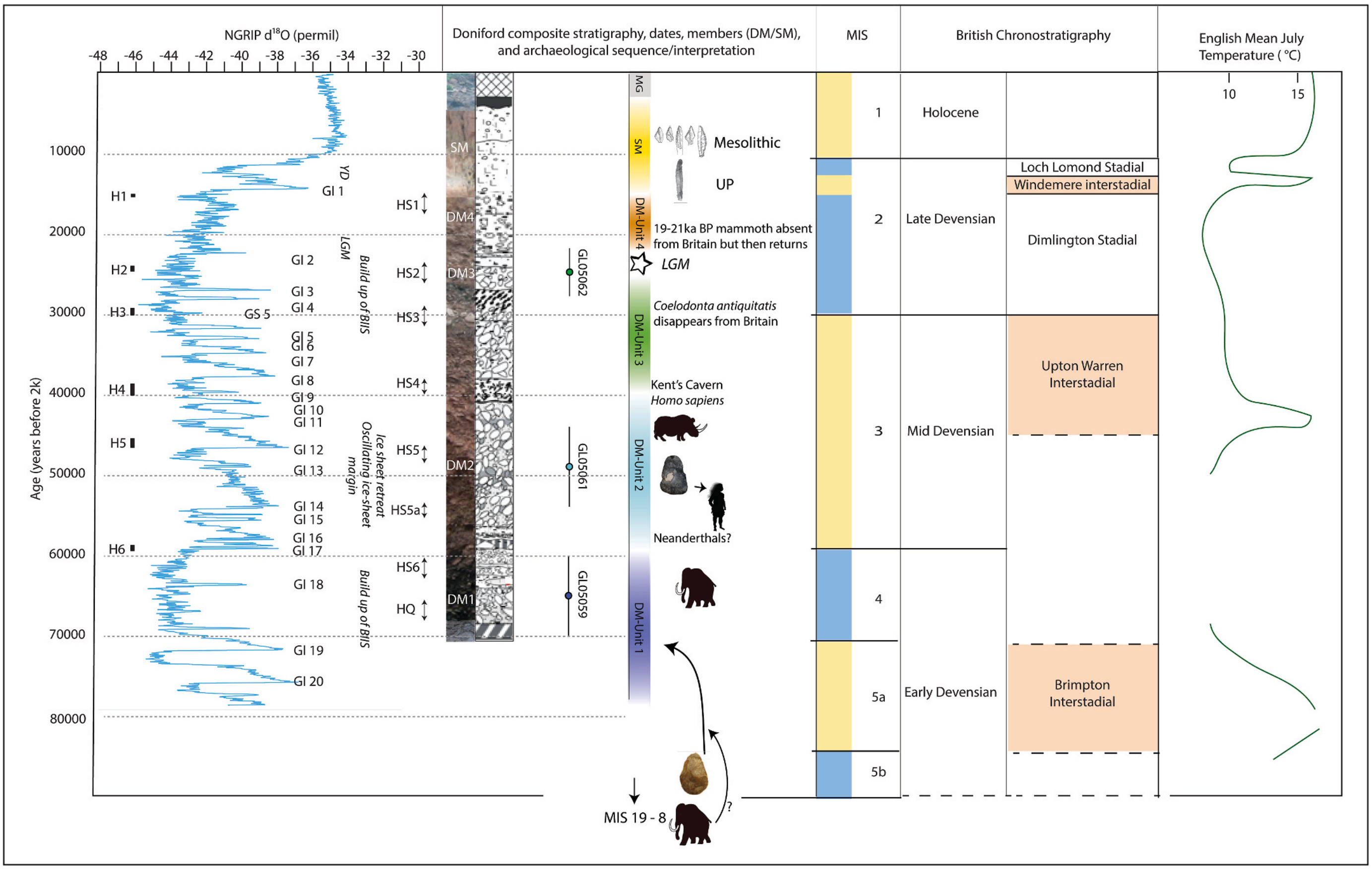


Fig. 9. Summary diagram of the Doniford sequence showing key units and archaeology in relation to NGRIP data, MIS, and broader palaeoenvironmental events. From left to right: NGRIP data (Rasmussen et al., 2014). All Doniford data derived from this paper. Doniford composite stratigraphy created from multiple logs and photographs (see Fig. 5 and **SI2.**). This is for illustrative purposes only. Fig. 5 main log and **SI2.** should be used for any discussion/interpretation of the same. MIS divisions, British Chronostratigraphy and English mean July temperature (based on pollen and beetle evidence) adapted from Rex et al. (2023, Fig. 1). GI: Greenland Interstadials. GS: Greenland stadials; H: Heinrich events; HS: Heinrich stadials (including HQ, see Bassis et al., 2017; Zhou et al., 2021) are derived from Rolfe et al. (2012, Fig. 7) and Toucanne et al. (2023, Fig. 2).

with the caveat that the interpretation of the Fremington Clay is complex and may be MIS 12 (Croot et al. 1996; Scourse, 2024; Gibson and Gibbard, 2024)); and 2) the proposed Middle Pleistocene glaciation associated with ice which filled the entire outer and central Bristol channel (Gibbard et al., 2017; Gibson et al., 2022; Gibson and Gibbard, 2024). The aggradation of sediments at the base of the Doniford Member (dated to 65 ± 5 ka) supports the suggested ice marginal retreat in the Celtic–Irish Sea sector at ~68–65 ka (HQ – see Bassis et al., 2017; Toucanne et al. 2023).

After the Doniford valley was incised, subsequent fluvial events eroded upstream bedrock, reworked ancient braidplain deposits, and redeposited them downstream. During this process, Acheulean bifaces (and possibly Middle Pleistocene faunal remains like mammoth and rhino, but see discussion in 5.2) were reworked with the gravel and redeposited. This occurred during the Devensian as gravels began to aggrade in downstream reaches. The pollen evidence from DM–Unit 1 provides further data to support a limited and intermittent presence of boreal trees in the south–west region during a period more commonly characterised as tundra–steppe (cf. West, 2000; Kelly et al., 2010; Rivals and Lister, 2016).

The stacked deposits at Doniford (older at the base and younger at the top) suggest that once the valley had been created, despite ample sediment supply there was insufficient water power (due to the small catchment area), for continued incision. This prevented a typical MIS 4–1 staircase sequence forming (Brown et al., 2010, 2015). The rich sediment supply may also stem from the frost susceptibility of the bedrock geologies. Frost action would have promoted bedrock brecciation providing a ready supply of gravel alongside reworked former braidplain deposits and ice as well as water would have contributed to sediment transportation (Lotsari et al., 2015). At Doniford, vertical stones and frost-cracked pebbles were noted, but no ice-wedge pseudomorphs, probably due to gravel frost susceptibility or taliks in the permafrost (Bryant, 1983; Worsley, 2014; Brown et al., 2015). The sequence appears to have undergone multiple phases of cryoturbation. Models indicate continuous permafrost during the Last Permafrost Maximum in southwest Britain, so snow insulation may have limited the evidence (Renssen and Vandenberghe, 2003; Stadelmaier et al., 2021; Croot and Griffiths, 2001), except in high-altitude areas like Dartmoor (Hägg, 2009; Gunnell et al., 2013; Harriott and Evans, 2022).

The present underfit Doniford stream has incised 3–4m into the DM gravels. Stratigraphically, this must have occurred following the LGM and probably during the later Holocene. Several factors probably contributed to this incision. Since deglaciation, the southwest has experienced long-term subsidence, though it is less pronounced in the Doniford region than the south coast of Devon and Cornwall (Lambeck, 1993a, 1993b; Stockamp et al. 2016; Gehrels et al. 2011). Modelling isostatic rebound and relative sea level changes is complex (Shennan et al. 2018) but isostatic rebound initiated by ice-sheet retreat from South Wales, has been used to explain elevated raised beach platforms in the southern Bristol Channel area (Gibson and Gibbard, 2024). Relative sea level rose after the LGM, resulting in high cliff regression rates (north to south). This erosion would have steepened lower valley gradients, intensifying short-distance fluvial incision. Such factors, alongside catchment specific changes including flow, vegetation cover and bedload supply would account for the extent of the current stream incision into the gravels but further research would be required to refine the timing and relative importance of each of these.

5.3. Archaeology and faunal remains

Based on artefact condition and form (SI1), the dates and stratigraphy, our interpretation is that the Lower Palaeolithic artefacts found in the gravel have been reworked and are not *in situ* or even in a proximal context (Brown et al., 2010). They have been worked into the gravels from locations on former landsurfaces higher up the catchment. By contrast, the find of a fresh bout–coupé biface at the site suggests that the immediate area was frequented by Neanderthals during MIS 3. This supports broader patterns of Late Pleistocene activity in Britain and evidence from Europe that Neanderthals were able to tolerate cold climates (Basell et al., 2011a; White and Pettitt, 2011; Ruebens and Wragg Sykes, 2016; Weiss et al., 2022).

Other than sporadic incursions into southern Europe, the earliest dated *Homo sapiens* in continental Europe comes from the Rhône Valley at 56.8–51.7 ka (Higham et al., 2014; Slimak et al., 2022). The earliest *Homo sapiens* fossils in Britain come from Kent's Cavern and are dated to 44.2–41.5 ka cal BP (or possibly c. 32 ka) (Higham et al., 2011; Proctor et al., 2017). The latest Neanderthal remains in Europe date to 42–40 ka (Higham et al., 2014), while their Mousterian technologies ended by ~41–39 ka (Higham et al., 2014). Whether Neanderthals and *Homo sapiens* were present contemporaneously in southwest England is not known due to the resolution of geoarchaeological and chronometric data.

The condition of the woolly mammoth (*Mammuthus primigenius*) remains suggests they are contemporaneous with the Doniford Member, though they could have been reworked into the deposits like the Acheulean bifaces. *Mammuthus primigenius* was adapted to cold steppe–tundra, was present in Britain from c. 150 ka (MIS 6) and widespread across Western Europe from c.116–12 ka (Stuart et al., 2002; Lister et al., 2005). The species is absent from ca. 21–19 ka cal BP returning to Britain by ca.15 ka cal BP (Stuart et al., 2002; Lister, 2009). The Doniford remains must come from a pre–LGM mammoth population since they were recovered from the "Lower" gravels (Table 1). Recent research has improved understanding of Pleistocene mammoth species transitions between MIS 16–3 so re-evaluating Doniford's faunal remains could refine species attributions and clarify their age and contemporaneity with the DM (Lister, 2022). The presence of a thermophilous fungal spore in a cold stage deposit may indicate faunal contemporaneity with the deposits, since animal dung would be one of the few microenvironments with a high enough temperature that would allow the fungus to thrive.

In 2008, a woolly rhino tooth (*Coelodonta antiquitatis*) was found in the Doniford deposits (Membery, 2008). A woolly rhino pelvis was also recovered from Minehead foreshore in 2001 (Table 1). Woolly rhinos disappeared from Britain by ca. 35 ka corresponding with the onset of Interstadial GI–7 during MIS 3 (Stuart and Lister, 2012, Fig. 9). Mendip caves (35 km to the east) are rich in Pleistocene fauna, but open site finds like Doniford are rare. Based on discovery dates, locations, and remains, at least five mammoths and one rhino have been identified from the Doniford area, an important addition given the scarcity of dated cold-stage fauna from Somerset's fluvial deposits (see **SI4**).

During the Devensian, the Quantocks and Brendons Hills flanked a much broader floodplain with braided channels, which was populated by animals including now extinct megafauna like woolly rhino, woolly mammoth and Neanderthals. Sparse trees dotted the tundra–steppe, which, despite harsh winds, offered species-rich vegetation for large cold–adapted grazing herbivores. Periodic thawing led to solifluction and increased water flow causing sediment–laden flows onto the foreshore. The Doniford gravels represent specific episodes of dynamic change over long time periods, but their character and content offer a glimpse into these ancient landscapes, visually, aurally and olfactorily. Pre–LGM Devensian Doniford was cold in mean annual terms, but was not species or resource poor and was attractive to Neanderthals. Post–LGM *Homo sapiens* were also present in the region.

6. Conclusion

Our new investigations at Doniford, including environmental data and archaeological finds allow a re–interpretation of this important multiperiod site. Although the number of unequivocally Lower–Middle Palaeolithic lithics is smaller than previously reported, examination of lithics, maps, notes and drawings made by A.L. and R. Wedlake, confirms that Lower–Middle Palaeolithic bifaces, cores and flakes have originated from the Doniford Member gravels. Upper Palaeolithic blades came from the Swill Member and Mesolithic artefacts from an overlying alluvial palaeosol of early Holocene age. A 2011 discovery of a bout–coupé handaxe from the Doniford Member aligns with OSL dates, supporting Neanderthal presence during periods of dynamic landscape change. A further previously unpublished bout–coupé handaxe from North Petherton further extends information on Neanderthal presence in the region.

Sedimentological logging of a new 150 m section reveals complex, horizontally variable gravels characteristic of braided fluvial channels, probably with some solifluction input and periods of *in–situ* cryoturbation. Our research confirms earlier suggestions that the palaeo-Washford and palaeo-Doniford Rivers were tributaries of a proto–River Severn during times of lowered sea level. Further research is required to refine the geochronological relationship between Doniford Formation, the terraces of the River Tone and their relationship to the terraciform features of the proto–River Severn identified in the bathymetry of the Bristol Channel (Gibbard et al., 2017). The Bristol Channel including Lundy Island provides evidence of early Devensian ice dynamics (Rolfe et al. 2012; Gibbard et al., 2017) though this is debated (Carr et al., 2017). The basal date and the erosive boundary at the base of the Doniford Member supports such an early glacial ice advance. The Doniford Member, Helwell Bay Member and potentially the Swill Member are consistent with a proximal ice margin. This is evidenced on the ground and via modelling. The gravels record the repeated periglacial processes combined with pulses of sediment deposition during periods of glacial retreat or seasonal thawing.

The first OSL dates on the sequence show that the gravels accumulated as a stacked aggradation from *c.*65 ka to the Holocene. A driving force for these pulses of activity could be Heinrich episodes (Toucanne et al. 2022, 2023, Fig. 9). There appears to be a depositional hiatus during the LGM probably due to frozen ground conditions. The cold stage faunal remains probably date from the period of gravel aggradation (MIS4–3) along with the bout–coupé handaxe. Upper Palaeolithic material is likely contemporaneous with the Late Glacial floodplain. However, the analysis reveals that the Acheulean bifaces must have been reworked from earlier landscapes. Mapping the gravels of the valley suggests the Acheulean bifaces could have derived from the higher fragments of ancient braidplain terraces such as the Helwell Bay Member, and interfluve gravels with the Tone catchment. Frost susceptible bedrock brecciated by repeated periglacial processes contributed to the sediment supply. While the Doniford sequence has not clarified the degree to which permafrost was present in the region, it is a rare example of a dated periglacial sedimentary archive in the south west.

This study also shows how a mixed low–density assemblage can arise due to the reworking of gravels during the highly active fluvial environment that persisted in NW Europe during the Middle–Late Devensian, and how this can be resolved using a combination of geomorphic mapping, sediment investigations, archaeological and archival research, and chronometric dating. This analysis of the Doniford sequence, considers the history of research, geomorphology, sedimentology and taphonomy of the site and using new data explains precisely how the artefacts have accumulated, and the landscape has changed during the Devensian through to the Holocene. This geoarchaeological approach has enabled an interpretation of site formation, sequence stratigraphy and hominin behaviour at the edge of the BIIS in a highly dynamic environment during MIS3 and into MIS2, in a region that was probably the most inhabitable region close to the glaciated zone.

Author contributions

Research conceptualisation and methodology: LSB, AGB and RH. **Funding acquisition**: AGB, RH and LSB. **Formal analyses:** Sedimentological logging, geomatic survey, sampling, GIS and lithic analyses: LSB. Museum (lithic) analyses and archival studies: LSB, CN and RH. Geomorphological mapping fieldwork and environmental sampling and analysis: AGB. OSL sampling and dating: PST and JW. Lithic scanning: PT. **Software:** shown in individual figure captions. **Graphics and GIS Modelling:** All LSB except Table 3 (AGB)tbl3 and **SI1** Fig. 2 (RH). **Writing**: LSB wrote the paper with all authors contributing, reviewing, and editing.

Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests:

Professor Anthony Brown, co-author on this manuscript, is married to Professor Inger Greve Alsos who is on QSR's editorial advisory board.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.quascirev.2025.109509.

Data availability

All data and/or code is contained within the submission.

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