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

Highlights

- Comprehensive account of the geology and archaeology at Happisburgh Site 1,
- Lower Palaeolithic assemblage comprising flakes, flake tools, cores and a handaxe,
- Reconstruction of local environment and landscape of human occupation,
- Assessment of wider context for human occupation of Europe in MIS 13.

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ABSTRACT

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

Keywords

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

1. Introduction

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

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

Although Pakefield and Happisburgh Site 3 provided evidence of humans in northern Europe prior to 500 ka, the lithic assemblages were small, with 32 and 80 artefacts respectively, and the technology was simple core and flake working. It was suggested that these sites represent occasional pioneering events that ultimately failed to secure a sustained occupation of northern Europe. The threshold at 500 ka marks a significant increase in the number of sites and the size of the lithic assemblages and presumably in population size and/or duration of occupation. The debate has now focused on why there is a major shift in the archaeological record at this time and how it relates to the emergence of new technologies, adaptation to northern, as well as more continental, environments and possibly the arrival in Europe of new hominin species from Africa or Asia (Ashton and Lewis, 2012; Cohen et al., 2012; Ashton, 2015; Moncel et al., 2015). Happisburgh Site 1 is one of at least five sites in the UK (others include Boxgrove, High Lodge, Warren Hill and Waverley Wood) that date to this major turning point in the Lower Palaeolithic of Europe at 500 ka and contribute to the debate. This paper reports the results of recent research at Happisburgh Site 1, in particular the excavations conducted by members of the Ancient Human Occupation of Britain (AHOB) project and the University of Leiden. The lithic assemblages recovered during these two phases of fieldwork are described and set within the British and European archaeological context and the implications of these new data for understanding human presence in northern Europe around 500 ka ago are discussed. The palaeobotanical and palaeontological investigations that were undertaken at Happisburgh Site 1 will be presented in forthcoming papers (Field et al., in prep.; Parfitt et al., in prep.).

2. Background to Happisburgh Site 1

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

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

2.1. Archaeological investigations since 2000

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

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

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

2.2. The Pleistocene succession at Happisburgh

The Pleistocene sediments exposed along a ca 4 km stretch of coastline from Ostend (TG 365 326) to Cart Gap (TG 397 299) (Fig. 1) have been observed and studied since the early 19th century. Clement Reid provided the first systematic descriptions of the CF-bF (Reid, 1882, 1890) and in the 1960–70s Richard West conducted a detailed regional study of the CF-bF along the coast of Norfolk and Suffolk (West, 1980). West made a number of stratigraphic observations at Happisburgh (his locations HA–HG) including a borehole at location HC, beneath the now-destroyed lifeboat ramp, which penetrated the full thickness of the Pleistocene deposits down to Chalk bedrock. West also undertook detailed palaeobotanical analyses of the sediments. Happisburgh is regarded as the most southerly exposure of the CF-bF in Norfolk; Reid (1890, p.173) recorded exposures “within a quarter of a mile of the Low Lighthouse” (which was located at TG 3915 3041 until its demise in the 19th century) and West’s location HG (356m south-east of HC) was the most south-easterly outcrop of these sediments observed during the second half of the 20th century.

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

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

South-east of HC, beds i and j pinch out and are not known beyond West’s location HG. Parfitt et al. (2010) described laminated sediments and lag gravel at Happisburgh Site 3, equivalent to beds i–j and extending some 400 m north-west of HC. These deposits are up to ca 5 m thick, they overlie marine sands and are overlain by glacigenic sediments of the Happisburgh Formation. The laminated silts are interpreted as intertidal mud flat deposits and, along with the lag gravel, have yielded Palaeolithic artefacts, and contain a horizon with human footprints (Parfitt et al., 2010; Ashton et al., 2014).

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

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

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

3. Material and methods

3.1. The 2004 AHOB excavation

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

3.2. The 2009–2012 University of Leiden excavations

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

3.3. Borehole investigations

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

3.4. Sample collection and analysis

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

3.5. Palaeomagnetic analysis

A total of 33 pairs of samples were taken for palaeomagnetic analysis from HAP10-L7 including 14 (seven pairs) from the overlying till. A further five samples were taken from a monolith through the sediments. The sediments were sampled for both stepwise progressive Alternating Field (AF) and THermal (TH) demagnetisation because the potential presence of greigite (Maher and Hallam, 2005; Parfitt et al., 2010) may seriously interfere with AF demagnetisation as a gyroremanent magnetisation (GRM) often develops (e.g. Snowball, 1997; Roberts et al., 2010).

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

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

3.6. Micromorphological analysis

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

3.7. Lithic artefact analysis

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

4. Happisburgh Site 1: stratigraphy and sedimentology

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

4.1. Grey sand

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

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

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

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

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

4.2. Organic mud (Low Lighthouse Member)

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

During the 2004 excavation, this unit was extensively exposed on the foreshore, some 50–100 m seaward of the 2009–2012 excavation trenches (Fig. 2d). The outcrop formed a wave-cut platform extending laterally over 100 m of the foreshore and beyond the low water line, as shown by bathymetric survey data. The exposed surface in places also preserved remnants of the overlying Happisburgh Till, for example in auger holes 1, 3 and 4 and in Test Pit 7 (Fig. 8). The organic mud varies in thickness across the outcrop; along the western edge of the outcrop (trimmed by wave erosion and by machine excavation of a trench through the sediments) this unit is generally less than 1 m in thickness but it thickens rapidly away from this 'edge' and in auger holes 4 and 5 up to 1.4 m of organic mud was proved overlying the grey sand. In these two auger holes there was a change from a lower organic silt and clay to a more sandy organic deposit in the upper part. These sandier organic deposits were also exposed in Area I, where excavated surfaces revealed lighter coloured sandy lineations suggestive of sand horizons or lenses within the organic sediments. This sandy upper portion of the organic deposits may be equivalent to, though somewhat thicker than, the sandier upper 0.2 m of the unit seen in HAP11-L1.

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

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

The organic mud is interpreted as the infill of an abandoned channel. The micromorphological evidence indicates episodic colluvial processes, while rill formation suggests drier phases followed by periods of overland flow. Traces of soil formation are very weak, shown mainly in the form of the blocky structure, which requires a sufficient clay content as well as an alternation of wet–dry conditions. Additional faint traces of soil formation are indicated by the development of marcasite and other authigenic minerals. Marcasite also occurs in combination with pyrite associated with organic material, indicating brackish to fresh water depositional swamp environments (Mees and Stoops, 2010). The drier, more stable phases were very short, up to a few months in duration, as no traces of biological activity were documented.

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

4.3. Palaeomagnetic interpretation

The ChRM was determined by step-wise heating between 150 and 350°C (12 steps) or, in some cases, starting at 210°C and ending at 310°C (Table 3; Fig. 9). This captures the typical behaviour of greigite which simultaneously unblocks and thermochemically alters in this temperature interval (Roberts et al., 2011). ChRMs from the AF demagnetised samples were not interpreted due to a strong GRM above 35–40mT, even though NRM values and ChRM directions below 35mT are in line with the TH samples from the same levels. This includes the five samples from the monolith which were demagnetised using the 'per component protocol' as these too showed a GRM, again behaviour that is often indicative of greigite (e.g. Snowball, 1997). From Table 3 it appears that all the till samples and those from HAP10-L7 that were TH demagnetised are of normal polarity. The mean declination is 15.6° with an inclination of 71.2°, close to the current inclination of around 67° at Happisburgh (Fig. 9).

4.4. Glacigenic deposits

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

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

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

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

5. Correlation and age of the Site 1 succession

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

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

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

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

6. Site 1 lithic assemblages

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

6.1. The AHOB assemblage (organic mud)

The first assemblage was excavated in 2004 from the organic mud with a total of 219 artefacts, the vast majority being chips (≤ 20 mm maximum length) and flakes (Table 5). Most of the artefacts are in mint or fresh condition with very slight edge abrasion, probably caused by slight movement in a fluvial context (Table 6). There is a high ratio of chips to flakes (ca 5:1), suggesting that there has been little loss of the smaller elements, such as by winnowing. Two of the flakes have a greater degree of rolling and are likely to be in secondary context. Over 55% of the flakes are broken, which seems to have been caused by natural flaws in the flint and probably occurred during knapping, rather than through post-depositional damage. The flint is a distinctive black colouration, which might have been accentuated as a surface colouration from burial within the organic mud. Overall the condition suggests that most of the assemblage has undergone minimal movement since original deposition.

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

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

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

A notable aspect of the assemblage is the low number of artefacts, with only 40 flakes or flake tools. Although it was excavated in a variety of ways it is clear that the density of artefacts is very low with a thin distribution across an extensive area. In Area 1, four flakes were recovered from ca 2.5 m^3 of sediment, an artefact density of 1.6 artefacts per m^3. Although most artefacts were recovered from the top 0.2 m of the organic mud, others were found at depths of up to 0.6 m. There is also a lack of refitting or distinct knapping scatters, which suggests that most knapping occurred elsewhere in the landscape, perhaps at the source of raw material, with selected artefacts brought into the Site 1 area. The relatively high number of flake tools or modified pieces and the lack of cores support this suggestion.

6.2. The Leiden assemblage (grey sand)

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

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

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

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

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

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

There are a total of 19 tools (Table 5), of which 15 are on flakes, and four on modified natural or shattered flint. The majority of these tools are notches and multiple notches or denticulates. The remainder are flakes with lightly retouched edges, one of which can be classed as a scraper. The retouch is on the dorsal side, but with no preference for the location of the working edges, which were on proximal, distal and lateral locations. Two of the denticulates have heavy reduction, possibly indicative of resharpening. Although in some cases reduction has made it difficult to estimate the original blank size, the tools are only slightly larger on average than the unmodified flakes. As with the AHOB assemblage, tool production seems to have occurred in an *ad hoc* fashion with little regard for specific form and with the use of the nearest available blank.

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

6.3. NMS surface assemblage

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

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

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

6.4. Comparison between assemblages

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

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

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

Due to the difficulties of excavating wet sand, the vertical distribution of the artefacts from the grey sand is not known. During fieldwork at least some of the artefacts were documented to come from the upper part of the unit and it is possible that this was the context for the majority of this assemblage. A little more is known about the vertical distribution of the artefacts from the organic mud. Due to the nature of the excavation, most artefacts were recovered from the surface or top 0.1 m of the unit, although in Area 1, several were found at greater depths. Three artefacts were also found on the interface between the organic mud and the grey sand.

6.5. The human habitat and occupation at Happisburgh

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

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

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

The lithic assemblages were found in both the grey sand and organic mud, which has implications for the duration and possible episodic nature of human presence at the site. The micromorphology suggests a similar mode of deposition in the upper part of the grey sand and in the organic mud. If Holocene floodplain environments can be used as a guide, a timescale of centuries to millennia might be realistic (Brown, 1996; Lewin et al., 2005), but in the case of Site 1, the absence of traces of soil formation in the colluvial deposits suggests a significantly faster build-up of the organic mud. The Site 1 evidence thus converges on a short duration and perhaps continuous human presence at the site spanning the deposition of the upper parts of the grey sand and the organic mud.

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

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

7. Discussion

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

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

7.1. Lithic technology

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

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

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

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

The second component of the Happisburgh Site 1 assemblages is the handaxe. The absence of soft hammer flakes suggests that the handaxe was brought to the site. It is ovate in form and similar to most other MIS 13 handaxes, such as those from Boxgrove and High Lodge (Bed E). The majority of the handaxes from Warren Hill are also ovate in form, but there is a second slightly more rolled component, consisting of handaxes that are more irregular in shape, often retaining cortex, which may be earlier in date (Wymer, 1985; Moncel et al., 2015). The small assemblage of handaxes collected from Waverley Wood includes finely-made ovate handaxes on local erratics of good quality andesite, but also more irregular handaxes made on poor raw materials of flint and quartzite. It seems that when good quality raw material was available, ovate handaxes were the preferred form, as with other MIS 13 sites.

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

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

7.2. Human habitats

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

The other MIS 13 sites provide a similar picture. The occupation at High Lodge during the deposition of Bed C was on a floodplain with pools and marshland, and surrounding vegetation dominated by pine and spruce together with juniper and heathland plants (Hunt, 1992). The MCR temperature estimates from the beetles show summers between 15 and 16°C and winters between –4 and 1°C (Coope, 2006). Little can be said about the handaxe assemblage from Bed E as it is probably derived from underlying sediment.

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

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

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

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

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

Unfortunately, comparison with other sites in Europe is difficult due to the paucity of assemblages that can be securely dated to MIS 13. In north-west Europe the record is limited to both old and new sites in the Somme Valley (France; Fig. 12). New fieldwork at Carrière Carpentier in Abbeville has dated the fluvial sediments to MIS 15, and these underlie deposits that are thought to have contained the handaxes that were collected in the 19th and early 20th centuries (Antoine et al., 2015, 2016). The handaxes, which have been cautiously attributed to MIS 14, are predominantly ovate in form (Tuffreau and Antoine, 1995). Upstream in Amiens the site of Rue du Manège has been assigned to MIS 13, but so far only a few artefacts and no handaxes have been recovered (Antoine et al., 2015). The best excavated assemblages are from the nearby sites at Cagny-la-Garenne, which have been attributed to early MIS 12 (Antoine et al., 2007, 2015). The sites have been described as workshop locations that used the flint eroding out from nearby Chalk for the production of a range of handaxes, from crude unfinished forms to more refined elongated cordiforms (Tuffreau, 1981; Antoine and Tuffreau, 1993; Lamotte and Tuffreau, 2001a, 2001b; Tuffreau and Lamotte, 2010). The core technology is similar to that found in Britain with alternate and single platform technique, but also a possible ephemeral use of Levallois-like technology. Flake tools consist of notches, denticulates and occasional scrapers. The sites at Cagny-la-Garenne are difficult to compare to other sites because they are workshop locations. However, there are ovate handaxes from other sites in the Somme valley, such as Abbeville, which probably date to MIS 14 and show similarities to the handaxes from Britain (Antoine et al., 2016).

For southern Europe there is an intermittent record of handaxe technology or bifacial working of tools from as early as 900 ka (Mosquera et al., 2013; Moncel et al., 2015). At La Boella near Taragona (Spain) two crude bifacial tools were found in Early Pleistocene sediments (Vallverdú et al., 2014). But this seems to be an isolated record and it is not until about 700–600 ka that a large handaxe assemblage occurs at La Noira in the Cher Valley (France) with ESR dates on quartz of 690 ± 80 ka (Despriée et al., 2011; Moncel et al., 2013). The assemblage of handaxes, cores and flake tools was made on slabs of local siliceous ‘millstone’. In many cases the form of the slabs has influenced the shape of the handaxes. A further occurrence of early handaxe technology occurs at Caune de l’Arago in Tautavel, southern France (Barsky and de Lumley, 2010; Barsky, 2013). In units I and II, attributed to MIS 14 and 13, handaxes, sometimes made on local pebbles, occur alongside crudely-shaped cleavers. In southern Italy, Notarchirico has been dated to ca 650 ka, where chopping tools, cleavers and occasional crude handaxes were made on quartzite, limestone and flint pebbles (Lefèvre et al., 2010). In all these cases raw material has heavily influenced the final handaxe forms.

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

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

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

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

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

8. Conclusion

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

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Figure captions

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

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

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

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

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

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

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

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

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

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

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

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

Table captions

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

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

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

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

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

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

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

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

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

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

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

Table 1.

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

Table 2.

Sample	Schorlite	Quartzite	Vein quartz	Total flint	(PM flint as % total flint)	Carbon-iferous chert	Green-sand chert	*Rhaxella* chert	Silicified limestone	Sand-stone	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	Declin-ation	Inclin-ation	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.

	AHOB (organic mud)		Leiden (grey sand)		NMS (organic mud or surface)	
Method	Sieved (1 mm mesh)		Sieved (10 mm mesh)		Surface collected	
Types	***n***	**%**	***n***	**%**	***n***	**%**
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	
		n	%	*n*	%
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	
		n	%	*n*	%
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.

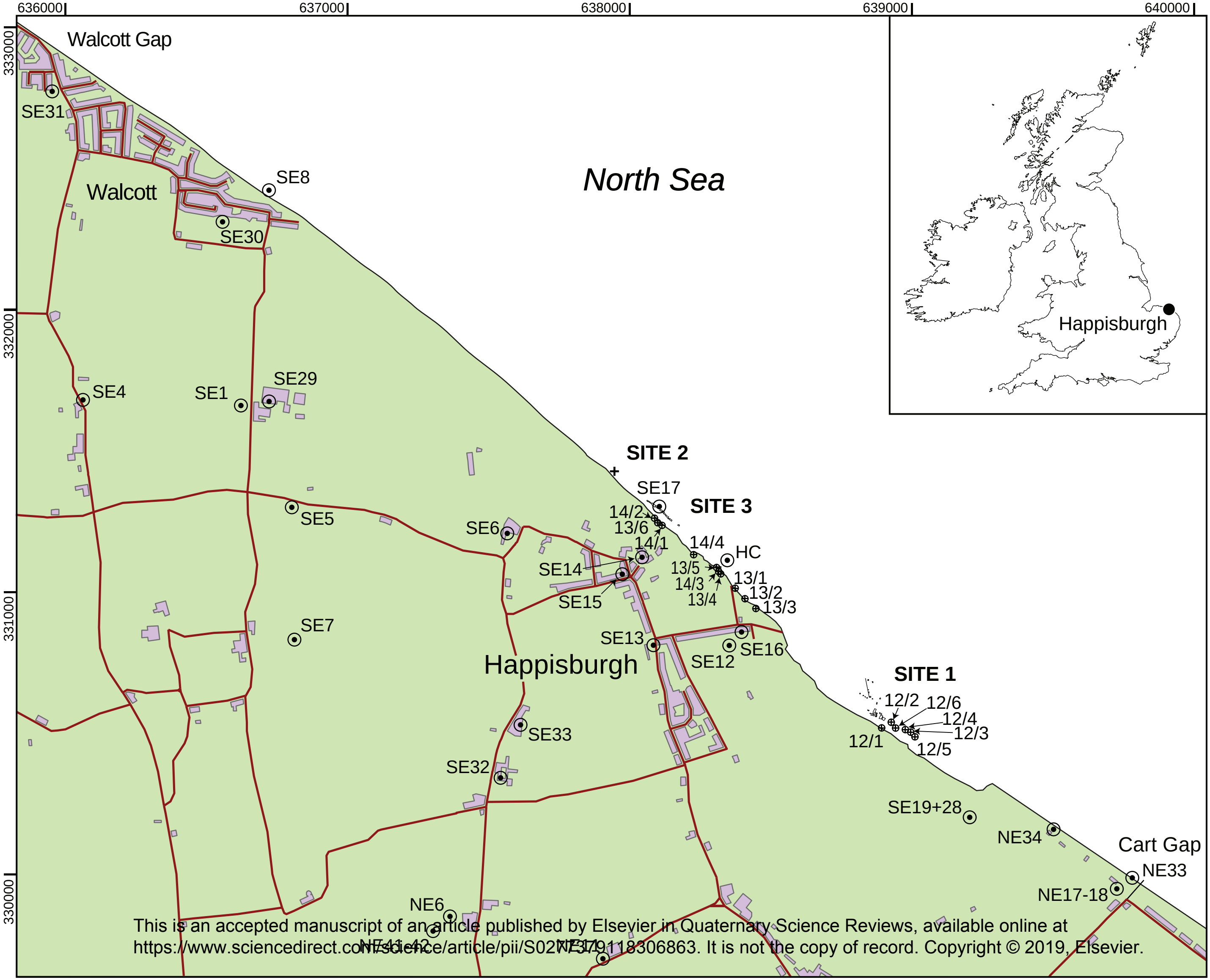
Condition	Channel edge		Mid-channel	
	n	%	*n*	%
Mint	50	48.5	7	18.4
Fresh	50	48.5	30	78.9
Slightly rolled	3	2.9	1	2.6
Rolled	0	0	0	0
Total	103		38	

Table 10.

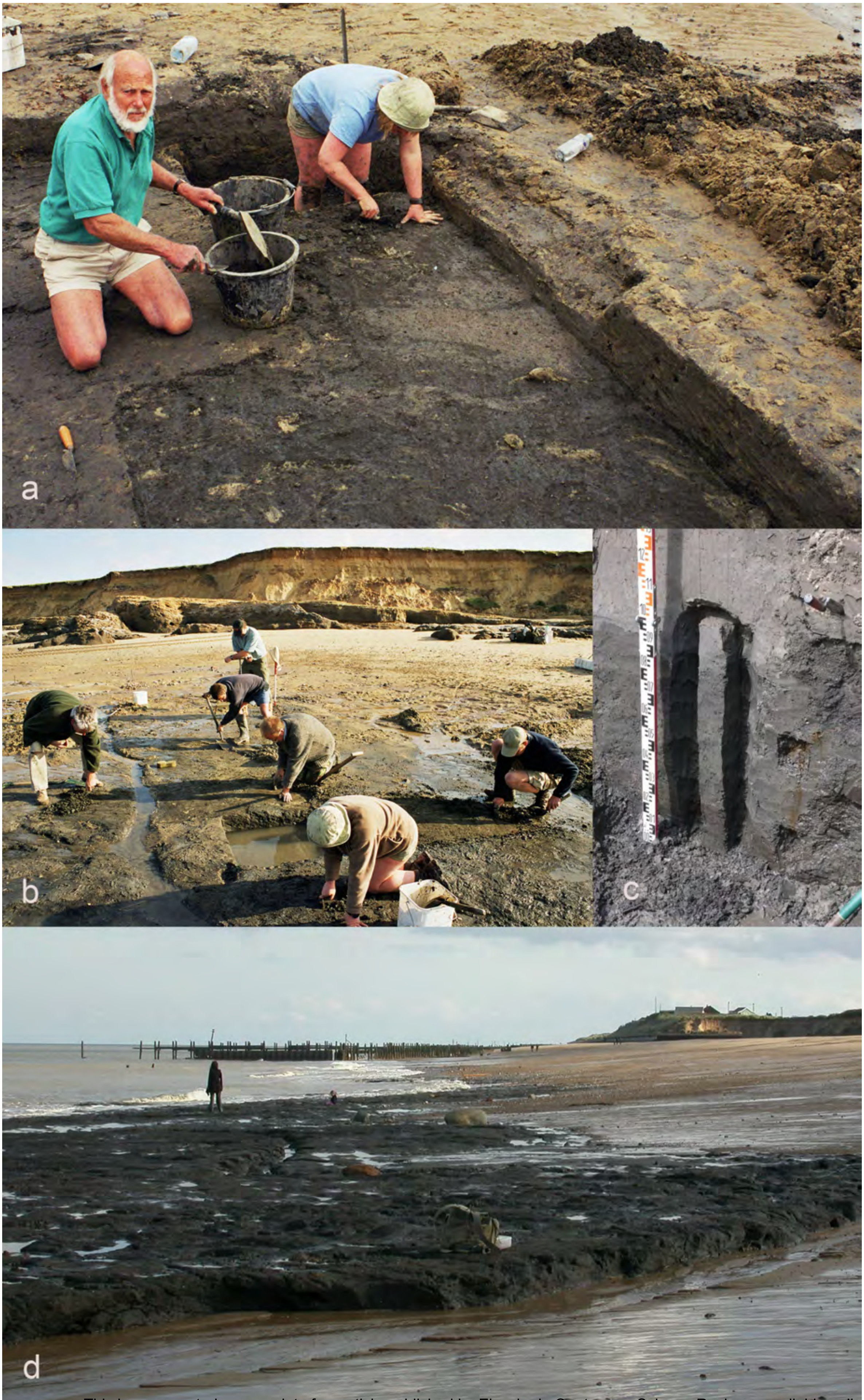
Assemblage	**Age**	**Method**	**Core technology**	**Flake tools**	**Handaxes**
Happisburgh Site 1	MIS 13	Excavated	Alternate and single platform	*ad hoc* tools	Ovate (1)
Boxgrove	MIS 13	Excavated	Alternate and single platform	*ad hoc* tools	Ovates
Waverley Wood	MIS 13	Collected			Mixed
Warren Hill	MIS 13/12	Collected		Refined scrapers	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	*ad hoc* tools	Ovates

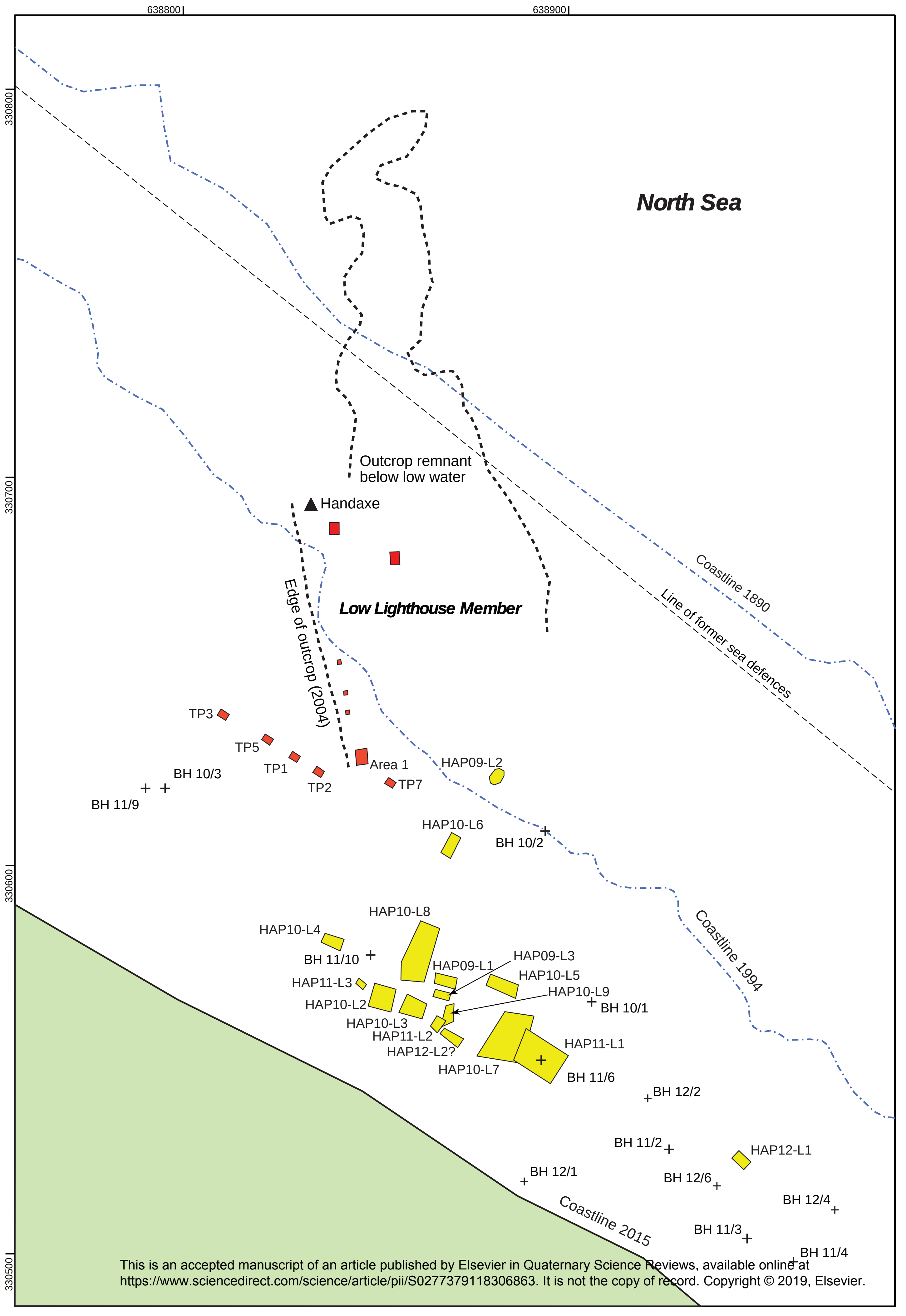
Table 11.

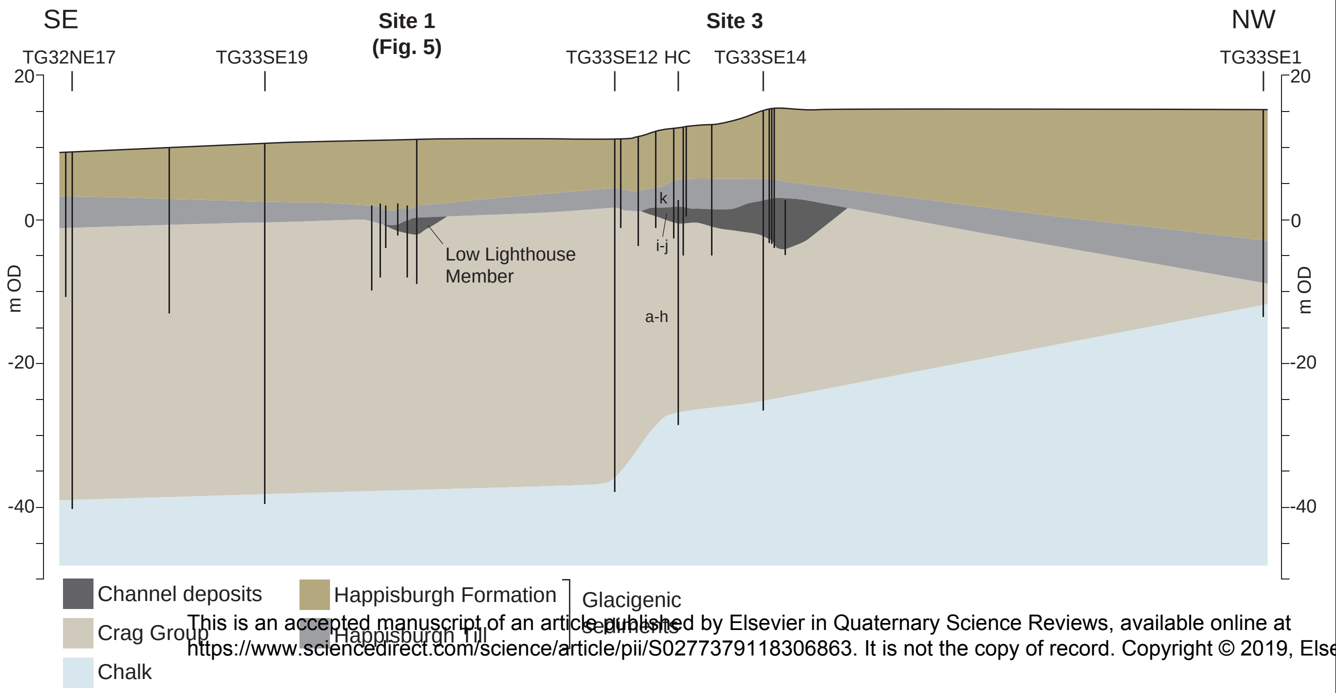
Group	Sites	Assemblage Age	Assemblage characteristics
Group 1	Warren Hill	MIS 13 or earlier	Irregular handaxes with cortex
Group 2	High Lodge (Bed C) Warren Hill	MIS 13 MIS 13	Alternate and single platform technique; finely made scrapers
Group 3	Boxgrove High Lodge (Bed E) Warren Hill Waverley Wood Happisburgh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

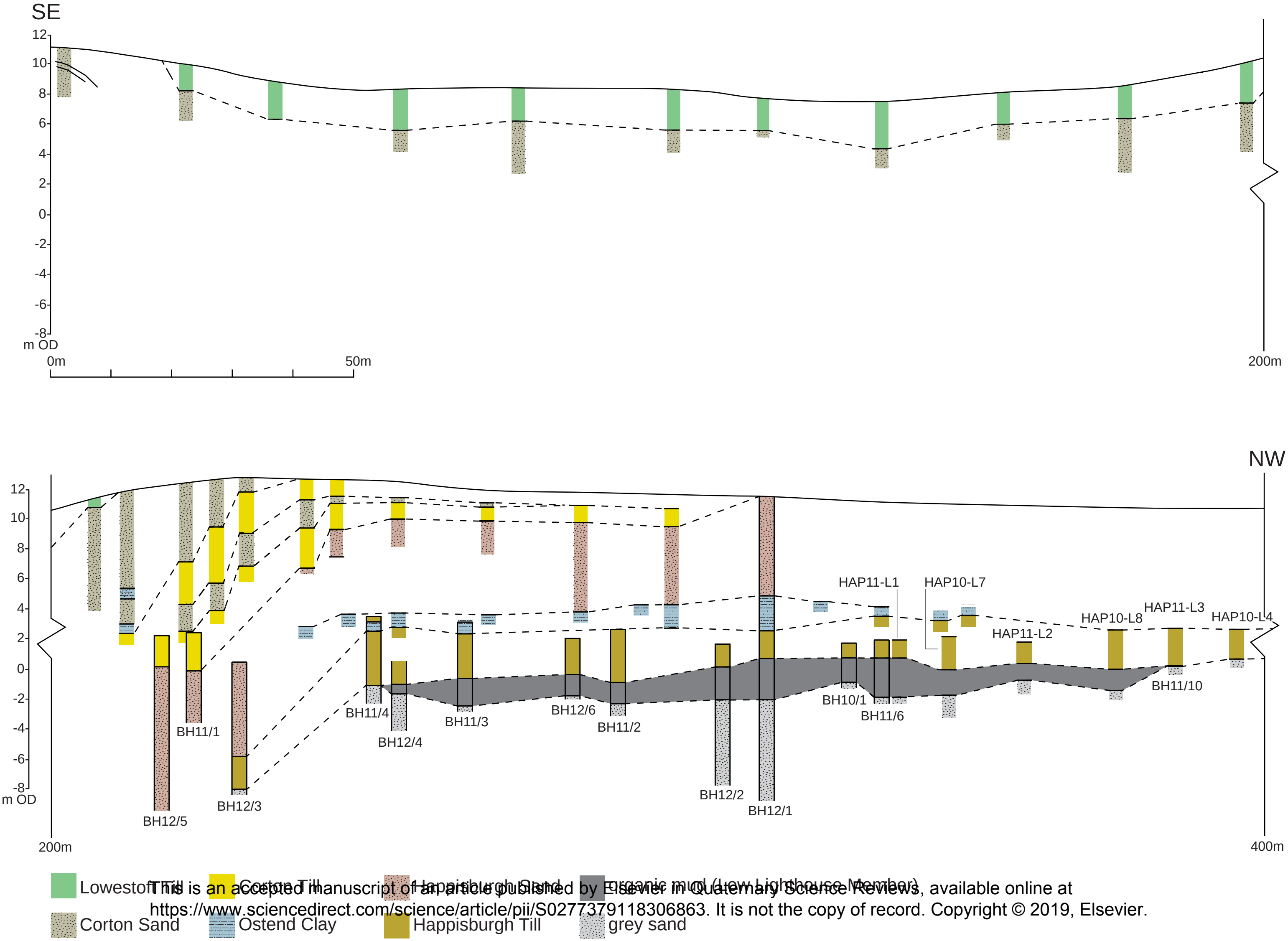


636000
637000
638000
639000
640000
333000
332000
331000
330000
Walcott Gap
Walcott
North Sea
SE31
SE8
SE30
SE29
SE4
SE1
SE5
SE6
SE7
SITE 2
SE17
SITE 3
14/2
13/6
14/1
14/4
HC
13/5
14/3
13/4
13/1
13/2
13/3
SE14
SE15
SE13
SE12
SE16
Happisburgh
SITE 1
12/2
12/6
12/4
12/3
12/1
12/5
SE33
SE32
SE19+28
NE34
Cart Gap
NE33
NE17-18
NE6
NE41-42

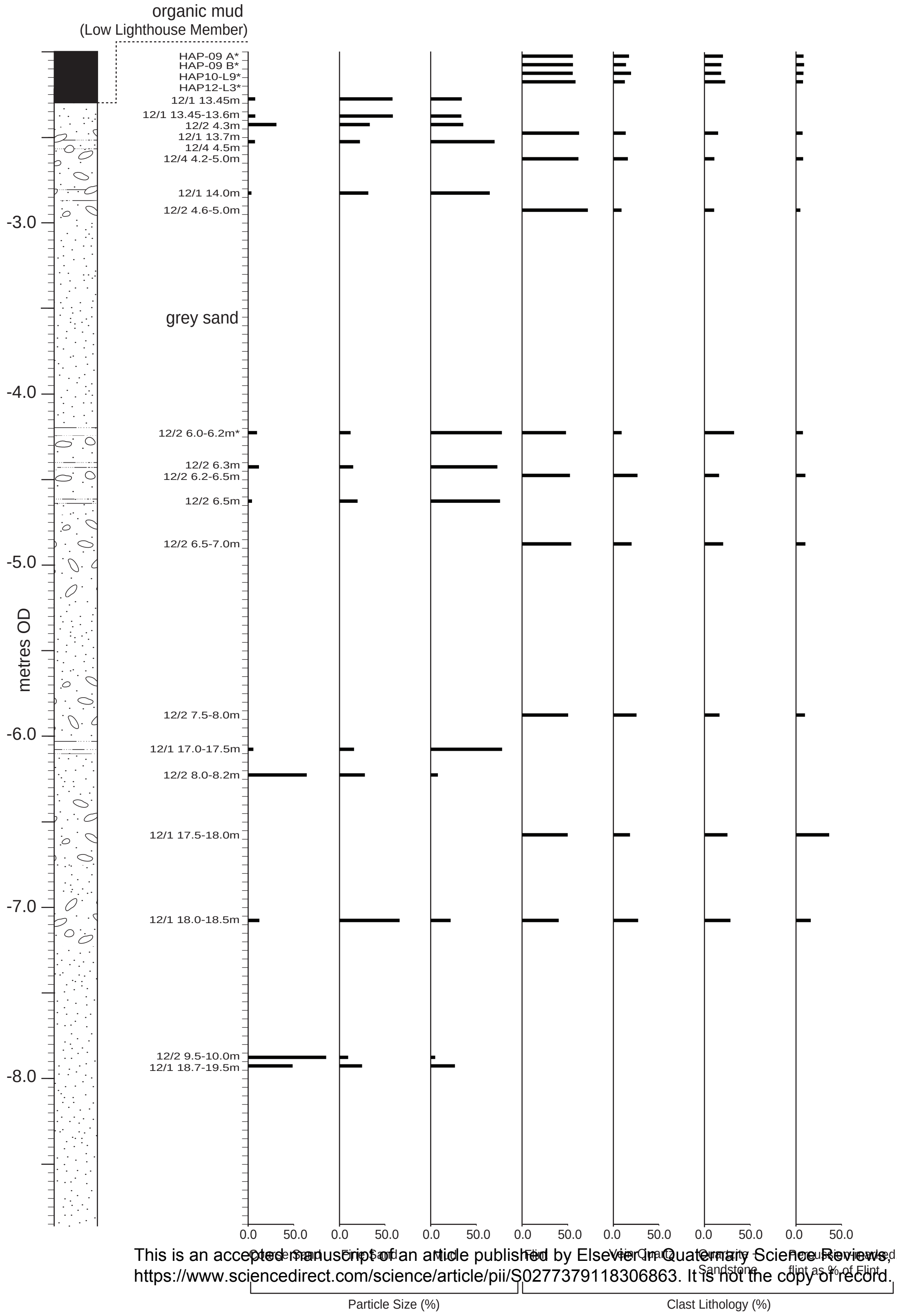

a
b
c
d

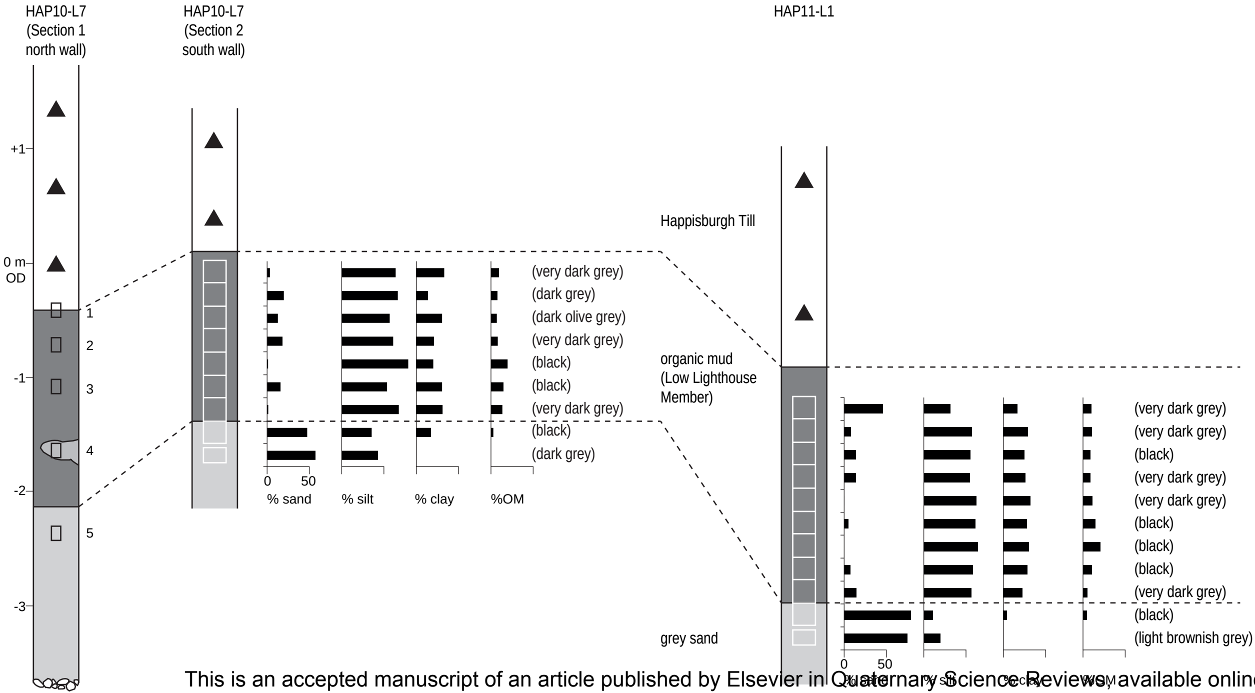

638800
638900
330800
330700
330600
330500
North Sea
Outcrop remnant
below low water
Handaxe
Low Lighthouse Member
Edge of outcrop (2004)
Coastline 1890
Line of former sea defences
Coastline 1994
Coastline 2015
TP3
TP5
TP1
TP2
TP7
Area 1
BH 10/3
BH 11/9
HAP09-L2
HAP10-L6
BH 10/2
HAP10-L8
HAP10-L4
BH 11/10
HAP09-L1
HAP09-L3
HAP10-L5
HAP11-L3
HAP10-L9
BH 10/1
HAP10-L2
HAP10-L3
HAP11-L2
HAP12-L2?
HAP10-L7
HAP11-L1
BH 11/6
BH 12/2
BH 11/2
HAP12-L1
BH 12/1
BH 12/6
BH 12/4
BH 11/3
BH 11/4

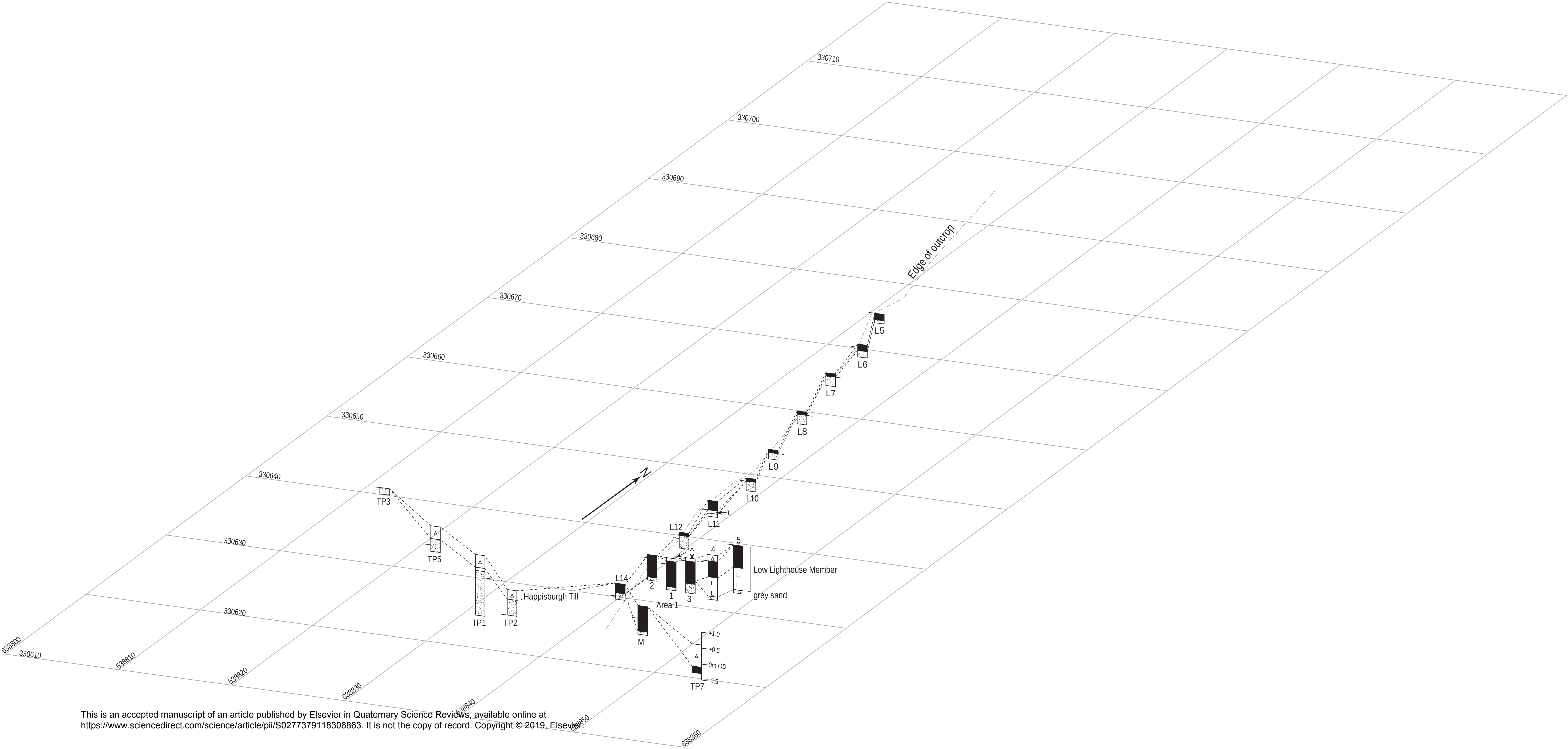

SE
Site 1
(Fig. 5)
Site 3
NW
TG32NE17
TG33SE19
TG33SE12 HC
TG33SE14
TG33SE1
20
0
-20
-40
m OD
k
i-j
a-h
Low Lighthouse
Member
Channel deposits
Happisburgh Formation
Glacigenic
sediments
Crag Group
Happisburgh Till
Chalk

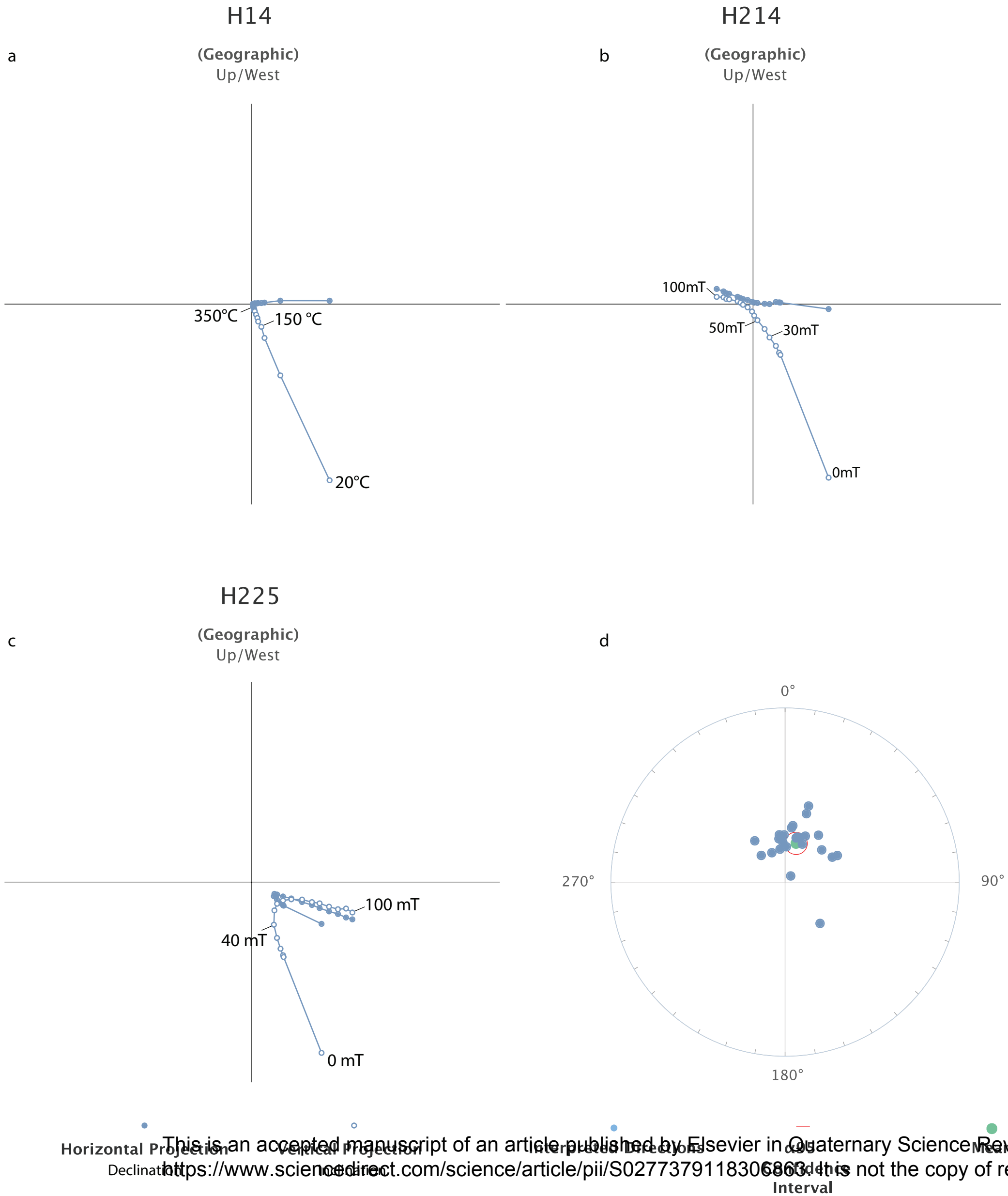


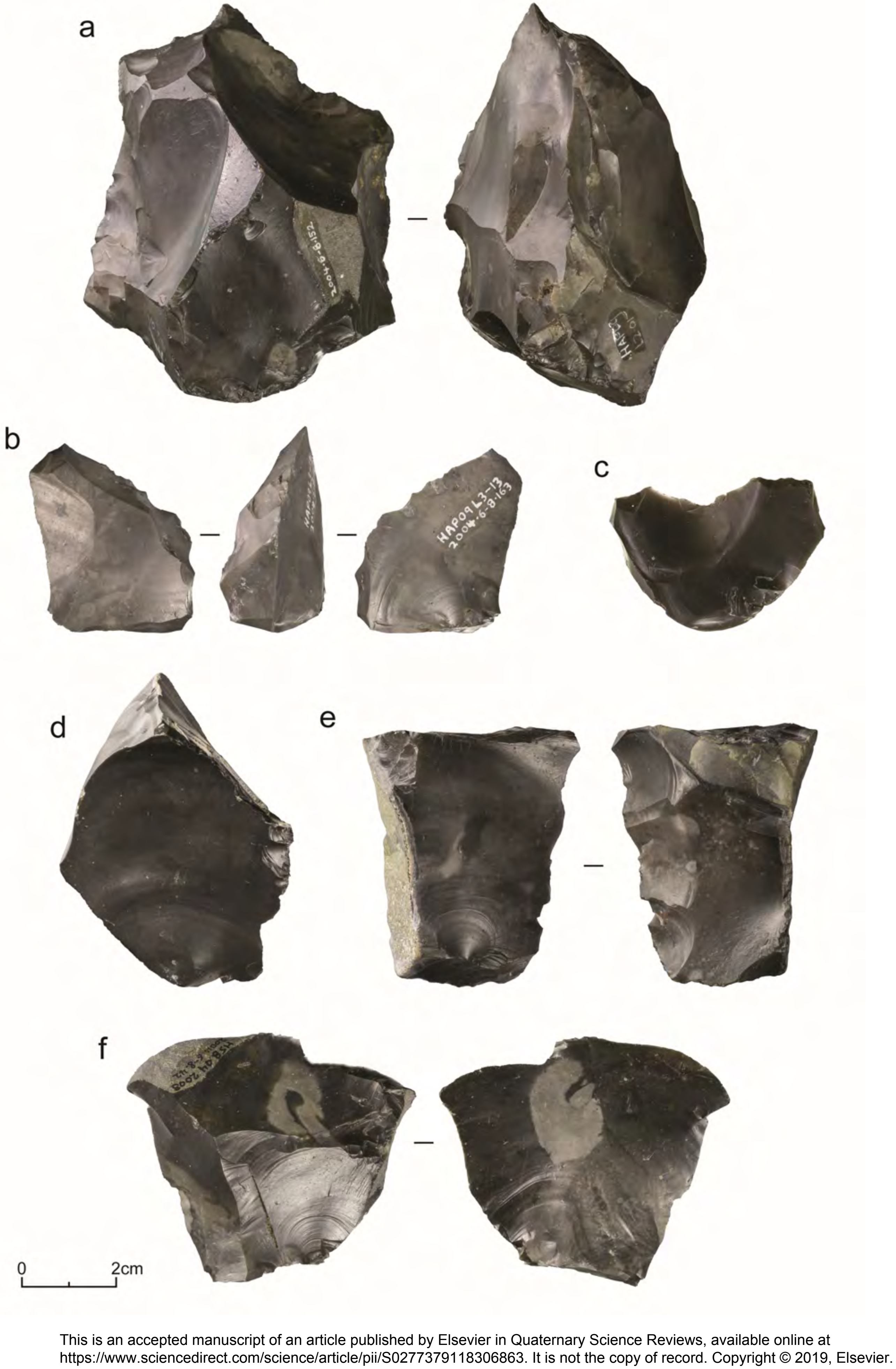
SE
NW
m OD
0m
50m
200m
400m
BH12/5
BH11/1
BH12/3
BH11/4
BH12/4
BH11/3
BH12/6
BH11/2
BH12/2
BH12/1
BH10/1
BH11/6
BH11/10
HAP11-L1
HAP10-L7
HAP11-L2
HAP10-L8
HAP11-L3
HAP10-L4
Lowestoft Till
Corton Till
Happisburgh Sand
Organic mud (Low Lighthouse Member)
Corton Sand
Ostend Clay
Happisburgh Till
grey sand

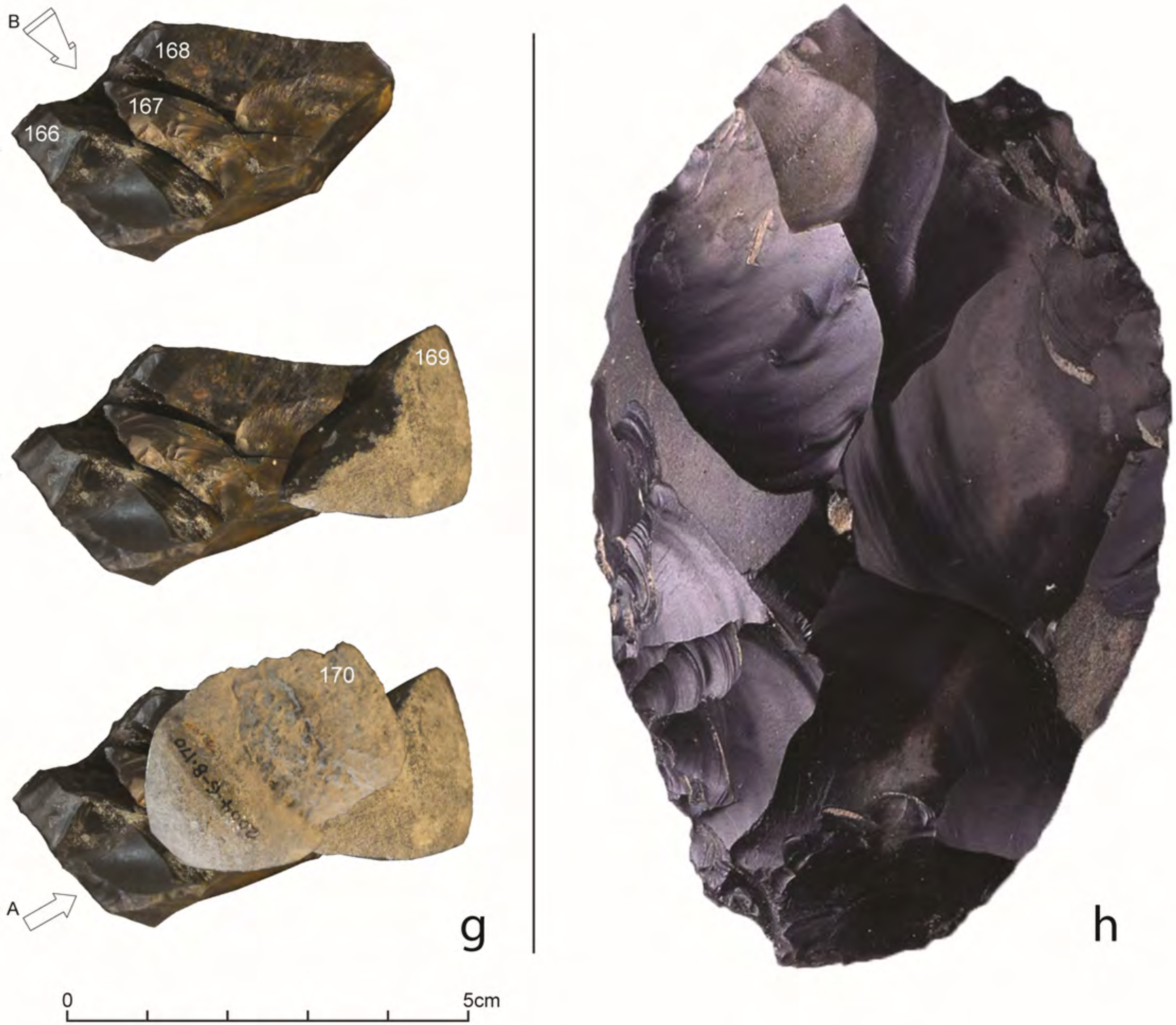

organic mud
(Low Lighthouse Member)
grey sand
metres OD
-3.0
-4.0
-5.0
-6.0
-7.0
-8.0
HAP-09 A*
HAP-09 B*
HAP10-L9*
HAP12-L3*
12/1 13.45m
12/1 13.45-13.6m
12/2 4.3m
12/1 13.7m
12/4 4.5m
12/4 4.2-5.0m
12/1 14.0m
12/2 4.6-5.0m
12/2 6.0-6.2m*
12/2 6.3m
12/2 6.2-6.5m
12/2 6.5m
12/2 6.5-7.0m
12/2 7.5-8.0m
12/1 17.0-17.5m
12/2 8.0-8.2m
12/1 17.5-18.0m
12/1 18.0-18.5m
12/2 9.5-10.0m
12/1 18.7-19.5m
0.0 50.0
Sandstone
flint as % of Flint
Particle Size (%)
Clast Lithology (%)

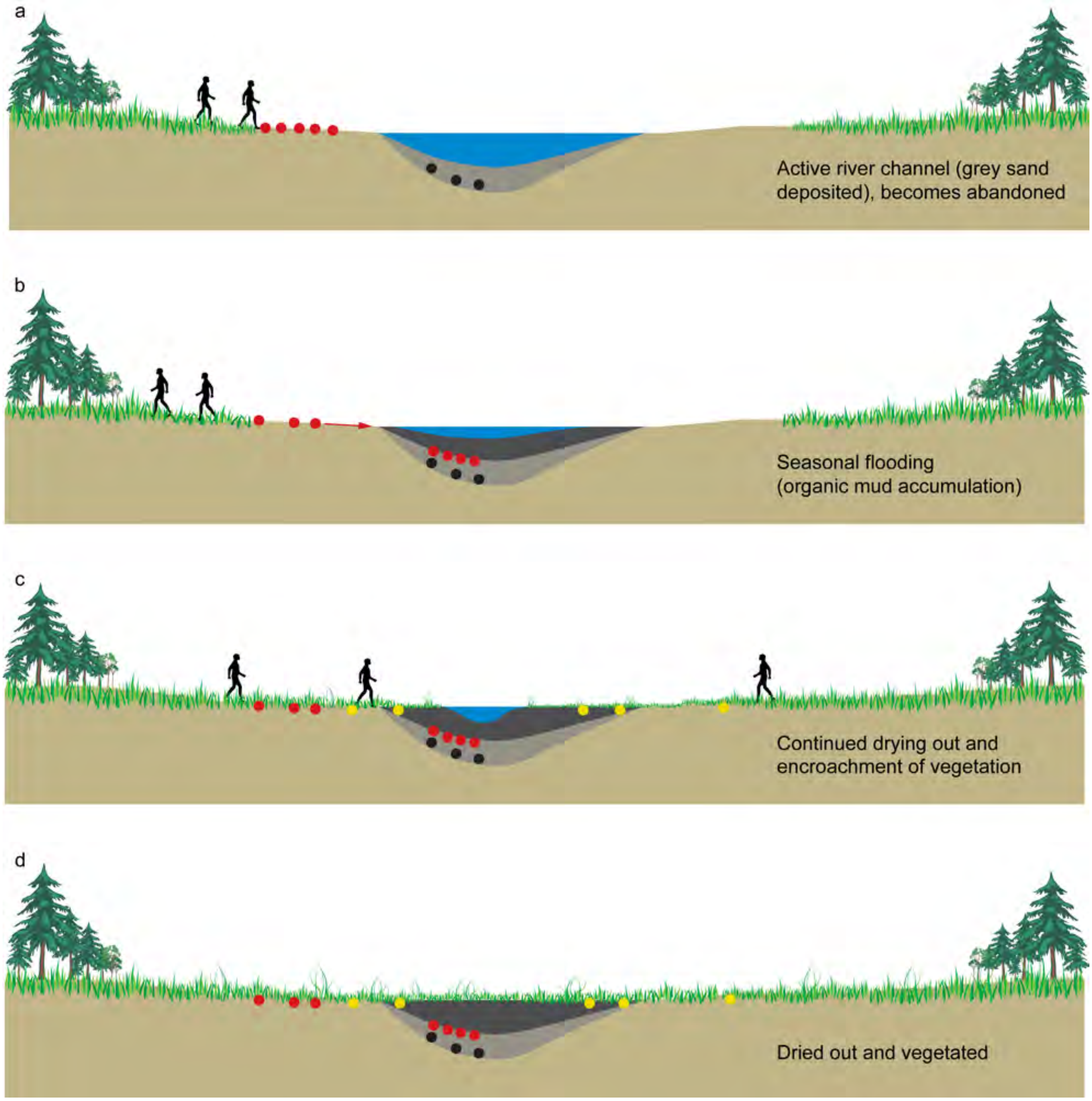

HAP10-L7
(Section 1
north wall)
HAP10-L7
(Section 2
south wall)
HAP11-L1
+1
0 m
OD
-1
-2
-3
1
2
3
4
5
Happisburgh Till
organic mud
(Low Lighthouse
Member)
grey sand
(very dark grey)
(dark grey)
(dark olive grey)
(very dark grey)
(black)
(black)
(very dark grey)
(black)
(dark grey)
0
50
% sand
% silt
% clay
%OM
(very dark grey)
(very dark grey)
(black)
(very dark grey)
(very dark grey)
(black)
(black)
(black)
(very dark grey)
(black)
(light brownish grey)


330710
330700
330690
330680
330670
330660
330650
330640
330630
330620
330610
638800
638810
638820
638830
638840
638850
638860
Edge of outcrop
N
L5
L6
L7
L8
L9
L10
L11
L12
L14
TP3
TP5
TP1
TP2
Happisburgh Till
Area 1
M
TP7
Low Lighthouse Member
grey sand
+1.0
+0.5
0m OD
-0.5


H14
a
(Geographic)
Up/West
350℃
150 ℃
20℃
H214
b
(Geographic)
Up/West
100mT
50mT
30mT
0mT
H225
c
(Geographic)
Up/West
100 mT
40 mT
0 mT
d
0°
90°
180°
270°
Horizontal Projection
Declination
Vertical Projection
Inclination
Interpreted Directions
α95
Confidence
Interval
Mean


a
2004-6-8-152
b
HAPO9 L3-13
2004-6-8-163
c
d
e
f
0
2cm


B
168
167
166
169
170
A
g
h
0
5cm


a
Active river channel (grey sand deposited), becomes abandoned
b
Seasonal flooding (organic mud accumulation)
c
Continued drying out and encroachment of vegetation
d
Dried out and vegetated


Happisburgh
Waverley Wood
High Lodge
Warren Hill
Boxgrove
Schöningen
Abbeville
Cagny, St Acheul
Menez Dregan
La Noira
Atapuerca
Arago
Aldène
Fontana Ranuccio
La Boella
Notarchirico
Loreto
0
500
1000km

MICROMORPHOLOGICAL DESCRIPTION AND INTERPRETATION OF UNDISTURBED SEDIMENT SAMPLES TAKEN IN TRENCH HAP10-L7, HAPPISBURGH SITE 1

by
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INTRODUCTION

Five undisturbed samples, 9 x 6 cm, were taken in trench HAP10-L7. Thin section M1 sampled the transition from the lowermost part of the Happisburgh Till to the upper part of the organic mud, M2 sampled the organic mud, while M3 sampled a transition within the organic mud, changing from a brownish black (2.5YR 3/1) to a more brown (7.5YR 2/3), laminated deposit with up to 2cm thick organic layers. M4 was taken in a sandy lens which also contained an in situ artefact and M5 sampled the grey sands which yielded the artefacts.

In the laboratory the undisturbed samples were air dried, and under vacuum impregnated with unsaturated polyester resin. After hardening, sawing and grinding thin sections were prepared according to the method of Benyarku and Stoops (2005). The vertical thin sections (9 x 6 cm, and 20 µm thick) were studied with the aid of a Leitz Orthoplan polarizing microscope in plane (PPL) and crossed polarized light (XPL), in the case of opaque material, the colour in oblique incident light is also mentioned. The thin sections are described micromorphologically using the terminology of Stoops (2003). This is followed by an interpretation of these observations.

OBSERVATIONS

Thin section M1

Characterization
<u>*Macroscopic*</u>: Brown groundmass, upper part (1/2) massive, lower half aggregated, size: 1-8 mm. In the upper half very few fine material < 10 µm, in the lower part few to common fine material.
<u>*Microscopic*</u>: Brown groundmass with in the lower half subangular blocky aggregates with common intrapedal planes. Dominant clay with silt up to medium sand-sized mineral grains, such as quartz with very few flint, feldspars and micas. $C/f_{10\,\mu m}$ ratio 2:10, open porphyric related distribution pattern. B-fabric mainly speckled, locally monostriated, porostriated or granostriated.
<u>*Pedofeatures*</u>: diffusely and sharply bounded iron nodules, and quasi iron coatings. In addition crystal intergrowths of gypsum rosettes. Organic material: few organic remnants with cell structure and black, opaque root remnants.

Description
<u>*Microstructure*</u>: brown groundmass with mainly in the lower half common subangular blocky aggregates, highly to moderately separated, and partially accommodated, diameter 0,2-8 mm. Common intrapedal zigzag and curved planes, diameter 20-900 µm, random and locally linear arrangement. Microstructure: subangular blocky.
<u>*Groundmass*</u>: Dominant brown clay with common subangular to subrounded mineral grains consisting of silt up to medium sand, mainly quartz, very few angular flint (1 x 1.8 mm), feldspars and colourless micas. $C/f_{10\ \mu m}$ ratio 2:10, $C/f_{10\ \mu m}$ related distribution pattern open porphyric. B-fabric mainly speckled, locally monostriated, porostriated or granostriated. Mosaic b-fabric occurs very rare.
<u>*Organic material*</u>: Very few pale to dark brown organic material, with celstructure and interference colours, diameter 450 µm, and black (black)opaque elongated root remnants, diameter 90-250 µm.
<u>*Pedofeatures*</u>:
Coatings, hypocoatings and quasicoatings:
- Very few brown (orange) quasicoatings of iron with diffuse boundaries.
Crystal and crystal intergrowth:
- Crystal intergrowth: few rosettes of gypsum, diameter: 200-400 µm. The rosettes occur mainly in the groundmass in a random distribution pattern, and locally in voids, close to organic remnants (roots) or iron nodules.
Nodules:
- Very few, black or brown (orange) diffusely bounded, iron nodules, diameter 200-700 µm.
- Very few, dark brown to black (orange) sharply bounded, iron nodules, diameter 450 µm.
Excrements: not observed.
Fragmented, dissolved, deformed pedofeatures: not observed

Thin section M2

Characterization
<u>*Macroscopic*</u>: brown groundmass with subangular aggregates and planes mainly in the upper part. Size of the aggregates 3-10 mm.
<u>*Microscopic*</u>: brown groundmass with subrounded aggregates in the upper part, subangular blocky microstructure, with intrapedal planes. Dominant clay with silt up to medium sand, mainly quartz, very few flint, micas and feldspars. $C/f_{10\ \mu m}$ ratio 2:10, open porphyric. Mainly mosaic b-fabric. Very few root remnants.
<u>*Pedofeatures*</u>: coatings of marcasite and nodules, iron nodules and very few rosettes of gypsum.

Description
<u>*Microstructure*</u>: brown groundmass with subrounded aggregates mainly in the upper part, size 0.4-11.5 mm. Diameter of the planes 45-900 µm, mainly curves planes and partially accommodated, and are common intrapedal planes. Subangular blocky microstructure.
<u>*Groundmass*</u>: dominant brown clay with common subangular to subrounded grains, locally in clusters, consisting of silt up to medium sand, mainly quartz, very few angular flint, size 225x 140 µm, very few micas and feldspars. $C/f_{10\ \mu m}$ ratio 2:10, in sandy clusters 8:1. C/f_{10}

μm related distribution pattern: open porphyric, b-fabric mainly mosaic b-fabric, and locally monostriated, porostriated or granostriated.
Pedofeatures:
- Very locally, very few, black (white-silver) plane and quasi coating, 50-200 μm thick, of marcasite (FeS_2).
- Very few black (white-silver) irregular marcasite nodules with sharp boundaries, diameter 900 μm.
- Very few to few, dark brown (orange), sharply to weak diffusely bounded iron nodules, diameter 150-900 μm.
- Crystal intergrowths: very few rosettes of gypsum ($CaSO_4$. $2H_2O$), diameter 500 μm. They occur in the groundmass in a random distribution pattern close to organic root remnants in the top.

Organic material: Very few elongated brown and partly black (black) root remnants. The brown part shows interference colours, with a unistrial b-fabric. Diameter: 200-1800 μm. In addition black (black) root remnants in planes, diameter 90-150 μm.
Excrements: not observed.

Thin section M3

Characterization
Macroscopic: upper part dark brown with an inclined brown band, 1.5-2.0 cm wide. Lower part is brown with planes.
Microscopic: lower part (A) brown groundmass with mainly clay and planes and locally blocky, but mainly massive. C/f $_{10\ \mu m}$ ratio 2:10, in sandy clusters 8:10. Very few dark brown plant remnants, related distribution pattern porphyric. Mainly parallel striated b-fabric.
Special features: common irregular black (PPL) mottles and white in oblique incident light of marcasite, diameter 100-250 μm, very few iron mottles, and plane iron hypocoatings.
Organic constituents: very few, locally few, dark brown-opaque, elongated plant remains, 10-100 μm thick, they occur in a random distribution pattern, locally inclined and parallel in a cluster.
Upper part (B). Two dark groundmasses with a light brown band in between, consisting mainly of clay and massive with planes. Mineral grains silt up to medium sand sized grains. C/f $_{10\ \mu m}$ ratio 1:10 and porphyric related distribution pattern. B-fabric parallel and strong striated, common black marcasite mottles. Few dark brown plant remains, very few iron nodules.

Description
Microstructure: **Lower part A**, 3 cm thick, brown to dark brown groundmass of clay and less sand grains, and with common intrapedal planes, size of the unaccommodated zig-zag planes 20-500 μm, and very few vughs, diameter 450 μm. Microstructure: locally (sub)angular blocky, partly massive.
Groundmass: dominant brown to dark brown clay with common sand grains, locally in clusters or bands, consisting of subangular to subrounded silt to medium sand, mainly quartz.
C/f $_{10\ \mu m}$ ratio: 2:10, in sandy clusters 8:10. C/f $_{10\ \mu m}$ related distribution pattern: open porphyric. B-fabric: mainly parallel striated, locally cross-striated, unistrial or porostriated.

B-fabric also: speckled b-fabric.
Microstructure:
Upper Part B, 4.5 cm thick. Two dark brown groundmasses with a light brown, inclined band in between, consisting mainly of clay and much less sand grains, with few to common unaccommodated zig-zag planes, diameter 20-500 µm. The planes are only locally accommodated. Microstructure: mainly massive.
Groundmass: dominant dark brown and in the band light brown, consisting of clay with few larger mineral grains. The larger mineral grains consist of subangular to subrounded silt up to medium sand grains (diameter 300 µm). Silt, very fine and fine sand are dominant, mainly quartz minerals. The mineral grains occur in a random distribution pattern. $C/f_{10\,\mu m}$ ratio: 1:10, $C/f_{10\,\mu m}$ related distribution pattern: open porphyric. B-fabric mainly parallel striated, locally cross-striated. Common irregular black (PPL) and in incident light white magnetite (?).
Organic constituents: few, dark brown, elongated, locally with weak interference colours, plant remains, 10-60 µm thick. Probably root remnants, they occur in a random distribution pattern. In the light brown band they occur parallel to the walls of this band.
Pedofeatures:
- Nodules in part A: very few, dark brown (PPL) and orange (in incident reflected light) diffusely bounded iron nodules. Only very few, dark brown (PPL) and orange (in incident reflected light) plane iron hypocoatings.
- One rill infilling, v-shaped, 6 mm deep, and 4.5 mm wide. The infilling consists of light brown clay with a cross-striated b-fabric.
- In part B: very few iron nodules, diameter 200 µm.

Thin section M4

Characterization
Macroscopic: A sharp boundary from left bottom corner to the top corner between two different materials A and B. A on the right site shows a dark brown groundmass with subangular blocky peds, dimensions 5x5 mm. The left part B is very pale brown to grey with some dark spots.
Microscopic: **Part A**: a brown groundmass with subangular blocky peds with straight intrapedal planes. Groundmass: very dominant brown clay with enclosed, dark brown to black, organic components. $C/f_{10\,\mu m}$ ratio: 1:10. $C/f_{10\,\mu m}$ related distribution pattern: porphyric. Mainly parallel striated b-fabric.
Pedofeatures: crystal intergrowth of carbonates.
Part B: white to grey groundmass with simple packing voids between silt, and very fine to medium sand grains. Mainly quartz grains with enclosed few organic components and clayey aggregates. $C/f_{10\,\mu m}$ ratio: 10:1. $C/f_{10\,\mu m}$ related distribution pattern: coarse monic. B-fabric: undifferentiated.

Description
Microstructure:
Part A. A brown groundmass with subangular blocky peds, consisting mainly of clay, size: 5x5 mm and smaller, highly separated, partially accommodated. Voids: common straight planes, size 50-250 µm wide, intrapedal, mainly vertical and inclined.

Groundmass: Mineral and organic constituents: Mineral: very dominant brown clay with enclosed few larger mineral grains, such as silt and very fine to medium sand, mainly quartz, and very few colourless micas. Organic constituents: few to common, elongated, dark brown to black (PPL) organic components, locally with parallel cel structure, 20-450 µm thick, with a random distribution pattern in the clayey matrix, without interference colours. C/f $_{10\ \mu m}$ ratio: 1:10. C/f $_{10\ \mu m}$ related distribution pattern: porphyric. B-fabric: mainly parallel striated and less cross striated.
Pedofeatures: Crystal intergrowths. In the most upper part of the thin section random crystal intergrowths of carbonates.
Part B. *Microstructure*: A white to grey groundmass with mineral grains and mainly simple packing voids, size mainly between 10-100 µm in diameter.
Groundmass: Mineral and organic constituents: the minerals are mainly silt and very fine to medium sand grains, consisting mainly of quartz, in addition very few feldspars, colourless micas and glauconites, with locally enclosed dark brown, sometimes pale brown or black (PPL), elongated organic components, 20-100 µm thick. Locally enclosed angular to subrounded, grey to brown (PPL), clayey aggregates. The aggregates consist mainly of clay, and, but less, of silt, very fine and fine sand grains, they occur in a random distribution pattern. C/f $_{10\ \mu m}$ ratio: 10:1. C/f $_{10\ \mu m}$ related distribution pattern: coarse monic. B-fabric: undifferentiated.
Pedofeatures: Only in part A very weak pedogenesis, i.e. formation of subangular blocky clay and of crystal intergrowths of carbonates. The boundary zone between A and B is locally mixed. In A clusters of sand and in B clayey aggregates.

Thin section M5

Characterization
Macroscopic: Part A. Dark brown sandy groundmass, 5 cm thick. Part B. The top 2.5 cm contains more gravel than below. A very dark brown, inclined intrusion, length 3.5 cm and 3 cm thick.
Microscopic: In part A very few channels and vughs. In part B only very few channels. In parts A and B a massive microstructure. In part A dominant rounded to subrounded very fine to medium sand grains, very coarse sand and gravel. In part B: dominant fine sand, frequent medium to very coarse sand and gravel. Parts A and B: massive microstructure with very few organic constituents. Part A: C/f $_{10\ \mu m}$ ratio: 2:1 and in part B 1:1. Parts A and B: c/f $_{10\ \mu m}$ related distribution pattern: close porphyric. Part A dark brown (PPL) and orange (incident reflected light) micromass, b-fabric speckled and granostriated.
Pedofeatures: in parts A and B iron coatings and iron nodules.

Description
Microstructure: Aggregates: not observed in parts A & B.
- Voids: in part A: very few channels, diameter 200-300 µm, occasionally larger ones up to 700 µm in diameter and even less vughs with a diameter of about 700 µm in diameter.
In part B: very few channels with a diameter of 250 µm. Voids in parts A & B occur in a random distribution pattern.
- Microstructure: Parts A & B have a massive microstructure.
Groundmass:

- Mineral and organic constituents.
Mineral grains: **Part A:** Dominant rounded to subrounded, very fine to medium sand grains. Frequent rounded to subrounded, coarse, very coarse sand and gravel up to 4.5 mm, consisting mainly of quartz, locally polycrystalline, and chert (flint), and only very few micas, feldspars and green glauconites.
Part B: dominant fine sand grains, frequent medium to very coarse sand and gravel up to 5 mm, consisting mainly of quartz, locally polycrystalline, and chert. Very few micas and feldspars.
- Organic constituents: **Part A:** very few, pale brown (PPL) root remnants, diameter 850 µm, with cel structure and interference colours, and elongated brown (PPL) fibrous root remnants, diameter 70 µm.
Part B: very few black (PPL) elongated opaque organic remnants, diameter 40 µm.
$C/f_{10\ \mu m}$ ratio: Part A: 2:1, part B: 1:1, $c/f_{10\ \mu m}$ related distribution pattern: Part A: close porphyric, part B: close porphyric.
Micromass: **Part A:** dark brown (PPL) and light orange in incident reflected light, b-fabric mainly speckled, locally granostriated.
Part B: brown to dark brown (PPL) and orange in incident reflected light micromass, b-fabric mainly speckled, locally granostriated.

Pedofeatures:
- Coatings: **Part A:** very few black to dark brown (PPL) and orange in reflected light embedded grain iron coatings, 250-700 µm thick.
Part B: very few black to dark brown (PPL) and orange in reflected light embedded grain iron coatings, 45-400 µm thick.
- Nodules: **Part A:** very few dark brown to black (PPL) and orange in reflected light, sharply bounded ferric nodules, 250-700 µm, and but even less, nodules with diffuse boundaries, diameter: 2.5 mm. Only one black (PPL) and black in reflected light nodule observed, with sharp boundaries, diameter: 450 µm.
Part B: very few dark brown to black (PPL) and orange in reflected light, diffusely bounded ferric nodules, diameter: 400-1000 µm. Very few dark brown to black (PPL) and orange in reflected light, sharply bounded ferric nodules.

INTERPRETATION

Thin section M1: Indications of a specific mode of deposition are not observed, although a till deposit is not excluded in view of the presence of dominant clay with silt up to medium sand-sized mineral grains, $c/f_{10\ \mu m}$ ratio 2:10, and an open porphyric related distribution pattern. Certain indications could be masked by the internal movements in the groundmass due to shear and pressure stresses. This thin section shows soil formation, such as subangular blocky microstructure, reorientations (b-fabric) in the fine groundmass, diffusely bounded iron nodules, quasi-coatings of iron and crystal intergrowth with rosettes of gypsum. These rosettes of gypsum resemble, more or less, the crystal intergrowths as in the case of desert roses (Poch et al., 2010). The b-fabrics indicate movements in the groundmass as a result of swelling and shrinkage, movements by shear stress. Precipitations of iron oxides and hydroxides as a result of hydromorphism. Presence of carbonates is not observed.

*Thin section M2***:** The matrix of this sample resembles that of M1 regarding the presence of dominant brown clay with common subangular to subrounded grains, locally in clusters, consisting of silt up to medium sand, c/f $_{10\ \mu m}$ ratio 2:10, in sandy clusters 8:1, and c/f $_{10\ \mu m}$ related distribution pattern: open porphyric. This horizon shows indications of soil formation: subangular blocky microstructure, marcasite (FeS_2) coatings and nodules, iron nodules, crystal intergrowths of gypsum. Gypsum is a remarkable mineral because it occurs mainly in (semi)arid regions (Dixon and Weed, 1977, p.76). In addition it also occurs in acid sulphate soils (Poch et al., 2010). If certain conditions are fulfilled it can occur in marine clay after poldering and ripening of the sediment. But it precipitates only in the case that the calcium content can neutralize the sulfate in the marine deposit (Pons and Zonneveld, 1965; Dost, 1973). If there is a deficit in calcium, jarosite ($KFe_3(SO_4)^2(OH)^6$) will be formed, with a yellow colour. Jarosite is characteristic for the so-called "cat clay soils", a very acid sulphate soil. However, both developments of gypsum and jarosite are rare in temperate climates. Gypsum occurs also in some estuarine and marsh soils through the oxidation of pyrite (FitzPatrick, 1984, p.84). Minerals like marcasite indicate an environment at the boundary of marine and terrestrial settings. Marcasite occurs also in combination with pyrite associated with organic material, indicating fresh water to brackish depositional swamp environments (Mees and Stoops, 2010). Pyrite usually forms in tidal or marshy soils through the interaction of iron in the soil and sulphate in the sea water (FitzPatrick, 1984, p.96).

Indications for a specific mode of deposition are not observed. The optical characteristics, such as black, opaque, rod-like shape, and in oblique incident light silver-rose, strongly suggest marcasite. Also the presence of gypsum ($CaSO_4$. $2H_2O$) is in agreement with the mineral marcasite. Other possibilities are ore minerals such as magnetite and ilmenite. To be 100 % certain other methods are necessary, for example microscopic investigation with incident light of mineral polished sections or EDXRA or XRD submicroscopy.

*Thin section M3***:** The lower part A shows indications for weak soil formation (blocky structure, iron nodules and iron hypocoatings, and probably marcasite nodules). The rill infilling shows an interruption during the sedimentation of part A. The upper part B shows more depositional features such as the inclined light brown band, parallel striated, with plant remnants parallel to the walls, probably deposited by overland flow. Other indications for a specific mode of deposition are lacking. Regarding the organic material only very few, locally few, dark brown-opaque, elongated plant remains, 10-100 µm thick, are observed.

Thin section M4: Part A resembles a till sediment with very dominant brown clay with enclosed few larger mineral grains, such as silt and very fine to medium sand, c/f $_{10\ \mu m}$ ratio: 1:10 and c/f $_{10\ \mu m}$ related distribution pattern: porphyric. Two different groundmasses occur next to each other; part A with subangular blocky clay, and part B with the coarse monic sand groundmass. In part A, clay orientations as a result of shear and pressure stress. In addition crystal intergrowths of carbonates. In the polarization microscope it is not possible to differentiate between the various carbonate minerals, such as calcite, aragonite, and dolomite. Identification of the mineral composition of the various carbonates is only possible by chemical tests, staining the carbonates in uncovered thin sections or in polished blocks (Stoops, 2003). The most common carbonate is however calcite, which occurs also in loess and loess-derived deposits. Aragonite occurs mainly in shells. Flint has not been observed in this thin section.

Thin section M5: The groundmass is a not well sorted loamy sand, part B contains slightly more clay than part A. Flint occurs in parts A and B. The undifferentiated massive groundmass with coarse sand and gravel resembles a till sediment. The brown colour is due to iron segregation, regarding the orange colour in incident reflected light. The mineral grains are rounded to subrounded indicating fluvial transport. The material contains very few weatherable minerals, mainly quartz and flint. Pedofeatures are rare, only very few sharply bounded ferric nodules, and fewer diffusely bounded nodules, which are formed in situ, indicating weak hydromorphic conditions. In addition very few iron coatings are formed.

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