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Strategic Support for Marine Development Management: Palaeolithic archaeology and landscape reconstruction offshore

R Bynoe, M J Grant and J K Dix

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R Bynoe, M J Grant & J K Dix, with contributions by T Hill, M Law, A Howard, P Toms and J Wood

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SUMMARY
The beach replenishment programme from Clacton-on-Sea to Holland-on-Sea, Essex, carried out between 2014 and 2015, has resulted in the appearance and collection of both Pleistocene mammalian remains and stone tools, including Early Middle Palaeolithic Levallois; one of the largest in the country (Scott pers. comm.). The sands used in this coastal protection scheme derived from offshore Licence Area 447. As such, this raised questions surrounding the measures of mitigation that had been in place for Area 447, the subsequent beach replenishment programme during the marine licence application stage, and the potential to recover information from pre-existing, split-open vibrocores.

Due to these concerns, Historic England commissioned the University of Southampton (Project 7738, led by Dr Rachel Bynoe) to assess the existing datasets available for Area 447 to permit the reconstruction of a narrative around the formation of the archaeological deposits extracted from Area 447 and their subsequent use, which would in turn help understand why the industry methodologies used at the time and the associated curatorial process did not identify this archaeological resource.

Several geophysical, geotechnical and dredging-related datasets, collected between 1990 and 2015, were made available for this project, analyses of which indicate that the sequence can be dated to Marine Isotope Stage (MIS) 7/6. Clast analysis identified four flint clast types, with three showing limited abrasion and attrition, while the fourth could be associated with a beach environment. Molluscs present throughout the sequence were associated with a shallow intertidal/sublittoral coastal environment. Pollen indicated a late temperate stage assemblage comparable to dated British terrestrial sequences from late MIS 7, and paired mineral luminescence dating, with quartz and feldspar, has provided statistically consistent dates confirming that these deposits are of late MIS 7/early MIS 6 age. The results from vibrocore VC23 in Area 447 firmly place the site within late MIS 7/early MIS 6, probably correlated with the MIS 7a–6e interglacial to glacial transition, fitting in with the dominant archaeological signature from the site.

Through the reconstruction of a narrative around the formation and hominin use of these landscapes, at a point immediately prior to the abandonment of Britain from MIS 6–3, this project raises important questions about how we interpret early human occupation. Are we starting to see the evidence for relatively increased exploitation of these lower-lying areas, either because of resource availability, dispersal routes, or both, or is this simply a result of visibility provided by these beach replenishment schemes – large areas of dredged material being laid out in a publicly accessible area? While impossible to say at this stage, the results of this project, combined with those from Area 240 (e.g. Tizzard et al. 2014) and the current work at Walcott (Davis et al. forthcoming), are starting to provide more evidence with which to inform and support interpretations of these obscured landscapes. Furthermore, this study demonstrates that luminescence dating can be successful on vibrocores which have not been sampled under optimal conditions. It demonstrates that archived vibrocores can be successfully used to reassess a site where the archaeological deposits have already been removed and primary context

lost. Recommendations for future mitigation against the loss of information provided by such deposits have been provided as a result of these analyses.

ACKNOWLEDGEMENTS
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Front cover photo by John Ratford.

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1. INTRODUCTION

1.1 Background

The 2014–2015 beach replenishment programme from Clacton-on-Sea to Holland-on-Sea, Essex, resulted in the immediate appearance and collection of large numbers of both Pleistocene mammalian remains (n >300) and stone tools (n >800) deriving from the newly placed sands (Figure 1). While finds densities have decreased, bones and stone tools are still being found as of 2022. The finds came to light through community engagement related to Historic England (HE) project 7204 (*Investigating the submerged Pleistocene landscapes of the Wallet off Clacton*; Bynoe 2017) and resulting links with local collectors have since been ongoing. What is significant about these finds are two things: first, the sands derive from an offshore licence area (Area 447) and therefore potentially link to submerged Palaeolithic deposits. Second, they form a coherent group of Middle Palaeolithic artefacts, with fauna most representative of a cool, open environment.

Given how this archaeology came to light, questions exist as to how we effectively and manageably recognise archaeological potential in deposits that have not had any archaeological finds previously reported, especially when the targeted deposits have the potential to be used in beach nourishment schemes for coastal protection.
Due to these concerns, Historic England commissioned the University of Southampton (Project 7738, led by Dr Rachel Bynoe) to assess the existing datasets available for Area 447 to permit the reconstruction of a narrative around the formation of the extracted archaeological deposits and their subsequent use, which would in turn help understand why the industry methodologies used at the time and the associated curatorial process did not identify this archaeological resource.

1.2 Marine Licence Dredging Area 447

Area 447 was a licence area covering an area of 9.2 km^2 that was awarded a Government View by the Department for Communities and Local Government (DCLG) on 30 April 2007 (Figure 2). It is situated approximately 18 km east of Walton-on-the-Naze, Essex, and considered as part of the Outer Thames dredging region. An application to dredge up to 15 million tonnes over a 15-year period was consulted upon and determined in accordance with the approved Government View procedures in April 2007 and dredging commenced on 29 April 2008. In April 2011, the Marine Management Organisation (MMO) carried out an Environmental Impact Assessment (EIA) review and determined that the Area 447 EIA was sufficient to meet the requirements of the EIA Directive (85/EEC as amended), and that appropriate processes had taken place to ensure they were consistent with those required by the EIA Directive. On 6 April 2011, the Coast Protection Act consent for Area 447 (Ref: 34943/100909) issued by the former Marine and Fisheries Agency became a deemed marine licence under Paragraphs 2(1) to (3) of Schedule 9 of the Marine and Coastal Access Act 2009. The Government View conditions were transferred onto the deemed marine licences for the three operating dredging companies, Hanson Marine, Tarmac Marine and CEMEX, on 12 March 2014.

Figure 1 A selection of the faunal and lithic artefacts found on Clacton–Holland-on-Sea beach (courtesy of J Ratford and P Buisson)

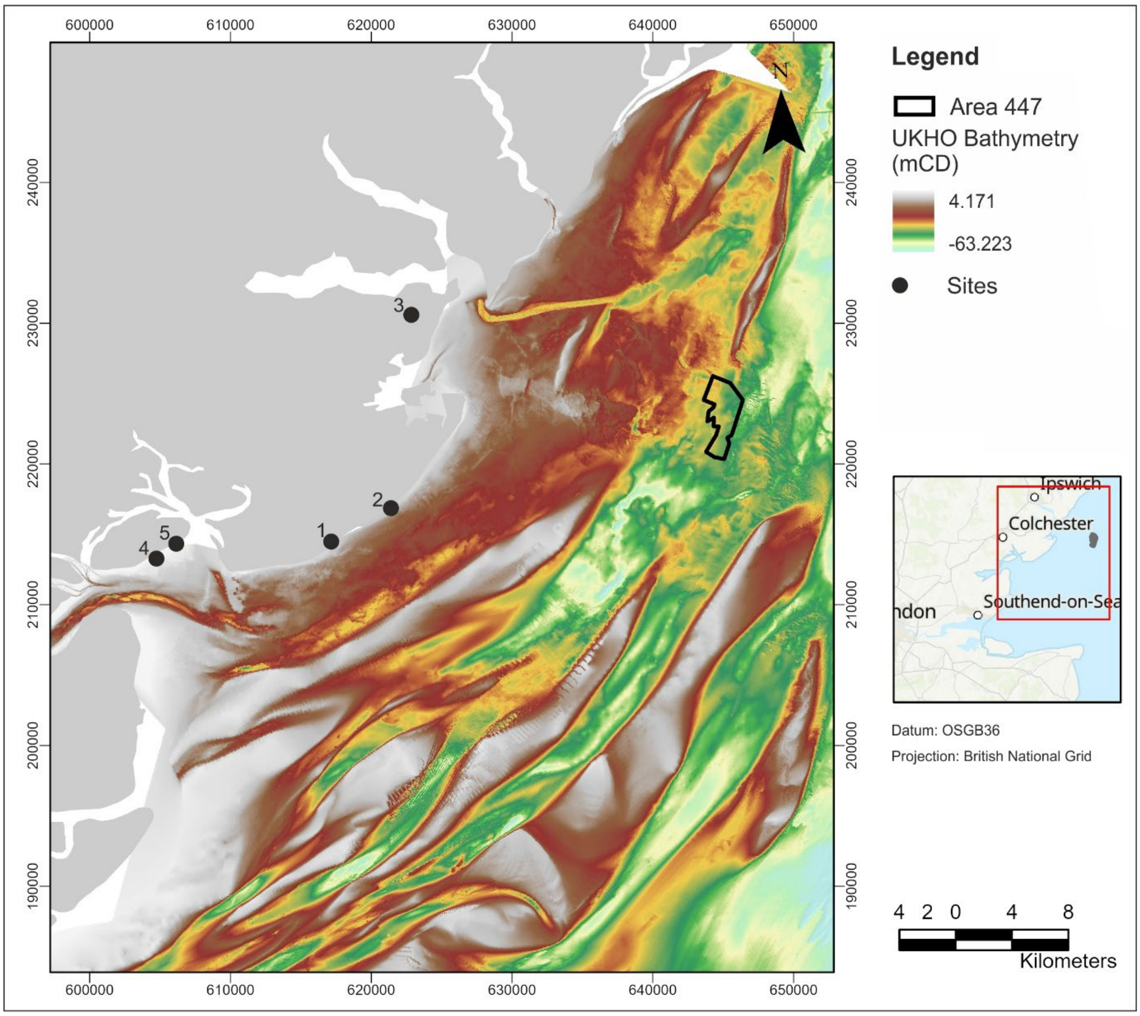

Figure 2 Location map showing Area 447 and the surrounding region, as well as sites mentioned in the text (1: Clacton-on-Sea, 2: Holland-on-Sea, 3: Little Oakley, 4: East Mersea, 5: Cudmore Grove). Data: UKHO bathymetry

The Environment Agency in partnership with Tendring District Council and Essex County Council funded a scheme to provide protection (including the use of marine minerals) along a 5 km stretch of Essex coastline from Clacton Pier in the south to Holland Haven in the north with the aim of reducing coastal erosion for the next 100 years. In doing so a marine licence from the MMO was required (and attained in February 2014) due to the nature of the works and need for beach replenishment. This included a total of 2,385,000 tonnes of mixed seabed material to be deposited, comprising 1,431,000 tonnes of gravel and 954,000 tonnes of sand (Royal Haskoning DHV, 2019, *Alternative use of dredge material in the north east, north west, south east and south west marine plan areas* (MMO1190)). The project was one of the first of its type since the inception of the marine licensing and planning system.

Boskalis Westminster were commissioned by the project to carry out the replenishment work. The project utilised trailing suction hopper dredgers that once fully loaded were manoeuvred nearshore, with the cargo then sprayed in a 'rainbow' to form bedding platforms for the new groynes, or pumped ashore through an 800 m long sinker-line pipe on the seabed to each of the inter-groyne bays. Three calm weather seasons were earmarked for the replenishment; however, the work was completed during 2014 and 2015.

Dredging ceased in Area 447, by all three licencees, in December 2016, and all licences were relinquished in August 2017.

1.3 Identifying extraneous material

The archaeology being recovered from the beach at Clacton-on-Sea–Holland-on-Sea must be distinguished from any pre-existing, locally eroding archaeology that could be confusing the picture (e.g. see Lyon 2005 for similar problems). What is the pre-existing archaeological record along this coastline and how might this be distinguished from the artefacts now being recovered?

Before moving into its current position as a result of the Anglian ice sheet (MIS 12, 474 ka), the early Middle Pleistocene Thames river system was migrating southwards across East Anglia and the Tendring peninsula, on which Clacton-on-Sea is situated (Bridgland 2006). River terrace gravels dating to this broad period (c. 780–474 ka) therefore exist in the region around Clacton-on-Sea–Holland-on-Sea (Bridgland 1988; Bridgland et al. 1990), in addition to the immediately post-Anglian deposits found to yield the MIS 11 Palaeolithic sites at Clacton (Figure 2) (Bridgland et al. 1999). Other known deposits, such as those found to the south at Cudmore Grove (MIS 9) and East Mersea (MIS 5e) (Figure 2) have not been found to yield archaeology (Roe et al. 2011). Similarly, nearby pre-Anglian deposits on the Tendring peninsula at Little Oakley have been subject to archaeological investigations that have not revealed any archaeological material (Bridgland et al. 1990). The archaeological deposits associated with the localities at Clacton are therefore the main potential source of confusion. However, these deposits have not been seen to outcrop in the vicinity for several years and the condition (mainly in terms of distinctive staining) and typology of the Clacton artefacts are distinct from those being found within the replenishment sands (McNabb 2007 and pers. comm.). Furthermore, given the pre-Anglian (Lower Palaeolithic) date of potential channel deposits further to the north of Clacton-on-Sea, these are also unlikely to be confused with the distinctive Levallois stone tools being studied here, which are associated with the Early Middle Palaeolithic (c. MIS 9–MIS 6).

1.4 History of archaeological assessment

While the archaeology deriving from beach replenishment came to light relatively recently, the Government View for Area 447 was granted in 2007, with the archaeological desk-based assessment (DBA) conducted several years prior to this (Wessex Archaeology 2003) and encompassing a broader study area than was finally licensed (then both Areas 446 and 447).

The initial DBA (Wessex Archaeology 2003) consisted of a review of the National Monuments Record, the UK Hydrographic Office, the Sites and Monuments Records of Essex and Suffolk County Councils and geophysical survey data provided by Resource Management Association (then CEMEX UK Marine Ltd, Hanson Aggregates Marine Ltd and United Marine Dredging Ltd). The geophysical data, collected by Andrews Survey (now Gardline) in 2000, consisted of side-scan sonar and sub-bottom profiler, both of which were analogue paper rolls. A pre-dredge assessment of geophysical data collected in 2007 (side-scan sonar and multibeam bathymetry), also including the 2000 (sub-bottom profiler) data, was later carried out, specifically relating to Area 447 (Wessex Archaeology 2008). Subsequent geophysical surveys over aspects of, or the entirety of, Area 447 were carried out on five separate occasions (2009, 2010, 2011, 2012, 2015 [PMSS 2012]). Vibrocores were initially collected in 2001, with later surveys in 2012 and 2015 (Andrews Survey 2001; Coastline Surveys Ltd 2012; CMS Geotech Ltd 2015), but it does not appear that the vibrocores were archaeologically assessed.

Due to the changing sea-levels and palaeogeography of the study area throughout the Quaternary, the DBA identified archaeological potential that was broadly categorised as: Lower to Middle Palaeolithic ex- or in-situ artefacts within the aggregate deposits; in-situ Upper Palaeolithic to Mesolithic artefacts within the upper reaches of the gravel deposits; and wrecks and related material from more recent periods on the seabed. While onshore terrestrial archaeology from the Palaeolithic was reported (Wessex Archaeology 2003: 17–19), only shipwrecks were specifically identified offshore within Area 447 (Marine Ecological Surveys Ltd 2008; Wessex Archaeology 2008). As such, despite a recognised potential for Palaeolithic archaeology associated with these sands and gravels (e.g. Wessex Archaeology 2003: 20–22) there was no direct mitigation proposed.

Given the dominant paradigm of the early 2000s — that nothing but derived and isolated Palaeolithic material existed in the southern North Sea — this position is not surprising. This was a period when discussions surrounding the likely preservation and potential of submerged Palaeolithic archaeology were increasingly frequent (e.g. Coles 1998; Wenban-Smith 2002) but largely hypothetical. A document commissioned by the British Marine Aggregate Producers Association (BMAPA) and Royal Commission on the Historical Monuments of England (RCHME), as part of a commitment to sustainable and responsible aggregate extraction, went as far as to make definitive statements about the presence of Palaeolithic archaeology, possibly even as undisturbed horizons within offshore sand deposits (Wenban-Smith 2002: 15). The same document called for improved methods of identification and analysis of archaeological material in advance of extraction, recognising the consequent benefits of aggregate extraction for the archaeological record (Wenban-Smith 2002: 16). Despite these calls, the evidence and resources required to instigate such change was lacking.

The 2007 chance discovery of Middle Palaeolithic archaeology from Area 240, off Great Yarmouth, provided further realisation of the need for change (Russell and Tizzard 2011; Tizzard et al. 2014; 2015), demonstrating the preservation of submerged deposits and associated archaeology despite repeated glacial, transgressive and regressive phases. This work was supported by the (Marine) Aggregate Levy Sustainability Fund (MALSF/ALSF, which ran from 2002–2011), through Historic England (then English Heritage) working with the aggregates industry, a levy that funded a significant number of projects relating to the environmental impacts of aggregate extraction. Coinciding with this discovery, therefore, were a range of MALSF projects exploring submerged landscapes and their archaeological potential, particularly the Regional Environmental Characterisations (e.g. Limpenny et al. 2009; Emu Ltd/University of Southampton 2009; Dix and Sturt 2011; Tappin et al. 2011). This period saw a significant increase in the geophysical and geotechnical mapping, and in some cases dating, of areas of the southern North Sea, contributing to a greater understanding of the preservation and distribution of Pleistocene deposits.

With a renewed focus on large-scale landscape mapping, alongside the acknowledgement that archaeology and palaeogeography are not spatially defined by aggregate extraction zones, the need for regional approaches to the record was recognised (e.g. Wessex Archaeology 2010). Taking this one step further, in an attempt to quantify and refine the archaeology surrounding Area 240, the Palaeo-Yare Catchment Assessment project was initiated (Wessex Archaeology 2013). The identification of a suite of deposits associated with this catchment, from the Pliocene/Early Pleistocene through to the Holocene, allows archaeological material recovered from operational sampling of dredge loads to be more clearly understood in their wider context, offering potential insights into hominin use of this landscape (Wessex Archaeology 2015) and informing future, longer-term seabed licences. Although initially restricted to aggregated licences within the Palaeo-Yare catchment region (off East Anglia), this approach is beginning to inform other seabed areas around the coast of England, reflecting a move towards addressing some of the concerns and problems raised in the early 2000s (Wenban-Smith 2002).

1.5 Wider significance and the management potential of this resource

As has been highlighted repeatedly (e.g. Westley et al. 2013; Sturt et al. 2015), and despite the aforementioned progress, our understanding of the nature of submerged Pleistocene sites, their location and contemporary environments, landscape configuration and how, as a discipline, we identify and engage with them, remains opaque. With the Levallois component of the lithics indicating an Early Middle Palaeolithic (i.e. pre-abandonment) occupation, this also has the potential to provide key information on hominin use of these landscapes. Whilst the glacial conditions of MIS 6 and subsequent rapid rise in sea level at the start of MIS 5e (Streif 1989; Siddall et al. 2006) have been put forward as factors in the continued absence of early humans (e.g. Lewis et al. 2011), insights into hominin use of these lower-lying, resource-rich landscapes have the potential to enrich, and potentially re-write, our understanding of their behaviour in these geographically peripheral environments.

Due to the period in which the EIA for the dredging in Area 447 was produced, it is acknowledged that applying effective mitigation was not fully understood or possible (Wessex Archaeology 2003: iii). Given the archaeology now being found, however, questions exist as to how we effectively and manageably recognise archaeological potential in deposits that have not had any archaeological finds previously reported. Operational sampling at wharf facilities of regional deposits as part of the Palaeo-Yare work (Area 240 Unit 3b in particular) has recovered significant archaeology from a wider area of seabed (Wessex Archaeology 2013), highlighting the need for increased analysis of deposits prior to the commencement of work in order to fully understand their nature, chronology and archaeological potential at a site-specific level.

The ongoing sampling work being undertaken in the wider Anglian dredging block, as a result of finds made from Licence Area 240 (Wessex Archaeology 2013), could be a useful management method to consider in relation to the nature of the finds after they are dredged from their primary context. However, as the dredged material was, in this case, ‘rainbowed’ directly onto the beach from the dredging vessel, with no wharf processing carried out in between, additional consideration would have to be made. While this poses limitations upon archaeologists' opportunities to make observations as part of a sampling procedure, it provides an additional benefit of having larger volumes of material deposited in a publicly available space. This could again mean looking more critically at how we approach the EIA stage of the marine licensing process, thinking more broadly about mitigation in these circumstances to address the dredged-up sands and gravels from established marine licence dredging areas that are then used for marine-licensed beach nourishment schemes. The aim would be to consistently bridge the marine planning gap between what is known about a licence area's archaeological potential, what conditioned provisions are in place and how they can be factored in when a beach scheme sub-contracts a third party for project-specific dredging and beach deposition works.

Through gaining an understanding of the nature of the archaeology and its depositional context, this work therefore aims to identify ways in which these types of artefact-bearing deposits can be recognised at an earlier stage of the development process; increasing the knowledge base from which archaeologists can advise regulatory bodies and, as such, providing better heritage and management protection.

1.6 Project Aims

Drawing and expanding upon existing work conducted by geologists at Tarmac Marine, this project aimed to reconstruct a narrative around the formation of the archaeological deposits exploited within Area 447 and their subsequent use, which will in turn develop advice available for regulatory bodies for the production of EIAs and coastal and offshore mitigation.

It sought to do this by addressing the following objectives:

- Integrate geophysical datasets and dredge data to investigate Area 447 and the wider study area, identifying possible artefact-bearing deposits (Section 3)

- Palaeoenvironmental assessment and analysis of vibrocores collected in 2015 to investigate the palaeoenvironmental signals associated with potential artefact-bearing horizons and, where possible, date these deposits through luminescence dating (Section 2)

- Lithic and faunal assessment and analysis to gain a better understanding of the period/s represented and their taphonomic history (Section 4)

- Increasing the amount of material available for analysis and wider understanding of the resource through a local community engagement event (Section 4)

- Integration of data from the wider region: existing data from the Outer Thames Regional Environmental Characterisation links in with this area and was interpreted by members of the project team (Section 3)

- Make recommendations to inform existing processes, and consider new methods and approaches that could be adopted to better identify and work with Palaeolithic deposits offshore (Section 5).

2. SEABED INTERPRETATION

2.1 Background

Area 447 is part of a larger area of seabed prospected for potential aggregate extraction as early as 1990. An Environmental Statement was submitted in 1999 for seven sub-areas and an annual extraction of 2.5 million tonnes over 25 years, which was subsequently reduced to one area with an extraction rate of one million tonnes per year (on average) over 15 years. Consultation on the proposals continued until the Department for Communities and Local Government (DCLG) approved Government View procedures on 30 April 2007, the day before the new statutory dredging regulations under the Marine Works Act came into force. Dredging began in Area 447 on 29 April 2008, continuing until the licence was relinquished by all licence holders (CEMEX, Tarmac Marine and Hanson Marine) in January 2017.

Area 447 sits approximately 16 km south-east of Felixstowe and covers an area of 9.2 km^2 between –15 and –20 mLAT. A series of geophysical and geotechnical surveys were carried out both pre- and post-extraction and those used as part of this work are shown in Table 1. Figure 3 shows the pre- and post-extraction multibeam surveys from 2012 and 2015. The vibrocores collected in 2015 were taken immediately prior to the main phase of dredging for the beach recharge.

Data	Date undertaken
TEDA MBES	Post-2015 survey
MBES	12 Dec 2015
Boskalis freeway dredge	May/June 2015
Geotechnical Vibrocores	Feb 2015
Boskalis Causeway dredge	Nov 2014
MBES	Oct/Dec 2012
Sediment isochore maps	1990/2000
Boomer survey (traces and trackplots)	2000
Boomer survey (traces and trackplots)	1990

Table 1 Data used as part of this project

In addition to the geophysical surveys and vibrocores, dredge-plots were provided by Boskalis Westminster; for the Clacton-on-Sea–Holland-on-Sea beach recharge, aggregate was extracted from four zones within Area 447: G, H, I and J, a total area of 1.67 km^2 (Figure 4). The majority of aggregate was extracted from zone H (29.4%), with zone G also relatively heavily exploited (25.8%). Subtracting the 2012 from the 2015 MBES enabled visualisation of the main areas of seabed exploited. This was further confirmed by plotting the density of the Boskalis dredge plots. The MBES time-series, dredge plots and extraction data all confirm that zones H and G were the most heavily exploited parts of Area 447 (Figure 4).

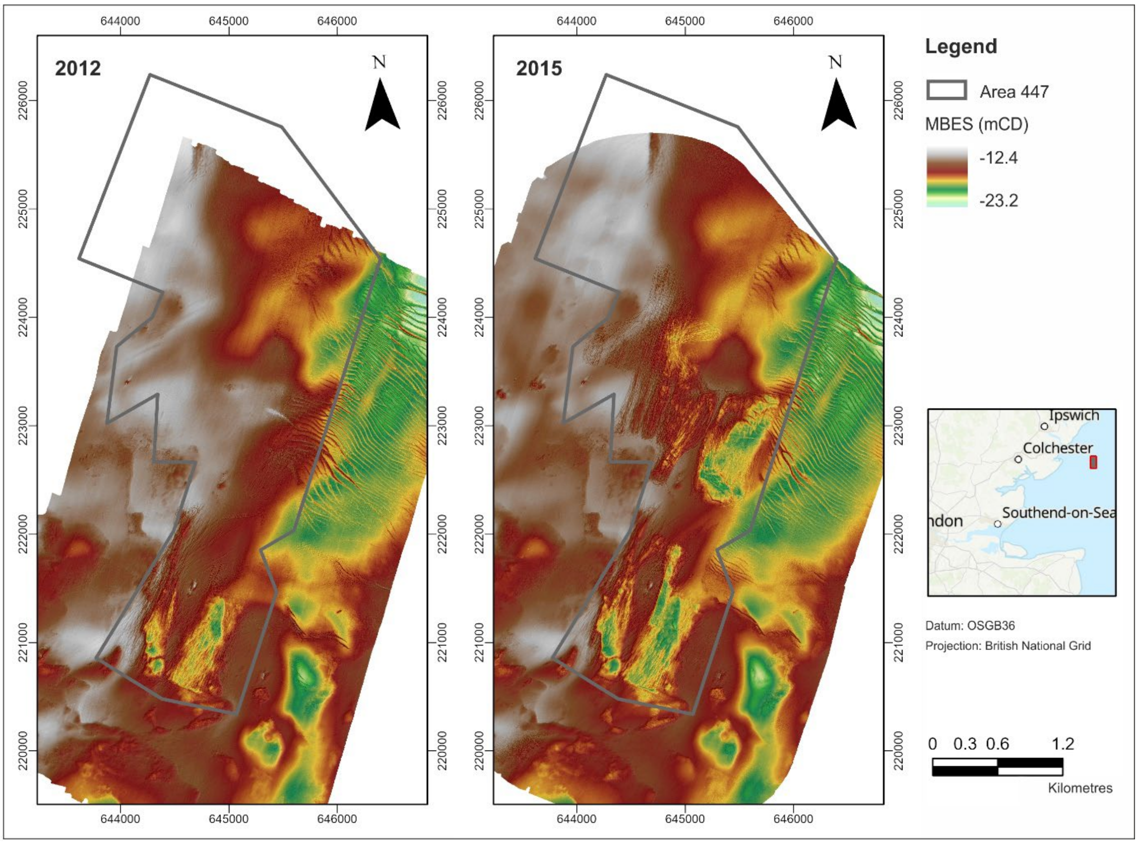

Figure 3 Multibeam bathymetry surveys from 2012 (pre-dredge) and 2015 (post-dredge)

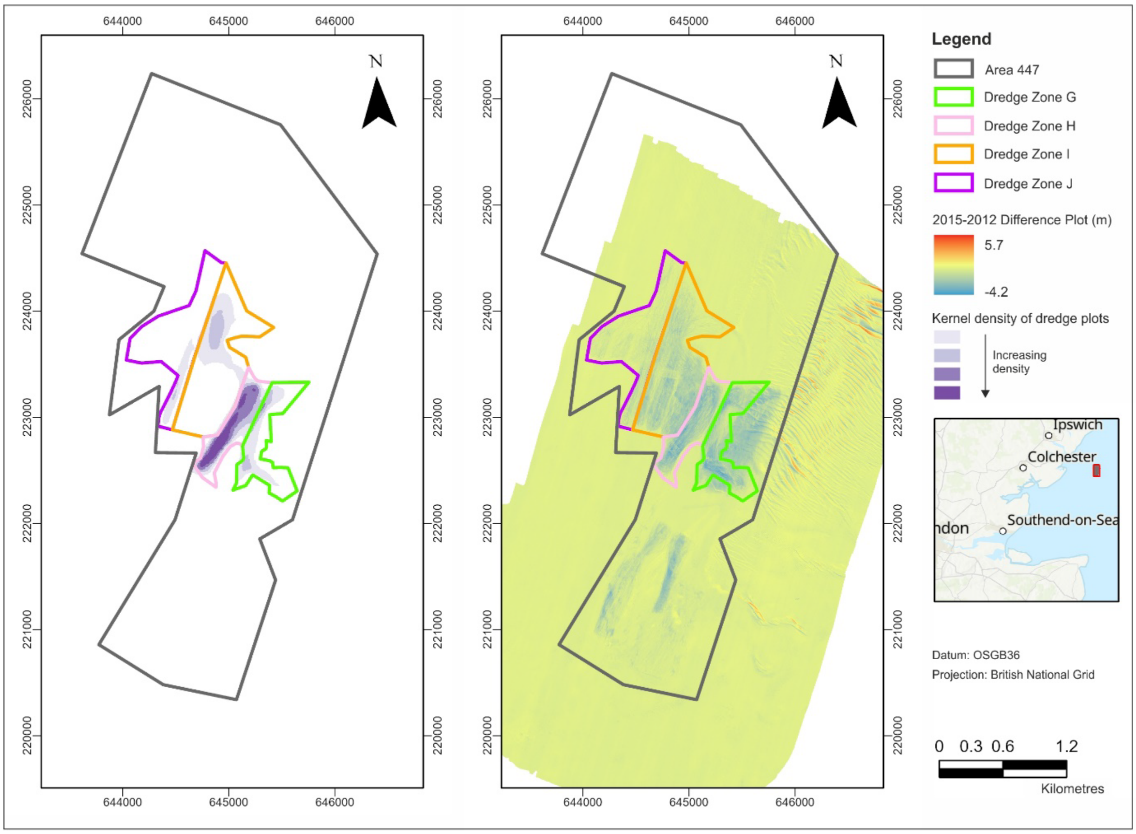

Figure 4 Dredge areas, kernel density plots of dredge tracks (left) and time-series MBES difference plot (right) in Area 447

The track plots of the boomer data were digitised, as was the sediment isochore of the area (the thickness of unconsolidated sediments above the predominantly London Clay bedrock). Sediment thickness contours were converted into a topographic thickness map (Figure 5) which clearly show how the major sediment accumulations match the distribution of palaeo-channels across the area.

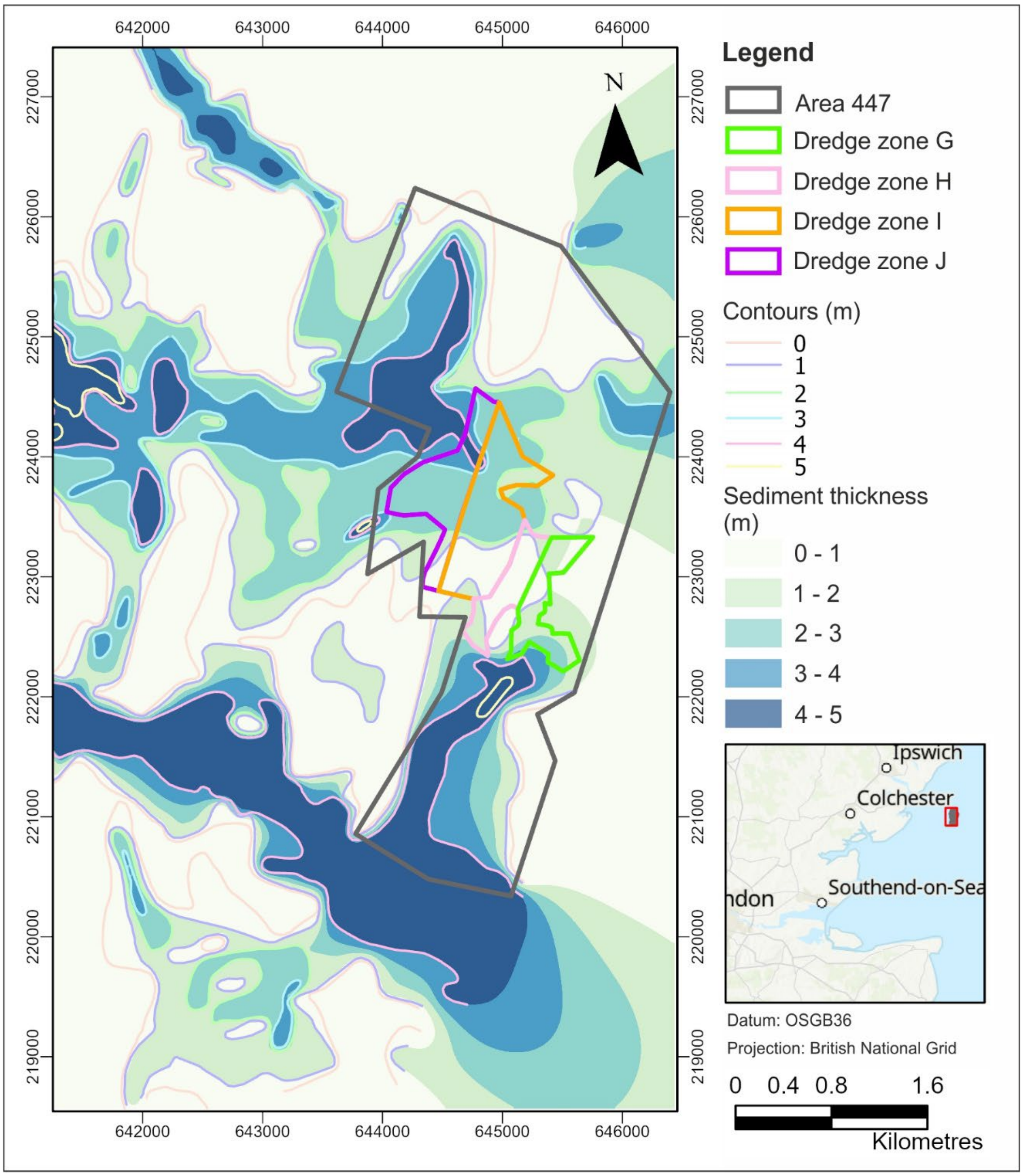

Figure 5 Sediment isochore in the wider study area (after D'Olier 1990/2000)

2.2 Sub-bottom profiler data

As part of the pre-dredge process, two separate sets of sub-bottom boomer data were acquired for Area 447 and adjacent zones, in 1990 and 2000 (Table 1; Figure 6). The 1990 data consists of 26 lines at approximately 250 m line spacing, running NNE-SSW, parallel with the eastern extent of Area 447, and three lines running perpendicular to these at approximately 2 km line spacing (Figure 6). In 2000, 30 boomer lines were acquired, oriented E-W at a line spacing of approximately 200 m across Area 447.

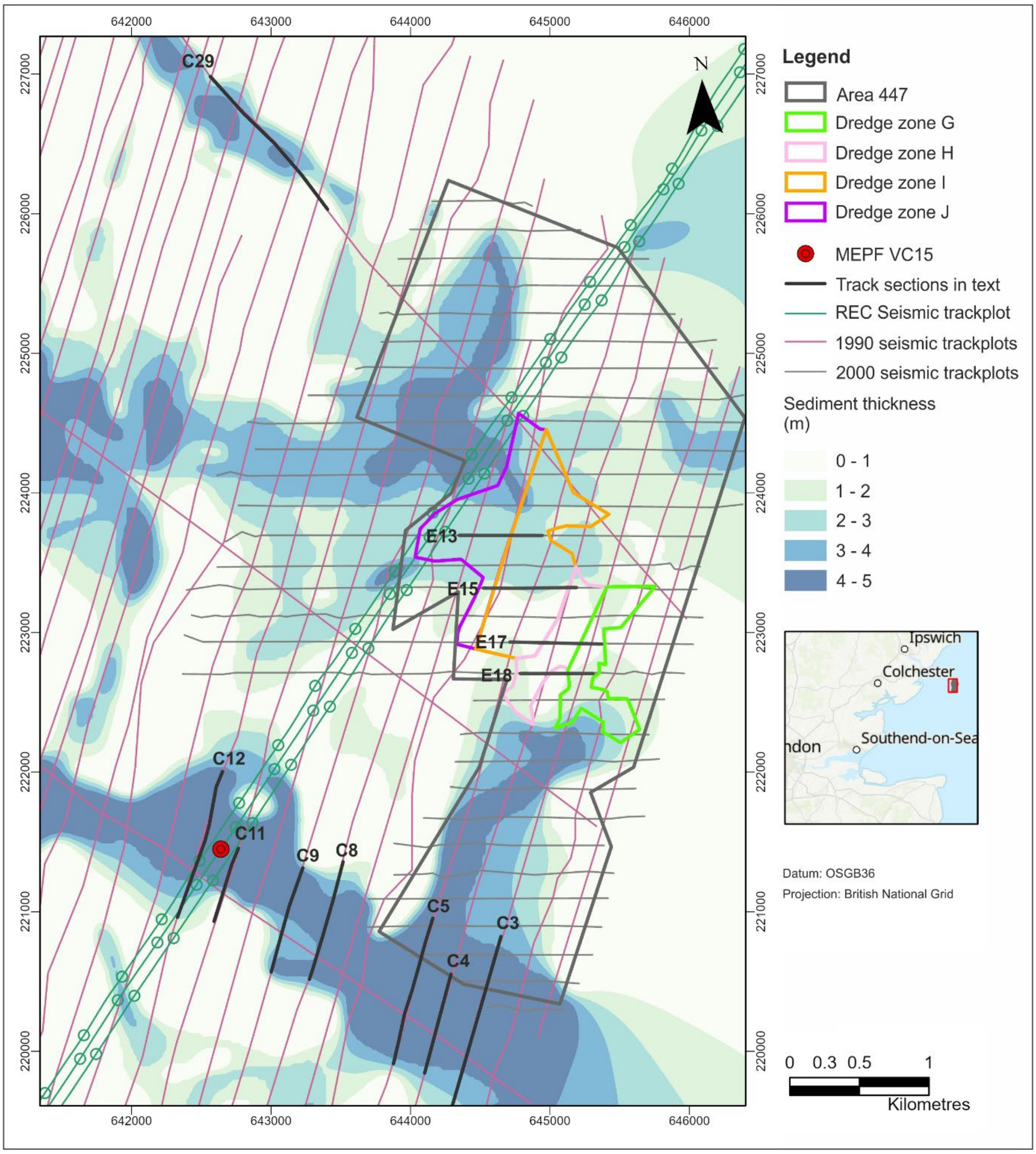

Figure 6 Trackplots from 1990, 2000 and MEPF seismic data, with MEPF VC15, against a background of sediment thickness. Sections of seismic lines discussed in the text are shown in bold and labelled.

Having these paper rolls converted to digital traces was considered an option early on so that they could be analysed in Petrel. After an initial assessment of the data, however, it became clear that this was not necessary as the area of 447 that was dredged for the beach replenishment was characterised by a relatively thin veneer of non-channelised deposits, and there would have been limited gain in replicating the thorough interpretations already made by D'Olier (after the 1990 and 2000 data). Having digitised the fix points from both these surveys we were able to compare the paper traces with the

D'Olier interpretation and are confident it is a high-quality interpretation of the data and suitable to be used in the project.

Running approximately north-south to the east of Area 447 is a seismic line taken as part of the Outer Thames Regional Environmental Characterisation (OTREC) survey and subsequent interpretation funded by the Aggregates Levy Sustainability Fund (ALSF) and the Marine Environment Protection Fund (MEPF). Its location relative to the 1990 and 2000 surveys can be seen in Figure 6. The associated MBES data showed the presence of a small north-south trending channel that appeared to correlate with a channel feature apparent in the seismic line (Figure 7). A vibrocore was taken through the gravels at the edge of this feature, providing an OSL date of 116±6.5 ka (176/TE09; MIS 5d) towards the base of this aggrading sequence (Dix and Sturt 2011).

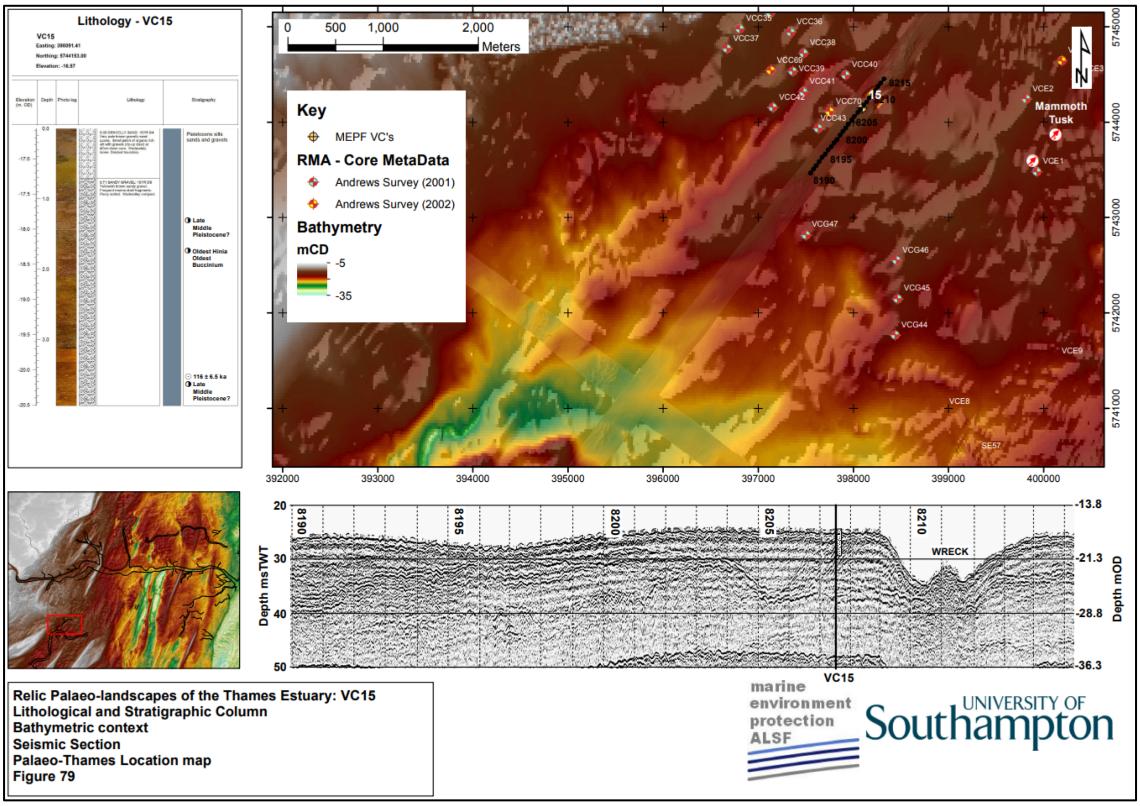

Figure 7 VC15 and corresponding data from OTREC, with inset showing the presence of the north-south trending channel

2.3 Overall interpretation of the area

The aggregated seismic data and interpretations clearly indicate the presence of a significant NNW-SSE channel system running to the south of Area 447, the presence of which is confirmed at varying levels of clarity in all of the 1990s boomer lines that cross this feature (e.g. Figure 8). Whilst the evidence available for the OTREC implied that the channel seen and sampled at VC15 (Figure 7) was part of a small north-south trending tributary, the addition of the 1990 and 2000 boomer data indicates that this feature is in fact part of this larger east-west channel.

Several NNE-SSW lines from the 1990 data cross this feature, with those discussed in the text shown in Figure 6. These lines demonstrate the presence of multiple channel phases. Towards the western extent of the interpreted area this feature becomes increasingly ephemeral, but in line C12, 120 m west of VC15, we can see three phases of activity, the most stratigraphically recent being that sampled by VC15 and MIS 5d in age (Figure 9). However, the Thames REC line with core VC15_MEPF and C11 (130 m east [Figure 8]) shows only one channel feature. This is interpreted as the MIS 5d channel on the basis of internal structure as well as spatial correlation with the OTREC data.

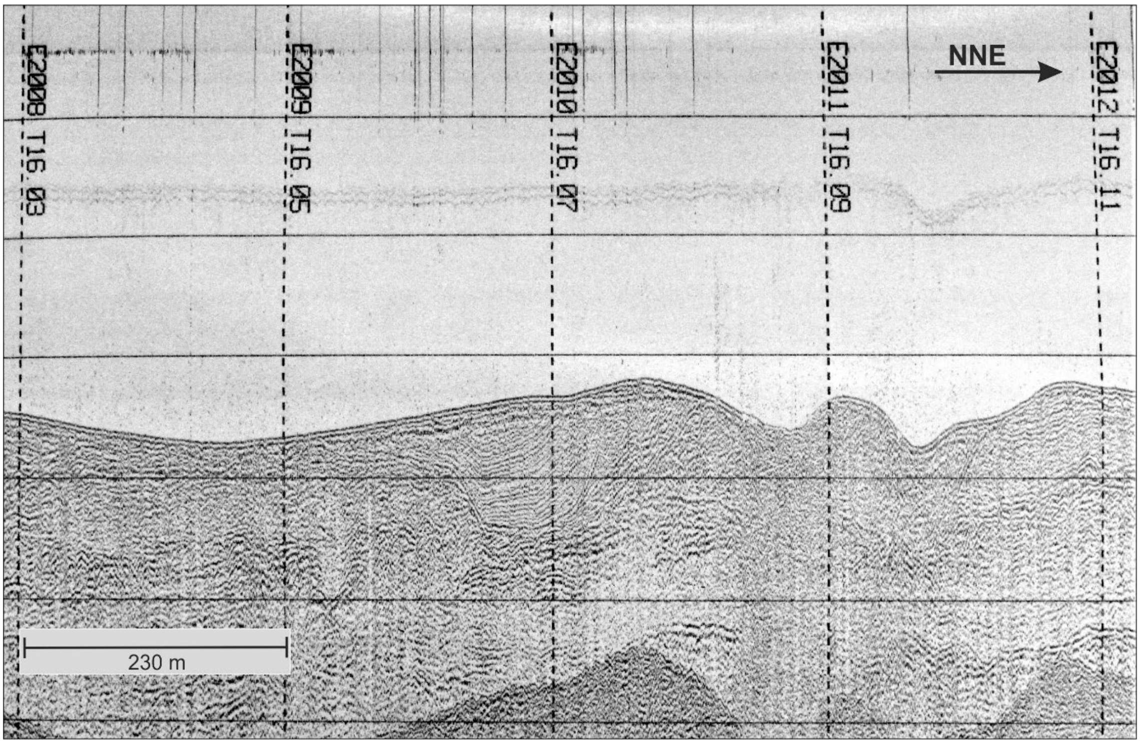

Figure 8 Line C11 from the 1990 boomer survey, oriented SSW-NNE across the east-west channel

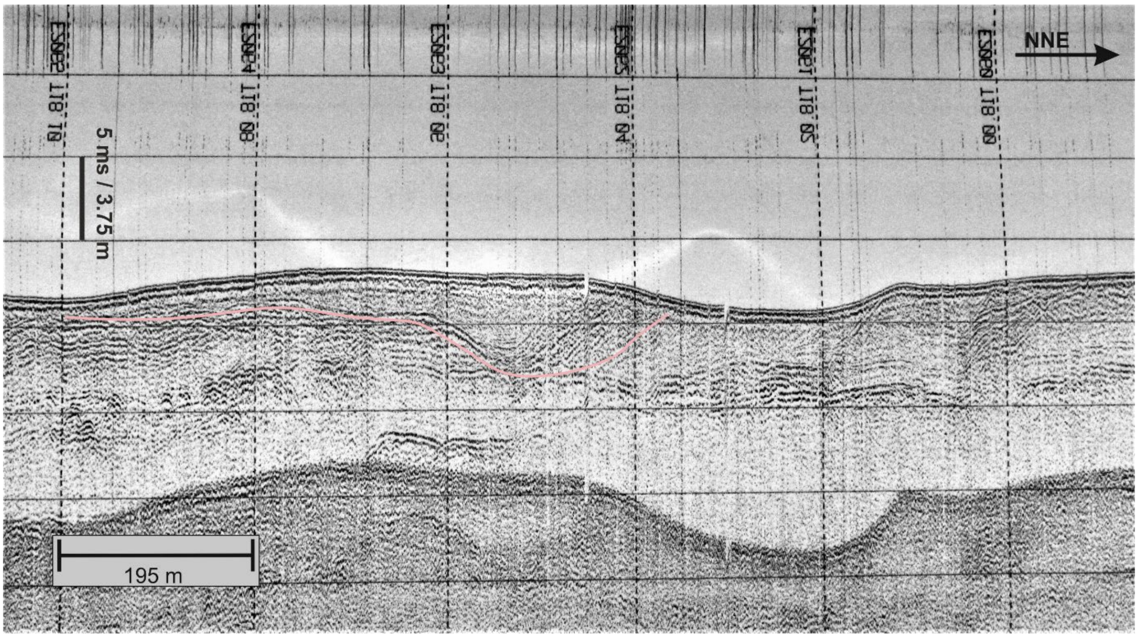

Figure 9 Line C12 showing three phases within the east-west channel, with that interpreted as the MIS 5d channel to the south and stratigraphically youngest shown in pink

Approximately 1.5 km to the east from C12 — from lines C5 onwards — we see this main channel cutting through an earlier channel phase, this time to its south, in line C5 (Figure 10).

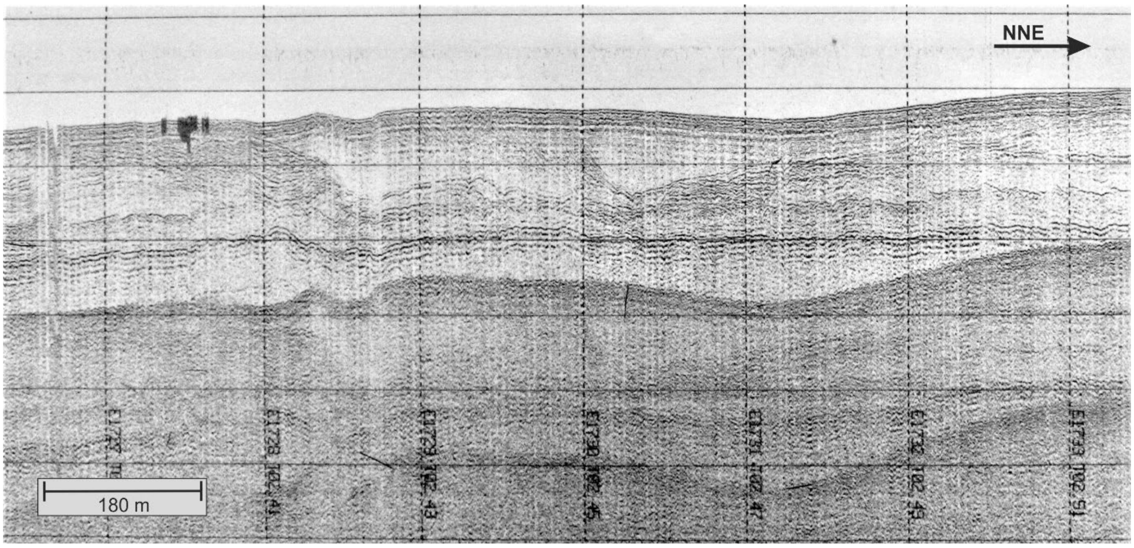

Figure 10 Line C5 showing two phases of the east-west channel

With current line spacing and a lack of analysed or dated palaeoenvironmental material other than VC15, two scenarios can be tentatively proposed for the east-west channel feature:

(a) The two earlier phases seen in line C11 to the west relate to the dynamic movement of a fluvial system that is broadly contemporary with the youngest phase of incision and deposition in MIS 5d.

(b) The three phases seen towards the west are previous phases of incision and deposition that took place in earlier periods of the Pleistocene which the MIS 5d channel is cutting through. For the central expression of this feature the MIS 5d channel is scouring out and occupying these earlier incisions, with this changing further to the east, where we see these earlier phases now preserved to the south of, and cut by, the MIS 5d incision.

Running approximately perpendicular with this east-west feature are two possible tributaries, seen at the eastern and western extents of the study area, with that at the easternmost extent being the most clearly defined and relating most directly to the main dredge area (Figure 6). Assessment of the boomer data, however, does not provide any clear indication of tributary features, indicating instead that there are a series of cut-and-fill features characterising this area; a remnant channelised surface. Due to the wide line spacing of the boomer data, it is not possible to make a clear interpretation of these features at this stage. However, the relationship between these features, the surface that they are cutting through, and the east-west channel is central to clarifying the chronology of the study area.

There is a further channel feature seen in the sediment thickness maps to the north-west of the study area, seen clearly in line C29 (Figure 6 and Figure 11). In contrast to the north-south-trending potential tributaries, this channel feature can be clearly seen in the 1990s boomer data, where it is cutting through the surface sediments. The continuation of this feature into the study area, however, is not clear, as the channel signature disappears approximately 2.5 km north-west of Dredging Zone J. In the intervening area, we see a similar picture to that which characterises the entire study area: a series of cut-and-fill features associated with a veneer of deposits. This has previously been interpreted as a braid-plain environment (Wessex Archaeology 2003), but with current evidence it is not possible to state conclusively what these features represent. As above, the relationship of this deposit with the channel features seen in the data is key.

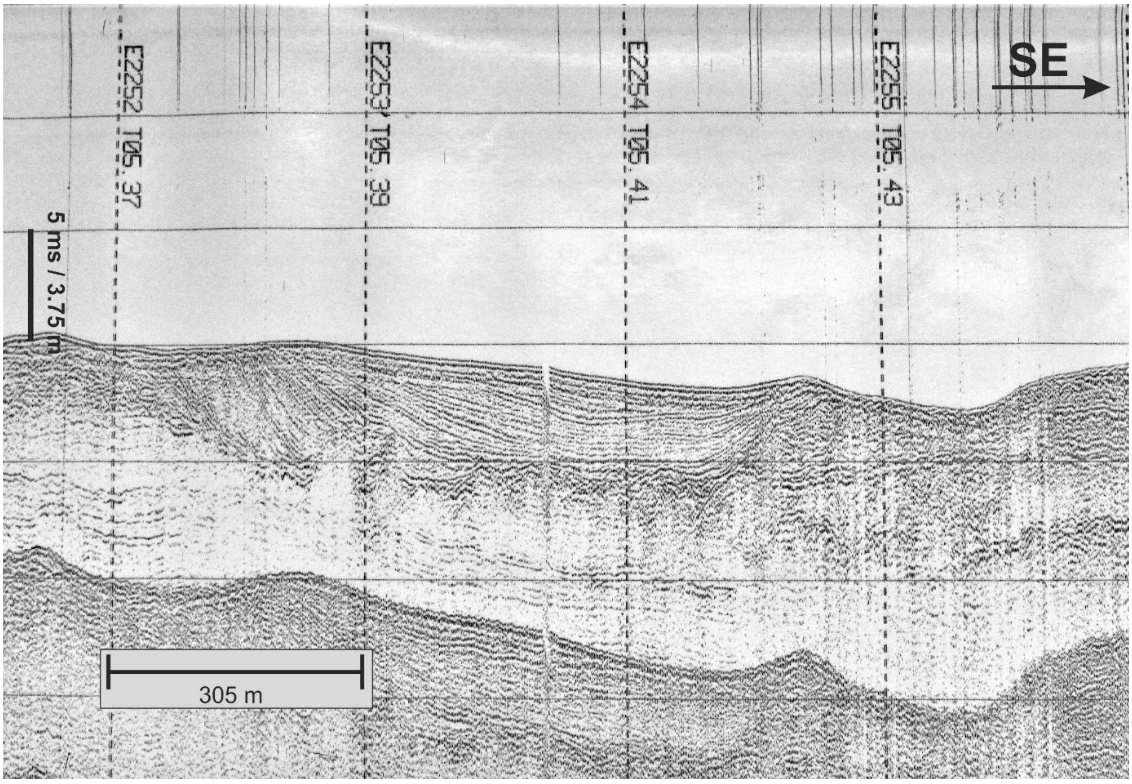

Figure 11 Channel seen to the north-west of the main study area, line C29 (see Figure 6 for location in the wider context)

Clarification of these relationships requires lines to run across the channel system, continue across the study area, and have clear stratigraphic relationships. What we see in a few lines of the 1990 data is a clear indication that the E-W channel system is cutting through the surface sediments (Figure 12); this relationship is seen most clearly in lines C5, C4 and C3. These lines continue to the north, moving through some of the key areas of dredging (Zones G, H and I). It is clear that there are some more ephemeral cut-and-fill features in the top few metres of these lines, possibly representing a channelised remnant surface. What is not clear from this is how these features relate to the surface cut by the east-west channel.

As outlined by Wessex Archaeology (2003), and discussed above, the seabed within the area of dredging for the beach recharge does not lie within any clearly incised channel. Rather, what we see in this area are relatively thin Pleistocene deposits (0–5 m) with frequent erosional features that cannot be laterally traced between lines (Figure 13). As stated above, this has been previously interpreted as a possible braid-plain, but, given the line spacing available, it is not possible to determine whether the incisions relate to channels or more localised features.

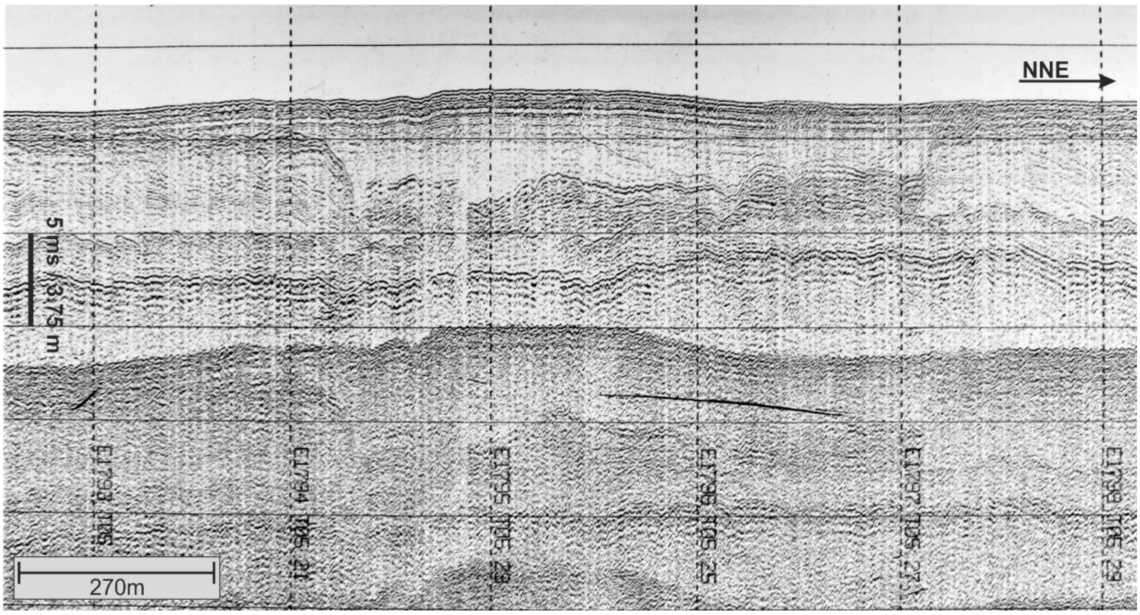

Figure 12 Line C3 showing channel cutting through surface

Overall there is a thinner (0–2 m) spread of Pleistocene deposits towards the south of the area — where the highest density of dredging has taken place — with the underlying London Clay occasionally appearing at, or close to, the surface (seen most clearly in Line E17: Figure 13). Vibrocore VC05, recovered from the seabed surveyed in Line E17, shows the superficial nature of these deposits, hitting London Clay at 0.93 m below the seabed. Line E18 shows an example of a possible channelised feature, which appears to be related to, rather than cutting through, the surface. Figure 14 shows these lines in the context of the dredge zone and vibrocores discussed above.

Given the vertical resolution of the lines, these thinner veneers of deposit — from which vibrocores show occasionally alternating facies of archaeologically high-potential channel edge/floodplain deposits — are sometimes difficult to pick out and describe. However, tying the lines collected in 2000 in with the 1990s data does indicate that these surface deposits are the same unit of sediments being cut by the east-west channel to the south. This has important implications for the chronology of these deposits and the understanding of the recovered archaeology, implying that the channelised remnant surface pre-dates MIS 5d. This agrees with the palaeoenvironmental and dating evidence from VC23, which places these deposits within late MIS 7/early MIS 6 (see Section 3).

2.4 Correlation with the 2015 Vibrocores

As described in Section 3.5, seven cores out of a total of 23 were chosen for assessment using information contained in available core logs (Figure 15). These were chosen based on palaeoenvironmental potential, as well as the presence of potential lower energy floodplain/channel edge deposits linked to the fresh appearance of stone tools; these are unlikely to have seen significant fluvial transport. All cores are from the 2015 round of coring, which took place immediately prior to the main dredging for the beach replenishment scheme and sit within, or just outside, the dredge zones shown in Figure 4. Of these, VC23 was investigated in more detail. The relationship of this core with the data described here will be briefly outlined.

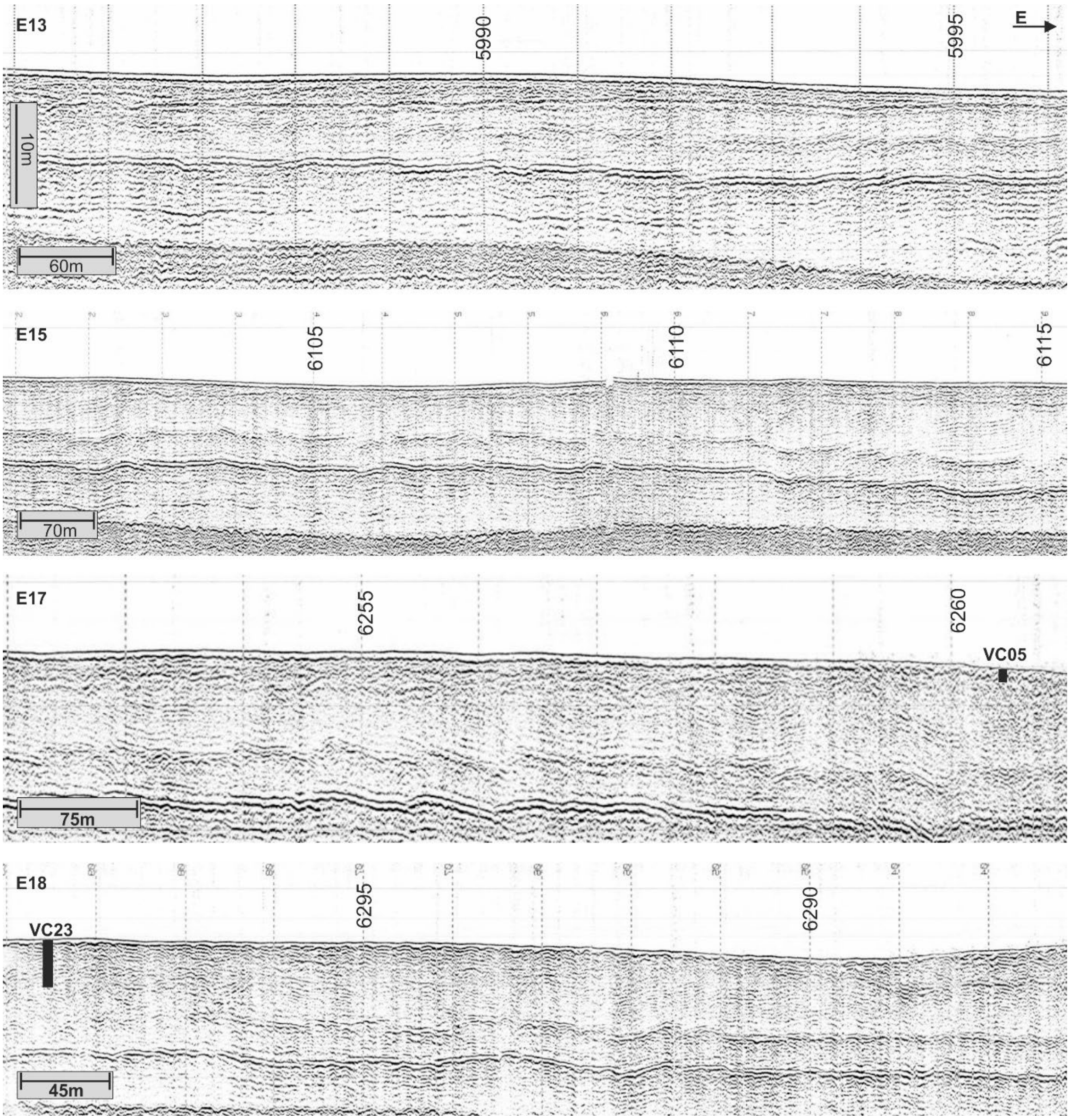

Figure 13 2000s boomer lines discussed in the text, showing VC05 and VC23

VC23 sits on line E18 between points 6298–6299 (Figure 16), it is c. 160 m west of C4 and c. 140 m east of C5. The isochore map indicates that there is approximately 2–3 m of deposit before bedrock, but the seismic reflection in this area is unclear and this is open to interpretation – possibly the rationale for this core location. Assessment of this core shows that, at 5.03 m, it still has not reached London Clay, but is characterised by a layer of modern marine sediments (0.93 m) overlying 4.10 m of Pleistocene channel edge/floodplain deposits.

Using the pre- and post-dredge MBES it is possible to see that the depth of deposit exploited at the location of VC23 is approximately 2 m, indicating that the Pleistocene floodplain/channel edge layers would have been impacted. The depth of the dredge head throughout the area is unclear, but it appears that within the surrounding 50 m, sub-bottom depths ranged from 0–9.63 m.

Of the remaining cores assessed, three others showed the presence of floodplain / channel edge deposits: VC5, VC15 and VC16 (Figure 15), the seismic signature of which is difficult to define at the current resolution. Combining again with the difference plot from the pre- and post-dredge data, it appears that these lower energy deposits in both cores VC15 and VC16 (within the lesser exploited dredge zone J) would have been impacted.

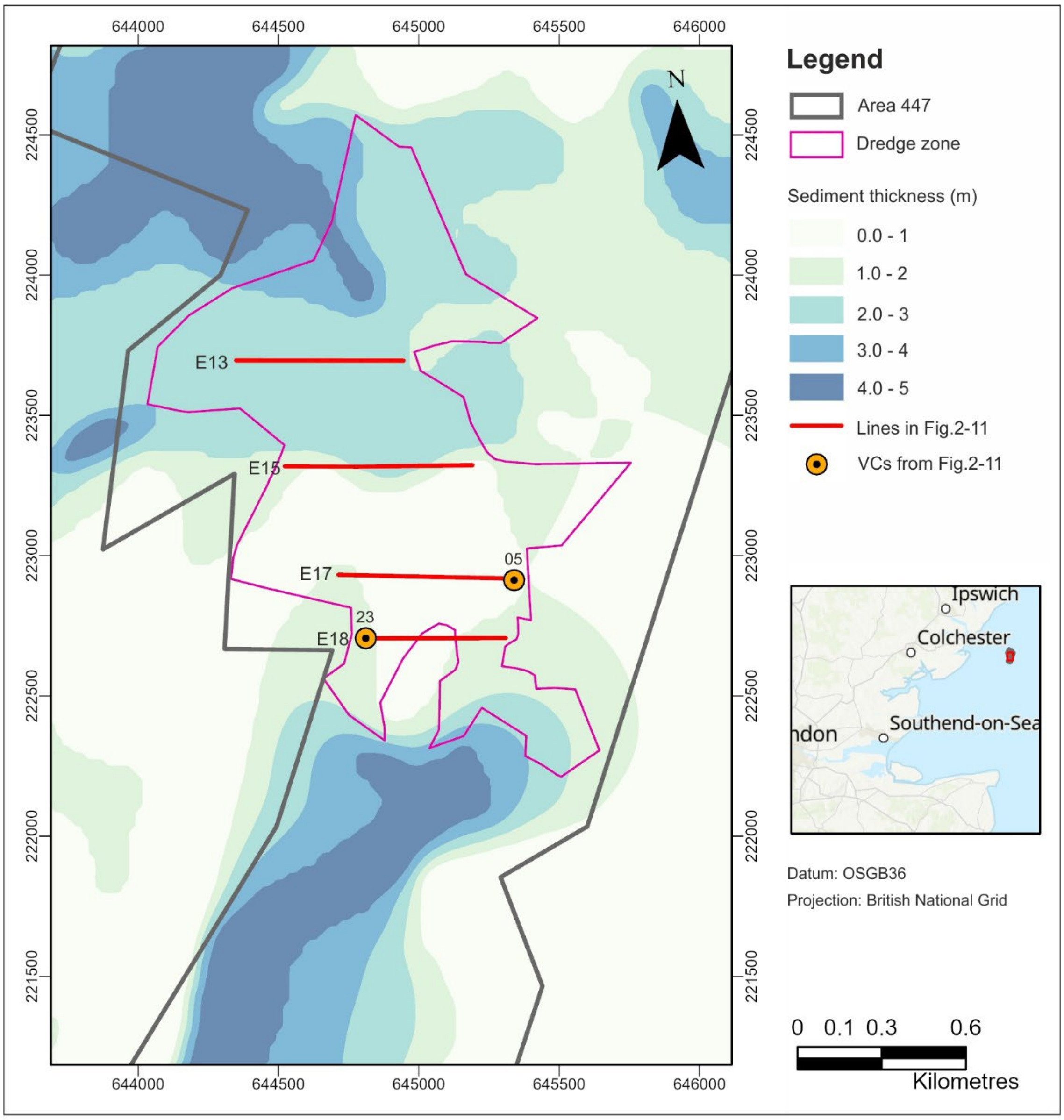

Figure 14 2000s boomer tracks discussed in the text, with lines representing tracks seen in Figure 13, and VCs 05 and 23

Given the stratigraphically younger relationship of the MIS 5d east-west channel with the older remnant surface seen within the dredge area, as well as the evidence from VC23 (Section 3.4), it is likely that at least elements of this surface date to the MIS 7/6 boundary.

2.5 Summary

The seabed in the area exploited for the beach recharge (dredge zones G, H, I and J) consists of a channelised remnant surface. From current data the chronological and stratigraphic relationships of these cut-and-fill features with one another are unclear, but indications are that they are related to, rather than cutting through, the surface deposits. To the south of Area 447, however, sits a large east-west trending channel system. This can be picked out in both the sediment thickness maps as well as the seismic data; its secure identification as a channel system contrasts markedly with the cut-and-fills of the remnant surface.

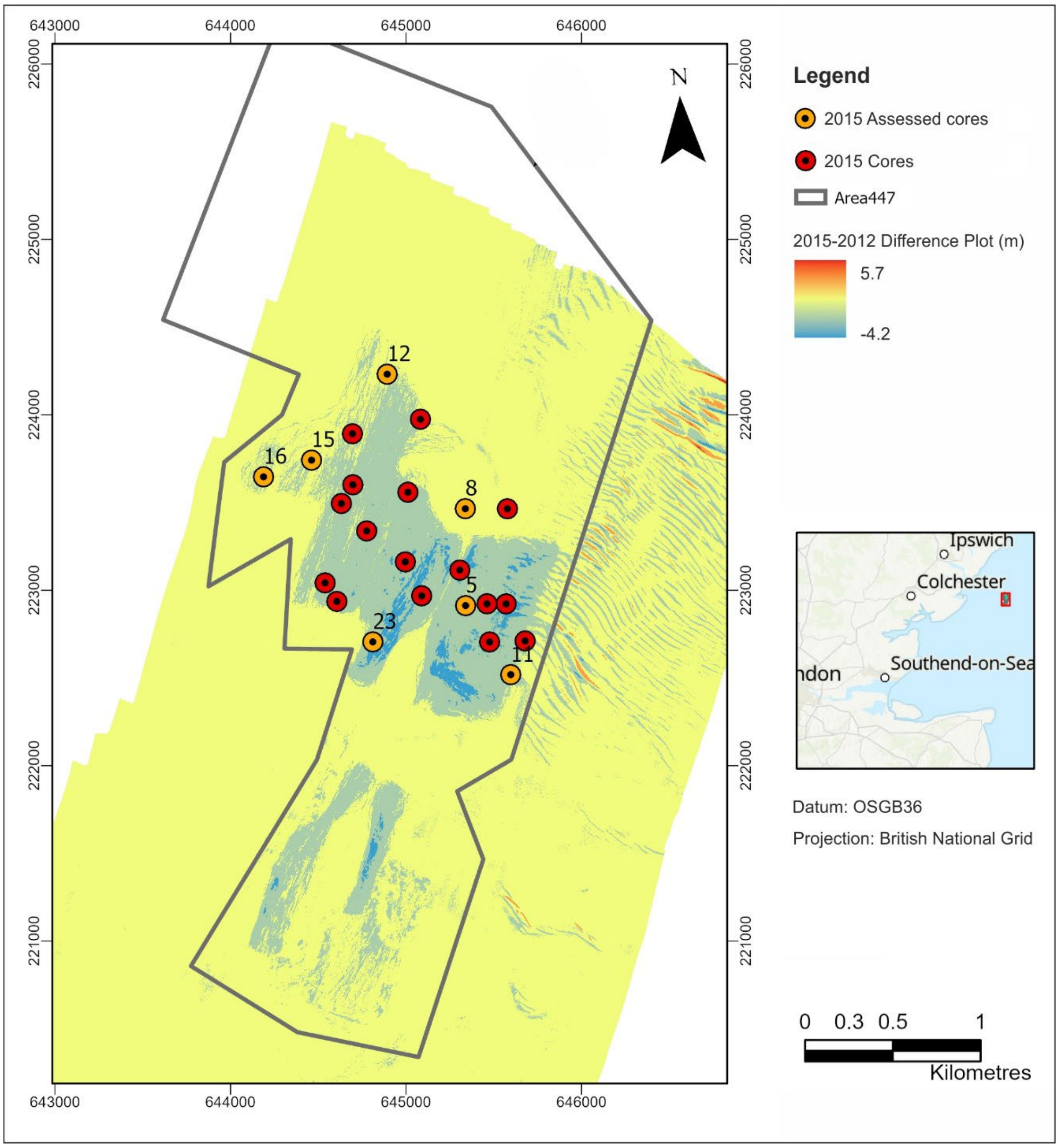

Figure 15 Vibrocores assessed and their relationship to the main exploited areas

The combination of 1990s and 2000s boomer data indicates that there is a stratigraphic relationship between the cut of the main channel, OSL-dated to MIS 5d (116±6.5 ka [Dix and Sturt 2011]) and the remnant surface, with the channel cutting through the surface, as indicated in Figure 12. The surface must therefore pre-date MIS 5d, which is supported by palaeoenvironmental and dating evidence from VC23 placing these deposits at the MIS 7/6 boundary (Section 3.4).

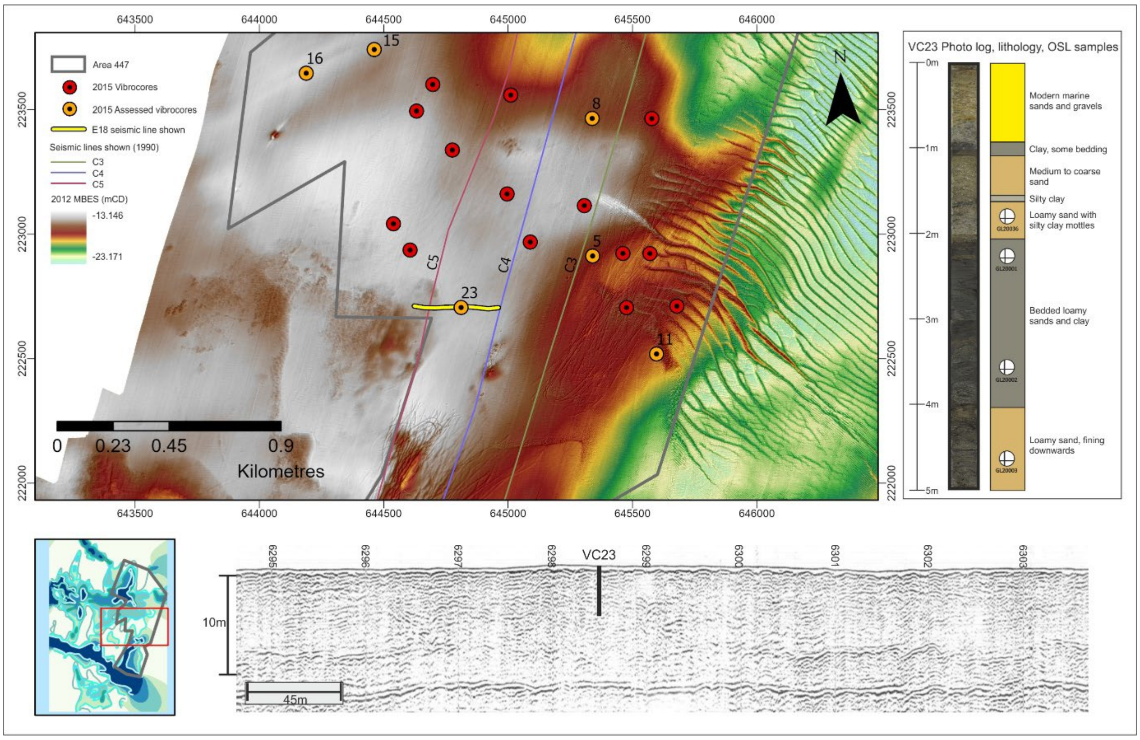

Figure 16 VC23 in its wider context, showing location on 2012 MBES, within Seismic (2000) line E18 and where this sits in the wider area (inset map shows sediment thickness to bedrock, after D'Olier 1990/2000). Lithological and luminescence dating sample information provided with depth below seabed scale.

Cores taken in 2015 from within the study area, including VC23 (Section 3), show the presence of floodplain/channel edge deposits at depth. These not only sit within the area identified as a channelised remnant surface, but within the area that was subsequently most heavily dredged for the beach recharge (Figure 4).

3 2015 AREA 447 VIBROCORE SITE INVESTIGATIONS

A component of the Project Design for Project 7738 was to undertake an assessment of existent core material from Area 447. Twenty-three cores had been identified as being held at Hanson Aggregates in Southampton and would be made accessible for geoarchaeological assessment, with 19 of these being from the area of concentrated dredge plots (Figure 17).

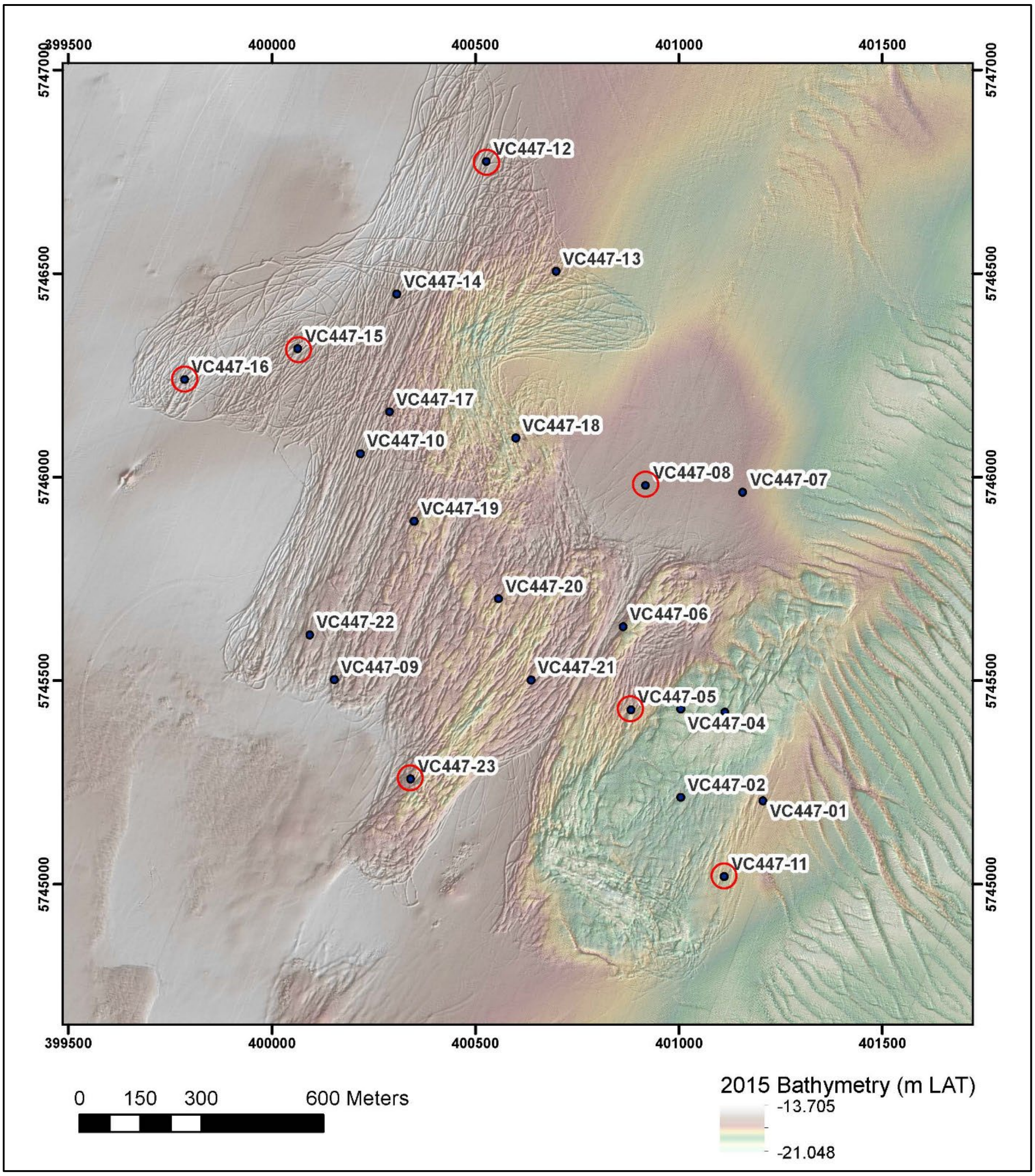

Figure 17 Vibrocores collected in 2015 from Area 447. Cores circled in red were subject to a Stage 2 assessment.

Vibrocores were collected by CMS Geotech Ltd in February 2015, commissioned by Cemex Marine UK LTD (CMUK), Hanson Aggregates Marine LTD (HAML) and Lafarge Tarmac Marine LTD (LTM), collectively operating as the Resource Management Association. The overall investigation was intended to provide information on seabed conditions necessary for the Client to manage marine aggregate extraction activities at Licence Area 447, also known as 'Cutline', located to the east of Harwich/Felixstowe.

The fieldwork comprised the collection of twenty-three 6 m vibrocores within Licence Area 447 (Table 2). The work was carried out on board CMSG's dedicated survey vessel 'MV FlatHolm' on the 9th and 10th February 2015. Cores were obtained using the CMSG C-CoreHP High Penetration Corer in 6 m mode.

Core ID	Easting (WGS84 UTM 31N)	Northing (WGS84 UTM 31N)	Water Depth (m)	Recovery (m)	Stage 2 Assessment?
VC01	401207	5745204	18.5	2.65	No
VC02	401005	5745212	19.6	1.5	No
VC03	401114	5745422	20.4	2.05	No
VC04	401005	5745430	20.4	1.4	No
VC05	400883	5745428	18.7	1.75	Yes
VC06	400864	5745632	16.1	2.6	No
VC07	401158	5745962	18.2	2	No
VC08	400919	5745979	18.1	2.25	Yes
VC09	400153	5745502	16.4	3.15	No
VC10	400217	5746057	17.5	2	No
VC11	401112	5745018	16.5	3.15	Yes
VC12	400528	5746774	17.9	4.5	Yes
VC13	400699	5746505	20.1	3.65	No
VC14	400307	5746449	18.7	2.8	No
VC15	400065	5746315	19	4.35	Yes
VC16	399786	5746239	18.6	2.75	Yes
VC17	400290	5746159	20.1	3.5	No
VC18	400599	5746095	20.1	3.55	No
VC19	400350	5745891	21.2	1.55	No
VC20	400558	5745700	20.6	1.5	No
VC21	400637	5745501	18	2.9	No
VC22	400094	5745612	18.3	1.7	No
VC23	400342	5745258	17.3	5.1	Yes

Table 2 Vibrocores collected from Area 447 in February 2015

Following completion of the field investigation, the vibrocore samples were split, photographed, described and logged in accordance with BS EN ISO 14688. A schedule of laboratory testing involving only particle size distribution (PSD) was carried out on the cores, with sampling taking place where a change of lithology or aggregate composition was noted (see CMS Geotech 2015). Cores were subsequently re-wrapped and transported to Hanson Aggregates Marine Ltd, Southampton, where they remained stored until the current project.

3.1 Staged geoarchaeological assessment

Following COWRIE guidance (Gribble and Leather 2011), the aims of archaeological assessment of geotechnical data are achieved through a programme of staged recording, assessment and analysis:

- Stage 1. Geoarchaeological review of core logs: consists of a desk-based assessment of geotechnical core logs by a trained geoarchaeologist to determine which cores contain sediments of archaeological interest. Recommendations are made to the client as to which cores the geoarchaeologist would like to look at in Stage 2. For Stage 1 to be undertaken the core logs must be recorded in a manner that will allow identification of sediments of archaeological interest. The luminescence dating potential of the sediments is also assessed.

- Stage 2. Geoarchaeological recording: a detailed inspection and recording of the cores identified in Stage 1 to further assess archaeological potential. This requires physical access by the geoarchaeologist, who will make a record of the sediments encountered, their archaeological potential, and recommendations for any Stage 3 assessment, if required.

- Stage 3. Geoarchaeological assessment: samples are taken from the cores recommended (and recorded) in Stage 2 for specialist assessment to determine the age and palaeoenvironmental potential of the sediments. This stage comprises the sampling and laboratory analysis of a selected core, or cores, to a level sufficient to enable an assessment of the value of the palaeoenvironmental material (e.g. pollen, diatoms and foraminifera) surviving within the core(s). The assessment seeks to establish the preservation, diversity and quantity of palaeoenvironmental material, in order to further refine the interpretation of the sedimentary environment, and past human activity, identified in the Stage 2 recording. Recommendations are made as to whether a Stage 4 analysis programme, including dating, should take place on any of the core material.

- Stage 4. Geoarchaeological analysis: consists of more detailed investigation of the core material typically using the same techniques as Stage 3, but with extended counting and/or higher sampling intervals within key stratigraphic units. The work will be undertaken to a high standard which should permit the publication/dissemination of the results.

- Stage 5. Publication

Modifications to the COWRIE guidance are now common, with typically Stages 1 and 2 combined, while scientific dating is better undertaken during a Stage 3 assessment to establish: 1) if deposits can be dated; 2) which methods are most suitable for dating; 3) the age of the deposits; and 4) whether any additional dating is required during Stage 4 analysis.

3.2 Stage 1 Review

A review of the core logs and photographs was conducted in December 2019. Provisional interpretation of the vibrocores was undertaken by the geoarchaeologist, identifying which cores had potential and might be suitable for Stage 2 geoarchaeological recording

(Table 2). The majority of cores contained three main facies: a modern seabed sand and gravel, overlying Pleistocene sands and gravels, which unconformably lay above the London Clay. Within a number of cores, horizons of clays and silts were also observed within the Pleistocene facies. In most cores the London Clay surface appeared to be heavily eroded, though in some instances there was potential that a palaeosol upon this surface might have been preserved in situ.

Seven vibrocores were identified as suitable for Stage 2 geoarchaeological recording. These had a good geographical distribution across Area 447 and were selected on the following basis:

- Potential palaeosol horizons above London Clay
- Laminated fine-grained deposits within Pleistocene sands and gravels
- Changes in particle size distribution or clast appearance through the Pleistocene sands and gravels

3.3 Stage 2 Geoarchaeological Recording

3.3.1 Methodology

The geoarchaeological assessment followed the guidelines given in Historic England (2015), with descriptions according to Hodgson (1997) including sediment type, depositional structure, texture and colour. Interpretations regarding mode of deposition, formation processes, likely environments represented and potential for palaeoenvironmental analysis were also noted. The results have been tabulated and are given below. A photographic record of the samples, including key stratigraphic features, has been made to supplement the sedimentary descriptions.

3.3.2 Geoarchaeological recording

VC05

Geoarchaeological recording of VC05 is provided in Table 3 and shown in Figure 18.

Depth (m)	Description	Interpretation
0-0.81	10YR4/3 brown sand, medium to coarse. Coarse 10YR3/1 very dark grey mottles, clay, at 0.51-0.57 m. Very slightly stony, small, rounded with rare <5 mm sub-angular platy fragments, predominantly lighter flint. Broken shell, 1%, <5 mm, some rounding. Rare intact marine bivalves at top of core. No organics. Clear boundary to:	Pleistocene sands and gravel
0.81-0.93	10YR5/3 brown loamy sand, fine to medium. Some visible horizontal bedding in sand observed by subtle colour variations rather than grain size (darker horizons 2-4 mm thick). Very slightly stony, angular platy (quite fresh) dark flint. No shell, no organics. Sharp boundary to:	Pleistocene channel edge / floodplain

0.93-	10YR3/2 very dark greyish brown London Clay. Some reworking of coarse sand and natural flint flakes into the upper 5 cm but no visible structures.	London Clay

Table 3 Sediment description of VC05

Figure 18 Photograph of vibrocore VC05

This vibrocore was taken from a recently dredged area, so modern seabed deposits were absent and very little remained of the Pleistocene gravels overlying the London Clay. The base of the Pleistocene deposits, overlying the London Clay, contained a series of dark angular flint fragments coupled with some horizontally bedded sands. Some reworking of the underlying London Clay was present, though it was unclear if any palaeosol features remained. The base of the Pleistocene sequence suggested a low-energy environment within which aggradation of freshwater/estuarine deposits had taken place.

The presence of very fresh-looking black flint fragments, similar in colour to the recovered artefacts, might suggest these deposits were contemporary with hominin activity within Area 447.

The VC05 sequence replicates those found in other cores, notably VC16 and VC23. No further work was recommended for VC05.

VC08

Geoarchaeological recording of VC08 is provided in Table 4 and shown in Figure 19.

Depth (m)	Description	Interpretation
0.00-0.32	7.5YR 5/3 to 10YR 5/6 strong brown sandy gravel. No mottles, very stony, small to medium, predominantly flint (7.5YR 4/2 brown) sub-angular to sub-rounded, platy to tabular, with grain size reducing to base (<8 mm sub-rounded to rounded, rounded). Rare quartz, rounded, rounded. Very slightly shelly, broken (<10 mm, mainly <4 mm) fragments with rounding. No organics. Clear boundary to:	Pleistocene sands and gravel
0.32-0.49	10YR 4/1 dark grey silty clay loam with loamy sand horizontal bedding. Very slightly stony, small, angular (dark flint) with fine (<2 mm) broken shell in sandy horizons. No organics. Sharp boundary to:	Pleistocene sands and gravel
0.49-1.09	10YR 5/3 brown sand. Sand medium. No mottles. Stoneless, very slightly shelly (broken, <2 mm). No organics. Sharp boundary to:	Pleistocene sands and gravel
1.09-1.17	10YR 5/1 grey clayey loam, weekly bedded. No mottles. Stoneless, no shells, no mottles. Sharp boundary to:	Pleistocene sands and gravel
1.17-1.37	10YR 6/2 light brownish grey loamy sand. No mottles. Sand fine to medium, stoneless at top becoming moderately stony at base. Stone sub-angular to sub-rounded, platy to rounded. Mixed clast, predominantly darker flint but rare small patinated flint. Smaller stones (<10 mm) rounded. Very slightly shelly, small (<4 mm) angular fragments. No organics. Sharp boundary to:	Pleistocene sands and gravel
1.37-2.00	10YR 3/1 very dark grey London Clay.	London Clay

Table 4 Sediment description of VC08

The top of sequence (modern marine sands and gravels) is missing, presumably due to dredging. Generally, the deposits in this core represent a lower energy setting. Phases of fairly clean sand and silt deposition are attributed to channel margin or overbank flooding. The upper gravel appears very mixed, compared to those deeper in the core where large dark sub-angular platy flint, similar in appearance to the worked flint artefacts, is present. The stratification within this core is similar to that observed in VC12, except no small fresh-looking flint fragments were visible in VC08 as seen in other cores. There is no evidence of reworking of the top of the London Clay, though it is unconformably overlain by the Pleistocene deposits.

The VC08 sequence is similar to other cores recorded, so no further work on this core was recommended.

Figure 19 Photograph of vibrocore VC08

VC11

Geoarchaeological recording of VC11 is provided in Table 5 and shown in Figure 20.

The content of VC11 suggests remobilised Pleistocene sands and gravels, lying between an eroded London Clay and transgressional marine sands and gravels. The Pleistocene gravel lacks the magnitude of dark fresh flint flakes seen in core VC12 but has a full range of clasts (except quartzite), which may suggest a reworked sequence or possible analogy to the deposits from the middle of VC12.

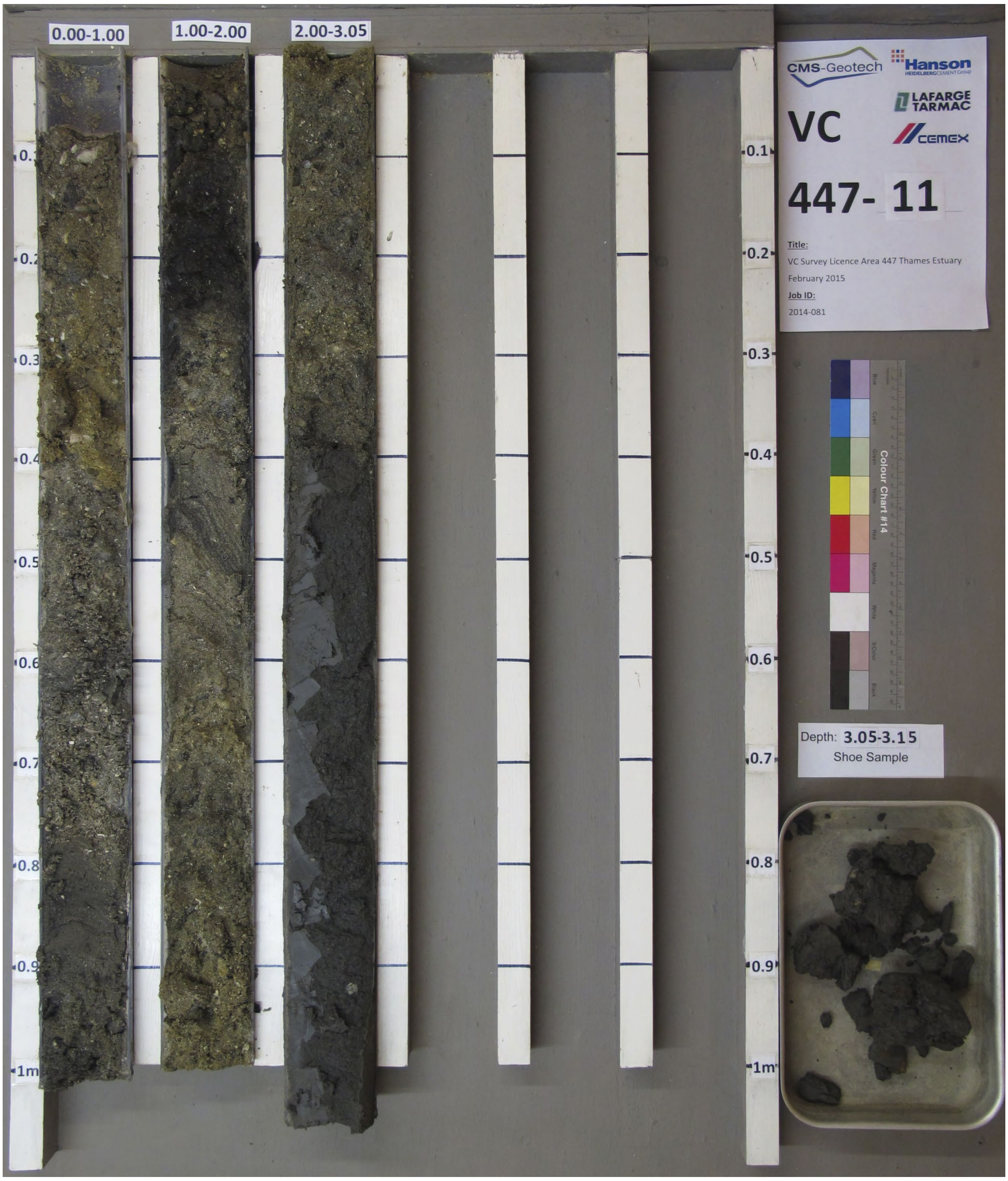

Figure 20 Photograph of vibrocore VC11

Depth (m)	Description	Interpretation
0-0.79	10YR5/3 brown shelly sand. Predominantly bivalves, 5-30 mm, with many valves intact. Between 0.40-0.6 6m intact oyster shells present, while below 0.66 m mixture of broken and intact bi-valves (c. 35%). Very slightly stony, sub-rounded to rounded, small to medium, mainly flint with some smaller (<10 mm; 1%) rounded stones. No organics. No mottles. Clear boundary to:	Modern marine sands and gravels
0.79-0.92	10YR4/2 dark greyish brown loamy sand. Some coarse silty clay mottles, 10YR3/2 very dark greyish brown, c. 15%. Very rare (1%) fine broken shell. Stoneless. Clear boundary to:	Pleistocene sands and gravel

Depth (m)	Description	Interpretation
0.92-1.26	10YR4/1 dark grey gravelly loamy sand, transitioning to a sandy gravel at base. No mottles. Very stony, medium, sub-rounded to rounded, platy to tabular, flint. Mixture of flint colours and patination. Rare sub-angular flint. Rare (1%) broken shell, <4 mm. No organics. Gradual boundary to:	Pleistocene sands and gravel
1.26-1.70	10YR6/3 pale brown sand. No mottles. Rare, small, stone, mixture of sub-angular platy flint and sub-rounded quartz. Fine (<2 mm) broken shell. No organics. Gradual boundary to:	Pleistocene sands and gravel
1.70-2.40	10YR6/4 light yellowish brown sandy gravel. Mixture of stone lithologies including brown (some patinated; c. 50%) and dark flint (c. 30%), along with quartz (c. 20%). Stones are small to large, mainly sub-rounded to rounded, tabular to platy. Angular to sub-angular flint shows signs of rolling. Rare broken shell, <10 mm, rolled. No organics. Sharp (erosive) boundary to:	Pleistocene sands and gravel
2.40-3.00	10YR 3/1 very dark grey London Clay.	London Clay

Table 5 Sediment description of VC11

The core was thought to have no potential for luminescence dating, so no further investigation of VC11 was recommended.

VC12

Geoarchaeological recording of VC12 is provided in Table 6 and photographs shown in Figure 21.

Modern marine sands and gravels are present above 2.13 m. Under these are Pleistocene sands and gravels, probably fluvial in origin. Through the sequence there appears to be stratification of flint type and preservation, from very pale to darker in colour going down the core. Patination of flints is also prevalent in the centre of the core. Some quartzite is present, and only appears at the top of this sequence. Any shell present is heavily rolled and broken. In the base of the core (below c. 3.8 m) angular platy dark flint fragments are present, many appearing very ‘fresh’. Below 4 m there is a change in colour suggesting incorporation of fines, possibly derived from the London Clay. Some horizontal bedding contains fresh-looking flint chips, though none that could be classed as archaeological. This might suggest some form of stabilisation horizon rather than any true palaeosol.

The apparent stratification of the flint through the core warranted investigation to identify if there is indeed restriction of the darker flint, visibly comparable to that used for the recovered artefacts, to the deeper part of the sequence. This pattern is seen in other cores, but best preserved in VC12. AAR dating of shell would not be suitable for this core, but luminescence dating would be possible with the deeper (below 4 m) deposits. Palaeoenvironmental assessment associated with deposits below 4 m could also help to identify the nature of the local environment.

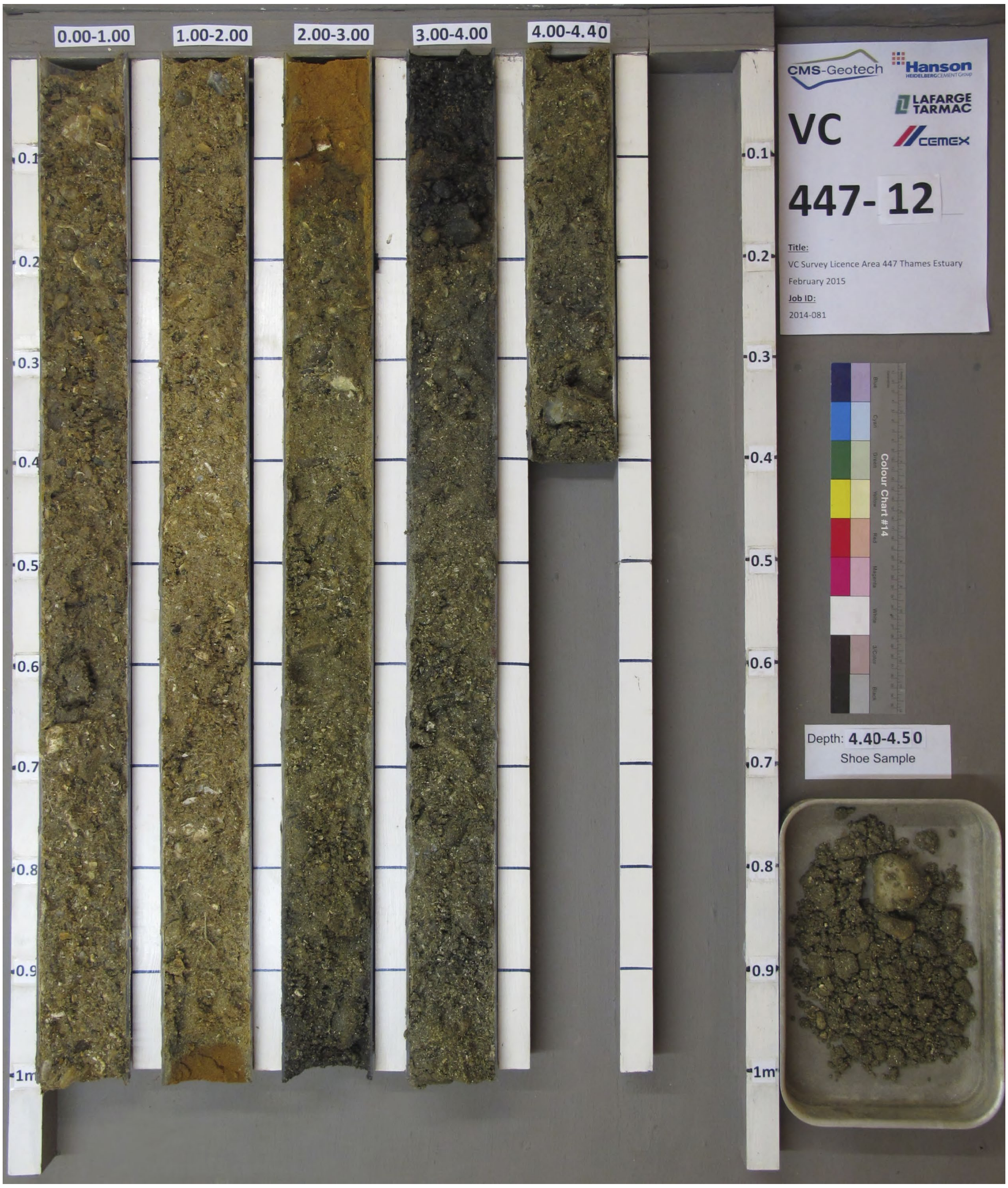

Figure 21 Photograph of vibrocore VC12

Depth (m)	Description	Interpretation
1.00-1.97	7.5YR6/6 reddish yellow. No mottles, Gravelly coarse sand, slightly stony (7%) sub-rounded to rounded, small to medium. Stone is mainly brown (e.g. 7YR5/6 strong brown). Large sub-rounded stones at base, 1.90-1.97 m. Shell 3%, broken, 2-20 mm, predominantly bivalves. No organics. Abrupt boundary to:	Marine sands and gravels
1.97-2.13	5YR6/8 reddish yellow sand (fine to medium), no stones. Intact *Mytilus* bivalves with some ?Hydrobiidae gastropods (<4 mm). No organics. Abrupt boundary to:	Marine sands and gravels

Depth (m)	Description	Interpretation
2.13-2.94	7.5YR6/6 reddish yellow sandy gravel, sand medium to coarse. No mottles. Very stony, sub-angular to sub-rounded, predominantly medium flint (predominantly brown; 7.5YR4/6 strong brown) with rare large sub-rounded quartzite. Coarse sand includes c. 5 small (3-5 mm) broken and heavily rounded shall fragments, unable to ID. No organics. Abrupt boundary to:	Pleistocene sands and gravel
2.94-3.20	5YR3/1 very dark grey, turning to 7.5YR 4/2 brown at base. Slightly silty sandy gravel. No mottles. Flint is predominantly 10YR4/4 dark yellowish brown with 7.5YR5/6 strong brown outer stain, predominantly sub-rounded small (<8 mm) with some sub-rounded larger nodules (10%). Dark colour is the silt staining the stone. Towards bottom of unit some darker (10YR4/2 dark greyish brown) flint is also present, but with similar strong brown outer staining. No shell, no organics. Clear boundary to:	Pleistocene sands and gravel
3.20-4.00	10YR5/4 yellowish brown sandy gravel. 3.20-3.55 m contains white patinated small flint, sub-angular to rounded, with interior 10YR4/3 brown. Below 3.55 m predominantly non-patinated darker small to medium flint (10YR4/1 dark gray), mainly sub-rounded to rounded. Fine stone fraction (<8 mm) is angular (very fresh; 10YR4/1)) to rounded (10YR5Y8/4 pale yellow), ratio c. 20:80. Broken shell fragments (bivalves) present throughout, mainly <5 mm but rare 10 mm fragments. No organics. ?Abrupt boundary to:	Pleistocene sands and gravel
4.00-4.24	7.5YR4/4 brown slightly gravelly silty sand. Flint (c. 15%) is small to medium, sub-angular to sub-rounded, non-patinated with 10YR4/1 centre. Small stone fraction (5%; <5 mm) is angular to sub-rounded. <4 mm <2% broken shell, no organics. Clear boundary to:	Pleistocene sands and gravel
4.24-4.27	7.5YR4/1 dark grey silty gravel. No mottles. Very stony, stone is platy dark (10YR4/1 dark grey) unpatinated flint, angular (fresh) to sub-angular, horizontally bedded, <2 cm matrix is a sandy loam. No shell, no organics. Boundary is indistinctive (?clear) to:	Pleistocene sands and gravel
4.27-4.40	7.5YR4/4 brown slightly gravelly silty sand. Predominantly tabular to platy dark (10YR4/1 dark grey) unpatinated flint, with two rounded quartz stones (10 mm and 40 mm). Sand is medium to coarse. No shell, no organics.	Pleistocene sands and gravel

Table 6 Sediment description of VC12

VC15

Geoarchaeological recording of VC15 is provided in Table 7 and Figure 22.

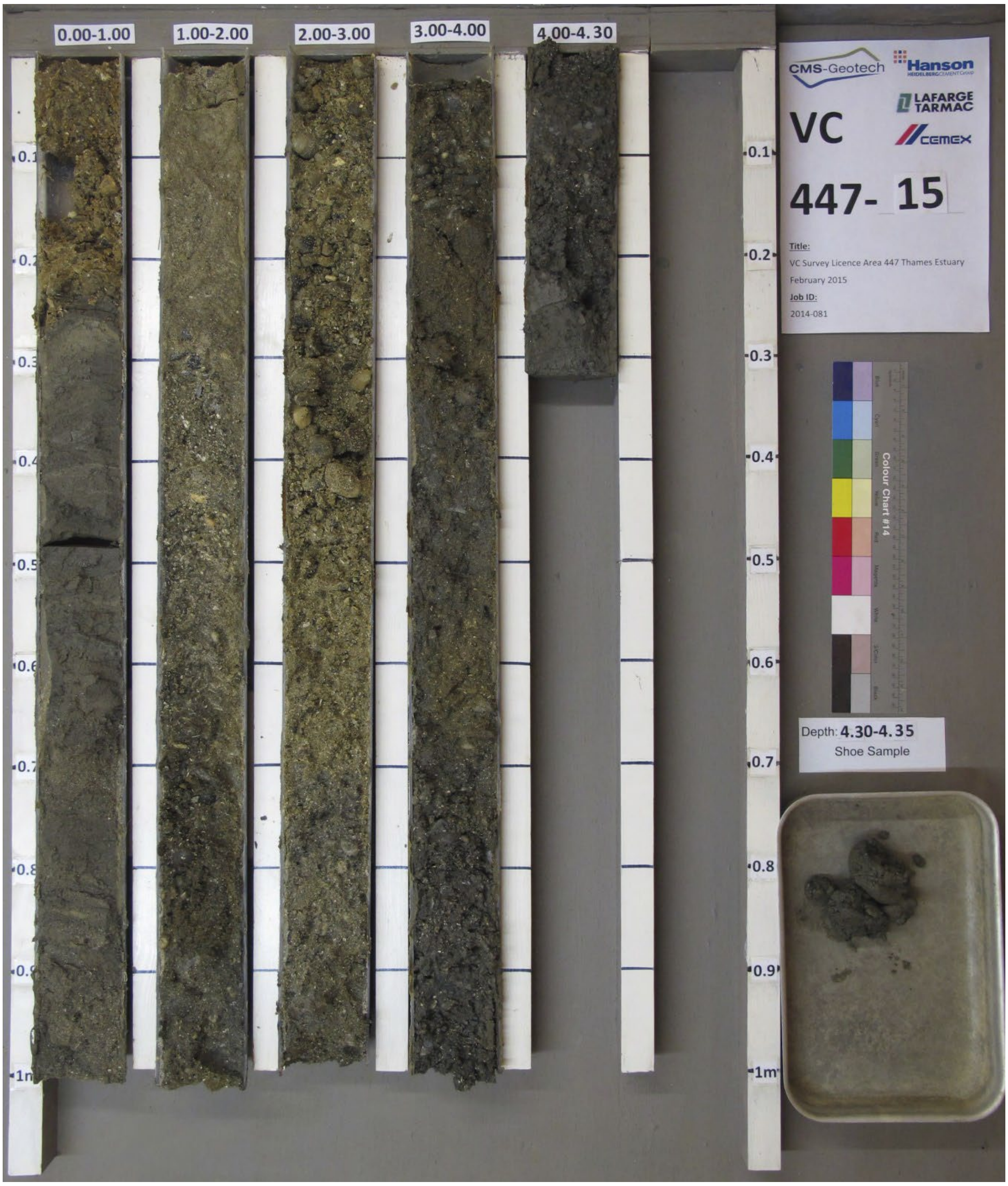

Figure 22 Photograph of vibrocore VC15

Depth (m)	Description	Interpretation
0.00-0.22	2.5Y 6/4 light yellowish brown gravelly silty sand. No mottles. Medium sub-rounded to grounded gravel, moderately stony. Broken bi-valves (including oysters), 20-30 mm. No organics. Sharp boundary to:	Holocene marine sands
0.22-1.00	7.5YR 4/2 brown silty clay, with sandy silt horizons 0.65-0.74 m and 0.81-1.00 m. No mottles. Rare small (<10 mm) angular to sub-rounded stones, mixed lithology. Fine broken shell, ?bivalves, associated with sandy horizons. No organics	Pleistocene channel edge / floodplain
1.00-1.20	GAP – presumed sandy gravels	

1.00-3.20	2.5Y 4/3 olive brown sandy gravel. No mottles. Very stony, stones angular to rounded, platy to rounded, small to very large, mixed lithology. No shells, no organics. Clear boundary to:	Pleistocene sands and gravel
3.20-3.76	7.5YR 4/3 brown gravelly sandy clay. No mottles. Gravel angular to sub-rounded, platy to tabular, small to medium. Mixed lithology including black flint angular pieces which are angular to sub-angular. Very slightly shelly, small broken fragments <3mm. No organics. Clear boundary to:	Pleistocene channel edge / floodplain
3.76-4.00	2.5Y 3/3 dark olive brown gravelly clay. Occasional 5Y 4/3 brown mottles (10%), up to 20 mm.Gravel sub-angular to rounded, platy to rounded, small to medium, mixed lithology including both dark and patinated flint. Broken shell, <3mm visible throughout unit, up to 10%. No organics	Pleistocene channel edge / floodplain

Table 7 Sediment description of VC15

VC15 appears to have a series of high and low energy environments. The upper clay appears quite sterile compared to that deeper in the sequence. 'Fresh' dark flint fragments are increasingly prevalent towards the base of the bottom clay. Some gaps are present in the core sequence, probably created by loss of gravels and/or slumping in cores, making identification of boundary conditions difficult. The base of the sequence appears to include a low-energy environment that has incorporated an eroded London Clay, grading into a silty clay higher up in the sequence. Broken shell is present towards the base, but probably too small to permit identification. This deposit is likely to represent a riffle or other slow-movement fluvial feature, superseded by the main gravel outwash. The fine-grained deposits higher in the sequence suggest some channel migration with point bar or other marginal feature forming, with the uppermost clay horizon truncated by erosion by modern marine sands and gravels.

The sequence shows similarities to VC23 and VC16, which contain more intact sequences that could be investigated. No further work on VC15 was recommended.

VC16

Geoarchaeological recording of VC16 is provided in Table 8 and shown in Figure 23.

Depth (m)	Description	Interpretation
0.00-0.02	7.5YR 4/1 dark grey clayey gravel. Gravel medium, sub-rounded, rounded. No shell, no organics. Sharp boundary to:	Modern seabed gravel – eroded boundary (?dredged)
0.02-1.58	7.5YR 4/1 dark grey clay with 7.5YR 3/4 dark yellowish brown mottles, up to 50 cm diameter, up to 15%, reducing down core. Some thin, <10 mm, sand horizontal horizons at 0.52 m, 0.70 m, 0.84 m and 1.40 m (angular bedding – possible shear in core liner) Very rare rounded small gravel. No shells, no organics. Abrupt boundary to:	Pleistocene channel edge / floodplain
1.58-1.92	5Y 4/3 olive silty sand with 7.5YR 4/1 dark grey clay (with 7.5YR 3/4 dark yellowish brown mottles) at 1.76-1.79 m. Very slightly stony, predominantly dark flint lithology, angular, to sub-angular, platy to tabular small stones. Fine (<2 mm) broken shell, increasing at base of unit. No organics. Abrupt boundary to:	Pleistocene channel edge / floodplain

Depth (m)	Description	Interpretation
1.92-2.77	2.5Y 4/4 olive brown gravelly sand. No mottles. Moderately stony, small stones mainly dark flint lithology, angular to sub-angular, platy to tabular. Some medium to large stones at base, sus-angular to sub-rounded, tabular to rounded, dark flint. Shell (c. 2%) mainly broken but does include some bivalve fragments, <8 mm, quite rounded. No organics.	Pleistocene channel edge / floodplain

Table 8 Sediment description of VC16

Figure 23 Photograph of vibrocore VC16

VC16 largely replicates the sequence seen in VC15 with an estuarine/alluvial sequence of basal sands and gravels, including dark flint, overlain by sands that grade into alluvial clay. The alluvial clay contains frequent sand horizons decreasing in thickness and frequency up-core. It is probable that the clay post-dates the local archaeology. No organics are visible, though mottling suggests some former root channels in the upper clays. The top of the clay is truncated, probably through dredging, with a thin layer of gravel at the very top likely to have been introduced by recent dredging across the site.

Opportunities for luminescence dating exist and could potentially provide a minimum age on the archaeology, if it is presumed that the upper clay, due to the absence of dark flint, post-dates the archaeology. This would likely correlate with upper parts of VC12. Luminescence dating of the base of the sequence is likely to be unsuccessful due to disturbance, probably allowing partial bleaching to have occurred.

VC23

Geoarchaeological recording of VC23 is provided in Table 9 and shown in Figure 24.

Depth (m)	Description	Interpretation
0.00-0.66	2.5Y 6/2 light brownish grey gravelly sand. No mottles. Medium sand, very slightly stony, sub-rounded to rounded tabular to rounded small to large stones, mixed flint types. Very slightly shelly, including intact cockle and oyster shell. No organics. Abrupt boundary to:	Modern marine sands and gravels
0.66-0.93	2.5Y 7/3 pale yellow gravelly sand. No mottles, Fine sand. Slightly stony, sub-rounded to rounded, tabular to rounded, small to medium stones. Mixed flint types. Very slightly shelly, <10 mm fragments. No organics. Sharp boundary to:	Modern marine sands and gravels
0.93-1.09	10YR 3/2 very dark greyish brown clay. No mottles, some horizontal bedding. Stoneless, no shell, no organics. Abrupt boundary to:	Pleistocene channel edge / floodplain
1.10-1.57	2.5Y 6/2 light brownish brown shelly medium to coarse sand. No mottles. Small sub-rounded to rounded, rounded stones, mixed flint but predominantly brown flint. Slightly shelly, <5 mm broken fragments. No organics. Abrupt boundary to:	Pleistocene channel edge / floodplain
1.57-1.64	10YR 3/2 very dark greyish brown stony shelly silty clay. Stone is small, angular to sub-angular, platy. Shell includes intact bivalves, <10 mm, with one intact 10mm diameter gastropod at 1.33 m. No mottles. Clear boundary to:	Pleistocene channel edge / floodplain
1.64-2.08	2.5Y 5/3 light olive brown loamy sand. 10YR3/2 very dark greyish brown silty clay coarse mottles at 1.72-1.83 m. Very slightly stony, angular to sub-angular, platy (fairly fresh), small, dark flint. Very slightly shelly, <4 mm broken fragments. No organics. Clear boundary to:	Pleistocene channel edge / floodplain
2.08-4.07	10YR 4/3 brown loamy sands and 7.5YR 3/1 very dark grey clays, latter prevalent at 2.19-2.25, 2.30-2.67, 2.27-2.89, 3.00-3.26, 3.53-3.58, 3.67-3.74 and 4.00-4.07 m. Gleyed clays (GLEY1 3/1 10GY very dark greenish black) between 3.00-3.24 m. Sand is fine to medium, with broken shell. Both sands and clays have bedding, predominantly horizontal. Very slightly stony, stone all black flint, angular to sub-angular, platy or tabular, small to medium. Some appear fairly fresh breaks with limited rounding. Bivalves and gastropods appear intact within some clay horizons, coupled with some organics ?wood fragments, 2.55-2.66 m.	Pleistocene channel edge / floodplain

Depth (m)	Description	Interpretation
4.07-5.03	2.5Y 3/2 very dark greyish brown to 2.5Y 4/3 olive brown loamy sand. Sand medium to coarse, becoming finer near base. Very slightly stony, small to medium, predominantly black flint, angular to sub-rounded, platy to rounded. Some small pieces appear very thin and fresh with little rounding. Very slightly shelly, including visible intact gastropods and bivalves. Fine fibrous organics present in coarse mottle, 7.5YR3/2 dark brown, at 4.56 m, probably herbaceous roots.	Pleistocene channel edge / floodplain

Table 9 Sediment description of VC23

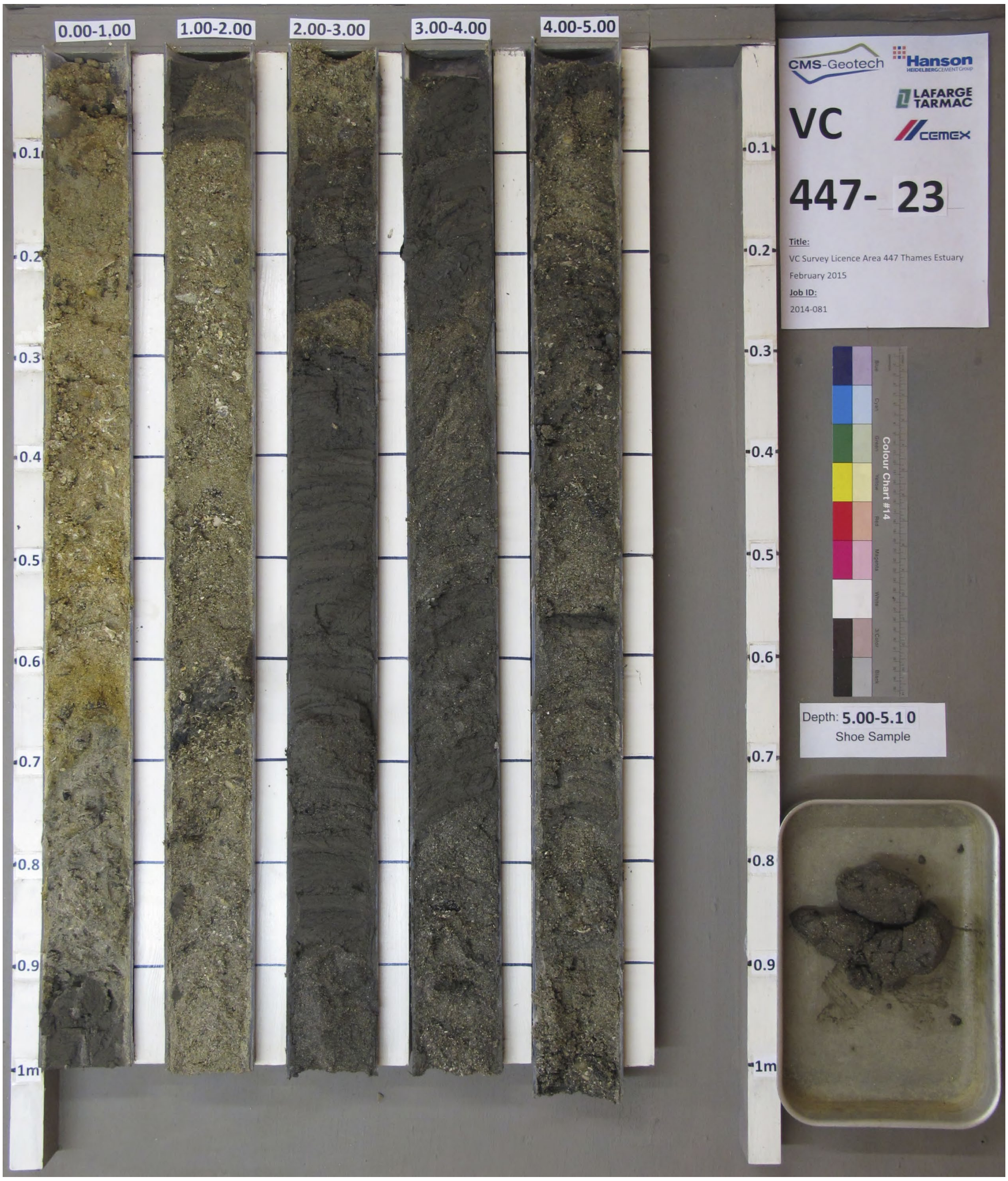

Figure 24 Photograph of vibrocore VC23

Core VC23 contains alluvial deposits probably associated with a channel or channel edge environment. Laminations within the sand and clay suggest periodic deposition. Good preservation is suggested by the presence of intact shell and organics within deposits below 2 m. Shells might be suitable for AAR. Predominance of black flint, similar in appearance to that within recovered artefacts, is present within channel deposits, much showing similar preservation of 'fresh' angular fragments. The base of the sequence does not reach the underlying London Clay.

VC23 contains a predominantly fine-grained sequence with good potential for mollusc and organic preservation. Presence of dark flint material throughout the sequence might be comparable to the base of VC12. VC23 is likely to provide the best resolved palaeoenvironmental sequence from all cores recorded.

3.4 Stage 3 Assessment and Stage 4 Analysis

After discussions with Historic England, it was agreed that one core, VC23, would proceed to a Stage 3 assessment. This core was selected as it had the highest potential for palaeoenvironmental information and luminescence dating. Following the Stage 3 assessment, Stage 4 analysis of the pollen was recommended; this is included within the results presented here.

3.4.1 Methodology

Sampling

Proposed sample depths for each technique are given in Table 10.

Depth (m)	**Description**	**Samples**
0.00-0.66	2.5Y 6/2 light brownish grey gravelly sand. No mottles. Medium sand, very slightly stony, sub-rounded to rounded tabular to rounded small to large stones, mixed flint types. Very slightly shelly, including intact cockle and oyster shell. No organics. Abrupt boundary to:	
0.66-0.93	2.5Y 7/3 pale yellow gravelly sand. No mottles, Fine sand. Slightly stony, sub-rounded to rounded, tabular to rounded, small to medium stones. Mixed flint types. Very slightly shelly, <10mm fragments. No organics. Sharp boundary to:	
0.93-1.09	10YR 3/2 very dark greyish brown clay. No mottles, some horizontal bedding. Stoneless, no shell, no organics. Abrupt boundary to:	*P & D: 0.98m*
1.10-1.57	2.5Y 6/2 light brownish brown shelly medium to coarse sand. No mottles. Small sub-rounded to rounded, rounded stones, mixed flint but predominantly brown flint. Slightly shelly, <5mm broken fragments. No organics. Abrupt boundary to:	*CA: 1.20-1.50m*
1.57-1.64	10YR 3/2 very dark greyish brown stony shelly silty clay. Stone is small, angular to sub-angular, platy. Shell includes intact bivalves, <10 mm, with one intact 10 mm diameter gastropod at 1.33 m. No mottles. Clear boundary to:	*FM: 1.57-1.67m*

Depth (m)	Description	Samples
1.64-2.08	2.5Y 5/3 light olive brown loamy sand. 10YR3/2 very dark greyish brown silty clay coarse mottles at 1.72-1.83 m. Very slightly stony, angular to sub-angular, platy (fairly fresh), small, dark flint. Very slightly shelly, <4 mm broken fragments. No organics. Clear boundary to:	*LD: 1.75-1.85m*
2.08-4.07	10YR 4/3 brown loamy sands and 7.5YR 3/1 very dark grey clays, latter prevalent at 2.19-2.25, 2.30-2.67, 2.27-2.89, 3.00-3.26, 3.53-3.58, 3.67-3.74 and 4.00-4.07 m. Gleyed clays (GLEY1 3/1 10GY very dark greenish black) between 3.00-3.24 m. Sand is fine to medium, with broken shell. Both sands and clays have bedding, predominantly horizontal. Very slightly stony, stone all black flint, angular to sub-angular, platy or tabular, small to medium. Some appear fairly fresh breaks with limited rounding. Bivalves and gastropods appear intact within some clay horizons, coupled with some organics ?wood fragments, 2.55-2.66 m.	*LD: 2.25-2.35, 3.59-3.67m* *P & D: 2.20, 2.60, 3.10, 3.70m* *FM: 2.55-2.70, 2.90-3.00m*
4.07-5.03	2.5Y 3/2 very dark greyish brown to 2.5Y 4/3 olive brown loamy sand. Sand medium to coarse, becoming finer near base. Very slightly stony, small to medium, predominantly black flint, angular to sub-rounded, platy to rounded. Some small pieces appear very thin and fresh with little rounding. Very slightly shelly, including visible intact gastropods and bivalves. Fine fibrous organics present in coarse mottle, 7.5YR3/2 dark brown, at 4.56 m, probably herbaceous roots.	*LD: 4.67-4.74m* *CA: 4.25-4.50, 4.80-5.00m* *P & D: 4.25, 4.58m* *FM: 4.50-4.70m*

LD = Luminescence Dating; CA = Clast Analysis; P = Pollen, D = Diatoms; FMW = Foraminifera and Molluscs

Table 10 Stage 3 sampling of Core VC23

Luminescence Dating

Luminescence dating on samples from cores typically requires shielding from light using opaque core liners and sampling within control laboratory conditions (Duller 2008). However, this approach is not always possible, especially when attempting to work with samples collected for geotechnical purposes. A modification to this approach has been utilised in a series of studies where procedures can be put in place after cores have been split to preserve samples for luminescence dating, such as on the Humber Regional Environmental Characterisation (REC) project (Tappin et al. 2011) and recent studies on the Hornsea Offshore Wind Farms (Grant 2021; Toms and Evans 2018). However, the application of this technique using archived cores, taken on behalf of aggregate companies and kept in storage without safeguards for luminescence dating, had not been tested before. Nevertheless, luminescence dating of such deposits should still be possible if samples retain their stratigraphic integrity, retain sufficient sediment thicknesses not exposed to light (to permit full or partial bleaching), and have not been subject to an external radiation source. An initial assessment of the cores suggested that luminescence dating of cohesive sediments within sections of the cores could be successful, so this methodological approach was tested through this project.

Samples were transported to the luminescence dating laboratory, University of Gloucestershire, where sampling was undertaken under controlled laboratory conditions. To preclude optical erosion of the datable signal prior to measurement, the samples were opened and prepared under controlled laboratory illumination provided by Encapsulite

RB-10 (red) filters. To isolate that material potentially exposed to daylight during sampling, sediment located within 10 mm of each core face was removed. The remaining sample was dried and then sieved. The fine sand fraction was segregated and subjected to acid and alkaline digestion (10% HCl, 15% H_2O_2) to attain removal of carbonate and organic components respectively. The sample was then divided in two. For one half, a further acid digestion in HF (40%, 60 mins) was used to etch the outer 10-15 μm layer affected by α radiation and degrade each sample's feldspar content. During HF treatment, continuous magnetic stirring was used to effect isotropic etching of grains. 10% HCl was then added to remove acid-soluble fluorides. Each sample was dried, re-sieved and quartz isolated from the remaining heavy mineral fraction using a sodium polytungstate density separation at 2.68g cm^{-3}. For the second half, density separations at 2.53 and 2.58 g cm^{-3} were undertaken to isolate the K-feldspar fraction. Twelve 8 mm multi-grain aliquots (c. 3-6 mg) of quartz and K-feldspar were then mounted on aluminium discs for determination of D_e values.

All drying was conducted at 40°C to prevent thermal erosion of the signal. All acids and alkalis were Analar grade. All dilutions (removing toxic-corrosive and non-minerogenic luminescence-bearing substances) were conducted with distilled water to prevent signal contamination by extraneous particles.

D_e values were quantified using a single-aliquot regenerative-dose (SAR) protocol (Murray and Wintle 2000; 2003 for quartz; Li et al. 2014 for K-feldspar) facilitated by a Risø TL-DA-15 irradiation-stimulation-detection system (Markey et al. 1997; Bøtter-Jensen et al. 1999). Within this apparatus, optical signal stimulation of quartz is 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 for K-feldspars is provided by 6 IR diodes (Telefunken TSHA 6203) stimulating at 875±80 nm delivering ~40 mW cm^{-2}. 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. K-feldpar emissions were filtered by 2 mm Schott BG-39 and 3mm Schott BG-3 glass. Aliquot irradiation was conducted using a 1.48 GBq $^{90}Sr/^{90}Y$ β source calibrated for multi-grain aliquots of 180-250 μm quartz and feldspar against the 'Hotspot 800' 60Co γ source located at the National Physical Laboratory (NPL), UK.

For each aliquot, five different regenerative doses were administered to allow imaging of the dose response. D_e values for each aliquot were then interpolated, and associated counting and fitting errors calculated, by way of exponential plus linear regression. Weighted (geometric) mean D_e values were calculated from 12 aliquots using the central age model outlined by Galbraith et al. (1999) and are quoted at 1σ confidence. The accuracy with which D_e equates to total absorbed dose and that dose absorbed since burial was assessed. The former can be considered a function of laboratory factors, the latter, one of environmental issues. Diagnostics were deployed to estimate the influence of these factors and criteria instituted to optimise the accuracy of D_e values.

For lithogenic radiation external to the grains of quartz and K-feldspar, D_r values were defined through measurement of U, Th and K radionuclide concentration and conversion of these quantities into β and γ D_r values. β contributions were estimated from sub-samples by laboratory-based γ spectrometry using an Ortec GEM-S high purity Ge coaxial detector system, calibrated using certified reference materials supplied by CANMET. γ dose rates can be estimated from in situ NaI gamma spectrometry or, where direct measurements are unavailable as in the present case, from laboratory-based Ge γ spectrometry. In situ measurements reduce uncertainty relating to potential heterogeneity in the γ dose field surrounding each sample. The level of U disequilibrium was estimated by laboratory-based Ge γ spectrometry. Estimates of radionuclide concentration were converted into Dr values (Adamiec and Aitken 1998), accounting for Dr modulation forced by grain size (Mejdahl 1979) and present moisture content (Zimmerman 1971).

Lithogenic radiation internal to K-feldspar grains was assumed to be derived from a K content of 12.5%. Cosmogenic D_r values were calculated on the basis of sample depth, geographical position and matrix density (Prescott and Hutton 1994).

Clast Lithological Analysis
Lithological analysis can be undertaken on a variety of clast sizes, although the most commonly used are those ranging from 8–16 mm and 16–32 mm in diameter (Bridgland 1986). It is an important tool used by Quaternary scientists to determine sediment provenance and degree of transportation (sediment maturity reflected by the ratio of durable to non-durable components of the assemblage). Clast type is usually determined visually with the aid of a magnifying light; where necessary and if appropriate (e.g. not an artefact), a fresh surface is created using a geological hammer. For purposes of statistical validity, it is considered best practice to identify at least 300 individual clasts (Bridgland 1986). However, when analysing borehole cores, this sample size is often a challenging goal due to the relatively small volume of the retained sample. Therefore, to maximise the potential of the samples, the gravelly sands were passed through 5 mm- and 10 mm-diameter sieves, allowing a greater volume of material to be retained for lithological analysis. Clast type was determined visually with the aid of a magnifying light; when necessary, a fresh surface was created using a geological hammer. Published clast lithological data for the region provided a classification of rock types for identification (e.g. Bridgland 1988).

In addition to determining sediment provenance and maturity, the quantification of clast shape (roundness and sphericity) can provide insights into site formation processes and the history of sediment transport. Shape is the relationship of the three main axes of any clast and typically measured using calipers (longest, intermediate and shortest axes, a-b-c respectively); roundness is measured using the visual sheets devised by Krumbein (1941a). It is important when measuring shape to recognise that this parameter is not simply a function of the degree of transportation and can be influenced by other factors; for example, the mechanical strength of individual rock types (Krumbein 1941b). In the context of this study, shape analysis was applied to the flint component using the methodology of Krumbein (1941b).

Pollen
Standard preparation procedures were used (Moore et al. 1991). 2 cm^3 of sediment was processed from each sample. All samples received the following treatment: 20 mls of 10% KOH (80°C for 30 minutes); 20 mls of 60% HF (80°C for 120 minutes); 15 mls of acetolysis mix (80°C for 3 minutes); stained in 0.2% aqueous solution of safranin and mounted in silicone oil following dehydration with tert-butyl alcohol. Due to the highly

minerogenic nature of some of the samples additional sieving and decanting was undertaken between the KOH and HF stages.
Pollen counting was undertaken at a magnification of x400 using a Nikon Eclipse Ci-L transmitted light microscope. Determinable pollen and spore types were identified to the lowest possible taxonomic level with the aid of a reference collection kept at COARS, University of Southampton. The pollen and spore types used are those defined by Bennett (1994; Bennett et al. 1994), with the exception of Poaceae which will follow the classification given by Küster (1988), with plant nomenclature ordered according to Stace (2010). The pollen assemblage is calculated as %TLP. The TLP sum excludes aquatics and pteridophyes, which are calculated as % + Group. Initially a total land pollen (TLP) sum of 100 grains was sought for the pollen assessment, with counts extended to 400 TLP to permit full pollen analysis of the sequence.

Diatoms
For the diatom assessment preparation, 0.5 g of sediment was required. Samples were first treated with sodium hexametaphosphate to assist in minerogenic deflocculation. Samples were then treated with hydrogen peroxide (30% solution) and/or weak ammonia (1% solution) depending on organic and/or calcium carbonate content, respectively. Samples were finally sieved using a 10 µm mesh to remove fine minerogenic sediments. The residue was transferred to a plastic vial, from which a slide was prepared for using the mountant Naphrax for subsequent assessment.

A minimum of 100 diatoms were to be identified for each sample depth. Diatom species were identified with reference to van der Werff and Huls (1958–74), Hendy (1964) and Krammer and Lange-Bertalot (1986–91). Ecological classifications for any observed taxa were achieved with reference to Vos and deWolf (1988; 1993), Van Dam et al. (1994), Denys (1991–2; 1994) and Round et al. (2007). If preservation was found to be low, a minimum of ten slide traverses were undertaken in an attempt to extract the diatom data available from the sample under assessment.

Foraminifera and Molluscs
Foraminifera and mollusc assessments follow guidance for environmental archaeology set out by Historic England (2011), more specifically Cearreta (2018) and Campbell (2017) respectively. For foraminifera, samples were weighed and washed through a 63 µm mesh sieve, then air dried before being sorted into fractions using a nest of sieves (4 mm, 2 mm, 1 mm, 500 µm, 250 µm, 125 µm, 65 µm). Biological remains were identified using a low-power binocular microscope with a reference collection. Ecological information for Mollusca is derived from Allcock et al. (2017) and Graham (1971). Nomenclature for Mollusca follows WoRMS Editorial Board (2021).

3.4.2 Results
Luminescence Dating
Ages reported in Table 11 provide an estimate of sediment burial period based on mean D_e and D_r values and their associated analytical uncertainties. Uncertainty in age estimates are reported as a product of systematic and experimental errors, with the magnitude of experimental errors alone shown in parenthesis. Cumulative frequency plots indicate the inter-aliquot variability in age. The analytical validity of each sample was acceptable with no caveats for consideration.

For each pair of Quartz and K-feldspar dates, the Ward and Wilson (1978) test was applied to assess whether measurements were consistent between the two methods. Dates GL20001-3 passed the test, but in GL20036 the quartz date was significantly younger than the K-feldspar one. Following comparison to the other dates, the K-feldspar date from GL20036 was accepted and the quartz rejected. A Bayesian model was constructed in OxCal 4.4 using a Sequence Model for the seven accepted dates (paired GL20001–3 and K-feldspar from GL20036). The model has good overall agreement (Amodel=101), with dates in stratigraphic order (Figure 25). The basal date (GL20003) provided a modelled age of *227.5–179.9 ka* (*95.4% probability*). This date has an 80.6% probability that it falls within MIS 7 (see Table 12), which ends at 191 ka (Lisiecki and Raymo 2005). The overlying date (GL20002) provided a modelled age of *215.5–168.2 ka* (*95.4% probability*), which has a probability of 44.9% of falling within MIS 7, though with a slightly higher probability (55.1%) that is falls within MIS 6. GL20001, dated *187.4–145.8 ka* (*95.4% probability*) and GL20036 (K-feldspar), dated *171.3–124.1 ka* (*95.4% probability*) are both firmly placed within MIS 6 (99.5% and 91.0% probabilities respectively). When MIS sub-stages are considered, there is a 96.8% and 79.0% probability that GL20003 and GL20002 respectively both pre-date MIS 6d, which commenced c. 180 ka, indicating that the lower section of the VC23 sequence was deposited within the late MIS 7/early MIS 6 period.

The dates from Area 447 are comparable to select dates from Area 240, associated with Stratigraphic Unit 3b from which the majority of artefactual and faunal material is thought to derive. These deposits were dated to MIS 7 or possibly the beginning of MIS 6, with the beginning of deposition modelled to have started *248–206 ka* (*68% probability*) and finished *210–178 ka* (*68% probability*) (Marshall forthcoming). Dates from Area 240 were only based upon the quartz mineral and the results contained several caveats; Toms (2011: 16) stated that dates should only be accepted tentatively or with strong reservations. No such caveats exist with the Area 447 dating and, due to the paired approach of using both quartz and K-feldspar minerals, greater confidence can be placed in these results.

Clast Analysis

Each of the three samples were divided into six different rock types comprising both durable and non-durable components (Tables 13 and 14). Figures 26–28 provide illustrations of the lithological assemblage of each sample retained after sieving.

The non-durable component comprised locally derived siltstone/mudstone and shell fragments, together accounting for between 28% and 34% of the samples. The durable component accounted for 66–72% of the samples and comprised non-local (exotic) lithologies. All have been introduced into the region through a combination of glacial and fluvial processes; the latter associated with the ancestral Thames-Medway system, which was confluent in the Clacton-on-Sea area during pre-Anglian (pre-MIS 12) times (Bridgland 1988; 2006). Flint constituted 52–59% of the three samples.

Since the primary aim of this study was to consider the characteristics of the flint within the three samples rather than the general provenance of deposits, no further consideration is given in this report to the topic of sediment sources.

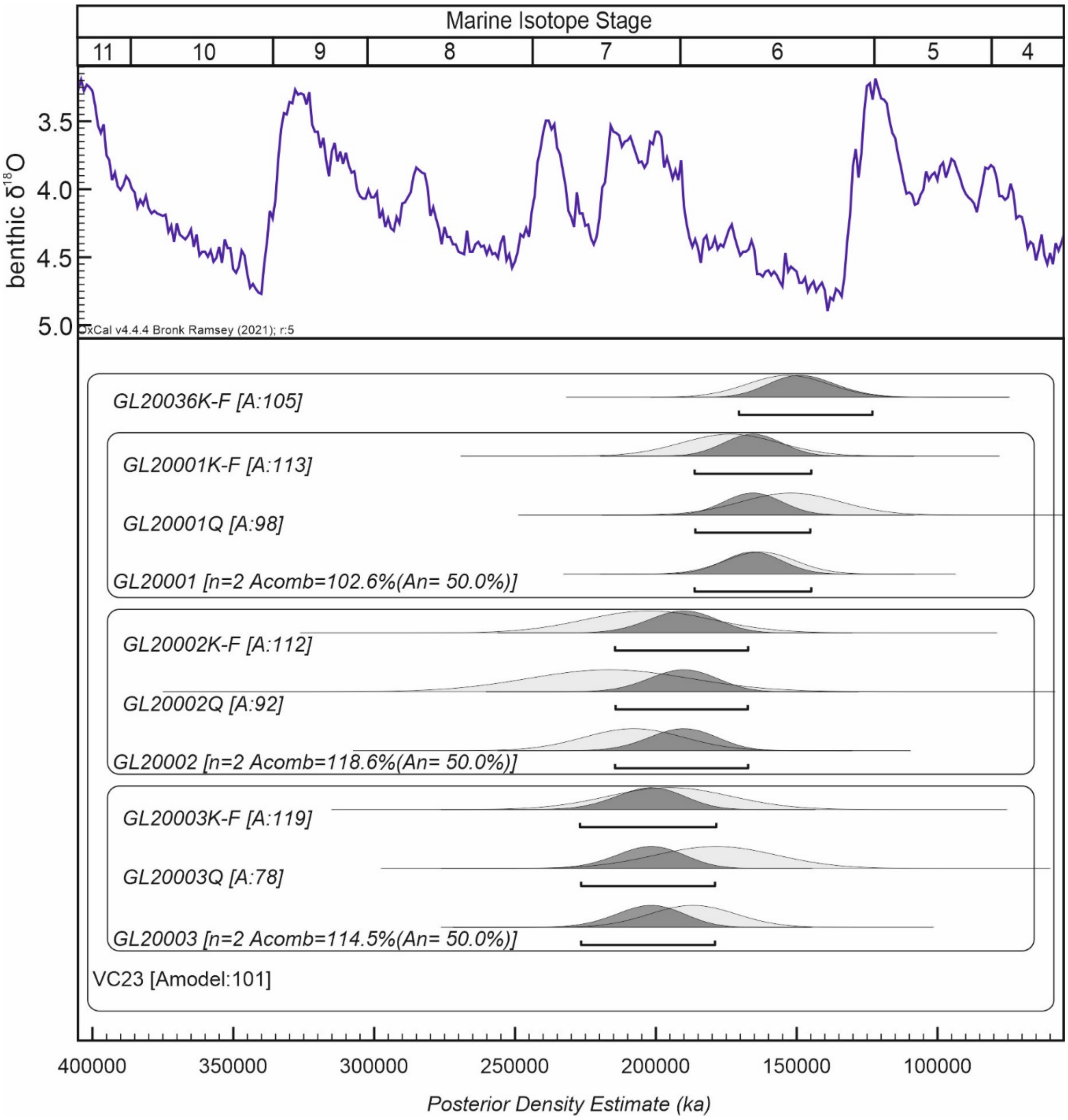

Figure 25 Modelled luminescence dates from VC23, plotted against Lisiecki and Raymo (2005) benthic δ18O stack

In all three samples, the flint component could be subdivided into at least three types with a fourth type also identified in two of the samples (Figures 29–31). The most commonly observed flints can be separated into two types.

The first type comprised fractured clasts of dull olive-grey-brown material with very little in the way of visible rinds (cortex) or patination upon surfaces. The proportion varied from 31% in the lowermost sample (4.80–5.00 m) to 23% in the uppermost (1.20–1.50 m), though the entire number of clasts analysed was low (nine to 34 individual pieces). The pieces were of a generally uniform size and their fractured character resulted in low roundness values and sub-angular to angular appearance when measured on the Krumbein scale (Table 15). There was no significant change in roundness value between the three samples. However, despite its angular appearance, the individual edges of this type of flint were smooth to the touch, suggesting they had been blunted through abrasion and attrition.

Lab Code	Depth (m)	Mineral	Moisture content (%)	Ge γ-spectrometry (ex situ)			Internal β D_r (Gy ka^{-1})	External α D_r (Gy ka^{-1})	External β D_r (Gy ka^{-1})	External γ D_r (Gy ka^{-1})	Cosmic D_r (Gy ka^{-1})	Low Dose Repeat Ratio	Low Dose Repeat Ratio	Post-IR OSL Ratio
				K (%)	Th (ppm)	U (ppm)								
GL20036	1.75-1.85	Quartz	5±1	0.67±0.06	1.53±0.30	0.68±0.09			0.56±0.07	0.29±0.06	0.15±0.01	1.02±0.04	1.01±0.04	1.00±0.04
		K-feldspar					0.74±0.12	0.05±0.01				0.98±0.05	1.00±0.04	
GL20001	2.25-2.32	Quartz	6±1	0.54±0.06	2.40±0.31	0.54±0.09			0.47±0.07	0.18±0.06	0.14±0.01	1.04±0.04	1.04±0.04	1.03±0.04
		K-feldspar					0.74±0.12	0.05±0.01				0.96±0.04	0.98±0.04	
GL20002	3.59-3.67	Quartz	11±3	0.44±0.07	2.81±0.51	0.61±0.09			0.39±0.07	0.27±0.06	0.11±0.01	1.05±0.04	1.06±0.04	1.02±0.04
		K-feldspar					0.74±0.12	0.05±0.02				0.96±0.04	0.98±0.03	
GL20003	4.67-4.74	Quartz	3±1	0.37±0.06	1.14±0.30	0.44±0.09			0.33±0.06	0.19±0.06	0.10±0.01	1.03±0.04	1.01±0.04	1.00±0.04
		K-feldspar					0.74±0.12	0.03±0.01				0.98±0.03	0.99±0.02	

Lab Code	Mineral	Total D_r (Gy ka^{-1})	D_e (Gy)	Age (ka)	X2-Test of paired dates	Unmodelled Date (ka)	Modelled Date (ka; 95.4%)
GL20036	Quartz	1.01±0.08	107.6±7.2	106.2±10.7 (9.4)	df=1 T=7.2 (5% 3.8)	180.8-123.5 *	*169.5-122.1 **
	K-feldspar	1.80±0.15	277.0±12.6	154.2±14.3 (12.9)			
GL20001	Quartz	0.90±0.07	138.1±11.2	153.1±17.6 (16.1)	df=1 T=0.8 (5% 3.8)	186.7-137.2	*185.3-143.8*
	K-feldspar	1.69±0.14	295.3±15.2	174.6±17.4 (16.0)			
GL20002	Quartz	0.78±0.07	169.8±15.8	217.6±28.8 (27.1)	df=1 T=0.1 (5% 3.8)	242.6-171.2	*213.6-166.2*
	K-feldspar	1.57±0.14	320.4±19.7	203.6±22.5 (21.1)			
GL20003	Quartz	0.62±0.06	11.2±6.7	179.7±21.6 (19.9)	df=1 T=0.3 (5% 3.8)	216.9-154.6	*225.6-178.0*
	K-feldspar	1.39±0.14	272.7±13.0	196.2±21.8 (20.5)			

* using K-feldspar date for GL20036

Table 11 Luminescence Dating: D_r, D_e and Age data of samples from VC23. Age estimates expressed relative to year of sampling. 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

Probability $T_1<T_2$	*T_2*							
T_1	*GL20003*	*GL20002*	*GL20001*	*GL20036K-F*	*MIS 8/7*	*MIS 7/6*	*MIS 6e/6d*	*MIS 6/5*
GL20003		100.0	100.0	100.0	0.0	80.6	96.8	100.0
GL20002	0.0		100.0	100.0	0.0	44.9	79.0	100.0
GL20001	0.0	0.0		100.0	0.0	0.5	6.6	100.0
GL20036K-F	0.0	0.0	0.0		0.0	0.0	0.0	91.0
MIS 8/7	100.0	100	100	100.0		100.0	100.0	100.0
MIS 7/6	19.4	55.1	99.5	100.0	0.0		100.0	100.0
MIS 6e/6d	3.2	21.0	93.4	100.0	0.0	0.0		100.0
MIS 6/5	0.0	0.0	0.0	9.0	0.0	0.0	0.0	

Table 12 Luminescence Dating: Probability of dates pre/post-dating Marine Isotope Stage (MIS) boundaries

	Durable component							Non-durable component		
	Flint									
Depth (m)	Fractured, grey	Fractured, olive-grey-brown	Nodular / with rind or patinated	Sub-rounded to rounded, grey-black	Chert	Quartzite	Quartz	Siltstone / mudstone	Shell fragments	Sample Total Clasts
1.20-1.50 m	5 [3.36]	34 [22.82]	38 [25.50]	- -	6 [4.03]	12 [8.05]	4 [2.68]	19 [12.75]	31 [20.81]	149 [100]
4.25-4.50 m	5 [4.72]	21 [19.81]	21 [19.81]	8 [7.55]	8 [7.55]	3 [2.83]	10 [9.43]	20 [18.87]	10 [9.43]	106 [100]
4.80-5.00 m	2 [6.90]	9 [31.03]	3 [10.34]	3 [10.34]	- -	3 [10.34]	1 [3.45]	6 [20.69]	2 [6.90]	29 [100]

Table 13 Lithological characteristics of samples from VC23 (number [%])

Depth (m)	Total: Durable lithologies	Durable: Flint	Durable: Other	Total: Non-durable lithologies	Sample Total clasts
1.20-1.50m	99 [66.44]	77 [51.67]	22 [14.77]	50 [33.56]	149 [100]
4.25-4.50m	76 [71.70]	55 [51.89]	21 [19.81]	30 [28.30]	106 [100
4.80-5.00m	21 [72.41]	17 [58.62]	4 [13.79]	8 [27.59]	29 [100]

Table 14 Lithological characteristics of the durable and non-durable components of samples from VC23 (number [%])

Depth (m)	Grey, fractured	Olive-grey-brown, fractured	Nodular / with rind or patinated	Sub-rounded to rounded
1.20-1.50m	0.2	0.2	0.4	-
4.25-4.50m	0.3	0.3	0.4	0.7
4.80-5.00m	0.3	0.3	0.4	0.6

Table 15 Roundness of flint measured on the scale of Krumbien (1941b)

Figure 26 Lithological sample 1.20–1.50 m retained after sieving

Figure 27 Lithological sample 4.25–4.50 m retained after sieving

Figure 28 Lithological sample 4.80–5.00 m retained after sieving

Figure 29 Flint sub-groups in sample 1.20–1.50 m retained after sieving. Clockwise from bottom right: nodular with rind and / or patinated; fractured grey; and fractured olive-grey-brown

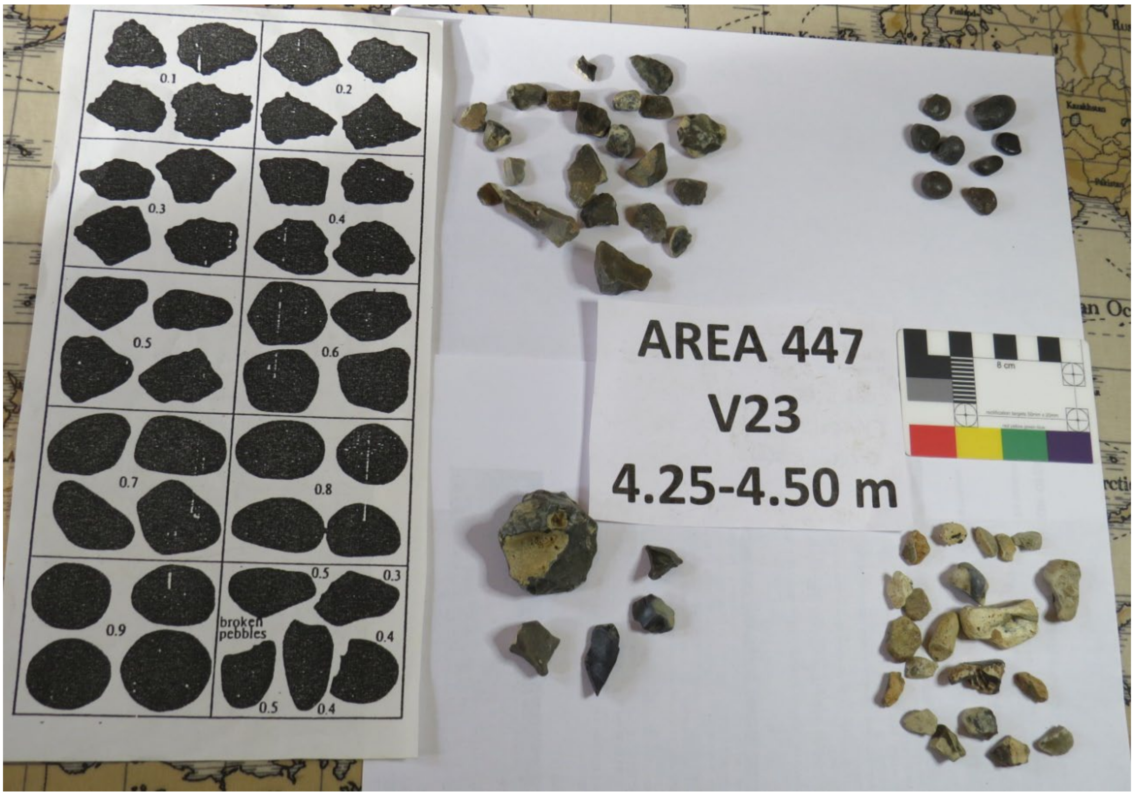

Figure 30 Flint sub-groups in sample 4.25–4.50 m retained after sieving. Clockwise from bottom right: nodular with rind and/or patinated; fractured grey; fractured olive-grey-brown; and sub-rounded to rounded grey-black

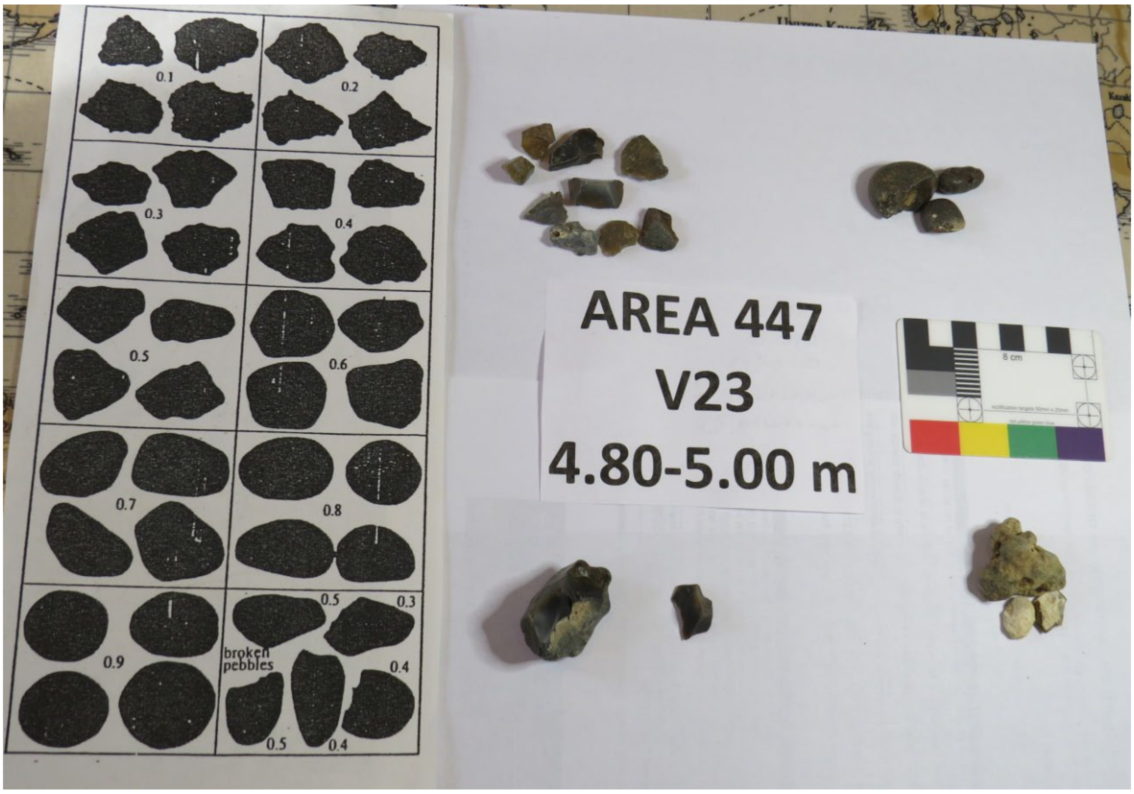

Figure 31 Flint sub-groups in sample 4.80–5.00 m retained after sieving. Clockwise from bottom right: nodular with rind and/or patinated; fractured grey; fractured olive-grey-brown; and sub-rounded to rounded grey-black

The second type of flint was either covered extensively with white cortex or characterised by greyish-white patinated surfaces. Where the flint surface was exposed below the cortex, the colour usually had a brownish hue. The clasts comprised a mixture of fractured clasts and those which retained a nodular character, either complete or in a partial form. In at least two samples, small rod-like clasts of nodular material provided evidence for the replacement of belemnite shells with crystalline silica. The proportion of nodular/patinated clasts varied from 10% in the lowermost sample (4.80–5.00 m) to 26% in the uppermost (1.20–1.50 m); whilst this variation might appear significant, it should be noted that the sample size was small. The clasts had an overall angular appearance when measured on the Krumbien scale (Table 15), which did not vary between the samples. The edges of individual clasts were smooth to the touch, suggesting they had been blunted through abrasion and attrition.

The third type of flint observed in all three samples, though in low numbers (3–7%), comprised fractured grey flint of varying size. The clasts had little in the way of visible cortex and/or patination, though the pieces had a dull lustre. The clasts had an overall sub-angular to angular appearance when measured on the Krumbien scale (Table 15), though the sample size is small. Individual edges were smooth to the touch, suggesting they had been blunted through abrasion and attrition.

The fourth type of flint was only observed in the lowest two samples (4.25–4.50 m and 4.80–5.00 m, S3) and though appearing in relatively small numbers (8–10%), these pieces are notably distinct from the remainder of the material. These clasts are black to greyish-black in colour but are notable since they are sub-rounded to rounded on the

Krumbien scale (Table 15). The surfaces of individual clasts were characterised by numerous small semi-circular indentations interpreted as chatter marks; such patterning is commonly observed on beach pebbles and is the result of material colliding together as it rolls around. Whilst rising sea levels during the Late Pleistocene and early Holocene may have provided suitable conditions for the rolling of this material and creation of chatter marks, the fact that this type is very different to the rest of the flint suggests that it is probably an inherited characteristic from processes of abrasion and attrition that have occurred over several glacial-interglacial cycles (i.e. the flint may have been derived from older deposits which have been reworked on multiple occasions, including climatic stages beyond the Quaternary).

Flint constitutes a major durable component of the three assessed samples. Initially derived from the Chalk (Rawson 2006), it has been introduced into these offshore sediments by a combination of past glacial and fluvial processes, the latter associated with the ancestral Thames-Medway system. The flint can be subdivided into four types of material, primarily on the basis of colour, degree of fracture and patination, and the presence or absence of cortex. However, none of the types stands out as having diagnostic characteristics (signs of working) that might be associated with the lithic material recovered from the beach between Clacton-on-Sea and Holland-on-Sea. With the exception of the sub-rounded to rounded flint pebbles with surface chatter marks, the remainder of the flint types were fractured and sub-angular to angular in form. The shape of these latter types varied little across the three samples and suggests that they have undergone limited transportation prior to deposition; however, the smoothness of edges, especially of the fractured flints, suggests some abrasion and attrition.

Pollen

Pollen preservation was good in all samples assessed, with final analysis counts exceeding 400 TLP in all samples. The results of the pollen analysis are shown in Figure 32. The pollen assemblage is dominated by Poaceae (grasses) and Cyperaceae (sedges), with *Pinus* (pine), *Quercus* (oak), *Corylus avellana*-type (hazel) and Pteropsida (monolete) indet. (fern spores). Other trees present throughout the sequence include *Picea* (spruce), *Ulmus* (elm), *Carpinus betulus* (hornbeam), and *Juniperus communis* (juniper), with *Taxus baccata* (yew), *Betula* (birch), *Alnus glutinosa* (alder), *Tilia cordata* (small-leaved lime) and *Salix* (willow) present in most samples. *Ribes spicatum* (downy currant), *Sorbus*-type (whitebeams) and *Stellaria holostea* (greater stichwort) are also indicative of woodland components.

Throughout the sequence is Chenopodiaceae (goosefoots), along with occurrences of *Glaux maritima* (sea-milkwort) and *Armeria maritima* (thrift), probably indicating the local proximity of saltmarsh and coastal communities. *Calluna vulgaris* (heather), *Vaccinium*-type (cowberry and heath) and *Sagina* (pearlwort) might indicate local sandy soils, possibly coastal heath and dunes. Brassicaceae (cabbage family), *Cichorium intybus*-type (dandelions and chicory) and *Solidago virgaurea*-type (goldenrods), along with *Plantago major* (greater plantain) and *P. lanceolata* (ribwort plantain), may be indicative of areas of disturbed grassland. *Filipendula* (meadowsweet) and *Glyceria*-type (sweet-grasses) are probably associated with areas of damp ground or marsh. Aquatic pollen types are represented by *Sparganium emersum*-type/*Typha latifolia* (bulrush), along with *Nymphaea alba* (white waterlily), *Myriophyllum spicatum* (spiked water-milfoil) and *Iris* (iris), which are likely to be associated with marsh, river margins and/or slow-moving/still water.

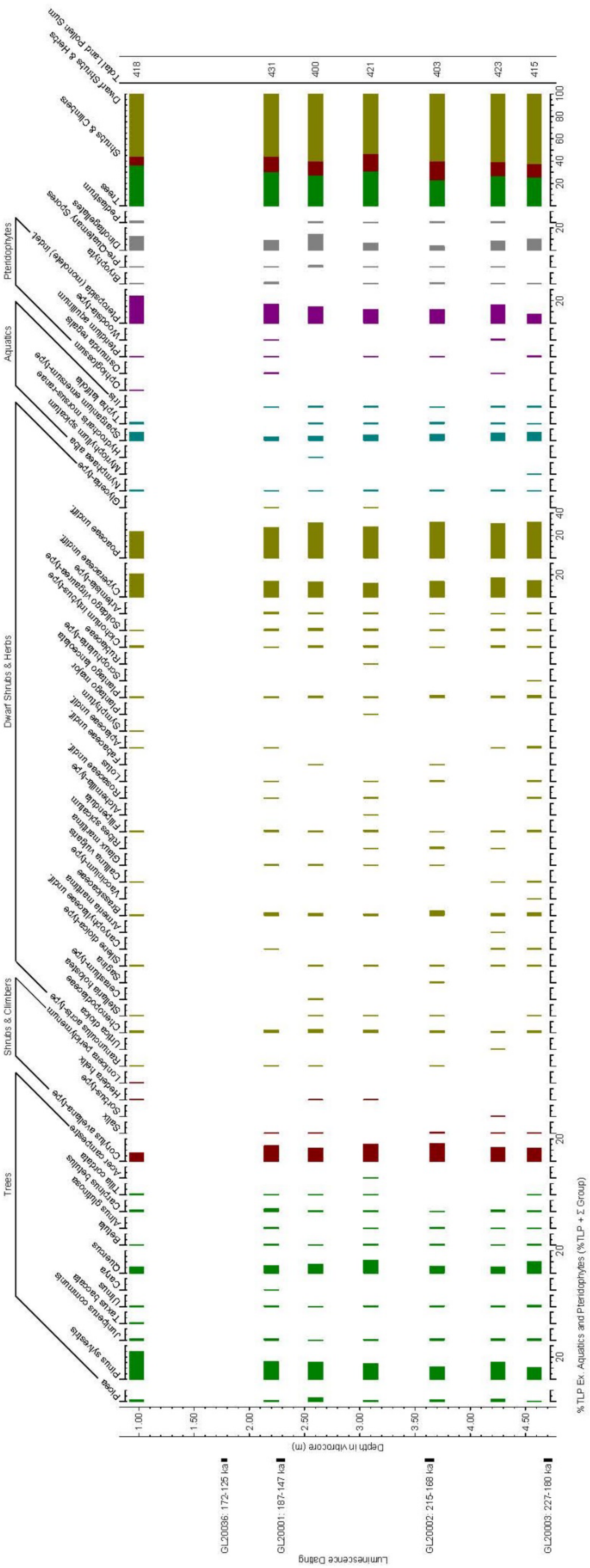

Figure 32 Pollen diagram for VC23

The presence of *Dinoflagellates*, coupled with *Carya*, pre-Quaternary spores and *Pediastrum*, throughout the sequence probably derives from the local Palaeogene geology. This source may also explain the presence of pyrtised centric diatoms, which have been observed in a number of Eocene deposit (de Jonghe et al. 2011). Several of the *Dinoflagellates* present are typically associated with cool-temperate conditions (cf. Head 1996). For example, *Bitectatodinium tepikiense* is strongly associated with cool-temperate North Atlantic conditions (Edwards and Andrle 1992). Although these could be derived from contemporary conditions within the North Sea, it is likely that these are also derived from the local Palaeogene geology.

Attempting to use pollen to establish the age of the vibrocore sequences, using a biogeographical approach (West 1980), has been shown to be problematic because this assumes a simple climatic warming–cooling–warming cycle that can be characterised, with all stages of the glacial-interglacial sequence fully understood and dated, and that mixed assemblages from different temperate episodes do not exist (Rose 2009: 8).

The pollen assemblage from Area 447 does contain similarities to a number of contemporary dated MIS 7/6 terrestrial sequences. Within the Late Glacial channel (B) sequence at Whittlesey (Unit 2a: Langford et al. 2014), AAR dated to MIS 7, the palaeoenvironmental record indicates the late temperate part of an interglacial substage, which supported woodland dominated by *Quercus*, *Carpinus*, *Pinus* and *Corylus avellana*-type, with areas of grassland among the woodland. Both the Whittlesey and Area 447 sequences show similarities to Zone f of the Ilford pollen sequence (West et al. 1964), including the presence of *Tilia cordata*-type, which immediately post-dates the Aveley sequence (West 1969) from which the MIS 7 Aveley Interglacial derives its name. Some similarities also exist with the pollen sequence from Stoke Goldington Site C (Green et al. 1996), dated to MIS 7 using AAR and Uranium-series, which also contained *Ribes* and *Juniperus* pollen as part of the woodland component, though *Corylus avellana*-type percentages are lower at that site. These comparable sites support the interpretation that the Area 447 sequence is late MIS 7/6 in age.

The presence of Levallois material and a luminescence-dated sequence of MIS 7/6 in Area 447 should permit a direct comparison to be made with Unit 3b from Area 240, the purported lithic-bearing stratigraphic unit. Although Tizzard et al. (2014; 2015) have stated that Unit 3b was deposited in MIS 8/7, Marshall (forthcoming) has subsequently shown that the published OSL dating actually correlates Unit 3b to MIS 7/6. This should therefore make Area 447 and Area 240 broadly comparable in age.

No pollen analysis was undertaken on the Unit 3b deposits in Area 240, partly due to poor preservation within the coarser-grained deposits. However, immediately north of Area 240, in Area 254, two sequences with comparable OSL dates have been subject to pollen analysis. In VC1, the base of the sequence (locally called Unit 2) was OSL dated between 577.2±65.4 ka and 175.7±11.2 ka, and directly overlain by MIS 5 deposits. The pollen from the base of this sequence was dominated by *Betula*, *Juniperus*, *Artemisia* (mugwort) and Poaceae, which Scaife (2008) suggested represented an open landscape, with evidence for permafrost/soliflucted soils, and initial temperature amelioration with pioneer tree and shrub elements arriving. Within the Area 254 seismostratigraphy, this was recorded as Unit 2, which Tizzard (2009) subsequently re-interpreted to be equivalent to the Area 240 Unit 4 seismostratigraphy, and therefore chronostratigraphically overlapping and younger than Unit 3b. This interpretation would be compatible with the pollen record, showing a late glacial amelioration prior to the overlying temperate flora expansion in MIS 5e. However, the OSL date from the top of that unit, 175.7±11.2 ka, has subsequently been reclassified by Tizzard et al. (2014: Table 2) as being part of Unit 3b.

A second sequence from Area 254 was collected in vibrocore VC29_2, reported in Limpenny et al. (2011). This core, located in the southwest of Area 254, produced three OSL dates between 222±28.7 ka and 188±28.7 ka from a dark-grey interbedded sandy clayey silt unit. Limpenny et al. (2011) summarise the pollen results as being of a boreal (interglacial) stage or interstadial in character, dominated by a grass-sedge fen and *Pinus* woodland (Limpenny et al. 2011: 117), with no temperate woodland. This sequence is different to the dated pollen sequence from Area 447 where temperate woodland components are more abundant. It is therefore probable that deposition of the Area 254 deposits was during a different sub-stage, probably associated with colder climatic conditions, and does not correlate with the late MIS 7/6 pollen records from Area 447 and other dated terrestrial sequences, including the MIS 7 type-site sequences at Aveley and Ilford.

Diatoms

Diatoms were found to be absent in all samples assessed. One explanation could relate to the high iron oxide content of the samples under consideration. All samples were very red in colour, and slide analysis revealed an abundance of iron oxide precipitation present. This was further evidenced through the exothermic reaction often experienced with a number of the Area 447 samples during hydrogen peroxide pre-treatment. Assuming diatoms were originally present within the sediments at the time of deposition, iron oxides can be responsible for the dissolution of the biogenic silica which makes up the diatom frustule (Mayer 1991).

Foraminifera and Molluscs

Results of the assessment are presented in Table 16. Full counts are given for Mollusca, while estimated abundance is given for other remains. The samples did not yield any Foraminifera. The molluscan assemblage presents a relatively consistent ecological picture throughout the sequence. Mollusc shell is well-preserved, and for the most part does not appear to be wave-transported.

The sample from the base of the sequence, 4.50–4.70 m, is dominated by the marine gastropod *Bittium reticulatum*, with lesser numbers of a predatory marine gastropod (*Odostomia* sp.), the bivalve *Spisula solida*, which burrows into clean sandy substrates, and the gastropod *Margarites helicinus*. This is a fauna of shallow sublittoral waters on rocky coasts. Of particular note, *Margarites* is a circumboreal species whose range in modern times extends from northern Norway to northern Britain as far south as Yorkshire, with very few records from elsewhere in southern Britain.

The subsample from 2.90–3.00 m contains far fewer shells and a less diverse assemblage, but again reflecting a shallow subtidal setting. In addition to *Spisula solida*, there is *Skeneopsis planorbis*, a gastropod associated with fine algae, which in modern times is scarce or absent from the North Sea, although its range extends north from the western Mediterranean to Arctic Norway. There is also an unidentifiable fragment of cockle shell (*Cerastoderma* sp.).

Depth (m)	1.57-1.67	2.55-2.70	2.90-3.00	4.50-4.70
Weight before processing (g)	600	700	790	1400
Weight after processing (g)	340	371	660	1027
MOLLUSCA				
Margarites helicinus (Phipps, 1774)	3			1
Lacuna vincta (Montagu, 1803)	1	1		
Littorina saxatilis (Olivi, 1792)	1			
Skeneopsis planorbis (O. Fabricius, 1780)	3		1	
Bittium reticulatum (da Costa, 1778)	23			13
Nucella lapillus (Linnaeus, 1758)	10			
Odostomia sp.	1			4
Cerastoderma sp.	3	1	1	
Spisula solida (Linnaeus, 1758)	17	1	4	2
Echinoid spine				+

Scale of estimated abundance: + = 1-10 items

Table 16 Molluscan remains in VC23 samples

The subsample from 2.55–2.70 m again contains a restricted fauna of few shells. A new arrival is *Lacuna vincta*, a circumboreal species that is common among weeds on rocky shores.

The subsample from 1.57–1.67 m contains the most diverse and largest assemblage. Once again it is dominated by *Bittium reticulatum*, with a significant proportion of *Spisula solida* and the dog whelk *Nucella lapillus*, a common species of intertidal to barely subtidal settings on rocky coasts in all British waters. The rough periwinkle *Littorina saxatalis*, another common species of rocky shores, is also present.
The molluscs from the samples point to sediment deposition in a shallow subtidal setting at a high energy coast. Variations in the diversity and numbers of molluscs between samples is difficult to interpret with confidence but may be the result of differing rates of sediment accumulation. The presence of *Margarites helicinus* in two of the samples may suggest that waters were cooler than in the present day as it tends to be found in more northerly waters today. However, it should be noted that the biogeography of mollusc species that are still extant in British waters is a rather poor proxy for Pleistocene palaeoclimate and indeed there are a small number of modern records of this species from south Wales, the south-west peninsula and the Isles of Scilly, although it is not recorded on the east coast of Britain south of Yorkshire.

3.5 Discussion

The sedimentary sequence in VC23 indicates an estuarine environment within which alternations between sand and clay suggest periodic deposition. The majority of clast types suggest limited transportation prior to deposition, though some smoothness of edges, especially of the fractured flints, suggests some abrasion and attrition.

The molluscan evidence shows the presence of intertidal and sublittoral assemblages, while the pollen suggests the local presence of brackish communities, such as saltmarsh. Local beach/dune sequences are also implied from the pollen and mollusc evidence, with the fourth flint clast type showing patterning commonly observed on beach pebbles.

The pollen from VC23 shows a late temperate stage, indicating the onset of cooling, that is comparable to dated late MIS 7 terrestrial sequences. Cooling is also implied by the molluscs present, which show cooler conditions and consist of a number of taxa more commonly found in northern territories. While the climate may have been cooling, the surrounding landscape would have had a range of communities including woodland, marsh, floodplain and coastal intertidal zones, providing a rich set of resources.

The luminescence dating of VC23 has confirmed that these deposits are of late MIS 7/6 age. The use of paired mineral luminescence dating, with quartz and K-feldspar, has provided statistically consistent dates both between most paired dates and within their stratigraphic order, increasing confidence in the results. Unlike many previous OSL dates from Area 240 (Toms 2011), the dates from Area 447 do not have associated caveats, increasing confidence in the results.

Westaway (2009) has attempted to quantify vertical crustal movements in East Anglia during the Quaternary, and although highly complex, especially within the coastal zone, he has suggested c. 10 m of uplift since c. 200 ka. Coupling this with current water depth (c. 17 m) and core length (c. 5 m) for VC23, it could suggest a contemporary sea level around -30 to -35 m for this sequence. Using existent global sea level records (e.g. Grant et al. 2014; Spratt and Lisiecki 2016; Waelbroeck et al. 2002; Bintanja et al. 2005) and climate ice-sheet models (e.g. Choudhury et al. 2020), these could suggest sea levels dropped below the Area 447 elevation between c. 195-185 ka, which would be compatible with luminescence dates GL20002-3 (91.8% and 64.6% probability of predating 185 ka respectively), though would predate GL20001 and GL20036. Based upon this interpretation, it could imply that sedimentation in the VC23 sequence commenced during the MIS 7a–6e interglacial to glacial transition. White et al. (2006) have stated that a regional population crash in Britain occurred during early MIS 6 coupled with the disappearance of Levallois technology, with no evidence for hominin occupation until MIS 3. The dated sequence from Area 447, coupled with the recovered Levallois material from between Clacton-on-Sea to Holland-on-Sea that originated from Area 447, supports the presence of hominins within the area at the start of MIS 6 immediately prior to this proposed regional population crash.

This study also demonstrates that luminescence dating can be successfully achieved using archived core material. The cores, collected in 2015, had spent five years stored prior to sampling for luminescence dating. While some light exposure is likely to have occurred to the outside of these cores (due to being taken in clear liners), the compact and cohesive nature of the sediments has meant that no partial bleaching has occurred within the centre of the cores selected for dating. The ability to date VC23, using a paired mineral approach of quartz and K-feldspar, demonstrates significant opportunities that may exist for future collaborative work with aggregates companies utilising geotechnical samples that have already been obtained. It could also provide opportunities for increased flexibility in the development of protocols to optimise sample integrity during collection, geotechnical sampling, and archiving/storage. Such procedures have already been successfully implemented with other offshore developments, such as offshore wind farms (e.g. Toms and Evans 2018; Grant 2021), permitting greater opportunities for the use of luminescence dating in conjunction with geotechnical site investigations. While such approaches may be less preferable to standard approaches (Duller 2008), where opportunities exist to establish collaborative sampling protocols with industry partners during geotechnical site investigations, these should be implemented at an early stage.

The clast analysis was limited by the availability of material within the vibrocore, resulting in full assessment counts (of 300 individual clasts) not being reached. Counts could have been higher in other cores where the gravel component is more dominant, but these would have been detached from the palaeoenvironmental record contained within the finer-grained deposits of VC23. While counts are limited, these are able to provide key insights into the four flint types present: one possibly associated with deposition upon a beach, while the other three show limited signs of abrasion and attrition. The abrasion and attrition of these flints is similar to that present upon the lithics recovered after beach replenishment between Clacton-on-Sea to Holland-on-Sea. When studying flint artefacts, physical damage is often used as a proxy to indicate how much the items were subjected to movement after deposition (Wymer 1968), with extensive abrasion or rolling considered to be a partial indicator of long transport distance (Hosfield 2011). The clast analysis therefore supports the assumption that both the recovered lithics and three of the flint clast groups in VC23 were subjected to similar taphonomic processes after deposition. While not explicitly linking the lithics to Area 447, the clast analysis supports the interpretation of the artefacts' original context prior to dredging.

Clast analysis therefore has the potential to both predict and retrospectively assess the potential for the recovery of lithic material from offshore aggregate areas. In a predictive manner, by identifying flint taphonomy and type within vibrocores, and comparing these to the known Palaeolithic record from the region, it might be possible to better predict if a site could yield lithics and, if so, from which seismo-stratigraphic context(s). For this to be successful, a larger number of vibrocores from across the site would need to be assessed to identify spatial variations in clast type and taphonomy. A retrospective approach, comparing recovered lithics to the clast analysis undertaken on pre-licence cores (coupled with the known dredging area from which the artefact(s) were recovered), could allow provenance of discoveries and enable the adoption of more proactive mitigation procedures (e.g. avoidance of specific deposits or increased monitoring of these during dredging).

Finally, provenance of the flint (e.g. Bridgland 1999) itself could provide an additional method to predict the likelihood of archaeological discoveries. Within the Thames valley, rich archaeological horizons with Levalloisian assemblages were only discovered at sites where a source of raw material was present, with smaller assemblages found when a source of flint was not immediate (White et al. 2006). Such associations support an economical model based on optimised behaviour (Renfrew 1977; Wilson 2007). Within Lower Palaeolithic sites, distinct clast-lithological differences exist between the Bytham River gravels at sites like Warren Hill and true glacial outwash gravels, which occur at other locations in the region (Bridgland and Lewis 1991; Wymer et al. 1991; Bridgland et al. 1995). The latter have not yielded archaeology, whereas artefacts invariably occur at low-level Bytham Sand and Gravel localities, Warren Hill having the distinction of being one of Britain's richest Lower Palaeolithic sites (Hardaker 2012). Provenance and quantification of clast type within vibrocores could therefore facilitate the development of predictive approaches that consider raw material procurement and exploitation strategies (e.g. Duke and Steele 2010; Ekshtain and Zaidner 2021) to better identify and interpret archaeological sites found within offshore aggregate areas.

4. ARCHAEOLOGICAL FINDS FROM AREA 447

Stone tools and Pleistocene mammalian remains have been recovered from the replenished beach from Clacton-on-Sea to Holland-on-Sea since the deposition of sands in 2015. Two main collectors are responsible for the bulk of the finds recorded here, but ten others also provided their collections. Recording took place over the summer of 2021 and was undertaken by Rachel Bynoe and Robert Davis of the British Museum, with the help of Kathryn Price (BM) and collectors John Ratford and Paul Buisson. Simon Parfitt and Adrian Lister of the Natural History Museum helped with faunal identification and visual assessment at both the outreach event and via email.

4.1 Clacton-on-Sea – Holland-on-Sea outreach event

In July 2019 a fossil and stone tool outreach day was organised in Holland-on-Sea to gauge local interest, engage new collectors and visually assess some of the recovered material. With the help of local collectors John Ratford and Paul Buisson this was advertised locally via posters as well as via an article in the Clacton Gazette. John and Paul were instrumental in organising this event.

On the day the event was run by John and Paul, Rachel Bynoe, Simon Parfitt and Rebecca Ferreira (UoS). Although initially unsure of what the turnout would be like, it turned out to be a huge success with people turning up before we had even officially opened and packed rooms spilling out into corridors. The heavy involvement of local collectors was a real benefit as it showcased the incredible knowledge that they have gained over the course of their collection, encouraging others to see this as something they can get involved with themselves.

Throughout the day, six talks were given to introduce people through the project, highlighting the involvement of Historic England and the aggregate companies (Figure 33). Subsequently, several attendees located archaeology themselves on the beaches and sent through information. This event fed through into the numbers of finds that were able to be subsequently studied for this work.

Another event was originally planned, tying in with the local Finds Liaison Officer (FLO) and the Portable Antiquities Scheme. Unfortunately, however, the original FLO involved moved on to a new job and the Covid-19 pandemic made any plans for such events impossible. Despite this, informal feedback from the event was that local communities such as that at Clacton-on-Sea/Holland-on-Sea rarely see engagement in this way and, should there be the capacity for events in future, this is something that people would be keen to attend.

4.2 Pleistocene mammalian remains

Although visually assessed to support this work, the Pleistocene mammalian remains have not had in-depth analysis due to issues of reference collection availability and expert assistance during the Covid period.

Figure 33 Outreach day talks in 2019

From this visual assessment it is clear that the species represented relate to a cool and open environment, characteristic of the 'mammoth steppe' that dominated northwest Europe from approximately MIS 8 through the end of the Devensian (MIS 2). Species include *Mammuthus primigenius* (woolly mammoth), *Coelodonta antiquitatis* (woolly rhinoceros), *Bison priscus* (bison), *Megaloceros* sp. (giant deer) and *Equus* sp. (horse). Although part of this assemblage may relate to the Devensian — implied by some of the *M. primigenius* molars (Lister pers. comm.; Figure 34) — indications based on the large size of *Equus* metapodials are indicative that at least part of the assemblage may date to MIS 7 (Parfitt pers. comm.). As a result of these varied faunal signatures, as well as the varied condition of the remains, it is likely that this collection has sampled units of varied ages throughout the Early Middle to Upper Palaeolithic.

4.3 Stone tool analysis

A sample of 400 stone tools were analysed as part of this project, from a total exceeding 600. Of the humanly modified component, 36% are Levallois and 64% are non-Levallois. Artefact types are shown in Table 17 and Figure 35.

Initial examination of the lithic assemblage indicated a relatively fresh Levallois component, a core-and-flake component of varied conditions and an abraded handaxe collection. Given their collection from the Clacton-on-Sea – Holland-on-Sea beach replenishment in 2015, these components are mixed, with limited associated spatial or temporal data. Their analysis therefore concentrates on grouping by typology, with further splitting out based on degree of abrasion, staining and patination.

As would be expected with a dredged beach assemblage, all the pieces show moderate recent edge damage. It is impossible to say whether this occurred during the dredging and transport process, or once it was deposited on the beach, but it is demonstrably recent.

Figure 34 Mammuthus primigenius*, identified by Adrian Lister (photo: John Ratford)*

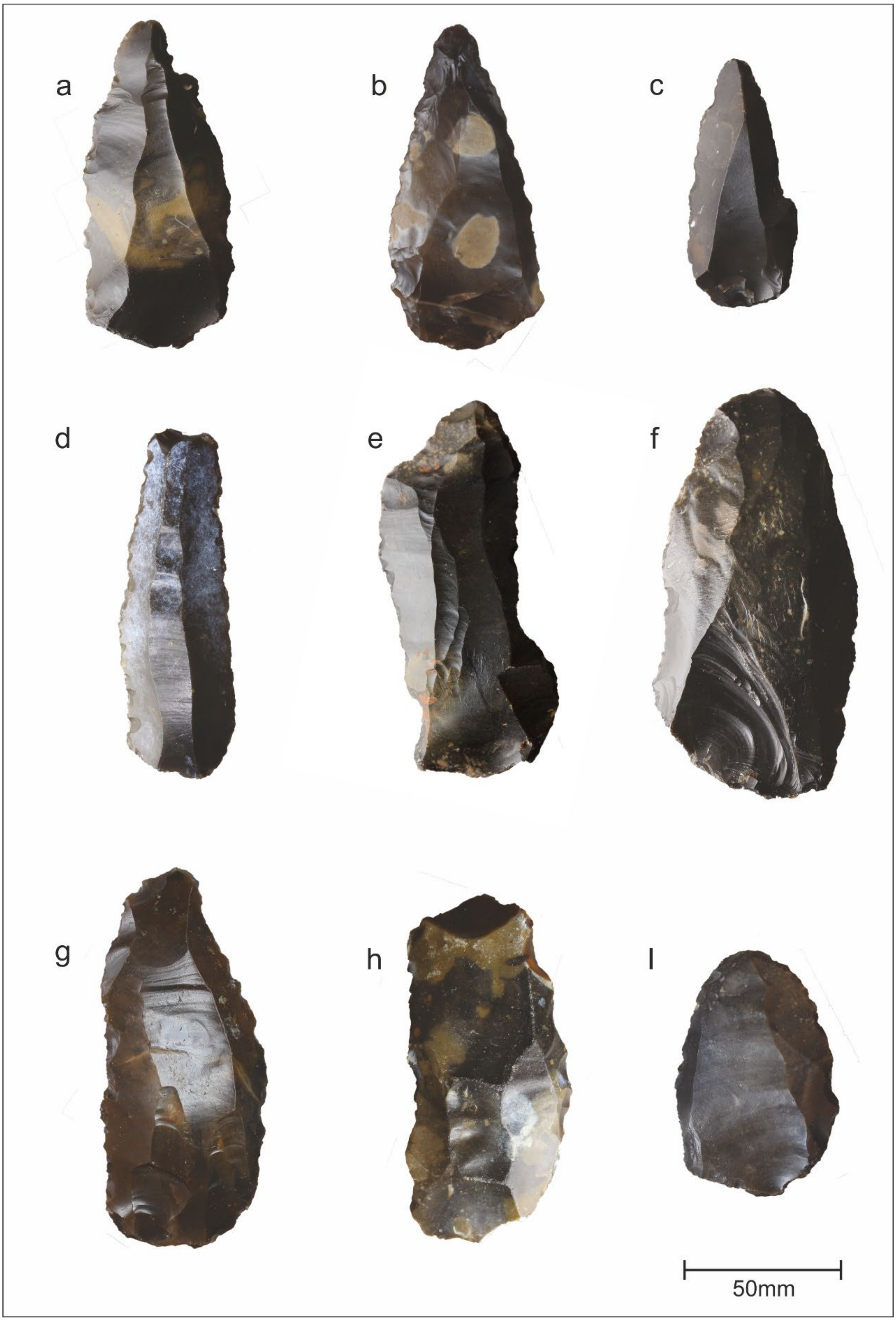

Figure 35   A selection of Levallois flakes: a-c) points (b with continuous retouch), d-e) blades, f-i) flakes

	n	Collection %	No. retouched	Type %
Flakes	338	84.5%	28	7%
Levallois flakes	121	30.3%	17	4.3%
Unbroken	*65*	*19.8%*		
Non-Levallois flakes	217	54.3%	11	2.8%
Unbroken	*104*	*31.6%*		
Cores	40	10%		
Levallois cores	21	5.3%		
Non-Levallois cores	19	4.8%		
Handaxes	22	5.5%		
Crude (Type D and E)	6	1.5%		
Pointed (Type F)	7	1.8%		
Sub-cordate (Type G)	2	0.5%		
Bifacially worked piece	2	0.5%		
Indeterminate	5	1.3%		

Table 17 Composition of the stone tool collection

4.3.1 Methods

The core and flake flint artefacts were analysed according to the system of Ashton and McNabb (1994), with Levallois artefacts identified and recorded following Boeda's six criteria (1995) and Scott (2011). Table 21 shows the various aspects recorded. Handaxes were recorded using a standard set of measurements and attributes following Wymer (1968). Digital callipers were used to take a series of measurements for morphometric analysis following Roe's (1968) method.

Artefact condition relates to the smoothing of edges and aretes during transport and was determined visually, on a scale of 1–4, with 1 being very fresh and 4 very abraded. Patination and staining refer to the surface characteristics of the artefact and were visually assessed on the same four-point scale (with 1 being no surface modification). Dorsal cortex retention was recorded on a six-point scale (100% cortex, 99–75%, 75–50%, 50–25%, 25–1%, 0%).

Where metrical analyses are discussed below, these have been calculated on the unbroken components of the collection.

4.3.2 Results

The following analysis has been broken down into typological groupings, with overlaps discussed where appropriate. Table 17 shows the composition of the collection as a whole, and Table 18 gives an overview of condition and surface modification of each typological group.

The majority of the Levallois products overall are medium-sized flakes (69.4%) and points (14%), and relatively large blades (15.7%), with a single debordant flake (0.8%). The average length of these pieces is 85.89 mm (Table 19), with the size distribution comparable for each of the Levallois product classes (Figure 36) and blades exhibiting greater average values. The majority of Levallois products are unbroken (58.7%), but a significant number (41.3%) are broken (Table 19).

	Levallois products (n=121)	Levallois cores (n=21)	Flakes (n=217)	Cores (n=19)	Handaxes (n=22)
Condition (%)					
1 - Fresh	1.7%	0%	1.4%	0%	0%
2 - Slightly rolled	72.7%	30%	34.6%	47.1%	23%
3 - Moderately rolled	22.3%	60%	47%	47.1%	36%
4 - Very rolled	3.3%	10%	17.1%	5.9%	41%
Patination (%)					
1 - Unpatinated	74.4%	100%	73.3%	94.1%	77%
2 – Slightly patinated	20.7%	0%	12.4%	5.9%	9%
3 - Moderately patinated	0.8%	0%	10.6%	0%	9%
5- Very patinated	4.1%	0%	3.7%	0%	5%
Staining (%)					
1 - Unstained	87.6%	95%	80.7%	94.1%	32%
2 – Slightly stained	9.9%	5%	15.7%	5.9%	36%
3 - Moderately stained	1.7%	0%	3.7%	0%	27%
4 - Very stained	0.8%	0%	0%	0%	5%

Table 18 Surface modification of all classes of find

The majority of Levallois products are relatively fresh (72.7%), with a small amount moderately abraded (22.3%) (Table 18). Splitting these out into comparable groups of fresh and abraded indicates a higher number of products prepared using a unipolar method in the fresh group, with higher proportions of bipolar preparation for the abraded (Figure 37). The fresh group also has a wider range of preparatory scars than those that are abraded. However, a Kolmogorov-Smirnov (KS) test shows no statistically significant difference between numbers of preparatory scars, method of preparation or method of exploitation between either group (level of significance at 0.05).

The products are predominantly unstained (87.6%) and unpatinated (74.4%), with small proportions of moderately stained (9.9%) and patinated (20.7%) (Table 18). When analysed within condition groupings, those that are very abraded (although a small sample of four) show a high proportion (66.6%) of patination and 33.3% very stained. The reverse is true of the very fresh (n=2) group, where these pieces show no staining or patination. Within the moderately fresh and abraded groups, staining follows a similar pattern (predominantly none and increasing proportions with increasing surface changes). Patination is slightly different, with the fresh group exhibiting decreasing numbers with increasing patination, whilst the abraded group have clearly lower numbers of unpatinated and higher numbers of moderately patinated pieces. A KS test performed on the different distribution of the patination and staining between condition groups two and three shows that there is a statistically significant difference at the 0.05 significance level. The causes of surface patination in flint assemblages are not clearly understood, but the differences potentially relate to different taphonomic histories.

	Levallois flakes	Non-Levallois flakes
Breaks		
Complete	58.7%	47.9%
Broken	41.3%	52.1%
n	121	217
Length	85.89 mm	66.63 mm
Width	44.28 mm	41.67 mm
Thickness	11.80 mm	13.92 mm
Weight	54.88 mm	48.95 mm
Butt type		
Plain	11.6%	29%
Dihedral	2.5%	3.2%
Facetted	54.5%	12.9%
Marginal	0.8%	8.29%
Chapeau de Gendarme	12.4%	0.5%
Puntiform	2.5%	1.4%
Missing	15.7%	37.3%
Crushed	0%	2.3%
NA	0%	0.5%
n	121	217
Cortex retention/natural		
100%	0%	0.9%
99-76%	0%	0%
75-51%	0%	3.7%
50-26%	0.8%	10.1%
25-1%	14.0%	34.6%
0%	85.1%	50.7%
n	121	217
Dorsal scars	5.9 (2-16)	5 (0-25)
Dorsal scar direction		
1	42.2%	38.7%
2	13.2%	20.3%
3	1.7%	3.2%
4	5%	9.7%
5	0%	1.4%
6	0.8%	1.4%
7	33.1%	16.6%
8	0%	1.8%
9	3.3%	3.7%
10	0%	0.9%
11	0.8%	0.5%
12	0%	0.5%
Unclear	0%	1.4%
n	121	217

Table 19 Characteristics of Levallois and non-Levallois flakes

The majority of the Levallois products retain no cortex (85.1%), with small numbers retaining <25% (14.8%), implying that these are not from the initial stages of reduction and tying in with proportions found on the Levallois cores (Table 21).

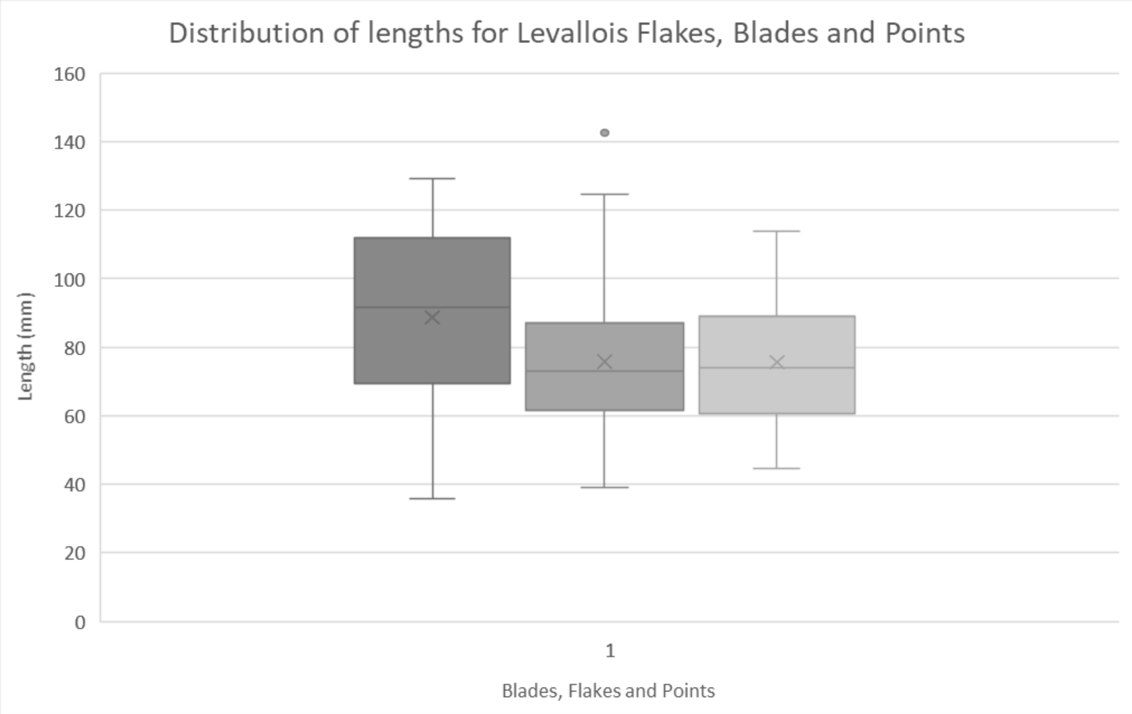

*Figure 36 Boxplot of length distribution of Levallois flakes, blades and points. Outliers are defined as values that fall below Q1 – 1.5*Inter Quartile Range (IQR) or above Q3 + 1.5*IQR. For boxplots, the highest and lowest occurring value within this limit are indicated by whiskers of the box and outliers are illustrated as individual points. Median values are shown by the solid line.*

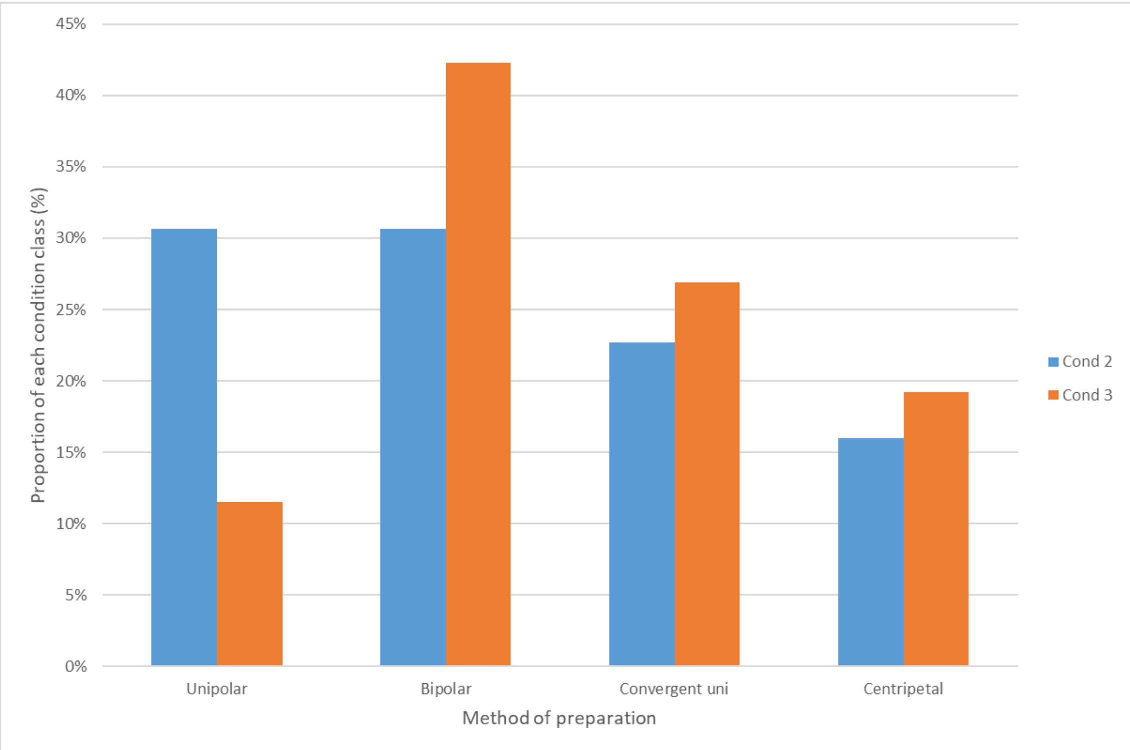

Figure 37 Preparation method for condition 2 and condition 3

Levallois products (n = 121)	
Levallois product type	
Flake	69.4%
Point	14%
Blade	15.7%
Debordant flake	0.8%%
No. Levallois product scars	
0	79.1%
1	20.9%
2	0%
No. Levallois preparatory scars	
0	0%
1-5	50.4%
6-10	44.3%
11-15	4.3%
15+	0.9%
Method of preparation	
Unipolar	27.8%
Bipolar	31.3%
Convergent unipolar	23.5%
Centripetal	17.4%
Method of exploitation	
Lineal	0%
Single removal	79.1%
Unipolar recurrent	20.9%
Centripetal recurrent	0%
Bipolar recurrent	0%

Table 20 Levallois products

The lengths of unbroken Levallois products generally exceed those of the flake scars retained on the surface of the cores recovered (Figure 38), which is in line with these cores having been reduced; we are seeing the end-product of the cores, but the discard of a range of their products. Similarly, the surface preparation shown on the dorsal side of the Levallois products (Table 20) broadly reflects that of the preparation method (Figure 40). Discrepancies between the relative proportions are likely in such an assemblage, but it is also generally the case that flakes will not remove the entire prepared surface of the core, making interpretations about preparation and exploitation methods subject to error.

Figure 41 shows that the products produced using the unipolar technique tend to be smaller in length and have a smaller spread around the average. This is supported by the average length of Levallois scar removals on cores with unipolar preparation, which are the smallest of the four categories recorded at 55.6 mm (Figure 39). Products prepared using a bipolar technique, in contrast, have the widest spread of lengths, and the greatest proportion of larger products (although this remains fairly constant throughout the size classes). This is supported by the distribution of the preparation methods shown on the cores (Table 21), with those demonstrably used for unipolar flaking having the highest proportion of smaller scars and both bipolar and convergent unipolar showing the highest proportion of larger product scars. There are recorded instances from the European record showing an indication that bipolar reduction was preferentially used for the initial removal of larger flakes (e.g. Biache St Vaast IIA, MIS 7 [Dibble 1995]; Baker's Hole, MIS 7 [Scott 2011]).

	Levallois cores (n = 22)
Length	73.2 mm
Width	65.6 mm
Thickness	27.5 mm
Weight	169 g
Flaking surface preparation	
Unipolar	41.2%
Bipolar	35.3%
Convergent unipolar	11.8%
Centripetal	11.8%
Exploitation method	
Lineal	64.7%
Unipolar recurrent	23.5%
Bipolar recurrent	5.9%
Re-prepared but unexploited	5.9%
No. Levallois product scars	
1	64.7%
2	23.5%
3	5.9%
4	5.9%
No. prep scars on flaking surface	
Mean (range)	4.9 (2-9)
No. prep scars on striking surface	
Mean (range)	10.8 (3-25)
Striking surface working	
Steep	29.4%
Minimally invasive	0%
Semi-invasive	29.4%
Invasive	41.2%
Cortex on striking surface (%)	
0%	11.8%
>75%	23.5%
75-49%	11.8%
50-26%	29.4%
25-1%	23.5%
0%	0%
Position of cortex on striking surface	
None	5.9%
One edge only	11.8%
More than one edge	11.8%
Central and one edge	11.8%
Central and more than one edge	29.4%
All over	29.4%

Table 21 Levallois core reduction

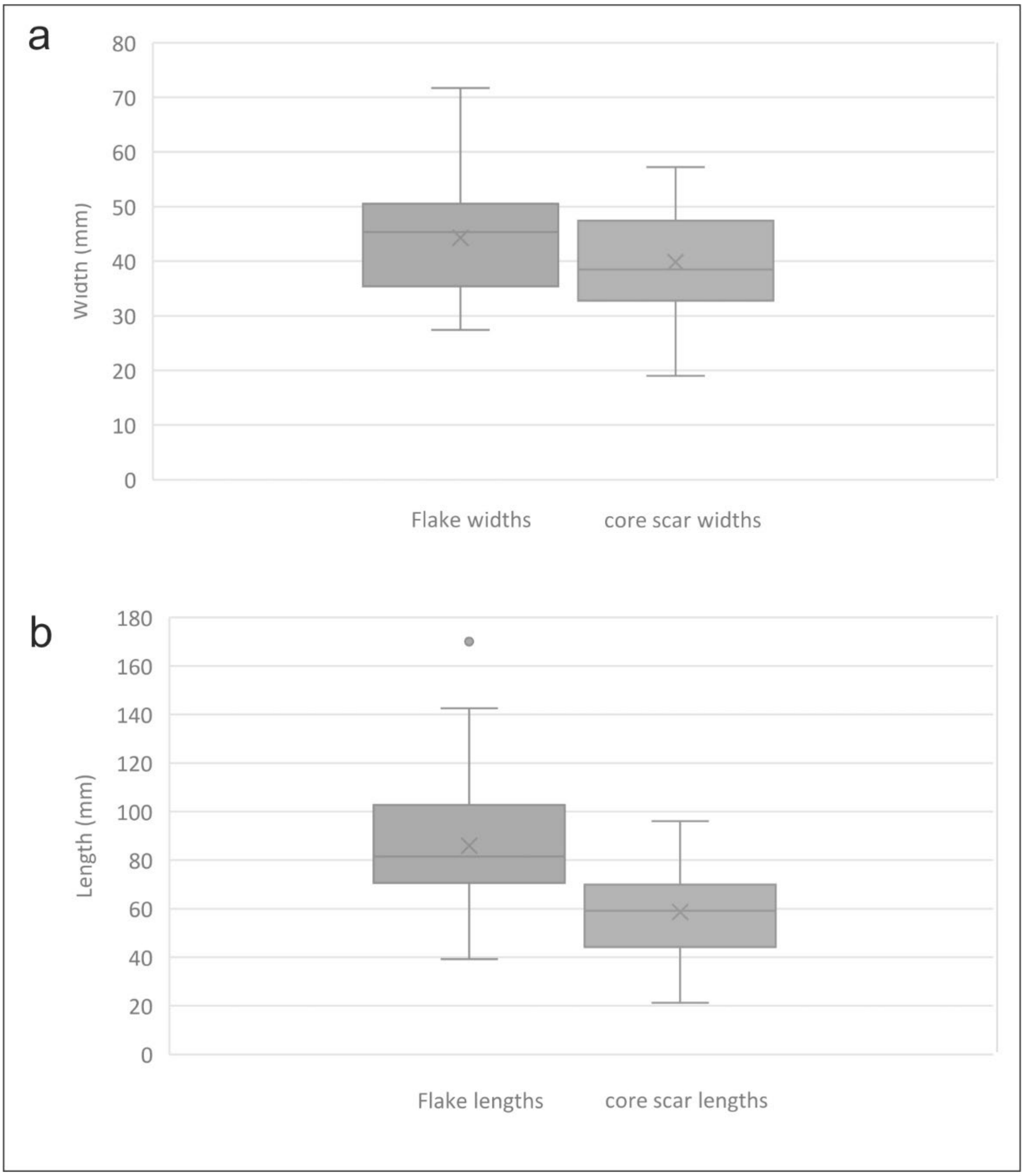

*Figure 38 Boxplots of a) flake scar lengths against core scar lengths and b) flake scar widths with core scar widths. Outliers are defined as values that fall below Q1–1.5*Inter Quartile Range (IQR) or above Q3+1.5*IQR. For boxplots, the highest and lowest occurring value within this limit are indicated by whiskers of the box and outliers are illustrated as individual points. Median values are shown by the solid line.*

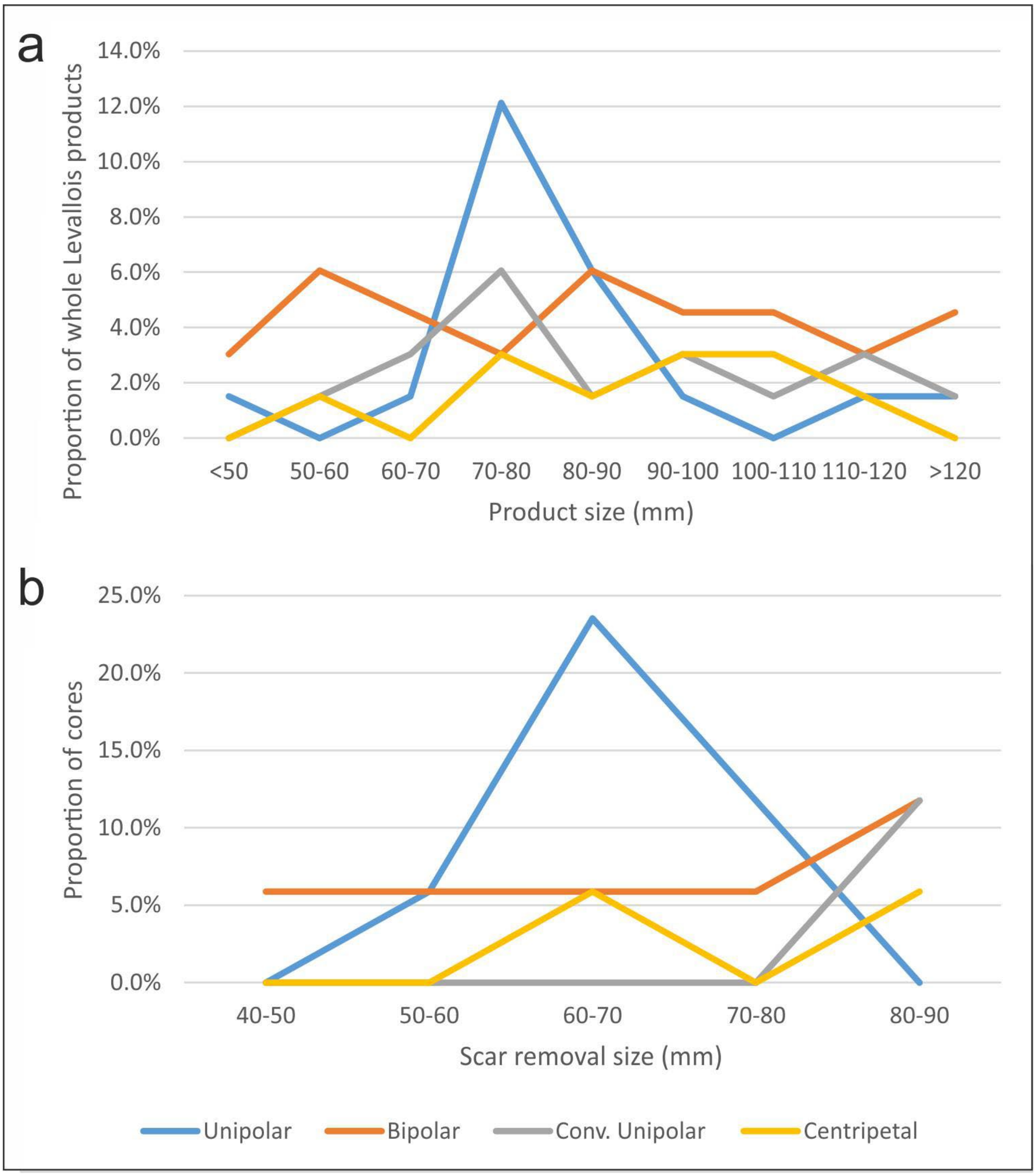

Figure 39 a) product size from varying preparation methods of Levallois products and b) scar removal size from cores exhibiting the same preparation methods

The Levallois products retain relatively low numbers of preparatory scars on their dorsal surfaces (92.2% have fewer than 10, with nearly half [45.2%] having between four and six, the median being five) (Table 20). This is reflected by low numbers of preparatory flake scars retained on the surface of the cores, where the majority (52.9%) have between four and six, indicating a relatively low emphasis on the preparation and shaping of the core surface prior to striking.

The majority of the Levallois products have facetted butts (54.5%), with moderate numbers of Chapeau de Gendarme (12.4%), plain (11.6%) and missing (15.7%). Other types are represented in small numbers (Table 19). Although products are therefore being removed with minimal preparation of the striking surface, there is a clear indication that the majority of cores were being prepared in this area prior to striking, providing greater control over the success of the removal.

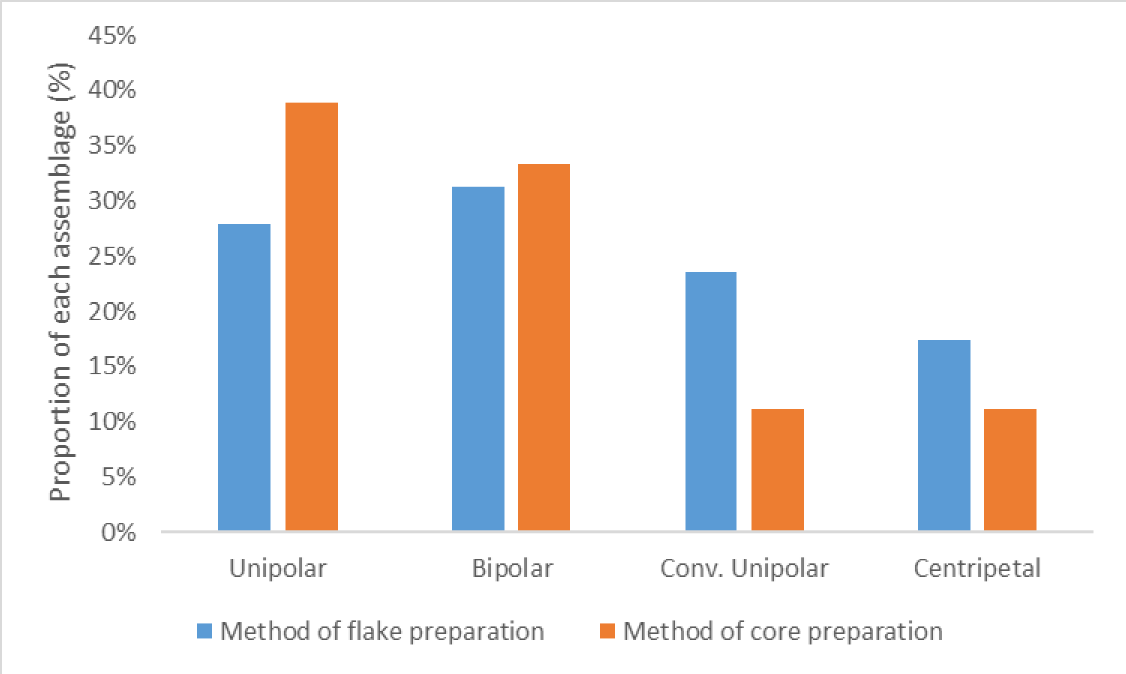

Figure 40 Flake preparation shown with core preparation methods

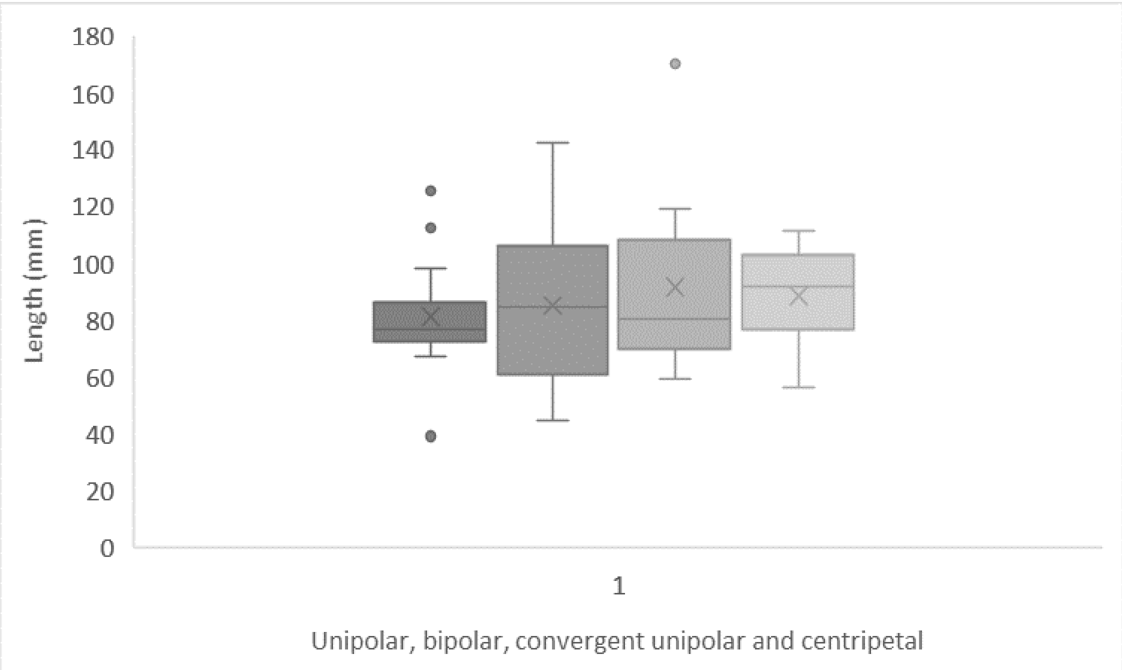

*Figure 41 Box plot showing the distribution of the size of Levallois products by methods of preparation. Outliers are defined as values that fall below Q1–1.5*Inter Quartile Range (IQR) or above Q3+1.5*IQR. For boxplots, the highest and lowest occurring value within this limit are indicated by whiskers of the box and outliers are illustrated as individual points. Median values are shown by the solid line.*

The size categories shown in Figure 42 can be used to illustrate the relationship between length and elongation. Although forming small proportions of the overall collection, those that are most elongated (B/L<0.4) fall within the middle and largest size categories, whilst those that are least elongated (B/L>0.8) are in the smallest. In terms of which preparation methods relate to elongation classes, this is relatively unclear, with the only clear pattern that the majority (31.8%) of the relatively general (0.4<0.8) collection were made using the bipolar technique (Figure 43). Centripetal reduction (with a small sample size of nine) is only represented by this middle elongation category. What this means in terms of reduction is uncertain, but, in combination with many of the larger products being produced using bipolar reduction, it could tentatively suggest that this is the preferred method by which to begin the reduction process on relatively large, more difficult to handle cores. Subsequent reduction looks fairly equally split between other reduction methods.

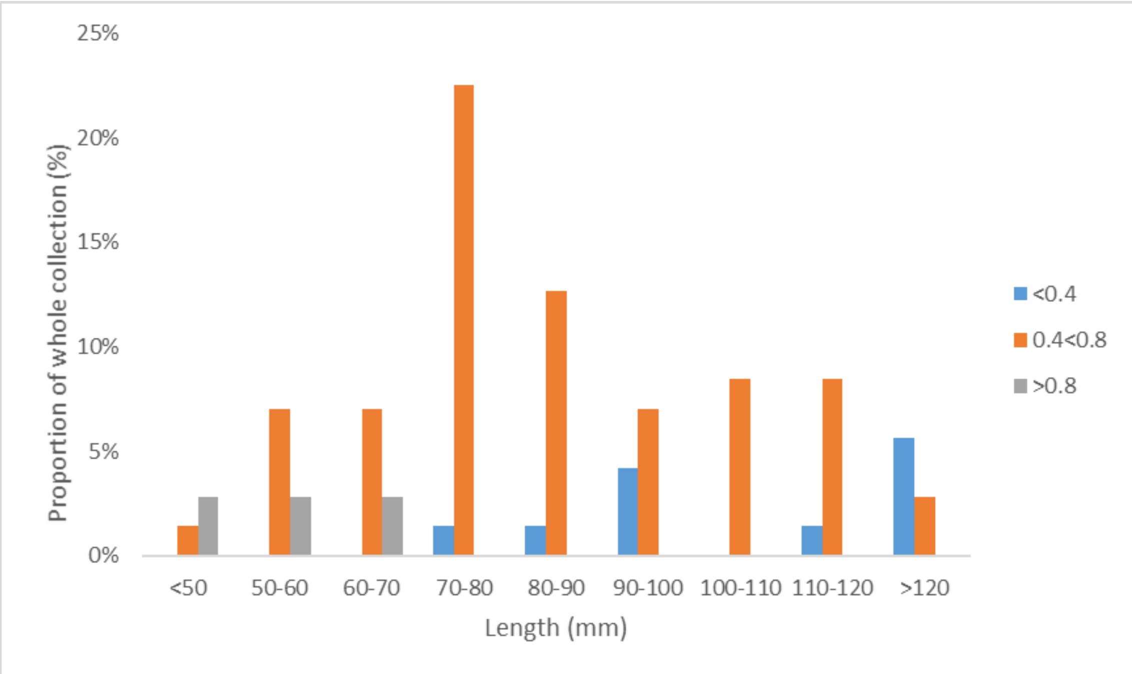

Figure 42 Length classes of Levallois products by elongation categories

Retouched flakes

There are 19 retouched Levallois products in the collection (15.7%). All of these exhibit scaly retouch, which is direct, and move between minimally invasive to invasive. One is marginal. They show a range of areas being targeted, with an almost even split between left (35.7%) and right (28.6%); 64.3% of the retouch is lateral. There are single incidences of both sides, proximal, distal and two incidences of continuous. The majority of the retouched products are flakes (64.3%), with 14.3% on points and 21.4% on blades.

The relatively small proportions of retouched products, in conjunction with relatively little evidence of intensive reduction, may relate to hominin use of the area. With Area 447 situated within what would have been a resource-rich environment for flora and fauna as well as, presumably, river-derived raw material clasts, it could tentatively be interpreted as falling into Turq's (1988; 1989) 'extraction and production' category.

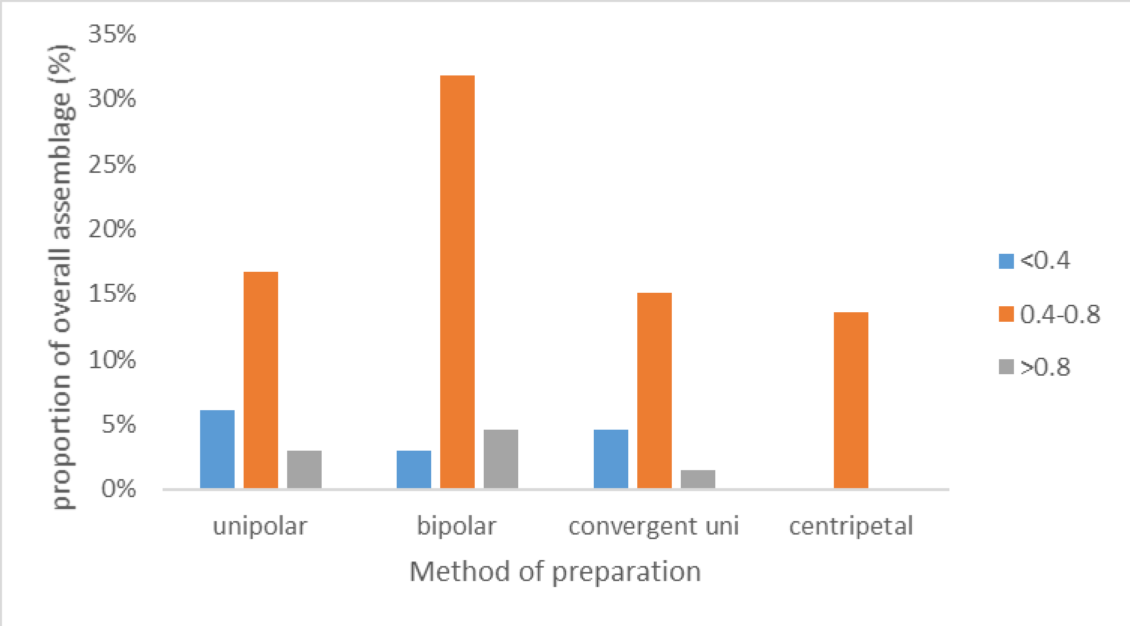

Figure 43 Relative proportions of each elongation class by method of preparation

The Levallois cores (Figure 44) vary in their condition, which is dominated by 'abraded' specimens (60%), with only 30 % being 'fresh'. However, staining and patination show 100 % of cores are unpatinated with 95 % unstained, with 5 % moderately stained (Table 18).

The majority of the collection (61.1%) only show one Levallois removal, but smaller numbers (22.2%) show two removals (Table 21). Preparatory scars on the flaking surface range between two and nine, with the peak at four (22.2%) and similar proportions for other categories (Table 21). The flaking surface preparation falls into four categories: unipolar (38.9%), bipolar (38.9%), convergent unidirectional (11.1%) and centripetal (11.1%). The exploitation method then falls into lineal (61.1%), unipolar recurrent (22.2%), bipolar recurrent (5.6%) and re-prepared but unexploited (5.6%).

The dominance of uni- and bipolar reduction methods and the relatively low numbers of preparation scars indicates that there was not a high degree of shaping of the lateral and distal convexities needed to detach the flakes discussed above. In comparison, the majority of cores have only a small amount of striking platform preparation (38.9% have 6–10 scars), with 27.8% having between 11 and 15 removals. As a result, while all striking surfaces show cortex removal, in contrast to the products themselves this is relatively evenly split, with 55.6% retaining >49–<100% cortex and 44.4% having <50% cortex. Only 11.1% have no cortex remaining. Taken together with the indications of generalised reduction methods, this hints at relatively expedient reduction of these Levallois cores; the main area of working was the flaking surface.

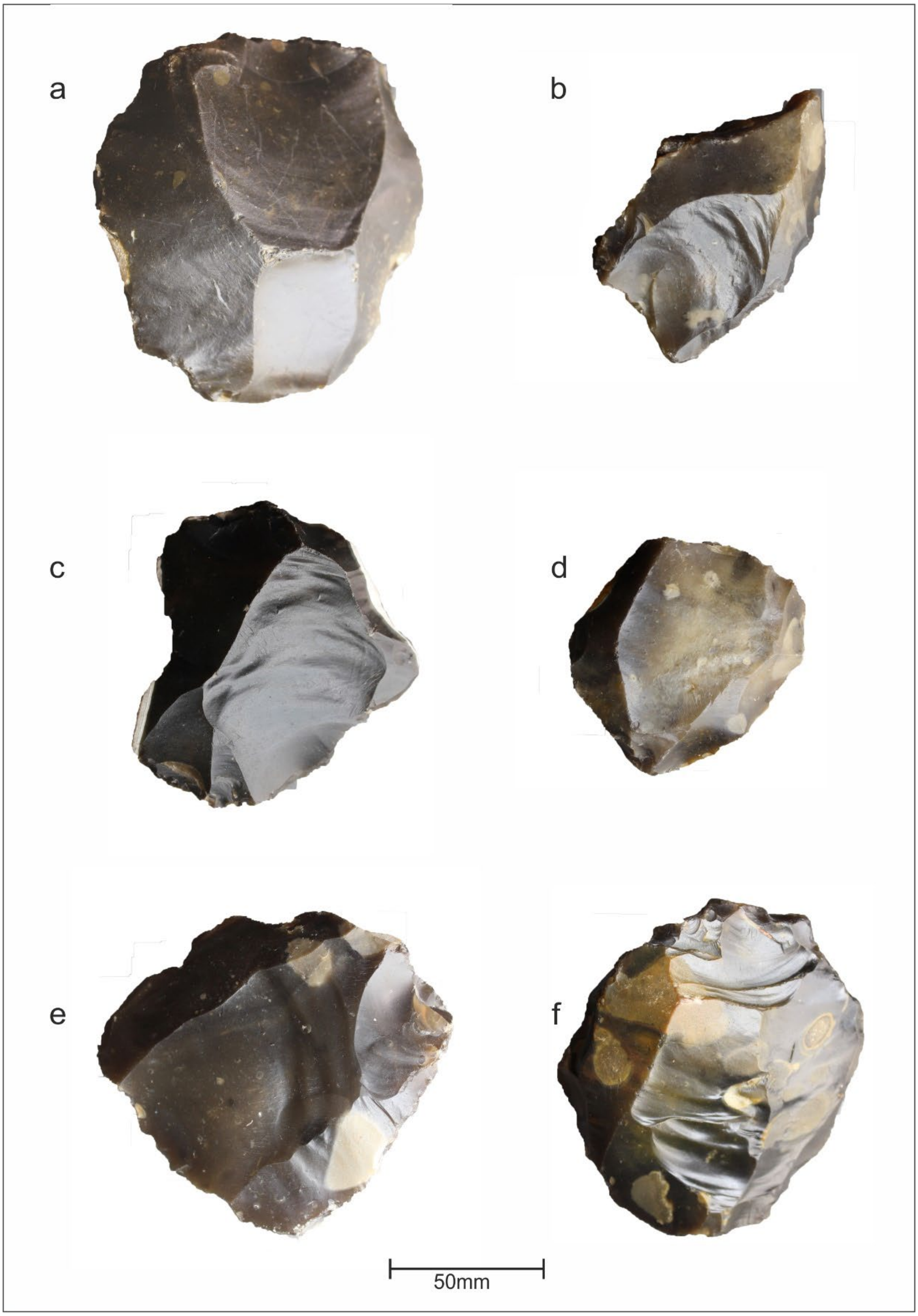

Figure 44 A selection of Levallois cores from the collection

Cores are relatively round in shape, with elongation values of 0.67 and above, and relatively flat, with flattening indexes (Th/W) of most between 0.2 and 0.5 (Figure 45). The cores are relatively small in size (Table 21), which may reflect repeated exploitation or small clasts with which to work, or possibly both. Whilst most cores show evidence of a single removal, later removals can easily obscure earlier removals, making this assessment problematic. The fact that many of the products recovered are larger than the Levallois scars on the cores (Figure 38) supports the assertion that this collection reflects repeated reduction of these cores, which is supported by their low flattening index. To put this another way, most of the Levallois products appear to have been produced earlier in the lives of the cores. This is a pattern that is most clearly seen when looking at the lengths of the scars compared with the products, rather than the width, where the two measurements are more in line. This pattern is also seen at Baker's Hole (Scott 2011: 91), where it is suggested that this is due to initial stages of core reduction requiring far greater effort for the removal of large flakes that took up a lot of the core surface. As such, this earlier, larger flaking stage is characterised by long and relatively narrow flakes. As the cores are reduced in size the ease with which flakes consuming more of the surface area were detached would increase, but with decreasing size of core surface — particularly through reshaping and convexity accentuation — these would be characterised by shorter flakes but of a similar width to the earlier exploitation methods. Whilst this broadly fits for this data, the products that dominate are lineal in nature, rather than centripetal. Plotting the width of flake scar removals against the width of the core gives an R^2 of 0.1943, indicating that the width of the scar cannot really be explained by the width of the core itself; there is more going on, which may be as simple (but obscure) as hominin preference.

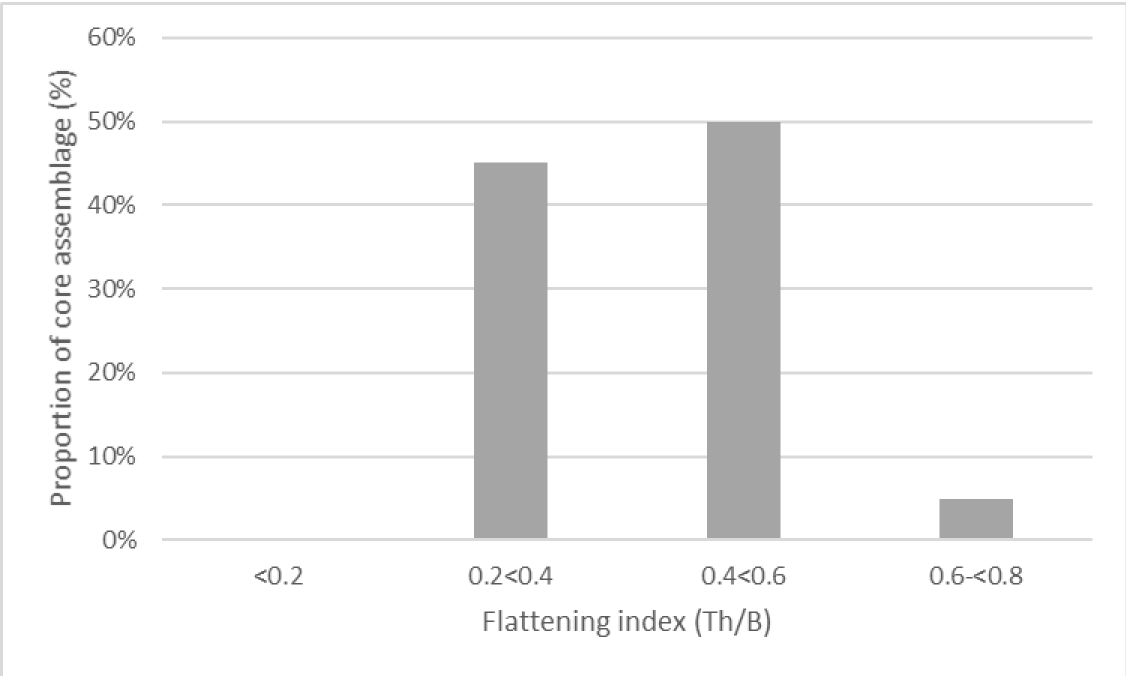

Figure 45 Proportions of Levallois cores in relation to flattening index

Within the beach collection there are 208 flakes (including 29 'blades' defined as flakes twice as long as they are wide), eight retouched flakes and one retouched thermal spall, of which 99 of the flakes, and five of the retouched flakes, are unbroken (Table 19; Figure 46). The flakes are small, with lengths relatively normally distributed around a mean of 66.6 mm (Figure 47). Widths are predominantly skewed towards the smaller end of their range, with a mean of 41.7 mm and a median of 39.4 mm.

Figure 46 A selection of non-Levallois flakes of varied condition and surface modification

Elongation (W/L) measures show a predominance of relatively standard-sizes flakes, with smaller proportions of elongated (blade-like) flakes and moderate proportions of short, wide flakes (Figure 48).

The condition of the flakes fall predominantly into the 'moderately abraded' category (47%), but with 34.6% appearing 'relatively fresh' and 17.1% 'very abraded'. Patination and staining follow similar patterns to one another, with the majority of flakes unpatinated (73%) and unstained (81%) (Table 18).

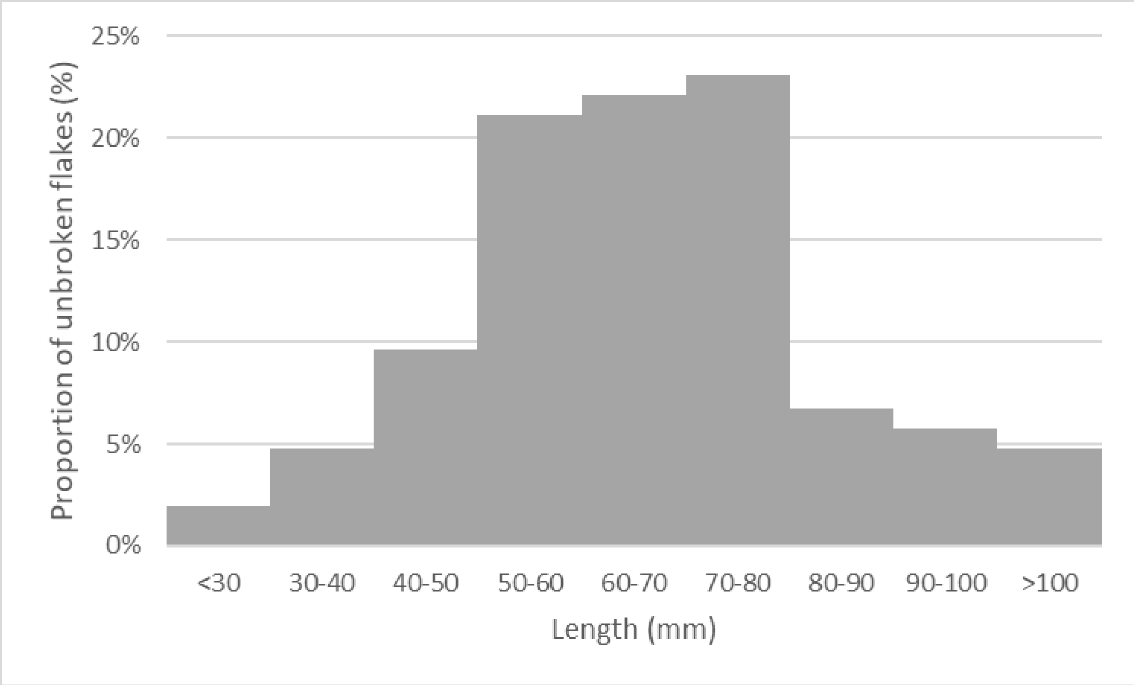

Figure 47 Lengths of non-Levallois flakes

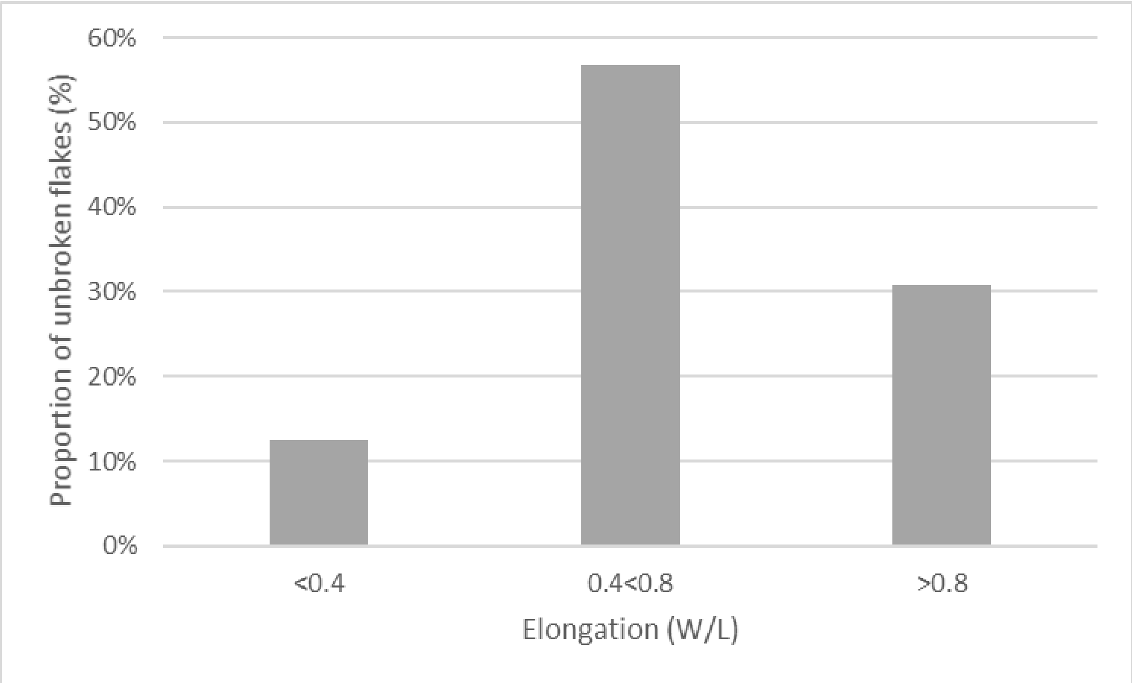

Figure 48 Proportions of flakes in each elongation class

Given that flakes are found ubiquitously throughout the Pleistocene record and, when not part of a clear assemblage, can be difficult to assign to any particular period, looking at the characteristics of each collection of flakes by condition may provide clues to their taphonomic (and potentially archaeological) histories.

As with the Levallois products, increasing proportions of staining is seen with increasing abrasion, but within each condition category the majority remain unstained. This pattern holds for patination, but the changes are more marked, implying that the chemical alteration of the surface may in some way correlate with taphonomic history. However, the reasons for and implications of this are poorly understood for flint artefacts.

Assessing the size classes by length within condition groups does not appear to give any indication of difference (Figure 49). Each group has a similar spread around the mean, with groups of larger sample sizes having correspondingly more outliers. The only place where any discernible difference is seen in relation to condition is in the dorsal scar counts and butt types of these condition groups.

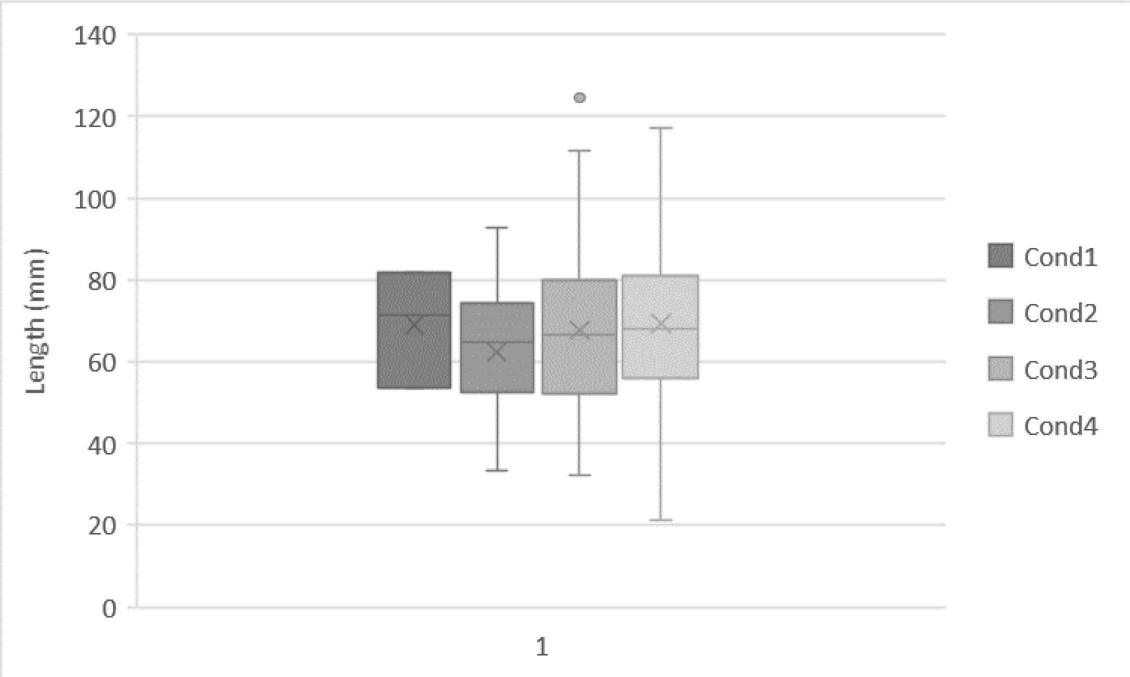

*Figure 49 Box plot of length distribution by condition class. Outliers are defined as values that fall below Q1–1.5*Inter Quartile Range (IQR) or above Q3+1.5*IQR. For boxplots, the highest and lowest occurring value within this limit are indicated by whiskers of the box and outliers are illustrated as individual points. Median values are shown by the solid line.*

Although these do not show any stark difference, there is a slight indication that the most heavily abraded flakes exhibit fewer dorsal scar removals (Figure 50). A small increase in the numbers of these flakes with increased cortex on their dorsal side potentially indicates that these represent an earlier phase of core reduction, but their dorsal scar patterning gives no indication that the method of reduction is significantly different from the fresher component (Figure 51). Where butt type is concerned, there is some indication that the more abraded flakes are dominated by 'plain' butts, while the fresher components are dominated by 'facetted' butts (Figure 52).

As a whole, the flakes show small numbers of previous scar removals, with a peak at 6–8 scars and a scar index of 45.5 (Table 19); few flakes show >9 removals (Figure 53). Similarly, the dorsal scar pattern is dominated by removals from only the proximal end (39.3%) and 'proximal plus one lateral side' (20.6%), with a distal scar index of 32.7 (Figure 54). Only 5.1% show evidence of retouch, of which (CLA417) also has the highest numbers of scar removals (n=25) (mainly due to extensive working at the proximal end), which dramatically skews the overall distribution.

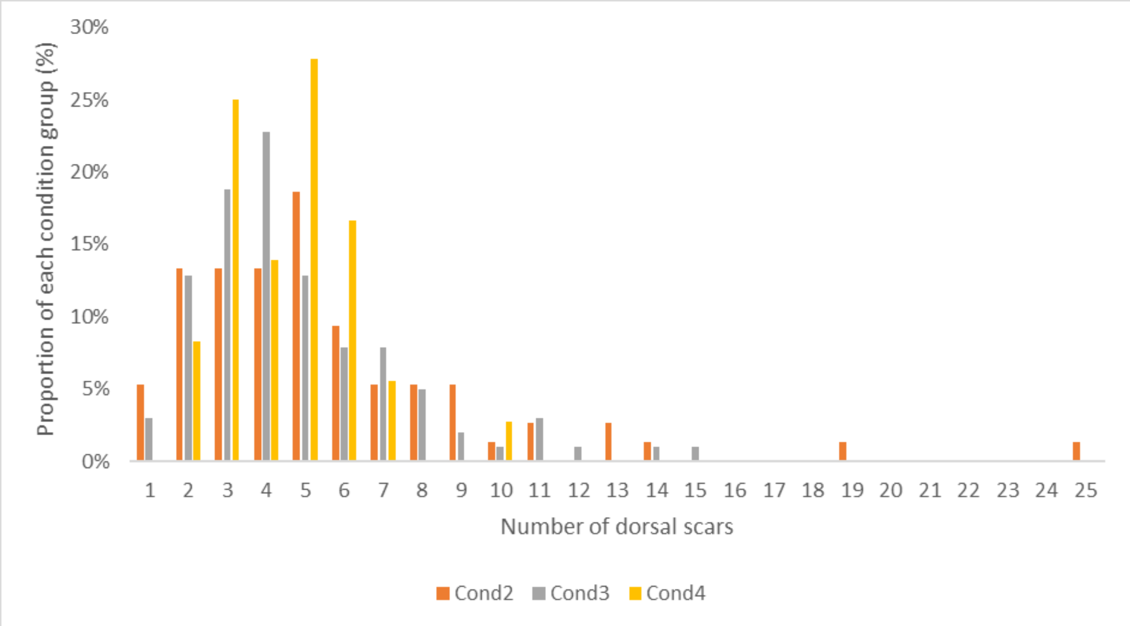

Figure 50 Dorsal scar counts in relation to condition

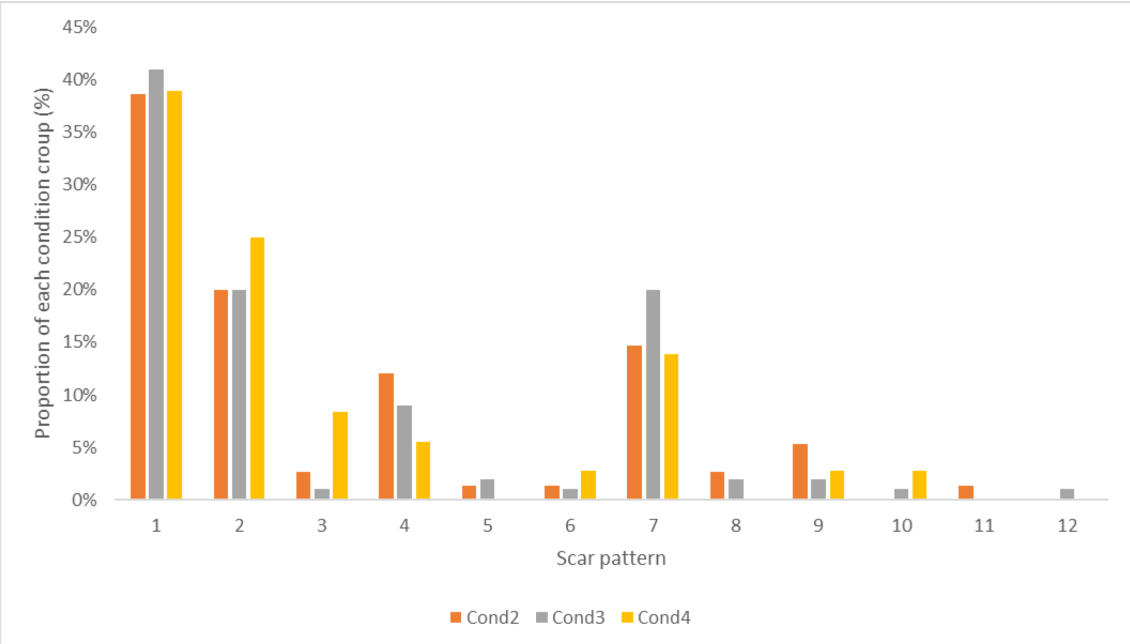

Figure 51 Scar pattern in relation to condition

Including information from the lack of cortex remaining on the flakes (Figure 55), with the majority having 0–<26%, indicates that whilst these flakes do not show a huge amount of reduction in terms of previous removals, they are not representative of the very earliest stages of core reduction.

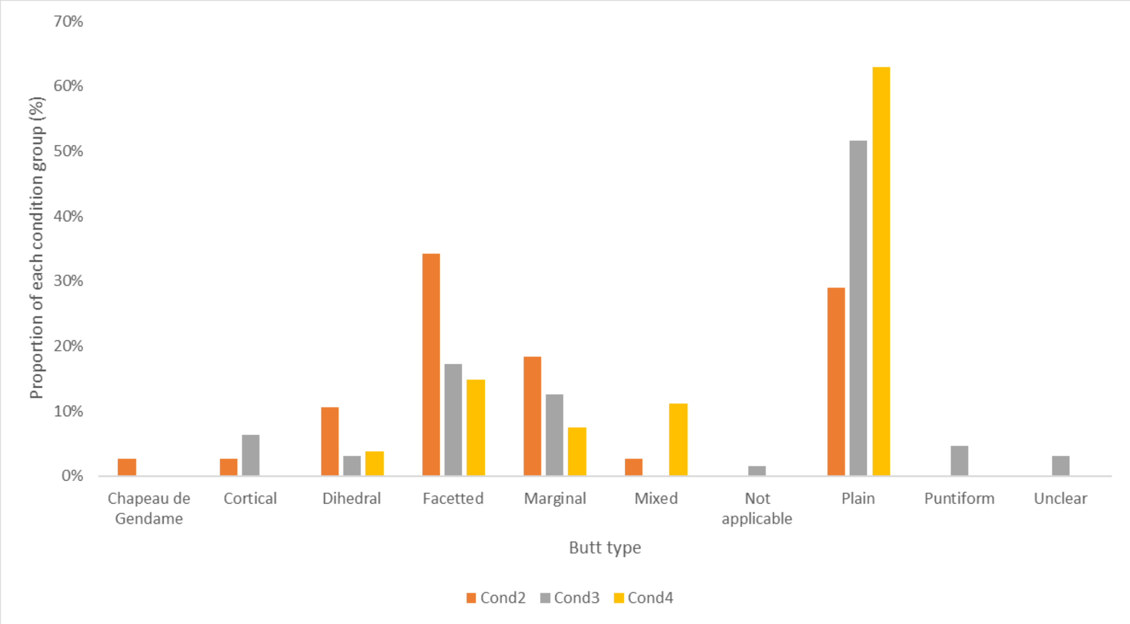

Figure 52 Butt type by condition

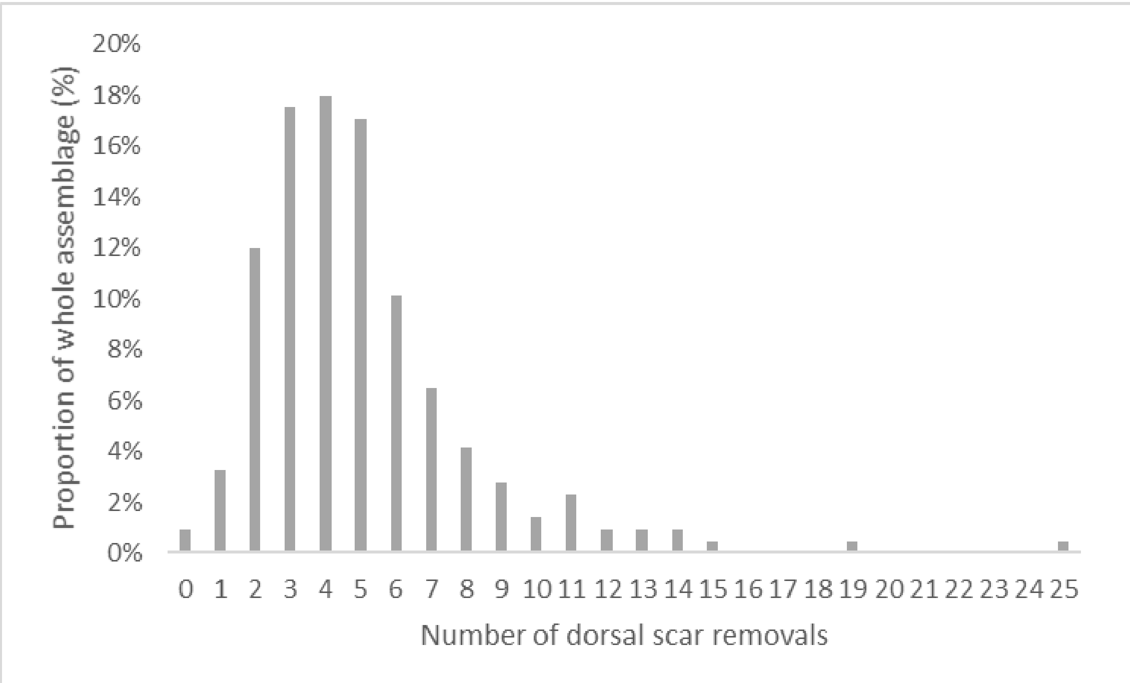

Figure 53 Dorsal scar removals on non-Levallois flakes

The relatively small sizes of the flakes is reflected by the correspondingly small cores, but contrasting with this is the proportion of cortex on each. Figure 55 shows that while flakes exhibit predominantly no cortex, only a small numbers of cores fit into this category. However, given the migrating nature of core reduction (33.3%) and the ad hoc areas of removals seen on other cores, it is perfectly feasible that while portions of cores were being reduced, and producing cortex-less flakes, other areas of the core remained relatively cortical and unexploited.

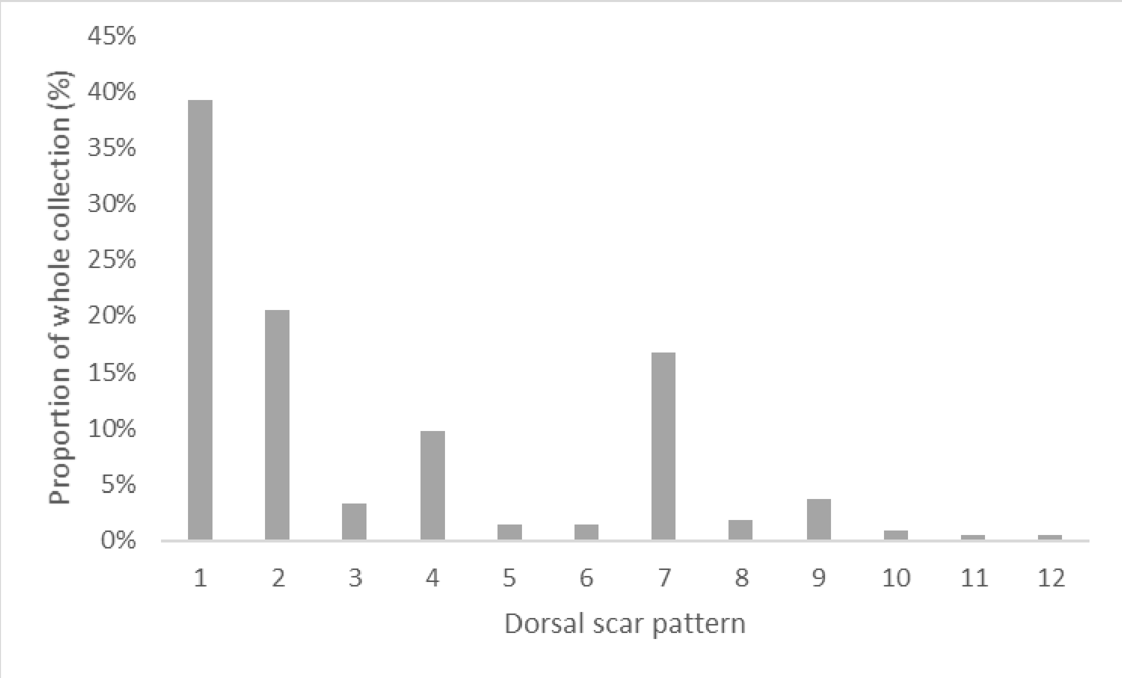

Figure 54 Dorsal scar pattern on non-Levallois flakes

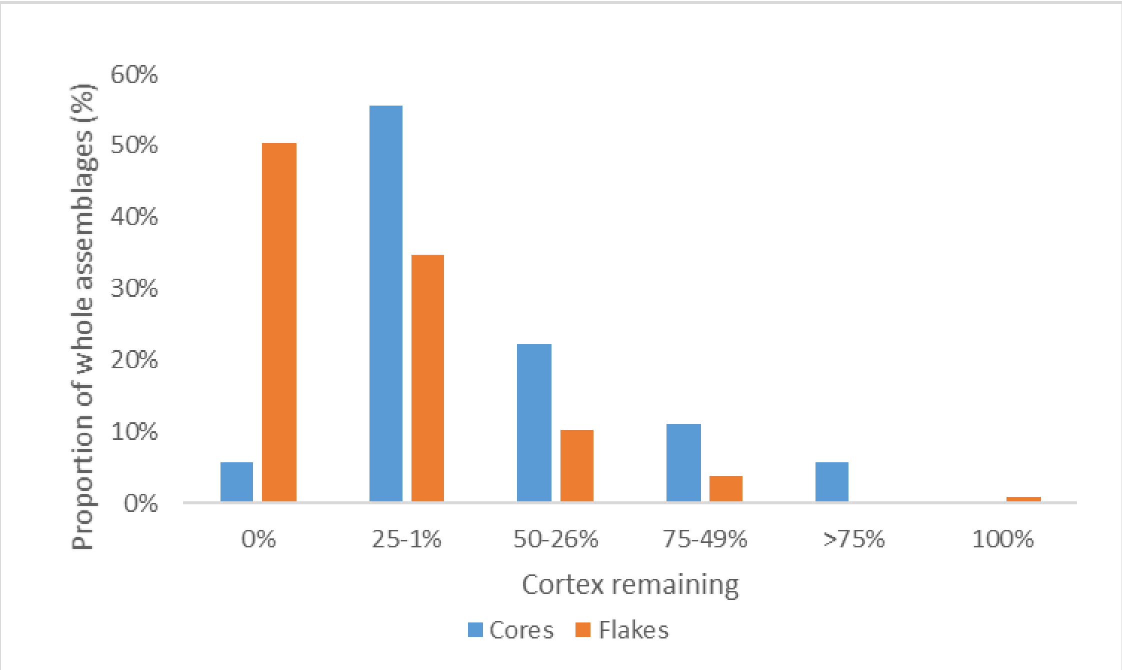

Figure 55 Cortex on non-Levallois flakes and cores

One key aspect of the flakes that is of relevance to discerning any potential relationship, or not, with the Levallois collection, is the butt type. This collection has quite high proportions of facetted butts for a standard core and flake assemblage (Figure 56). Faceting in this sense generally indicates preparation of the core for flake removal, which is something unexpected at these proportions in a core and flake industry. The inclusion of a Chapeau de Gendarme has similar implications.

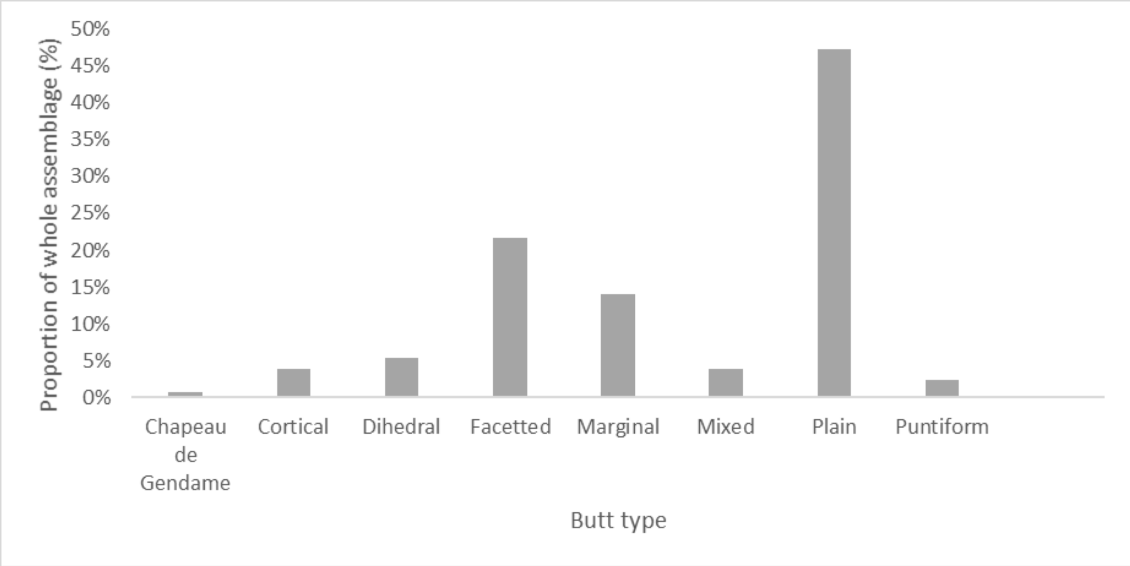

Figure 56 Butt types of non-Levallois flakes

Splitting out the dominant, contrasting butt types of 'plain' and 'facetted' shows clear similarities in the dorsal scar patterning, scar removal numbers and cortex. However, differences lie in condition and dimensions: flakes with facetted butts have lower levels of abrasion than the plain group, and they appear to be more evenly dispersed in terms of their length. Figure 57 shows that whilst the plain butted flakes have more of a 'normal' distribution, with a peak length of 70–80 mm, the facetted group have no clear dominant length class (Figure 57). When elongation is then plotted, the plain group are skewed towards being shorter and wider, whilst the facetted group are predominantly 0.4<0.8 (Figure 58). In contrast, when the facetted group are plotted against the Levallois products' elongation values, the distribution is very similar (Figure 59).

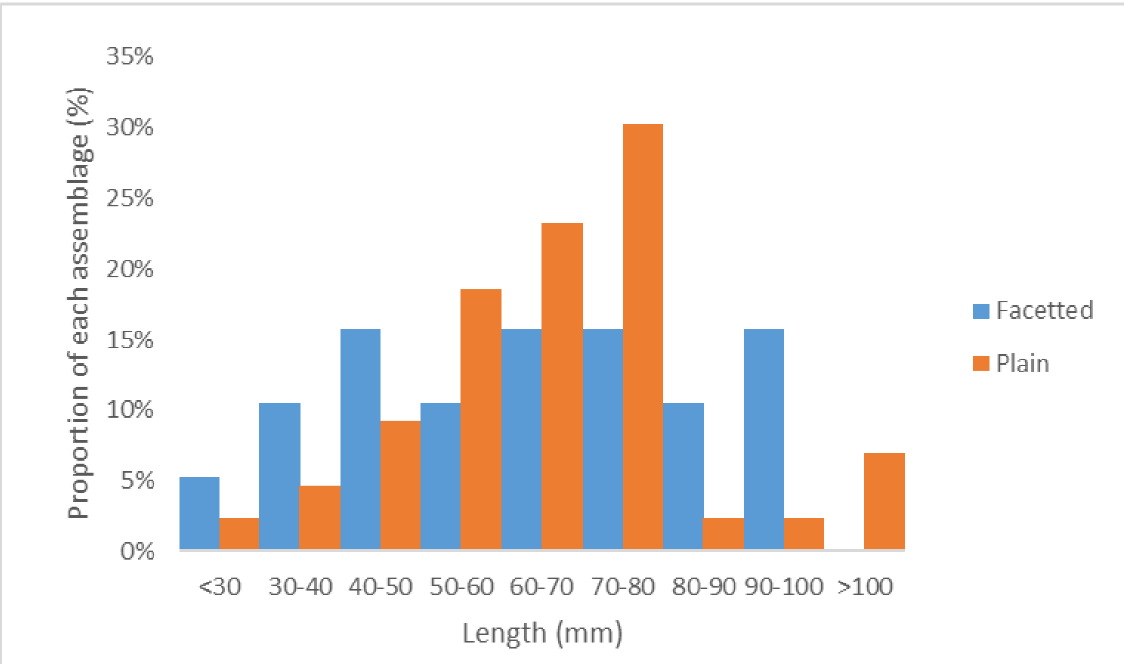

Figure 57 Lengths of flakes with plain and facetted butts

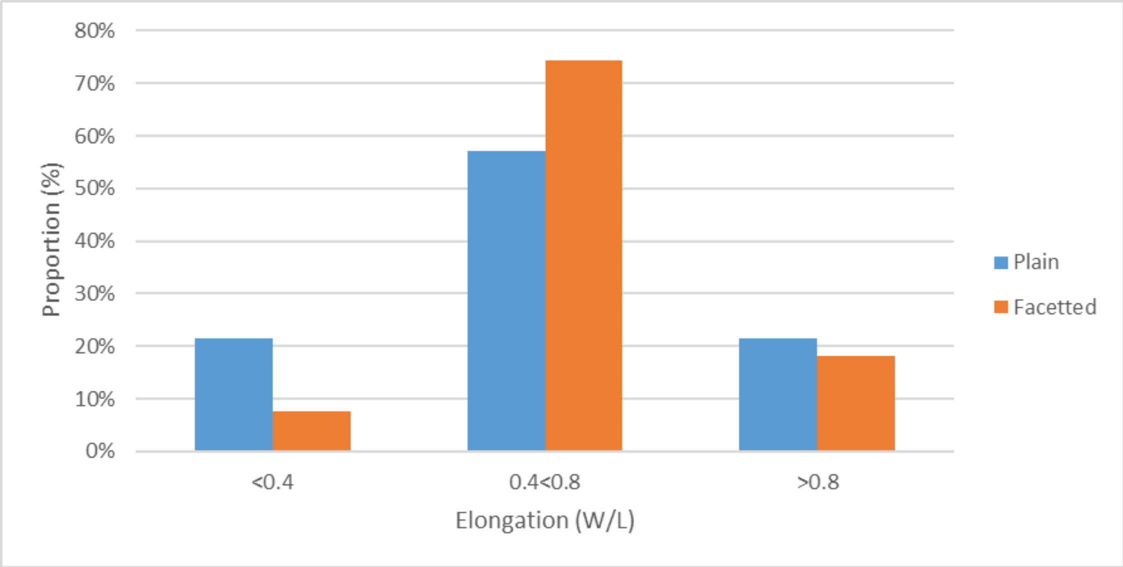

Figure 58 Elongation classes of Levallois flakes with plain and facetted butts

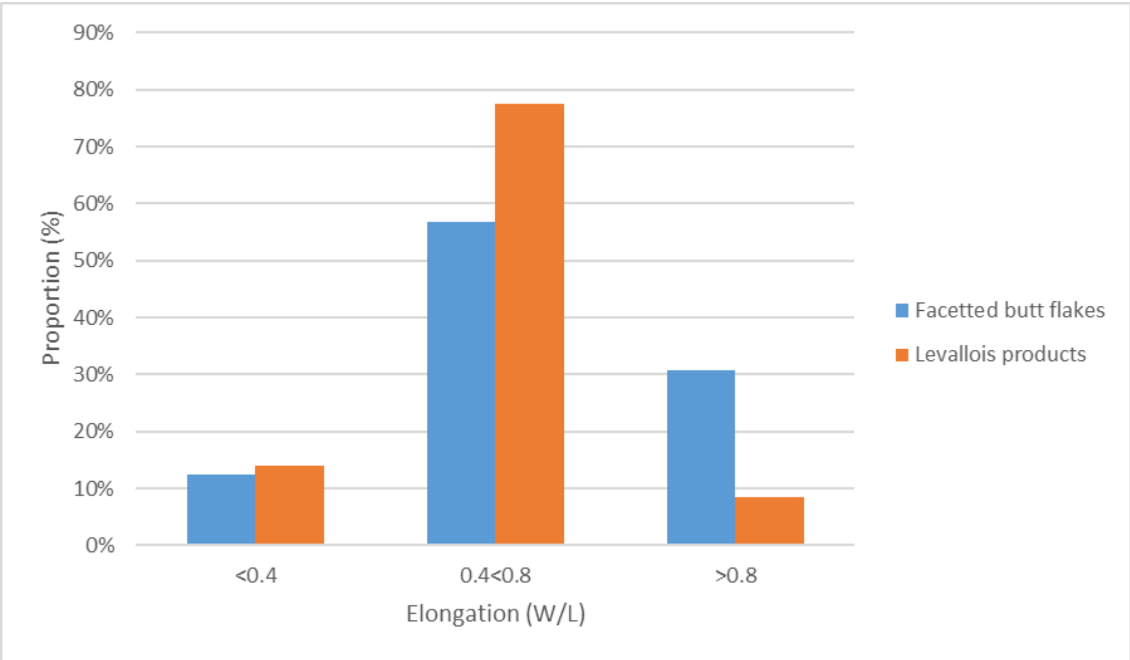

Figure 59 Elongation values of non-Levallois flakes with facetted butts and Levallois products as a whole

Assignation of a flake as being part of a Levallois reduction sequence is difficult when working with out-of-context assemblages, as without direct association many of the flakes produced throughout the process have the potential to look like standard flakes. As such, it is likely that some proportion of the flakes identified here — particularly those exhibiting prepared butts — are in fact part of the Levallois collection. With small sample sizes and a derived collection, however, this assertion is necessarily cautious.

Non-Levallois Cores

The non-Levallois core collection (Figure 60) is comparable in size to that of the Levallois cores, with a sample size of 18. These are small in size, ranging from 56.2 mm to

117.3 mm and with mean value of 76.9 mm and a median of 70.3 mm (Figure 61, Table 22). The condition of the cores shows almost equal proportions of 'relatively fresh' and 'moderately abraded' (50% and 44.4% respectively), with a single core 'very abraded'. As with the rest of the collection, the cores are predominantly unstained and unpatinated (Table 18).

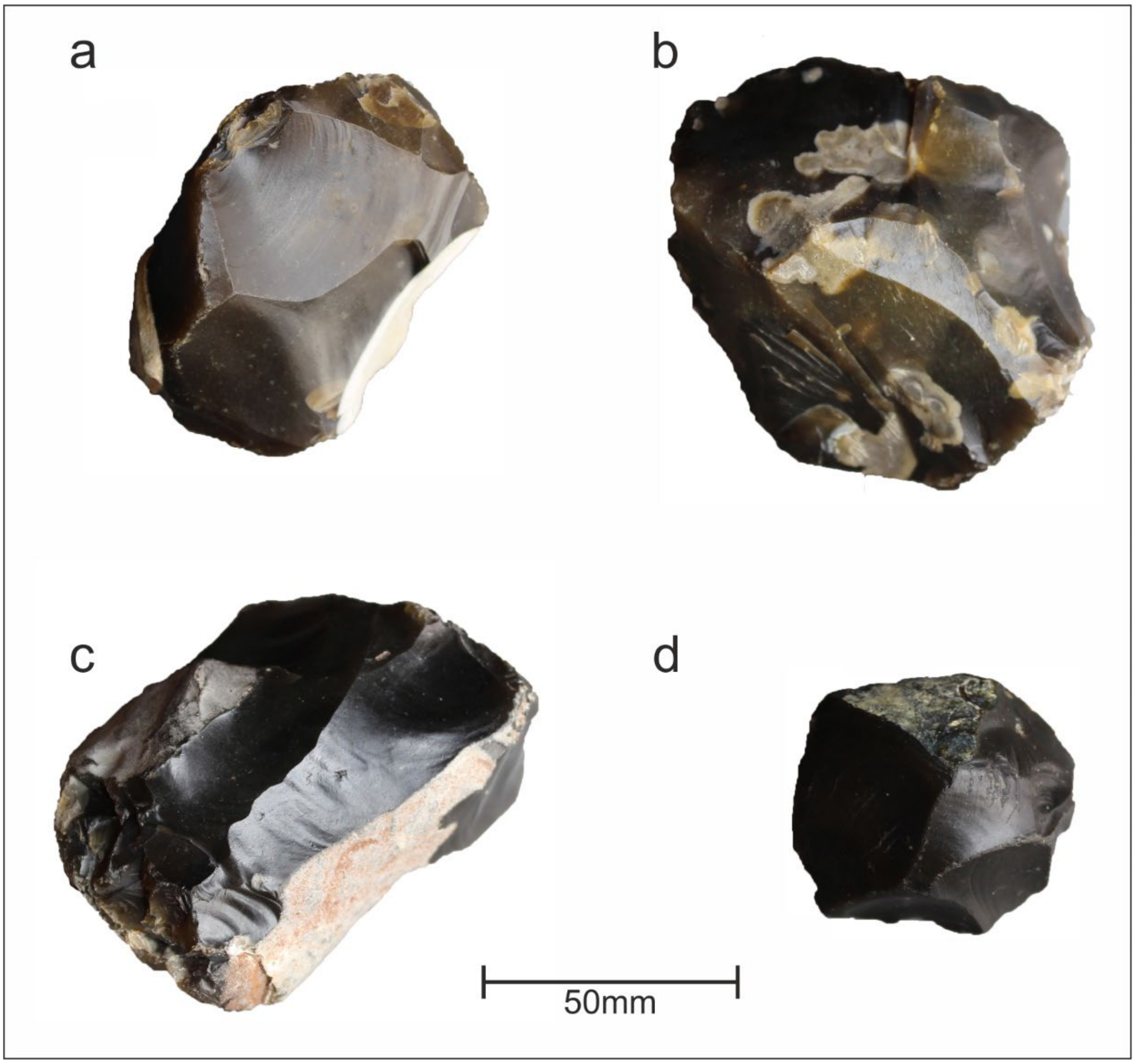

Figure 60 A selection of non-Levallois cores

The cores have an average elongation of 0.88 and flattening of 0.58, showing that they are relatively round in plan form and exhibit less flattening than the Levallois cores (Table 22). The method in which these cores have been reduced explains this shape difference, with the majority of cores exhibiting a migrating platform with no focused reduction of a particular surface. This is further reflected by the numbers of scars, which are skewed towards the lower end of the scale with the majority of cores having less than 15 removals (Figure 62, Table 22).

As discussed above, and shown in Figure 55, the cores have more remaining cortex than the flakes within this collection, but this is likely to be a result of the ad hoc nature of reduction.

Non-Levallois cores (n=18)	
Core type	
Discoidal/roughout	5.6%
Migrating platform	50%
Simple	16.7%
Indeterminate	27.8%
Length	76.9 mm
Width	67.4 mm
Thickness	37.4 mm
Weight	232.8 g
Elongation (W/L)	0.88
Flattening (Th/W)	0.58
Cortex	
100%	0%
99-76%	5.6%
75-51%	11.1%
50-26%	22.2%
25-1%	55.6%
0%	5.6%
No. scars	
<10	33.3%
10-15	38.9%
16-20	5.6%
21-25	16.7%
>25	5.6%

Table 22 Non-Levallois cores

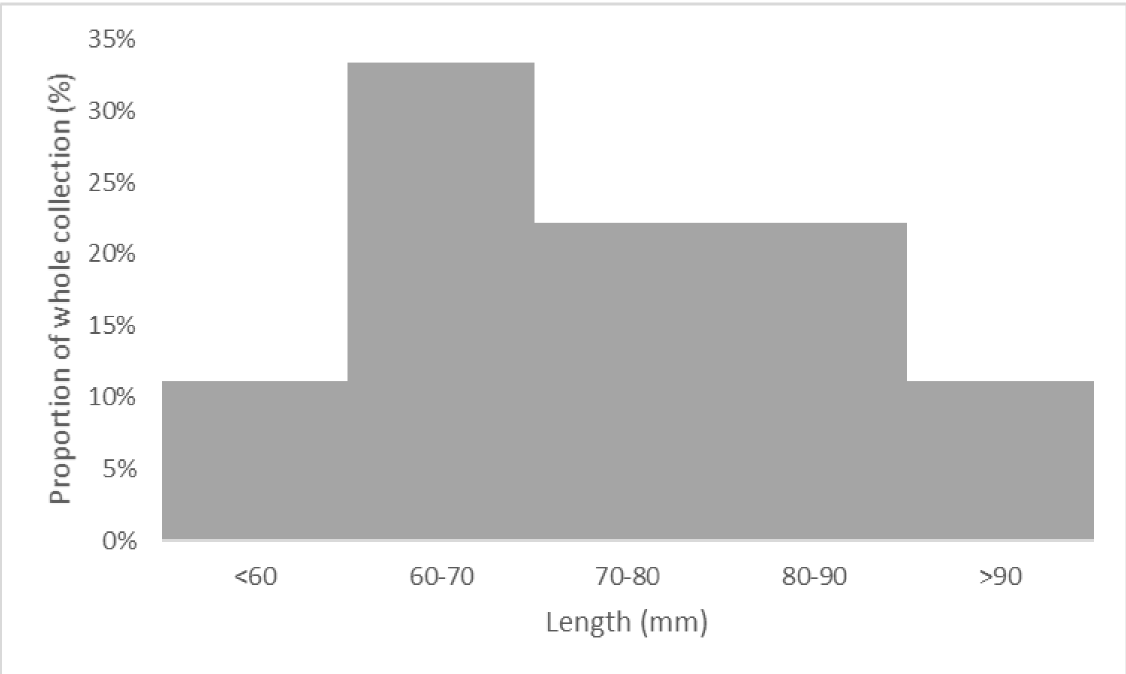

Figure 61 Non-Levallois core length distribution

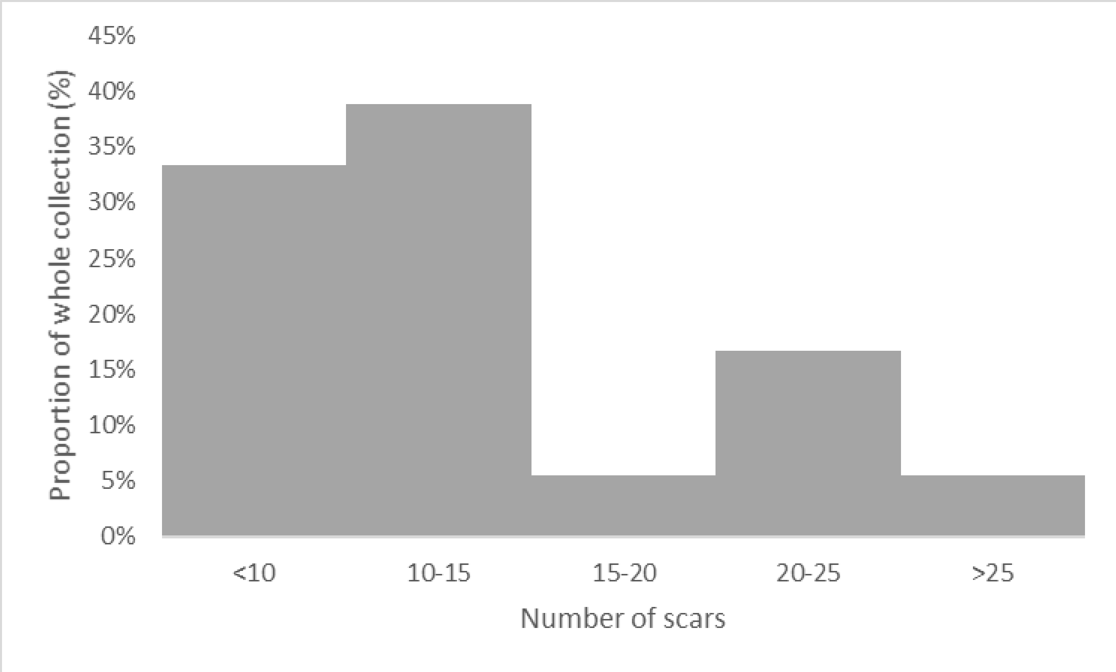

Figure 62 Scar counts on non-Levallois cores

Handaxes

There is a small sample of 22 handaxes (Figure 63) from this beach assemblage, all of which were recorded for this analysis. Of these, the majority (61.5%) are broken and two are bifacially worked pieces. There appears to be a bi-modal distribution, with two dominant classes of handaxe size (Figure 64). This does not appear to relate to broken pieces as there are several small, complete handaxes and larger broken pieces; splitting out the unbroken collection shows the same pattern. Furthermore, a Runs test at the 0.05 level shows no significant difference between the lengths of the unbroken and broken components.

Overall, the condition of the handaxes is variable and they appear more abraded than the Levallois material, but similar to the flakes: the majority are 'very abraded' (43%), 33% are 'abraded' and 24% are 'fresh' (Figure 65, Table 18). Conversely, the majority are unpatinated (76%), with only 5% very patinated. The majority (38%) are moderately stained.

The blank type of most of the handaxes is unclear (71%), with 19% and 10% on cobbles and flakes respectively. The majority of the handaxes are Wymer type F (31.8%), which is a pointed type, but with 18.2% being type D ('large, irregular') and smaller proportions of E, 'small, irregular' (9.1%), and 9.1% sub-cordate 'G'. 22.7% are indeterminate and 9.1% are bifacial pieces. There is some indication that the bifacial pieces and sub-cordate handaxes are less abraded than the pointed and irregular handaxes, with the latter group all abraded or very abraded compared with the former that are 75% fresh.

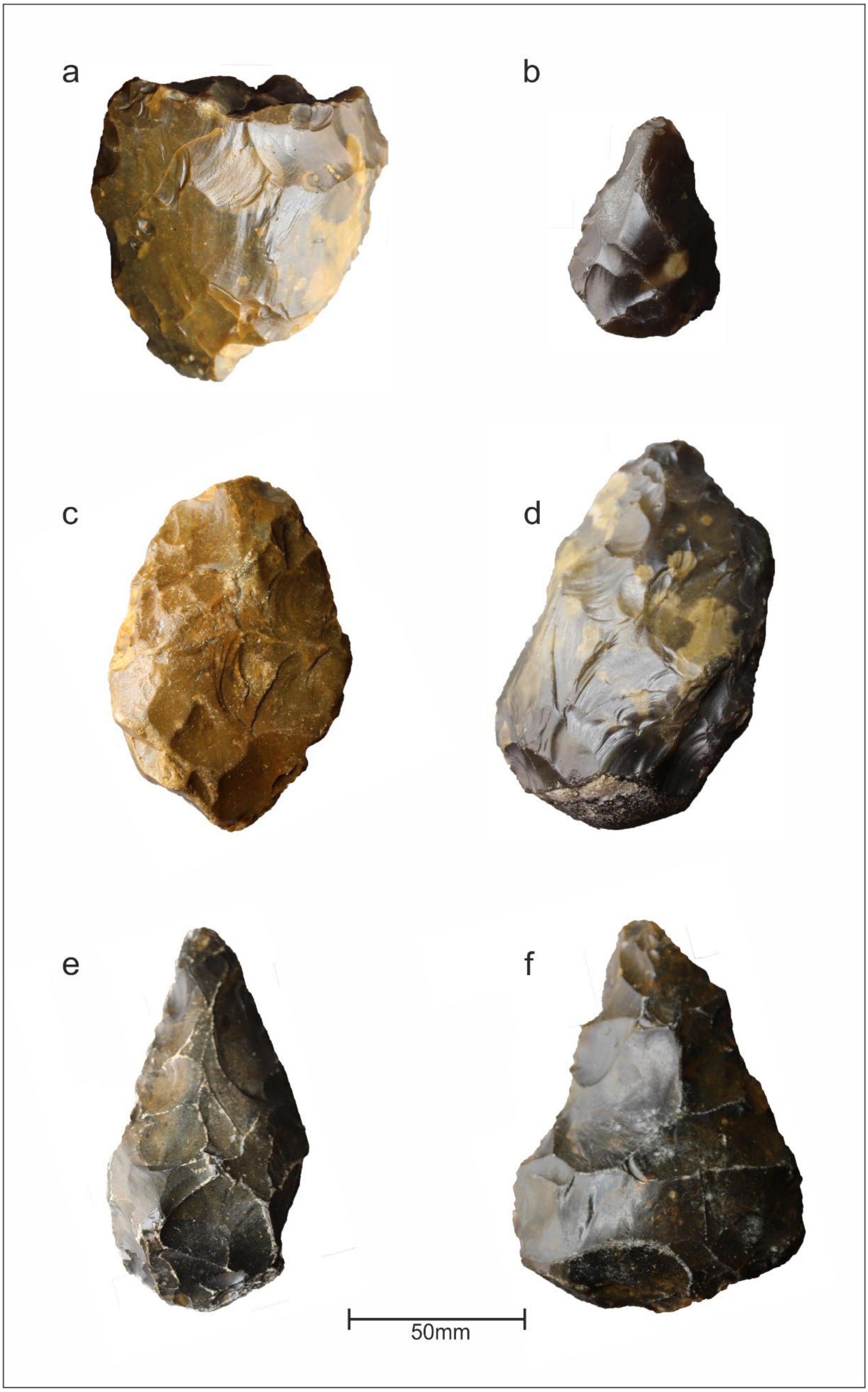

Figure 63 A selection of handaxes: a) sub-cordate, b) unifacial, irregular, c-d) irregular, e-f) pointed

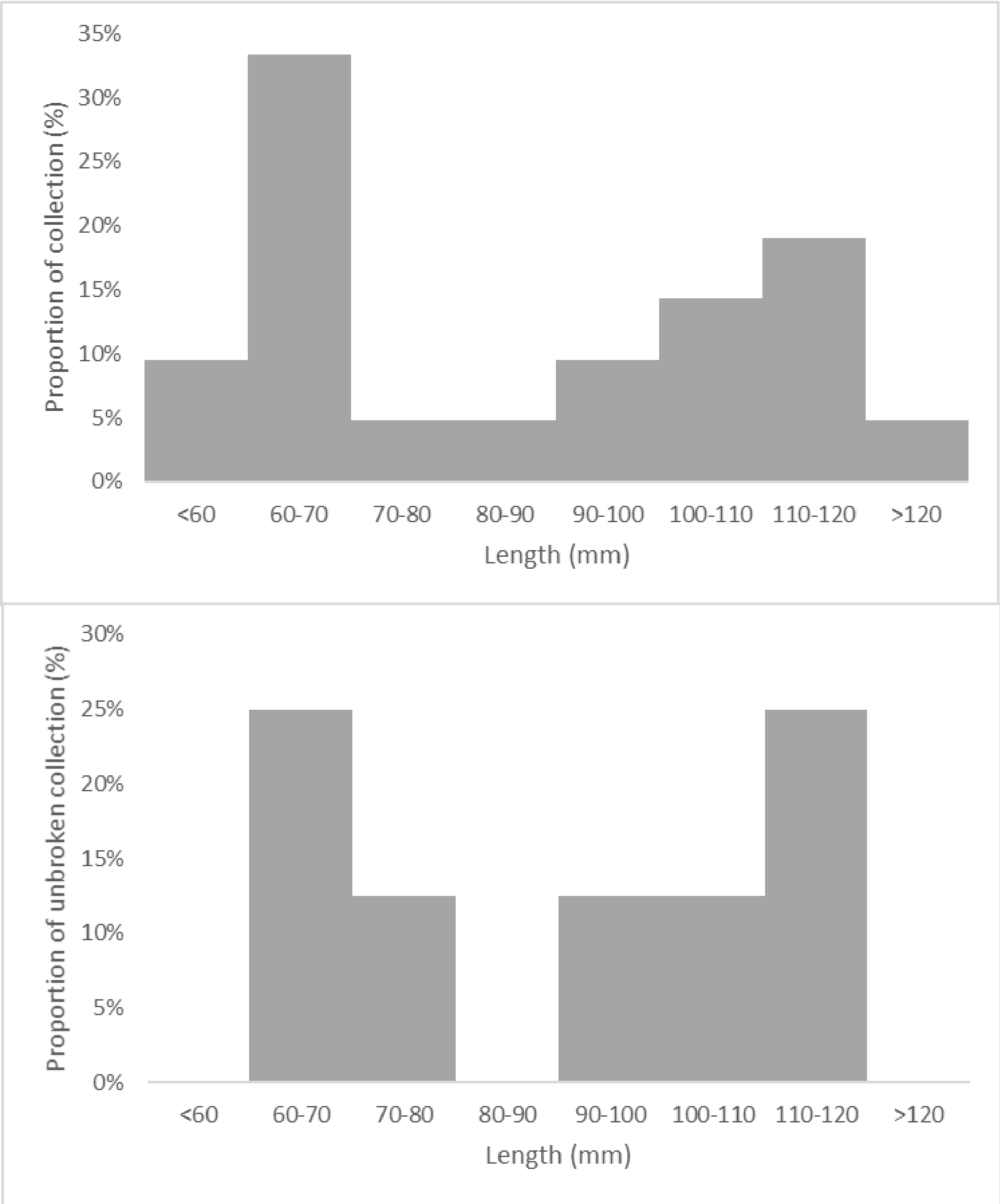

Figure 64 Bimodal distribution of handaxes, with top image showing whole collection and bottom image showing unbroken collection

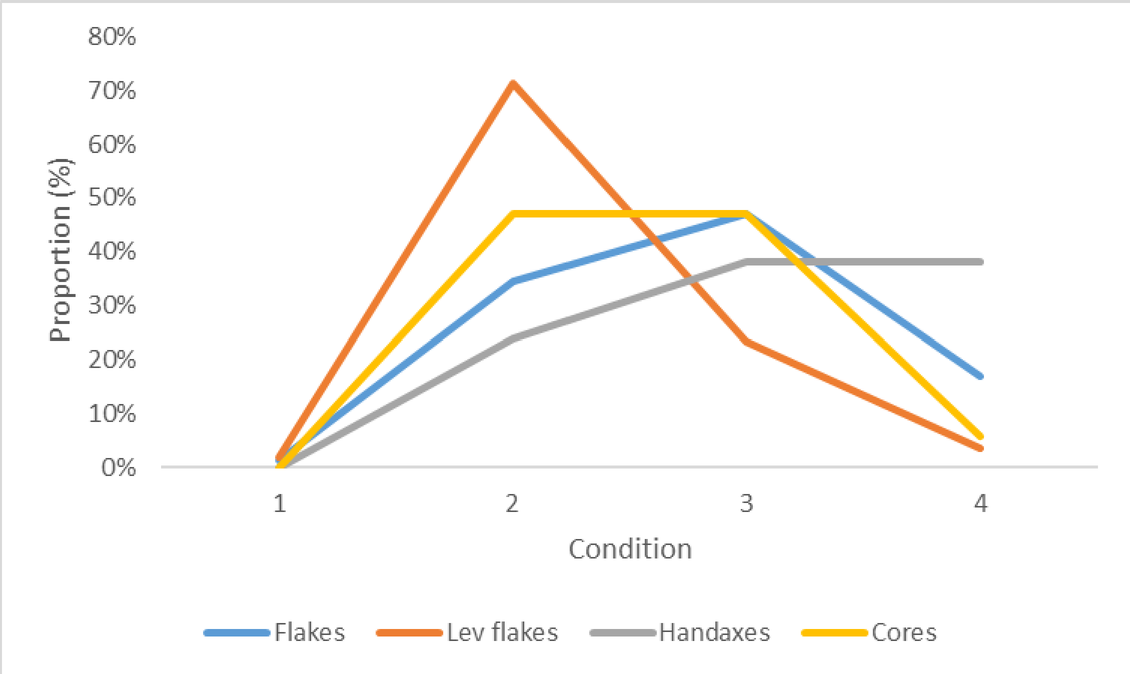

Figure 65 Condition of each typological category

4.3.3 Discussion

Making the assumption that the material described above has all undergone dredging and subsequent redistribution onto the beach, as well as any post-(re)depositional changes resulting from general coastal processes, it is unsurprising that edge damage is a feature of the entire collection. Working from this starting point, we can then assume that any other differences in condition relate to the conditions of the artefacts when on the seabed. From this, there appears to be a mixture of at least two (but very likely more) main groupings: the Levallois flakes and cores, which on typological and condition grounds appear cohesive, and the cores, flakes and handaxes. As stated above, it is likely that a component of the flakes recorded here with prepared (facetted and Chapeau de Gendarme) butts are associated with the Levallois assemblage. There is a very tentative further indication that the bifacially worked pieces, as well as the sub-cordate group of handaxes, could be part of this group, but at present this is based solely on condition.

These assertions are supported statistically, where a KS test on condition of Levallois flakes compared with non-Levallois flake returns a threshold (D_{max}) of 0.37 against a calculated value (D_{calc}) of 0.16 (significance level = 0.05). Significant differences are also seen when looking at proportion of cortex, but not patination or staining. Comparison of the condition of Levallois cores against non-Levallois also returns a significant difference. Interestingly, significance is also seen when comparing the conditions of the Levallois products vs Levallois cores, with the main area of difference being the higher proportion of fresh flakes. It is unclear whether this suggests that there is more to this picture than currently being picked out, or whether this relates instead to the different effects of burial environment on the larger, heavier cores from both assemblages. Sample size is also a complicating factor, with less than ideal samples of non-Levallois cores.

As a result, while it is possible that splitting these typologies out on the grounds of condition may be masking a more complex technological repertoire at Area 447, it appears likely — particularly given the complex nature of the deposits in the area that saw intense dredging — that we are seeing several lithic assemblages, the Levallois assemblage being the most prolific and from an environment conducive to lower levels of abrasion. This supports interpretations put forward in previous sections that the deposits sampled in VC23 are the most likely source of these artefacts.

Issues with the collection

This collection comes from beach replenishment and has come to light as a result of local collectors walking the beach and recovering what they find. As a result, there are some clear caveats to making interpretations on the basis of this collection. First, the stone tools are without context. This does not translate into a lack of value, but, despite good indications that they derive from environments outlined in Section 3, does complicate the picture: are all the Levallois pieces contemporary? How much of the assemblage is missing? A second complicating factor is collection bias: smaller debitage is easier to miss, cores are heavy to carry, more abraded pieces are arguably less attractive, cortical pieces are harder to recognise, handaxes and retouched pieces are often prized finds. While this makes numbers of at least handaxes likely to be a good, representative sample, it limits what we can say about the entire reduction process. The answers to these types of questions unfortunately cannot be known, but we can mitigate this somewhat through taking a parsimonious approach to our interpretations and using the findings here to inform future work.

Wider archaeological implications

The adoption and widespread use of Levallois is a feature of the Early Middle Palaeolithic across Europe, but particularly from MIS 7 when a rapid increase in the numbers of sites (relative to MIS 9/8) can be seen (Herisson et al. 2016). A drop in evidence can be argued moving into the glacial of MIS 6, particularly for northern regions such as Britain, but evidence from La Cotte de St Brelade and Biache St Vaast indicates that total depopulation of these northerly latitudes, at least in the early stages, did not occur.

While use of Levallois predominates during the Early Middle Palaeolithic in Britain, handaxes are not absent, but continue to be present in generally smaller numbers at a few sites. These appear towards the west of the country (Pontnewydd [Aldhouse-Green et al. 2012], Harnham [Bates et al. 2014], Cuxton [Scott 2011]), but with such small sample sizes the implications of this are tenuous. Indeed, these indications are now complicated by the east-coast discoveries of both Area 240 and the recent collections at Walcott, both of which contain Middle Palaeolithic handaxes (Tizzard et al. 2014 and personal observation), with OSL dating placing Area 240 in MIS 7/6 (Marshall forthcoming). While the collection from Area 447 does contain handaxes, their more abraded condition makes it unlikely that they are contemporary with (or from the same context as) the Levallois component, and their dominant typologies (pointed/irregular) give an impression that these are Acheulean and potentially unrelated to the EMP cordates found at Area 240 (De Loecker 2010).

Subsequent re-occupation of Britain appears to have occurred from c. 60 ka with evidence coming from the site of Lynford Quarry, Suffolk (Boismier et al. 2012), although with earlier, more ephemeral indications from the site of Dartford within MIS 5d (Wenban-Smith et al. 2010). This reoccupation during the Late Middle Palaeolithic is characterised not by Levallois technology, but by an apparent move towards the

Mousterian of Acheulean Tradition (MTA: as the name implies, a resurgence of handaxe manufacture supplemented by Mousterian tool forms).

The Early Middle Palaeolithic in Britain

Several sites attest to occupation of Britain from late MIS 8, through MIS 7, which saw fluctuation between warm and cool phases (Schreve 2001; White et al. 2006; Scott 2011) and into the cooling limb of the interglacial, seen for example at Jordan's Pit, Brundon (Schreve 1997; White et al. 2006). These sites are dominated by Levallois artefacts but, as described above, are not devoid of handaxes, with Pontnewydd (Aldhouse-Green et al. 2012) as well as the east-coast site of Area 240 showing a mixture of Levallois with handaxes. The co-occurrence of different styles of Levallois reduction—unipolar, bipolar, centripital—indicates that these methods were often interchangeable; the potential switch from bipolar at the earliest stages of reduction to centripetal once cores were of a more manageable size being hypothesised for the site of Baker's Hole, Northfleet (Scott 2011: 92). The Levallois assemblage from Area 447 potentially demonstrates these shifts, with bipolar reduction dominating but tentative indications that this shifted to unipolar and centripetal as cores reduced in size.

Whilst Levallois technology is generally regarded as a curated and mobile technology, raw material availability within a hominin landscape has long been invoked as a factor in the degree of intensive curation and re-shaping of stone tools. There are indications of this in the EMP British (and European) record, where sites in close proximity to raw material sources have larger, less intensively worked assemblages than those further away; raw material sources here being chalk outcrops or availability within gravel deposits (e.g. Purfleet, Northfleet, Ebbsfleet, Crayford [White et al. 2006; Scott 2011]. Collection intensity and visibility related to aggregate extraction may be one way to explain this pattern (e.g. Ashton and Lewis 2002), but with indications that a structured use of landscape is present within the Lower Palaeolithic (e.g. Pope and Roberts 2005), is it difficult to imagine that the patterning we see is a true reflection of Neanderthal spatial and technological organisation – indeed one that appears far more complex than simple proximity to raw material sources? Recent work at La Cotte De St Brelade offers further insights here, with Neanderthals rapidly and effectively re-occupying the area when preferable conditions prevailed (Scott and Shaw 2017; Bates et al. 2022); an intensification of, and flexibility in, the structured use of landscape (Kolen et al. 1999; White et al. 2006; Turq et al. 2013).

Although the use of a probably mixed and out-of-context assemblage makes any in-depth behavioural interpretations problematic, the necessarily more simplistic explanations of landscape use could go some way to explaining the large assemblage recovered from Area 447 in what appears to be a low-energy, channel edge/floodplain deposit in proximity to freshwater and coastal resources, presumably with access to river-derived flint clasts. The palaeoenvironmental evidence indicates that the deposits here were laid down in the cooling limb of the interglacial, declining soil development and increased fluvial activity therefore potentially making raw material easier to access. This could be thought of as an area of landscape that provided multiple resources and where hominins would extract, work and possibly use flint tools (White et al. 2006). The apparent dominance of cores with a single removal (although see Section 4.3.3 for issues with this interpretation) at Area 447, further supports this assertion; the ready availability of raw materials making excessive curation unnecessary at this location.

One final point relates to the chronology of the Levallois material from Area 447. With the luminescence dating from VC23 providing a late MIS 7/early MIS 6 date, this site potentially presents some of the latest evidence of occupation prior to the abandonment of Britain or localised extinction during MIS 6 (Wymer 1988; Ashton and Lewis 2002; Lewis et al. 2011). At what point within this period of time the occupation took place is difficult to say when working from an ex-situ assemblage. However, we can assume occupation at this elevation would only be possible when sea levels were lower, ruling out mid-interglacial periods with highstands and pointing towards cooler periods. This assertion is supported by the palaeoenvironmental and dating evidence from VC23, indicating the cooling limb of MIS 7 into MIS 6.

Some things to think about as we move forward with submerged landscape research are whether these lower-lying fluvial landscapes preserved in the North Sea are more heavily exploited at this date, whether due to dispersal patterns or resource availability, or if this is simply to do with visibility provided by these beach replenishment schemes – large areas of dredging leading to an increased incidence of finds. This is where comparisons with the evidence from Area 240 and the Walcott replenishment come into play: whilst these assemblages have different stone tool signatures to Area 447, being characterised by Middle Palaeolithic handaxes as well as Levallois reduction (not necessarily contemporaneously), they all provide us with evidence for occupation of these now-submerged landscapes at an apparently similar period in time (Area 240 at MIS 7/6 [Marshall forthcoming], although Walcott is currently undated), something we could only previously hypothesise about. The large size of these assemblages (Tizzard et al. 2014; Davis et al. forthcoming) is likely the result of both intensive hominin use (either as a single event or repeated activity) and visibility afforded by the terrestrial emplacement of aggregate in an area of public access.

4.3.4 Conclusions

The stone tools reported here have a significant Levallois flake and core component, which, although potentially related to some of the undiagnostic flake tools, appears distinct from the more heavily abraded handaxe, core and flake components. There is some indication from cortex recording that the Levallois component represents reduction after the primary exploitation of the cores, potentially indicating that either this has not been recovered, or that these cores have been moved to this area after an initial exploitation elsewhere in the landscape. Given the indications that these environments are in close proximity to channels, providing possible sources of raw materials, as well as the large size of the collection, it is likely that the cores seen here (and others that the products relate to) have not been moved a huge distance. The further lack of intensive reduction also may relate to this location within the landscape, with ready availability of raw materials in the vicinity.

The date of late MIS 7/early MIS 6 on VC23, correlating with the most intensive area of dredging and a low-energy environment, provides a good indication of the likely date range for this assemblage.

5 DISCUSSION

5.1 Archaeological context

Submerged archaeology in the North Sea belongs, on current evidence (e.g. Parfitt et al. 2010), to approximately the past million years, with archaeological signatures relating to a range of hominin species whose use of these previously terrestrial landscapes remains frustratingly obscure. Given the potential time-depth of archaeological deposits, and the variety of post-depositional processes that have impacted them, they are likely to be fragmented and, therefore, extremely difficult to target. As such, commercial developers working within the area may provide an effective means by which to better understand these submerged landscapes through the extensive marine geophysical datasets that they create, and access to the deposits themselves, providing potential windows into landscapes and behaviours that are poorly understood.

Recognising and reacting to areas of exploited seabed that have a high archaeological potential is a crucial part of this process, but the ways in which we do this are, in practice, problematic. This is not necessarily a criticism of current methods, but reflects the difficulties in resolving areas of assumed high potential with how we then evidence that and the need to constantly readdress and develop these methodological approaches. Previous attempts to map out archaeological potential on the seabed have resulted in unworkably large zones that, given the absence of actual finds, lack the nuance needed to take this any further (e.g. Goodwyn et al. 2010) and can be so broad in their definitions or coverage that they become meaningless. Conversely, watching briefs (operational sampling exercises) that only exist around serendipitous locations where archaeology has been found (e.g. Tizzard et al. 2014; Wessex Archaeology 2015), are helpful, but if only carried out in discrete areas serve to create and reinforce a biased picture. The large numbers of Middle Palaeolithic artefacts from the 2019 beach replenishment at Walcott, taken from extraction zones within this watched area (Wessex Archaeology 2020), in turn demonstrate that whilst these operational sampling exercises are helpful for evaluating presence or absence, the knowledge gained appears, so far, to have had little impact on how the subsequent large-scale beach replenishment could be managed, or how current adopted methods can be improved.

With increasing beach replenishment schemes going ahead around the coast of the UK, we have a real opportunity to drive this understanding forward through new approaches to the investigation of the resulting archaeology. This project aims to demonstrate this potential and put forward workable methods by which to do so.
At the start of this work, the following was known:

- Large numbers of stone tools and faunal remains were deposited from Clacton-on-Sea to Holland-on-Sea as part of a beach replenishment scheme, which subsequently came to light through ties with local collectors;
- These sands were extracted from Area 447, in an area of Pleistocene fluvial activity;
- Pre- and post-dredge data was available, showing areas exploited and providing insights into the sub-seabed features in this area;

- Dredging data provides the potential to trace recovered finds back to areas of the seabed;

- Vibrocores from 2015, pre-dating dredging, had been retained by the aggregate company and were available for analysis.

The aim of this project was to gain insights into where the archaeology was coming from, allowing a retrospective analysis of the possibly primary context and setting from which the Palaeolithic beach finds had originated. Such information could then be used to construct a narrative around the Pleistocene submerged landscapes and the nature of the archaeological signature(s) they contain, and to think strategically about how archaeologists can work with industry to make best use of these situations in future. Through analysis of stone tools, geophysical data, palaeoenvironmental analysis and luminescence dating, this work has been able to demonstrate the following:

- The seismic signature of the exploited area is not associated with clear landscape features, but rather a relatively thin, remnant channelised surface; our inclination towards linking potential with palaeochannels is unhelpful – while these are ideal for the recovery of stratified palaeoenvironmental records, people did not live in rivers but would have been found along their margins and within the wider floodplain area. Further to this, these locations — outside the channels themselves — can be difficult to interpret and can result in a conglomerate deposit (e.g. Unit 3b, Area 240; Tizzard et al. 2014), making contextualising the encapsulated archaeology difficult. As such, we need to be thinking more holistically about landscape use, what we should expect and how we understand this. The recent drive towards regional studies, which aims to view licence areas in their wider context, has the potential to move this in the right direction.

- The stone tools and fauna potentially relate to more than one episode of occupation, with the Levallois component forming the clearest and most cohesive dataset. Whilst Levallois assemblages are relatively poorly represented in the British record, the nature of this collection implies an Early Middle Palaeolithic age (MIS 8–MIS 7/6). This is further constrained by visual assessment of aspects of the fauna present. The more ephemeral presence of relatively abraded handaxes, cores and flakes, as well as indications that Devensian-stage *M. primigenius* are present, may indicate that fragments of both earlier and more recent deposits also exist within the dredged area.

- Geoarchaeological assessment of vibrocores collected within Area 447 showed the presence of lower energy floodplain/channel edge deposits. Given the fresh appearance of the majority of the Levallois artefacts, these deposits were considered their most likely source. One of these, VC23, had the greatest potential for analysis and was also located in an area that saw some of the highest concentrations of dredging. Despite previous splitting and a five year period of storage, palaeoenvironmental evidence was well preserved, with pollen evidence indicating deposition during a late temperate/post-temperate interglacial stage, with a pollen assemblage similar to those found onshore and associated with the Aveley interglacial (late MIS 7). Remarkably, this core was also able to be used for luminescence dating, which produced a series of coherent dates that tie the deposits into late MIS 7/early MIS 6, supporting the palaeoenvironmental interpretation for a late Aveley interglacial. Combining the luminescence dating results with palaeogeographical data including vertical crustal movements (Westaway 2009), global sea level models (e.g. Grant et al. 2014; Spratt and Lisiecki 2016; Waelbroeck et al. 2002; Bintanja et al. 2005) and ice sheet models (e.g. Choudhury et al. 2020), the context of these deposits, identified through palaeoenvironmental analysis, suggest that deposition was most likely between c. 195–185 ka, within the MIS 7a–6e interglacial to glacial transition.

- This information places the palaeoenvironmental context for the Levallois activity within a cooling climate at the end of the interglacial, with a coastal landscape within which a range of vegetation communities would be present. These included woodland, marsh, floodplain and coastal intertidal zones, providing a rich set of resources. Given the condition of these split cores after a long period of storage, this result demonstrates opportunities that may exist for future collaborative work with aggregates companies utilising geotechnical samples that have already been obtained. It also highlights the importance of obtaining and retaining such geoarchaeological material so that, if archaeology is discovered post-dredging, its context can still be investigated. Refining protocols for the collection, handling and storage of cores by aggregate companies could, in the future, further safeguard material from other licence areas, by facilitating a retrospective assessment of deposits as and when archaeology is found.

5.1.1 Implications for archaeology
The Lower Palaeolithic in Britain and north-west Europe has a long history of study, with many large, terrestrial often aggregate-derived assemblages, investigated for well over a hundred years (Harris et al. 2019). In contrast, the Early Middle Palaeolithic (MIS 8/7/early 6) has long been thought of as poorly represented and poorly understood. Various hypotheses have been put forward to account for this. Ashton and Lewis (2002) assert that these declining densities reflect a real decline in population numbers from MIS 11 until a total collapse from MIS 6–MIS 3. Contrasting responses to this argue instead that this declining picture lies more in behavioural change reflecting differing use of landscape and artefact curation/ discard (e.g. White et al. 2006; Scott 2011), a pattern seen elsewhere in the European record (White and Pettit 1995; Roebroeks et al. 1988; 1992). In addition, whilst consisting of relatively few sites, those that are known are chronologically well-constrained, providing grounds to think about how hominins at this time were structuring their landscapes and what this means in terms of behavioural trajectory (White et al. 2006).

This collection has an important place within this narrative, based on three key points:

- Given the proposed timing of occupation to late MIS 7/early MIS 6, it provides evidence for occupation at a time when there is little else, and immediately before the inevitable population crash of the MIS 6 glaciation.

- Situated in what is now the North Sea, it provides a tangible opportunity to start thinking about hominin use of these submerged landscapes and the impact that their invisibility has had on our archaeological interpretations.

- The discovery of Area 240 — dated to the same period of time (Marshall forthcoming) — and the recent, although chronologically unconstrained with no palaeoenvironmental context, finds from the beach replenishment at Walcott, help to support these interpretations and provide exciting lines of enquiry for the future.

5.2 Strategy and recommendations

Industry work is really the only way we find submerged archaeology, due to the financial cost of investigating these areas, the logistical difficulties in reaching them, and the unrivalled large datasets that industry generate with clear archaeological benefits.

Given the time-depth we are dealing with in the Pleistocene, and the fragmentary nature of the record, targeting sites is almost impossible, with current interpretations for offshore archaeology reliant on what we know of the record onshore (Bates et al. 2007). Onshore, however, the indication is that fluvial terraces and their associated floodplain deposits are highly productive archives of Palaeolithic archaeology (Wymer 1999; Tuffreau and Antoine 1995; Wenban-Smith 2002; 2013). Whilst likely to, at least in part, be a factor of hominin preference (e.g. Brown et al. 2013), this pattern is also due to enhanced preservation (Bridgland 2006) and subsequent visibility via aggregate extraction (e.g. Ashton and Lewis 2002; Harris et al. 2019).

With climate projections for increased storminess and the move towards beach replenishment as a 'soft' coastal defence management method (Newell and Woodcock 2013; also seen in The Crown Estate's annual statistics: https://www.thecrownestate.co.uk/en-gb/what-we-do/on-the-seabed/minerals-dredging/), it is likely that we will see archaeology like that reported here becoming an increasing feature of these schemes. This is due to the heightened visibility of any potential archaeological artefacts provided by their emplacement in a terrestrial setting, providing easy access for archaeologists and collectors alike. This is further boosted by the growing online communities of collectors around the country, sharing information on fossil and archaeologically-rich beaches and promoting the recording and reporting of these finds. As a result, the archaeological community, dredging industry, local councils undertaking coastal protection schemes (and all necessary stakeholders) need to work together to develop effective ways to harness this information, gaining insights into the otherwise opaque and abstract submerged Pleistocene record. Steps being taken currently, such as the guidance for a Protocol for Coastal Protection and Contract Fill projects (commissioned by BMAPA and The Crown Estate), as well as – crucially – regional palaeolandscape studies, demonstrate the prioritisation of this goal.

The work reported here was a retrospective approach to dealing with Palaeolithic archaeology only after it had been discovered and the primary context lost. Having archive material available, in the form of geophysics, geotechnical material and logistic mapping (logs of dredging activity), it has been possible to gain a lot of information about the site. However, the retention of this data is down to luck rather than careful foresight—there is no standard procedure for the archiving of core material guided by Historic England (but see Gribble and Leather 2011: 46), so their availability for this project was fortuitous and incredibly beneficial—illustrating that a proactive approach to Area 447 could have yielded much greater results and understanding. A search for relevant (regional scale) archive material should form a significant part of any future DBA or WSI.

5.2.1 Recommendations

The proposed response to this work is a three-staged approach:

Proactive

When dealing with landscapes, as opposed to discrete areas of wreckage, for example, a downfall appears to be in a lack of understanding of the potential — albeit latent — of submerged landscapes in conjunction with the difficulties of making solid proposals about what could constitute effective, proactive work. A lack of archaeological finds from other beach replenishment schemes, some of which, such as LincShore, have utilised millions of tonnes of dredged material over nearly two decades, highlights the need for proactive engagement. In these cases, we are either dealing with archaeologically sterile dredged material, often from outside the (currently) known limits of occupation, or a lack of public engagement has led to a corresponding lack of reporting. Anecdotal evidence from recharge at Southend-on-sea implies that the latter is, at least sometimes, the case.

Whilst current schemes, such as the BMAPA protocol for the reporting of archaeological finds, are clearly worthwhile, they are arguably not a proactive approach to archaeological analysis, but rather act as a safety net and identify finds generally after their primary context is disturbed or destroyed.

The approach advocated in light of this work is that, first, on all new/renewal aggregates applications (i.e. for both new and established licence areas) the continued and consistent use of regional archaeological interpretations should guide area-specific requirements for mitigation. Within this framework, putting collaborative sampling protocols in place at the start, providing the opportunity to constrain the chronology of the deposits if the need arises, is a clear route forward. Where the potential of an offshore site cannot be fully identified during the Environmental Impact Assessment, proactive investigation of vibrocores, including luminescence dating of suitable deposits, may be a necessary stipulation within a licence-conditioned WSI. Understanding the age of the deposits would permit a better establishment of archaeological potential and the development of site-specific procedures, including raising awareness of likely Palaeolithic material to be encountered or pre-defining the dredging pattern in conjunction with the licensee, and to put these in place during aggregate extraction, rather than a reliance upon the standardised BMAPA find protocol (Wessex Archaeology 2017) to capture any discoveries post-dredging.

One of the key issues that has arisen through Area 447 is the difficulty of making statements of potential about varied landscape features. The ability to compare finds coming from different palaeolandscape features (channel margins, wider floodplains etc), would not only provide clarification about where these ‘high potential’ areas are, but would be immensely helpful for understanding the context of any subsequent finds. In the day-to-day extraction of aggregates from a single dredging licence area to be processed at the wharf, a working relationship between archaeologists and dredging vessels should be considered to plan areas of extraction to facilitate this, in line with the procedures followed with the Palaeo-Yare Regional WSI method statements. With regard to beach nourishment projects, there is a need for the marine licence application and the curators commenting on them to be aware of the particular working practices required for the coastal protection project, such that any existing mitigation requirements conditioned are carried over to any new licence for the beach nourishment project, and that any vessel and plant depositing and moving such deposits can record and capture positional data in a way that also facilitates an opportunity to address a subsequent find's context. This is especially true where Marine Plan objectives and policies lack specific detail and do not interact effectively for associated coastal and offshore developments.

On a similar note, after the appearance of Palaeolithic finds in the Walcott replenishment sands from licence areas subject to operational sampling, it is clear that communication is needed between those producing EIAs for the coastlines being replenished, those producing them for the licence areas, and the subcontractors overseeing the dredging. It is unclear why this disconnect exists; it may be due to the timing with which the East Marine Plan was produced (2014), but any barrier to effective mitigation and recognition of archaeology needs to be rectified.

Ongoing

Careful monitoring of aggregates, both at wharves and deposited on beaches, is necessary for the recognition of artefacts, and this is something that does, in some cases, take place (e.g. Wessex Archaeology 2020). However, recognition of Palaeolithic stone tools can be difficult and they are not something that an untrained eye, whether or not an archaeologist, will necessarily pick out. Where monitoring is currently occurring – through operational sampling – it is recommended that this is undertaken by a Palaeolithic specialist (see Hosfield et al. 2020). It is unclear, however, how effective this process is, or whether Palaeolithic specialists are being properly involved. In the first instance, the recommendation here is that a Palaeolithic stone tool specialist is always part of this process. If this does not happen, a specialist needs to have a staged input to assess how effectively material is being identified, which then feeds back into how the screening process is run. Understanding how effective this work is, and how successfully stone tools are being identified, is crucial for the wider understanding of these submerged deposits; negative evidence is as important as presence.

Another issue that arises here is the sheer volume of aggregate being assessed during and after beach nourishment projects, and the corresponding chance of artefacts being visible on any given day. Anecdotal reports from collectors, and the lack of finds that have arisen from such walkover surveys, indicates that this will only be sustainably effective if repeated over an undefinable, but at least more substantial, period of time. As a result, there are two options. First, trained archaeologists spend more time assessing replenished beaches and/or, second, we work to engage the growing community of collectors and interested members of public within areas of beach replenishment schemes.

There is a significant, and growing, network of collectors around Britain aware of recording and reporting finds from beaches (e.g. Bynoe et al. 2021; Davis et al. forthcoming). These local communities are often supported in-person by archaeologists (e.g. CITiZAN; Bynoe et al. 2021) but are equally engaged in online forums with frequent input from specialists, including Finds Liaison Officers (FLOs) as part of the Portable Antiquities Scheme (PAS; https://finds.org.uk/). The combination of this existing engagement with the prevalence of GPS and camera-equipped mobile phones makes for a perfect solution, if we are willing and able to be proactive:

- Identify coastal locations that have planned beach replenishment;

- Prior to the replenishment, engage with the local community and local FLO about the process and what has the potential to be found, how to record and report via FLO and the PAS.

With recently surveyed, cored and dredged extraction zones, utilising high-resolution positioning technology, and engaged communities of collectors reporting accurately positioned finds soon after emplacement, we have the potential to respond far more rapidly. This increases the likelihood of linking back to precise areas of seabed and, in certain situations, gaining access to in-situ archaeology before it is disturbed. At the very least, the proactive approach outlined above would provide the context of landscape features and a route towards a chronological context.

The recent finds at Walcott are a good example of this situation, with collectors that already have good links to local museums and archaeologists working at Happisburgh. These finds were reported online within a week of the beach being re-opened and are currently under analysis (Davis et al. forthcoming). Although these instances reflect communities who are already engaged and mobilised, and this will not always be the case, the example of Clacton-on-Sea, where no previous relationships existed, demonstrates the possibilities of networks of collectors developing organically. Clearly there is a gap in terms of defined lines of responsibility for collating finds reports and communication, which beach nourishment projects will need to factor in. Time and funding are likely to remain an issue, however, meaning flexible methods such as beach signage and online reporting mechanisms may need to be more heavily relied upon in some cases.

Reactive

Finally, the availability of data to link finds in with is crucial. As mentioned above, this provides the key component for contextualising, and potentially assessing in situ, any archaeological signatures. This requires that:

- Appropriate geophysical and geotechnical data is readily available

- Geotechnical samples have been taken and archived in a way that facilitates further work.

In order for this work to progress, these recommendations need to be guided by Historic England in consultation with the offshore industry as a whole, then carefully and explicitly laid out in the Written Scheme of Investigation for each licensed area, as well as forming part of the licence conditions, where applicable.

Moving forward from this, and with the potential highlighted by industry support for this work, greater transparency in data availability is an important step towards integrating commercial datasets in ongoing research. Although some data is available through the Crown Estate's Marine Data Exchange (https://www.marinedataexchange.co.uk) or Archaeological Data Service (ADS; https://www.archaeologydataservice.ac.uk), a greater push to an open-access database will expand the potential for far more evaluation of seabed areas. Far too often, knowledge of an individual aggregate area is held by a single archaeological contractor or within commercially sensitive reports, meaning that a holistic overview of a region's submerged palaeolandscapes from aggregate zones is limited to a few sites where a deliberate attempt to disseminate the data has occurred, or referring back to the Regional Environmental Characterisation (REC) studies from 10–15 years ago, which themselves often contained very little scientific dating to establish the age of different deposits. Recently funded AHRC projects working 'Towards a National Collection' (https://historicengland.org.uk/whats-new/news/towards-national-collection/), particularly, for maritime collections, 'Unpath'd Waters', demonstrates the prioritisation of accessible data.

The final question to address is one of cost. As previously stated, commercial exploitation of the seabed currently provides the best means by which to understand the submerged record. As such, it is important that this work is supported by industry and that the costs do not disproportionately impact a single developer or repeated groups of developers. In the past, the Aggregate Levy Sustainability Fund (ASLF) was available where further investigations of sites with Palaeolithic importance could be undertaken. This scheme would have funded the current work on Area 447 but, since its abolition, the responsibility for such work would either fall to aggregate companies, for which it is unlikely that costs would have been ring-fenced, or Historic England, as was the case with this study and that for Walcott. Establishment of a new fund specifically to support such studies when archaeology is discovered, using the ALSF model, could be of benefit to curators, licensees and archaeologists. Without such a fund, it is likely that Historic England will be left to fund this work for the foreseeable future.

6 CONCLUSIONS

This project has worked with geophysical and geotechnical data collected at points over a 25-year period from the seabed of and around licence Area 447, in order to re-contextualise a significant collection of archaeology that appeared as a result of dredging and subsequent beach replenishment. The assessment and analysis of previously split and archived industry cores has provided evidence for low-energy floodplain/channel edge environments in the cooling limb of MIS 7 and into early MIS 6. This is supported by stone tool analysis, which points to a period in the Early Middle Palaeolithic (MIS 8–6). The combination of low-energy environments from palaeoenvironmental evidence, the location of which corresponds with the highest density of dredging, and the relative freshness of the Levallois stone tools, supports this interpretation. What this project has therefore demonstrated, or, more accurately, reinforced, is that significant assemblages of Pleistocene archaeology are preserved within submerged deposits off the coast of the Britain. When relating to in-situ 'sites', however, this archaeology is likely to be contained within the wider landscape in proximity to, but not within, channels, making its identification in seismic data problematic and meaning that its potential is often overlooked, or is difficult to pinpoint, in the initial stages of planning. The visibility of this archaeology, though, once removed from context, is greatly increased by the nature of beach replenishment schemes. We therefore need to take a more proactive approach to mitigating the loss of information that comes from the removal of archaeology from the seabed; a three-staged approach for which is laid out in the discussion above.

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