

1 **Human occupation of northern Europe in MIS 13: Happisburgh Site 1 (Norfolk, UK) and its**
2 **European context**

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25 **ABSTRACT**

26 The timing, environmental setting and archaeological signatures of an early human presence
27 in northern Europe have been longstanding themes of Palaeolithic research. In the space of
28 20 years, the earliest record of human occupation in Britain has been pushed back from 500
29 ka (Boxgrove) to 700 ka (Pakefield) and then to >800 ka (Happisburgh Site 3). Other sites
30 also contribute to this record of human occupation; a second locality at Happisburgh,
31 referred to as Site 1, attests to human presence at around 500 ka (MIS 13). This paper
32 provides the first comprehensive account of research undertaken at Happisburgh Site 1
33 since 2000. The early human landscape and depositional environment was that of a river
34 floodplain, where an active river channel, in which the grey sand was deposited, was
35 abandoned, forming a floodplain lake, with marginal marsh/swamp environments, which
36 was infilled with organic mud. This succession is sealed by Middle Pleistocene glacial
37 deposits. An assemblage of 199 flint flakes, flake tools and cores was recovered from the
38 grey sand and organic mud. The evidence from Happisburgh Site 1 is placed in the context of
39 the wider British and European MIS 13 record. The growing evidence for a significant
40 dispersal of humans into northern Europe around 500 ka raises critical questions concerning
41 the environmental conditions under which this took place. We also consider the
42 evolutionary and behavioural changes in human populations that might have enabled the
43 more widespread and persistent period of human presence in northern Europe at this time.

44

45 **Keywords**

46 Pleistocene; Europe; Lower Palaeolithic; handaxe; MIS 13; Cromer Forest-bed Formation

47

48 **1. Introduction**

49

50 A major research theme in Palaeolithic archaeology over the last 25 years has been the
51 timing and the nature of the early human occupation of Europe. The seminal edited volume
52 of Roebroeks and Van Kolfshoten (1995) scrutinised, through a series of papers, both the
53 dating and the human workmanship of the lithic industries from the earliest sites. The main
54 conclusion was that most, if not all, of these sites were either poorly dated or the putative
55 lithics were considered not to be of human manufacture. They argued that the oldest well-
56 dated sites were from around 500 ka; the so-called 'short chronology' of Roebroeks and Van
57 Kolfshoten (1994). Importantly, this work set a rigorous standard against which new
58 discoveries could be tested and gave new impetus to the debate over the earliest human
59 occupation of Europe.

60

61 A number of new sites in southern Europe dated at around 1 Ma passed the test and led to
62 modification of the 'short chronology' model (Carbonell et al., 1995, 2008; Dennell and
63 Roebroeks, 1996; Gilbert et al., 2006; Arzarello et al., 2007). While the picture emerging
64 from southern Europe was that of a longer chronology for human presence, in northern
65 Europe the threshold of 500 ka still held firm until new sites were discovered in the UK:
66 Pakefield and Happisburgh Site 3 at ca 700 ka and over 800 ka respectively (Parfitt et al.,
67 2005, 2010; Ashton et al., 2014).

68

69 Although Pakefield and Happisburgh Site 3 provided evidence of humans in northern Europe
70 prior to 500 ka, the lithic assemblages were small, with 32 and 80 artefacts respectively, and
71 the technology was simple core and flake working. It was suggested that these sites

72 represent occasional pioneering events that ultimately failed to secure a sustained
73 occupation of northern Europe. The threshold at 500 ka marks a significant increase in the
74 number of sites and the size of the lithic assemblages and presumably in population size
75 and/or duration of occupation. The debate has now focused on why there is a major shift in
76 the archaeological record at this time and how it relates to the emergence of new
77 technologies, adaptation to northern, as well as more continental, environments and
78 possibly the arrival in Europe of new hominin species from Africa or Asia (Ashton and Lewis,
79 2012; Cohen et al., 2012; Ashton, 2015; Moncel et al., 2015). Happisburgh Site 1 is one of at
80 least five sites in the UK (others include Boxgrove, High Lodge, Warren Hill and Waverley
81 Wood) that date to this major turning point in the Lower Palaeolithic of Europe at 500 ka
82 and contribute to the debate. This paper reports the results of recent research at
83 Happisburgh Site 1, in particular the excavations conducted by members of the Ancient
84 Human Occupation of Britain (AHOB) project and the University of Leiden. The lithic
85 assemblages recovered during these two phases of fieldwork are described and set within
86 the British and European archaeological context and the implications of these new data for
87 understanding human presence in northern Europe around 500 ka ago are discussed. The
88 palaeobotanical and palaeontological investigations that were undertaken at Happisburgh
89 Site 1 will be presented in forthcoming papers (Field et al., in prep.; Parfitt et al., in prep.).

90

91

92 **2. Background to Happisburgh Site 1**

93

94 The coastal cliffs and foreshores of East Anglia (Fig. 1) are well known for exposures of the
95 Early and early Middle Pleistocene freshwater sediments of the Cromer Forest-bed

96 Formation (CF-bF) (Reid, 1882, 1890; West, 1980). However, despite more than a century of
97 geological, botanical and palaeontological research, it is only since 2000 that undisputed
98 evidence of human presence has been found within the CF-bF. The discovery, in that year,
99 of an *in situ* handaxe at Happisburgh (Ashton et al., 2008) led to the current phase of
100 archaeological research. This discovery, along with a growing number of beach-finds along
101 this part of the Norfolk coast (Robins et al., 2008), testifies to the contribution made by local
102 collectors and also highlights the vulnerability of this important archaeological resource to
103 coastal erosion.

104

105

106 **2.1. Archaeological investigations since 2000**

107 The progressive failure of the sea-defences and rapid cliff retreat since the mid-1990s at
108 Happisburgh has wrought significant changes to the coastline. Along the stretch of coast
109 between Beach Road, Happisburgh (National Grid Reference TG 3853 3086) and the start of
110 the concrete sea wall at Cart Gap (TG 3899 3047), up to 150 m of retreat has taken place
111 resulting in a large embayment and the exposure of Pleistocene sediments on the foreshore
112 (Poulton et al., 2006). These sediments are subject to rapid erosion or reburial beneath
113 modern beach sand and have been only intermittently accessible for study. Even when they
114 are exposed, the conditions for concerted and systematic archaeological investigations are
115 challenging owing to groundwater and tidal ingress. However, following the handaxe
116 discovery at Happisburgh, a period of sustained good exposure of the Pleistocene deposits
117 on the foreshore enabled research to be undertaken. Initial field investigations in 2001–
118 2002 led by Professor J. Rose (Royal Holloway University of London) demonstrated that the
119 organic deposits, in which the handaxe was found, are overlain by glacial sediments of the

120 Happisburgh Formation and that the organic sediments contained both pollen and
121 coleopteran remains (Coope, 2006). Regular monitoring by Norfolk Museums Service (NMS)
122 also recovered further artefacts together with palaeobotanical and palaeontological
123 remains.

124

125 The first systematic excavation of the handaxe locality was undertaken by the AHOB project
126 in 2004 (Figs 2, 3). This yielded an archaeological assemblage and further
127 palaeoenvironmental information (Ashton et al., 2008). The discovery of two further
128 archaeological sites on the foreshore at Happisburgh necessitated their differentiation as
129 Sites 1, 2 and 3 (Fig. 1), the last (and oldest) of which is reported by Parfitt et al. (2010). A
130 second phase of archaeological investigations at Site 1 took place between 2009 and 2012
131 by the Faculty of Archaeology, University of Leiden, and members of the AHOB project.

132

133

134 **2.2. The Pleistocene succession at Happisburgh**

135 The Pleistocene sediments exposed along a ca 4 km stretch of coastline from Ostend (TG
136 365 326) to Cart Gap (TG 397 299) (Fig. 1) have been observed and studied since the early
137 19th century. Clement Reid provided the first systematic descriptions of the CF-bF (Reid,
138 1882, 1890) and in the 1960–70s Richard West conducted a detailed regional study of the
139 CF-bF along the coast of Norfolk and Suffolk (West, 1980). West made a number of
140 stratigraphic observations at Happisburgh (his locations HA–HG) including a borehole at
141 location HC, beneath the now-destroyed lifeboat ramp, which penetrated the full thickness
142 of the Pleistocene deposits down to Chalk bedrock. West also undertook detailed
143 palaeobotanical analyses of the sediments. Happisburgh is regarded as the most southerly

144 exposure of the CF-bF in Norfolk; Reid (1890, p.173) recorded exposures “within a quarter of
145 a mile of the Low Lighthouse” (which was located at TG 3915 3041 until its demise in the
146 19th century) and West’s location HG (356m south-east of HC) was the most south-easterly
147 outcrop of these sediments observed during the second half of the 20th century.

148

149 The borehole at HC proved Chalk at a depth of -27.7 m OD (Ordnance Datum) and in
150 boreholes TG33SE16 and SE19 it was encountered at -39.3 m and -37.4 m OD respectively
151 (Figs 3, 4). Boreholes north of Happisburgh record Chalk at shallower depths and borehole
152 TG32NE18 ca 1 km south-east of Site 1 proved Chalk at -39.0 m OD, indicating that, broadly,
153 the bedrock surface declines in a south-easterly direction in the vicinity of Happisburgh.
154 None of the boreholes sunk during the present investigation at Site 1 reached the Chalk.

155

156 The deposits overlying the Chalk and underlying the glacial succession in borehole HC were
157 divided into beds a–j by West (1980). Beds a–h comprise 23.4 m of sands with layers of silty
158 clay and sandy gravel. The sedimentological and biological information from these deposits
159 suggests a near-shore marine environment. They may be broadly equated with the
160 widespread marine Crag deposits and have been assigned to the Red Crag, Norwich Crag
161 and Wroxham Crag formations by the British Geological Survey (BGS) (Rose et al., 2001;
162 Moorlock et al., 2002). The CF-bF is represented by a thin gravel unit (bed i) and laminated
163 sediments (bed j).

164

165 South-east of HC, beds i and j pinch out and are not known beyond West’s location HG.
166 Parfitt et al. (2010) described laminated sediments and lag gravel at Happisburgh Site 3,
167 equivalent to beds i–j and extending some 400 m north-west of HC. These deposits are up to

168 ca 5 m thick, they overlie marine sands and are overlain by glacial sediments of the
169 Happisburgh Formation. The laminated silts are interpreted as intertidal mud flat deposits
170 and, along with the lag gravel, have yielded Palaeolithic artefacts, and contain a horizon
171 with human footprints (Parfitt et al., 2010; Ashton et al., 2014).

172

173 Relatively little is known about the sediments underlying the Happisburgh Formation in the
174 vicinity of Site 1. The most south-easterly location mentioned by Reid (1890) roughly
175 corresponds to the location of Site 1, though the cliff line was in a more seaward position at
176 that time (Fig. 3), suggesting that lateral equivalents of the sediments investigated at Site 1
177 were exposed in the late 19th century. Reid (1890, p. 173) described the exposures of the CF-
178 bF hereabouts as follows: “its lithological character is peculiar, and does not clearly indicate
179 to which division the strata here exposed belong. The deposit consists of carbonaceous silt,
180 full of small pieces of wood, and occasionally fir-cones, passing laterally into hard blue-black
181 carbonaceous clay with earthy ferruginous concretions containing scattered twigs”.

182

183 The glacial deposits at Happisburgh are exposed extensively in the coastal cliffs between
184 Walcott and the sea wall at Cart Gap (Fig. 1). They were described by Reid (1882) and
185 subsequently a number of surveys of the coastal exposures have been undertaken (Lunkka,
186 1994; Hart, 1999; Moorlock et al., 2000; Lee, 2003; Lee et al., 2008). In the lithostratigraphic
187 scheme of Lee et al (2017), the lowermost glacial formation, the Happisburgh Formation
188 consists of the Happisburgh Diamicton, the Ostend Clay and the Happisburgh Sand members
189 which are interpreted as subglacial, glaciolacustrine and deltaic sediments respectively. The
190 Corton Diamicton and the Corton Sand members of the Corton Formation, subglacial-
191 subaqueous till and distal glaciofluvial outwash respectively, and the subglacial Lowestoft

192 Diamicton Member of the Lowestoft Formation are also exposed in the cliffs. In this paper
193 (Table 1) the Happisburgh, Corton and Lowestoft diamictons are referred to as tills following
194 Lee et al. (2004a).

195

196

197 **3. Material and methods**

198

199 **3.1. The 2004 AHOB excavation**

200 This excavation was the first controlled attempt to recover lithic artefacts, and faunal and
201 floral remains (Figs 2, 3). The deposits of interest at Site 1 are at or below the level of the
202 modern beach, therefore the excavation, recording and sampling methods had to be
203 adapted to suit the conditions. The excavated trenches were flooded at high tides and, in
204 addition, wind-driven waves and ground water presented particular challenges for the
205 fieldwork. The deposits were exposed only at low tide and up to 0.5 m of beach sand was
206 removed each day by mechanical excavator to expose extensive areas of the surface of the
207 CF-bF, which was sometimes sealed beneath glacial sediments of the Happisburgh
208 Formation. A trench (Area 1) 3 x 4 m in size was excavated and five 1 x 1 m squares were
209 selected and dug in 0.1 m spits through ca 0.6 m of organic mud to reach the underlying
210 grey sand. Finds were recorded by metre square and spit, and the sediment was wet-sieved
211 over a 1 mm mesh. Three further 1 x 1 m test pits were located to the north of Area 1, while
212 at very low tide two additional areas were excavated through the top 0.1 m of organic mud.
213 Material was also recovered by cleaning the surface of the exposed CF-bF and from re-
214 exposure of the 2002 geological trench along the western margin of the channel. Most finds
215 consisted of flint artefacts and mammal bones, some of which had evidence of butchery. A

216 number of shallow hand-auger holes were completed through the archaeological sediments
217 and test pits were dug in the vicinity of the site using a mechanical excavator in order to
218 establish the geometry of the deposits.

219

220 **3.2. The 2009–2012 University of Leiden excavations**

221 New excavations were initiated in 2009, with the specific objectives of increasing the size of
222 the artefact assemblage from Site 1 and generating new palaeoenvironmental data. By 2009
223 the cliffs had retreated by over 50 m and beach sand had built up considerably since 2004,
224 in some areas up to 2 m in depth, and consequently a different approach to excavation was
225 required. A mechanical excavator was used to remove modern beach sand over a wide area
226 and expose the Happisburgh Till. Trial pits (Fig. 3), which are all prefixed HAP, followed by
227 the excavation year and the trench number (L1, L2 etc.), were then dug by machine, through
228 the till to the top of the CF-bF. These remained largely dry while the organic mud was being
229 removed, but once the excavator broke through into the underlying grey sand the trenches
230 flooded rapidly. The organic mud was therefore recorded and sampled while the trial pit
231 remained dry. Excavation proceeded and the grey sand was removed using the mechanical
232 excavator and 'stockpiled' on plastic sheeting for later processing. Most trenches flooded
233 rapidly necessitating immediate backfilling; however, in trench HAP10-L7 exposures were
234 accessible for four days, enabling more detailed sampling of the sections, including for
235 palaeomagnetic, micromorphological and palaeobotanical analyses, as well as small-scale
236 excavation of the artefact-yielding sandy deposits. This excavation strategy proved to be an
237 effective and pragmatic solution to the on-site conditions. The stockpiled organic mud and
238 grey sand was wet-sieved over a 10 mm mesh to recover lithic artefacts and larger

239 vertebrate material. Subsamples were also sieved through a 2 mm mesh mainly for the
240 recovery of small vertebrate remains.

241

242 **3.3. Borehole investigations**

243 Between 2010 and 2012 a series of boreholes were completed using a range of drilling
244 methods (Fig. 3). Boreholes 10/1 and 10/3 utilised a tracked, vehicle-mounted, percussion
245 drilling rig, BHs 11/1–10 were drilled using Cobra-driven window samplers. For BHs 12/1–6 a
246 cable percussion system was employed, which was better able to cope with the sediments,
247 the ground conditions and also enabled continuous sampling of the organic sediments.

248

249 **3.4. Sample collection and analysis**

250 Fourteen samples were taken for clast lithological analysis from stockpiles of sediment
251 recovered from trenches by mechanical excavator and from boreholes. The samples were
252 sieved and the 11.2–16.0 mm fraction and, in most cases, the 8.0–11.2 mm fractions were
253 retained for analysis. Clast lithological data are presented for the combined size fractions
254 where both are available and the 11.2–16.0 mm fraction for the remaining samples. Particle
255 size analysis was carried out using standard pretreatment and sieving techniques for the
256 sand fraction (Gale and Hoare, 2011) and laser granulometry using a Beckman Coulter
257 particle sizer for the silt and clay fraction. Organic matter content was determined by loss
258 on ignition (Gale and Hoare, 2011).

259

260 **3.5. Palaeomagnetic analysis**

261 A total of 33 pairs of samples were taken for palaeomagnetic analysis from HAP10-L7
262 including 14 (seven pairs) from the overlying till. A further five samples were taken from a

263 monolith through the sediments. The sediments were sampled for both stepwise
264 progressive Alternating Field (AF) and Thermal (TH) demagnetisation because the potential
265 presence of greigite (Maher and Hallam, 2005; Parfitt et al., 2010) may seriously interfere
266 with AF demagnetisation as a gyroremanent magnetisation (GRM) often develops (e.g.
267 Snowball, 1997; Roberts et al., 2010).

268

269 Samples were taken for TH and AF demagnetisation in quartz and perspex sample
270 containers with standard dimensions of 25 x 25 x 22 mm for TH (33 samples) and AF (38
271 samples) demagnetisation respectively. The containers were gently pushed into a freshly-
272 cut 2 m deep section in HAP10-L7. After orientation with a magnetic compass and
273 clinometer they were removed from the face and sealed for measurement. Samples were
274 analysed in the laboratories of 'Fort Hoofddijk' (Utrecht University, The Netherlands) or
275 Centro Nacional de Investigación sobre la Evolución Humana (Burgos, Spain). Measurements
276 were done within one month after retrieval to ensure that the samples were processed
277 while fresh. Natural Remanent Magnetization (NRM) and its TH demagnetisation was
278 performed with ASC thermal demagnetisers (residual field < 50 nT) and measured with a DC-
279 SQUID (direct current superconducting quantum interference device) magnetometer
280 (instrument sensitivity $2 \times 10^{-12} \text{ Am}^2$). The noise level of the magnetometers is well below
281 the magnetisation intensity of the measured samples. All the AF samples were processed on
282 a robotised horizontal DC-SQUID magnetometer equipped with an in-line AF capability
283 (Mullender et al., 2016). A so-called per component protocol (Dankers and Zijdeveld, 1981;
284 Stephenson, 1993) to compensate for possible GRM caused by greigite (Fe_3S_4) was adopted
285 for the five monolith samples. Greigite often shows GRM during AF demagnetisation,

286 therefore preference is given to thermal demagnetisation for the interpretation of the NRM
287 components.

288

289 Characteristic Remanent Magnetisation (ChRM) directions were calculated with principal
290 component analysis (Kirschvink, 1980) on at least four consecutive demagnetisation steps
291 using the open-source, multi-platform online environment for palaeomagnetic data analysis
292 Paleomagnetism.org (Koymans et al., 2016).

293

294 **3.6. Micromorphological analysis**

295 Five undisturbed samples, 90 x 60 mm, were taken from trench HAP10-L7. Thin section box
296 M1 sampled the transition from the lowermost part of the till to the upper part of the
297 organic mud, M2 sampled the organic mud, while M3 sampled a transition within the
298 organic mud, changing from a brownish black (Munsell colour 2.5YR 3/1) to a browner
299 (7.5YR 2/3), laminated deposit with up to 20 mm thick organic layers. M4 was taken in a
300 sand lens which contained an *in situ* artefact and M5 sampled the upper part of the
301 (artefact-yielding) sandy deposits. In the laboratory the samples were air-dried and, under
302 vacuum, impregnated with unsaturated polyester resin. After hardening, sawing and
303 grinding, thin sections were prepared according to the method of Benyarku and Stoops
304 (2005). The thin sections were examined with the aid of a Leitz Orthoplan polarizing
305 microscope in plane (PPL) and crossed polarized light (XPL). In the case of opaque material
306 the colour in oblique incident light is noted separately. Photographs were taken using a
307 polarizing microscope with plane polarized light PPL and with XPL. The thin sections were
308 described micromorphologically using the terminology of Stoops (2003).

309

310 **3.7. Lithic artefact analysis**

311 The excavations produced three lithic assemblages, the first from the organic mud (AHOB,
312 2004), the second from the grey sand (Leiden, 2009–2012) and the third consisting of
313 surface finds from the organic mud (NMS). The assemblages have been studied using the
314 approach adopted by Ashton and McNabb (1996), which has been used on several British
315 Lower Palaeolithic sites. Additional attributes were selected from the system of De Loecker
316 (2004) that was originally used on the early Middle Palaeolithic site of Maastricht-Belvédère.

317

318

319 **4. Happisburgh Site 1: stratigraphy and sedimentology**

320

321 The deposits exposed during the archaeological excavations consist of grey sand and organic
322 mud, which are overlain by the Happisburgh Till Member of the Happisburgh Formation (Fig.
323 5). The grey sand and organic mud are present between approximately 345 m and 485 m
324 from the northern end of the sea wall at Cart Gap. The Happisburgh Till crops out at the
325 base of the cliff in the northern part of the embayment, but dips below beach level at
326 around 300–350 m north of the end of the sea wall. The grey sand was only visible at the
327 base of excavation trenches which were prone to rapid flooding, precluding detailed
328 description of the deposits. Bulk sampling of the deposits for artefact sieving and disturbed
329 samples recovered from boreholes provide some additional information though again
330 detailed sedimentological observations were not possible.

331

332

333 **4.1. Grey sand**

334 The grey sand was proved to a depth of -8.8 m OD (Fig. 6). It is subdivided into a lower
335 predominantly sandy unit and an upper more gravelly unit, the latter is about 0.7 m in
336 thickness and the boundary between the upper and lower parts is at ca -3.0 m OD. The
337 lower part of the grey sand (below -3.0 m OD) consists of grey, gravelly, sand. The texture
338 of the <2 mm fraction varies from medium-coarse to silty fine sand, with some mud-
339 dominated horizons. The gravel component consists mainly of flint, vein quartz,
340 quartzite/sandstone and small quantities of chert (Table 2); a few siderite pebbles were also
341 noted. The proportion of flint pebbles displaying rounded surfaces with percussion marks is
342 around 30% at ca -6.5 m OD, decreasing to less than 10% in the overlying sediments. Above
343 ca -6.0 m OD the sands are finer with a higher proportion (>60%) of silt and clay. Between -
344 6.0 and -4.2 m OD the sediments are gravels and sandy gravels, grading upwards into
345 interbedded sands and gravels with horizons of mud-dominated possibly laminated
346 sediments. At -4.2 m OD there is a textural change above which is 1.2 m of grey sand.

347

348 The upper 0.7 m of the grey sand (above ca -3.0 m OD) consists of more gravelly sediments
349 with interbedded mud-dominated horizons in the lower part grading upwards into fine to
350 very fine silty sands above -2.5 m OD. This unit immediately underlies the organic mud in
351 the HAP excavation trenches (Fig. 5) where it is typically light brownish grey (2.5Y 6/2) to
352 light yellowish brown (2.5Y 6/3) and pale yellow (5Y 7/4) where the sediments are oxidised.
353 There is a colour change from grey to black and a small increase in organic matter content in
354 the uppermost 0.2 m (Fig. 7). The clast lithological composition of the gravelly facies is
355 dominated throughout by flint (Table 2). Four samples (HAP09A and B, HAP10-L9 and
356 HAP12-L3) from stockpiles of grey sand extracted from the base of excavation trenches,
357 display consistent inter-component ratios and, together with the uppermost samples from

358 BH 12/1 and 12/2 and that from BH 12/4, have >55% flint and <40% quartzose lithologies
359 (vein quartz, quartzite and sandstone); this is a slight increase in flint and reduction in
360 quartzose content compared with the gravelly facies in the lower part of the grey sand.
361 There are also small quantities of Carboniferous chert (including silicified limestone),
362 *Rhaxella* chert, and igneous and metamorphic lithologies.

363

364 Micromorphological analysis of the upper part of the grey sand in HAP10-L7 (sample M5,
365 see Supplementary Information for detailed descriptions and Fig. 7 for sample location)
366 indicates a dominantly very fine to medium sand with some coarser grains, mainly
367 consisting of rounded to sub-rounded quartz; there is minimal organic material and a
368 massive microstructure. Sample M4 from a sand body within the organic mud has similar
369 micromorphological properties.

370

371 The lower unit of the grey sand (below -3.0 m OD) may be a marine deposit, in common
372 with sediments at similar depth in the borehole at HC. The occurrence of muddy sediments
373 may suggest some tidal influence. The upper part of the unit (above -3.0 m OD) is
374 interpreted as in-channel fluvial deposition of a mixed bedload of sands and gravels. In the
375 absence of diagnostic sedimentological evidence this is based on the reduction in
376 percussion-marked flint and the increased proportion of gravel in the upper 0.7 m of the
377 grey sand. It is also consistent with in-channel deposition prior to its abandonment and
378 infilling with organic mud. This interpretation is further supported by the presence of
379 freshwater mollusca in the upper part of the grey sand (R.C. Preece, pers. comm., 2015;
380 Parfitt et al., in prep.). The micromorphological indications of a massive microstructure in
381 the uppermost part of the grey sand suggests colluvial processes have contributed to its

382 formation. This may reflect cessation of active channel deposition following abandonment
383 of the channel and prior to the onset of significant deposition of organic mud.

384

385 **4.2. Organic mud (Low Lighthouse Member)**

386 The lower boundary of this unit has a channel geometry and ranges in elevation between ca
387 -2.3 and -1.0 m OD (Figs 5, 6). The unit attains its maximum observed thickness in BH12/1
388 and trench HAP11-L1 and it thins at the north-western and south-eastern margins of its
389 distribution (Fig. 5). The western margin of the channel is aligned NNW-SSE and it occurs
390 between BH 11/10 and trench HAP10-L8 (Figs 3, 5). The eastern margin is less well
391 constrained but the most easterly location where the organic mud has been recorded is in
392 BH 11/4. The channel feature is approximately 120 m in width. The upper boundary with the
393 overlying Happisburgh Till is sharp and varies in elevation between +0.5 m and -1.0 m OD.

394

395 During the 2004 excavation, this unit was extensively exposed on the foreshore, some 50-
396 100 m seaward of the 2009-2012 excavation trenches (Fig. 2d). The outcrop formed a wave-
397 cut platform extending laterally over 100 m of the foreshore and beyond the low water line,
398 as shown by bathymetric survey data. The exposed surface in places also preserved
399 remnants of the overlying Happisburgh Till, for example in auger holes 1, 3 and 4 and in Test
400 Pit 7 (Fig. 8). The organic mud varies in thickness across the outcrop; along the western edge
401 of the outcrop (trimmed by wave erosion and by machine excavation of a trench through
402 the sediments) this unit is generally less than 1 m in thickness but it thickens rapidly away
403 from this 'edge' and in auger holes 4 and 5 up to 1.4 m of organic mud was proved overlying
404 the grey sand. In these two auger holes there was a change from a lower organic silt and
405 clay to a more sandy organic deposit in the upper part. These sandier organic deposits were

406 also exposed in Area I, where excavated surfaces revealed lighter coloured sandy lineations
407 suggestive of sand horizons or lenses within the organic sediments. This sandy upper
408 portion of the organic deposits may be equivalent to, though somewhat thicker than, the
409 sandier upper 0.2 m of the unit seen in HAP11-L1.

410

411 The unit consists of up to 2.6 m of dark grey to black organic mud, largely massive, with
412 some interbedding of sandy horizons. Analysis of sample columns from trenches HAP10-L7
413 and HAP11-L1 indicates a clear textural contrast with the underlying grey sand. It is
414 dominantly mud, though somewhat sandier in the upper part in HAP11-L1 (Fig. 7). Organic
415 matter content is up to 35%, though more typically it is around 10%. It contains woody
416 debris, with concentrations of woody material particularly noticeable in the upper part of
417 the unit. In places sand has been injected upwards into the organic mud.

418

419 Micromorphological analysis of three samples of the organic mud (M1-3, see Supplementary
420 Information for details, Fig. 7 for sample locations) shows that the sediments are massive,
421 undifferentiated and without any clear structure, with only very rare indications of a specific
422 transport mechanism. The sediments have a weak, sub-angular blocky microstructure.
423 Coatings and nodules of marcasite (FeS_2), together with other iron nodules and crystal
424 intergrowths of gypsum, were also observed. A very small rill was noted in M3. No biopores
425 or any excrements were seen.

426

427 The organic mud is interpreted as the infill of an abandoned channel. The
428 micromorphological evidence indicates episodic colluvial processes, while rill formation
429 suggests drier phases followed by periods of overland flow. Traces of soil formation are very

430 weak, shown mainly in the form of the blocky structure, which requires a sufficient clay
431 content as well as an alternation of wet-dry conditions. Additional faint traces of soil
432 formation are indicated by the development of marcasite and other authigenic minerals.
433 Marcasite also occurs in combination with pyrite associated with organic material, indicating
434 brackish to fresh water depositional swamp environments (Mees and Stoops, 2010). The
435 drier, more stable phases were very short, up to a few months in duration, as no traces of
436 biological activity were documented.

437

438 The grey sand and organic mud therefore represents a transition from a marine to a fluvial
439 depositional environment. Abandonment of the river channel was followed by infilling with
440 fine-grained organic sediments under seasonal wetting and drying conditions, with
441 contributions from colluvial deposition, and periodic influxes of coarser material. This is
442 similar to sequences in Holocene abandoned channel fills associated with meandering rivers
443 (Brown, 1996; Toonen et al., 2012).

444

445 **4.3. Palaeomagnetic interpretation**

446 The ChRM was determined by step-wise heating between 150 and 350°C (12 steps) or, in
447 some cases, starting at 210°C and ending at 310°C (Table 3; Fig. 9). This captures the typical
448 behaviour of greigite which simultaneously unblocks and thermochemically alters in this
449 temperature interval (Roberts et al., 2011). ChRMs from the AF demagnetised samples were
450 not interpreted due to a strong GRM above 35–40mT, even though NRM values and ChRM
451 directions below 35mT are in line with the TH samples from the same levels. This includes
452 the five samples from the monolith which were demagnetised using the ‘per component
453 protocol’ as these too showed a GRM, again behaviour that is often indicative of greigite

454 (e.g. Snowball, 1997). From Table 3 it appears that all the till samples and those from
455 HAP10-L7 that were TH demagnetised are of normal polarity. The mean declination is 15.6°
456 with an inclination of 71.2° , close to the current inclination of around 67° at Happisburgh
457 (Fig. 9).

458

459 **4.4. Glacigenic deposits**

460 At Site 1, the contact between the Happisburgh Till (the lowest member of the Happisburgh
461 Formation) and the underlying organic mud is a sharp, sub-horizontal boundary, with soft
462 sediment load structures where the till has been forced into the mud. The elevation of the
463 contact varies across the site between about 0 m and -2 m OD (Fig. 5). The glacial
464 succession was not investigated in detail, though its extent was mapped in order to
465 establish the large scale geometry of the deposits at Site 1.

466

467 In the vicinity of Site 1 there is a marked change in the dip of the glacial deposits about 300
468 m north of the end of the Cart Gap sea wall. Here the tills and sands, which are generally
469 horizontal to the north of this point, dip steeply southwards; the Happisburgh Till dips
470 beneath beach level and was identified in BH 12/3 between -6 and -8 m OD (Fig. 5). Further
471 south-east at Cart Gap the Happisburgh Till is present immediately below the beach and in
472 boreholes TG32NE33 and NE34 it is present between approximately +4 m and -3 m OD,
473 suggesting that the till has regained its original elevation. In the cliff sections south-east of
474 the dipping feature, a partially decalcified equivalent of the Lowestoft Till extends for some
475 200 m along the cliffs towards Cart Gap, where (at around TG 3914 3036) the sands in the
476 cliffs display northerly dipping structures. It is also noteworthy that the ground surface
477 immediately landward of this part of the cliff shows a marked depression approximately

478 180–200 m in diameter that is coincident with the outcrop of decalcified Lowestoft Till in
479 the cliffs. Its margins are coincident with the steeply dipping structures and the extent of
480 the decalcified till exposure (Fig. 5). Exposures of the Happisburgh/Corton tills on the
481 foreshore show an arcuate/circular disposition, with the deposits dipping towards the
482 approximate centre of the feature. Geophysical investigations also show an area with a low
483 resistivity infilling which closely matches the surface expression (Ashton et al. 2018).

484

485 The dip of the glacial deposits has been interpreted as a thrust feature resulting from
486 glacitectonic deformation by ice moving from a southerly direction (Hart, 1999; Hart and
487 Boulton, 1991) or as the northern limb of a syncline (Lee, 2003). These new observations
488 suggest a roughly circular feature, with downward displacement of the glacial deposits,
489 including the Lowestoft Till. This may be the result of solution of the underlying Chalk and
490 resultant collapse of the overlying sediments.

491

492

493 **5. Correlation and age of the Site 1 succession**

494

495 Proposed correlatives of the Site 1 succession are shown in Table 1. The lower part of the
496 grey sand is interpreted as marine and is correlated with the Wroxham Crag Formation as its
497 clast lithology includes a significant quartzose component, consistent with the Wroxham
498 Crag Formation elsewhere (Rose et al., 2001; Lee et al., 2015). The upper part of the grey
499 sand is correlated with the CF-bF (Table 1). The organic mud is also assigned to the CF-bF
500 and is designated as a new lithostratigraphic unit, named the Low Lighthouse Member
501 (Table 4).

502

503 The minimum age of the Low Lighthouse Member is constrained by its stratigraphic position
504 beneath glacial sediments of the Happisburgh and Lowestoft Formations. These are
505 generally considered to be Anglian in age and correlated with Marine Isotope Stage (MIS) 12
506 (Bowen, 1999; Preece and Parfitt, 2012), though it has been suggested that the Happisburgh
507 Formation may be as old as MIS 16 (Lee et al., 2004b). An early Middle Pleistocene age for
508 the Low Lighthouse Member is also consistent with its normal magnetic polarity which
509 indicates an age within the Brunhes normal polarity Chron with a maximum age of 780 ka
510 (Hilgen et al., 2012). The lithostratigraphic and magnetostratigraphic evidence therefore
511 constrains the age for these deposits to the early Middle Pleistocene (780–478 ka).

512

513 Further constraints on the age of the Low Lighthouse Member are provided by the
514 biostratigraphic evidence (Ashton et al., 2008; Preece and Parfitt, 2008; Parfitt et al., in
515 prep.). The vertebrate assemblages from the organic mud and grey sand contain unrooted
516 molars from the water vole *Arvicola*. This species has a first appearance datum during the
517 second half of the 'Cromerian Complex' (Preece and Parfitt, 2012) and it is present at both
518 Sidestrand (Preece et al., 2009) and Waverley Wood (Shotton et al., 1993; Keen et al., 2006).
519 At both these sites, amino acid racemisation age estimates support an MIS 13 attribution
520 (Penkman et al., 2011). Correlation of Happisburgh Site 1 with Waverley Wood has also
521 been suggested based on the similarity of their insect assemblages (Coope, 2006). Of
522 particular note is the occurrence at both sites of *Micropeplus hoogendorni* which has been
523 equated with the modern Siberian species *M. dokuchaevi*, and is known in Britain from two
524 other sites (Pools Farm Pit, Brandon, and Brays Pit, Mathon) which are also interpreted as
525 late 'Cromerian Complex' in age (Barclay et al., 1992; Maddy et al., 1994; Coope, 2006).

526

527 The combination of litho-, magneto- and biostratigraphic evidence from Happisburgh Site 1
528 suggests that the Low Lighthouse Member dates to the latter part of the 'Cromerian
529 Complex' and is probably attributable to MIS 13. This stands in contrast to the different
530 suite of sediments at Happisburgh Site 3 where the evidence supports a late Early
531 Pleistocene age (Parfitt et al., 2010).

532

533

534 **6. Site 1 lithic assemblages**

535

536 Site 1 has produced two excavated lithic assemblages, the first from the organic mud during
537 the 2004 (AHOB) fieldwork, and the second from the grey sand with the 2009–2012 (Leiden)
538 fieldwork. A third assemblage, consisting of material found on the surface or embedded in
539 the organic mud, has been recovered since 2000 by local collectors and is curated by NMS
540 (Table 5).

541

542 **6.1. The AHOB assemblage (organic mud)**

543 The first assemblage was excavated in 2004 from the organic mud with a total of 219
544 artefacts, the vast majority being chips (≤ 20 mm maximum length) and flakes (Table 5).
545 Most of the artefacts are in mint or fresh condition with very slight edge abrasion, probably
546 caused by slight movement in a fluvial context (Table 6). There is a high ratio of chips to
547 flakes (ca 5:1), suggesting that there has been little loss of the smaller elements, such as by
548 winnowing. Two of the flakes have a greater degree of rolling and are likely to be in
549 secondary context. Over 55% of the flakes are broken, which seems to have been caused by

550 natural flaws in the flint and probably occurred during knapping, rather than through post-
551 depositional damage. The flint is a distinctive black colouration, which might have been
552 accentuated as a surface colouration from burial within the organic mud. Overall the
553 condition suggests that most of the assemblage has undergone minimal movement since
554 original deposition.

555

556 All the artefacts are made from Cretaceous flint originally derived from Chalk. However, the
557 nearest outcrop of Chalk today is 25 km to the west. The slight abrasion on cortical surfaces
558 suggests limited movement within a fluvial context as material derived from a marine or
559 coastal deposit is likely to be more rounded and display percussion marks. The gravel
560 material encountered in the excavation would not have been suitable for knapping, but it is
561 likely that a gravel containing suitable nodules was available within the local landscape. The
562 relatively small size and the occurrence of both cortical and non-cortical flakes suggest that
563 small to medium nodules or pebbles were being selected and reduced to small cores (Tables
564 7, 8), and that good raw material was in short supply. There were no cores in the
565 assemblage other than two frost-damaged nodules, each with a single flake removal.

566

567 The flakes demonstrate a simple technology (Table 8; Fig. 10). They are all hard-hammer
568 struck, with distinct, but small, bulbs of percussion. Over 50% of the butts are plain, with a
569 smaller percentage being dihedral. The relatively high number of cortical and natural butts
570 (25%) together with the low number of flake scars suggests the use of small nodules. The
571 simple technology is shown in the dorsal scar pattern, where almost 75% of removals are
572 from the proximal end or lateral edges. Several of the butts and one relict core edge on the
573 dorsal face show that alternate platform technique was sometimes used.

574

575 There are four flake tools, three of which are denticulates or multiple notches (Table 5; Fig.
576 10) and a further flake with marginal retouch. A frost-shattered piece has also been
577 modified to form a steep-edged multiple notch. One further flake has possible damage from
578 use. Overall the flake tools show little consistency in form and seem to reflect an *ad hoc* use
579 of the nearest available flake or even natural piece.

580

581 A notable aspect of the assemblage is the low number of artefacts, with only 40 flakes or
582 flake tools. Although it was excavated in a variety of ways it is clear that the density of
583 artefacts is very low with a thin distribution across an extensive area. In Area 1, four flakes
584 were recovered from ca 2.5 m³ of sediment, an artefact density of 1.6 artefacts per m³.
585 Although most artefacts were recovered from the top 0.2 m of the organic mud, others
586 were found at depths of up to 0.6 m. There is also a lack of refitting or distinct knapping
587 scatters, which suggests that most knapping occurred elsewhere in the landscape, perhaps
588 at the source of raw material, with selected artefacts brought into the Site 1 area. The
589 relatively high number of flake tools or modified pieces and the lack of cores support this
590 suggestion.

591

592 **6.2. The Leiden assemblage (grey sand)**

593 A total of 218 artefacts was found during the 2009–2012 field seasons, most of which are
594 flakes (Table 6). The low ratio of chips to flakes (1:3) is mainly attributed to sieving the bulk
595 of the sediment with a mesh of 10 mm. The artefacts have undergone little abrasion, with
596 the majority being mint or fresh in condition (Table 6). There are six medium to heavily
597 rolled artefacts with a glossy surface that are probably derived from a secondary context.

598 The fresh artefacts are characteristically black which is also apparent on fresh breaks. The
599 presence of two refitting groups of flakes from individual trenches, together with the
600 general condition of the other artefacts, indicates minimal natural movement.

601

602 The raw material is similar to the AHOB assemblage being Cretaceous flint with slightly
603 abraded cortical surfaces suggesting that the source was local fluvial gravel. Other than
604 generally small-sized gravel at the base of the grey sand, there was no other gravel of a
605 suitable size that was encountered during the fieldwork. It is likely that there were other
606 outcrops of gravel nearby with adequate nodules. As with the AHOB assemblage, the
607 variable quantities of cortex and small artefact size suggest that small to medium sized
608 nodules were highly reduced and that access to good quality raw material was rare (Tables
609 7, 8).

610

611 The flakes were produced by hard hammer, indicated by their pronounced bulbs of
612 percussion. The majority of the butts are plain with moderate numbers being dihedral,
613 cortical or natural. The dorsal scar patterns are simple with the large majority of removals
614 coming from proximal and lateral directions (Table 8). The number of dorsal scars is similar
615 to the AHOB assemblage with most flakes having one to three scars. Three relict core edges
616 show the use of alternate platform technique, which is also supported by evidence on the
617 butts. Unlike the AHOB assemblage there are six cores, four of which show the use of
618 alternate platform technique, while the remaining two have single removals from different
619 parts of the nodule (Fig. 10a).

620

621 There are two refitting groups, one of which, from trench HAP09-L2, is composed of five
622 small flakes (2004.0608.166–170) and clearly demonstrates the use of alternate platform
623 technique (Fig. 10g). One edge of the nodule was worked in two directions, A and B, with
624 evidence of at least nine removals (four flakes are missing). A platform had been created
625 from a different part of the core by the first missing removal (flake 1). This was used as a
626 platform to remove cortical flake 2 (170) in direction A. The scar created a platform for the
627 removal of missing flake 3, together with flakes 4 and 5 (166 and 169) in direction B. The
628 core was turned to remove missing flakes 6 and 7 in direction A. Finally the core was turned
629 once more to remove flakes 8 and 9 (167 and 168) in direction B. The whole sequence
630 shows the removal of nine flakes from one side of a pebble, alternating platforms three
631 times. Three of the resulting flakes (167–169) have sharp edges and would have been
632 suitable for use. One of these (168) has a small area of marginal retouch on the left lateral
633 edge.

634

635 Group 2 from trench HAP11-L3 consists of two flakes (2004.0608.254–256), one of which
636 has broken in two. The flakes were removed at right angles to each other from the same
637 plain, possibly natural, platform. The first flake shattered into several pieces on knapping,
638 two of which have been recovered, and shows evidence of at least one previous removal
639 from the same platform. The second flake was detached close to the point of impact of the
640 first flake and also has a lateral break across its wide platform. It is likely that both flakes
641 were removed from the same impact.

642

643 There are a total of 19 tools (Table 5), of which 15 are on flakes, and four on modified
644 natural or shattered flint. The majority of these tools are notches and multiple notches or

645 denticulates. The remainder are flakes with lightly retouched edges, one of which can be
646 classed as a scraper. The retouch is on the dorsal side, but with no preference for the
647 location of the working edges, which were on proximal, distal and lateral locations. Two of
648 the denticulates have heavy reduction, possibly indicative of resharpening. Although in
649 some cases reduction has made it difficult to estimate the original blank size, the tools are
650 only slightly larger on average than the unmodified flakes. As with the AHOB assemblage,
651 tool production seems to have occurred in an *ad hoc* fashion with little regard for specific
652 form and with the use of the nearest available blank.

653

654 Overall the density of artefacts is low, with 218 artefacts from ten trenches, although the
655 trenches nearer the channel edge contained higher numbers (HAP09-L1: 40 artefacts and
656 HAP11-L2: 47 artefacts). The presence of two refitting groups from separate trenches
657 indicates some *in situ* knapping, but otherwise the low density of the distribution suggests
658 that some finished artefacts were introduced into the area. No artefacts were recovered
659 from the organic mud, even though large quantities of sediment were sieved.

660

661 **6.3. NMS surface assemblage**

662 The surface assemblage yielded a total of 54 artefacts, which includes 41 flakes and,
663 significantly, one handaxe. Chips are absent due to the method of recovery. The artefacts
664 are usually unbroken, with the majority in fresh condition. The few rolled artefacts have a
665 glossy surface condition. As with the other assemblages, the artefacts are black with no
666 patination or staining. The raw material is similar to that from the excavated assemblages
667 and the slightly abraded cortex also suggests a gravel source.

668

669 The flakes are large, as would be expected in a collected assemblage. Although no detailed
670 technological analysis is presented here due to the recovery method and small assemblage
671 size, the artefacts display a similar technology to the excavated assemblages; hard hammer
672 percussion has produced flakes with plain butts and predominantly flake scars from
673 proximal or lateral directions with between two and four scars. Two cores have been found.
674 One large core has 12 flake removals, struck from multiple directions. The other core is
675 flaked from a nodule with five removals from the right dorsal side.

676

677 The assemblage includes three denticulates and two notches, all retouched on the dorsal
678 face. The handaxe is ovate in shape and has an old break at the butt, caused by a natural
679 fissure in the flint (Fig. 10h). As with the rest of the assemblage, the handaxe is in very fresh
680 condition. It was probably flaked by soft hammer percussion, but the absence of soft
681 hammer flakes in any of the Site 1 assemblages suggests that the knapping of the handaxe
682 took place elsewhere. Indeed, the original nodule must have been at least 140 mm in length
683 and there is no obvious source for this raw material in the immediate area.

684

685 **6.4. Comparison between assemblages**

686 The three assemblages have much in common, including the use of a similar raw material
687 source, probably from a nearby fluvial gravel, and the selection of small- to medium-sized
688 nodules or pebbles. The knapping technology was simple hard-hammer removal of flakes
689 using a combination of single platform or alternate platform techniques, usually from plain
690 or natural platforms. Larger flakes were selected for the production of simple notches,
691 denticulates and occasionally minimally retouched flakes, with little regard for form. One
692 handaxe was introduced into the area, perhaps made from a more distant raw material

693 source. All the assemblages were thinly dispersed across the site, whether from within the
694 grey sand or from the organic mud.

695

696 There are also a few differences between the two excavated assemblages. In the grey sand
697 there is a greater number of cortical flakes and cores, which, together with the refitting,
698 suggests that this assemblage reflects *in situ* knapping. In addition, most measurements,
699 other than maximum length, show that the flakes from the grey sand are slightly smaller,
700 which indicates the use of smaller nodules compared with the assemblage from the organic
701 mud. During deposition of the organic mud, it seems that the knapping of larger nodules
702 was taking place away from the excavated areas and that larger flakes were brought into
703 the area. The presence of cut-marked bone supports this interpretation with artefacts
704 carried into the area for carcass butchery and little evidence of *in situ* knapping (Ashton et
705 al., 2008; Parfitt et al., in prep.)

706

707 There are also slight differences in the condition and horizontal distribution of the artefacts
708 in the grey sand. The refitting artefacts are from trenches close to the inferred channel edge
709 (HAP09-L2 and HAP11-L3) and there is also a considerably higher percentage of mint-
710 condition artefacts in channel-edge locations (Table 9). This suggests that there may have
711 been some transport of artefacts from the margins to the centre of the channel. There is no
712 clear pattern in the condition or distribution of the artefacts from the organic mud.

713

714 Due to the difficulties of excavating wet sand, the vertical distribution of the artefacts from
715 the grey sand is not known. During fieldwork at least some of the artefacts were
716 documented to come from the upper part of the unit and it is possible that this was the

717 context for the majority of this assemblage. A little more is known about the vertical
718 distribution of the artefacts from the organic mud. Due to the nature of the excavation,
719 most artefacts were recovered from the surface or top 0.1 m of the unit, although in Area 1,
720 several were found at greater depths. Three artefacts were also found on the interface
721 between the organic mud and the grey sand.

722

723 **6.5. The human habitat and occupation at Happisburgh**

724 The geological investigations have established that the depositional context for the site was
725 a fluvial system, with sedimentation occurring within a channel complex. In-channel
726 deposition of the grey sand, which also has a gravel component, was followed by
727 abandonment of the active channel and infilling with organic mud. Human occupation was
728 therefore in a floodplain landscape and one that was probably close to the estuary. The
729 wider palaeogeography of eastern England prior to MIS 12 was dominated by the easterly
730 flowing Thames and Bytham rivers (Rose, 2009; Rose et al., 2001). The course of the Bytham
731 River was some 30 km to the south of Happisburgh so it is unlikely that the Happisburgh Site
732 1 channel is part of that river system. A reconstruction of the pre-Anglian landscape of
733 eastern Norfolk (Thurston, 2017) indicates that there may have been a series of ENE-flowing
734 streams in this area. None of these postulated rivers reached Happisburgh, but it is possible
735 that the river channel at Happisburgh Site 1 was either an extension of the most northerly of
736 these or another north-easterly-flowing river system.

737

738 The biological evidence adds to the local reconstruction of the human habitat, suggesting
739 that the floodplain was dominated by grasslands with reed swamp and sedges surrounding
740 abandoned channels and pools (Coope, 2006; Ashton et al., 2008; Field et al., in prep.;

741 Parfitt et al., in prep.). The valley was fringed by pine and birch woodland during a period of
742 cool-temperate climate.

743

744 The lithic assemblages were found in both the grey sand and organic mud, which has
745 implications for the duration and possible episodic nature of human presence at the site.

746 The micromorphology suggests a similar mode of deposition in the upper part of the grey
747 sand and in the organic mud. If Holocene floodplain environments can be used as a guide, a
748 timescale of centuries to millennia might be realistic (Brown, 1996; Lewin et al., 2005), but
749 in the case of Site 1, the absence of traces of soil formation in the colluvial deposits suggests
750 a significantly faster build-up of the organic mud. The Site 1 evidence thus converges on a
751 short duration and perhaps continuous human presence at the site spanning the deposition
752 of the upper parts of the grey sand and the organic mud.

753

754 From the combined evidence it is possible to develop a model of human behaviour at the
755 site. An earlier presence of humans may be indicated by the few rolled or slightly rolled
756 artefacts in the grey sand, presumably derived from underlying or upstream fluvial gravel
757 (Fig. 11a). The grey sand accumulated in a river channel and most artefacts were probably
758 discarded in or on the upper part of this unit. The large number of mint condition artefacts,
759 including refitting pieces, would not have survived in a high energy river environment,
760 suggesting that the channel had been abandoned but may have experienced seasonal
761 flooding (Fig. 11b). A plausible interpretation is of seasonally dry channel margins that were
762 used for occasional knapping, production of tools and their use. Sheet wash or seasonal
763 flooding may have reworked some artefacts into the centre of the depression.

764

765 The organic mud was deposited under still-water conditions with reed and sedge growing
766 around the swampy fringes (Fig. 11c). Periods of drier conditions (a few months at most)
767 were too brief for any indicators of biological activity to develop. Humans continued to
768 venture into the area bringing with them ready-made tools, including a handaxe, and sharp
769 flakes. At least one of the activities was butchery of bison and roe deer, as shown by cut-
770 marks on the bones. There is little evidence of knapping in the area, limited to resharpening
771 of tools, with only a thin distribution of artefacts and no refitting. The varied depth of the
772 artefacts shows that use of the area continued throughout the accumulation of the organic
773 mud. Thin sand lenses within the organic mud indicate occasional flooding, which may have
774 dispersed some of the artefacts across the area. Activity in the area continued at least until
775 the water body had completely infilled and dried out, when perhaps attention turned to
776 other abandoned channels on the river floodplain (Fig. 11d).

777

778

779 **7. Discussion**

780

781 Happisburgh Site 1 has been attributed to MIS 13 on lithostratigraphic and biostratigraphic
782 grounds and is one of several sites in Britain that date to this stage or to the start of MIS 12
783 (Fig. 12, Table 10). Comparisons can be made between the various lithic industries and
784 inferred behavioural traits, and also between the types of human habitat represented at
785 these sites, which include Warren Hill, High Lodge, Waverley Wood and Boxgrove. The
786 assemblage from Warren Hill was collected rather than excavated and therefore provides
787 more limited data about the technology, but it does contain important information about
788 handaxe and other tool forms (Wymer, 1985; Bridgland et al., 1995; Moncel et al., 2015;

789 Voinchet et al., 2015). The assemblage was recovered from sands and gravels attributed to
790 the lowest terrace of the Bytham River and dated to the end of MIS 13, or the beginning of
791 MIS 12. High Lodge lies 1 km to the north of Warren Hill and has two main assemblages. The
792 lower non-handaxe assemblage was excavated from the alluvial clays of Bed C, which are
793 attributed to floodplain sediments of the Bytham River during MIS 13 (Ashton et al., 1992;
794 for an alternative interpretation see West et al., 2014). The assemblage is in primary context
795 with refitting material. The higher handaxe assemblage (Bed E) is from the lowest part of a
796 sequence of glaciofluvial sands and gravels, which are attributed to MIS 12. The assemblage
797 is in a fresh to slightly rolled condition and might be derived from underlying sediments such
798 as Bed C or other floodplain sediments. The small assemblage from Waverley Wood was
799 collected from sands and gravels associated with a series of channel deposits that also have
800 been attributed to the Bytham River and dated to MIS 13 (Shotton et al., 1993; Keen et al.,
801 2006). Finally, the main assemblages from Boxgrove are all in primary context in lagoonal or
802 coastal plain sediments, again attributed to MIS 13 (Roberts and Parfitt, 1999).

803

804 **7.1. Lithic technology**

805 The technology at Happisburgh Site 1 has two components, the major one of which is core
806 and flake working with the production of simple flake tools. Small nodules were knapped
807 using a combination of single platform and alternate platform techniques with no evidence
808 of platform preparation. The flakes were removed in a methodical fashion from suitable
809 platforms and adapted as the shape of the core evolved, rather than any plan from
810 beginning to end. This characterises all Lower Palaeolithic core reduction in Britain and can
811 be clearly identified at High Lodge (Beds C and E), Boxgrove, Warren Hill and Waverley

812 Wood, and also in assemblages from MIS 11 sites, such as Barnham, Elveden and
813 Swanscombe (Conway et al., 1996; Ashton et al., 1998, 2005).

814

815 At Happisburgh Site 1, the products from the core reduction were a range of small flakes,
816 some of which were modified into flake tools. They consist of notches, denticulates and
817 marginally retouched pieces, with little consistency in form and modification occurring on
818 lateral, distal and occasionally proximal edges, predominantly on the dorsal face. As with
819 the core reduction, the *ad hoc* nature of their production is similar to most other Lower
820 Palaeolithic assemblages, including the few flake tools from Boxgrove and from Bed E at
821 High Lodge, but also the later assemblages at Barnham, Elveden and Swanscombe. Although
822 there are occasionally scrapers from the later sites there is still little consistency in form.

823

824 The flake tool assemblage from Bed C at High Lodge stands in stark contrast. Although
825 notches and denticulates contribute to the assemblage, there is also a series of finely-made
826 scrapers with invasive retouch usually executed on carefully selected dorsal edges. At the
827 nearby site of Warren Hill, the collected assemblage from the sands and gravels includes
828 scrapers of a similar form, with careful, invasive retouch. Although they are slightly abraded,
829 they have a close similarity to the scrapers from High Lodge, which strongly suggests that
830 they are derived from that site or a similar location nearby.

831

832 The second component of the Happisburgh Site 1 assemblages is the handaxe. The absence
833 of soft hammer flakes suggests that the handaxe was brought to the site. It is ovate in form
834 and similar to most other MIS 13 handaxes, such as those from Boxgrove and High Lodge
835 (Bed E). The majority of the handaxes from Warren Hill are also ovate in form, but there is a

836 second slightly more rolled component, consisting of handaxes that are more irregular in
837 shape, often retaining cortex, which may be earlier in date (Wymer, 1985; Moncel et al.,
838 2015). The small assemblage of handaxes collected from Waverley Wood includes finely-
839 made ovate handaxes on local erratics of good quality andesite, but also more irregular
840 handaxes made on poor raw materials of flint and quartzite. It seems that when good
841 quality raw material was available, ovate handaxes were the preferred form, as with other
842 MIS 13 sites.

843

844 In summary, there is a base core and flake technology, which underlies all the MIS 13
845 assemblages, but beyond that three groups of assemblages can be identified (Table 11).
846 Group 1 is possibly the oldest and may pre-date MIS 13. It consists of less regular handaxes,
847 sometimes more pointed in form, often retaining cortex on their butts and is found
848 intermixed with other groups at Warren Hill. There are similar handaxes in the assemblages
849 from the nearby sites of Brandon Fields and Maidscross Hill, which are probably from the
850 second (earlier) terrace of the Bytham River (Ashton and Lewis, 2005; Moncel et al., 2015;
851 Voinchet et al., 2015; Davis et al., 2017). Group 2 is characterised by the finely-made
852 scrapers at High Lodge (Bed C) which are also present in a derived context at Warren Hill.
853 This group probably dates to MIS 13. Group 3 forms the majority of the record, consisting of
854 assemblages with finely-made ovates, but with more *ad hoc* flake tools. The assemblages
855 include High Lodge (Bed E), a component of the Warren Hill assemblage, Waverley Wood,
856 Boxgrove and Happisburgh Site 1. They date either to MIS 13 or very early in MIS 12. The
857 dating of the three groups hints at a possible chronological pattern and might represent
858 different incursions into Britain at slightly different times, although a larger archaeological

859 dataset and much better dating resolution is needed before this pattern can be fully
860 examined.

861

862 It is also apparent from the British record that there is a marked increase in the number of
863 sites and the size of assemblages during MIS 13 compared with the earlier record, which is
864 limited to Happisburgh Site 3 and Pakefield (Parfitt et al., 2005, 2010). This is matched by
865 the fluvial archive, which shows a large increase in the number of artefacts recorded in river
866 terrace deposits that probably date to MIS 13, such as in the Middle Thames and Solent
867 river valleys (Ashton and Lewis, 2002; Ashton and Hosfield, 2010; Ashton et al., 2011; Davis,
868 2013).

869

870 **7.2. Human habitats**

871 Four of the British MIS 13 sites have environmental information that is associated with lithic
872 assemblages and enables the reconstruction of the human habitats. At Happisburgh Site 1
873 humans occupied an open floodplain close to its estuary, bordered by pine and birch forest.
874 Temperature estimates using Mutual Climatic Range (MCR) methods suggest average July
875 temperatures between 12 and 15°C and average January temperatures between -11 and -
876 3°C (Coope, 2006; Parfitt et al., in prep.). These compare with modern average July and
877 January temperatures of 17 and 3°C, indicating that summers and particularly winters were
878 considerably cooler than today.

879

880 The other MIS 13 sites provide a similar picture. The occupation at High Lodge during the
881 deposition of Bed C was on a floodplain with pools and marshland, and surrounding
882 vegetation dominated by pine and spruce together with juniper and heathland plants (Hunt,

883 1992). The MCR temperature estimates from the beetles show summers between 15 and
884 16°C and winters between -4 and 1°C (Coope, 2006). Little can be said about the handaxe
885 assemblage from Bed E as it is probably derived from underlying sediment.

886

887 Virtually all the artefacts from Waverley Wood were found in gravel spoil heaps, but a small
888 quartzite flake was recovered *in situ* from one of a series of four organic-rich channels
889 (Shotton et al., 1993; Keen et al., 2006). The combined evidence from the floral and faunal
890 remains shows a sluggish river with ox-bow lakes and marshland supporting a variety of
891 vegetation from pondweeds, reeds, sedges and grassland meadows with woodland of pine,
892 spruce and birch beyond. Generally the MCR estimates from the beetles show conditions
893 similar to northern England today with mean July temperatures of 15°C. Winter
894 temperatures were cool, but no estimates were provided.

895

896 Most of the archaeological assemblages from Boxgrove were found in the lagoonal silts of
897 units 4b and the palaeosol of unit 4c. The rich array of microfauna, molluscs and vertebrates
898 shows the change from grasslands around the coastal lagoons and ponds to the incursion of
899 some open scrub and mixed woodland (Parfitt, 1999; Holmes et al., 2010). The mammalian
900 evidence suggests a slightly cooler climate than present. This is supported by the Mutual
901 Ostracod Temperature Range (MOTR) estimates of 14 to 20°C for July and -4 to 4°C for
902 January (Holmes et al., 2010; Whitaker and Parfitt, 2017). Artefacts from slope deposits
903 higher in the sequence (units 8 and 11) show that humans continued to inhabit the area
904 during a complex series of oscillations as overall climate deteriorated into MIS 12 (Roberts
905 and Parfitt, 1999).

906

907 There is a remarkably consistent picture of the environments associated with the MIS 13
908 human occupation of Britain. The evidence is associated with either open, river valleys in
909 both estuarine and upstream locations, or in coastal grasslands and scrub associated with
910 lagoons and freshwater pools. Surrounding vegetation seems to have been largely
911 coniferous woodland, which accords with the evidence of both cooler summers and winters
912 than today. Inevitably this leads to questions about how humans survived the long, cool
913 winters and how this relates to the emergence of new technologies from MIS 13 or slightly
914 earlier. It is even possible that the signals of early human presence were left by hominins
915 who ventured into these northern areas in summers only and overwintered somewhat
916 further to the south. To try and address these questions a wider range of sites from across
917 Europe can be considered.

918

919 **7.3. Humans in Europe at the end of the early Middle Pleistocene**

920 During MIS 13 Britain was a peninsula of north-west Europe with a permanent land-bridge
921 providing easy access for human groups from Europe (Smith, 1985; Gibbard, 1995;
922 Toucanne et al., 2009; Ashton et al., 2011). In Britain there seems to have been a marked
923 increase in the size and number of sites from MIS 13 onward, which was coincident with the
924 introduction of handaxe technology. Can a similar record be identified in mainland Europe?

925

926 Unfortunately, comparison with other sites in Europe is difficult due to the paucity of
927 assemblages that can be securely dated to MIS 13. In north-west Europe the record is
928 limited to both old and new sites in the Somme Valley (France; Fig. 12). New fieldwork at
929 Carrière Carpentier in Abbeville has dated the fluvial sediments to MIS 15, and these
930 underlie deposits that are thought to have contained the handaxes that were collected in

931 the 19th and early 20th centuries (Antoine et al., 2015, 2016). The handaxes, which have
932 been cautiously attributed to MIS 14, are predominantly ovate in form (Tuffreau and
933 Antoine, 1995). Upstream in Amiens the site of Rue du Manège has been assigned to MIS
934 13, but so far only a few artefacts and no handaxes have been recovered (Antoine et al.,
935 2015). The best excavated assemblages are from the nearby sites at Cagny-la-Garenne,
936 which have been attributed to early MIS 12 (Antoine et al., 2007, 2015). The sites have been
937 described as workshop locations that used the flint eroding out from nearby Chalk for the
938 production of a range of handaxes, from crude unfinished forms to more refined elongated
939 cordiforms (Tuffreau, 1981; Antoine and Tuffreau, 1993; Lamotte and Tuffreau, 2001a,
940 2001b; Tuffreau and Lamotte, 2010). The core technology is similar to that found in Britain
941 with alternate and single platform technique, but also a possible ephemeral use of Levallois-
942 like technology. Flake tools consist of notches, denticulates and occasional scrapers. The
943 sites at Cagny-la-Garenne are difficult to compare to other sites because they are workshop
944 locations. However, there are ovate handaxes from other sites in the Somme valley, such as
945 Abbeville, which probably date to MIS 14 and show similarities to the handaxes from Britain
946 (Antoine et al., 2016).

947

948 For southern Europe there is an intermittent record of handaxe technology or bifacial
949 working of tools from as early as 900 ka (Mosquera et al., 2013; Moncel et al., 2015). At La
950 Boella near Taragona (Spain) two crude bifacial tools were found in Early Pleistocene
951 sediments (Vallverdú et al., 2014). But this seems to be an isolated record and it is not until
952 about 700–600 ka that a large handaxe assemblage occurs at La Noira in the Cher Valley
953 (France) with ESR dates on quartz of 690 ± 80 ka (Despriée et al., 2011; Moncel et al., 2013).
954 The assemblage of handaxes, cores and flake tools was made on slabs of local siliceous

955 'millstone'. In many cases the form of the slabs has influenced the shape of the handaxes. A
956 further occurrence of early handaxe technology occurs at Caune de l'Arago in Tautavel,
957 southern France (Barsky and de Lumley, 2010; Barsky, 2013). In units I and II, attributed to
958 MIS 14 and 13, handaxes, sometimes made on local pebbles, occur alongside crudely-
959 shaped cleavers. In southern Italy, Notarchirico has been dated to ca 650 ka, where
960 chopping tools, cleavers and occasional crude handaxes were made on quartzite, limestone
961 and flint pebbles (Lefèvre et al., 2010). In all these cases raw material has heavily influenced
962 the final handaxe forms.

963

964 Galería II at Atapuerca (northern Spain) shows the sudden introduction of handaxe
965 technology at about 500 ka after an apparent gap in human presence of over 300 ka (Ollé et
966 al., 2013). Shaped cobbles, but also distinct handaxes, were made on local chert, quartzite
967 and sandstone. Sites of a similar age to Galería II with occasional evidence of handaxe
968 technology include Aldène in France (Rossoni-Notter et al., 2016), and the Italian sites of
969 Loreto (Mussi, 1995; Muttoni et al., 2009) and Fontana Ranuccio (Lefèvre et al., 2010).
970 These sites, together with those of a later date, provide some evidence of a shift in the scale
971 of occupation in southern Europe from about 500 ka.

972

973 Very few of the sites on mainland Europe have an environmental record that allows detailed
974 reconstruction of the human habitat. From sites such as Caune de l'Arago there does seem
975 to have been persistent occupation through cold stages correlated to MIS 14 and MIS 12,
976 and it is perhaps these southern areas that were the refugia for human populations from
977 the north. Survival in southern Europe would have led to adaptations and innovations that
978 were critical to coping with northern Europe during periods of cooler climate.

979
980 It is currently difficult to discern exactly when new technologies were introduced, but there
981 does seem to have been a suite of innovations and behaviours that emerged between 600
982 and 400 ka (Mosquera et al., 2013; Ashton, 2015). Handaxes provided custom-made,
983 curatable tools for butchery, for which there is abundant evidence; systematic carcass
984 processing has been described for both Boxgrove and Atapuerca (Roberts and Parfitt, 1999;
985 Ollé et al., 2013). The overprinting of cut-marks from butchery by hyaena gnawing at
986 Boxgrove also shows that humans were probably the top carnivore by 500 ka. Evidence of
987 hunting may be shown by a probable puncture wound in a horse scapula caused by a spear
988 (Roberts and Parfitt, 1999, but see Gaudzinski-Windheuser et al., 2018; Milks, 2018). Direct
989 evidence of wooden spears comes from the later site of Clacton at 400 ka (Warren, 1911;
990 Oakley et al., 1977). Hunting provided access not only to meat, but also to hides, as strongly
991 suggested by the butchering patterns described for horses from the later (MIS 9) site
992 Schöningen (Germany), indicative of careful removal of the skins of these animals
993 (Voormolen, 2008; Van Kolfschoten et al., 2015). Although there is no direct evidence of
994 hide use, the refined scrapers at High Lodge and Warren Hill at ca 500 ka perhaps reflect
995 hide processing and use as clothing or shelter, although there is only equivocal evidence for
996 the existence of archaeologically visible dwelling structures. Evidence for the controlled use
997 of fire is lacking until ca 400 ka with the possible hearths at Beeches Pit (UK: Gowlett et al.,
998 2005; Preece et al., 2006, 2007) and at Menez Dregan (France: Monnier et al., 1998; Molines
999 et al., 2005). Its rarity suggests that it may not have been a persistent behaviour in Europe
1000 till much later (Roebroeks and Villa, 2011), an observation also made on the basis of
1001 evidence from the Levant (Shimelmitz et al., 2014).

1002

1003 A final innovation may have been increased mobility. Handaxes lent themselves to planned
1004 use beyond the raw material source, which may have been linked to strategies for hunting,
1005 rather than chance-encounter scavenging. Improved mobility also provided greater
1006 flexibility in acquiring plant (Henry et al., 2014) and animal resources at times of scarcity,
1007 which would have been important in the seasonal environments of Europe. Evidence of such
1008 movement is scarce, but hints come from sites such as Caune de l'Arago (France), where
1009 some good quality flint was transported over distances of ca 30 km to the site (Barsky and
1010 de Lumley, 2010). At Waverley Wood, the flint handaxes may have been transported over
1011 an even greater distance, in excess of 100 km (Keen et al., 2006). Both Boxgrove and to
1012 some extent Happisburgh Site 1 show the recurrent usage of specific parts of a landscape,
1013 possibly indicating organisation of activities around such foci (Roberts and Parfitt, 1999),
1014 while Arago and Galeria II also show the careful repetitive selection of raw materials (Barsky
1015 and de Lumley, 2010; Ollé et al., 2013). All these sites contribute to a growing body of
1016 evidence that shows a more logistical use of the landscape and its resources as part of the
1017 introduction of new technologies from ca 500 ka.

1018

1019 It has been suggested that these innovations and changes in human behaviour correspond
1020 to the arrival of *Homo heidelbergensis* in Europe (Stringer, 2011; Mosquera et al., 2013; Ollé
1021 et al., 2013; Ashton, 2015). However, recent research has thrown into some doubt the
1022 origins and validity of *H. heidelbergensis* as a single species (Stringer, 2012; Manzi, 2016)
1023 and has stressed the high antiquity of the Neanderthal lineage, back to the beginning of the
1024 Middle Pleistocene (Meyer et al., 2016; Roebroeks and Soressi, 2016). More human fossil
1025 evidence is required before firmer links can be made between the suite of innovations that

1026 appear in Europe during the later part of the early Middle Pleistocene and particular
1027 hominin species.

1028

1029

1030 **8. Conclusion**

1031 Happisburgh Site 1 is one of several British sites that make a major contribution to our
1032 understanding of the first adaptations of humans to northern Europe ca 500 ka. The site
1033 provides important evidence on human habitats that reinforces a pattern from other sites of
1034 human adaptation to cool summers and cold winters. The change in scale of occupation at
1035 500 ka is particularly marked, with generally larger sites and possibly more persistent
1036 occupation. It needs to be established whether the morphological changes associated with
1037 the beginning of the Neanderthal lineage may have been a biological adaptation to the
1038 colder settings of the middle latitudes, with the robust Boxgrove tibia having been
1039 interpreted as reflecting cold-adapted body proportions (Stringer et al., 1998). Alongside
1040 biological adaptations, there may have been innovations in the behavioural domain, such as
1041 hunting, more systematic butchery, hide-processing, thermal buffering through clothing and
1042 shelter and eventually the occasional use of fire. The focus on coastal and riverine
1043 environments so visible in the British, as well as the wider European, record may reflect a
1044 preference for oceanic regimes as well as diverse food and raw material resources offered
1045 by these locations (Cohen et al., 2012). This was arguably part of a more logistical use of
1046 landscapes providing greater flexibility in times of resource stress. More direct evidence of
1047 how humans coped with the cold, long winters of northern Europe, including biological
1048 adaptations, is still required, but continued work on the Cromer Forest-bed Formation, with

1049 its exceptional preservation of organic materials, provides an ideal opportunity for
1050 answering this question.

1051

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1065

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1562
1563 Wymer, J.J., 1985. Palaeolithic Sites of East Anglia. Geo Books, Norwich.
1564

1565 **Figure captions**

1566

1567 Figure 1. Location of Happisburgh Sites 1, 2 and 3, boreholes completed during this
1568 investigation, borehole HC (West, 1980) and borehole records held in the British Geological
1569 Survey database. Scale and orientation indicated by 1 km National Grid (Ordnance Survey).

1570

1571 Figure 2. Happisburgh Site 1: a, excavation of Area I in 2004; b, excavation of surface of the
1572 organic mud (Low Lighthouse Member of the CF-bF) in 2004; c, close-up of upper part of the
1573 organic mud in HAP10-L7 (2010), showing position of micromorphology samples M2 and
1574 M3, and palaeomagnetic samples; the contact with overlying Happisburgh Till is at the top
1575 of image; d, View of Site 1 in 2007 showing outcrop of organic mud (Low Lighthouse
1576 Member) on the foreshore. Photos: a, b and d, Nigel Larkin; c, Wil Roebroeks.

1577

1578 Figure 3. Happisburgh 1 site plan, showing location of AHOB 2004 and University of Leiden
1579 2009–2012 excavation trenches and boreholes. The approximate location of the handaxe
1580 discovery in 2000 is also shown. Scale and orientation indicated by 100 m National Grid
1581 (Ordnance Survey).

1582

1583 Figure 4. Schematic cross-section from Cart Gap to Ostend showing the disposition of the
1584 main Pleistocene deposits, based on boreholes completed during this investigation and from
1585 the BGS borehole database. Bed designations in borehole HC from West (1980).

1586

1587 Figure 5. Section showing Pleistocene deposits at Happisburgh Site 1 exposed in the cliffs
1588 and observed in excavation trenches and boreholes. 0 on the horizontal scale bar in the
1589 upper panel is approximately 100 m from the end of the Cart Gap sea wall (TG 3927 3033).

1590

1591 Figure 6. Composite log based on boreholes 12/1, 2 and 4 through the grey sand and organic
1592 mud (Low Lighthouse Member) at Happisburgh Site 1.

1593

1594 Figure 7. Trenches HAP10-L7 and HAP11-1 showing particle-size distributions (percentage
1595 sand, silt and clay), organic carbon (% OM) and colour properties and position of
1596 micromorphology samples 1–5 in HAP10-L7.

1597

1598 Figure 8. AHOB 2004 excavation area (Area I) and test pits, boreholes and sections recorded
1599 in the vicinity of Area 1.

1600

1601 Figure 9. Palaeomagnetic results from Happisburgh Site 1: a, typical TH Zijdeveld diagram of
1602 sample H14 (for NRM values see Table 3); b, typical AF Zijdeveld diagram of sample H214
1603 showing GRM (this sample was taken at same level as sample H14 and no ChRM was
1604 determined); c, another clear example of GRM in Zijdeveld diagram of sample H225, no
1605 ChRM was determined; d, characteristic Remanent Magnetization (ChRM) directions for
1606 HAP10-L7 (with maximal angular deviation (MAD) < 15°, $n = 24$) projected in a stereogram
1607 with full circles having positive inclinations (for individual directions see Table 3; mean
1608 declination is 15.6°, mean inclination 71.2°).

1609

1610 Figure 10. Core, flakes, flake tools, refitting group and handaxe from Happisburgh Site 1: a,
1611 alternating platform core; b, flake with denticulated edge; c, flake with single notch; d, flake;
1612 e, flake with multiple notches; f, flake; g, refitting group (arrows A and B indicate direction
1613 of flake removals); h, handaxe found in 2000 at Happisburgh Site 1. Photos: Jordan
1614 Mansfield (a-f), Craig Williams (g), British Museum (h).

1615

1616 Figure 11. Reconstruction of the development of the local landscape, depositional sequence
1617 and archaeological assemblages at Happisburgh Site 1. See Section 6.5 for discussion.

1618

1619 Figure 12. Locations of key European sites discussed in the text.

1620

1621 **Table captions**

1622 Table 1. The Pleistocene succession at Happisburgh Site 1, after Lee et al. (2004a, 2017), but
1623 retaining the use of the term 'till'. See Table 4 for details on the Low Lighthouse Member of
1624 the Cromer Forest-bed Formation.

1625

1626 Table 2. Clast lithological analysis of the grey sand at Happisburgh Site 1.

1627

1628 Table 3. Results of thermal (TH) demagnetisation analyses of samples from HAP10-L7 (TH
1629 steps: 20, 90, 120, 150, 180, 210, 240, 260, 280, 300, 310, 320, 330, 340 and 350 °C).

1630

1631 Table 4. Definition of the Low Lighthouse Member of the Cromer Forest-bed Formation.

1632

1633 Table 5. Artefact types present in the AHOB, Leiden and Norfolk Museums Service (NMS)
1634 assemblages.

1635

1636 Table 6. Condition of flakes and flake tools from the AHOB and Leiden assemblages.

1637

1638 Table 7. Dimensions of all flakes and flake tools, and complete flakes and flake tools from
1639 the AHOB and Leiden assemblages.

1640

1641 Table 8. Flake technological attributes for the AHOB and Leiden assemblages, where
1642 attributes can be characterised.

1643

1644 Table 9. Comparison of condition of flakes and flake tools from channel edge and mid-
1645 channel positions.

1646

1647 Table 10. Principal MIS 13 or early MIS 12 archaeological sites in Britain.

1648

1649 Table 11. Suggested age and characteristics of assemblages from MIS 13 or early MIS 12
1650 sites in Britain.

1651

Table 1.

Stratigraphic units at				
Happisburgh Site 1	Member	Formation		
		Glacial	Freshwater	Marine
	Lowestoft Till	Lowestoft		
	Corton Sand			
	Corton Till	Corton		
	Happisburgh Sand			
	Ostend Clay	Happisburgh		
Happisburgh Till	Happisburgh Till			
organic mud	Low Lighthouse		Cromer	
grey sand (part)			Forest-bed	
grey sand (part)				Wroxham Crag

Table 2.

Sample	Schorlrite	Quartzite	Vein quartz	Total flint	(PM flint as % total flint)	Carboniferous chert	Green-sand chert	<i>Rhaxella</i> chert	Silicified limestone	Sandstone	Igneous & meta-morphic	TOTAL
11.2-16.0mm												
HAP-09 A	0.0	7.9	17.2	55.7	(8.4)	4.3	0.6	0.0	1.9	12.1	0.4	535
HAP-09 B	0.6	10.0	13.8	55.5	(8.9)	6.8	0.8	0.0	4.4	8.1	0.0	849
HAP10-L9	0.2	13.5	19.3	55.4	(8.2)	3.7	0.7	0.2	2.0	4.6	0.4	460
HAP12-L3	0.0	8.0	12.6	58.6	(7.7)	4.7	0.1	0.0	1.3	14.5	0.1	771
12/1 13.7m	0.0	7.4	18.5	63.0	(17.6)	7.4	0.0	0.0	0.0	3.7	0.0	27
12/1 17.5-18.0m	0.0	5.0	25.0	60.0	(50.0)	5.0	0.0	0.0	0.0	5.0	0.0	20
12/1 18.0-18.5m	0.0	25.8	16.1	48.4	(33.3)	3.2	0.0	0.0	0.0	6.5	0.0	31
12/1 17.5-18.5m	0.0	17.6	19.6	52.9	(33.3)	3.9	0.0	0.0	0.0	5.9	0.0	51
12/2 4.6-5.0m	0.0	9.6	16.3	65.4	(8.8)	1.9	0.0	1.0	1.0	4.8	0.0	104
12/2 6.0-6.2m	0.0	20.7	9.1	48.2	(7.6)	7.9	0.6	0.0	1.8	11.6	0.0	164
12/2 6.2-6.5m	0.0	9.3	25.5	54.7	(12.5)	5.6	0.0	0.0	0.6	4.3	0.0	161
12/2 6.5-7.0m	0.0	7.4	15.7	54.4	(11.0)	3.2	0.9	0.5	1.4	16.6	0.0	217
12/2 7.5-8.0m	0.0	9.4	21.3	46.8	(10.0)	5.5	1.3	0.4	2.1	13.2	0.0	235
12/4 4.2-4.5m	0.0	8.9	14.3	53.6	(10.0)	12.5	0.0	0.0	5.4	5.4	0.0	56
12/4 4.5-5.0m	0.0	8.0	22.5	60.1	(13.3)	3.6	0.0	0.0	0.0	5.8	0.0	138
12/4 4.2-5.0m	0.0	8.2	20.1	58.2	(12.4)	6.2	0.0	0.0	1.5	5.7	0.0	194
8.0-11.2mm												
12/1 13.7m	0.0	8.3	11.7	63.3	(2.6)	5.0	0.0	0.0	5.0	6.7	0.0	60
12/1 17.5-18.0m	0.0	25.0	12.5	41.7	(20.0)	8.3	0.0	0.0	0.0	12.5	0.0	24
12/1 18.0-18.5m	0.0	19.7	32.8	36.1	(4.5)	3.3	0.0	0.0	1.6	6.6	0.0	61
12/1 17.5-18.5m	0.0	21.2	27.1	37.6	(0.0)	4.7	0.0	0.0	1.2	8.2	0.0	85
12/2 4.6-5.0m	0.0	6.0	6.4	74.5	(3.6)	6.7	1.0	0.0	2.3	3.0	0.0	298
12/2 6.0-6.2m												
12/2 6.2-6.5m	1.0	12.1	27.1	50.2	(8.7)	3.9	0.0	0.0	0.5	5.3	0.0	207
12/2 6.5-7.0m	0.0	14.2	22.4	53.6	(10.1)	4.4	0.0	0.0	1.3	4.1	0.0	388
12/2 7.5-8.0m	0.6	6.7	28.1	52.9	(9.8)	5.8	0.0	0.3	0.6	4.9	0.0	327
12/4 4.2-4.5m	0.0	8.6	11.2	62.9	(4.1)	9.5	0.0	0.0	0.9	6.9	0.0	116
12/4 4.5-5.0m	0.0	7.0	14.4	64.7	(6.2)	9.0	0.5	0.0	3.0	1.5	0.0	201
12/4 4.2-5.0m	0.0	7.6	13.2	64.0	(5.4)	9.1	0.3	0.0	2.2	3.5	0.0	317

8.0-16.0mm

12/1 13.7m	0.0	8.0	13.8	63.2	(7.3)	5.7	0.0	0.0	3.4	5.7	0.0	87
12/1 17.5-18.0m	0.0	15.9	18.2	50.0	(36.4)	6.8	0.0	0.0	0.0	9.1	0.0	44
12/1 18.0-18.5m	0.0	21.7	27.2	40.2	(16.2)	3.3	0.0	0.0	1.1	6.5	0.0	92
12/1 17.5-18.5m	0.0	19.9	24.3	43.4	(0.0)	4.4	0.0	0.0	0.7	7.4	0.0	136
12/2 4.6-5.0m	0.0	7.0	9.0	72.1	(4.8)	5.5	0.7	0.2	2.0	3.5	0.0	402
12/2 6.0-6.2m	0.0	20.7	9.1	48.2	(7.6)	7.9	0.6	0.0	1.8	11.6	0.0	164
12/2 6.2-6.5m	0.5	10.9	26.4	52.2	(10.4)	4.6	0.0	0.0	0.5	4.9	0.0	368
12/2 6.5-7.0m	0.0	11.7	20.0	53.9	(10.4)	4.0	0.3	0.2	1.3	8.6	0.0	605
12/2 7.5-8.0m	0.4	7.8	25.3	50.4	(9.9)	5.7	0.5	0.4	1.2	8.4	0.0	562
12/4 4.2-4.5m	0.0	8.7	12.2	59.9	(5.8)	10.5	0.0	0.0	2.3	6.4	0.0	172
12/4 4.5-5.0m	0.0	7.4	17.7	62.8	(8.9)	6.8	0.3	0.0	1.8	3.2	0.0	339
12/4 4.2-5.0m	0.0	7.8	15.9	61.8	(7.9)	8.0	0.2	0.0	2.0	4.3	0.0	511

Table 3.

Sample	Declination	Inclination	NRM at 20 °C (µA/m)	Maximum angular deviation	Forced to origin	Number of steps	Min Step (°C)	Max Step (°C)	Unit
H01	62.13	64.97	41096.68	2.33	FALSE	9	210	340	organic mud
H02	46.08	44.55	1046.24	23.00	FALSE	5	210	310	organic mud
H03	5.71	59.33	641.92	16.59	FALSE	4	150	240	Happisburgh Till
H04	353.03	57.92	6448.87	17.36	TRUE	7	210	320	Happisburgh Till
H05	0.26	66.17	3977.85	1.86	TRUE	4	180	260	Happisburgh Till
H06	7.13	54.50	6580.83	2.55	TRUE	6	150	280	Happisburgh Till
H07	19.61	62.09	404.53	11.18	FALSE	6	150	280	Happisburgh Till
H08	343.69	48.45	1425.14	6.82	FALSE	11	150	340	Happisburgh Till
H09	355.71	66.18	3082.71	2.86	FALSE	12	150	350	Happisburgh Till
H10	17.36	56.16	6382.85	6.69	FALSE	12	150	350	organic mud
H11	14.03	68.71	7259.33	4.21	FALSE	11	150	350	organic mud
H12	323.72	66.01	7399.85	10.18	FALSE	8	150	310	organic mud
H13	2.12	73.50	4279.73	2.23	FALSE	11	180	350	organic mud
H14	351.28	74.46	8134.43	1.97	FALSE	12	150	350	organic mud
H15	18.47	67.96	25069.67	3.23	FALSE	12	150	350	organic mud
H16	7.85	63.26	9262.17	2.01	FALSE	11	150	340	organic mud
H17	358.90	67.91	5718.39	2.42	FALSE	11	180	350	organic mud
H18	356.79	71.34	15022.86	8.51	FALSE	12	150	350	organic mud
H19	42.62	86.13	5429.29	2.75	FALSE	11	180	350	organic mud
H20	15.07	68.20	4433.75	2.95	FALSE	12	150	350	organic mud
H21	353.07	67.70	21594.67	3.70	FALSE	12	150	350	organic mud
H22	48.70	67.15	2305.83	4.77	FALSE	10	180	340	organic mud
H23	187.91	60.90	1547.05	15.87	FALSE	9	180	330	organic mud
H24	335.74	74.98	2729.53	5.85	FALSE	8	150	330	organic mud
H25	63.02	62.46	2128.43	3.85	FALSE	11	180	350	organic mud
H26	35.48	62.97	4768.83	1.24	FALSE	12	150	350	organic mud
H27	17.17	52.30	4767.55	5.89	FALSE	8	150	350	organic mud
H28	351.90	69.53	37520.46	5.74	FALSE	8	180	320	organic mud
H29	6.82	64.34	4163.38	5.52	FALSE	10	180	340	organic mud
H30	24.46	70.49	2975.73	1.60	FALSE	11	180	350	organic mud
H31	23.78	66.47	4998.42	2.43	FALSE	9	150	320	organic mud
H32	139.76	64.61	3532.91	2.65	FALSE	8	180	320	organic mud
H33	318.23	73.30	4463.45	5.32	FALSE	11	180	350	organic mud

Table 4.

Formation:	Cromer Forest-bed
Member:	Low Lighthouse (named after the former lighthouse, now lost to coastal erosion, but was located on the cliff top at TG 3909 3044).
Type locality:	Happisburgh, Norfolk. Trench HAP11-L1 located at TG 3889 3055.
Upper boundary:	Contact of organic mud with Happisburgh Till (Happisburgh Till Member) of the Happisburgh Formation.
Lower boundary:	Base of organic mud in HAP11-L1.
Thickness:	2.0 m in HAP11-L1, maximum observed thickness 2.6 m (BH 12/1).
Lithological characteristics:	Very dark grey to black, massive silts or sandy silts, sandier at top and base, with variable organic carbon content up to 35%, though more typically around 10%. Macroscopic wood fragments and other macro and microscopic plant remains are present, particularly in the upper part. Fossil vertebrate remains and lithic artefacts are also present.
Distribution:	This unit is present beneath the modern sand and shingle beach and foreshore within the embayment between Happisburgh and Cart Gap. The south easterly limit of the unit is in BH 12/4 and its north easterly limit is at trench HAP10-L8, and it has a lenticular geometry. To seaward the extent of the deposits is, or was, as least to TG 3884 3069, though these sediments are vulnerable to wave erosion. Observations by Reid (1890, p. 173) may indicate that equivalent deposits were exposed "at the foot of the beach" around TG38893082 suggesting that these sediment extended at least 100–130 m to seaward of the current foreshore outcrop. The landward extent is known from BH 12/1 (TG 3889 3052). Geophysical surveys indicate that this unit may be traceable further inland.
Age:	early Middle Pleistocene

Table 5.

Method	AHOB (organic mud)		Leiden (grey sand)		NMS (organic mud or surface)	
	Sieved (1 mm mesh)		Sieved (10 mm mesh)		Surface collected	
	<i>n</i>	%	<i>n</i>	%	<i>n</i>	%
Types						
Flake	36	16.5	134	61.5	41	75.9
Chip	172	78.9	44	20.2	0	0
Knapping Frag	4	1.8	15	6.9	3	5.6
Handaxe	0	0.0	0	0.0	1	1.9
Flake tool	4	1.8	19	8.7	7	13
Core	0	0.0	6	2.8	2	3.7
Struck flake	2	0.9	1	0.5	0	0.0
Total	218		219		54	
Main types						
Flake	36	90.0	134	84.3	41	80.4
Handaxe	0	0.0	0	0.0	1	2.0
Flake tool	4	10.0	19	11.9	7	13.7
Core	0	0.0	6	3.8	2	3.9
Total	40		159		51	
Flake tools						
Denticulate	3		5		3	
Notch	0		6		2	
Marginal retouch	1		7		0	
Scraper	0		1		0	

Table 6.

		AHOB		Leiden	
		<i>n</i>	%	<i>n</i>	%
Condition	Mint	14	35.9	58	40.0
	Fresh	23	59.0	81	55.9
	Slightly rolled	2	5.1	5	3.4
	Rolled	0	0.0	1	0.7
Breakage	Complete	47	44.3	96	48.5
	Broken	58	55.7	102	51.4

Table 7.

Measurements (mm/g)	AHOB			Leiden		
	mean	sd	n	mean	sd	n
All flakes						
Maximum Length	33.9	17.4	39	35.8	10.9	145
Length	33.2	14.5	39	30.4	10.5	145
Width	30.9	11.8	39	28.6	10.6	145
Thickness	10.0	6.2	39	9.3	5.3	145
Weight	11.9	14.0	39	8.5	9.0	145
Butt Width	15.6	10.0	28	16.3	9.5	101
Butt Thickness	7.7	4.8	28	7.2	5.0	101
Complete flakes						
Maximum Length	35.1	18.0	28	37.0	11.1	100
Length	34.2	14.6	28	31.7	10.4	100
Width	33.4	12.1	28	29.4	11.3	100
Thickness	10.9	6.5	28	10.0	5.6	100
Weight	13.3	14.7	28	10.0	10.0	100

Table 8.

Flake technology		AHOB		Leiden	
		<i>n</i>	%	<i>n</i>	%
Cortex	100% cortex	3	7.7	11	7.6
	>50% cortex	8	20.5	34	23.4
	<50% cortex	18	46.2	45	31.0
	No cortex	10	25.6	55	37.9
Number of dorsal scars	0	4	10.3	22	15.2
	1	8	20.5	37	25.5
	2	8	20.5	45	31.0
	3	11	28.2	18	12.4
	4	5	12.8	12	8.3
	5	2	5.1	5	3.4
	6	0	0.0	2	1.4
	7	1	2.6	3	2.1
	8	0	0.0	1	0.7
Dorsal scar pattern	1 – proximal	17	43.6	53	36.6
	2 – proximal, L/R lateral	4	10.3	28	19.3
	3 – proximal, L+R lateral	1	2.6	2	1.4
	4 – proximal, L/R lateral, distal	3	7.7	3	2.1
	5 – L/R lateral	5	12.8	22	15.2
	6 – distal	0	0.0	5	3.4
	7 – proximal, distal	1	2.6	3	2.1
	8 – L+R lateral	2	5.1	3	2.1
	9 – proximal, L+R lateral, distal	4	10.3	2	1.4
	10 – cortical	1	2.6	20	13.8
	11 – L/R lateral, distal	1	2.6	4	2.8
	12 – L+R lateral, distal	0	0.0	0	0.0
Butt type	Plain	19	52.8	69	54.3
	Dihedral	6	16.7	19	15.0
	Cortical	7	19.4	20	15.7
	Natural	2	5.6	5	3.9
	Marginal	1	2.8	11	8.7
	Soft hammer	0	0.0	0	0.0
	Mixed	1	2.8	3	2.4

Table 9.

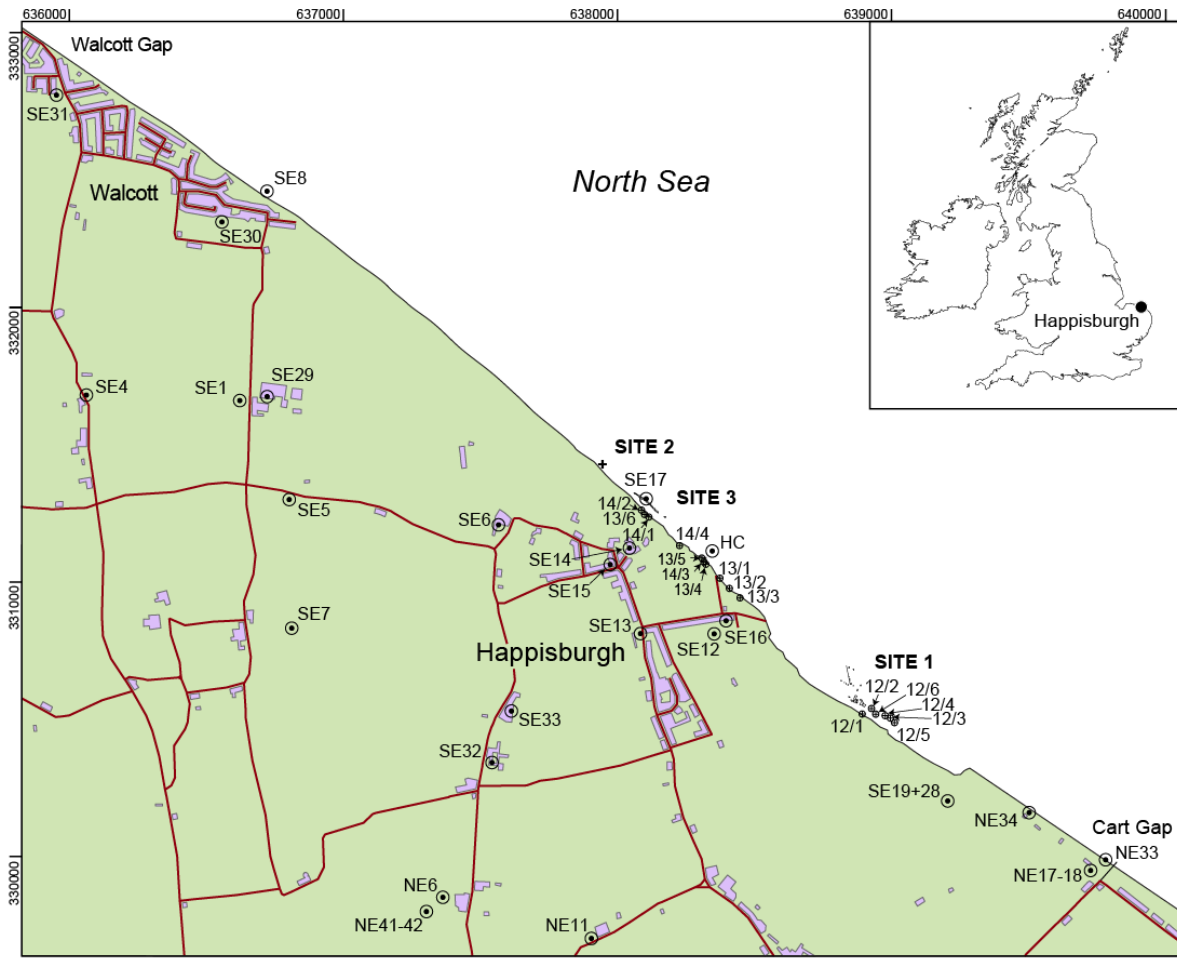
Condition	Channel edge		Mid-channel	
	<i>n</i>	%	<i>n</i>	%
Mint	50	48.5	7	18.4
Fresh	50	48.5	30	78.9
Slightly rolled	3	2.9	1	2.6
Rolled	0	0	0	0
Total	103		38	

Table 10.

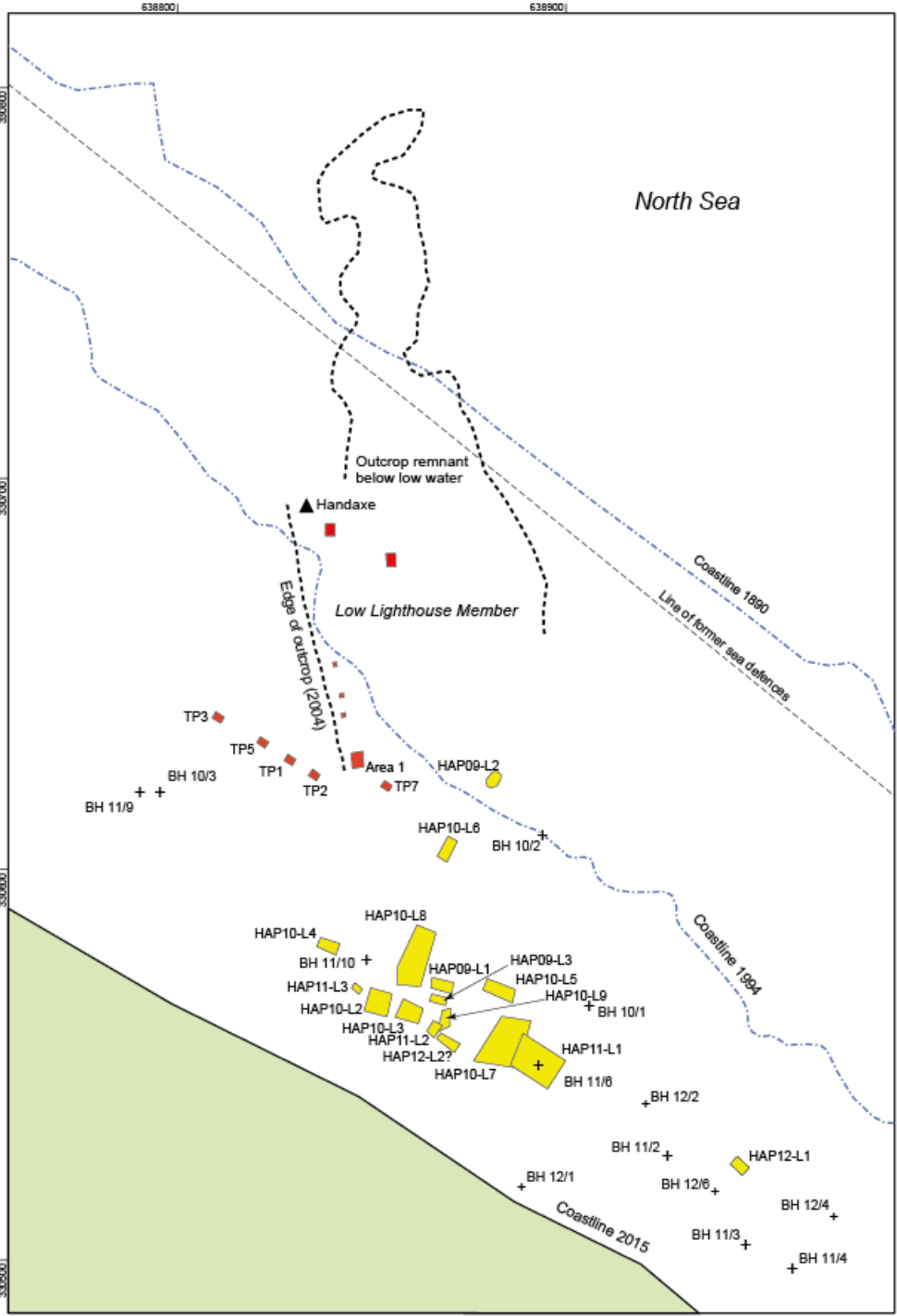
Assemblage	Age	Method	Core technology	Flake tools	Handaxes
Happisburgh Site 1	MIS 13	Excavated	Alternate and single platform	<i>ad hoc</i> tools	Ovate (1)
Boxgrove	MIS 13	Excavated		<i>ad hoc</i> tools	Ovates
Waverley Wood	MIS 13	Collected	Alternate and single platform	Refined scrapers	Mixed
Warren Hill	MIS 13/12	Collected			Ovates/irregular forms
High Lodge (Bed C)	MIS 13	Excavated	Alternate and single platform	Refined scrapers	-
High Lodge (Bed E)	MIS 13/12	Excavated	Alternate and single platform	<i>ad hoc</i> tools	Ovates

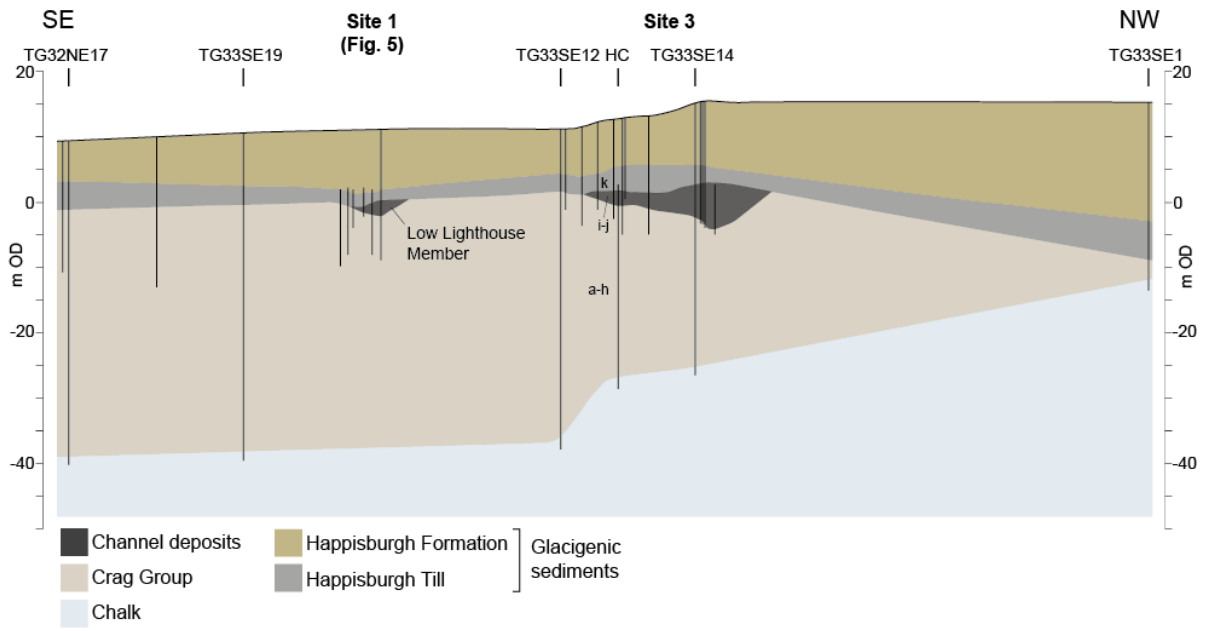
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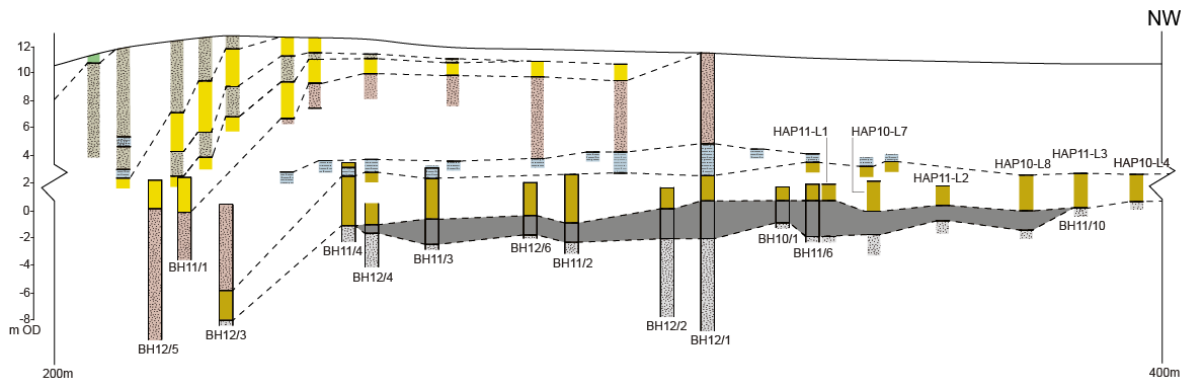
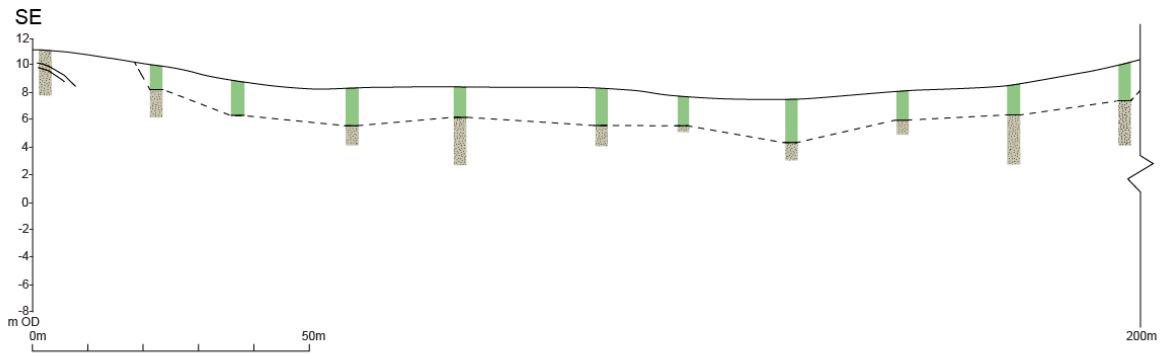
Group	Sites	Assemblage Age	Assemblage characteristics
Group 1	Warren Hill	MIS 13 or earlier	Irregular handaxes with cortex
Group 2	High Lodge (Bed C)	MIS 13	Alternate and single platform technique; finely made scrapers
	Warren Hill	MIS 13	
Group 3	Boxgrove	MIS 13	Alternate and single platform technique; <i>ad hoc</i> flake tools; ovate handaxes
	High Lodge (Bed E)	MIS 13/12	
	Warren Hill	MIS 13/12	
	Waverley Wood	MIS 13	
	Happisburgh Site 1	MIS 13	



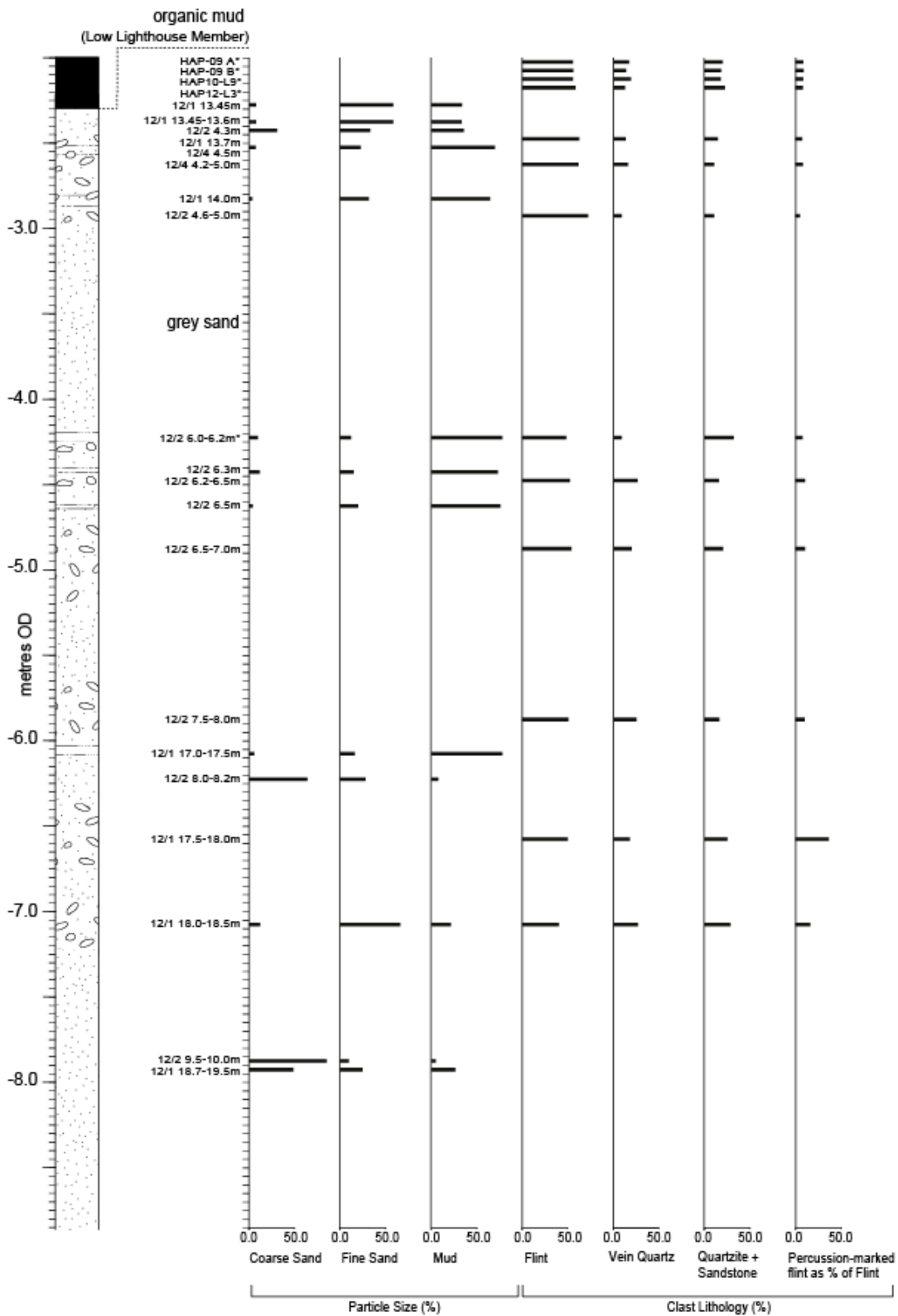


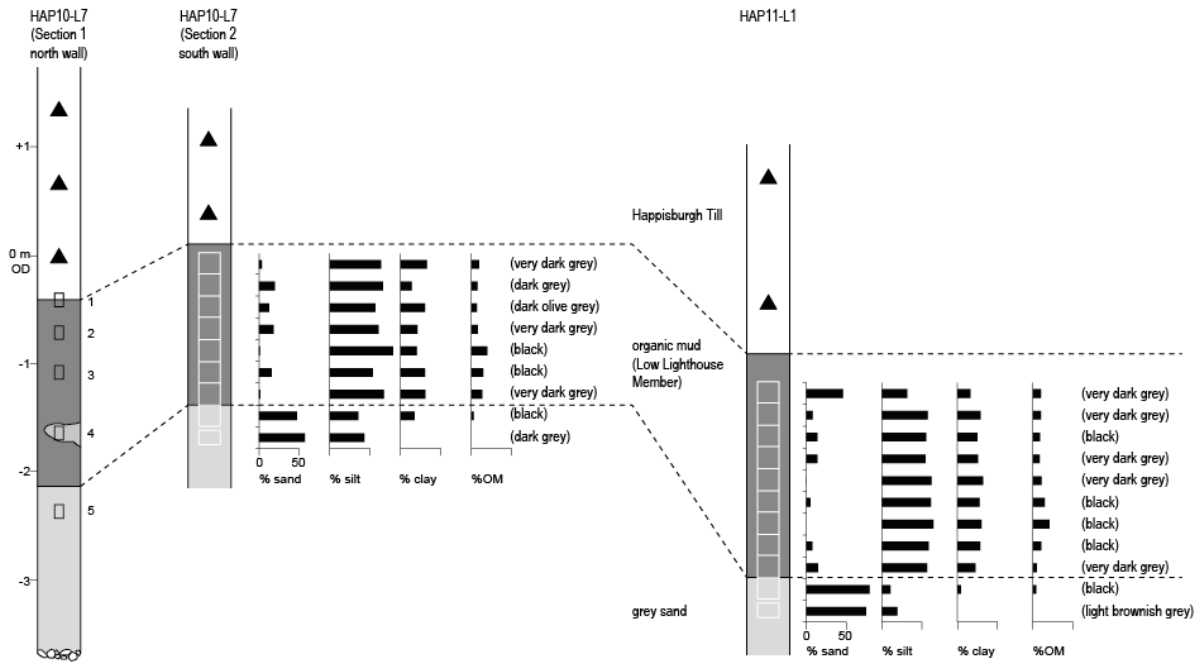


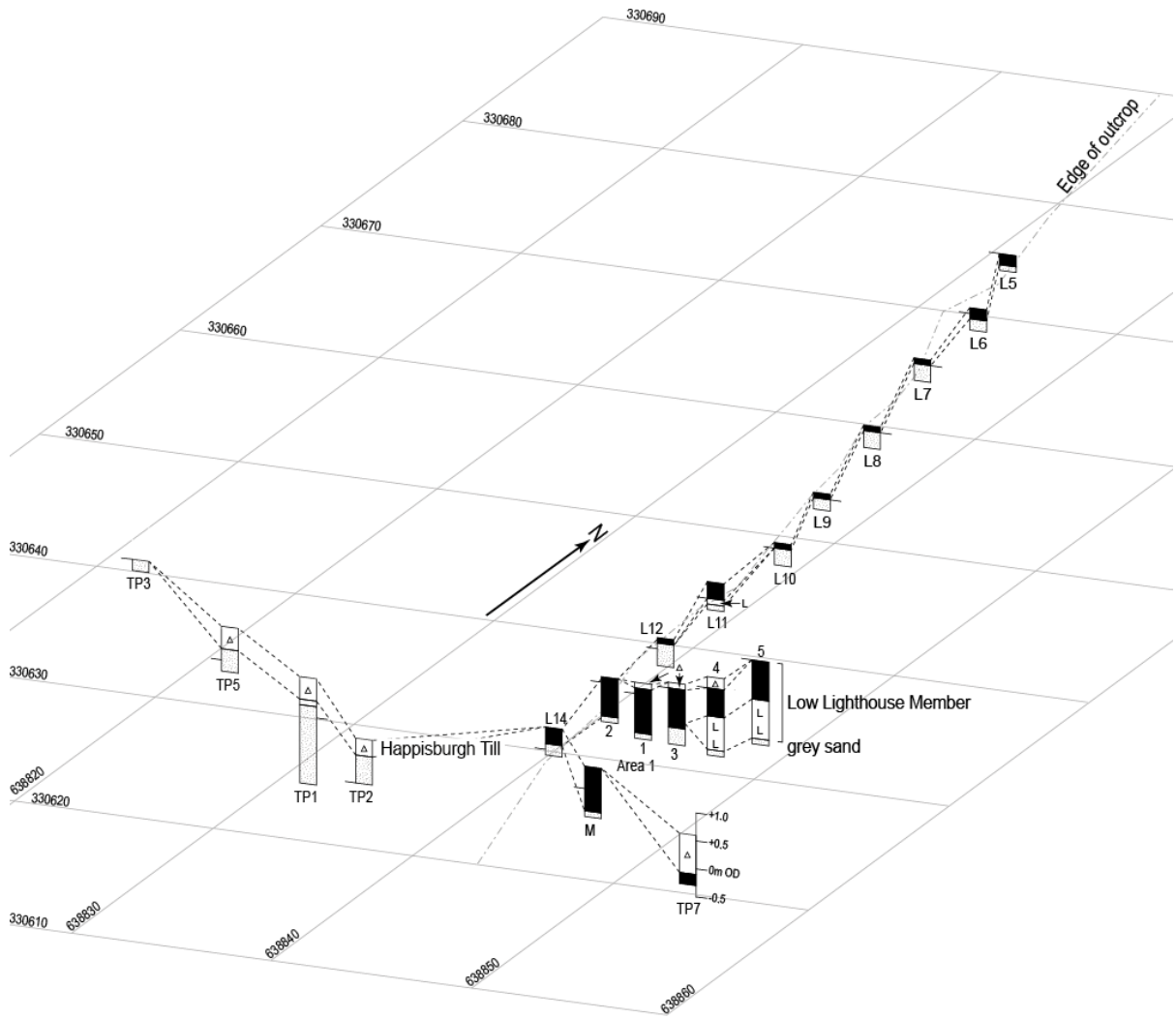


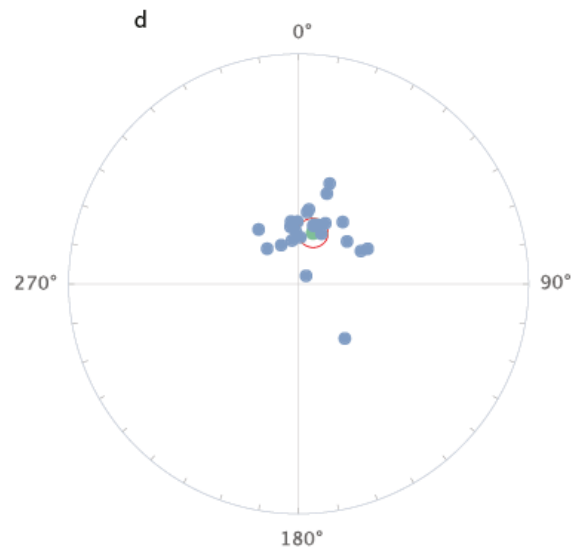
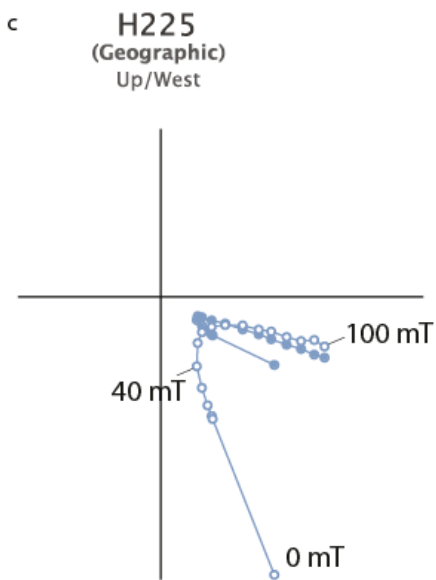
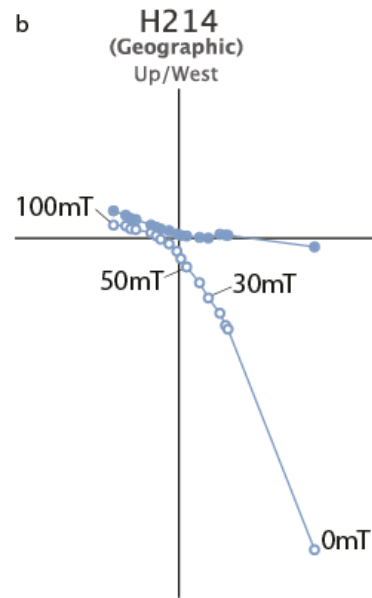
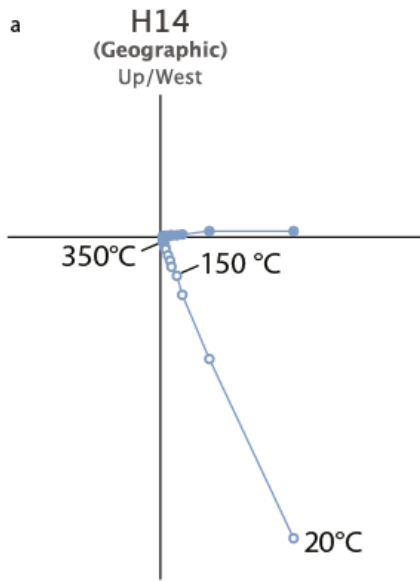


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|----------------|-------------|------------------|-------------------------------------|
| Lowestoft Till | Corton Till | Happisburgh Sand | organic mud (Low Lighthouse Member) |
| Corton Sand | Ostend Clay | Happisburgh Till | grey sand |









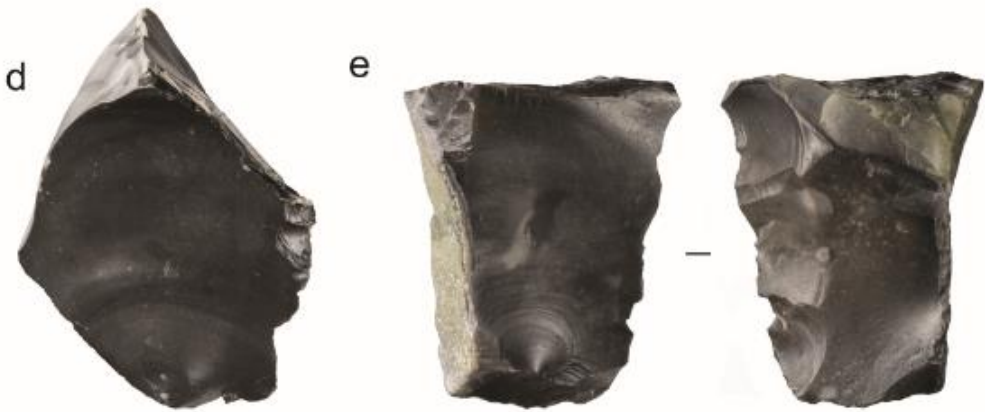
Horizontal Projection
Declination

Vertical Projection
Inclination

● Interpreted Directions

— $\alpha 95$ Confidence Interval

● Mean



0 2cm



g



h

