The earliest record of human activity in Northern Europe

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The colonisation of Eurasia by early humans is a key event following their spread out of Africa, but the nature, timing and ecological context of the earliest human occupation of northwest Europe is uncertain and has been the subject of intense debate[1]. The southern Caucasus was occupied about 1.8 million years ago[2], while human remains from Atapuerca-TD6, Spain (>780 ka)[3] and Ceprano, Italy (ca 800 ka)[4] show that early *Homo* had dispersed to the Mediterranean hinterland before the Brunhes-Matuyama magnetic polarity reversal (780 ka). Until now, the earliest uncontested artefacts from northern Europe were much younger, suggesting that humans were unable to colonise northern latitudes until after 500 ka[5,6]. Here we report flint artefacts from the Cromer Forest-bed Formation at Pakefield (52° N), Suffolk, UK, from an interglacial sequence yielding a diverse range of plant and animal fossils. Event and lithostratigraphy, palaeomagnetism, amino acid geochronology and biostratigraphy, indicate that the artefacts date to the early part of the Brunhes Chron (ca 700 ka) and thus represent the earliest unequivocal evidence for human presence north of the Alps.

The Cromer Forest-bed Formation (CF-bF), exposed discontinuously for a distance of over 80 km along the North Sea coast of eastern England, has long been famous for its early Middle Pleistocene fossils[7-11]. Spectacular finds include many extinct large mammals, molluscs, beetles, remains of fruits, seeds and even trees from which the deposits get their name. Recent work on vertebrate and molluscan faunas has shown that the CF-bF is much more complex than previously envisaged and includes evidence for at least six distinct temperate phases between *c*. 780-450 ka (ref. 12). The CF-bF sediments are primarily organic detritus muds and sands laid down within channels and on the floodplains of rivers, which drained central and eastern England before ice-sheets invaded the area about 450 ka ago[13]. During this time, Britain was connected to the Continent, East Anglia being located at the southwestern margin of a large coastal embayment around the subsiding North Sea basin. The flint artefacts found at Pakefield (52° 25.9′ N, 1° 43.8′ W) were recovered from river sediments, with a significant quartz and quartzite component, which formed the floodplain of the lower reaches of the erstwhile Bytham River that drained the English Midlands at this time (Fig. 1)[13, 14].

Despite two centuries of investigation no convincing artefacts have hitherto been found stratified within the CF-bF. However, several excavations in the recently re-exposed coastal sections of CF-bF (and associated deposits) between Pakefield and Kessingland[11, 14-16] resulted in the discovery of 32 worked flints (length >20mm), including a simple flaked core, a crudely retouched flake and a quantity of waste flakes (Fig. 2). These artefacts come from clear stratigraphic contexts and are associated with a wealth of evidence that allows a rare opportunity to reconstruct the environment inhabited by the humans who made the tools (see Supplementary Information Table 1). The artefacts, all in very sharp condition, are made of good quality black flint. Unworked surfaces, where present, are water-worn, suggesting that the raw material was collected from the adjacent river channel. The assemblage lacks formal tools and is thus consistent with a Mode 1 Technology (i.e. flakes, pebble tools and choppers made with hard hammers[17]), but this interpretation must remain provisional in view of the small sample size.

The artefacts came from four different contexts within an interglacial infill of a channel incised into Early Pleistocene marine sediments and overlain by a sequence of marine sands, glaciofluvial sediments and Lowestoft Till (Fig. 3). The oldest artefact was found in the upper levels of the estuarine silts (Fig. 3) containing marine and brackish-water ostracods, foraminifera and sparse marine mammals (including dolphin and walrus). All other artefacts were found in the CF-bF, which comprises the 'Rootlet bed', '*Unio* bed' and 'laminated silts' [14-16]. Two artefacts were found in overbank sediments with well-developed soil features including numerous fossil root-casts and pedogenic carbonate nodules ('Rootlet bed'). Most of the artefacts (n=28) came from a lag gravel ('*Unio*-bed') at the base of the laminated silts that fill the channel cut into the overbank sediments, but a single flake (Fig. 2c) was found in the laminated silts at the edge of the channel. Sediments overlying the channel infill were originally interpreted as glaciofluvial deposits attributed to the North Sea Drift Formation (Marine Isotope Stage (MIS) 12, refs 11, 18. Fig. 3), thus implying a long hiatus between the CF-bF and the glacial sequence. A new interpretation[14] suggests that a more complete sequence is represented (Fig. 3b) by the complex succession of marine sands, Bytham River sands and gravels, and glaciofluvial sands and gravels from the Happisburgh Glaciation, which are separated from the CF-bF by a periglacial interval indicated by the presence of frost-cracks. Another marine deposit overlies these sands and gravels and the whole sequence is capped by the Lowestoft

Till Member, deposited by the Anglian Glaciation[11], when ice sheets reached their maximum extent in Britain.

Fossils from sediments that contain the artefacts indicate that the local climate was significantly different from that of the present day in terms of temperature and seasonality of precipitation. Plant (*Trapa natans*, *Salvinia natans* and *Corema album*) and beetle (*Cybister lateralimarginalis*, *Oxytelus opacus* and *Valgus hemipterus*) remains include several thermophilous species no longer living in Britain, and the presence of *Hippopotamus* and frost-sensitive insects and plants implies warmer summers and mild winters. Mutual Climatic Range (MCR)[19] analysis of the beetle assemblage enables quantitative estimates to be made of the thermal climate at this time (Fig. 3b). These suggest that the mean temperature of the warmest month (July) was between 18°C and 23°C and the mean temperature of the coldest months (January/February) was between –6°C and 4°C. Pedogenic carbonate nodules in the 'Rootlet bed' indicate an annual moisture deficit, whilst their isotopic composition reflects intense soil moisture evaporation during their formation[20]. The combination of warmer summer and winter temperatures together with a strongly seasonal precipitation regime is indicative of a warm, seasonally dry Mediterranean climate.

Both the insects and plants indicate the presence of marshy ground with extensive reedy vegetation and alder trees adjacent to a meandering river with shallow riffles and deeper pools. Oak woodland grew on drier ground with open grassland nearby. This mixture of habitats supported a variety of large browsing and grazing mammals dominated by *Mammuthus trogontherii*, *Stephanorhinus hundsheimensis*, *Megaloceros savini*, *M. dawkinsi* and *Bison* cf. *schoetensacki*, and their predators and scavengers (*Homotherium* sp., *Panthera leo*, *Canis lupus* (small) and *Crocuta crocuta*). The floodplain would have provided a resource-rich environment for early humans, with a range of plant and animal resources. An additional attraction, in an area where good quality flint would have been scarce, was the flint-rich river gravels, which provided the raw material for tool manufacture.

Pollen analysis indicates that the channel infill accumulated during an interglacial with regional vegetation dominated by broad-leaf woodland that included *Carpinus* (hornbeam) in its later part[11]. These sediments were originally correlated with those at the Cromerian stratotype at West Runton, Norfolk, 60 km to the NW, on the basis of palynology[11] and malacology (e.g. presence of extinct freshwater mollusc *Valvata goldfussiana*[12]). This suggestion is broadly supported by the extent of racemization and the pattern of amino acid decomposition in the intra-crystalline fraction of *Bithynia* opercula (see Methods and Supplementary Information). However, although these sites are clearly close in age, several lines of evidence suggest that they are not exactly contemporary. West Runton lacks the important component of southern thermophile plants and beetles seen at Pakefield. Moreover, several large mammals, such as *Hippopotamus*, *Megaloceros dawkinsi* and *Palaeoloxodon antiquus* (the latter recorded only from unstratified material) known from Pakefield/Kessingland have never been found at West Runton, despite the much more extensive collections from that site[16]. Furthermore, the occurrence of two vole species of the genus *Mimomys*, *M. savini* and *M.* aff. *pusillus* (see Supplementary Information), at Pakefield, of which only the former is known from West Runton, is also consistent with a difference in age. *M. pusillus* is known from the Early Pleistocene to its latest occurrence in the early Middle Pleistocene Ilynian Complex

(European Russia)[21]. As the latter is overlain by the Don Till (Donian), correlated with MIS 16 (ref. 21), this suggests a minimum age for the Pakefield '*Unio*-bed'.

This evidence suggests that sediments containing the artefacts belong to an interglacial in the early part of the 'Cromerian Complex'[10]. This interpretation is supported by independent evidence derived from the lithostratigraphy. A maximum age is indicated by palaeomagnetic data from the laminated silts, which show normal polarity[14], consistent with the early part of the Brunhes Chron. A minimum age is indicated by the overlying Lowestoft Till Member, conventionally thought to have been emplaced during MIS 12 (refs 13, 18). The sediments between the CF-bF and the till have been traditionally interpreted as of glaciofluvial origin, deposited during the Anglian Stage[11, 17]. A longer chronology has recently been proposed on the basis of sedimentological evidence suggesting that the CF-bF may be separated from the MIS 12 till by two separate high sea-stands and two cold episodes[14] (Fig. 3b). Using the premise that temperate-climate marine deposits and cold-climate aggradations in the lower parts of large, temperate latitude rivers can be matched, respectively, to the peaks and troughs of orbitally-tuned MIS cycles[20], the archaeology can be dated to MIS 17 (*c*. 680 ka) at the very youngest. If evidence for ice-sheet extension across eastern England during MIS 16 is valid[21], then an additional temperate/cold cycle is required and the archaeology at Pakefield could be as old as the later part of MIS 19 (*c*. 750 ka).

The oldest human fossils in NW Europe are from Mauer[6], Germany and Boxgrove[24], UK, where they are part of vertebrate assemblages that include the water vole *Arvicola terrestris cantiana*. All other NW European sites containing early Middle Pleistocene archaeology in association with rich small mammal assemblages (e.g. Miesenheim I, Germany, Westbury-sub-Mendip and Waverley Wood, UK)[6, 25, 17], have likewise yielded *Arvicola* (with unrooted molars), rather than *Mimomys* (its ancestor with rooted molars). These early Middle Pleistocene archaeological sites with *Arvicola* have all been correlated with MIS 13, the basis for the belief in a short chronology for human occupation in this region[6]. The discovery at Pakefield of unequivocal artefacts in beds yielding *Mimomys* demonstrates a much longer human occupation of NW Europe, pre-dating other evidence by as much as 200 ka. There has been much discussion about what additional social, technological or physiological adaptations humans would have required to colonise NW Europe compared with their occupation further south[5, 26]. The Mediterranean climate reconstructed for the archaeological levels at Pakefield suggests that these pioneers were able to spread northwards in familiar climatic conditions, using their existing adaptations.

Methods

Amino acid geochronology

A new technique of amino acid analysis has been developed for geochronological purposes[27] that combines a new Reverse Phase-High Pressure Liquid Chromatography (RP-HPLC) method of analysis[28] with the isolation of an intra-crystalline fraction of amino acids by bleach treatment[29]. This combination of techniques results in the analysis of D/L values of multiple amino acids from the chemically-protected protein within the biomineral, enabling both decreased sample sizes and increased reliability of the analysis. The calcitic structure of the opercula of *Bithynia* (a genus of freshwater prosobranch gastropods) has been found to provide the most robust repository for the amino acids yet studied.

Amino acid racemization (AAR) analyses were undertaken using these procedures on three individual samples of *Bithynia troscheli* opercula (NEaar 1711-1712) from the laminated silts (PaCii) and four samples of *B. troscheli* opercula (NEaar 2165-2167) from the *Unio*-bed (PaCi). Each operculum was powdered and bleached for 48 hours with 12% NaOCl. Two subsamples were taken: one fraction was directly demineralised and the free amino acids analysed (referred to as the 'Free' fraction, F), and the second was treated with 7 M HCl under N_2 at 110°C for 24 hours (referred to as the 'Hydrolysed' fraction, H*) to release the peptide-bound amino acids, thus yielding the 'total' amino acid concentration. Samples were then dried using a centrifugal evaporator and rehydrated for RP-HPLC analysis with 0.01 mM L-homo-Arginine as an internal standard.

The amino acid compositions were analysed in duplicate by RP-HPLC using fluorescence detection, following the method of Kaufman and Manley[28]. A 2 µl sample was injected and mixed online with 2.2 µl of derivitising reagent (260 mM n-Iso-L-butyryl L-cysteine (IBLC), 170 mM o-phthaldialdehyde (OPA) in 1 M potassium borate buffer, adjusted to pH 10.4 with potassium hydroxide pellets). The amino acids were separated on a C_{18} HyperSil BDS column (5 mm x 250 mm) at 25°C using a gradient elution of 3 solvents: sodium acetate buffer (solvent A; 23 mM sodium acetate tri-hydrate, 1.5 mM sodium azide, 1.3 µM EDTA, adjusted to pH 6.00 ± 0.01 with 10% acetic acid and sodium hydroxide), methanol (solvent C) and acetonitrile (solvent D). The L and D isomers of 10 amino acids were routinely analysed. During preparative hydrolysis both asparagine and glutamine undergo rapid irreversible deamination to aspartic acid and glutamic acid respectively[29]. It is therefore not possible to distinguish between the acidic amino acids and their derivatives and they are reported together as Asx and Glx.

On the basis of protein decomposition (racemization and degradation of amino acids) we conclude that the results are consistent with attribution to an early part of the 'Cromerian Complex'[27]. All opercula from Pakefield are significantly older (95% confidence) than those analysed from Waverley Wood, but they cannot be statistically separated from opercula from the type Cromerian West Runton Freshwater Bed. One sample from the *Unio*-bed (NEaar 2166) appears to be slightly younger than the others. The amino acid data therefore indicate that the Pakefield opercula are at least as old as those from West Runton (see Supplementary Information Table 2).

Figure captions

Figure 1. A reconstruction of the palaeogeography of northwest Europe during the early Middle Pleistocene[10, 13, 14, 17, 24, 30], showing all known Anglian/Elsterian and earlier archaeological sites, and highlighting their concentration in southern England. These sites can now be shown to provide a record of intermittent early human occupation of ca. 300 ka duration. Human remains are known from Mauer and Boxgrove. M = Miesenheim I, W = Westbury-sub-Mendip, WR = West Runton, WW = Waverley Wood.

Figure 2. Lower Palaeolithic flint artefacts from the Cromer Forest-bed Formation at Pakefield. **a**, Core, partly alternate hard-hammer flaking, with several incipient cones

of percussion on platforms. **b**, Retouched flake. **c-j**, Hard hammer-struck flakes, with previous removals on dorsal surface, often from the same direction. (b, 'Rootlet bed' (PaB); c, laminated silts (PaCii); others, '*Unio*-bed' (Pa Ci)).

Figure 3. Stratigraphical context of the Pakefield artefacts. **a**, Coastal sections between Pakefield and Kessingland. Red dots record the location of artefacts. **b**, Geological profile and interpretation.

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Authors' contributions. S.A.P., J.R. and A.J.S. co-ordinated research on the site and S.A.P. wrote this article, with major contributions from R.C.P, A.J.S., J.R. and C.B.S. The stratigraphical and lithological sequence was described by J.R.L. and J.R., while I.C. investigated the sediment geochemistry. R.M. and P.D. recovered most of the artefacts and mammalian fauna; the artefacts were figured and described by J.J.W. The large mammals were studied by M.B., A.J.S. and A.M.L., whereas S.A.P. analysed the small mammal fauna. K.E.H.P. and M.J.C. are responsible for the amino acid geochronology and R.W.B. undertook the palaeomagnetic investigations. Beetles were analysed by G.R.C., molluscs by R.C.P., plant macrofossils by M.H.F., and ostracods and foraminifera by J.E.W. R.S. made major contributions in the field and in drawing the figures.

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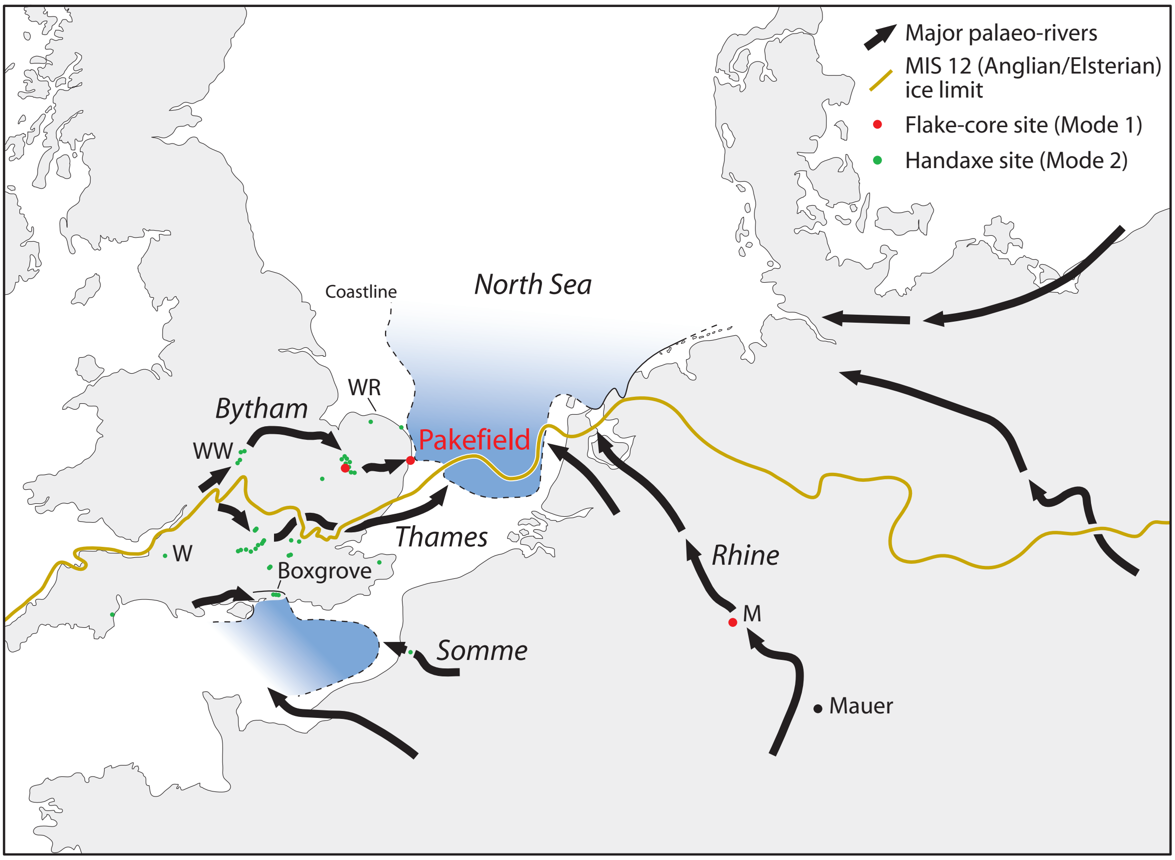
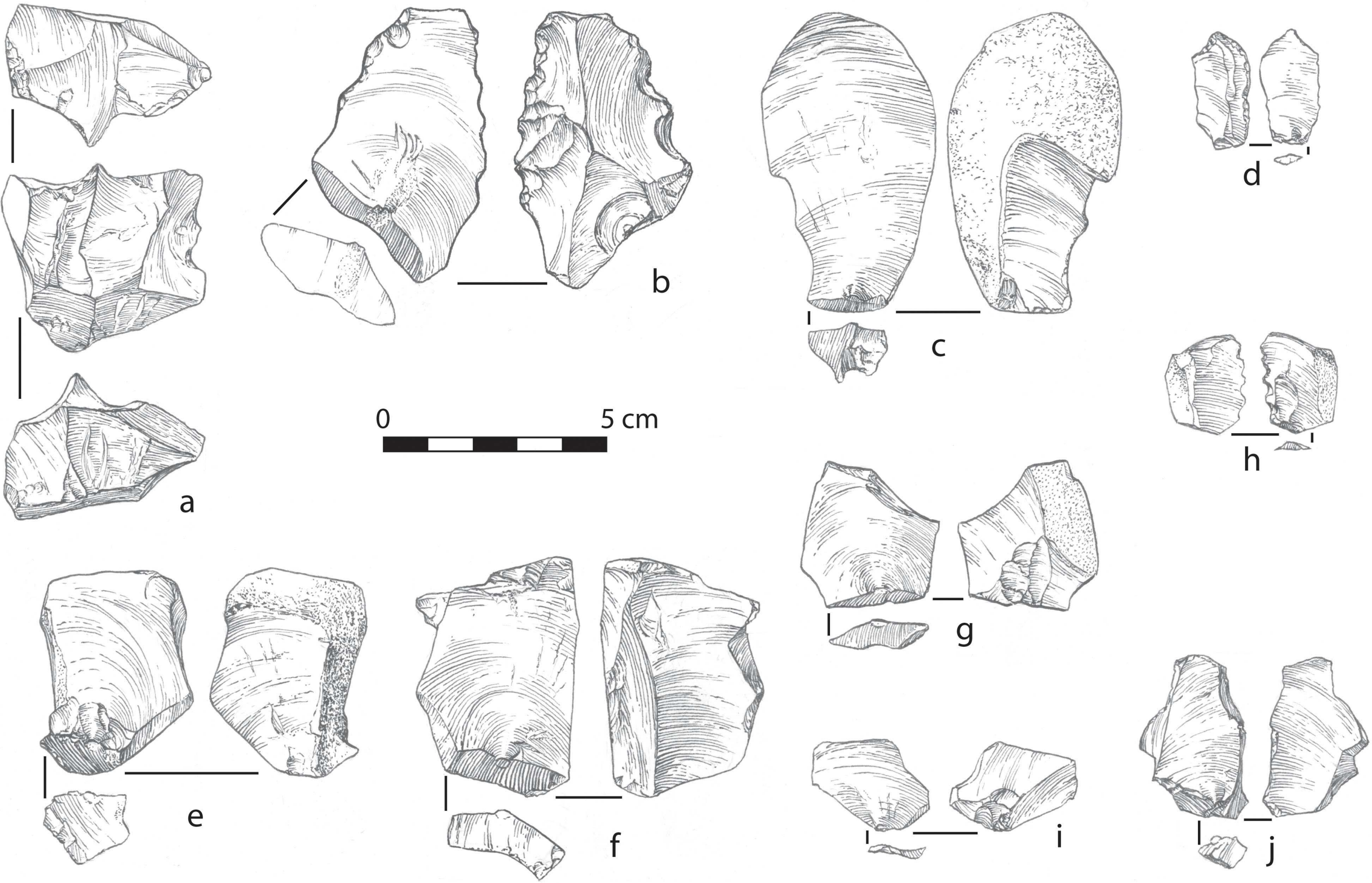

Major palaeo-rivers
MIS 12 (Anglian/Elsterian) ice limit
Flake-core site (Mode 1)
Handaxe site (Mode 2)
North Sea
Coastline
WR
Bytham
WW
Pakefield
Thames
W
Boxgrove
Somme
Rhine
M
Mauer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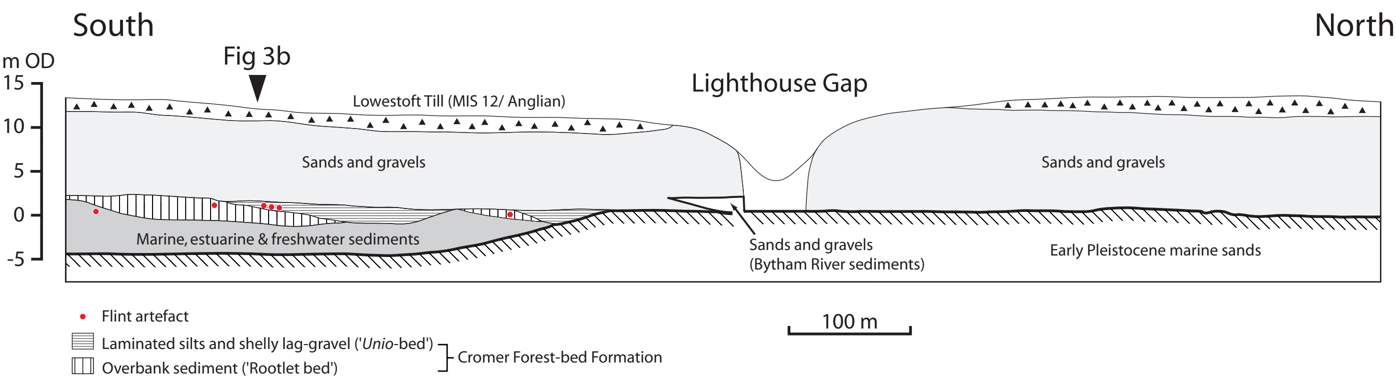

South
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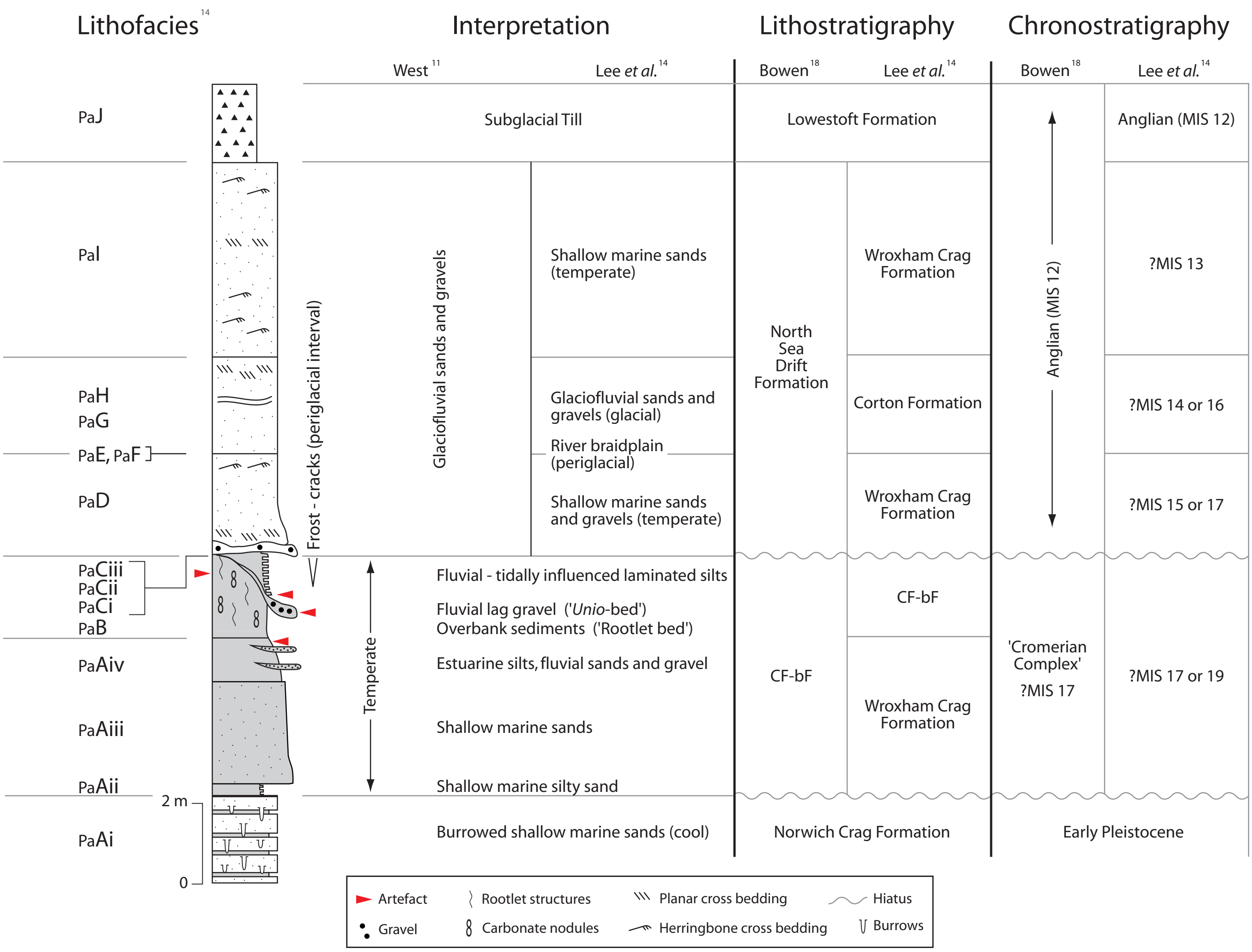
5
0
-5
Fig 3b
Lighthouse Gap
Lowestoft Till (MIS 12/ Anglian)
Sands and gravels
Sands and gravels
Marine, estuarine & freshwater sediments
Sands and gravels
(Bytham River sediments)
Early Pleistocene marine sands
Flint artefact
Laminated silts and shelly lag-gravel ('Unio-bed')
Overbank sediment ('Rootlet bed')
Cromer Forest-bed Formation
100 m



Lithofacies[14]
Interpretation
Lithostratigraphy
Chronostratigraphy
West[11]
Lee et al.[14]
Bowen[18]
Lee et al.[14]
Bowen[18]
Lee et al.[14]
PaJ
Subglacial Till
Lowestoft Formation
Anglian (MIS 12)
PaI
Shallow marine sands (temperate)
Wroxham Crag Formation
?MIS 13
PaH
PaG
PaE, PaF
PaD
Glaciofluvial sands and gravels
Glaciofluvial sands and gravels (glacial)
River braidplain (periglacial)
Shallow marine sands and gravels (temperate)
Frost - cracks (periglacial interval)
North Sea Drift Formation
Corton Formation
Wroxham Crag Formation
Anglian (MIS 12)
?MIS 14 or 16
?MIS 15 or 17
PaCiii
PaCii
PaCi
PaB
PaAiv
PaAiii
PaAii
PaAi
2 m
0
Temperate
Fluvial - tidally influenced laminated silts
Fluvial lag gravel ('Unio-bed')
Overbank sediments ('Rootlet bed')
Estuarine silts, fluvial sands and gravel
Shallow marine sands
Shallow marine silty sand
Burrowed shallow marine sands (cool)
CF-bF
CF-bF
Wroxham Crag Formation
'Cromerian Complex'
?MIS 17
?MIS 17 or 19
Norwich Crag Formation
Early Pleistocene
Artefact
Gravel
Rootlet structures
Carbonate nodules
Planar cross bedding
Herringbone cross bedding
Hiatus
Burrows