Understanding and Monitoring the Cromer Forest-bed Formation

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Management Report

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SUMMARY

The Cromer Forest-bed Formation that is exposed on the foreshores of the Suffolk and Norfolk coasts is of critical importance in understanding the earliest human occupation of northern Europe, but is under continual destruction from coastal erosion. This report is the culmination of a four year programme to monitor and understand better the process of erosion and the impact it is having on the contained Lower Palaeolithic archaeology and the associated fossil record. The long-term aim is to find effective ways of dealing with this significant threat. The report is divided into six main sections, which after the introduction deal with the geological and geophysical investigations both onshore and offshore (Section 2) and a summary of these results (Section 3). An assessment of future impact is provided in Section 4, which is followed by suggestions for dealing with future monitoring and work to deal with the impact (Section 5). A summary of recommendations is given in Section 6. These highlight the need for:

1. Further onshore geoarchaeological investigation at Happisburgh using coring and geophysics for better mapping of the archaeologically significant deposits.
2. Geophysical investigations in the Happisburgh to Eccles offshore zone to provide better seabed and sub-surface mapping of potential offshore sites. The area around the Monks is of particular interest.
3. Developing long-term links with local collectors and improving public awareness to monitor and record new surface finds of artefacts and fossils, and new exposures.
4. Using the case study at Happisburgh to investigate and monitor other coastal exposures for a broader regional study of the Cromer Forest-bed Formation on the Norfolk and Suffolk coasts.

ACKNOWLEDGEMENTS

We thank Historic England (formely English Heritage) for funding this work through Project Grants 6234 and 6441. Contributions were also made by the Ancient Human Occupation of Britain Project funded by the Leverhulme Trust and by the Pathways to Ancient Britain Project funded by the Calleva Foundation. We are also grateful to North Norfolk District Council for logistical support, site access and permission to undertake the work. Finally we thank the local community in Happisburgh for their interest and support of the project.

DATE

November 2016

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1. INTRODUCTION

Two projects were funded in 2012 by English Heritage (now Historic England) to develop ways of responding to the rapid coasta l erosion of Early and early Middle Pleistocene deposits that contain Lower Palaeolithic archaeology along the Norfolk and Suffolk coastlines in particular at Happisburgh (Figure 1). The project team was a consortium of specialists from various HEIs and national museums, some of whom have been working on the site for over 10 years. The report has been compiled by Dr Nick Ashton (British Museum) and Dr Simon Lewis (Queen Mary University of London) with contributions on the fieldwork and biological analyses by Simon Parfitt (Natural History Museum and UCL), the geology by Dr Simon Lewis and Dr Peter Hoare (Queen Mary University of London), the geophysics by Dr Martin Bates (University of Wales Trinity St David) and Dr Richard Bates (University of St Andrews) and on the offshore survey by Dr Justin Dix, Dr Fraser Sturt and Dr Rachel Bynoe (University of Southampton).

1.1 Background to the project

The project has developed from research undertaken since 2001 by the *Ancient Human Occupation of Britain* (AHOB) project, funded by the Leverhulme Trust, in which one of the main research themes was investigation of the earliest human occupation of northern Europe. At the start of the AHOB project there was an apparent gap in the record of occupation between southern and northern Europe. Whereas sites in Spain and Italy dated back to 1.5 million years, the oldest sites in northern Europe dated to only 0.5 million years. The key questions were: was the gap in the record real, or were there earlier sites in northern Europe yet to be discovered? If earlier sites could be discovered, what were the human habitats and what technologies were required, such as clothing, shelter and fire, to occupy northern Europe?

One of the key areas for investigation was the Norfolk and Suffolk coasts. The coastal cliffs are mainly composed of glacial sediments from the Anglian Glaciation, dating to *c* 450,000 years ago. At their base lie a complex series of river, estuarine and near-shore marine deposits, collectively known as the Cromer Forest-bed Formation (CF-bF). The deposits infill part of the Crag Basin, span a period of 2 to 0.5 million years, and interdigitate with Crag sediments, which are of marine origin. The CF-bF had long been known to contain fossil bones and other environmental remains and is a key area for understanding the Early and early Middle Pleistocene environmental history of northern Europe. Despite extensive collecting of fossils during the 19th and 20th centuries, there had been no discovery of undisputed artefacts. In 2000, flint artefacts were discovered in the CF-bF, both at Pakefield (Suffolk) and Happisburgh (Norfolk), which highlighted the rich potential of these deposits for discovering early human sites and, from the associated environmental evidence, for reconstructing the human habitats and the technology required to occupy northern Europe.

The discoveries led to extensive fieldwork and research by AHOB at several locations around the coast. At Pakefield further in situ artefacts were discovered and from the environmental remains argued to be associated with a 'Mediterranean type' climate and dated to *c* 700,000 years ago (Figure 1; Parfitt *et al* 2005). A model was proposed whereby humans extended their range into northern Europe only as climate warmed (cf Roebroeks 2005). A much larger programme of research was undertaken at Happisburgh with artefacts and cut-marked bones found in several different locations (Figure 1; Parfitt *et al* 2010; Ashton *et al* 2008, 2014). Work at the oldest location, Site 3, extended the human occupation of northern Europe back to over 800,000 years ago. However, in contrast to Pakefield, it also showed humans coping with colder winter temperatures than experienced in East Anglia today. The work has demonstrated that the CF- bF is a set of sediments of global archaeological importance which documents the first occupation by humans of cooler, northern latitudes, and which may have been the catalyst for developments in technology, such as the use of shelters, clothing and fire (Ashton and Lewis 2012).

Over the last 15 years, the offshore record of the Norfolk and Suffolk coasts has also been investigated with the mapping of ancient river systems in the southern North Sea Basin (for example Dix and Sturt 2011; Wessex Archaeology 2008). At the same time there has been the continued recovery of Pleistocene mammalian fauna from fishing, dredging and gravel extraction across the North Sea Basin (Bynoe 2014; Bynoe *et al* 2016) and the occasional recovery of Palaeolithic artefacts, such as in Area 240, 10km east of Great Yarmouth (Figure 1; Tizzard *et al* 2014).

The combination of onshore and offshore work confirmed the importance of the CF-bF and nearby submerged terrestrial deposits for understanding the earliest human occupation of northern Europe. Importantly, it also highlighted the need for a long-term strategy for dealing with deposits that crop out along the coast and are under constant threat from erosion, or offshore from dredging and gravel extraction. This directly led to the funding of the English Heritage (EH) projects in 2012.

The first of the EH projects sought to find ways of better monitoring the exposures and fossils from the CF- bF, in particular through developing better links with local collectors and improving public awareness through lectures, 'fossil road shows' and other public-engagement events. The second project aimed to improve understanding of the stratigraphic relationships between the onshore and offshore records through geophysics, drilling and offshore diving. It was hoped that improved understanding of the deposits might help with future research and find ways of dealing with the effects of future erosion. The work has focussed on Happisburgh, where three main archaeological sites have been recorded (Ashton *et al* 2008, 2014; Parfitt *et al* 2010).

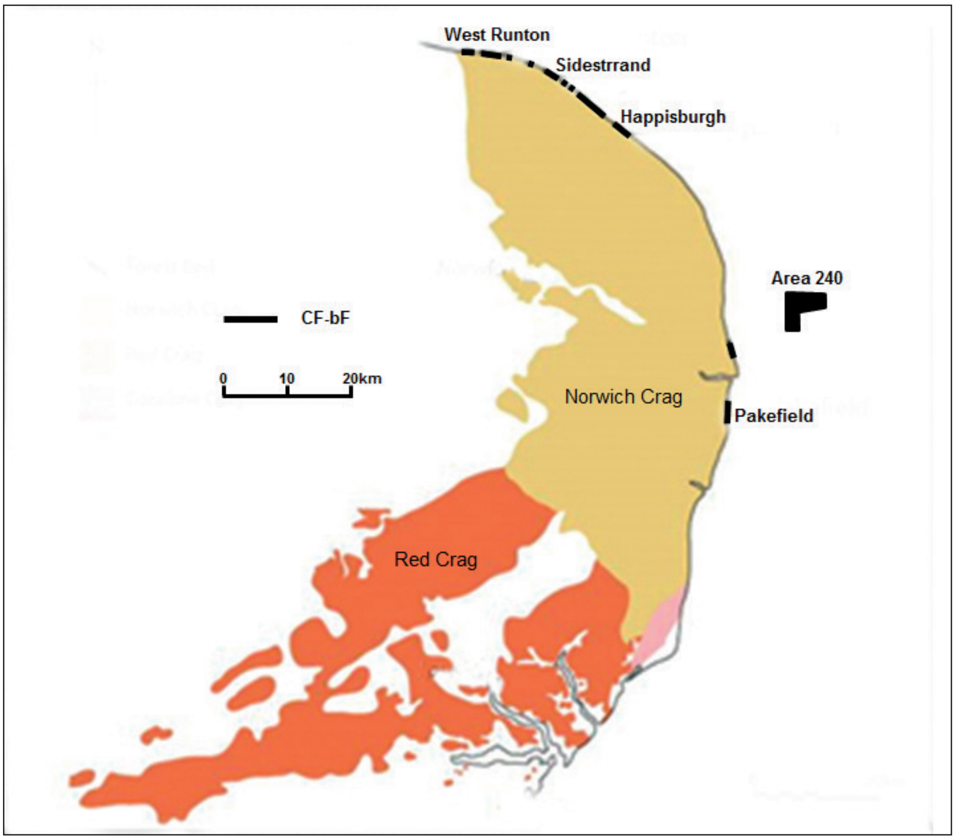

Figure 1 Location of coastal exposures of the CF-bF in East Anglia and the offshore site of Area 240. Adapted from map by Simon Parfitt.

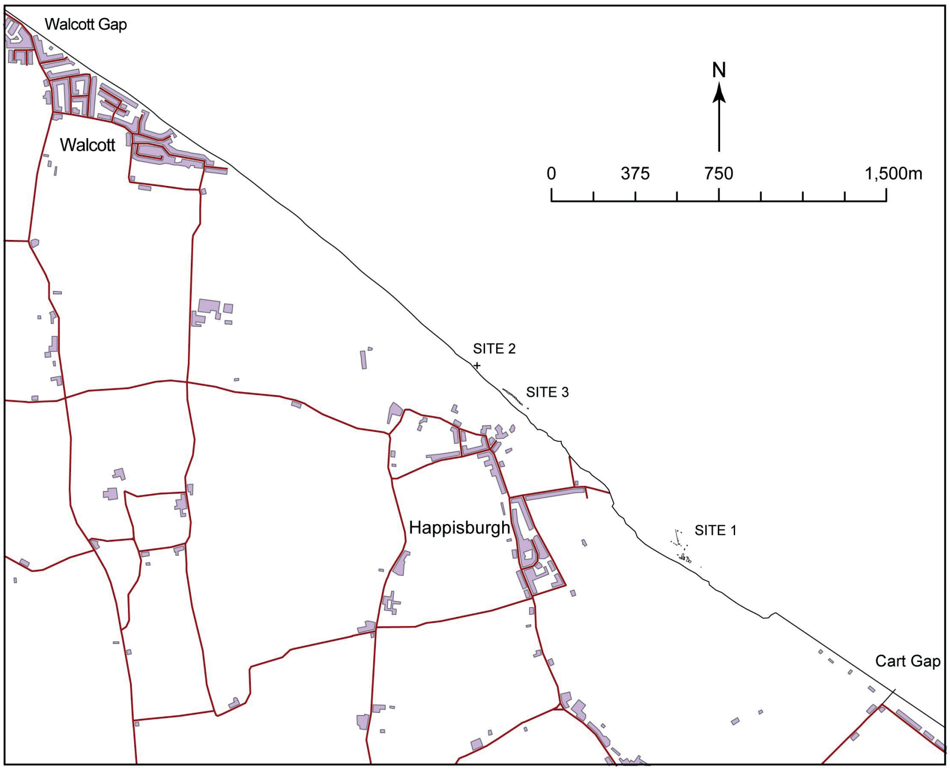

Figure 2 Location of Happisburgh Sites 1, 2 and 3. Based on Ordnance Survey (Digimap license).

1.2 The Happisburgh and Eccles sites

Prior to the start of the current projects, the most extensive programme of archaeological fieldwork was at Happisburgh, where since 2000 three main sites have been discovered. The work focused on two locations (Happisburgh Site 1 and Site 3; Figures 2 and 3; Table 1) both consisting of channel-fill deposits cut into marine sands and overlain by Happisburgh Till. Fieldwork by AHOB in 2004 and joint work with the University of Leiden from 2009 to 2012, together with the results from this project, showed that the channel at Site 1 is *c* 100m wide and filled with silty-sand overlain by organic mud (Figure 4). The sediments contain a wide range of environmental data together with flint artefacts, including a handaxe, and cut-marked bone (Ashton *et al* 2008). The faunal remains, including *Arvicola cantiana* (water vole), suggest an age of *c* 500,000 years ago. Several papers on the site are near completion.

Figure 3 (Left) Oblique aerial view of Happisburgh looking to the north-west showing Sites 1, 2 and 3. Photo by Mike Page.

Figure 4 (Below) Excavation of organic mud at Happisburgh Site 1 in May 2004. Photo by Nigel Larkin.

More extensive work was undertaken by AHOB at Site 3 from 2005 to 2012 (Figure 5). The site lies *c* 1km to the north-west of Site 1 on the northern edge of an approximately 700m wide series of channels. In the area of Site 3 the channel is filled with a complex sequence of gravels and estuarine sandy silts. Similar gravels and estuarine sediments were identified by West (1980) in a borehole *c* 400m to the south-east of Site 3 and also in exposures, a further 300m down the coast. The latter may be close to the southern edge of the channel complex. The channel sediments have yielded a rich array of environmental evidence together with simple flakes, flake tools and cores. The age of the site was constrained through the reversed palaeomagnetic signal from the sediments and biostratigraphy, suggesting an age between 1 million and 800,000 years old (Parfitt *et al* 2010).

During the current project in May 2013, an exposure of the Site 3 estuarine silts, *c* 100 m to the south-east of the previous excavation, revealed a surface with human footprints (Figure 6). It was estimated that at least six individuals were represented, including adults and children, and they appeared to be walking in a southerly direction (Ashton *et al* 2014). The footprint surface also dates to between 1 million and 800,000 years ago.

Happisburgh Site 2 was discovered in 2004 by Simon Parfitt and John Wymer in the cliff section *c* 150m north-west of Site 3. Here, beneath Happisburgh Till, a small gravel-filled gulley was identified, which contained a handaxe, a core and four flakes. Other than being pre-Anglian, the age of the site is unknown.

During the AHOB work archaeological and organic material was identified that derives from an unknown location or locations that probably lie a short distance off the coast; blocks of iron-concreted gravel, which contain bones and plant remains, were recovered from local beaches between Happisburgh and Eccles-on- Sea. Work by Simon Parfitt has shown that the mammalian fauna is a single assemblage and is probably early Middle Pleistocene in age (780-500,000 years ago). Importantly the bones retain cut-marks from human butchery. Apparently similar blocks of gravel were described by Clement Reid (1890) who suggested that they originated from a concreted formation with 'cliff-like' edges, lying offshore '1/2 mile' NNE from the 'Low Lighthouse'. The remains of the lighthouse can still be identified on the beach, *c* 200m to the south-east of Site 1. Surface artefacts have also been found some of which retain traces of concreted sediment. Most of these are concentrated near Eccles North Gap, although they have occasionally been found just south of Happisburgh Site 1.

Figure 5 Excavation of Happisburgh Site 3 in June 2010. Photo by Simon Lewis.

Figure 6 Happisburgh Site 3 footprint surface. Photo by Simon Parfitt.

Table 1 Archaeological sites at Happisburgh.

Site and code	Location	Research undertaken	Archaeology	Organic material
Site 1 HSB1	Beach/foreshore between Happisburgh village and Cart Gap NGR: 638900,330600	Initial discovery of handaxe in 2000 led to AHOB fieldwork 2002-2004 with the first systematic excavation in 2004. University of Leiden fieldwork in 2009-12 (Ashton *et al* 2008; Field 2011, in prep.; Lewis *et al* submitted; Parfitt *et al* in prep.)	>200 flakes and cores; 1 handaxe; cut-marked bone. Additional lithics from surface collection	Vertebrates, molluscs, pollen, plant macros
Site 2 HSB2	Base of cliff 150m north-west of Site 3. NGR: 637950,331440	Discovered and excavated by AHOB in 2004. Sections were cleaned and recorded.	1 handaxe; core, 4 flakes	
Site 3 HSB3	Beneath beach from old slipway to northern end of Caravan Park NGR: 638100,331300	Site first investigated by West in 1960s. Archaeological material discovered during AHOB geological survey work along Happisburgh beach in 2005, followed by excavations 2006-2012. Footprints discovered 2013 (West 1980; Parfitt *et al* 2010; Ashton *et al* 2014).	<100 flakes and cores. Additional lithics from surface collection	Vertebrates; beetles; forams; pollen; plant macros
HEOZ	Happisburgh to Eccles. Derived from Happisburgh-Eccles Offshore Zone (HEOZ)	Pieces of iron-concreted "Eccles Cromer Forest Bed" found on the beach between Happisburgh and Sea Palling by Reid (1890). Large blocks still being collected. Identification of cut-marked bone in pieces of Eccles Cromer Forest Bed in 2006. Derived from offshore location.	Cut-marked bone	Vertebrates; pollen; plant macros
ENG	Eccles North Gap NGR: 641600,328800	Regular 'field-walking' by local collectors has amassed a substantial collection of artefacts from the surface.	Surface collection flakes; cores	Vertebrates

1.3 Aims of EH funded projects

The sites at Happisburgh, offshore survey and the discovery of significant offshore work sites, such as Area 240, have brought into focus a major issue, which is the importance, but difficulty, of understanding the stratigraphic relationships and correlations between the onshore and offshore records (Bates *et al* 2007; Tizzard 2014). The purpose of Project 6234 has been to investigate methods by which the onshore and offshore records can be integrated to provide a seamless interpretation of the buried landscapes. At the same time Project 6441 has been identifying the best ways to record the artefacts and fossils that are being recovered by collectors and members of the public and to integrate these new records into the historic archives and collections from the CF-bF. The studies should inform future decisions about coastal management around Happisburgh. They will also provide a method for the assessment of other areas containing Pleistocene sediments that are under threat from coastal erosion. For both projects the main aims were to:

- Develop methodologies for mapping and understanding the relationships between onshore and offshore deposits. In particular identifying the best methods of onshore geophysics and coring, and of offshore mapping, diving and ROV investigation.

- Provide better understanding of the nature, extent and relationships between the various onshore and offshore deposits at Happisburgh. These have included identifying the extent of Sites 1 and 3, both off-shore and inland and locating the Happisburgh-Eccles offshore location.

- Encourage the recording of new finds from collectors and local walkers through existing procedures at Norfolk Museum Service (NMS), which would feed into the Historic Environment Records (HERs) and Portable Antiquities Scheme (PAS).

- Digitally record existing archives, in particular those of Richard West and Alfred Savin.

- Integrate all new data into a usable tool, such as a CF-bF GIS, to provide a central database that could be interrogated for future research.

- Disseminate the results of the project for different audiences through a variety of means, including archive reports, academic papers, public talks, website and a leaflet.

- Develop management plans for English Heritage to help formulate local, regional and national coastal management policy.

1.4 Management Report

The report will cover five aspects of the work, specifically:

- Methods and results from geological and geophysical investigations (Section 2)

- Summary of results from surveys to act as baseline data for future comparison (Section 3)

- Assessment of future impact from coastal erosion (Section 4)

- Continued monitoring of the fossils from the CF-bF (Section 5)

- Recommendations (Section 6)

In addition, in Appendix 1, there is a case study of an assessment of the impact on archaeologically significant deposits (ASDs) from work to realign rock groyne and remove failed sea defences at Happisburgh. Towards the end of the EH-funded project, in the summer of 2015, a separate watching brief and coring programme were commissioned in response to plans to undertake work on the beach at Happisburgh. The case study illustrates the need for: improved baseline data on the destruction of ASDs; the undertaking of fieldwork prior to, rather than during, the operation; and better dialogue between developers, planners and regulatory authorities in archaeologically sensitive coastal areas.

2. GEOLOGICAL AND GEOPHYSICAL INVESTIGATIONS AT HAPPISBURGH

2.1 Onshore Drilling Programme

2.1.1. Methods

Between 2009 and 2011 a variety of drilling techniques were deployed with varied degrees of success, including hand-augering, a Terrier mini percussion drilling rig, a Cobra percussion corer and a large shell and auger drilling rig. Most of these methods had limited success due to a combination of often thick beach sand, running sand in the deeper boreholes and with some of the methods, problems of retrieving sediment cores for sampling and archiving. However, the Pilot Study showed that the shell and auger drilling rig could overcome some of these problems (Figure 7). This drilling method offered the advantages of being able to cope with a range of sediment types and ground conditions and also capability to recover undisturbed samples. The potential disadvantages were mainly associated with gaining access for the rig onto the beach (Figure 8). The initial work took place in July 2012 over a period of four days with a total of six boreholes on both the cliff-top and on the foreshore around the channel feature of Site 1 (Figure 10).

A total of sixteen boreholes were drilled during this project, using a cable percussion drilling rig; six in 2012, six in 2013 and a further four in 2014. The location, depth and stratigraphy of these boreholes are summarised in Tables 2-4 and Figure 16. The 2012 boreholes were located at Site 1; BH12/1 was on the clifftop and BH12/2-6 was on the beach. The 2013 and 2014 boreholes were all located on the cliff top, on the caravan park above Site 3 and in the corner of the camping field in the vicinity of the old lifeboat ramp, which was the site of borehole HC (West 1980; Figure 9). One of the 2014 boreholes was deliberately located as close as possible to the location of the footprints discovered in 2013 (Ashton *et al* 2014). In addition, in 2015 a Cobra percussion drilling system was used to drill ten boreholes as part of an assessment of the impact of removal of remaining sea defences on the archaeologically important deposits along part of the beach at Happisburgh (see Appendix 1).

Table 2 2012 Pilot Study Borehole location and stratigraphy. Terminology of the glacial units follows Lee et al *(2004).*

BH	E	N	Elev (OD)	Depth (m)	Top (m)	Base (m)	Th (m)	Lithology	Stratigraphic unit
12-1	638889	330519	11.2	20.0	0.0	6.7	6.7	Sand	Happisburgh Sand
					6.7	9.0	2.3	Clay	Ostend Clay
					9.0	10.8	1.8	Till	Happisburgh Till
					10.8	13.5	2.7	Organic mud	Site 1 channel deposits
					13.5	20.0	6.5	Grey sand	Site 1 channel deposits/Crag group
12-2	638920	330540	1.9	10.0	0.0	0.6	0.6	Sand	Modern beach sand
					0.6	2.2	1.6	Till	Happisburgh Till
					2.2	4.3	2.1	Organic mud	Site 1 channel deposits
					4.3	10.0	5.7	Grey sand	Site 1 channel deposits/Crag group
12-3	638990	330503	2.1	10.2	0.0	1.8	1.8	Sand	Modern beach sand
					1.8	8.0	6.2	Sand	Happisburgh Sand
					8.0	10.1	2.1	Till	Happisburgh Till
					10.1	10.2	0.1	Sand	Crag Group?
12-4	638969	330511	2	6.0	0.0	0.8	0.8	Sand	Modern beach sand
					0.8	3.1	2.3	Till	Happisburgh Till
					3.1	3.8	0.7	Organic mud	Site 1 channel deposits
					3.8	6.0	2.2	Grey sand	Site 1 channel deposits
12-5	639005	330487	2.2	12.0	0.0	2.0	2.0	Till	Corton Till
					2.0	12.0	10.0	Grey sand	Happisburgh Sand
12-6	638938	330518	2.2	4.2	0.0	0.4	0.4	Sand	Modern beach sand
					0.4	2.9	2.5	Till	Happisburgh Till
					2.9	4.2	1.3	Organic mud	Site 1 channel deposits
					4.2	4.2	0.0	Grey sand	Site 1 channel deposits

Figure 7 Coring using a cable percussion drilling rig on the foreshore at Happisburgh Site 1, July 2012. Photo by Peter Hoare.

Figure 8 The difficulties of exiting the beach with the cable percussion drilling rig and support vehicle at Happisburgh Site 1, July 2012. Photo by Peter Hoare.

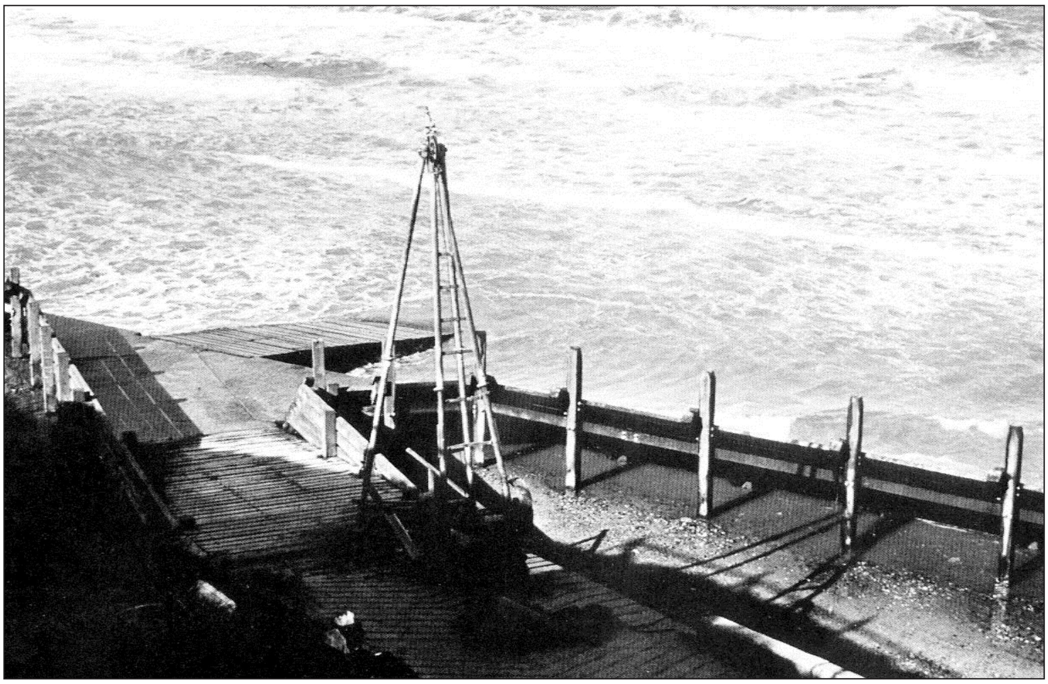

Figure 9 Drilling of borehole HC on the life-boat ramp at Happisburgh in 1966 (R.G. West Archive).

Figure 10 Using the cable percussion drilling rig on the cliff top above Happisburgh Site 1. Photo by Peter Hoare.

2.1.2. 2012 Pilot Study: evaluation of drilling method

The purpose of this part of the project was to establish the best approach to drilling the sediments at Happisburgh. One borehole (BH12/1) was located on the cliff-top over what was thought to be the deepest part of the Site 1 channel. The borehole penetrated the *c* 11m of glacial sediments that formed the cliff in less than two hours. None of these sediments were sampled or archived which speeded up this part of the operation. The borehole continued into the Site 1 channel deposits through 2.7m of organic muds. Good recovery of these sediments was achieved by continuous undisturbed sampling and the 0.45m long U4s were stored for later sub-sampling and archiving. The borehole went down a further 6.5m, but as this was running sand, retrieving material was considerably more difficult. Bulk samples were recovered using the bailer, but these have low stratigraphic resolution. The total depth was *c* 20m and took six hours.

A further three days were spent completing five boreholes on the foreshore (BHs 12/2-6). These were located on the south-eastern side of the channel in Site 1 in order to establish better the location of the channel margin (BHs 12/2-5) and to recover samples through the deposits in the centre of the channel (BH12/6). A ramp down the cliff close to Site 1 allowed access for the rig onto the foreshore, although this was only achieved by towing with a 16 tonne excavator. The accompanying 4x4 vehicle also managed to get on to the beach, although had to be towed off the beach on several occasions. Having the vehicle with all the drilling kit adjacent to the rig proved to be essential for effective operation.

The Pilot Study indicated that, overall, the drilling method provided an effective means of investigating the deposits beneath the beach. Drilling from the cliff top worked remarkably well with comparatively little time wasted on coring through the overlying sediments. Recovery was good through the important channel sediments, but as with all previous methods that had been tried did encounter problems with the running sands. Drilling on the beach presented significant logistical difficulties. The working time on the beach was four to five hours between the tides with considerable effort involved in getting the rig and vehicle on to and off the beach. Without the assistance of a tracked vehicle it would have been very difficult to operate in this way. The limited time window between high tides, coupled with the logistical problems of getting the rig and supporting equipment on and off the beach more than outweighed the extra time required to drill from the top of the cliffs.

Table 3 2013 Borehole location and stratigraphy.

BH	E	N	Elev (OD)	Depth (m)	Top (m)	Base (m)	Th (m)	Lithology	Stratigraphic unit
13-1	638367.98	331010.6	12.3	13.5	0.0	8.0	8.0	Sand	Happisburgh Sand
					8.0	10.5	2.5	Till	Happisburgh Till
					10.5	11.5	1.0	Laminated sands and silts	HC channel deposits
					11.5	13.5	2.0	Grey sand	Crag Group?
13-2	638405.72	330975.33	11.2	15.0	0.0	7.1	7.1	Sand	Happisburgh
					7.1	10.2	3.1	Till	Happisburgh Till
					10.2	15.0	4.8	Grey Sand	Crag Group?
13-3	638444.16	330941.97	11.2	12.0	0.0	6.5	6.5	Sand	Happisburgh Sand
					6.5	9.6	3.1	Till	Happisburgh Till
					9.6	12.0	2.4	Grey Sand	Crag Group?
13-4	638313.89	331066.19	12.8	14.8	0.0	6.7	6.7	Sand	Happisburgh Sand
					6.7	8.7	2.0	Clay	Ostend Clay
					8.7	11.8	3.1	Till	Happisburgh Till
					11.8	13.3	1.5	Laminated sands and silts	HC channel deposits
					13.3	15.0	1.7	Grey Sand	Crag Group?
13-5	638303.21	331084.1	12.8	12.5	0.0	6.7	6.7	Sand	Happisburgh Sand
					6.7	11.0	4.3	Till	Happisburgh Till
					11.0	12.0	1.0	Laminated sands and silts	HC channel deposits
					12.0	12.5	0.5	Grey Sand	Crag Group?
13-6	638101.42	331237.83	1	18.0	0.0	3.7	3.7	Sand	Happisburgh Sand
					3.7	5.5	1.8	Diamicton	unnamed diamicton unit
					5.5	10.0	4.5	Clay	Ostend clay
					10.0	11.0	1.0	Till	Happisburgh Till
					11.0	17.2	6.2	Laminated sands and silts	Site 3 channel deposits
					17.2	18.0	0.9	Grey Sand	Crag Group?

2.1.3. 2013-2014 drilling

Following the successful completion of the Pilot Study, which also provided significant new data on the geometry and distribution of the Site 1 channel deposits, it was decided to focus drilling resources on the north western end of the Happisburgh beach and the area between Site 3 and the old lifeboat ramp. The main objectives of this were:

- to define the south eastern extent of the Site 3/HC channel deposits,
- to recover samples of the HC channel deposits as close as possible to the location of borehole HC,
- to establish the continuity (or otherwise) of the deposits between the HC borehole and Site 3,

- to sample the complete profile of the deposits at Site 3, in particular the laminated sediments below the main artefact-bearing horizon (Bed E of Parfitt *et al* 2010), which were difficult to sample from the excavation trenches,

- to recover samples from sediments in close proximity to the footprint location.

These boreholes have provided a considerable quantity of new data on the distribution, geometry and sedimentological character of the Site 1 channel deposits and the Site 3/HC channel deposits and have contributed to the interpretation of the position of the channels along the coastline at Happisburgh (see below).

Table 4 2014 Borehole location and stratigraphy.

BH	E	N	Elev (OD)	Depth (m)	Top (m)	Base (m)	Th (m)	Lithology	Stratigraphic unit
14-1	638103	331236	15.1	17.5	0.0	3.5	3.5	Sand	Happisburgh Sand
					3.5	6.0	2.5	Diamicton	unnamed diamicton unit
					6.0	8.9	2.9	Laminated silts and clays	Ostend clay
					8.9	12.5	3.6	Till	Happisburgh Till
					12.5	17.0	4.5	Laminated sands and silts	Site 3 channel deposits
					17.0	17.5	0.5	Grey Sand	Crag Group?
14-2	638097	331243	15.1	17.6	0.0	4.0	4.0	Sand	Happisburgh Sand
					4.0	6.0	2.0	Diamicton	unnamed diamicton unit
					6.0	9.7	3.7	Laminated silts and clays	Ostend clay
					9.7	11.8	2.1	Till	Happisburgh Till
					11.8	17.2	5.4	Laminated sands and silts	Site 3 channel deposits
					17.2	17.6	0.4	Grey Sand	Crag Group?
14-3	638312	331071	12.8	18.0	0.0	6.8	6.8	Sand	Happisburgh Sand
					6.8	11.8	5.0	Till	Happisburgh Till
					11.8	13.2	1.4	Laminated sands and silts	HC channel deposits
					13.2	18.0	4.8	Grey Sand	Crag Group?
14-4	638223	331130	1	18.0	0.0	4.5	4.5	Sand	Happisburgh Sand
					4.5	7.0	2.5	Laminated silts and clays	Ostend clay
					7.0	12.2	5.2	Till	Happisburgh Till
					12.2	14.4	2.2	Laminated sands and silts	HC channel deposits
					14.4	18.0	3.6	Grey Sand	Crag Group?

2.1.4. Foreshore coring with Cobra percussion drill

In 2015 a project was undertaken by North Norfolk District Council to realign the rock defences in a 400m stretch running south-east from the old lifeboat ramp. The aim was to move the rocks back towards the cliff to provide better defence, but also to remove metal piled sheeting from the old wooden defences. As this involved heavy plant, a condition of the planning permission was to have a watching brief. However, when a large crawler crane using vibration was needed to remove the piled sheeting, a new planning condition was imposed by English Heritage, with a programme of coring on the foreshore adjacent to the piled sheeting (see Appendix 1). Previous work had shown that use of cable percussion rigs on the foreshore was problematic (see above), so a Cobra percussion corer was used instead.

As shown by previous experience, for effective operation a vehicle suitable for beach use is needed to transport the heavy coring equipment on and off the beach and between coring locations. Solid, in situ sediment is also required to provide a platform from which to drill. Any overlying beach sand not only provides an unstable base, but also immediately refills the hole with running sand. For these reasons it proved impossible to core near to the piled sheeting. It was also quite apparent that the Pleistocene sediments on this part of the foreshore had already been cut-out by the sea. Consequently most coring took place towards the cliff, where outcrops of till were found that created a suitable platform. The depth of boreholes depended on the thickness of the CF-bF silts because effective coring was difficult as soon as running sand was reached. The maximum thickness of CF-bF deposits adjacent to the cliff was *c* 4m. Several cores were attempted further down the foreshore, but still some distance from the piled sheeting. Here, it was necessary to clear overlying beach sand with a mechanical excavator from a wide area to find a solid base. The maximum depth achieved was *c* 2m. A further advantage of working near the cliff was the additional time between the tides, which was *c* 6 hours, compared to 2 hours towards the sea. (see full report in Appendix 1).

2.1.5. Conclusions

The drilling work undertaken for this project has shown that:

- Cable percussion rigs can quickly and successfully core from the cliff-top with good recovery of material down to wet sands. Greater depths can be achieved, but with poorer recording and recovery.

- Cable percussion rigs are more difficult to use on the foreshore because of difficulty of access, limited time between the tides and the need for a tracked vehicle next to the rig with the large amount of kit and accessories.

- Cobra percussion corers can be used on the beach, but are most effective near the cliff where a solid base can be found. A beach-worthy support vehicle is required to move equipment and a tracked excavator needed if any beach sand is encountered. Depth of coring is limited by wet sand and time on the beach is limited by the tides.

- The distribution, geometry and character of the archaeologically important deposits can be determined from the borehole data allowing the location of the channels to be reconstructed.

2.2 Onshore Geophysics

In June 2012 three geophysical techniques were tested along the beach and cliff sections around Happisburgh Site 1 to determine the best methods for mapping the buried palaeo-channel. The techniques were direct current resistivity imaging, electromagnetic ground conductivity mapping, and ground penetrating radar (GPR). The electrical resistivity and electromagnetic conductivity techniques were chosen as they have been extensively used in near surface geophysical investigations and have proved effective in mapping buried channels at other coastal localities in the UK (Bates and Bates 2000; Bates *et al* 2007). Most electrical techniques induce currents in the ground, which are used to measure the variation in ground conductivity, or its inverse, resistivity. Different materials, and the fluids within them, will show different abilities to conduct an electric current. In general, sequences with high clay contents show higher conductivity as do saturated sequences and especially where saline waters are present. GPR was chosen as it is known to give effective mapping of channel features in low conductivity sedimentary environments.

The geophysical methods were tested on the intertidal shore area and also on top of the cliffs immediately adjacent to Site 1. The shore is marked by coarse sand and gravels overlying occasional outcrops of Happisburgh Till, beneath which lie dense organic mud and silt resting in a channel. The low intertidal zone shows gentle seaward dip that steepens toward the high tide mark where significant accumulations of windblown sand have drifted against the eroding cliff line. The cliff shows a cross-section of the geology that consists of glacial clays and sands. The cliff is between 5 and 10m high, dipping towards the south-east into a small dry valley. No freshwater springs were observed in the cliff.

2.2.1. Direct Current Resistivity Imaging

This technique measures changes in ground resistivity by placing two metallic spikes into the ground and applying an electrical current across them. Two additional metallic spikes are generally used to measure the potential drop between the current electrodes. The current and potential are then used to calculate the apparent resistivity of the ground. By taking measurements at different electrode spacing it is possible to measure the apparent resistivity to different depths. These are then interpreted using geo-electrical models of the ground in terms of a true depth-resistivity sounding. In its simplest application, the method assumes a layered earth model. With modern equipment many electrodes are deployed at a time and computer control is used to select different electrode pairs for the current and potential electrodes. This produces a resistivity section which again can be modelled in terms of a geo-electrical cross-section or image of the earth to interpret the sub-surface geology and hydrology. Resolution of subsurface layers with this technique is determined by the electrode spacing, the geometry of current-potential pairs and the resistivity-depth section itself. In general, the deeper the section, the poorer the resolution as this requires the use of electrode pairs that are more widely separated and thus more lateral changes in sub-surface geology might be present.

Figure 11 Direct current resistivity survey at Happisburgh Site 1. Photo by Martin Bates.

The electrical imaging collected in this project was acquired using an ABEM Terrameter SAS4000 resistivity meter with 80 electrodes (Figure 11). The electrode spacing was set to different separations (1 to 5m spacing) across the site in order to test mapping resolution of the buried geological features. Lines were recorded from the cliff-top and on the foreshore. Positional errors were ± 10cm.

The full results of the DC resistivity imaging have been given in earlier reports (Bates and Bates 2012, 2013, 2016: see Appendices 2-4), but the main conclusion was that this technique successfully penetrated to depths > 20m from the cliff-top and could further be deployed on the foreshore using a variety of electrode spacings to achieve greater resolution or greater depth. It clearly identified zones of high and low resistivity that related to the channel features of Site 1 and deeper features were also recognised that have since been built into an interpretative model of channel formation in this area.

2.2.2. Electromagnetic Ground Conductivity

Electromagnetic techniques have been extensively developed and adapted over the last 15 years to map lateral and vertical changes in conductivity. Rather than directly applying an electrical current to the ground, an alternating current in a primary transmitter coil, usually at the ground surface, creates a changing magnetic field around the coil. This produces an electromotive force (EMF) which on passage through the ground can cause secondary eddy currents to flow in the ground. These in turn have their own magnetic field associated with them. The secondary currents and magnetic field differ in phase to the primary and can be resolved into a portion that is in phase with the primary (real) and one that is out of phase with the primary (quadrature or imaginary). For further details of this refer to standard geophysical text (Telford *et al* 1990) or technical notes (Geonics). For low induction numbers the quadrature signal is proportional to ground conductivity and the inphase reading is most sensitive to buried metal.

While the final output is similar to that from electrical techniques, several features of the electromagnetic techniques result in an increased horizontal resolution and more cost-effective application. Two types of electromagnetic survey are currently practised, i) time domain electromagnetic (TDEM) surveys which are mainly used for depth soundings and recently in some shallow metal detectors, and ii) frequency domain electromagnetic (FDEM) surveys that are used predominantly for mapping lateral changes in conductivity. In both electromagnetic survey techniques no direct contact is made with the ground and thus the rate of surveying can be far greater than for traditional electrical techniques where electrode probes must be placed in the ground for every measurement (see above). Further recent improvement in FDEM has seen the integration of dGNSS technology with the FDEM instruments and thus has led to a dramatic increase in the rate at which electromagnetic surveys can be accomplished. Typical results for FDEM surveys are contour maps of conductivity and inphase values and 2D geo-electric sections of conductivity.

Figure 12 Electromagnetic ground conductivity survey near Happisburgh Site 1. Photo by Martin Bates.

The survey instrument used was the Geonics EM-31 with digital acquisition and positioning provided by a Topcon Hiper dGNSS. This instrument records both conductivity and inphase signatures of the electromagnetic wave field. The effective exploration depth of the instrument in vertical mode is 3m.

Ground conductivity was mapped on the foreshore and intertidal areas in both vertical coil and horizontal coil orientation with effective exploration depths of 3 and 5m respectively (Figure 12). Positional errors were ±30cm.

The electromagnetic conductivity maps showed a clear difference between the central area of non- conductivity material and surrounding conductive response. This central zone not only corresponds to the changes noted in the DC resistivity imaging but also to the location of the near surface channel of Site 1.

2.2.3. Ground Penetrating Radar

Ground penetrating radar (GPR) uses high frequency electromagnetic waves to acquire subsurface information on lithology and pore fluid type. The EM wave energy is radiated downward into the ground from a transmitter and is reflected back to a receiving antenna. The reflected signals are recorded and produce a continuous cross-sectional 'picture' or profile of shallow subsurface conditions. Reflections of the radar wave occur where there is a change in the dielectric constant or electrical conductivity between two materials. Changes in conductivity and in dielectric properties are associated with natural hydrogeologic conditions such as bedding, cementation, moisture, clay content, voids, and fractures. Large changes in dielectric properties often exist between geologic materials and man-made structures such as buried utilities or can also exist where subsurface fluid properties change, for example over a saltwater table. As a general rule of thumb where ground conductivity is above approximately 30mS/m then GPR signals are unable to penetrate far distances.

Figure 13 Using Ground Penetrating Radar on the cliff top above Happisburgh Site 1. Photo by Martin Bates.

For this survey a Sensors and Software Pulse Ekko GPR system was used with both 100MHz and 250MHz antenna tested. This was operated in continuous radiating along lines with distance measured by a clocked wheel on the GPR cart (Figure 13). Positional errors were ±30cm. The survey showed results that indicated a compromise in penetration due to high conductivity of the clay in the cliffs and to the extremely high conductivity on the beach associated with salt water saturation. After test records were taken both on top of the cliff and on the beach the survey was terminated.

2.2.4. Conclusions. The work shows that:

- Direct current resistivity surveying was successful from both the cliff-top and the foreshore to depths up to 20m, distinguishing known channel features, but also probable deeper channels, about which less is known. The method could successfully be used inland.

- Electromagnetic Ground Conductivity provided a complimentary method on the beach, working at depths between 3 and 5m, also identifying channel features. The advantage is the increased speed of surveying.

- Ground Penetrating Radar was not successful due to high conductivity caused by salt water when deployed on the foreshore and low conductivity caused by the till when on the cliff-top.

2.3 Offshore Survey

2.3.1. Offshore mapping.

Through the project a large amount of offshore survey data has been compiled from existing sources for Happisburgh, which in combination with equivalent extant terrestrial data has provided a much clearer reconstruction of the onshore-offshore landscape. This data includes

- UKHO 20x30m bin bathymetry of the whole off-shore East Anglian coast. This dataset was referenced to Chart Datum (CD) and as it only represents the regional backdrop it has been retained in this datum format (Figure 14 for section adjacent to the Happisburgh frontage).

- Environment Agency (0.5m bin resolution) swath bathymetry data for a 1 km wide, 15km long strip between Walcott and Horsey and reduced to Ordnance Datum Newlyn (ODN) (Figure 15).

- Norfolk County Council (0.5m bin resolution) swath bathymetry for an area 1 x 0.25km infilling the embayment adjacent to Happisburgh 1. This data was provided in CD but was subsequently reduced to ODN by a simple static shift (Figure16).

- Environment Agency Lidar Data (1m bin resolution) taken in 2010 by the Environment Agency for the Walcott to Horsey coastal stretch (Figures 15 and 16).

- Admiralty Charts from the early 19th Century to present.

- Historic (1886) to present Ordnance Survey maps.

- Location of offshore vibrocores (Figure 17) and digital scans of extant seismic data (Figure 18) from the BGS marine geoindex.

- MALSF data (side scan and sub-bottom) collected for EH by Wessex Archaeology during their Seabed in Prehistory programme and covering the area offshore of Happisburgh 3 (Figure 19).

All these data have been geo-referenced with ArcGIS in OSGB (using the Petroleum 7 parameter transformation) and to ODN to facilitate integration with the terrestrial work.

Analysis of these datasets provides a basic geological context to the offshore regime. The area is gently shelving offshore reaching a maximum depth of -48.7m CD (*c* -51.6m ODN) in the Would before shallowing again towards the western margin of the Holocene, post-transgressive 'Haisborough' sandbank (Figure 14). A series of three linear ridges are oriented approximately perpendicular to the shore with a vertical expression of *c* 8m from the ambient seabed. The northerly two are *c* 8km in length, oriented WSW-ENE and go from *c* -13.5 to -29m CD (-16.4 to -31.9m ODN). The southerly ridge, 'The Monks', is significantly shorter (only *c* 2km in length), oriented due north and from the limited data available stands *c* 3m above the ambient seabed (Figure 14). Comparison with the BGS offshore bedrock map at 1:250,000 scale, indicates that the latter broadly coincides with the boundary between the Upper Cretaceous Chalk and undifferentiated Palaeocene. There is no such relationship with northerly ridges. Unfortunately the extant BGS borehole and seismic data does not provide any further clarification of the nature of the deposits making up these ridges.

The higher resolution swath bathymetry shows a clear pattern of south-easterly longshore drift in the 1km strip adjacent to the coastline (Figure 15). Although we only have a single time-step the asymmetry of bedforms (steep face pointing to the south-east) implies such a transport direction at least within the first 650m (Figure 16). Further offshore within the surveyed area, the seabed is characterised by a roughened but bedform-less gravel substrate, indicative of a winnowed surface with minor if any post-transgressive deposition. Although only qualitative, comparison of the EA swath with the Wessex side scan sonar suggests there is bed level change as topographic features immediately offshore and parallel to the coast at Happisburgh 3, they are no longer visible in the swath bathymetry taken about three years later.

A series of localised features were however present within the swath bathymetry:

1 Offshore of Happisburgh 1 there is a raised (0.8m above ambient) platform of seabed which is 35 m across and extends *c* 240m offshore from the Happisburgh 1 excavations (Figure 16). The feature is oriented just west of north and its linear western margin coincides closely (within 10m) with the hypothesised western margin of the Happisburgh channel. Its upper surface varies from -1.7m to -2.7m ODN with a gentle northerly gradient (0.56o) over a distance of *c* 100m. This is hypothesised to be an extension of the channel deposits offshore.

2 At (639372, 331083) there is a small irregular ridge extending for *c* 100m in a north-easterly direction. It has a total relief of 1.4m with a minimum depth of -10m ODN and a maximum depth on the flanks of -11.4m ODN. This locality coincides with the description of Reid (1890) of concreted gravel occurring 0.5 miles NNE of the Low Lighthouse (see Section 1.2 above). Although bedforms are developed on the flank the upper surfaces appear to have a rubble surface and high slope angles indicative of bedrock outcrop.

Analysis of these extant datasets enabled the identification of four primary dive sites including three possible locations for the source of the beach finds of concreted gravel with cut-marked bone. The dive locations could also investigate other possible exposures of the CF-bF and Crag Group on the seabed or in near surface deposits.

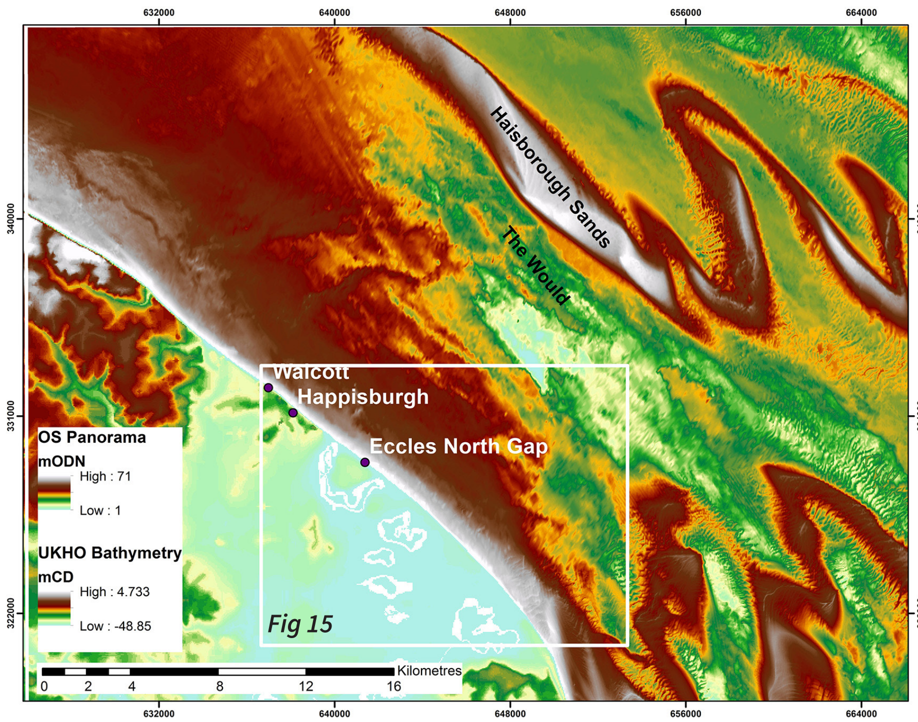

Figure 14 The regional UKHO 20x30m bin bathymetry off the north-east Norfolk Coast. Data courtesy of UKHO and Environment Agency.

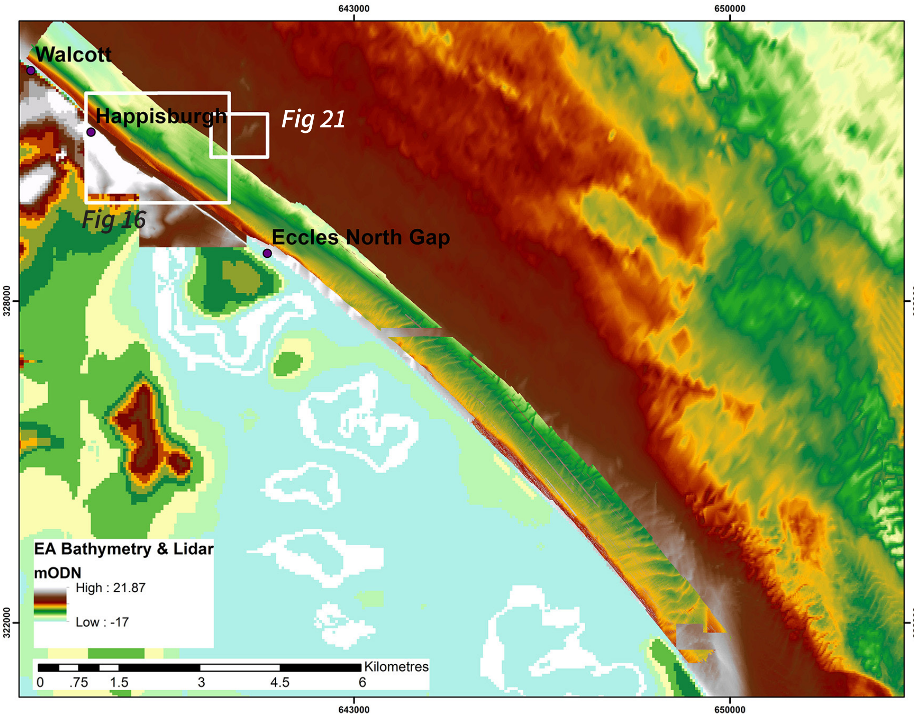

Figure 15. The Environment Agency bathymetry and Lidar for the north-east Norfolk Coastal section. Data courtesy of UKHO and Environment Agency.

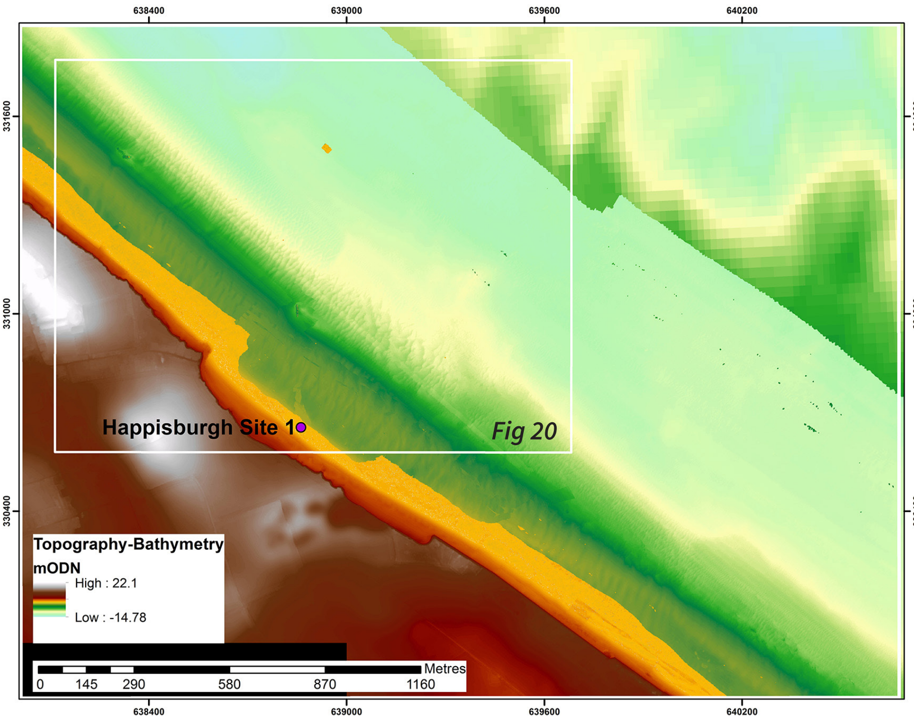

Figure 16. A merged image of the Environment Agency bathymetry and Lidar with the Norfolk County Council swath bathymetry along the Happisburgh section. Note the roughened strip in yellow represents scatter from the sea- surface in the Lidar data but for which there is no corresponding swath. See Figure 15 for location of map. Data courtesy of UKHO and Environment Agency

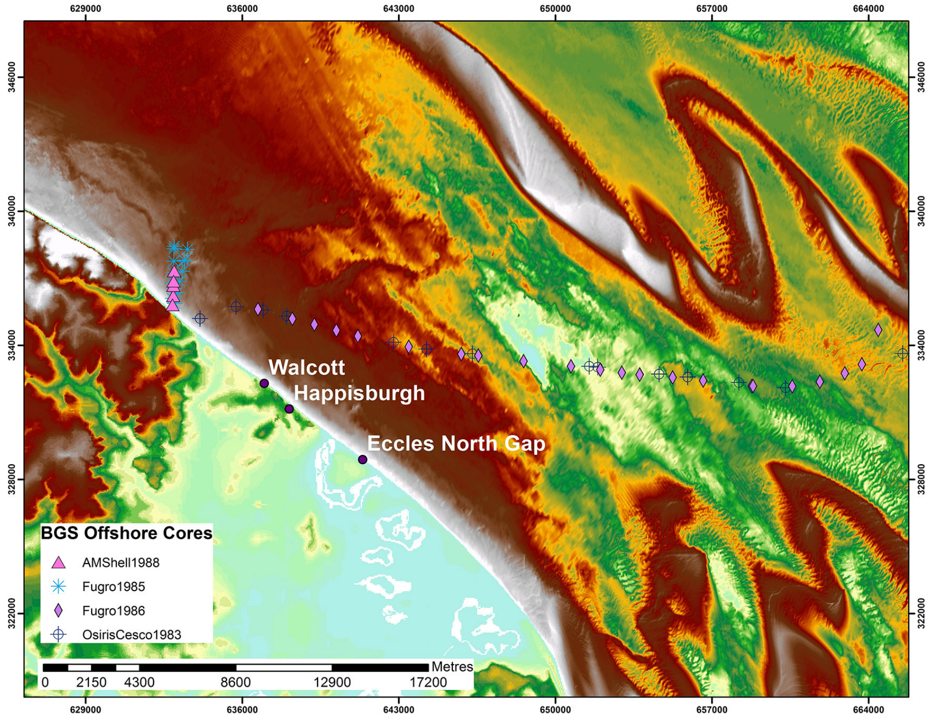

Figure 17 Publicly available BGS offshore core data, all associated with Bacton and associated offshore pipelines. The nearest data to the site are 4.5km away. Data courtesy of UKHO and Environment Agency.

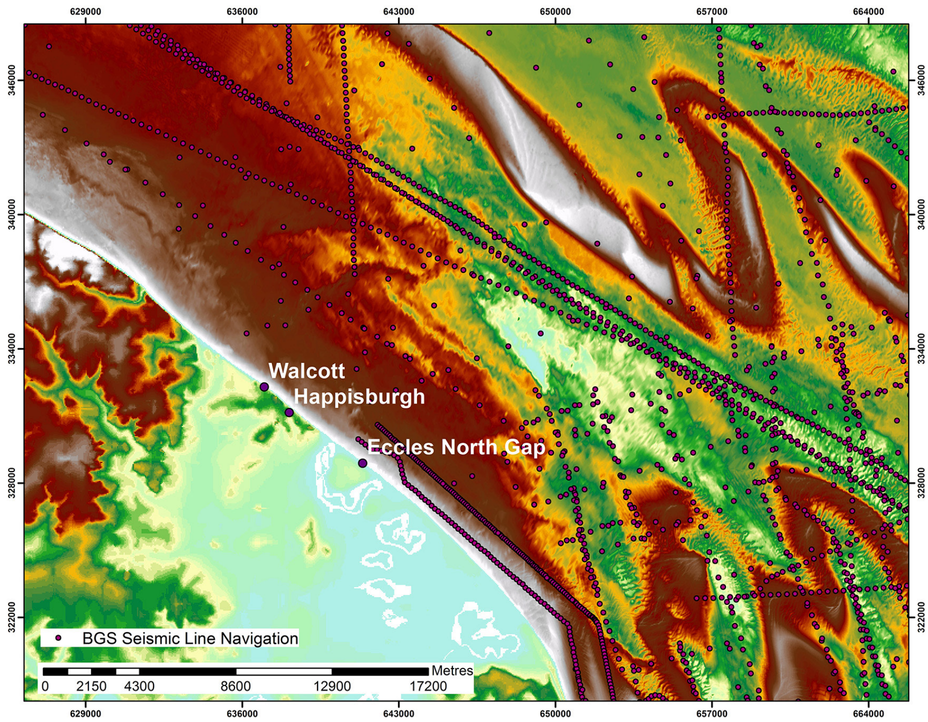

Figure 18 Publicly available BGS offshore seismic data, all associated with Bacton and associated offshore pipelines. Two lines run parallel to the coast but terminate to the south of Happisburgh. The nearest line is 5km offshore. Data courtesy of UKHO and Environment Agency.

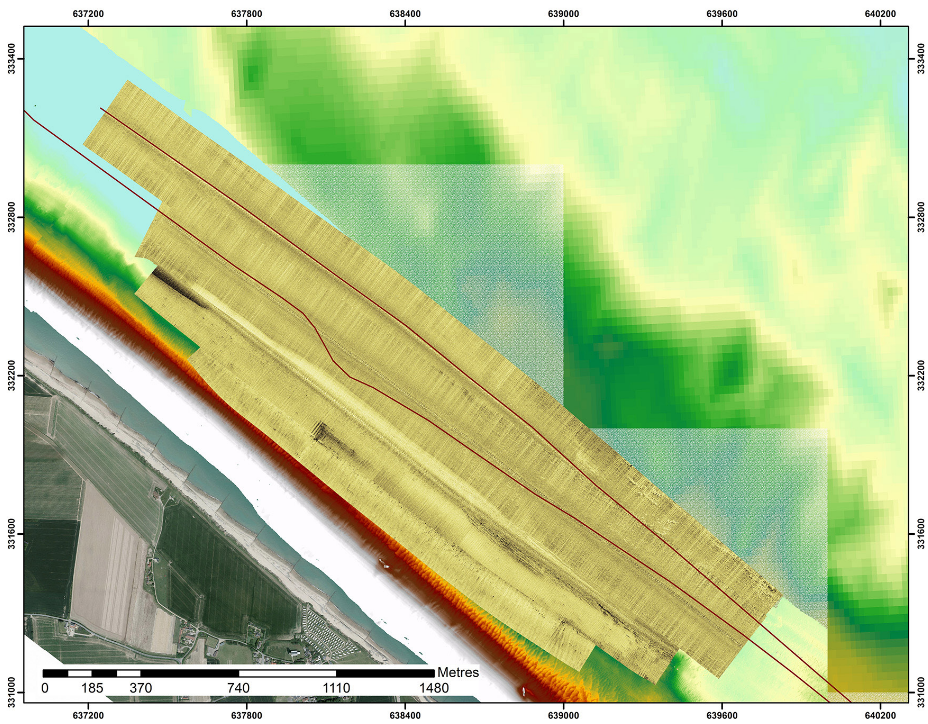

Figure 19 Area of coverage of the Wessex Archaeology side scan sonar data and two Chirp seismic lines undertaken as part of the Seabed in Prehistory programme. Data courtesy of UKHO and Environment Agency.

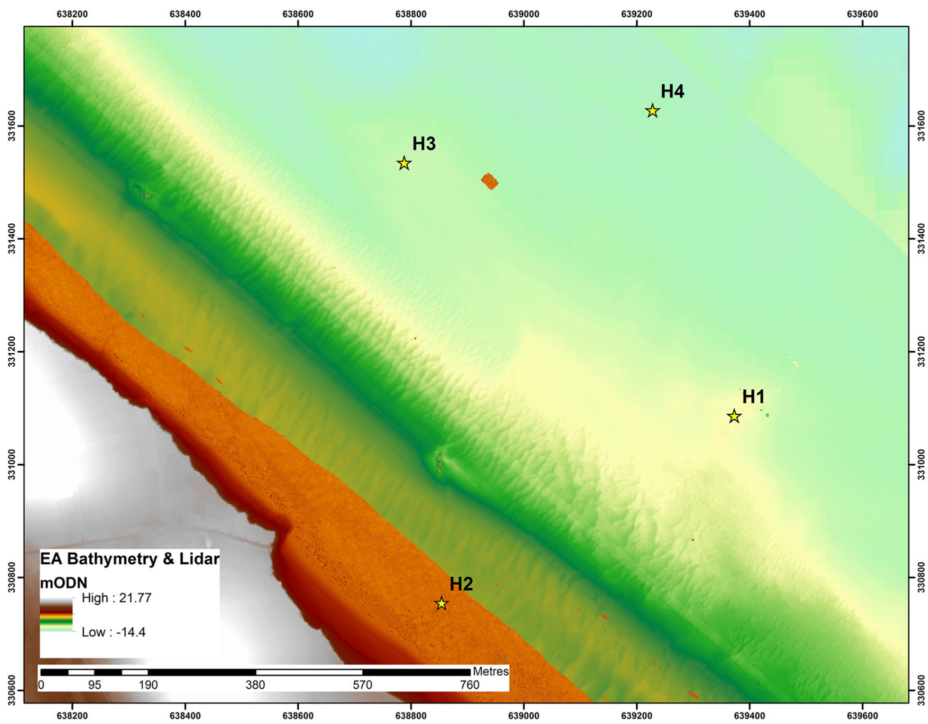

Figure 20 First season (2012) Dive Sites H1 to H4. Note that Dive Site 2 was not investigated. See Figure 16 for location of map. Data courtesy of UKHO and Environment Agency..

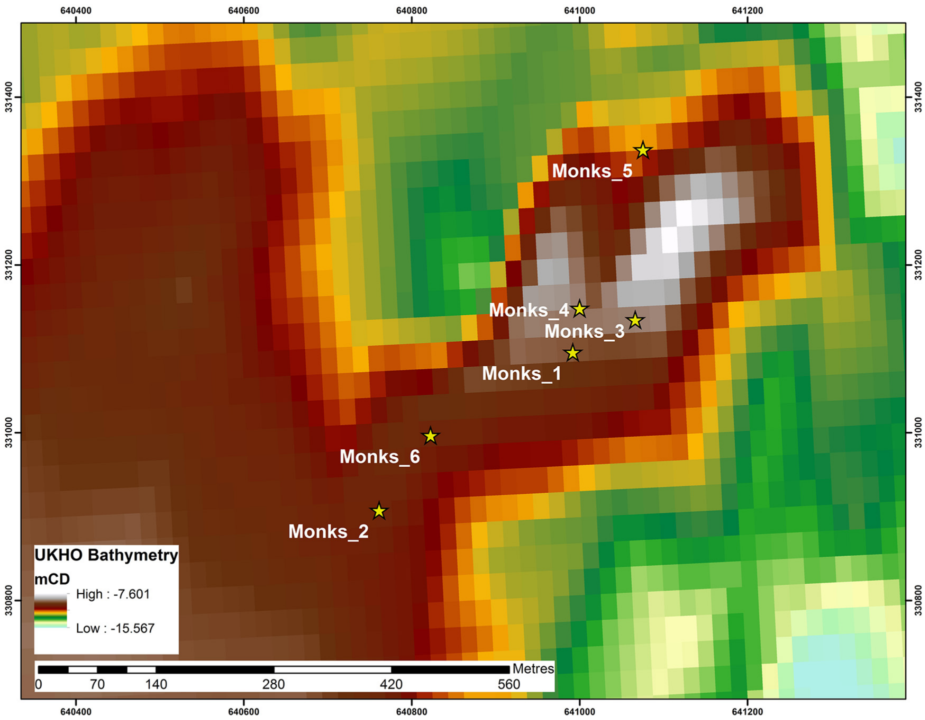

Figure 21 Third season (2015) Dive Sites M1 to M6 on the Monks. See Figure 15 for location of map. Data courtesy of UKHO and Environment Agency.

2.3.2. Offshore diving.

The GIS data integration described above allowed for identification of four locations (Dive Sites H1-H4) deemed to be of high potential for the first dive season in 2012 (Figure 20):

1 The ridge coinciding with the Reid description of the source of concreted gravel found on beaches between Happisburgh and Eccles.

2 Happisburgh Site 1 raised channel platform.

3 An area adjacent to Happisburgh Site 3 which showed bed level change, being the location of a stepped topography as inferred by Wessex Archaeology but then subsequently covered in the swath bathymetry data. The question was whether sections of the underlying stratigraphy had been re-exposed during recent storms.

4 A section of winnowed gravel seabed potentially of pre-transgressive origin.

The next stage in the project was to develop methodologies for ground truthing and exploration of three of the possible localities that could be the source of the concreted gravel found onshore. AHOB funded an initial underwater investigation using a Remotely Operated Vehicle (ROV) and an archaeological dive team. The mobilisation costs for such an operation were high and there were considerable risks of sea conditions being too poor for diving or ROV operation. Finding a suitable vessel for the work was not easy, but eventually a boat of the right specifications (the *High Flyer*) was selected from Great Yarmouth. The critical factor in choosing this vessel lay with the captain's familiarity with the area of interest and changing nature of the seafloor. As discussed below, this level of local knowledge was critical for successful operations on the day, and has helped to inform the conclusions reached through this part of the project.

In the first instance *High Flyer* was booked for the 13th to 15th of August 2012 during a period of neap tides. The on-board team consisted of five Health and Safety Executive qualified archaeological divers led by Fraser Sturt and Justin Dix from the University of Southampton. The ROV team was led by Adrian Glover from the Natural History Museum with the help of Diva Amon.

The weather conditions were remarkably good with a relatively calm sea. These optimal conditions allowed for diving and ROV operations to take place on the 13th and 14th of August (Table 5). On the 15th of August the weather deteriorated, and no diving was attempted. The diving and ROV work was limited to the two periods of slack water each day, giving up to an hour window on each occasion. The coordinates for the three dive sites were extracted from the GIS, with a RTK GPS then used to position *High Flyer* on site. At each dive location the ROV was used to scan the sea-bed prior to slack water, expanding the operational window and helping to locate areas of highest potential. This method enabled approximately a 60 x 60m area to be evaluated with continuous video images from the HD camera being provided on the boat. Once a promising location had been identified the diving team was mobilised with two divers in the water at any one time, being led to the location by the ROV 'umbilical cord' that connected the ROV to the boat. Unusually for the North Sea underwater visibility was up to 6m, providing ideal conditions for survey and sample recovery.

Of the four dive sites, only Dive Site H1 proved productive. This had concreted gravel deposits containing shells, which were sampled. These have since been examined by Dr Richard Preece (University of Cambridge) and are marine in origin. Dive Sites H3 and H4 were surveyed with the ROV but did not have visible Pleistocene deposits. With the priority being focused on potential sources for the concreted gravel, the dive near Happisburgh Site 1 (Dive Site H2) had been left to the final day, but unfortunately it was not possible to access it due to the weather conditions. This work has therefore identified one location with concreted gravel, but this is marine in origin.

Table 5 Summary of 2012 and 2015 dive locations off Happisburgh (H1-H4) and the Monks (M1-M6).

Site code	E	N	Date	Depth mOD	Description	Samples	Finds
H1	639373	331087	13/8/12 - 14/8/12	-10.2	Dive and ROV: sandy seabed with areas of outcropping concretion. Marine shells in samples	S_H001 S_H002 S_H003 S_H004	-
H2	638854	330755	14/8/12	-2.5	No dives or ROV: too shallow for the boat	-	-
H3	638788	331535	14/8/12	-11.5	No dives ROV: footage showed coarse sandy seabed with some gravel	-	-
H4	639228	331628	14/8/12	-12.6	No dives ROV: footage showed gravelly seabed	-	-
M1	640991	331096	24/6/15	-11.5	Dive: redeposited concretions found in sand waves	S_M001	-
M2	640761	330905	25/6/15	-12	Dive: sand waves	-	-
M3	641068	331132	25/6/15	-11	Dive: sand waves	-	-
M4	641001	331147	25/6/15	-11	Dive: sand waves	-	-
M5	641075	331336	25/6/15	-13.8	Dive: sand waves	-	-
M6	640823	330996	26/6/15	-12	Dive: *in situ* concretions found outcropping through large sand waves	S_M002 S_M003	F_M001

The methodology adopted in 2012 proved remarkably effective, allowing exposures to be examined via camera on board *High Flyer* and the dive team to be tasked to answer specific questions (for example to recover a sample or to examine a broader area of interest). The use of through-water communications between the dive team and the vessel further aided this process, with clear discussion between team members both above and below the water.

The combination of desk and field methods worked so efficiently that a subsequent season was arranged for August 2014. On this occasion poor weather conditions meant that it was not possible to reach the dive sites, nor safe for diving operations to commence. Therefore, the season was postponed until 23rd June 2015. The work for this season was focused on the site of the Monks (Figure 21), one of the linear topographic highs and in close proximity to one of the major sources of derived material found at the northern edge of the sea defences at Sea Palling. The Monks has anecdotally been described by local fishermen and divers as containing vertical exposures of bedrock and is considered a potential source for the concreted gravel. During this final season conditions proved suitable for diving. Although visibility was not as good as in the 2012 season, detailed investigations of outcrops and recovery of material was possible. During slack water a high frequency Sidescan system was deployed to provide some qualitative information on the nature of the substrate pre-dive.

A total of ten dives were made (each dive comprising a group of two or three divers) representing 12hrs 49mins of bottom time. Over the course of this time, six locations were investigated across the Monks (Figure 21), the most promising of which were sites M2 and M6, located at the shoreward end of the Monks. Dive Site M2, although being largely covered by sand waves, contained loose fragments of iron- concreted gravel similar to that being washed onshore. At this location, however, no *in situ* outcrops were found.

Dive Site M6 was the final dive of the season and was found to be a very significant location. Once divers descended the shot line it was immediately clear that there was a large amount of *in situ*, partially exposed, iron-concreted gravel. The outcrops were exposed in large blocks which were extremely difficult to sample with the nature of the material ranging from fine to more coarsely grained. It was at this site that the find of an *ex situ* Pleistocene rhinoceros radius was made (Figure 22), potentially indicating proximity to fossiliferous outcrops. It should be noted, however, that the condition of the bone (most notably the blackened colour) is not characteristic of the material that has been washing onshore at Happisburgh and Sea Palling. It is therefore possible that this element may have eroded from a non-local deposit or be representative of a hitherto unidentified outcrop. The remaining dive sites, despite showing up interesting seabed formations on the Sidescan sonar, were characterised by large sand waves and (flint?) boulders.

Figure 22 Diving on the Monks Dive Site M6 in June 2015 with the recovery of rhinoceros radius.

Over the two dive seasons a number of observations were made by the dive team. First, a considerable depth of knowledge was developed, both with regard to the archaeology and deposits of the area, and the practicalities of working on this stretch of coast. While weather conditions proved unfavourable for the 2014 season, the time was spent carrying out beach survey and with local specialists to help with recognition of key features underwater. This increased the confidence of the archaeologists working underwater. Second, the dynamism of the seabed was readily apparent between field seasons and correlated well with anecdotal evidence provided by John Old (the skipper of the *High Flyer*). Over the course of the project a good relationship was developed with the skipper, improving his understanding of what the dive team were trying to achieve. It allowed him to add detail to our coarse grained regional and theoretical higher resolution understanding of sediment transport in the region. This was significant as while the desk-based GIS evaluation allowed us to identify key features, they reflected either time averaged interpolations of the seabed (the UKHO data), or synchronic snapshots of the seabed on a given day. The impact of broader sediment transport processes and episodic storm events meant that such features might be covered or removed when the team was mobilised for ground truthing.

The presence of the ROV in the 2012 season, and the use of a high resolution Sidescan sonar in the 2015 season, allowed us to mitigate for this dynamism and to rapidly locate areas best suited for more detailed investigation. Crucially, it also allowed the contribution of local knowledge about the changing nature of the seabed in the study area, again saving time in the field.

2.3.3. Conclusion. The work has shown that:

- Much can be achieved in the mapping of offshore deposits from existing data and models built through georeferencing. It has been possible to investigate a number of sites as the possible source of the concreted gravel with cut-marked bone with the Monks being the most promising location. Future work should continue to be aware of survey plans by local government and government bodies such as the Environment Agency to maximise survey data. Notably data for the recent MCZs does cross into the north-west of our survey area (adjacent to Happisburgh Site 3) and this data has been requested when it becomes publicly available.

- There does however continue to be a dearth of sub-bottom data which is essential to understanding the stratigraphy of any potential offshore site.

- The combined use of the ROV, Sidescan sonar and diving team proved highly successful in underwater exploration of surface deposits.

- The risk of unsuitable sea conditions, as found on subsequent occasions since 2012, means that funding needs to cover the costs of several mobilisations (*c* £5000 each trip undertaken during this project) to ensure a successful dive. This cost needs to be written in to all future work.

- When the above points are taken together, highly effective and targeted underwater work is possible.

3. SUMMARY OF RESULTS FROM GEOLOGICAL AND GEOPHYSICAL SURVEYS

3.1 Introduction

The purpose of this section is to present a summary of the geological and geophysical data that has been generated through the work at Happisburgh which provides a baseline to inform any future survey and mapping projects. The results of the borehole investigations are summarised and a site-wide deposit model is presented based on the data collected during this project and also incorporating data collected by the project team as part of other research at Happisburgh. This is followed by an assessment of the impact of coastal erosion on ASDs over the last 20 years and the likely future impact of erosion along the coastal frontage at Happisburgh based on the known and probable distribution of the key sedimentary units and on projected rates of coastal retreat (Section 4).

3.2 Results

The results of the borehole programme are summarised in Tables 2-4. Additional data has been extracted from the BGS borehole archive (Table 6). The lithological units identified in the boreholes are equated with the established stratigraphy for the region. The glacial deposits are correlated with the scheme of Lee *et al* (2004). An unnamed diamicton unit recognised in BHs 13/6, 14/1 and 14/2 is possibly equivalent to that recently described from close to Site 1 and interpreted as a localised debris flow unit associated with retreat of the Happisburgh Till ice margin by Hodkin *et al* (2016). The basal marine sands are part of the Crag Group of marine sediments (Moorlock *et al* 2002).

The main components of the stratigraphy at Happisburgh, which are shown in the deposit model, are:

- Glacigenic sediments: These are well exposed in the cliffs. The Happisburgh Formation, consists of the Happisburgh Till (basal member) and overlying Ostend Clay, Happisburgh Sand, Corton Till and Corton Sand (Lee *et al* 2004) and a newly recognised, but as yet unnamed diamicton unit. The Walcott Till (member of the Lowestoft Formation) is poorly developed at Happisburgh, though it is exposed south-east of Site 1. These sediments are early Middle Pleistocene in age and were deposited during the Anglian glaciation (MIS 12).

- Channel deposits: These fluvial sediments constitute the ASDs at Happisburgh. Two channel complexes can be identified (Figures 23 and 24). At Site 1 the fluvial sediments consist of organic muds which occupy a channel feature, some 100m in width and trending approximately S-N. The immediately underlying fluvial sands are also archaeologically important. At Site 3 the channel deposits consist of a series of laminated sands and silts, referred to as the Hill House Formation by Parfitt *et al* (2010). These sediments extend over some 430m of the beach from north-west of Site 3 to the vicinity of the old lifeboat ramp (including the location of West's borehole HC). The channel deposits at Site 1 and Site 3 are Early Pleistocene to early Middle Pleistocene in age. A third, less well defined channel, may be present along the cliffs from south-east of the old lifeboat ramp, extending towards the new earth ramp. This channel is represented by grey laminated silts beneath Happisbrugh Till that have been recorded in boreholes and limited beach exposures, though this part of the cliff remains poorly documented.

- Marine sediments: Underlying the glacigenic and fluvial sediments is a series of marine sediments.

They have been proved down to Chalk bedrock at to *c* -27m OD in borehole HC (West 1980) and similar thicknesses have been recorded in other boreholes in the vicinity (Table 6). These sediments consist mainly of sands, with some silt/clay and gravelly beds and they are collectively part of the Crag Group of Early Pleistocene marine deposits and probably include representatives of the Red, Norwich and Wroxham Crag Formations (Moorlock *et al* 2002). Pollen analysis by West (1980) indicates a range of environmental conditions and on pollen biostratigraphic grounds they have been assigned to the Early Pleistocene.

3.2.1. Site 1

Six boreholes were completed at Site 1 (BHs 12/1-6). Four of the boreholes (BHs 12/1, 2, 4 and 6) went through the Site 1 channel deposits. They penetrated up to 2.7m of organic muds, beneath the Happisburgh Till. Undisturbed samples of the channel deposits were recovered using U4s and disturbed samples of the underlying sands were taken. Boreholes 12/3 and 12/5 proved to be located outside the channel margins. Borehole 12/3 penetrated Happisburgh Till at an anomalous depth (8m below beach level) on the south-eastern side of the channel. At the time of coring, the stratigraphy in this area was poorly understood, but the borehole work, together with remapping of the cliff exposures along this part of the beach, has demonstrated that the overlying glacial sediments appeared to be dipping steeply to the south-east at this point. This corresponds to a modern-day depression that can be clearly seen in the landscape behind the cliff line and is visible on the Lidar survey (Figure 16). This is tentatively interpreted as the result of Chalk solution, which has resulted in the downward displacement of the overlying Pleistocene sediments. As all the glacial deposits (including the Walcott Till) are displaced, the solution feature must have been activated after the emplacement of the glacigenic sediments during the Anglian glaciation (MIS 12).

Table 6 Boreholes from archive sources for the Happisburgh area. All records are from the BGS online borehole database except 1 which is from West (1980). (Contains British Geological Survey materials © NERC 2016).

BH code	E	N	Z (mOD)	Borehole name	Comment	Chalk top (nOD)
BH HC	638340	331112	1.3	HC	West (1980) BH HC on old slipway	-27.7
TG32NE10	639200	329300	7.6	Mill Farm, Happisburgh	does not reach Chalk	
TG32NE11	637900	329700	3.6	Manor Farm Happisburgh	insufficient stratigraphic detail	
TG32NE17	639720	329950	9.4	Mr Taylor's Bungalow, Cart Gap	same NGR as NE18 but not same record	-38.8
TG32NE18	639720	329950	8.2	Mr Mace, Cart Gap	same NGR as NE17 but not same record	-39
TG32NE33	639777	329985	8.5	Cart Gap Happisburgh Nfk A	does not reach Chalk	
TG32NE34	639497	330161	9.5	Cart Gap Happisburgh Nfk B	does not reach Chalk	
TG32NE41	637360	329850	8.0	Hall Farm, Happisburgh	same record as NE42	-33.2
TG32NE42	637360	329850	8.0	Hall Farm, Happisburgh	same record as NE41	-33.2
TG32NE6	637300	329800	12.2	Hall Farm		-19.4
TG33SE1	636620	331660	15.5	Chimneys Farm, Walcott		-11.9
TG33SE12	638390	330860	11.3	Coastguard Cottages		-36.5
TG33SE13	638080	330810	10.1	The Forge Happisburgh	insufficient stratigraphic detail	
TG33SE14	638040	331120	21.0	Hill House Hotel	top part is a well	-25.3
TG33SE15	637970	331060	19.8	Happisburgh Hill	top part is a well	-24.7
TG33SE16	638350	330810	9.8	Ye Cliffe, Beach Road Happisburgh		-39.3
TG33SE17	638100	331300	2.7	Happisburgh	Geol Surv BH on beach near Site 3	-4.8
TG33SE19	639200	330200	10.7	Romany, The Gap	same record as SE28	-37.4
TG33SE28	639200	330200	10.7	Romany, The Gap	same record as SE19	-37.4
TG33SE29	636720	331670	12.2	Chimney Farm Walcott	insufficient stratigraphic detail	
TG33SE30	636550	332310	10.1	Ostend Estate, Walcott		-23.4
TG33SE31	635940	332770	6.7	Poplar Drive estate, Walcott	XY wrong on BGS, adjusted 1000m to W	-11.6
TG33SE32	637540	330340	11.6	Littlewood's Farm Happisburgh	no data, same record as SE33	
TG33SE33	637610	330530	11.6	Littlewood's Farm Happisburgh	no data, same record as SE32	
TG33SE4	636060	331680	12.2	Church Cottage, Walcott	insufficient stratigraphic detail	
TG33SE5	636800	331300	14.6	RAF Station		-14.4
TG33SE6	637560	331210	12.6	Church Farm Happisburgh	insufficient stratigraphic detail	
TG33SE7	636810	330830	7.3	Walcott Hall Farm Walcott	insufficient stratigraphic detail	
TG33SE8	636720	332420	10.1	Walcott Camp Seaview Estate	same record as SE30?	-27.7

3.2.2. Site 3 to HC

The drilling undertaken in 2013 (six boreholes) and 2014 (four boreholes) focused on the stretch of the coastline from the caravan park to the old lifeboat ramp to investigate the deposits between Site 3 and HC, the latter being the location of West's (1980) borehole on the old lifeboat ramp. Three boreholes (BH 13/6, 14/1 and 14/2) were drilled on the cliff top above Site 3. BH 13/6 proved 6.0m of laminated sediments equivalent to the Site 3 channel deposits. Further drilling in 2014 was undertaken to sample the Site 3 channel deposits for palaeoenvironmental and palaeomagnetic analyses (BHs 14/1 and 14/2), these proved 4.5m and 5.4m of channel deposits respectively.

Boreholes 13/1-4 were located in the vicinity of West's (1980) borehole *HC* The boreholes demonstrated that the HC/Site 3 channel terminates to the south east of BH 13/1 and is absent in BH 13/2 and 13/3. BH 13/4 was located close to the HC borehole, but only recovered 1.5m of laminated sediments. They are thought to be equivalent to West's (1980) bed j, which was 2.9m in thickness in *HC* Borehole 13/5, 20m north-west of 13/4, recovered only 1.0m of sediments suggesting that they thin in a north westerly direction. BH 14/4, located a further 85m along the cliff top and close to the location of the footprint horizon, showed 2.2m of channel deposits.
The drilling at Site 3-HC has demonstrated that the channel deposits, which are archaeologically important, extend from the vicinity of BH 13/1 continuously in a north westerly direction to Site 3. They extend at least as far as the north westerly limit of the excavation trenches at Site 3 (Parfitt *et al* 2010), a distance of approximately 430m.

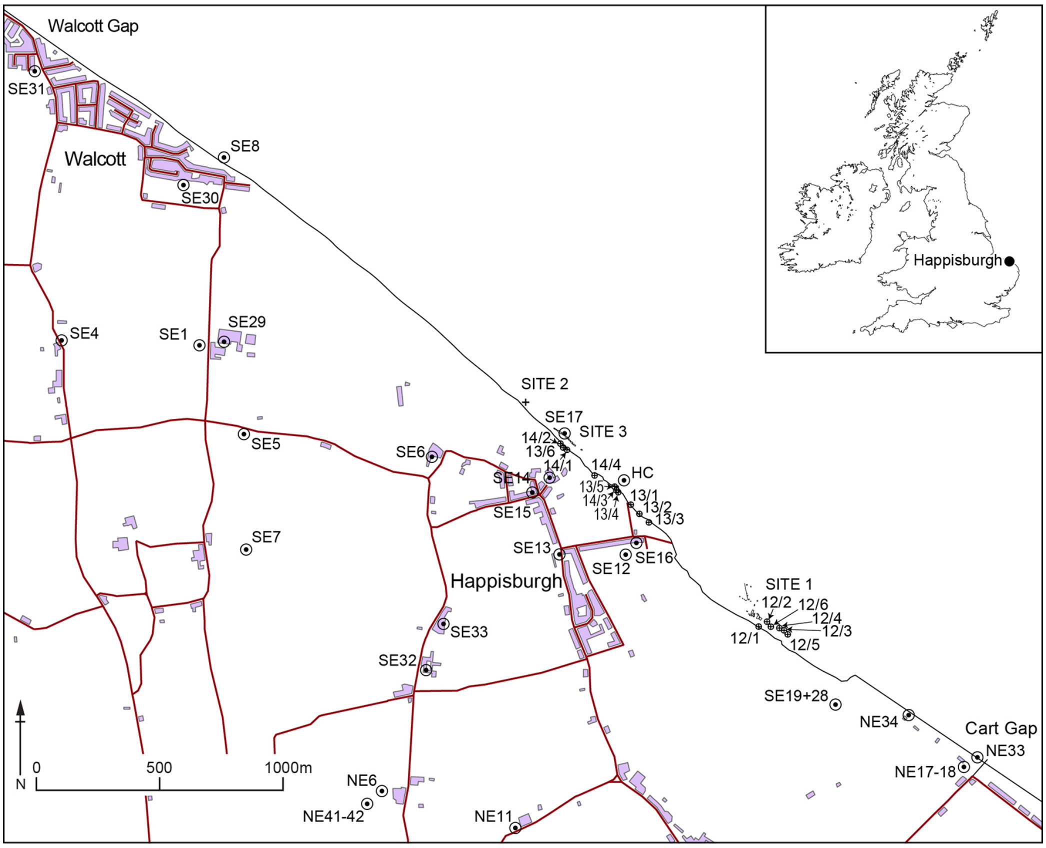

Figure 23 Happisburgh area showing location of archaeological sites 1 and 3, boreholes drilled during the current project and borehole records held by the BGS (Contains British Geological Survey materials © NERC 2016). Based on Ordnance Survey (Digimap license).

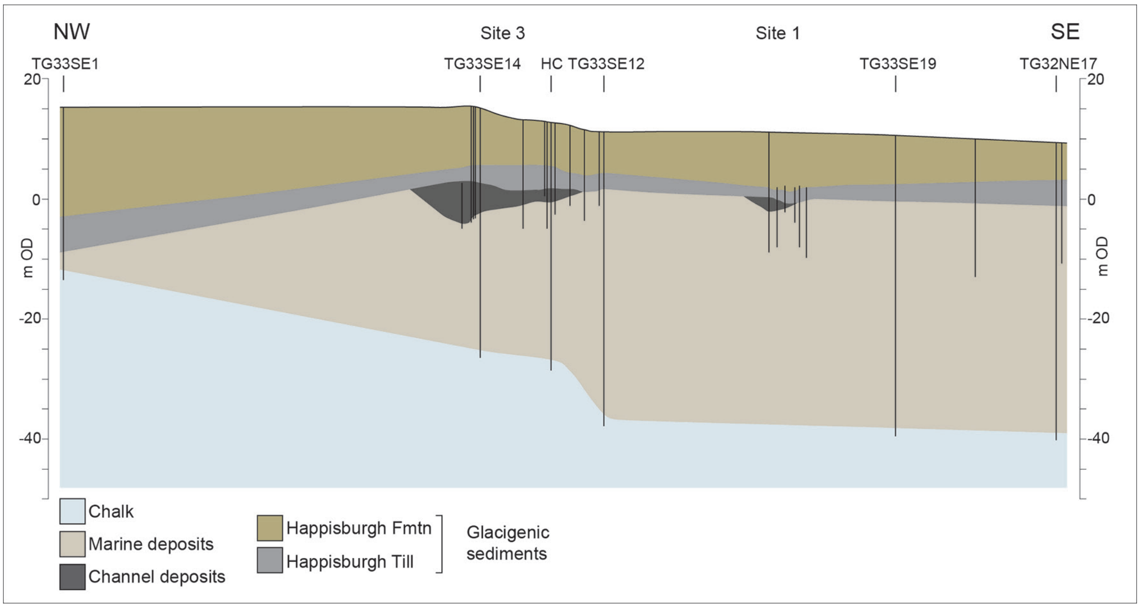

Figure 24 Cross section showing disposition of the main geological units at Happisburgh (see text for discussion) based on boreholes completed during the current project and borehole records held by the BGS (Contains British Geological Survey materials © NERC 2016).

3.3 A deposit model for Happisburgh

The work undertaken at Happisburgh since the discovery of the handaxe at Site 1 in 2000 has significantly increased both the quality and quantity of geological data that is available for this locality. Prior to the AHOB excavations at Site 1 in 2004 and the subsequent work there and at Site 3, West (1980) was the main source of data on the Early and early Middle Pleistocene sediments at Happisburgh, other than this the available data was not sufficiently detailed nor accurately located to be used in the construction of a deposit model (Table 7). It is only with the benefit of the large quantity of new information that has been gathered as part of the recent archaeological investigations at Happisburgh, including this project, that a site deposit model can be generated which establishes the distribution of the ASDs and places them into a stratigraphic context. However, as most of the data has been collected in a linear strip along the coast, at the present time it is only possible to generate a 2D rather than 3D deposit model.

The geological and geophysical data from Happisburgh provides the basis for the development of the deposit model. Drilling on the beach and cliff top has provided detailed stratigraphic information enabling a cliff-parallel section to be constructed showing the disposition of archaeological deposits and underlying (marine) and overlying (glacigenic) sediments. The Chalk surface can be reconstructed using the small number of well/borehole records that reached Chalk (Table 6). The marine sands, which form the basal component of the Happisburgh succession, extend from the Chalk to *c* 0mOD and are overlain by the fluvial sediments or, where the latter are not present, by the glacial deposits of the Happisburgh Formation. The geological and geophysical investigations at Happisburgh have demonstrated that the fluvial sediments occupy channel features cut into the underlying marine sands. At Site 1, the channel base is identified in boreholes and from the geophysics and the channel is infilled with sands and organic muds which represent deposition within the active channel and in an abandoned cut-off channel respectively. At Site 3 the base of the laminated sands and silts (Hill House Formation) is defined from boreholes, and the geometry of a deeper-seated underlying channel feature is also identifiable in the geophysical data (Appendix 4).

Table 7 Main phases of research and other work at Happisburgh that have contributed to current geological understanding of the locality.

Dates	Type of work	Data generated	Publication
Mid-late 19th century	Geological survey	• Descriptions of coastal exposures, • sections not accurately located	Reid (1890)
Late 19th – 20th century	Recording of wells and boreholes	• Well and borehole records • Locational accuracy variable • Quality of geological information • highly variable	Unpublished data (available online from BGS borehole database)
1960s	Recording of cliff and foreshore exposures at seven locations (HA-HG) and drilling of deep borehole (at HC)	• Sections • Borehole record (HC) • Palaeobotanical information	West (1980)
1960s-2000s	Mapping and interpretation of cliff sections, mainly focused on glacial stratigraphy and sedimentology,	• Mapping of laterally extensive cliff exposures • little/no information on deposits underlying the glacial sediments	Banham (1968), Hart (1999), Lunkka (1994), Lee (2003), Lee *et al* (2008)
2004-2012	Archaeological excavations at Happisburgh (focussed on sites 1 and 3)	• Recorded sections • Boreholes • Mapping beach exposures • Palaeoenvironmental information	Parfitt *et al* (2010), Ashton *et al* (2008, 2014)
2012-2015	Survey work associated with this project	• Boreholes • Onshore geophysics	Unpublished HE report

3.4 Offshore distribution of archaeological significant deposits

Offshore investigations at Happisburgh are at a very early stage and much of the work undertaken in this project was concerned with establishing a viable methodology rather than the delivery of significant new data. Nonetheless, some information has been obtained that is of relevance to understanding the distribution of ASDs at Happisburgh. There are two aspects to understanding the offshore distribution of Pleistocene sediments; the immediate near-shore area and the Happisburgh-Eccles Offshore Zone (Table 1) that has been explored by ROV and diving (Section 2).

3.4.1. Near-shore areas

Observations during the 19th century by Reid (1890) of exposures of the CF-bF at Happisburgh, when the contemporaneous coastline was approximately 50-150m seaward of its present position, suggests that these sediments extended seaward of the current coastline. However, landward encroachment of the cliff- line and shore-face has resulted in erosion of these deposits. At Site 1 the bathymetric data shows a platform immediately offshore from Site 1 aligned in a south to north orientation and remaining submerged at Low Water. This is interpreted as a remnant of the channel deposits, forming an offshore continuation of the surface that was examined in the AHOB 2004 excavation. A shore-normal section showing the topographic/bathymetric profile and the distribution of the channel deposits at Site 1 (Figure 25) indicates that at the seaward edge of this platform the sea bed rapidly falls to depths below the height envelope of the Site 1 channel deposits. Projection of the organic mud and the underlying grey sand in an offshore direction suggests that these deposits may crop out, beneath recent, highly mobile marine sediments, approximately 250-300m out from the present (2015) cliff line. Projection offshore of a channel base at *c* -3mOD (base of the upper gravelly part of the grey sand) indicates that there is limited potential for equivalent sediments to be preserved further offshore. The -6m contour along the projected line of the channel occurs *c* 460m from the inter-tidal excavations at Site 1 (Figure 27). There is no expression of the channel at this location and the sea bed further offshore is made up of mobile recent sediments. However, the buried deposits underneath the recent sediment drape, which as has been demonstrated could be significantly reduced under storm conditions, may include sediments associated with the Site 1 channel deposits. Further sub-bottom survey across the study area may help to resolve these relationships.

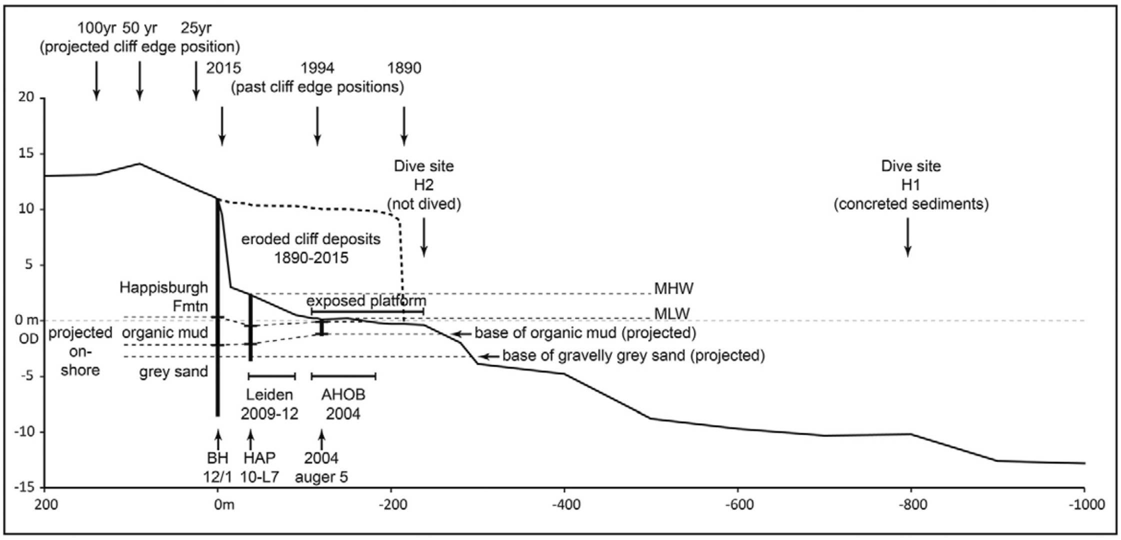

Figure 25. Profile through Happisburgh Site 1 from onshore to offshore. Organic mud and grey sand, which make up the channel deposits are described by Lewis et al *(submitted).*

At Site 3, there is no indication in the bathymetric data for any continuation of these sediments further out in the littoral zone. It is probable that seaward of the sea defences these sediments have been subject to significant erosion. The deposits may survive in places beneath the modern beach sands, though no information is available to verify this. Since 2011 the beach behind the sea defences has also been scoured and this has resulted in removal of Pleistocene sediments including deposits of archaeological significance. This has been highlighted by the separate programme of drilling in October 2015 (Appendix 1).

3.4.2. Happisburgh-Eccles Offshore Zone (HEOZ)

This offshore area has been studied using available bathymetric data and also through targeted dives and ROV surveys. The main purpose is to try and locate the source of the distinctive iron-cemented gravels that are found on the beaches at Happisburgh and Eccles. These blocks contain vertebrate remains including some that retain cut-marks. Clement Reid (1890) reported observations of cemented outcrops offshore from Happisburgh, the location of which corresponds to dive site H1 (Figures 20 and 25). Iron-cemented gravels were found in 2012 at Dive Site H1, and samples were recovered. However, as the samples contained marine molluscs and therefore are different to the beach finds, which lack any marine fauna, it is considered unlikely that the source is in the immediate vicinity of Happisburgh. The second area that was identified for dive survey was the Monks, a persistent feature on the sea bed, and this is currently thought to be the most likely candidate as the source of the iron cemented gravels and a series of six dives (M1-6) were undertaken in 2015 to explore it. Samples of iron-cemented gravel were recovered, though these have not yet been examined in detail.

The stratigraphic and geographic relationship between this potential outcrop of iron-cemented gravels and the reworked material found on the adjacent beach require some consideration. At present, there is no stratigraphic information or context for the outcrops at the Monks and only a small number of samples of material have been recovered. Its geographical location also poses some difficulties; if the Monks is the only source of this material large and very heavy blocks have to be moved up to 2.5km somewhat across the prevailing sediment transport direction. One hypothesis is that this occurs during major northerly storms which may bring material closer to the coast and which is then transported down the sediment pathway to be collected in the embayments created by the sea-defence structures at Sea Palling. Alternatively, there may be a continuation of the outcrop in a southerly direction from the Monks to the coast and thus material is being sourced more locally (although there is no expression in the Environment Agency swath). Again undertaking sub-bottom profiling from the Monks to the adjacent shore and across to Happisburgh may resolve this.

3.5 Inland distribution of archaeologically significant deposits at Happisburgh

The lateral and vertical geometry of the archaeological significant deposits (ASDs) determined from the geological and geophysical data also provides a basis for estimating their likely inland distribution, though there remains a paucity of ground-truth data in some areas so only limited confidence can be attached to these onshore projections. At Site 1 the ASDs lie in a channel-like feature approximately 100m wide and trending S-N. The landward extension of this channel system in a broadly southerly direction can also be estimated from the geophysical data (Figure 24); in geophysical Line 17 there is an indication of a possible inland continuation of the Site 1 channel feature (see Appendix 4). The feature shown in the resistivity profile has similar electrical properties to the channel at the coast and is consistent in width and elevation with the sediments at Site 1. No borehole coverage is available to verify the suggested inland continuation of these deposits.

At Site 3 the north-west limit of the ASDs may be placed at the north-west end of the area that has been subject to detailed archaeological excavation. It should be noted that at Site 2, some 100m beyond the north-west limit of Site 3 a small number of artefacts were found and it is therefore possible that the ASDs are more extensive in that direction, though the geological context of the handaxe found at this locality is different to that of the Site 3 artefact assemblage. At the present time the relationship between Site 2 and Site 3 is not fully established. The south-eastern edge of these deposits is to the south-east of the old lifeboat ramp (Figure 26). The ASDs can be regarded as continuous across this area, though their thickness varies from *c* 2m around HC to > 5m at Site 3 (an elevation range of -1 to+1mOD to -4 to +1mOD). The discovery of footprints as well as isolated artefact finds across this area also attests to the wide distribution of ASDs on this part of Happisburgh beach. Inland the geometry of these sediments is poorly constrained. On the basis of the geophysical data the inland extent can be tentatively established; line 39 suggests that the channel deposits can be traced inland and the estimated position of the channel deposits is shown in Figure 26. Two boreholes (TG33SE 14 and 15) lie within this distribution about 140m in from the present coastline. Unfortunately these are well records dating from 1954 and 1909 respectively and the geological description of the strata is not sufficiently detailed to verify the presence of the Site 3 channel deposits.

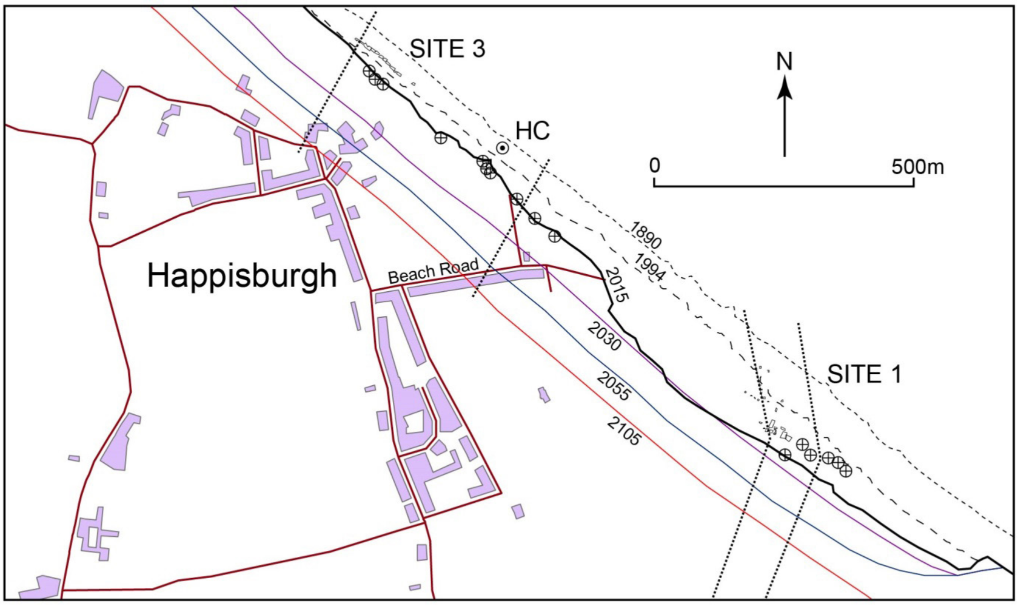

Figure 26 Happisburgh study area from Site 3 to the northern end of the sea wall at Cart Gap, showing location of Sites 1 and 3, boreholes completed during the current project, coastline positions and projected future coastline positions (see text for discussion). Edges of the estimated Site 1 and Site 3 channel edges are shown by the dotted lines. Based on Ordnance Survey (Digimap license).

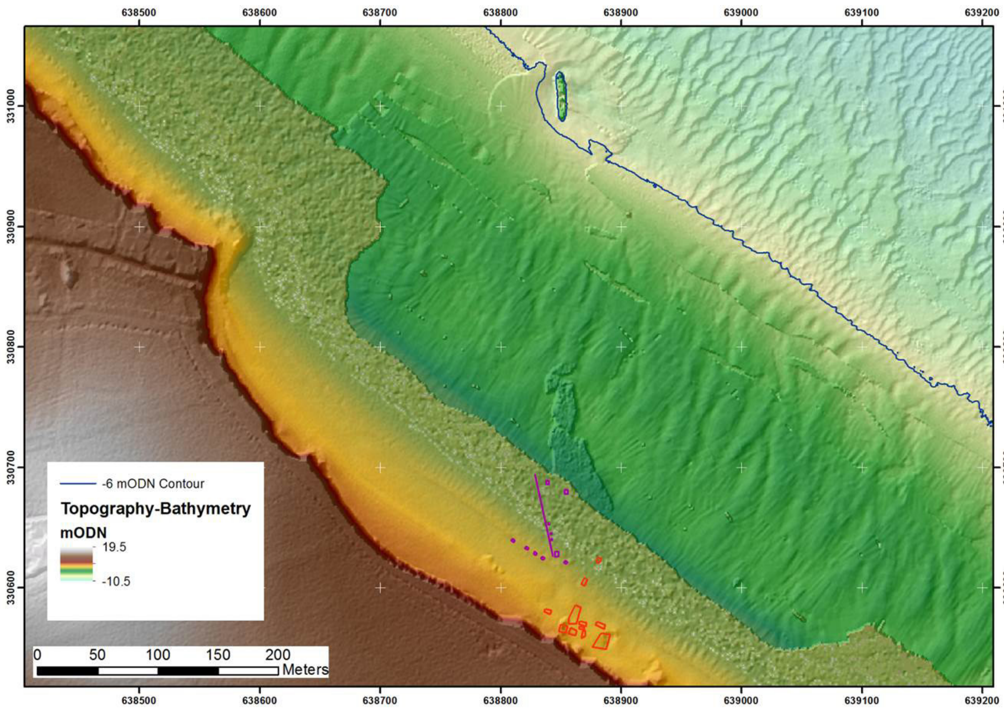

Figure 27 The location of Site 1, the submerged organic mud raised platform and the -6m ODN contour in the offshore zone. There is no evidence of channelization at distance from the shore beyond the raised platform. Data courtesy of UKHO and Environment Agency.

4. ASSESSMENT OF FUTURE IMPACT FROM COASTAL EROSION

4.1 Impact of cliff retreat on archaeologically significant deposits

In order to assess the likely impact of future cliff retreat and erosion on the ASDs at Happisburgh it is necessary to establish (1) the probable landward distribution of these sediments and (2) the timescale over which the deposits may become vulnerable to erosion. This project has been concerned mainly with the first of these two attributes and has provided baseline information on the disposition of the key geological units along the current coastline and, to a lower level of resolution, their landward continuation.

4.1.1. Distribution of archaeologically significant deposits

It has become apparent during the current project that the seaward distribution of ASDs is often dependent on the existence or state of preservation of the sea defences. In particular along the 800m stretch of coast from the northern end of Site 3 to the northern edge of the embayment, the ASDs have been scoured away up to the line of the current sea-defences. The realignment of sea defences in September 2015 caused the rapid erosion of ASDs in the zone between the old and new defences (Appendix 1).

There appears to be better preservation of ASDs on the seaward side of Site 1, which is probably due in part to the lower elevation of the channel deposits compared to Site 3 and the consequent protection from a larger build-up of beach sand. Better preservation has been shown by the ridge of offshore sediment that was identified in the near-shore bathymetry (Figure 27). In addition in May 2016 during a period of minimal beach sand cover, the degraded outline of a 2004 excavation trench could still be identified at low tide.

The inland continuation of the channel deposits is based on an assessment of the geological and geophysical data, and is shown in Figure 26. Beyond approximately 200m inland of the present coastline it is not possible to determine the position of the deposits as there is insufficient data.

4.1.2. Cliff erosion rates

This project has not specifically addressed rates of erosion along this coastline. Previous studies of the coastline of north-east Norfolk indicate that the historic erosion rate prior to the construction of the sea defences was approximately 0.9m/yr, with a slight reduction in the erosion rate since the sea defences were built (Cambers 1976; Clayton 1989). With the progressive failure of the coastal defences over the last 15-20 years the rate of erosion along this part of the coastline has changed; Poulton *et al* (2006) estimated erosion rates of up to 8m/yr between 1992 and 2004.

The Shoreline Management Plan for this region (SMP6) estimates the likely extent of future cliff retreat for the coastline from Ostend to Cart Gap. The position of the coastline is estimated for three time frames; 0-25 years, 25-50 years and 50-100 years (spanning the periods 2005-2030, 2030-2055, 2055-2105 respectively). This is represented by three shore-parallel strips of land with widths of approximately 100m, 50m and 50m respectively across nearly the whole length of the frontage from Cart Gap to Ostend (Figure 25). For the purposes of this assessment these zones are used to quantify the impact of coastal erosion on the ASDs at Happisburgh.

4.1.3. Estimating the impact of coastal erosion on archaeological significant deposits

Utilising the estimated inland distribution of the ASDs and the projected position of the cliff in 2030, 2055 and 2105 it is possible to quantify the area of sediments of potential archaeological significance that will be impacted (that is lost entirely or made vulnerable by removal of overlying sediments) for the periods 2015-2030, 2030-2055 and 2055-2105. In addition to assessing future impact on the deposits, an estimate is made, for comparative purposes, of the impact of erosion on the ASDs over the periods 1890-1994 and 1994-2015. The possible effect of any rise in sea level on coastal erosion rates is not included in these estimates, though it might be anticipated that sea level rise and storminess will enhance the rate of coastal erosion and therefore have an additional impact.

The 1890 coastline position can be established from old maps and the 1994 cliff line position is taken from HR Wallingford (2002) for the coastline south of Happisburgh and from 1999 aerial photography for the coastline along the frontage from the old lifeboat ramp to north of the Caravan Park. The 2015 cliff line position is based on a differential GPS survey conducted during the course of the current project.

The area of ASDs estimated to be impacted by coastal erosion is shown in Table 8 and Figures 26 and 28. To the south of Happisburgh village (at and around Site 1) there is a significant increase in impact during the period 1994-2015, with almost a nine-fold increase in the area of sediment impacted compared with the previous 100 year period. This increase coincides with the progressive failure of the sea defences and the current (2015) cliff line is close to, and in places inland of, the 25 year line (2030). Estimated impact for the period 2015-2030 is lower, though still higher than the pre-1994 estimate. After 2030 the area of sediment impacted remains at a fairly consistent level. Along the frontage from Beach Road to north of the Caravan Park there has been a similar, though less marked, five-times increase in impact from the 1890-1994 to the 1994-2015 period as the current position of the cliff has encroached a shorter distance into the 0-25 year zone. The estimate for the period 2015-2030 indicates that impact will further increase along this part of the beach to *c* 13 times the ‘historic’ level. After 2030 the levels of impact decline, though they remain about the ‘historic’ levels.

Table 8 Estimates of area of ASDs impacted by coastal erosion.

Year	Area m sq/yr Site 1	Area m sq/yr Site 3	Comment
1890-1994	102.0	185.1	This represents the historic 'background' level of impact prior to accelerated erosion following failure of the sea defences.
2015-2030	179.9	2397.5	During this time period, there was major failure of the sea defences south of Happisburgh (around Site 1) and significant retreat of the cliff line. In the northern part of the beach where the sea defences continued to be more effective, erosion is less, though a large area is lost owing to laterally extensive deposits at Site 3.
2030-2055	259.5	894.1	During this time period impact on the deposits at Site 1 is likely to decrease as the rate of cliff retreat is reduced, while at Site 3 significant impact is likely as a result of the failure of the sea defences along this frontage.
2055-2105	103.9	440.8	Impact at Site 1 will be at a level close to the historic (1890-1994) time period. At Site 3 the area of deposits impacted will continue to reduce as rate of erosion is reduced.

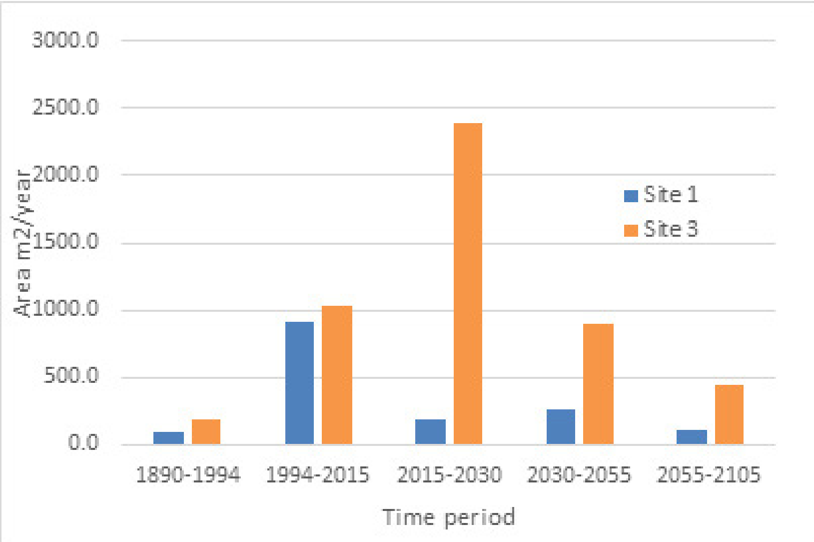

Figure 28 Estimated impact of coastal erosion on ASDs at Happisburgh Site 1 and Site 3. Figure 28. Estimated impact of coastal erosion on ASDs at Happisburgh Site 1 and Site 3.

Based on these estimates, the patterns for Site 1 and Site 3 are similar, though the peak impact for Site 1 has already happened, while for Site 3 it will be in next 15 year period. This reflects the fact that the sea defences south of Happisburgh failed some time ago and this was followed by rapid coastal retreat and the formation of an embayment along this part of the coast. The current rate of cliff retreat along this stretch is now somewhat lower, as some stabilisation of the cliff has taken place. The sea defences along the frontage from Beach Road to the Caravan Park have started to fail more recently and the consequent phase of rapid cliff retreat has only commenced in the last two to three years, punctuated by particularly significant episodes, such as that associated with the storm surge in the winter of 2013. The next 15 years, and possibly the next few years are likely to witness further erosion and impact on ASDs. The estimates suggest that this will be followed by reduced impact as the rate of cliff retreat declines.

4.2 Summary of impact

Table 9. Summary of impact of coastal erosion on ASDs at Happisburgh.

	Cart Gap to Beach Road (including Site 1)	Beach Road to north of Caravan Park (including Site 3)
Condition of sea defences and cliff retreat between 1994 and 2015	Rapid cliff retreat has taken place following failure of the sea defences; cliff retreat is now approaching the '25 year line', though minimal cliff retreat has taken place during 2012-2015 period.	Sea defences still extant though failing; prolonged low rates of cliff retreat have been followed by increase rates over the 2012-2015 period, particularly along the Beach Road frontage, though also extending across the Caravan Park.
Estimated impact on archaeologically important deposits during the period up to 2015	Significant impact on ASDs with removal of some deposits and increased vulnerability of remaining deposits as a result of removal of overlying sediments.	Significant impact on ASDs, though mainly over latter part of the time period. All channel sediments seaward of the revetments are thought to have been eroded. Landward of the sea defences, there is periodic scour of the modern beach to expose the underlying Quaternary sediments. There is partial or sometimes total removal of channel sediments and increasing vulnerability of remaining deposits as overlying glacial sediments are removed.
Likely impact on archaeologically important deposits over the next fifteen years	The reduced rate of cliff retreat may result in some stabilisation of the beach over this area, though it remains vulnerable. Over longer time periods (after 2030) the rate of cliff retreat is likely to reduce.	Continued rapid readjustment of the coastal configuration will result in exposure of ASDs on the beach and losses through erosion in the short term. It is likely that cliff erosion will be marked in the area between the remnants of the old lifeboat ramp and the new earth ramp as sea defences have now been removed along this stretch. Over longer period (after 2030) a reduction in losses of ASDs is likely.
Likely impact on archaeologically important deposits after 2013	The projected reduction in the rate of cliff retreat beyond 2030 will result in a reduction in impact. Rising sea levels may affect these projections and would be likely to increase the rate of erosion, with a resulting increase in the quantities of ASDs that are vulnerable to erosion.	The projected reduction in the rate of cliff retreat beyond 2030 will result in a reduction in impact. Rising sea levels may affect these projections and would be likely to increase the rate of erosion, with a resulting increase in the quantities of ASDs that are vulnerable to erosion.

5. CONTINUED MONITORING OF FOSSILS AND LITHICS FROM THE CF-BF AT HAPPISBURGH

A primary aim of the project has been to develop ways in which the rapidly eroding coastline can be better and more systematically monitored and to ensure that new fossil and lithic finds are being brought to the attention of curators and the research community and their details properly recorded. Through this project several means of facilitating this process have been developed.

5.1 Engagement with fossil collectors

One of the important aspects of the project has been to identify and engage better with existing fossil collectors who work along the coast. A great deal of work, particularly by Simon Parfitt, Nigel Larkin and David Waterhouse, has been undertaken prior to and during the project to record the fossils from well- known collectors. This work has been built on by running three day sessions of talks and 'Fossil Road Shows' at Cromer Museum and at the Time and Tide Museum (Great Yarmouth). These were attended by both known and new collectors, providing a good platform from which to make better contact, begin the recording of new finds and explain in more detail the significance of those finds.

5.2 Engagement with the public

A further aim of the project has been to engage and inform the general public, who mainly consist of local residents, but also a significant number of holiday-makers. The one day events in Cromer and Great Yarmouth were very well attended with approximately 220 participants and illustrated very clearly the level of interest in the subject among the wider public

The public talks have helped to garner this interest, together with the website that is hosted by AHOB: www.ahobproject.org. The latter needs to be regularly maintained and updated, but currently provides information about the Cromer Forest-bed, links to fossil and lithic identification services at Norfolk Museum Service and the British Museum together with information about new events.

5.3 Active monitoring of the beach

A notable success of the above initiatives has been the identification of several new collectors. Two collectors in particular have been regularly recovering flint artefacts and fossils over the last three years from the beaches between Bacton and Sea Palling, particularly around Happisburgh and Eccles-on-Sea. To help with recording the finds they have been equipped with a digital camera with GPS, which has proved ideal as a means of creating permanent records of the finds, their location and context. They now have over 130 new fossils and 300 flint artefacts from Happisburgh, including some *in situ* finds.

Of particular note is a handaxe from the beach between Site 2 and Site 3 and a hippopotamus canine from Site 3. In addition, the collectors have identified a new site at Eccles, from which almost 500 artefacts and 55 fossils have also been recovered.

5.4 Fossil and artefact recording systems

An additional component of this part of the project was evaluating the best way to develop a more systematic means of recording vertebrate fossils and artefacts from the CF-bF. There are currently four main ways that artefacts and fossils found by the general public are recorded (Table 10).

Table 10. Different systems of recording lithic artefacts and vertebrate fossils from the CF-bF in Norfolk.

System	Record type	Entered by public registered public	Finds	Location	Finder details	Quality control
Norfolk Museum Service (NMS) identification service	Paper/ digital	No	Lithics Fossils	Yes	Yes	Good
Portable antiquity Scheme (PAS)	Online	Yes	Lithics	Yes	Yes	Variable
CITiZAN	Online	Yes	Lithics	Yes (GPS)	Yes	Variable
Norfolk HER	Online	No	Lithics	Yes	Yes	Good

The NMS identification service, PAS and CITiZAN are the first portal for members of the public to report finds from the CF-bF. Only the NMS additionally records vertebrate fossils. PAS has a local Finds Liaison Officer with support network to upload some records, but registered finders can also use the system to upload their own finds at different levels of access. CITiZAN has been launched recently and encourages members of the public to use the downloadable CITiZAN App. It was designed for recording archaeological features under threat from coastal erosion, but some artefacts have also been recorded on the online database.

In principle all the records from the first stage of recording artefacts from NMS, PAS and CITiZAN should be transferred to the Norfolk HER as the final repository of information. There has been a recent project to upgrade the Palaeolithic records and it is now in good shape. Although it is a good database for information on Palaeolithic sites and associated artefacts, it has not been designed as a research tool. Nor at this stage does it consistently record vertebrate fossils.

One of the aims of the EH projects was to explore the feasibility of a PAS-type system, by using records of new vertebrate finds brought in by the public to NMS. A spreadsheet has been produced using similar data fields to PAS with additional fields and authority lists for vertebrate fossils. Palaeolithic artefacts could be added to the spreadsheet. Although these spreadsheets could be transferred onto a PAS-type database, it is no longer clear whether it is the best option for the future, particularly with the recent successful launch of CITiZAN. With both systems the problems lie in the initial costs of developing appropriate methods for recording CF-bF material and in the longer term the costs of providing good quality control. Any new system should also be designed to be usable as a research tool.

5.5 Overview

The project has made some progress towards developing ways in which the CF-bF can be better monitored in the future to help identify new exposures and provide more systematic recording of new vertebrate and artefactual finds. The key elements are:

- Full engagement with the fossil collecting community to ensure that they understand their role in recording the CF-bF. This can be achieved through the maintenance of current links and identifying new collectors.

- Better public engagement to ensure that members of the wider community understand the importance of the CF-bF, recognise new finds and know how to report them. A combination of public meetings, fossil road shows, public lectures and maintaining the website will help to maintain and generate new interest.

- Identifying and encouraging keen collectors who are able to monitor the critical areas on a regular basis. Equipping them with digital cameras with GPS is a simple and cheap way of reliably recording the information.

- The database structure for the recording of Palaeolithic artefacts and vertebrate fossils from the CF-bF has been designed and initially tested, but further discussion and funding is required to identify how this can be taken forward.

6. RECOMMENDATIONS

Archaeological investigations over a period of 15 years on the coast at Happisburgh have firmly established this location as among the most important archaeological sites in England, with discoveries of international significance that have reshaped understanding of early human presence in Britain and in Europe as a whole. It has raised new questions about the timing of dispersals of early human populations into Europe, the nature of the environments into which those populations dispersed and the technological and cultural adaptations that enabled them to take place.

Happisburgh lies within an area of major importance for Quaternary geology and Palaeolithic archaeology. The national and regional research frameworks all recognise this region as an area of international significance and the Palaeolithic more broadly as a period which requires more focused study and field based investigation both on land and underwater (Peeters *et al* 2008; Wessex Archaeology 2008; Blinkhorn and Milner 2014; Ransley *et al* 2013; Medlycott 2014). Consequently the resource has been marked by curators and the academic community as of high significance. However, within the study area the Shoreline Management Plan and recent Pathfinder projects for the study area have identified it to be one of erosion and loss. Therefore it has an acknowledged high potential and is a highly significant resource which is known to be subject to erosion. To add to this, the visible impact of this is occurring within one of the most dynamic environments (the inter-tidal foreshore) that archaeology can work within and one of the most challenging from which to capture data.

In order to address the issues raised by the on-going erosion and loss of this highly significant archaeological resource a number of recommendations are made based on the outcomes of this project.

Recommendation 1: Further geoarchaeological investigation at Happisburgh

The estimates of losses of archaeologically important deposits up to 2030 indicate that Site 3 will continue to be particularly vulnerable during the phase of rapid cliff retreat following failure of the sea defences along this part of the Happisburgh frontage. This rapid cliff retreat coupled with the laterally extensive nature of the Site 3 deposits will result in significant losses of deposits and the associated archaeological and palaeoenvironmental information.

- A programme of on-going survey, mapping and recording of the coastal area targeted to this period of rapid coastal erosion will allow recovery of some of this information. It is unlikely that systematic excavation will be possible. However monitoring, recording and sampling of deposits exposed by cliff retreat or beach scour will continue to provide important information. It is important that this occurs prior to the failure or removal of sea defences, as shown by the recent evaluation work reported in Appendix 1.

In order to better constrain the landward distribution of the deposits, at least to the limit of the 2055-2105 zone identified in the SMP, it would be necessary to undertake a further programme of borehole and possibly geophysical investigations.

- Drilling: using experience gained in this project it will be possible to deploy the most appropriate drilling technique to meet the needs of the project. Drilling from the cliff top with a cable percussion rig can quickly and successfully drill to several tens of metres with good recovery of material under most conditions. The work undertaken so far has also demonstrated that lighter drilling equipment can be deployed on the beach if necessary though with reduction in the depth of drilling and in the quality of sample recovery. Borehole positions would be targeted in areas where the ASDs are projected to be located.

- Geophysics: Geophysics would be used to establish the lateral extent of the deposits in areas where existing data is lacking or inconclusive. A combination of Direct Current Resistivity and Electromagnetic Ground Conductivity could be used, both of which can be undertaken from the cliff top and at beach level. Resistivity surveys, which are able to penetrate down to depths of over 20m, can be used to map the channel features at depth. The resistivity method could also be used further inland.

The combined data from the boreholes and geophysics would contribute to improving the deposit model for Happisburgh and could be used to refine the projections and estimates presented here for the time period up to 2105.

Recommendation 2: Offshore geophysical investigations

Work undertaken for this project has demonstrated both the potential and the challenges for carrying out research on archaeological deposits located offshore. The project has successfully developed a strategy for exploring these deposits and has identified a potential source for the iron-cemented gravels that are being washed onto the beaches between Happisburgh and Sea Palling. In order to understand the deposits offshore additional sea-time would be required, with specific objectives of:

- Acquiring and assessing high resolution bathymetric and sub-bottom data offshore particularly in the vicinity of the Monks. At present there is no detailed seabed or sub-surface mapping of this structure and such a 3D seabed survey could enable the identification of the iron-cemented, faunal rich, gravels to be properly identified.

This will allow for better understanding of the full extent of deposits and their vulnerability to erosion and storm events and will provide a much improved basis for targeting further diving expeditions. This should be requisite of any future diving, which would be funded as a separate project.

Recommendation 3: Active monitoring and recording of lithic and fossil finds

A key outcome of this project has been to demonstrate the value of active monitoring of the beaches and the systematic collecting and recording of both lithic and fossil finds. Maintaining an active beach monitoring programme ensures that there are 'eyes on the ground' on a regular basis and the continued monitoring, recovery and recording of the fossils and artefacts that will be eroded from the CF-bF deposits can be achieved through:

- Collector networks: continued engagement with the fossil collecting community to ensure that they understand their role in interpreting the CF-bF and for recording new finds.
- Public awareness: continued public engagement to ensure that members of the wider community understand the importance of the CF-bF, recognise new finds and know how to report them.
- Training and enabling: continued identification of keen amateurs and collectors who are able to monitor the critical areas on a regular basis and equipping them with digital cameras with GPS for better recording.
- Recording and disseminating: development of a system for recording and viewing of finds will provide a means of capturing the information in a standardised format and also a portal to allow people to view new discoveries, which will, in turn, generate further interest in artefact and fossil collecting along the Norfolk coast.

Recommendation 4: Beyond Happisburgh; investigating the archaeological potential of other CF-bF localities in East Anglia

The work at Happisburgh, together with that at Pakefield, has transformed understanding of the earliest evidence for human presence in Britain and enhanced the archaeological significance of the CF-bF. It has also demonstrated that systematic survey of the coastline can yield important new discoveries which may contribute to major research investigations. This can be achieved through:

- Deposit mapping: field surveying of cliff and foreshore exposures, recording sections and surveying to OSGB.
- Trial pitting: creating exposures at beach level to assess the archaeological and environmental potential of the deposits.

- Deposit sieving: coarse mesh sieving of sediments provides a rapid means of assessing artefact content. This method was instrumental in the discovery of Happisburgh Site 3.

- Drilling: targeted drilling, using appropriate methods, can be used to establish stratigraphic relationships and provide samples for geological and palaeoenvironmental analyses.

Research at Happisburgh provides a template that may be applied elsewhere along the coastline of Norfolk and Suffolk, where equivalent geological deposits are known to crop out. The rapid coastal erosion currently taking place at Happisburgh has focussed attention on this part of the coastline, but similar deposits elsewhere, though not as immediately vulnerable as those at Happisburgh, may prove to be equally archaeologically significant.

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APPENDIX 1: AN ASSESSMENT OF THE IMPACT OF WORKS TO REMOVE COASTAL DEFENCES ON ARCHAEOLOGICALLY SIGNIFICANT DEPOSITS AT HAPPISBURGH

April 2016
Dr Simon G Lewis

Introduction

During 2015 works were carried out to remove the remnants of the coastal defences along part of the Happisburgh frontage and to realign the rock groyne. These works involved bringing heavy plant onto the beach to move the rocks and to remove the wooden revetments and sheet piles. The final phase of the work to remove the sheet piles required them to be lifted vertically by a large crawler crane using a vibration removal method to release the sheet piles from the sediments. A watching brief was in place throughout the operations. However in order to assess the potential impact of the work on remaining archaeologically significant deposits a survey involving shallow drilling was required.

The purpose of the drilling programme was to establish the distribution of any remaining deposits of archaeological interest that may be impacted by the works to remove the sea defences. Drilling was undertaken at the same time as the final phase of removal of sheet piles relating to the old sea defences at Happisburgh between 28/09/15 and 01/10/15.

Drilling work was undertaken in two areas: first above the high tide line at the foot of the cliff and secondly in the intertidal zone. In the latter case, while located closer to the line of the sea defences, drilling was constrained by the tides and by ground conditions, in particular the waterlogged nature of the sediments. In addition, locations further to seaward were at lower elevations and therefore locating any remaining deposits of interest was less likely. It was not possible to drill in close proximity to the sea defences, as despite the equinoxial spring tides, this area was never sufficiently well exposed to allow drilling to take place safely and it was also in too close proximity to the machinery working on the removal of the sea defences. Drilling above the high tide line could take place under any tidal conditions and afforded the opportunity to refine understanding of the overall stratigraphy of the site and to relate the inter-tidal boreholes to a well-constrained stratigraphy in the immediate vicinity.

Reference was also made to results of previous drilling undertaken in the area and other geological observations which form part of on-going research into the Palaeolithic archaeology and Pleistocene stratigraphy at Happisburgh.

Drilling was undertaken using Cobra-driven window samplers. Previous experience of drilling on Happisburgh beach indicated that this would provide the most effective means of drilling shallow boreholes where mobilisation and set-up time was limited and where only a reconnaissance type investigation of the sediments is needed, though sampling of the sediments recovered is possible using this method.

A total of ten boreholes (BH15/1- 15/10) were drilled over a four day period providing a cumulative total drilled of *c* 30m (Table A1.1, Figure A1.1). The longest individual borehole (BH15/8) was 4.4m. Boreholes drilled in the intertidal zone were only 2-2.5m in length owing to the waterlogged sediments which resulted in rapid collapse of the borehole preventing further progress.

Results of the borehole investigation

The results indicate that in the intertidal zone, where the tops of the boreholes were at elevations between 0m and -1mOD, there were no deposits of archaeological interest preserved. This is for two reasons. First, they may have been removed by wave erosion of these deposits as the sloping beach-face has encroached landwards. This is best illustrated by BHs 15/8 and 15/9 (Figure A1.1). In BH15/8 the base of the archeologically-significant laminated silts is at -0.8mOD, whereas the top of BH15/9 (located in the intertidal zone), where the laminated silts are not present is at -0.8mOD. This suggests that, had the laminated silts once extended further seaward (and the available evidence indicates that they did), these deposits have been removed.

Secondly the discontinuous nature of the deposits themselves (see below) also accounts for the absence of these sediments. This discontinuity is indicated by the boreholes along the high tide line (BH15/1, 4, 5, 7, 8 and 10). The laminated silts are present in BH15/8 (*c* 1.8m thickness), but BH15/7 shows only very thin laminated sediments, which may not be equivalent deposits (Figure A1.1). Further south east in BHs 15/4 and 15/5 there are further examples of thin development of laminated silts, which are consistent with another, smaller, laminated silt-filled channel. This is supported by other observations along this part of the Happisburgh cliffs and foreshore.

Impact of works on archaeologically significant deposits

The results of the drilling programme and associated observations suggests that the works to remove the sea defences and relocate the rock groyne had little or no impact on archaeologically significant sediments. These sediments were not identified in the area adjacent to the sheet piles, nor, on the basis of the drilling results, were they present to any significant extent in the inter-tidal zone on the seaward side of the realigned rock groyne. The presence of a variable thickness of modern beach sand over much of the area in which the operations were being conducted also served to protect any remaining deposits from disturbance by vehicle tracks or wheels.

The only location where archaeologically significant sediments were identified is at the north western end of the area, in proximity to the old lifeboat ramp (BH15/8). This supports previous observations in that area of extensive exposures of laminated silts beneath the modern beach. These sediments are laterally equivalent to the deposits in which the footprints were found and the area is also close to the 'type locality' for the Happisburgh succession, which is based on a borehole sunk in 1966 and located on the former lifeboat ramp (borehole HC of West 1980). This is a critical area for understanding the Pleistocene deposits at Happisburgh.

Potential impact of further work on archaeologically important deposits

The data collected during the present investigation provides a basis for an assessment of the potential impact of any future work of a similar type on the beach and foreshore on this part of the frontage at Happisburgh.

An important aspect of any assessment of this type is understanding the distribution of the sediments in three, rather than two dimensions. This is significant because the beach profile has a sloping shore face, which at Happisburgh results in a change in elevation over the inter-tidal zone of the order of 2m. As the thickness of the sediments of interest is of a similar order and their altitudinal envelope essentially overlaps with that of the modern shore face, they will be vulnerable to erosion as the shore face profile migrates landwards. It is therefore important to assess the thickness as well as the lateral distribution of the sediments of interest. A further consideration is that little information is available on the inland distribution of these deposits. Some data has been collected as part of the ongoing research at Happisburgh but its spatial resolution is, at the present time, rather low.

The *c* 400m stretch of coast south eastwards from the old lifeboat ramp to the new earth ramp and landward of the line of the old sea defences can be divided into three zones of high, moderate and low sensitivity to describe the likely impact of any activities on the beach, such as removal of sea defences or realignment of the rock groyne on the archaeologically significant deposits (Figure A1.1). This is based on the known and probable spatial distribution of the archaeologically significant deposits and an altitudinal range of +1 to -1mOD. Areas currently below -1mOD are unlikely to retain any archaeologically significant sediments as the altitude is too low, in relation to their known height distribution. Erosion of the Pleistocene succession in the future to elevation below -1mOD is also likely to remove deposits of archaeological significance. These deposits are known to extend landward beneath the cliff, the zones should therefore be regarded as indicative with landward extension of them as a result of cliff retreat.

1. **High sensitivity**: the area in the vicinity of the old lifeboat ramp is regarded as highly sensitive at the present time as archaeologically significant deposits are present beneath and immediately in front of the cliff. The sediments have an altitudinal envelope of +1 to -1mOD in this area. These sediments are laterally extensive, though the precise distribution of the remaining deposits is unclear as they are covered by the modern beach at the present time. Removal of remnants of sea defences or other structures on this part of the beach is likely to have a significant impact on these deposits. The area of high sensitivity also extends north westwards as equivalent sediments are known to be present over this part of the beach, including the 2014 footprint site (Figure A1.1). The zone can be extended as far as Site 3.

2. **Moderate sensitivity**: the area shown as of moderate sensitivity is regarded as such because there are equivalent laminated sediments present on the foreshore and in cliff exposures. These sediments have not yielded archaeological information to date, though this remains a possibility as they are similar to and in the same stratigraphic position as the archaeologically important deposits further along the beach. A similar altitudinal envelope of +1 to -1mOD is assumed to encompass the sediments of interest.

3. **Low sensitivity**: There are no recorded occurrences of laminated silts or equivalent deposits in this area, though they may have been present and have been removed by erosion. The absence of archaeologically significant deposits makes this area of low sensitivity to disturbance in the course of any further work on the beach.

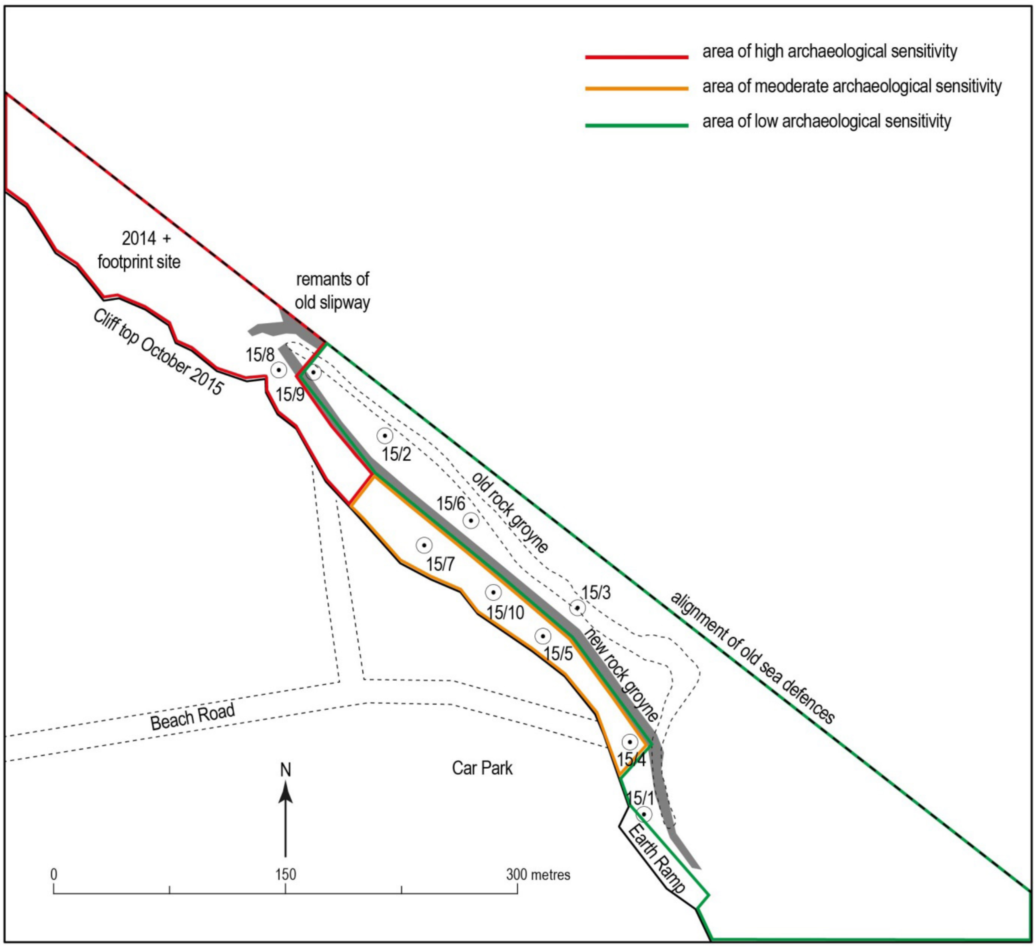


Figure A1.1 Happisburgh showing location of boreholes completed for this project (BHs 15/1-10), the former and current position of the rock groyne and the archaeological sensitivity zones discussed in the report. Based on Ordnance Survey (Digimap license).

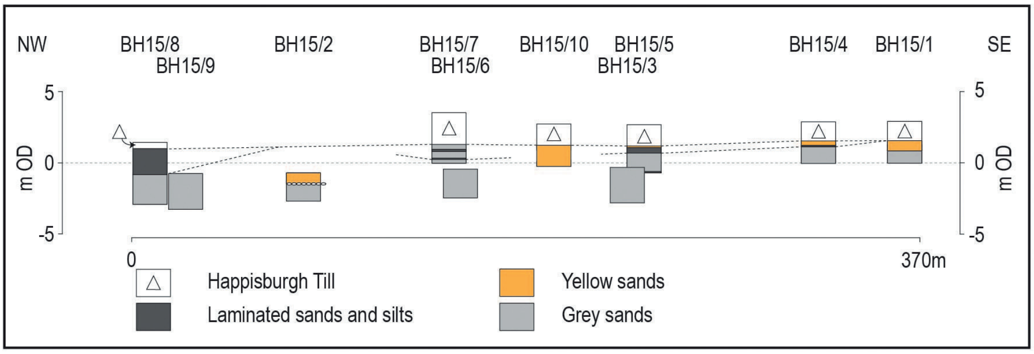


Figure A1.2 Logs of boreholes in vicinity of rock groyne and sea defences removed in 2015. See Figure 1 for location of boreholes.

Table A1.1 Summary of borehole data from drilling programme during removal of coastal defences at Happisburgh, September, 2015.

Borehole	Easting	Northing	Elevation	Total depth	Top	Base	Lithology
BH15/1	638563	330806	2.9	3.4	0.0	1.25	Till
					1.25	2.0	Sand
					2.0	3.35	Grey Sand
BH15/2	638395	331052	-0.7	2.0	0.0	0.8	Sand
					0.8	0.85	Gravel
					0.85	2.0	Grey Sand
BH15/3	638520	330940	-0.3	2.5	0.0	0.2	no recovery
					0.2	0.25	Peat
					0.25	0.5	Laminated silts
					0.5	2.5	Grey Sand
BH15/4	638554	330852	2.9	3.2	0.0	1.3	Till
					1.3	1.65	Sand
					1.65	1.75	Laminated silts
					1.75	2.9	Grey Sand
					2.9	3.2	no recovery
BH15/5	638497	330922	2.7	3.4	0.0	1.53	Till
					1.53	1.61	Sand
					1.61	2.0	Laminated silts
					2.0	3.16	Grey Sand
					3.16	3.4	Silt
BH15/6	638451	330997	-0.4	2.0	0.0	0.7	Sand
					0.7	0.8	Laminated silts
					0.8	1.8	Sand
					1.8	1.81	Clay
					1.81	2.0	Sand
BH15/7	638420	330981	3.6	4.0	0.0	2.25	Till
					2.25	2.6	Sand
					2.6	2.75	Laminated silts
					2.75	3.2	Sand
					3.2	3.3	Laminated silts
					3.3	3.6	Grey Sand
BH15/8	638326	331095	1.4	4.4	0.0	0.45	Till
					0.45	2.25	Laminated silts
					2.25	4.4	Grey Sand
B	638348	331093	-0.8	2.5	0.0	0.3	Grey Sand
					0.3	0.35	Peat
					0.35	2.5	Grey Sand
B	638465	330950	2.8	3.2	0.0	1.5	Till
					1.5	3.0	Sand
					3.0	3.2	no recovery

APPENDIX 2: INTERIM REPORT

Geophysical Test Survey, Happisburgh, Norfolk

December 2012
Prepared by Dr Richard Bates and Dr Martin Bates for English Heritage

Executive Summary

A geophysical test survey was conducted at Happisburgh, Norfolk in order to test the hypothesis that buried channel sequences cut in Crag and buried beneath till deposits could be mapped using geophysical methods. Three techniques were tested along the beach and cliff sections to the north and south of Happisburgh, namely electromagnetic ground conductivity mapping, direct current resistivity imaging and ground penetrating radar. The results of the EM and DC imaging showed features that correspond with the known location of channels and it is likely that these methods could be used across a wider area for mapping the buried channel network.

Objectives

As part of the Happisburgh-Pakefield Palaeolithic project an onshore geophysical survey was proposed to map buried sedimentary sequences including the channels containing interglacial sediments as well as the overlying till sequences. In order to determine the most appropriate field techniques a geophysical test survey was conducted in June, 2012 to the east of Happisburgh, Norfolk along the foreshore and cliff line. The primary objective of the test survey was to determine the best geophysical methods for mapping buried palaeo-channels.

Site Background

The geophysical test survey site comprised two areas: Area 1 consisted of the foreshore and intertidal area to the south east of Happisburgh. The shore was marked by coarse sand and gravels overlying occasional outcrops of clays and dense organic material resting in a channel eroded into a dissected platform extending to an area of 300-500m sq at approximately the mid-tide elevation. The low intertidal zone showed gentle sea-ward dip that steepened toward the high tide mark where significant accumulations of windblown sand had drifted against the eroding cliff line. The cliff showed a cross-section of the geology to the west that consists of a thin topsoil above glacial till interbedded with wind-blown sand and fine fluvial deposits. These deposits, as exposed in the cliff, were considered to overlie the channel feature that was assumed to continue westwards beneath the till sequence. The cliff was between 5 and 10m high increasing in height to the north. Area 2 included two sites on top of the cliff to the south and north of Happisburgh. The site to the south showed significant topographic variation with a small valley system crossing the site along an East-West axis. The northern site showed no variation in topography. No freshwater springs were observed in the cliff.

Methods

Three geophysical techniques were tested at the Happisburgh site, namely direct current resistivity imaging, electromagnetic ground conductivity mapping and 2D sectioning with ground penetrating radar. The electromagnetic and electric techniques were chosen as they have proved effective in mapping buried channels at other coastal localities in the UK (Bates and Bates 2000; Bates *et al* 2007) and the GPR chosen as it is known to give effective mapping of channel features in low conductivity sedimentary environments. The geophysical methods were tested on the intertidal shore area and also on top of the cliffs immediately adjacent to the cliff site. Figure A2.1 shows the location of the field sites.

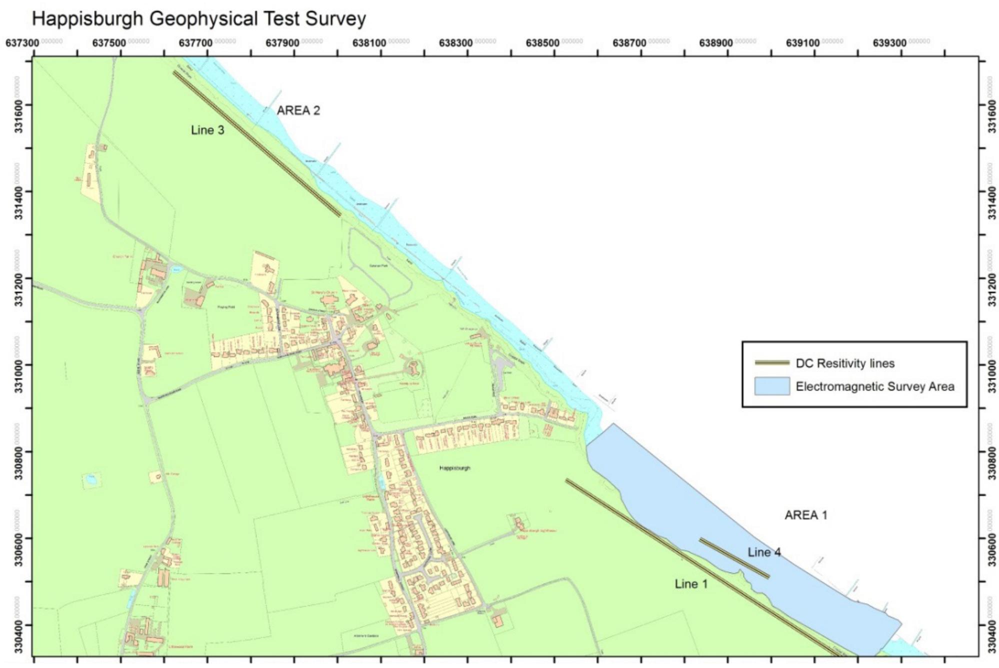


Figure A2.1 Geophysical test survey plan, Happisburgh. Based on Ordnance Survey (Digimap license).

Electrical and electromagnetic techniques are extensively used in near surface geophysical investigations. Most electrical techniques induce electrical currents in the ground, which are used to measure the variation in ground conductivity, or its inverse, resistivity. Different materials, and the fluids within them, will show different abilities to conduct an electric current. In general, sequences with high clay contents show higher conductivity as do saturated sequences and especially sequences where saline waters are present. In addition, manmade objects such as buried metallics (pipes, cables, rubbish), foundation remains (on archaeological sites) and sometimes chemical liquids such as leachates also cause higher conductivity than the surrounding material.

Electrical Imaging

Direct current resistivity surveying measures changes in ground resistivity by directly applying an electrical current to the ground. The method does this through placing two metallic spikes into the ground and applying an electrical current across them. Two additional metallic spikes are generally used to measure the potential drop between the current electrodes. The current and potential are then used to calculate the apparent resistivity of the ground. By making a number of measurements at different electrode spacings it is possible to measure the apparent resistivity to different depths within the ground. Traditionally this is done for a number of spacing-depth measurements and these are then interpreted using geo-electrical models of the ground in terms of a true depth-resistivity sounding. In its simplest application, the method assumes a layered earth model. With modern resistivity surveying equipment many electrodes are deployed at a time and computer control is used to select different electrode pairs for the current and potential electrodes. The result of this type of survey is an apparent resistivity section which again can be modelled in terms of a geo-electrical cross-section or image of the earth for interpretation in terms of sub-surface geology and hydrology. Resolution of subsurface layers with this technique is determined by the electrode spacing, the geometry of current-potential pairs and the resistivity-depth section itself. In general, the deeper in the section, the poorer the resolution as this requires the use of electrode pairs that are more widely separated and thus more lateral changes in sub-surface geology might be present.

Figure A2.2 DC ABEM Terrameter resistivity meter on clifftop near Happisburgh.

The electrical imaging collected in this project was acquired using an ABEM Terrameter SAS4000 resistivity meter with 80 electrodes (Figure A2.2). The electrode spacing was set to different separations (1 to 5m spacing) across the site in order to test mapping resolution of the buried geological features.

Electromagnetic Ground Conductivity Mapping

Electromagnetic techniques have been extensively developed and adapted over the last 15 years to map lateral and vertical changes in conductivity. In electromagnetic techniques rather than directly applying an electrical current to the ground, an alternating current in a primary transmitter coil usually at the ground surface creates a changing magnetic field around the coil. This produces an electromotive force (EMF) which on passage through the ground can cause secondary eddy currents to flow in the ground. These in turn have their own magnetic field associated with them. The secondary currents and magnetic field differ in phase to the primary and can be resolved into a portion that is in phase with the primary (real) and one that is out of phase with the primary (quadrature or imaginary). For further details of this refer to standard geophysical text (Telford *et al* 1990) or technical notes (Geonics). For low induction numbers the quadrature signal is proportional to ground conductivity and the inphase reading is most sensitive to buried metal. While the final output is similar to that from electrical techniques, several features of the electromagnetic techniques result in an increased horizontal resolution and more cost-effective application. Two types of electromagnetic survey are currently practised, i) time domain electromagnetic (TDEM) surveys which are mainly used for depth soundings and recently in some shallow metal detectors, and ii) frequency domain electromagnetic (FDEM) surveys that are used predominantly for mapping lateral changes in conductivity. In both electromagnetic survey techniques no direct contact is made with the ground and thus the rate of surveying can be far greater than for traditional electrical techniques where electrode probes must be placed in the ground for every measurement. Further recent improvement in FDEM has seen the integration of dGPS technology with the FDEM instruments and thus has led to a dramatic increase in the rate at which electromagnetic surveys can be accomplished. Typical survey results for FDEM surveys are contour maps of conductivity and inphase values and 2D geo-electric sections of conductivity. The survey instrument used was the Geonics EM-31 with digital acquisition and positioning provided by a Topcon Hiper dGPS (Figure A2.3). This instrument records both conductivity and inphase signatures of the electromagnetic wave field. The effective exploration depth of the instrument in vertical mode is 3m.

Figure A2.3 EM31 Ground conductivity meter with Topcon Hiper dGNSS.

Ground Penetrating Radar

Ground penetrating radar (GPR) uses high frequency electromagnetic waves to acquire subsurface information on lithology and pore fluid type. The EM wave energy is radiated down-ward into the ground from a transmitter and is reflected back to a receiving antenna. The reflected signals are recorded and produce a continuous cross-sectional "picture" or profile of shallow subsurface conditions. Reflections of the radar wave occur where there is a change in the dielectric constant or electrical conductivity between two materials. Changes in conductivity and in dielectric properties are associated with natural hy- drogeologic conditions such as bedding, cementation, moisture, clay content, voids, and fractures. Large changes in dielectric properties often exist between geologic materials and manmade structures such as buried utilities or can also exist where subsurface fluid properties change, for example over a saltwater table. As a general rule of thumb where ground conductivity is above approximately 30mS/m then GPR signals are unable to penetrate far distances. For this survey a Sensors and Software Pulse Ekko GPR system was used with both 100MHz and 250MHz antenna tested. This was operated in continuous radiating along lines with distance measured by a clocked wheel on the GPR cart. The wheel was calibrated before each run.

Results

Direct Current Resistivity Imaging

The results of the DC resistivity imaging are shown as a series of 2D geo-electric cross sections in Figure A2.4. (See Figure A2.1 for a ground plan showing the location of acquisition lines).

Along line1 very high resistivity was mapped for the cliff section down to -3mOD. Beneath this lower resistivity was noted with values less than 1ohm-m in two zones of over 100m wide to depths of greater than -20mOD. Along line 3 the very high resistivity associated with the cliff were not recorded however a dipping boundary showing decreased resistivity values from 0mOD to greater than -20mOD was mapped extending to the north. In the intertidal area Line 4, acquired with an electrode spacing of 1m, two distinct sections were recorded. To the south a very conductive near surface (resistivity values lower than 2 ohm-m) unit was mapped with higher resistivity unit below. To the north a higher resistivity “tongue” extended over a low resistivity unit.

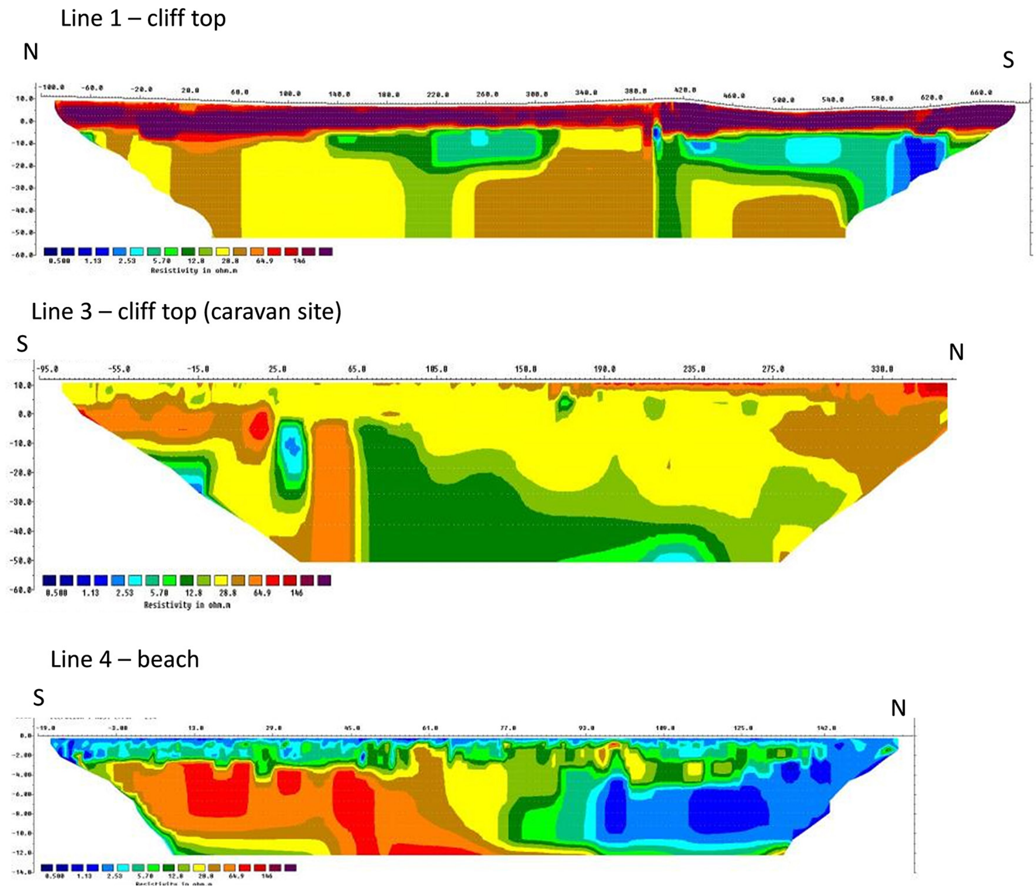


Figure A2.4 DC resistivity image sections for cliff and beach sections. Note both horizontal and vertical scales vary between images, however the resistivity scales are consistent.

Electromagnetic Ground Conductivity

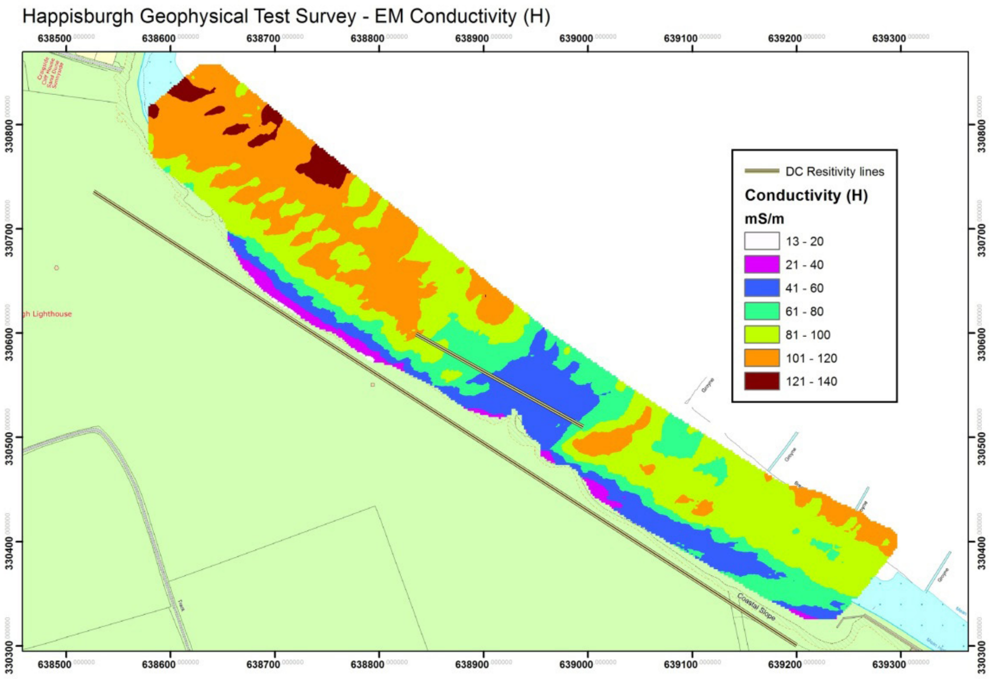
Ground conductivity was mapped on the foreshore and intertidal areas to the south=east of Happisburgh. The Genonics EM31 ground conductivity meter was used in both vertical coil and horizontal coil orientation with effective exploration depths of 3 and 5m respectively. The results are presented as colour contour maps of ground conductivity in Figures A2.5a and b.

GPR

The GPR survey showed results that indicated a compromise in penetration due to both high conductivity of the clay (see EM 34 and DC results) and on the beach the extremely high conductivity associated with salt water saturation. After test records were taken both on top of the cliff and on the beach the survey was terminated.

Discussion

Figure A2.6 shows an interpretation of the DC electrical imaging along lines 1 and 4. The highest resistivity is interpreted as till. Beneath this along line 1 two areas of more conductive material (blue to green) were imaged at the south and central section of the line. These areas are set in generally



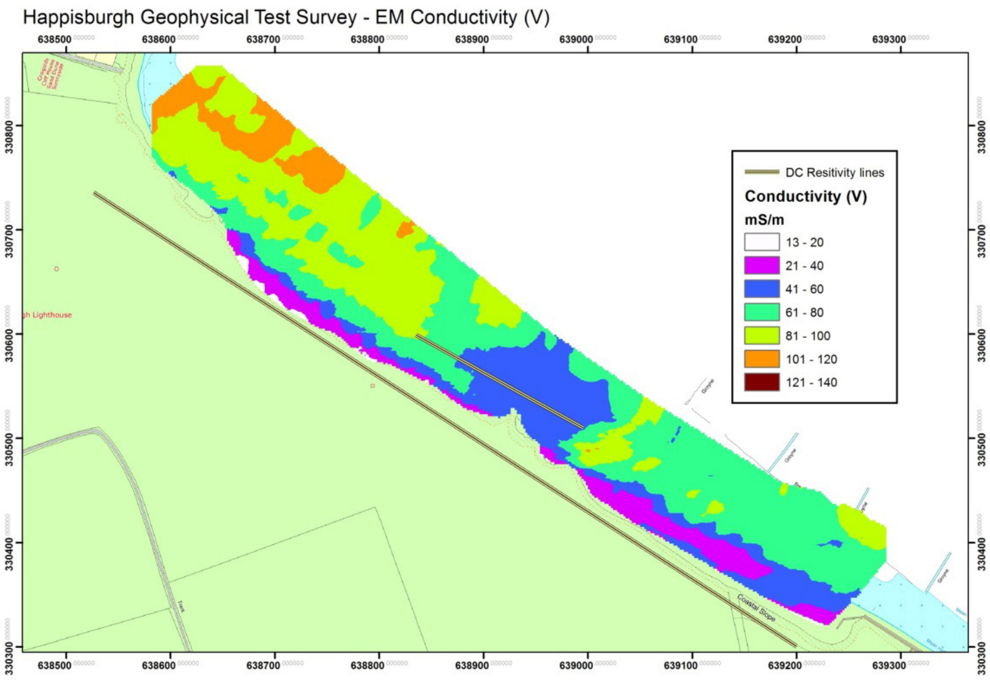


Figure A2.5. Ground conductivity for a) horizontal and b) vertical coil configuration. Based on Ordnance Survey (Digimap license).

more resistive material (yellow to brown). The morphology of the lower resistivity zones suggest that they might represent channel deposits in the Crag bedrock. Along line 4 across the beach two areas of very low resistivity (high conductivity) were recorded. A four metre thick zone extended north from the south end of the line reducing to less than 1m thick by 2/3rds of the distance along the line. Along the northern third of the line a large zone of low resistivity extends from the surface to a depth of over 10m. This northern pattern corresponds to that mapped on Line 1 for the deeper channel-like features cut into the Crag. The southern pattern corresponds to the known position of the shallow channel that outcrops on the beach. This suggests that from the geophysics it might be possible to identify more than one channel sequence in the geology.

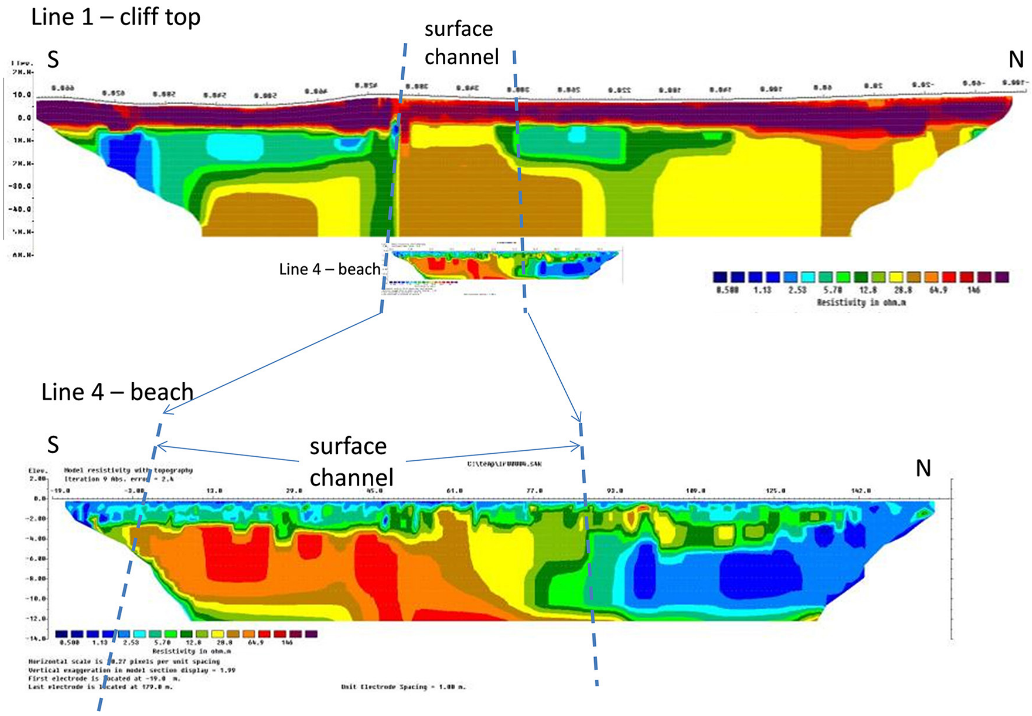


Figure A2.6 Line 1 and Line 4 DC resistivity interpretations.

The electromagnetic conductivity maps (Figure A2.5a and b) showed a clear difference between the central area of non-conductivity material and surrounding conductive response. This central zone not only corresponds to the changes noted in the DC resistivity imaging but also to the location of the near surface channel noted in pervious archaeological studies. The overall correspondence between the geophysics and the buried channels indicates that it is likely that these methods would be successful in mapping channel positions further inland beneath the till.

APPENDIX 3: INTERIM REPORT

Geophysical Test Survey, Happisburgh, Norfolk

May 2013
Prepared by Dr Richard Bates and Dr Martin Bates for English Heritage

Executive Summary

Following a test geophysical survey at Happisburgh, Norfolk in 2012 a series of electrical imaging cross sections were acquired in May 2013. These cross-sections were targeted over the buried channel sequences cut into Crag and buried beneath the till deposits that had previous been identified in the cliff and beach sections. The results showed features that correspond with the known location of channels and their extension inland.

Objectives

As part of the Happisburgh-Pakefield Palaeolithic project an on-shore geophysical survey was proposed to map buried sedimentary sequences including the channels containing interglacial sediments as well as the overlying till sequences. DC resistivity sections were chosen as the most appropriate technique to map the landward extension of channels. The goal of the 2013 survey was to test this hypothesis with further sections west of the beach/cliff line (Figure A3.1).

Site Background

The geophysical test survey site comprised two areas: an inshore area immediately to the west of Area 1 (2012 report) consisting of arable, gently undulating land. The second area included the northward extension along the cliffs through, and to the north of Happisburgh. Area 2 included two sites on top of the cliff to the south and north of Happisburgh (Figure A3.1).

Methods

2D electrical imaging (electrical resistivity tomography, ERT) was chosen as the most effective method of mapping the buried channels inshore from the sea cliffs and also in investigating the signatures of the section along the sea cliffs. Electrical techniques are extensively used in near surface geophysical investigations as different materials, and the fluids within them, show different abilities to conduct an electric current. In general, sequences with high clay contents show higher conductivity as do saturated sequences and especially sequences where saline waters are present. In addition, manmade objects such as buried metallics (pipes, cables, rubbish), foundation remains (on archaeological sites) and sometimes chemical liquids such as leachates also cause higher conductivity than the surrounding material. The application to Quaternary science and Palaeolithic archaeology has been demonstrated through the work of Bates and Bates (2000) and Bates et al (2007).

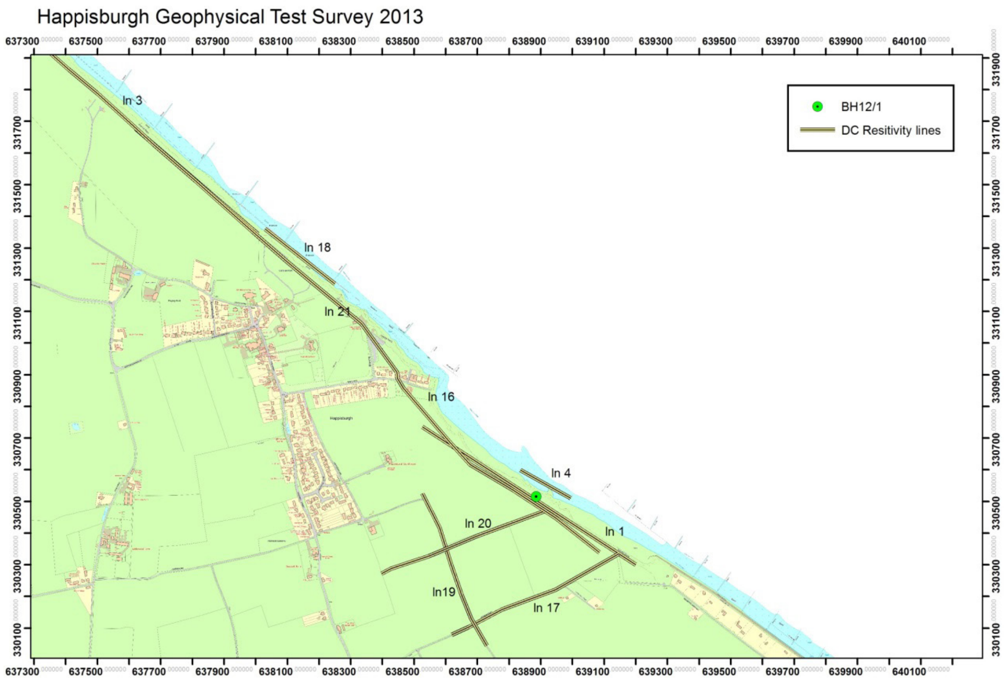


Figure A3.1 Geophysical test survey plan, Happisburgh. Based on Ordnance Survey (Digimap license).

Electrical Imaging

Direct current resistivity surveying measures changes in ground resistivity by directly applying an electrical current to the ground. The method does this through placing two metallic spikes into the ground and applying an electrical current across them. Two additional metallic spikes are generally used to measure the potential drop between the current electrodes. The current and potential are then used to calculate the apparent resistivity of the ground. By making a number of measurements at different electrode spacings it is possible to measure the apparent resistivity to different depths within the ground. Traditionally this is done for a number of spacing-depth measurements and these are then interpreted using geo-electrical models of the ground in terms of a true depth-resistivity sounding. In its simplest application, the method assumes a layered earth model. With modern resistivity surveying equipment many electrodes are deployed at a time and computer control is used to select different electrode pairs for the current and potential electrodes. The result of this type of survey is an apparent resistivity section which again can be modelled in terms of a geo-electrical cross-section or image of the earth for interpretation in terms of sub-surface geology and hydrology. Resolution of subsurface layers with this technique is determined by the electrode spacing, the geometry of current-potential pairs and the resistivity-depth section itself. In general, the deeper in the section, the poorer the resolution as this requires the use of electrode pairs that are more widely separated and thus more lateral changes in sub- surface geology might be present.

The electrical imaging collected in this project was acquired using an ABEM Terrameter SAS4000 resistivity meter with 80 electrodes. The electrode spacing was set to different separations (1 to 5m spacing) across the site in order to test mapping resolution of the buried geological features. The geophysical lines were positioned using a Topcon Hiper dGPS.

Results

Direct Current Resistivity Imaging

The results of the survey indicate a common pattern of electrical resistivity can be discerned across the individual lines (Figures A3.2 and A3.3):

Line 16. High resistance near surface (red colours) overlying pockets of low resistance (green/blue) and a basal unit of higher resistance (yellow/brown).

Line 17. High resistance near surface (red colours) overlying pockets of low resistance (green/blue) and a basal unit of high resistance (red).

Line 19. High resistance near surface (red colours) overlying pockets of low resistance (green/blue) and a basal unit of higher resistance (yellow/brown).

Line 18. A zone of low resistance (blue) at the surface overlying higher resistance at depth (brown/red) but with a more complex pattern at the far end of the transect where a resistant layer (red) underlies the surface conductive layer. A low resistance layer (blue/green) follows with a basal resistant layer (red).

Line 20. High resistance near surface (red colours) overlying pockets of low resistance (green/blue) and a basal unit of higher resistance (yellow/brown).

Line 21. High resistance near surface (red colours) overlying pockets of low resistance (green/blue).

Line 1. High resistance near surface (red colours) overlying pockets of low resistance (green/blue) and a basal unit of higher resistance (yellow/brown).

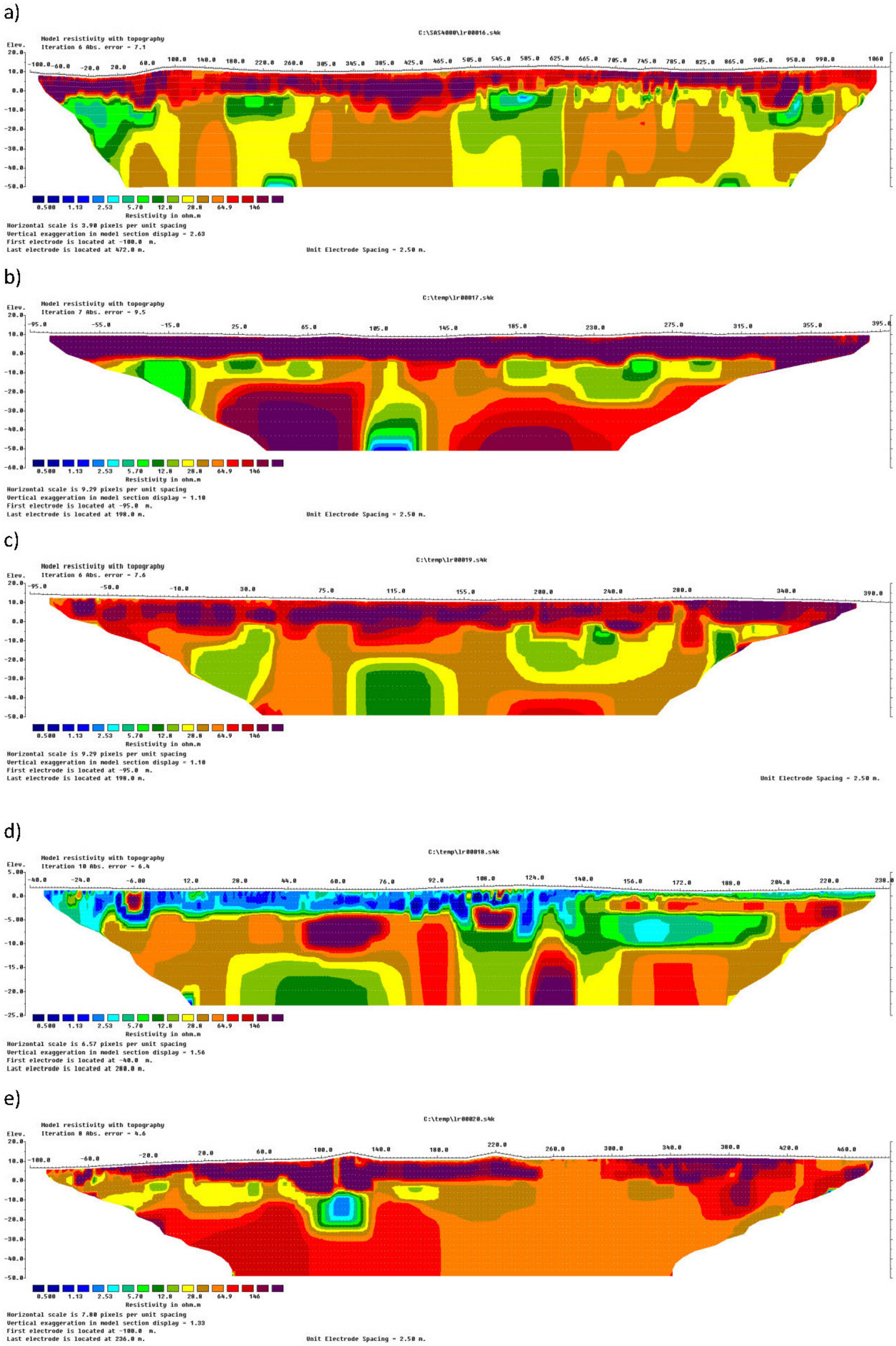


Figure A3.2 DC resistivity image sections for cliff and beach sections. Note both horizontal and vertical scales vary between images, however the resistivity scales a re consistent. a) Ln16, b) ln17, c) In 19, d) In 18, e) In 20. See Figure A3.1for a ground plan showing the location of acquisition lines.

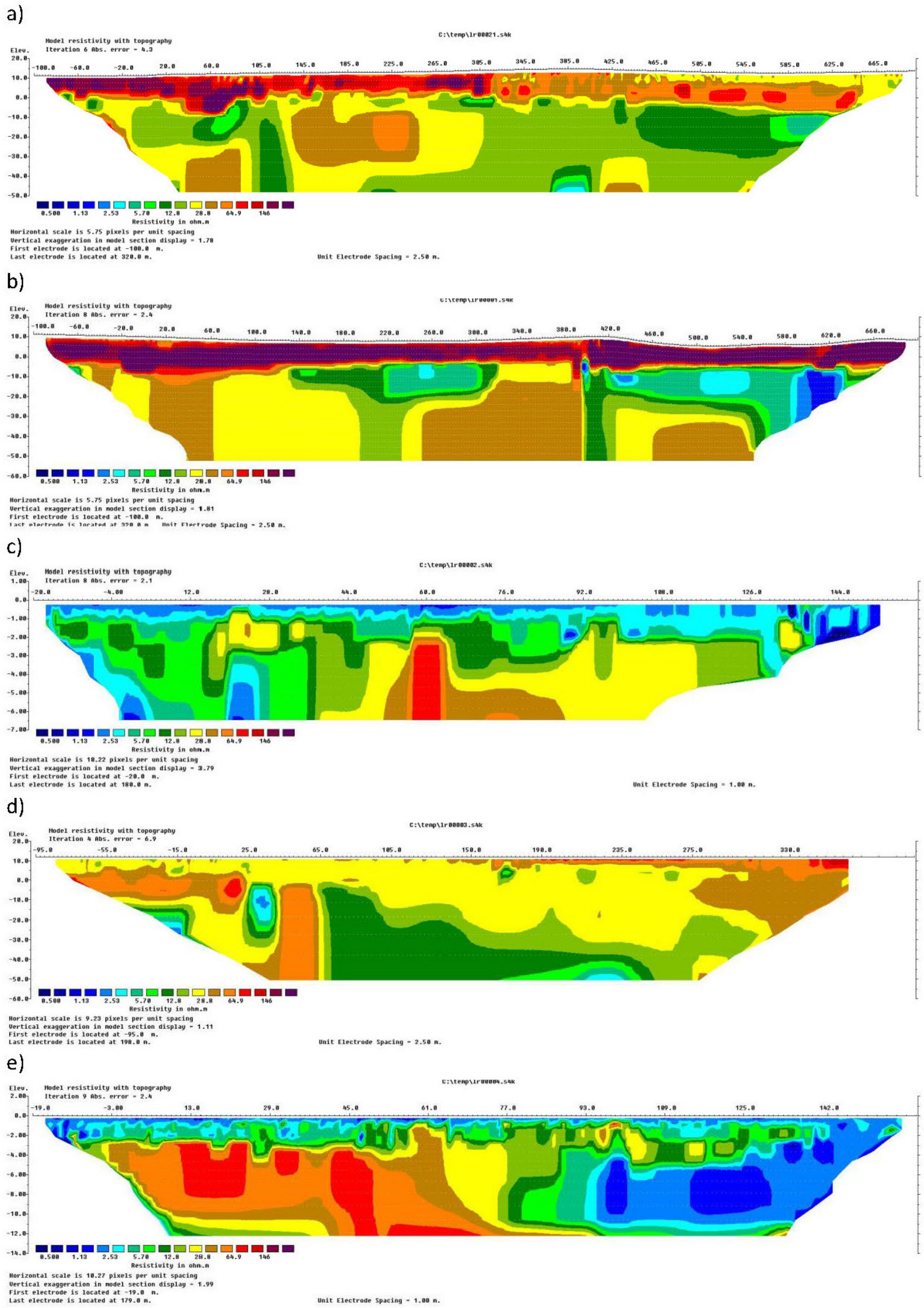


Figure A3.3 DC resistivity image sections for cliff and beach sections. Note both horizontal and vertical scales vary between images, however the resistivity scales are consistent. a) Ln21, b) 1n,l c) In 2, d) In 3, e) In 4. See Figure A3.1 for a ground plan showing the location of acquisition lines.

Line 2. A zone of low resistance (blue) at the surface overlying higher resistance at depth (green) but with a more complex pattern at the far end of the transect where a resistant layer (yellow/red) is present.

Line 3. A pattern of dipping layers commencing with a surface zone of high resistance (red) overlying a moderate resistance (yellow) and low resistance (green).

Line 4. A zone of low resistance (blue) at the surface overlying higher resistance at depth (red) but with a more complex pattern at the far end of the transect where a resistant layer (yellow/red) is present above a low resistance zone beneath (blue).

Discussion

The results of the DC resistivity survey prove the utility of this technique for tracing channels and the complex stratigraphy at Happisburgh Site 1. In particular, transects indicate that in most cases three discrete groups of geo-electrical sediment packages can be defined corresponding to sediments with high resistance (interpreted as sands and gravels), moderate resistance (sands) and low resistance (clays/silts). Consequently we have been able to simplify the stratigraphy on each section into an interpolated stratigraphy consisting of the following recognised units:

1. Red: Till (Anglian/post Anglian) sediments that overlie the buried stratigraphy.

2. Green: Channels beneath the till that include that of the archaeologically important Happisburgh Channel.

3. Yellow: Crag deposits into which the channels are cut.

4. Blue: Sands filling a channel cut into or contemporary with the till

5. Brown/Purple: Sediments associated with one of the channel infills.

This work demonstrates that:

a. channels can be mapped beneath both the beach and the till

b. channels (2-5m deep) are common at the site

c. channels can been seen in sections both close to the cliff and away from the cliff inland d) complex sequences can be seen in some channels (Figure A3.2d, A3.3e)

Significantly the channel containing the archaeology can be seen clearly in lines 1 and 16. However it is not seen in the eastern end of line 20 (Figure

A3.2e) and thus the channel probably swings north of line 20, perhaps clipping the end of line 19 (but this remains to be demonstrated). Other channel features are clearly visible within the area of the box defined by lines 1, 16, 17, 19 and 20. This indicates that perhaps the number and relationship of channels beneath the till is complex and multiple.

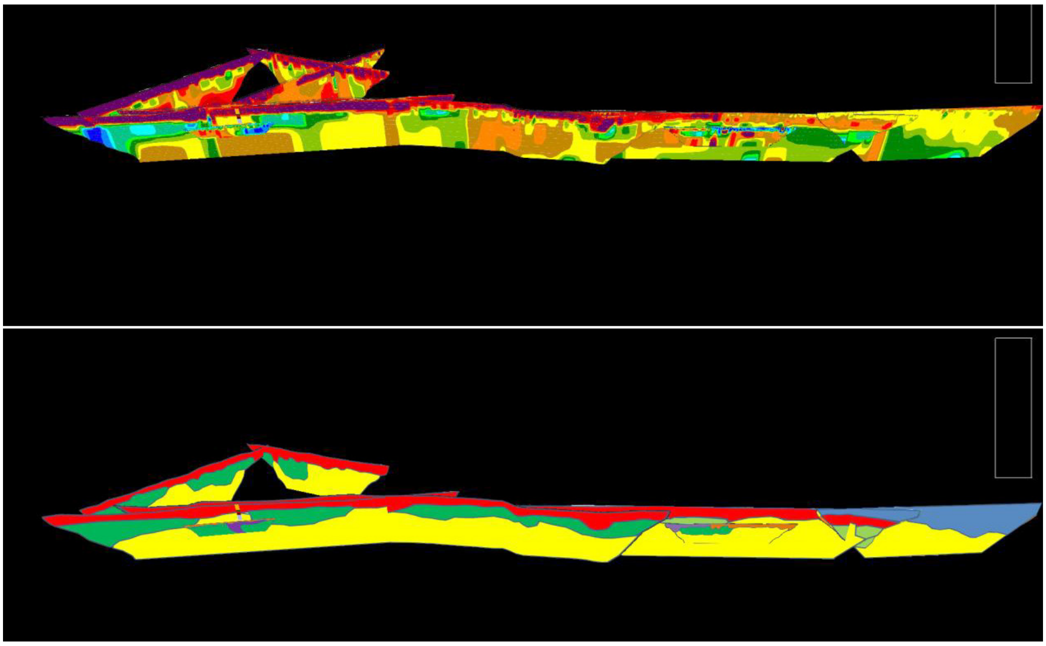


Figure A3.4a DC resistivity interpretations for all lines looking west.

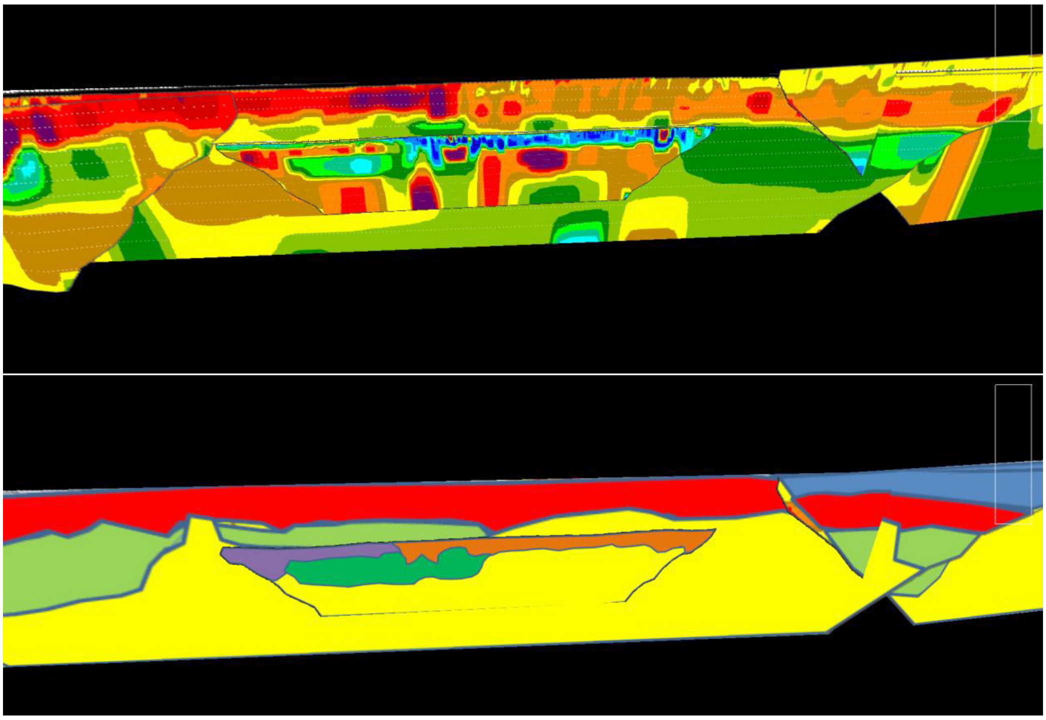


Figure A3.4b DC resistivity interpretations for northern cliff lines looking west.

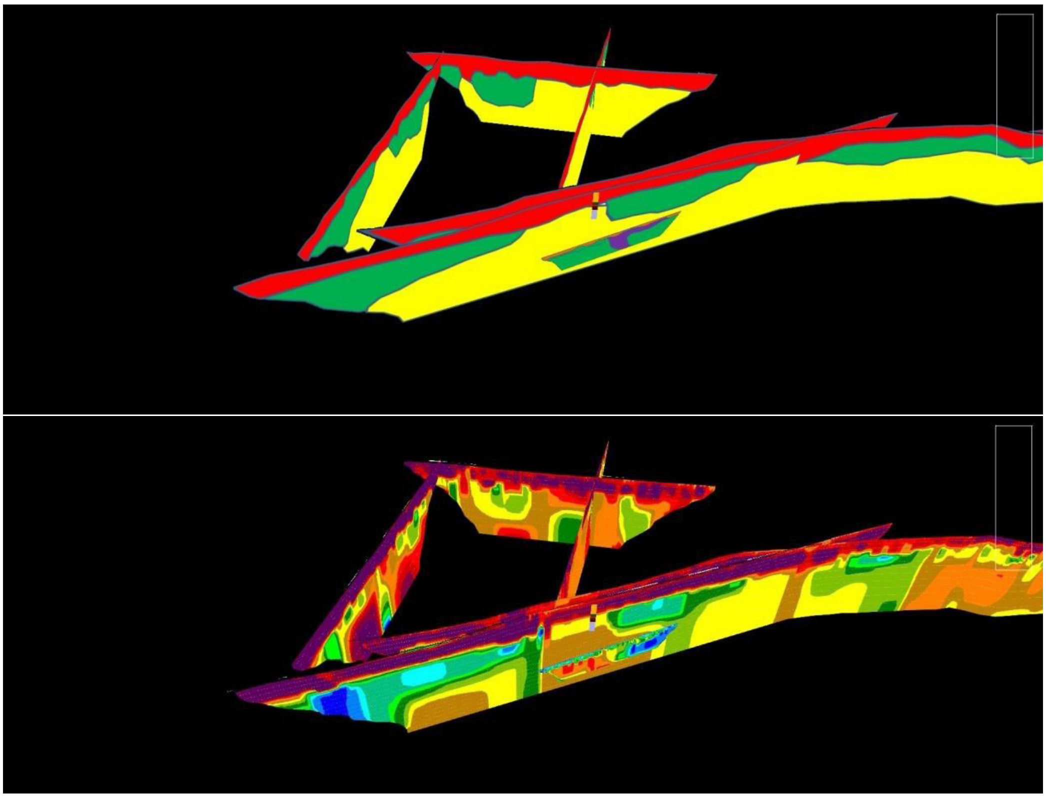


Figure A3.4C DC resistivity interpretations for beach lines looking west.

References

Bates, M R and Bates, C R 2000 Multi-disciplinary approaches to the geoarchaeological evaluation of deeply stratified sedimentary sequences: examples from Pleistocene and Holocene deposits in southern England, United Kingdom. *Journal of Archaeological Science* **27**, 845 - 858.

Bates, M R, Bates, C R and Whittaker, J E 2007 Mixed method approaches to the investigation and mapping of buried Quaternary deposits: examples from Southern England. *Archaeological Prospection* **14** 104-129.

APPENDIX 4: FINAL REPORT

Geophysical Test Survey, Happisburgh, Norfolk

February 2016
Prepared by Dr Richard Bates and Dr Martin Bates for English Heritage

Executive Summary

Following previous geophysical surveys onshore at Happisburgh, Norfolk new electrical imaging cross sections were acquired in June 2014. These cross-sections were targeted over the buried channel sequences cut into Crag and buried beneath the till deposits that had previous been identified in the cliff and beach sections. In particular, channels associated with previous archaeological site investigations were targeted with electrical arrays deployed on the beach at low tide. This report integrates these results with the previous results from the site investigation.

Objectives

As part of the Happisburgh-Pakefield Palaeolithic project an on-shore geophysical survey was undertaken to map buried sedimentary sequences including the channels containing interglacial sediments as well as the overlying till sequences. DC resistivity sections were deployed as the most appropriate technique to map the landward extension of channels. The specific goal of the 2014 survey was to further map the channels west of the beach/cliff line (Figure A4.1).

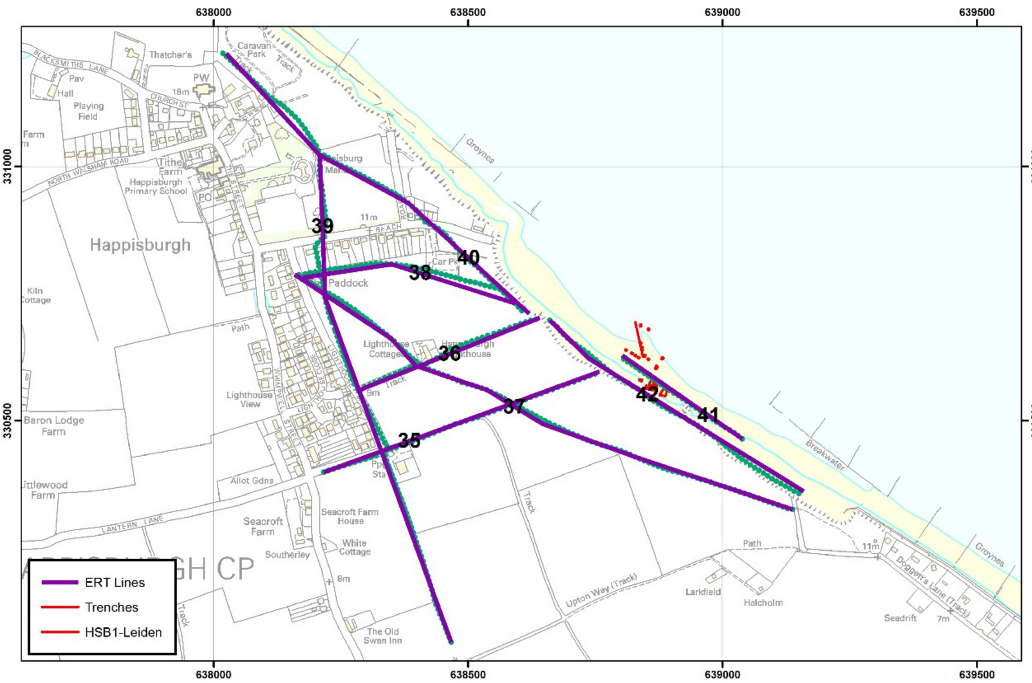


Figure A4.1 Geophysical survey plan showing 2013 and 2014 line locations, Happisburgh. Based on Ordnance Survey (Digimap license).

Site Background

The geophysical survey site comprised areas immediately to the south of Happisburgh and lines through the village towards the caravan park (Figure A4.1).

Methods

2D electrical imaging (electrical resistivity tomography, ERT) was chosen as the most effective method of mapping the buried channels inshore from the sea cliffs and also in investigating the signatures of the section along the sea cliffs. Electrical techniques are extensively used in near surface geophysical investigations as different materials, and the fluids within them, show different abilities to conduct an electric current. In general, sequences with high clay contents show higher conductivity as do saturated sequences and especially sequences where saline waters are present. In addition, manmade objects such as buried metallics (pipes, cables, rubbish), foundation remains (on archaeological sites) and sometimes chemical liquids such as leachates also cause higher conductivity than the surrounding material. The application to Quaternary science and Palaeolithic archaeology has been demonstrated through the work of Bates and Bates (2000) and Bates *et al* (2007).

Electrical Imaging

Direct current resistivity surveying measures changes in ground resistivity by directly applying an electrical current to the ground. The method does this through placing two metallic spikes into the ground and applying an electrical current across them. Two additional metallic spikes are generally used to measure the potential drop between the current electrodes. The current and potential are then used to calculate the apparent resistivity of the ground. By making a number of measurements at different electrode spacings it is possible to measure the apparent resistivity to different depths within the ground. Traditionally this is done for a number of spacing-depth measurements and these are then interpreted using geo-electrical models of the ground in terms of a true depth-resistivity sounding. In its simplest application, the method assumes a layered earth model. With modern resistivity surveying equipment many electrodes are deployed at a time and computer control is used to select different electrode pairs for the current and potential electrodes. The result of this type of survey is an apparent resistivity section which again can be modelled in terms of a geo-electrical cross-section or image of the earth for interpretation in terms of sub-surface geology and hydrology. Resolution of subsurface layers with this technique is determined by the electrode spacing, the geometry of current-potential pairs and the resistivity-depth section itself. In general, the deeper in the section, the poorer the resolution as this requires the use of electrode pairs that are more widely separated and thus more lateral changes in sub- surface geology might be present.

The electrical imaging collected in this project was acquired using an ABEM Terrameter SAS4000 resistivity meter with 80 electrodes. The electrode spacing was set to different separations (1 to 5m spacing) across the site in order to test mapping resolution of the buried geological features. The geophysical lines were positioned using a Topcon Hiper dGPS.

Results

Direct Current Resistivity Imaging

The results of the DC resistivity imaging are shown as a series of 2D geo-electric cross sections in Figure A4.2. They indicate that a common pattern of electrical resistivity can be discerned across the individual lines (Figure A4.2) that can be seen in the view of the lines shown in Figure A4.3.

Line 35 and 36. High modelled resistivity near surface (red colours) overlying pockets of low resistivity (green/blue). Line 37. High modelled resistivity near surface (red colours) overlying pockets of lower resistivity (yellow) and a large zone of low resistivity (green/blue) in hollow-hole feature at end of line.

Line 38. High resistivity near surface (red colours) with a continuous zone of lower resistivity (yellow/green) extending across entire section. Basal higher resistivity zone.

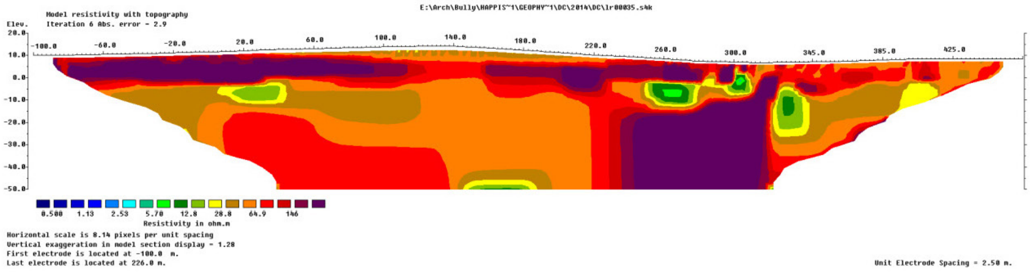
Line 39. High resistivity near surface (red colours) layer thins or is truncated/eroded gradually from the start of the line.

Line 40. High resistivity near surface (red colours) overlying pockets of low resistivity (green/blue) with indication of geometry for buried channels.

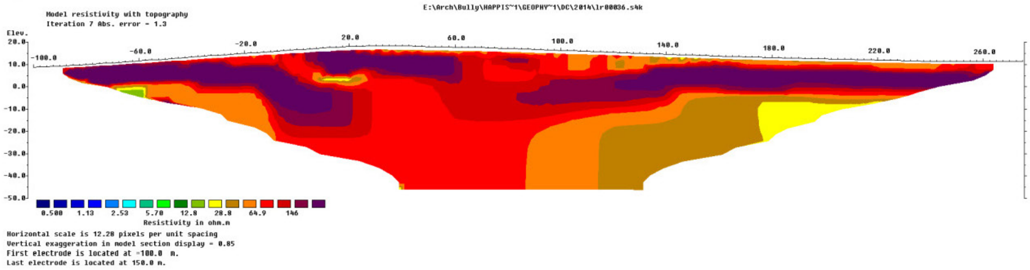
Line 41. Low resistivity (green/blue) sequence near surface expanding to deeper sections at the ends of each line. Pockets of high resistivity (red) across centre of line separating deeper low resistivity areas.

Line 42. Low resistivity (green/blue) sequence cut into high resistivity (red).

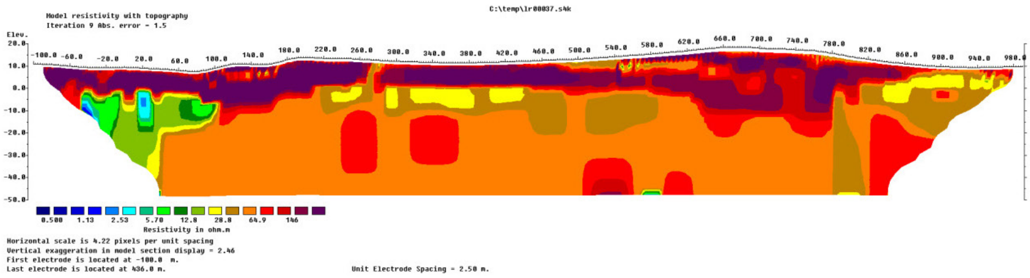
a) Line 35



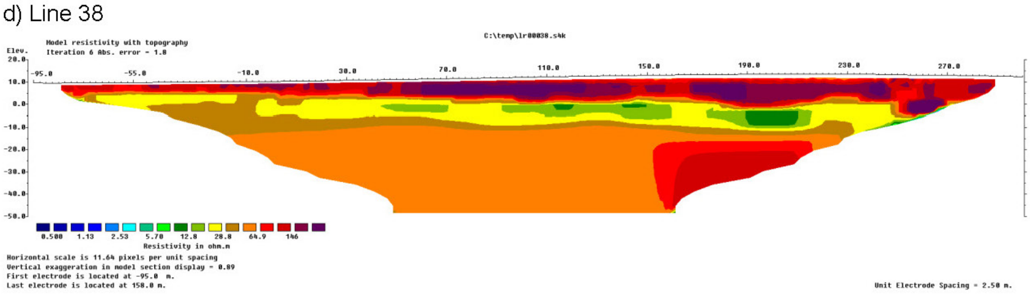
b) Line 36



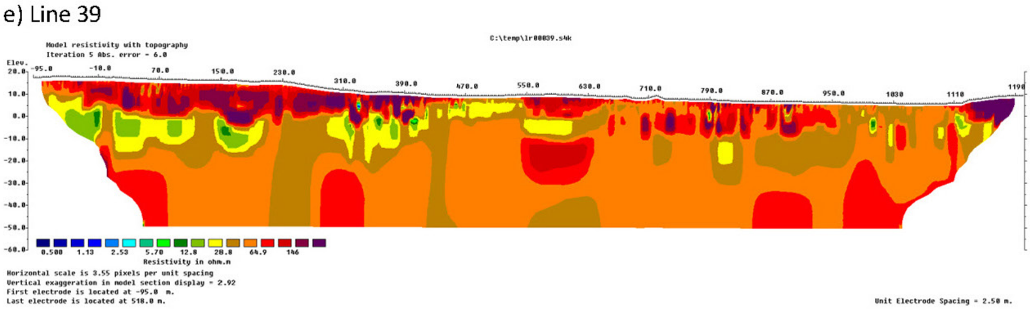
c) Line 37



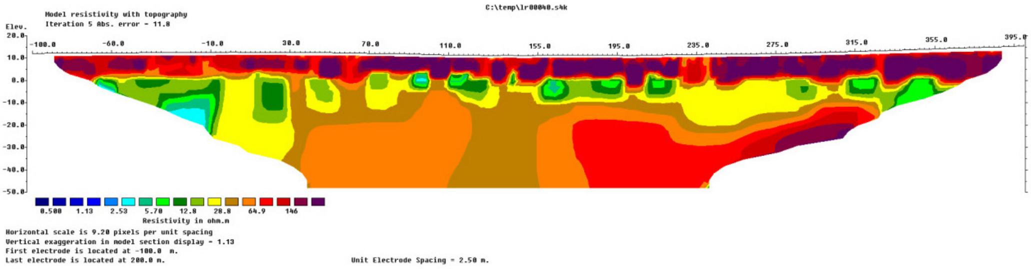
d) Line 38



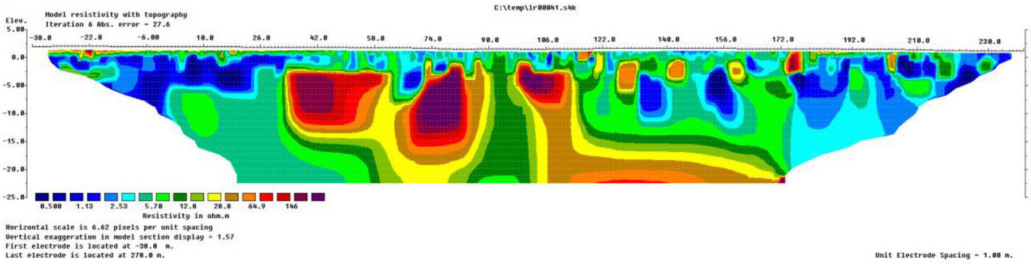
e) Line 39



f) Line 40



g) Line 41



h) Line 42

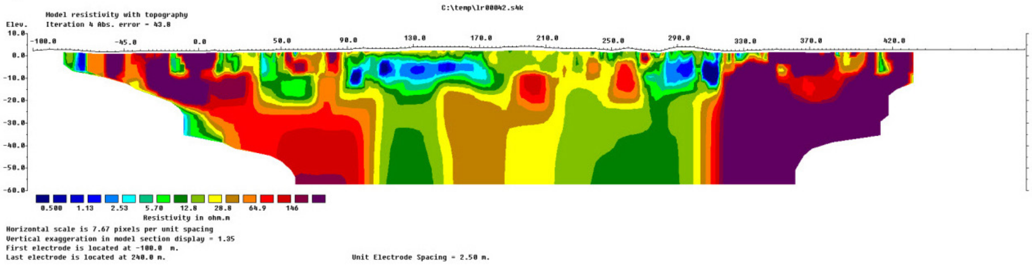


Figure A4.2 DC resistivity image sections for cliff and beach sections. Note both horizontal and vertical scales vary between images, however the resistivity scales are consistent.

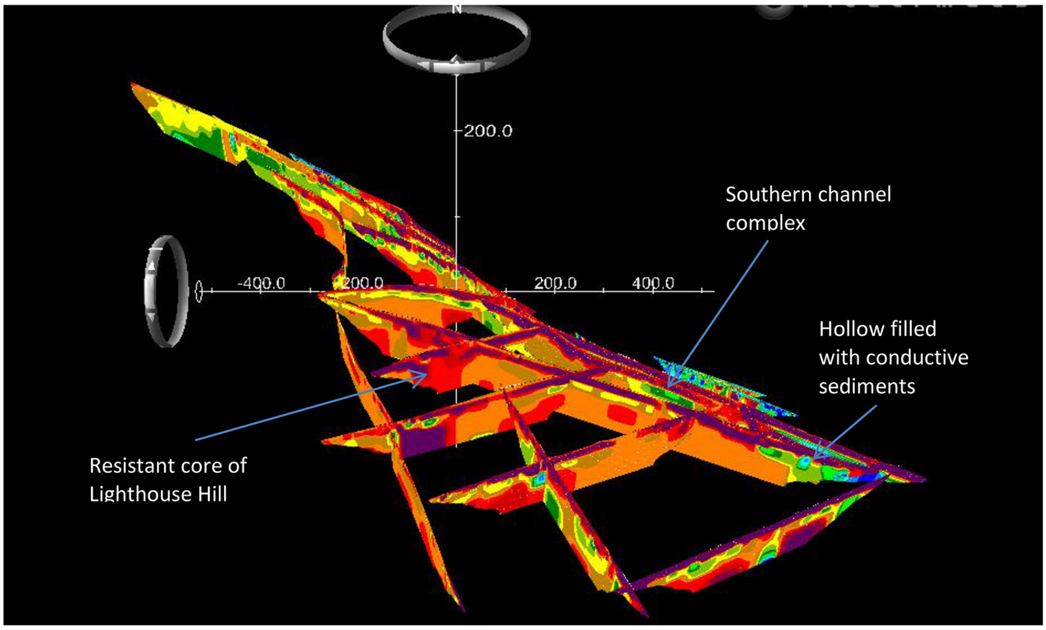


Figure A4.3 view of electrical resistivity lines.

Discussion

The results of the DC resistivity survey dovetail into the previous site surveys and prove the utility of this techniques for tracing channels and the complex stratigraphy at the Happisburgh site. In particular, transects indicate that in most cases three discrete groups of geo-electrical sediment packages can be defined corresponding to sediments with high resistivity (interpreted as sands and gravels), moderate resistivity (sands) and low resistivity (clays/silts). In addition, high resistivity is also associated with the chalk bedrock. Consequently we have been able to simplify the stratigraphy on each section into an interpolated stratigraphy consisting of the following recognised units:

1. Red: Till (Anglian/post Anglian) sediments that overlie the buried stratigraphy.

2. Green: Channels beneath the till that include that of the archaeologically important Happisburgh.

3. Yellow: Crag deposits into which the channels are cut.

4. Blue: Sands filling a channel cut into or contemporary with the till

5. Brown/Purple: Sediments associated with one of the channel infills.

This work demonstrates that:

a. channels can be mapped beneath both the beach and the till

b. channels (2-5m deep) are common at the site

c. channels can been seen in sections both close to the cliff and away from the cliff inland d) complex sequences can be seen in some channels (Figures A4.2g, A4.2h)

The sequences are interpreted in conjunction with previous resistivity data and electromagnetic data that are illustrated in Figures A4.4 to A4.7.

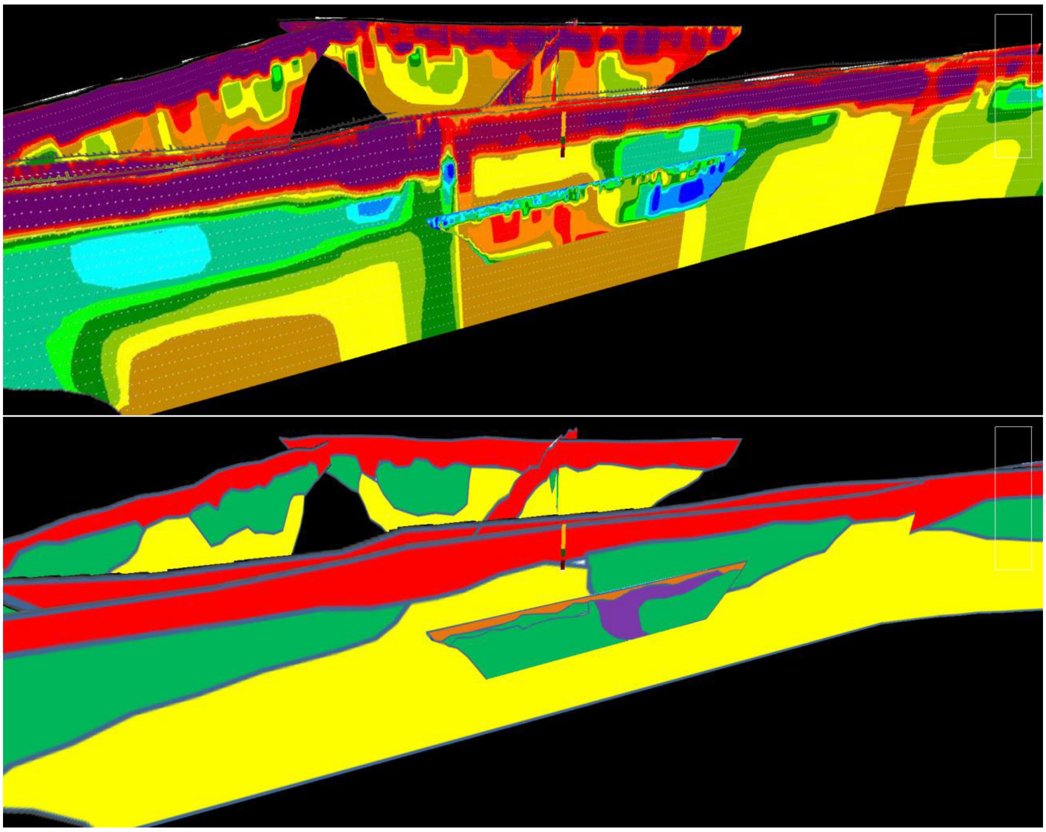


Figure A4.4 DC resistivity interpretations for lines in the southern section of site.

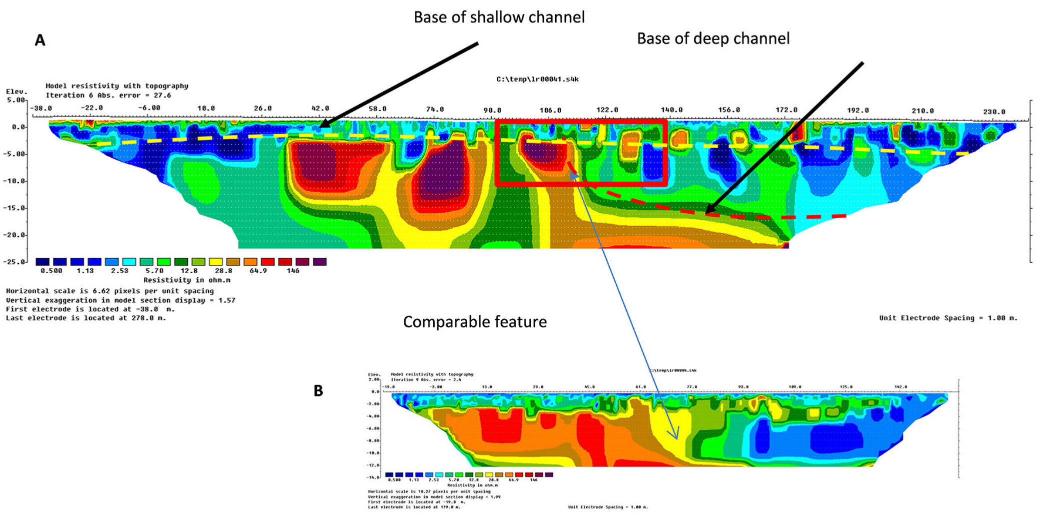


Figure A4.5 A: Line 41 (at 2m electrode spacings). B: Line 4 (previous study at 1m electrode spacings).

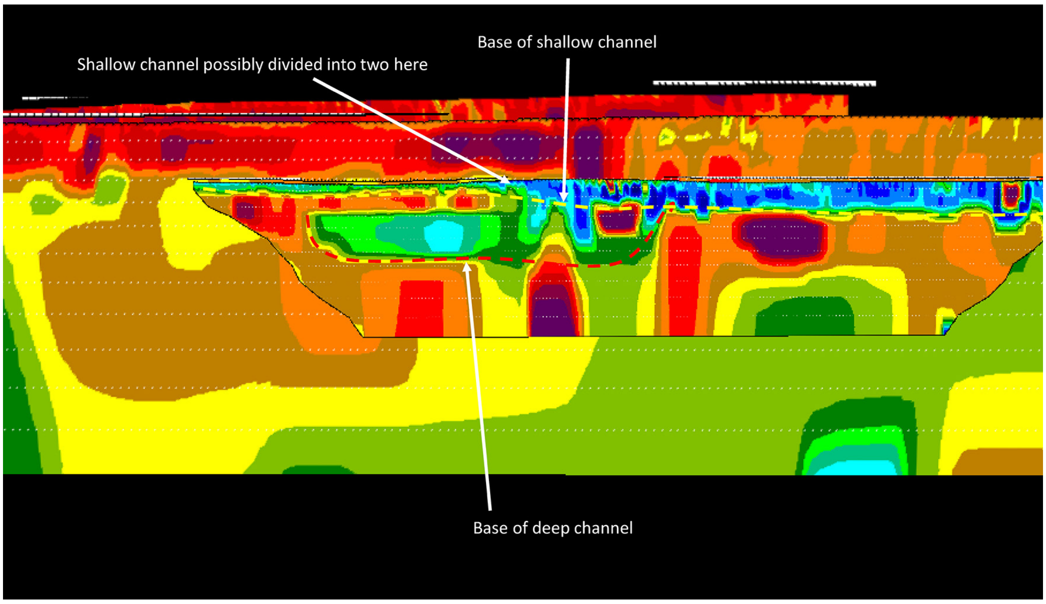


Figure A4.6 DC resistivity interpretations for northern section (at north end of footprint location).

This investigation has been able to visualise channel sequences preserved beneath the modern beach system. The geophysical survey results do however require careful consideration. The concept of the channel in geophysical terms differs from the concept of a channel from the excavated test pits and the boreholes. There is a tendancy in the geophysical survey to identify large scale and deeply buried channels (as seen in southern channel associated with line 41). Such large channels are typically in excess of 10m deep and cover significant spatial extent. By contrast channels interpreted from direct observation of lithologies in test pits and boreholes have been identifying channels of depths less than 5m and of more limited areal extent. Thus there is a mismatch between the two different approaches to site investigation.

What is clear from the detailed survey along line 41is that there appears to be a series of channels,in which larger, more deeply buried channels as mapped by the geophysics contain a series of nested channels within them. it is perhaps the latest of these nested channels that correlate with the channels under investigation containing the palaeoenvironmental and archaeological material.

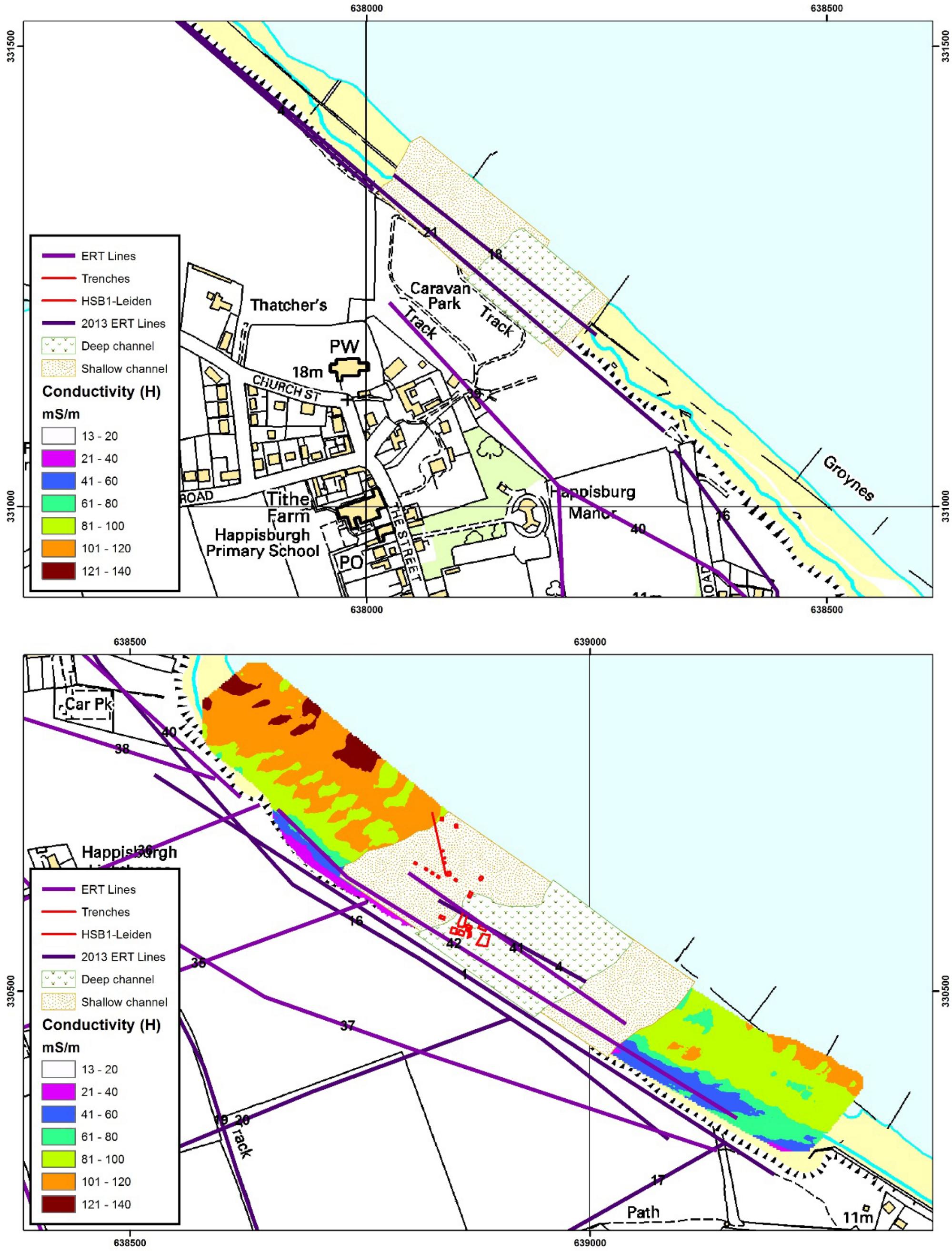


Figure A4.7 Location of channels based on DC resistivity sections and electromagnetic ground conductivity mapping for A,northern channel and B, southern channel. Based on Ordnance Survey (Digimap license).

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Bates, M R and Bates, C R 2000 Multi-disciplinary approaches to the geoarchaeological evaluation of deeply stratified sedimentary sequences: examples from Pleistocene and Holocene deposits in southern England, United Kingdom. *Journal of Archaeological Science* **27**, 845 - 858.

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