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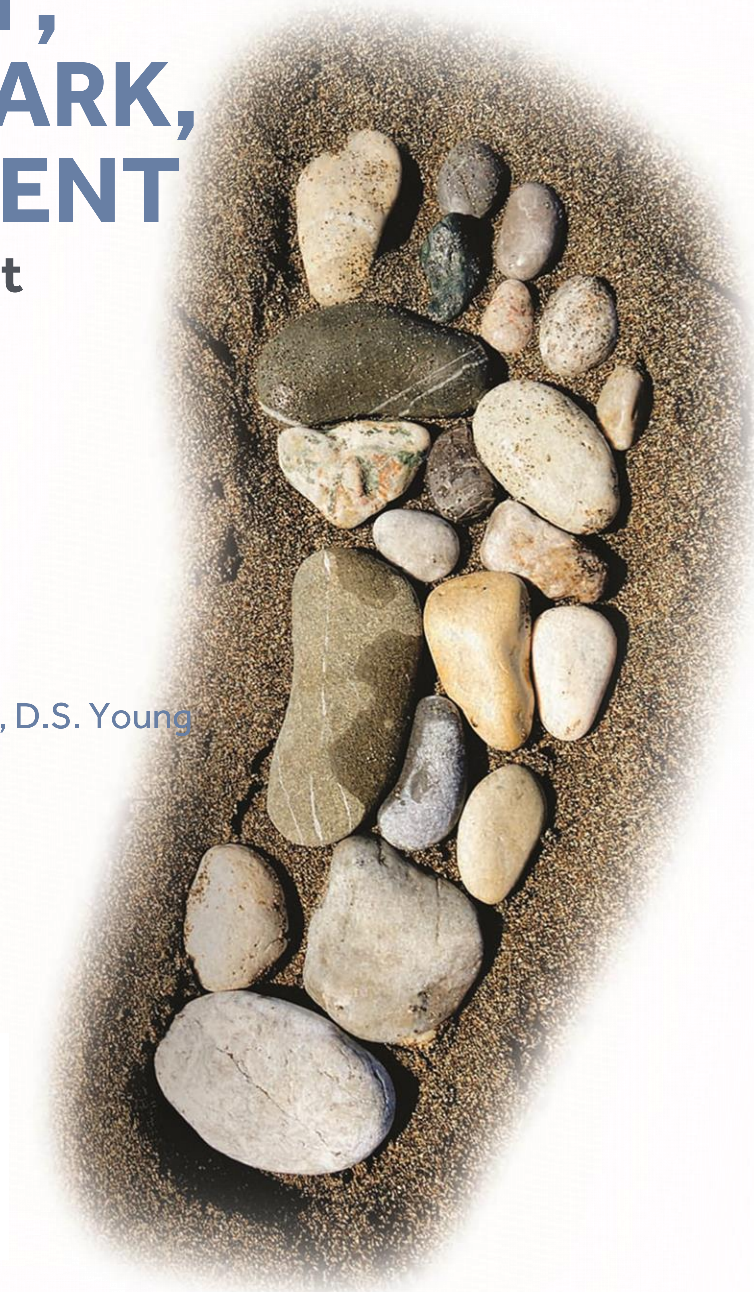
PROPOSED BIOMASS COMBINED HEAT AND POWER PLANT, DISCOVERY PARK, SANDWICH, KENT

Geoarchaeological Deposit Model Report



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1. NON-TECHNICAL SUMMARY

Following the results of previous archaeological and geoarchaeological desk-based assessments, a programme of geoarchaeological investigation was undertaken at the site of the Proposed Biomass Combined Heat and Power Plant in order to (1) recover sediment from Unit 3 (gravel and gravelly sand) for dating and the recovery of micro-fauna and flora; and (2) to explore the sequences of the fine-grained and potentially organic sediment of Unit 4 (fine-grained alluvium), in particular the deeper sequences underlying the western part of the site, with a view to radiocarbon dating. The results of the investigations confirm the broad stratigraphic scheme identified in earlier investigations of the Sandwich/Stonar/Ebbsfleet area. Within the Biomass site, well-bedded fine-grained alluvial sediments are present overlying the sloping flanks of a gravel (marine shingle) ridge representing part of the northward extent of the so-called Stonar Shingle or Stonar Bank. Sand sub-units within the gravel body are few in number and mainly thin, although undisturbed sediment was recovered from a thick (3.0m) body of sand in the lower part of borehole QBH1, along with fine-grained alluvium (Unit 4) overlying the gravel body in this borehole. The results of radiocarbon dating suggest that the middle-upper part of Unit 3 accumulated from no later than the late Bronze Age, and that open water was present in the Late Bronze Age/Early Iron Age on both the seaward and landward sides of the Stonar Bank with water depths of at least 6.0-9.0m and shingle movement at these depths actively shaping the shingle accumulation at that time. In addition, accumulation of the fine-grained alluvium on the landward side of the Stonar Bank commenced during the early medieval period. On the seaward side of the Stonar Bank intertidal marine conditions were still present during the late to post medieval period.

2. INTRODUCTION

2.1 Site context

This report summarises the findings arising out of the geoarchaeological investigations undertaken by Quaternary Scientific (University of Reading) in connection with the proposed development of land at the Proposed Biomass Combined Heat and Power Plant, Discovery Park, Sandwich, Kent (centred on NGR: TR 33467 59911; Figure 1). Quaternary Scientific were commissioned by CgMs Consulting to undertake the geoarchaeological investigations. The area of investigation is located on the west bank of the River Stour at a point known as 'Buzer's Belly'. The site lies immediately to the northeast and north of the Instro Discovery Park site, for which an Archaeological Impact Assessment (AIA; CgMs Consulting, 2015) and geoarchaeological desk-based assessment have been produced (Green, 2016a). The British Geological Survey (http://mapapps.bgs.ac.uk) shows the site is located in an area of complex geology: it is mapped as resting on bedrock deposits of the Thanet Formation (sands, silts and clays) deposited 56-59 million years ago, overlain by superficial Quaternary deposits of sands, silts and clays deposited over the course of the last 2.6 million years. In fact, the latter deposits are more likely to be of Holocene age (last 11,500 years). However, it is a few hundred meters to the north of an area mapped as bedrock Chalk (71-86 million years old), overlain by superficial Quaternary storm beach deposits of sands and gravels.

An Archaeological Desk-Based Assessment (DBA) has been prepared for the site (CgMs Consulting, 2013) which indicates that the stratigraphic sequence is more likely to comprise bedrock Chalk (19-20m bgl - below ground level), overlain by a 1.5-2m thick horizon of gravel/gravelly sands/sandy gravel (interpreted as storm beach deposits), and a generally fining upwards sequence of alluvial sands, silts and silty clays to a depth of 5m bgl. The sequence is capped by a late Medieval / post-Medieval ploughsoil, and approximately 1m of Made Ground. The conclusions of the Archaeological Impact Assessment were that the site has minimal archaeological significance and potential. During the prehistoric and Roman periods the site lay within an open seaway but during the medieval period was increasingly affected by the deposition of storm beach deposits and alluvial silts. No finds from the medieval period have been made within 500m of the site. The area was farmland in the late medieval and post-medieval periods but was extensively modified by 20th century land-use, including exploitation of the underlying gravel.

A recent geoarchaeological desk-based assessment (Green, 2016b) considered the topographical, geological and historical context of the site, integrating the findings from previous investigations at nearby sites such as Ramsgate Road, Astra Pyrotechnics, the Brown & Mason Yard, Pfizer sites and Sandwich Industrial Estate, and the results of a two month archaeological watching brief whilst ground floor slabs and foundations were removed. The Holocene sediments underlying the site were found to represent a record of deposition in the eastern arm of the Wantsum Channel, the open seaway that formerly separated the Isle of Thanet from the Kentish mainland. They also include elements of the Stonar Bank, a shingle accumulation of uncertain origin and age. The borehole records from within the Biomass site indicated the presence of a ridge of sand and gravel in a position somewhat to the east of the supposed alignment of the so-called Stonar Shingle and rising to a level of about 2.0m OD. These records demonstrate the presence of shingle at the ground surface much further north than previously indicated in the findings of Robinson & Cloet (1953). This ridge represents the local surface expression of a thick and extensive body of gravel and gravelly sand (Unit 3) that rests directly on the bedrock Thanet Sand, at levels between -10m and -15m OD. This sediment body can be traced both eastward and westward to and beyond the eastern and western limits of the site. This accumulation appears to represent continuity of depositional conditions on this southern margin of the Wantsum Channel for much of the Holocene, and tends to confirm the development there of a broad sand and shingle spit or bar (the Stonar Shingle) across the mouth of the Channel. Within the present site, the only indication of organic remains in this massive accumulation of sand and shingle is in the description of some of the sediment as 'shelly'. This probably reflects the presence of a mollusc fauna similar to the fauna described by Pratt *et al* (2000) from gravelly sand recovered from boreholes to the west of Ramsgate Road. In this detailed laboratory examination of the sediment, scattered and fragmentary woody and herbaceous remains were also recorded.

The seaward and landward slopes of the sand and shingle ridge underlying the present site are overlain by fine-grained sediments (Unit 4) which lap up onto the ridge and are almost certainly the estuarine alluvium of the River Stour and therefore represent the final stages in the infilling of the Wantsum Channel. Organic horizons and relic soils are recorded within these fine-grained sediments and it seems likely that the radiocarbon dates (2130-1880 BC) obtained by Spurr (2005, 2006) came from material preserved within sediment equivalent to Unit 4 of the present investigation.

In summary, the site is underlain by sediments that form part of the infill of the depression formerly occupied by the Wantsum Channel. In their lower part these sediments are probably entirely marine in origin comprising more or less gravelly and sometimes shelly sands which represent the remains of a broad sand and shingle spit or bar. Overlying this feature, finer-grained silts and clays are present reflecting the gradual silting-up of the Wantsum Channel. The bulk of the infill of the Wantsum Channel is mineral sediment of marine or peri-marine origin in which visible organic remains, apart from the shells of marine and estuarine Mollusca, are limited to scattered wood and herbaceous plant fragments. The potential for the survival of organic remains is greater in the overlying estuarine alluvium of the River Stour.

2.2 Palaeoenvironmental and archaeological significance

The stratigraphic sequence beneath the site was considered within the DBA (Green, 2016b) to have high significance and potential in various ways:

1. Variations in the nature of the deposits recorded represent different environmental conditions that existed from time to time both at or near the site of record and regionally. For example: (1) the sands / gravels may represent storm beach deposits; (2) the deposits of sands/silts/clays represent periods of varying hydrological conditions, and (3) the presence of soils or peat (if present) represent former terrestrial or semi-terrestrial land-surfaces, By studying the sub-surface stratigraphy across the site in greater detail, it will be possible to build a greater understanding of the former landscapes and environmental changes that took place over space and time.

2. Mineral-rich marine sediments have the potential to provide material for Optically Stimulated Luminescence (OSL) dating and may include remains of Mollusca suitable for radiocarbon dating, together with diatoms and Foraminifera which can provide information about the depositional environments represented in the sediment sequence and the history of relative sea level change.

3. Organic-rich sediments and relic soils have high potential to provide a detailed reconstruction and dating of prehistoric/historic environments on both wetland and dryland. In particular, they would contain the potential to increase knowledge and understanding of the interactions between hydrological change, human activity, vegetation succession and climate in this area of the Stour Floodplain. Investigations of such sediments is carried out through the assessment/analysis of palaeoecological remains (e.g. pollen, plant macrofossils & insects) and by radiocarbon dating. If organic remains are present they may provide information about the environment of deposition of the shingle/sand system; and may provide material suitable for dating the horizons in which they occur.

4. Areas of high gravel topography, soils and peat represent potential areas that might have been utilised or even occupied by prehistoric people, evidence of which may be preserved in the archaeological (e.g. features and structure) and palaeoenvironmental record (e.g. changes in vegetation composition).

2.3 Aims and objectives

The DBA for the site (Green, 2016b) concluded that there was an important opportunity to undertake geoarchaeological investigation of the Wantsum Channel and the so-called Stonar Shingle, to obtain a fuller understanding of their sedimentary history and possible significance in terms of historic patterns of navigation and trade. Of particular interest was the possibility of dating the development of the Stonar Shingle, and dating the associated stages in the infilling of the Wantsum Channel. It was recommended that a total of four boreholes were put down, forming a west-east transect across the site.

The aim of the investigations were therefore (1) to recover sediment from Unit 3 (gravel and gravelly sand) for Optically Stimulated Luminescence (OSL) dating and/or radiocarbon dating of molluscan shell and for the recovery of micro-fauna and flora; and (2) to explore the sequences of the fine-grained and potentially organic sediment of Unit 4 (fine-grained alluvium), in particular the deeper sequences underlying the western part of the site, with a view to dating and palaeoenvironmental investigation.

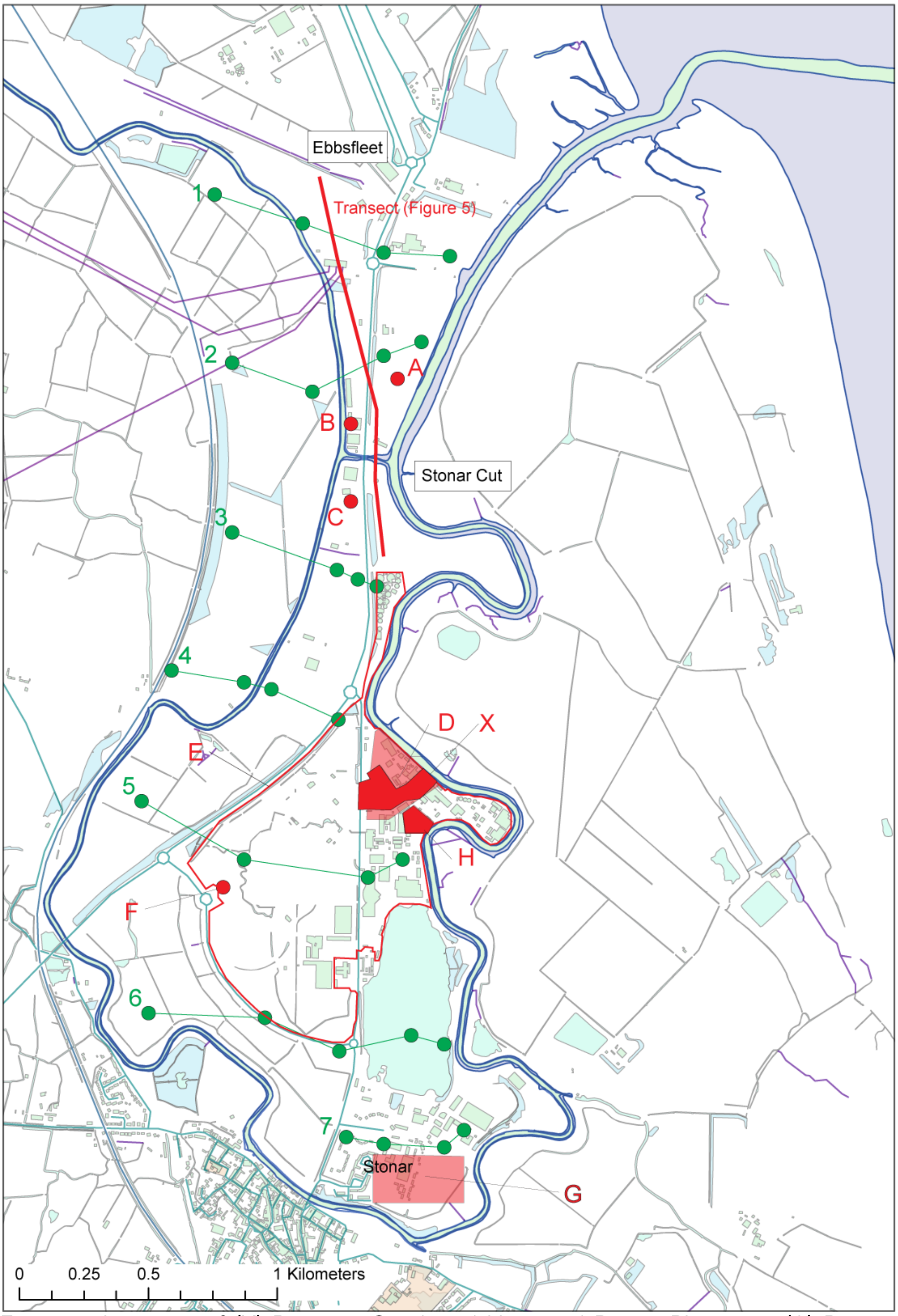

Figure 1: Location of (X) Biomass Combined Heat and Power Plant site; (A) Ramsgate Road, Richborough and location of borehole transect illustrated in Figure 5 (Green *et al*., 2012); (B) Astra Pyrotechnics (Mills, 1994); (C) Brown & Mason Yard (Spurr, 2005, 2006); (D) Pfizer 1953 site; (E) Discovery Park (CgMs Consulting, 2013); (F) Pfizer Sandwich Campus (Pratt *et al.,* 2000); (G) Sandwich Industrial Estate (Bates & Pine 1994); (H) Instro Discovery Park (Green, 2016); (1) to (7) Borehole transect locations from Robinson & Cloet (1953) (reproduced and modified from CgMs Consulting 2013) © *Crown copyright and database right [2016]*.

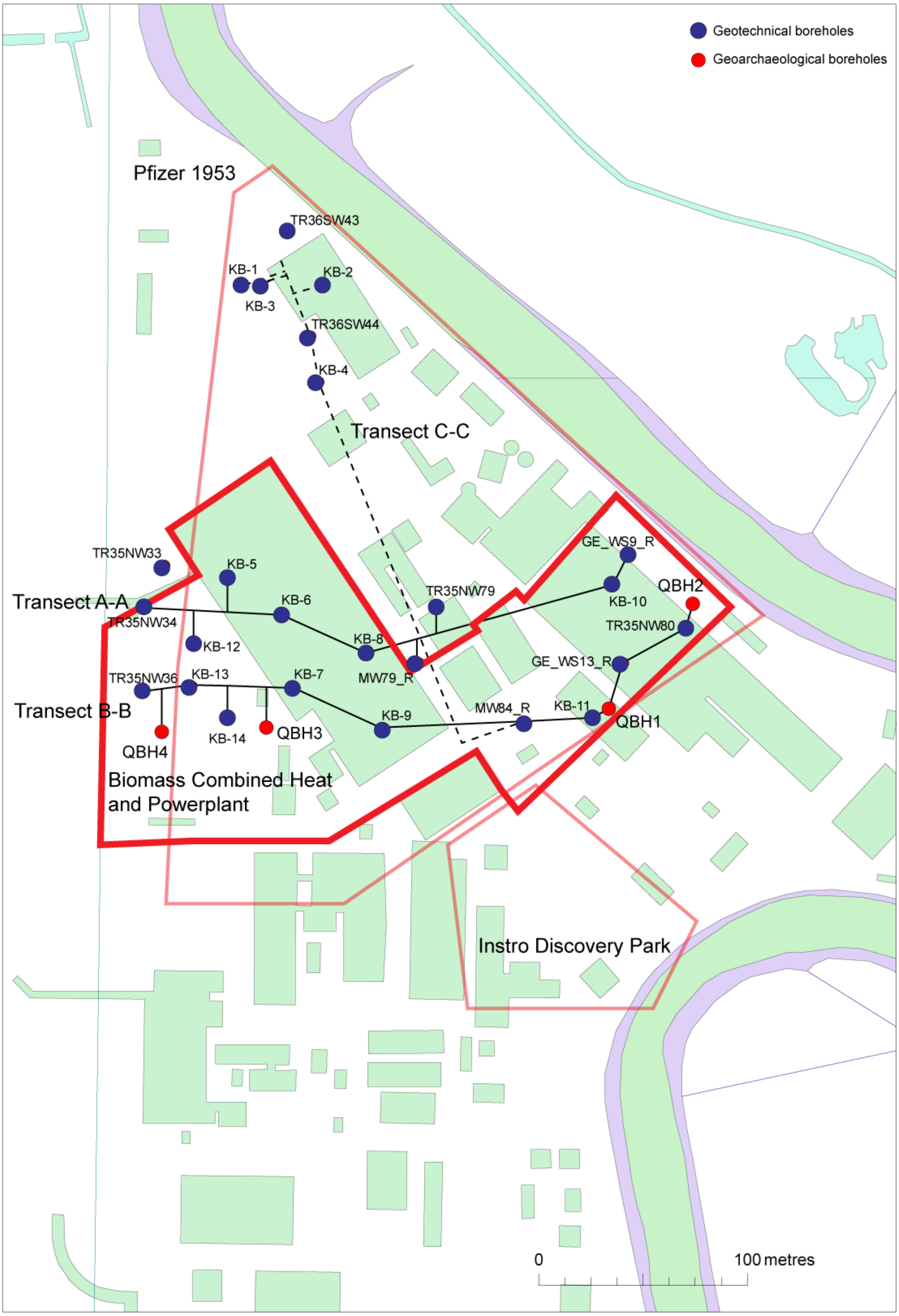

Figure 2: Existing boreholes put down within the confines of Biomass Combined Heat and Power Plant. Illustrating the position of Transects A-A, B-B and C-C (Figures 6-8). Location of the new geoarchaeological boreholes (QBH1 to QBH4) also shown.

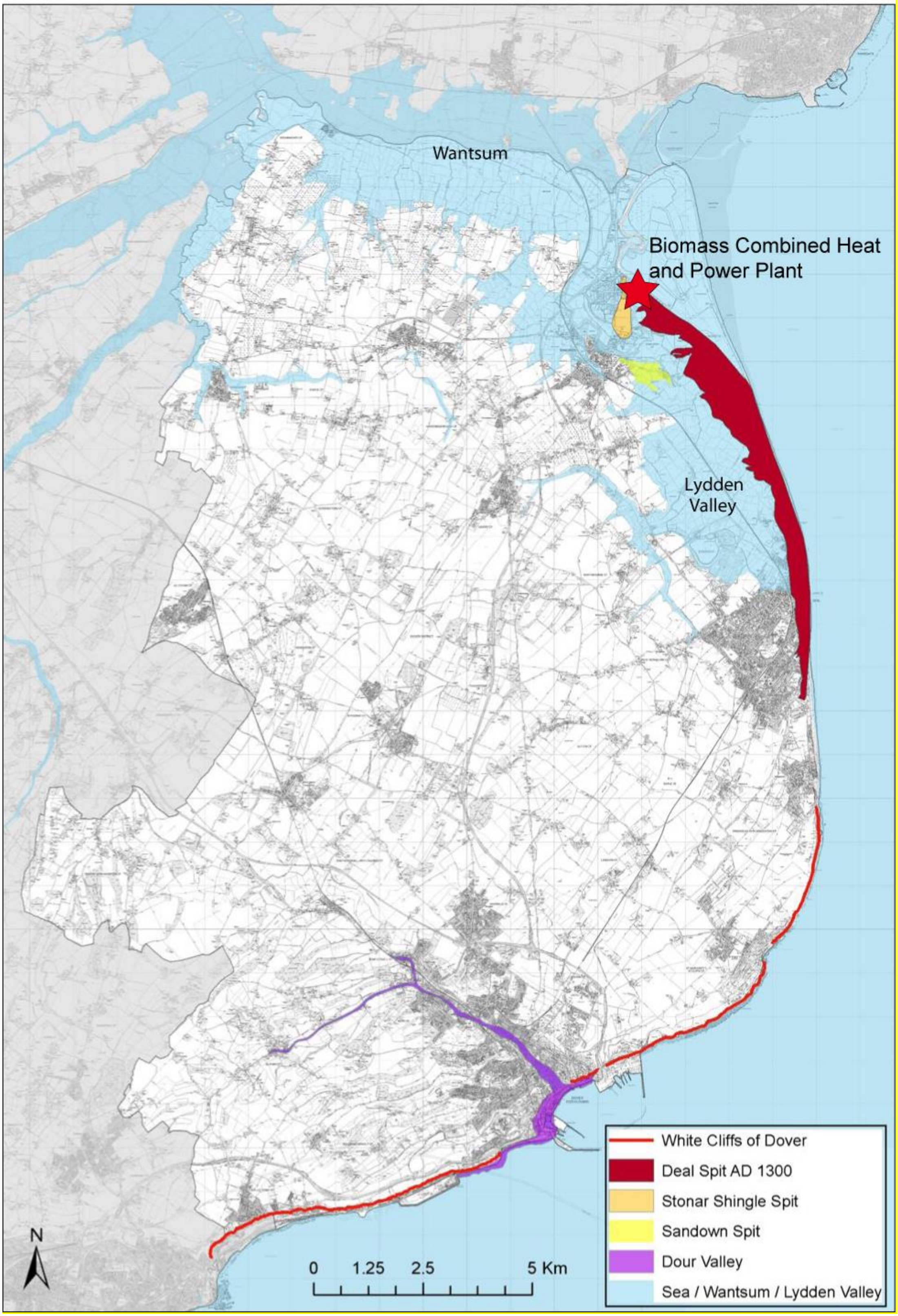

Figure 3: Map from Dover District Heritage Strategy showing presumed extent of Wantsum Channel, generalised position of Stonar Shingle and location of the Biomass Combined Heat and Power Plant site (reproduced from: Dover District Heritage Strategy, Appendix 1, Theme 1, Coastal Processes and Landscapes 2013, Figure 1)

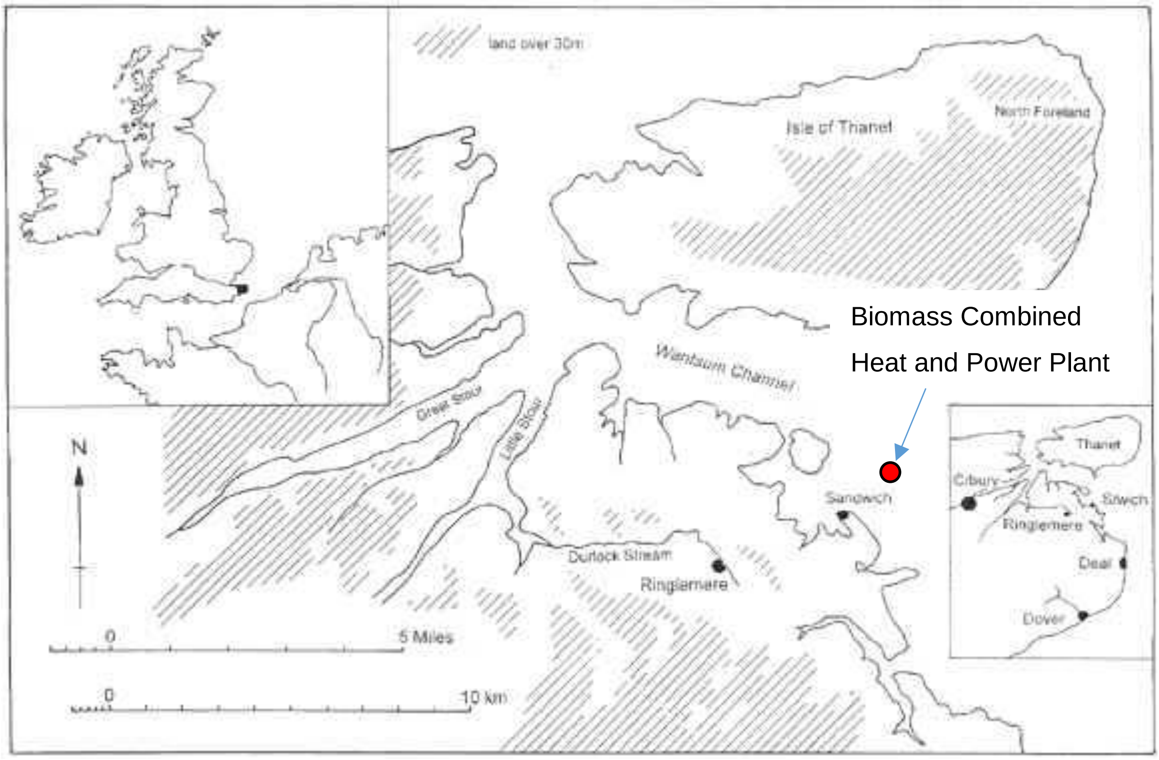

Figure 4: The Wantsum Channel, showing position of Biomass Combined Heat and Power Plant site (red dot) (reproduced from Parfitt & Needham, 2007)

3. TOPOGRAPHIC SETTING

The site lies on the estuarine floodplain of the Kentish River Stour (Figures 1 & 2) on the left (west) bank of the river, which here follows a meandering course flowing northward from the town of Sandwich to the mouth of the river where it enters the sea in Pegwell Bay near Ebbsfleet. The site is irregular in outline, bounded on the west by Ramsgate Road (formerly A256), and in the east, towards the southern end of the site, at its widest point, reaching the waterfront of the River Stour. Recorded ground levels within the site range from 2.13m to 4.22m OD (mean: 3.34, n=25) with lower levels recorded adjacent to Ramsgate Road and higher levels near the River Stour. However these levels have been affected by intensive industrial and military land-use since the beginning of the 20th century and Made Ground is recorded in all the boreholes and test pits within the site, varying in thickness from less than 1.0m up to nearly 3.0m. If the base of the Made Ground is regarded as equivalent to the pre-industrial land surface, the mean level is 1.66m OD (n=20).

The course of the River Stour and the form of its estuarine reach in the vicinity of the site (Figure 1) have been significantly shaped by the interaction of the river with marine beach development and coastal landforms in the mouth of the estuary. The Stour flows from the west to a point near Ebbsfleet, about 2.5km north of the site, where it is little more than a kilometre from its mouth in Pegwell Bay. From there it flows south for a distance of about 4.5km to the town of Sandwich where it loops northward for about 4.5km to reach its mouth in Pegwell Bay near Ebbsfleet. About 1.25km to the north of the present site, an artificial channel, the Stonar Cut links the south flowing and north flowing limbs of this great southward loop of the river Stour at the point where they are closest together, separated by a distance of about 150m.

The narrow, elongated area enclosed within the great southward loop of the River Stour and including the present site of investigation, marks the position of a depositional feature often called the Stonar Shingle or Stonar Bank (Hardman & Stebbing 1940). However, in previous investigations (Robinson & Cloet 1953) substantial amounts of shingle at the ground surface were identified only at the southern end of this area, near Sandwich, where the ground rises to about 5.0m OD. Further north Robinson & Cloet (1953, Figure 1) recorded the supposed position of the Shingle as a slight rise in the ground surface, defined in their mapping of the locality by an 8 foot (2.44m) contour. Historical and geological evidence suggested to Hardman & Stebbing (1940, 1941) that the Stonar Shingle developed as a shingle spit extending southward from the Isle of Thanet into the open water, known as the Wantsum Channel, that formerly separated the Isle of Thanet from mainland Kent. There is however debate regarding the direction from which the spit grew. Bates & Pine (1994) for example, suggest that it grew from the south. There is also uncertainty about the period during which this shingle feature developed.

To the west of this great southward loop of the river, the Stour flows from west to east in an area of low ground that extends from the Isle of Thanet in the north to the high ground of mainland Kent in the south. This area of low ground is the silted-up eastern arm of the Wantsum Channel (Figures 3 & 4). This seaway opened both northward into the lower estuary of the Thames and eastward into Sandwich Bay. The width and depth of this channel and the form of its opening into Sandwich Bay have long been matters of debate (Dowker 1897, Moody 2008) (see below).

To the east of the great southward loop of the River Stour and the lowest reach of the river where it flows northward from Sandwich, there is an area of coastal sand dunes which have been formed by the northward growth of a sand and shingle spit from the vicinity of Deal. Between the present coast and the river, recurves representing successive stages in the development of this spit are clearly visible in satellite imagery. No attempts to date the stages in the development of this spit have been identified during the present investigation.

4. GEOLOGICAL CONTEXT

The bedrock beneath the Biomass site and underlying much of the former Wantsum Channel is the early Tertiary Thanet Sand Formation. Overlying the Thanet Sand and representing sedimentation within the former Wantsum Channel is a thick sequence of mainly estuarine and peri-marine Holocene deposits. The commercial potential and stratigraphy of these deposits was first explored in boreholes put down by Dorman Long & Pearson (DL&P) in 1926/27 during an investigation of aggregate resources extending across the Stonar Shingle from Ebbsfleet in the north to Sandwich in the south (Figure 1). The borehole logs arising from these investigations were used by Robinson & Cloet (1953) to reconstruct the stratigraphy of the deposits underlying the ground within and immediately to the west of the great southward loop of the River Stour between Ebbsfleet and Sandwich.

The boreholes examined by Robinson & Cloet (1953; Figure 1) record shingle at the surface only beneath the highest ground within the loop of the Stour at its southern end (see Transect 6 in their Figure 2). Further north in their Transects 5 and 4, they recorded shingle only at depths at or below 40 feet (12.19m). To the north of these transects, no shingle was recorded, with boreholes recording finer grained deposits resting directly on 'compact fissile clay', presumed to be Thanet Sand Formation sediments.

The broad pattern of sedimentation recorded by Robinson & Cloet (1953) indicated the presence of a degraded sand and shingle spit represented by shingle at the ground surface in the south (Transect 6), passing northward to sand just reaching the ground surface in their Transect 5, apparently in the form of a substantial sand bar overlying shingle at depth. A sand bar may also be recognisable in degraded form in Transect 4 about 20 feet (6.09m) below the ground surface, again overlying shingle at depth. Beds of sand are present further north in Transects 3, 2 and 1, but no bar-like form is recognisable. The present site of investigation lies close to the eastern end of Transect 4.

With regard to the fine-grained deposits that are recorded in the DL&P boreholes and illustrated by Robinson & Cloet (1953), there is in general a fining-upward pattern, with sand overlain by 'silt', overlain in turn by 'clay'. There is however considerable variation in the sequences recorded to the north of Transect 4, with substantial beds of 'clay' recorded in the assumed position of the Stonar Shingle and nearby.

More recent investigations have largely confirmed the earlier findings and have extended the understanding of this eastern part of the Wantsum Channel. Investigation of a site immediately to the south of the Stonar Cut (Spurr, 2005, 2006; Figure 1) proved a rather consistent sequence of Holocene sediments overlying the Thanet Sand Formation. At the base of the sequence, generally between -12.0m and -9.5m OD sands were present representing sedimentation on a marine beach. These beach deposits were overlain by sandy silts and clays passing up to silty clays and representing a progressive transformation from estuarine mud and sand flats to low salt marsh. From the upper part of this sequence a radiocarbon date of 2130-1880 BC was obtained. The uppermost natural sediments were organic clays representative of mid to high salt marsh. Similar sediments were recorded in a borehole put down in a previous investigation of the area immediately to the north of the Stonar Cut (Mills, 1994). Further to the south and east, sediments recorded in boreholes put down at a Pfizer site on the west side of the Ramsgate Road and south-west of the present site of investigation (Pratt *et al* 2000) consisted almost entirely of marine sands, gravelly in places and containing a mollusc fauna indicative of a sub-littoral habitat with a few species more commonly found in deeper water off-shore. The sediments recovered from these boreholes also contained at various levels throughout the sequences infrequent fragmentary plant remains including small pieces of wood. These sediments probably accumulated in shallow open water near the southern shore of the Wantsum Channel.

Investigations to establish the context of a site (the Ramsgate Road site) to the north of the Stonar Cut (NGR: TR 3335 6150) (Green *et al.* 2012; Figure 1) showed the Thanet Sand Formation at a level of about -4m OD in the Ebbsfleet area, falling southward to about -6.5m to -8.0m OD at the Ramsgate Road site itself, and further to a level of -12.0m OD just south of the Stonar Cut (Figure 5). From this point the surface rose southward. This profile resembles the northern part of the transect illustrated by Spurr (2006 Figure 4), and can be interpreted as showing the north side of the bedrock depression underlying the Wantsum Channel, with its northern edge underlying Ebbsfleet. The profile showed that south of Ebbsfleet, i.e. within the Wantsum Channel, the bedrock surface is uneven, with a relief amplitude of *ca*. 4.0m. The transect also shows a well-marked contrast between the sediments overlying bedrock at and north of Ebbsfleet and those further south occupying the Wantsum Channel.

North of Ebbsfleet, the Thanet Sands Formation is overlain directly by peat, rather consistently *ca*. 5.0m in thickness, between -5.0m and +1.0m OD. The peat is overlain by silty clays which are probably alluvial floodplain deposits of the river Stour. To the south, and within the Wantsum Channel, the bulk of the sediment is also silty clay, but probably largely estuarine in origin. Detailed laboratory examination of three borehole sequences from within the Ramsgate Road site confirmed the sequences recorded in earlier boreholes, with a sandy component in the silts and silty clays in the lower part of the sequences and silty clays in the upper part. Mollusc shell was also present and remains of the intertidal bivalve species *Scrobicularia plana* were recognised at levels between 0.28m and -0.46m OD.

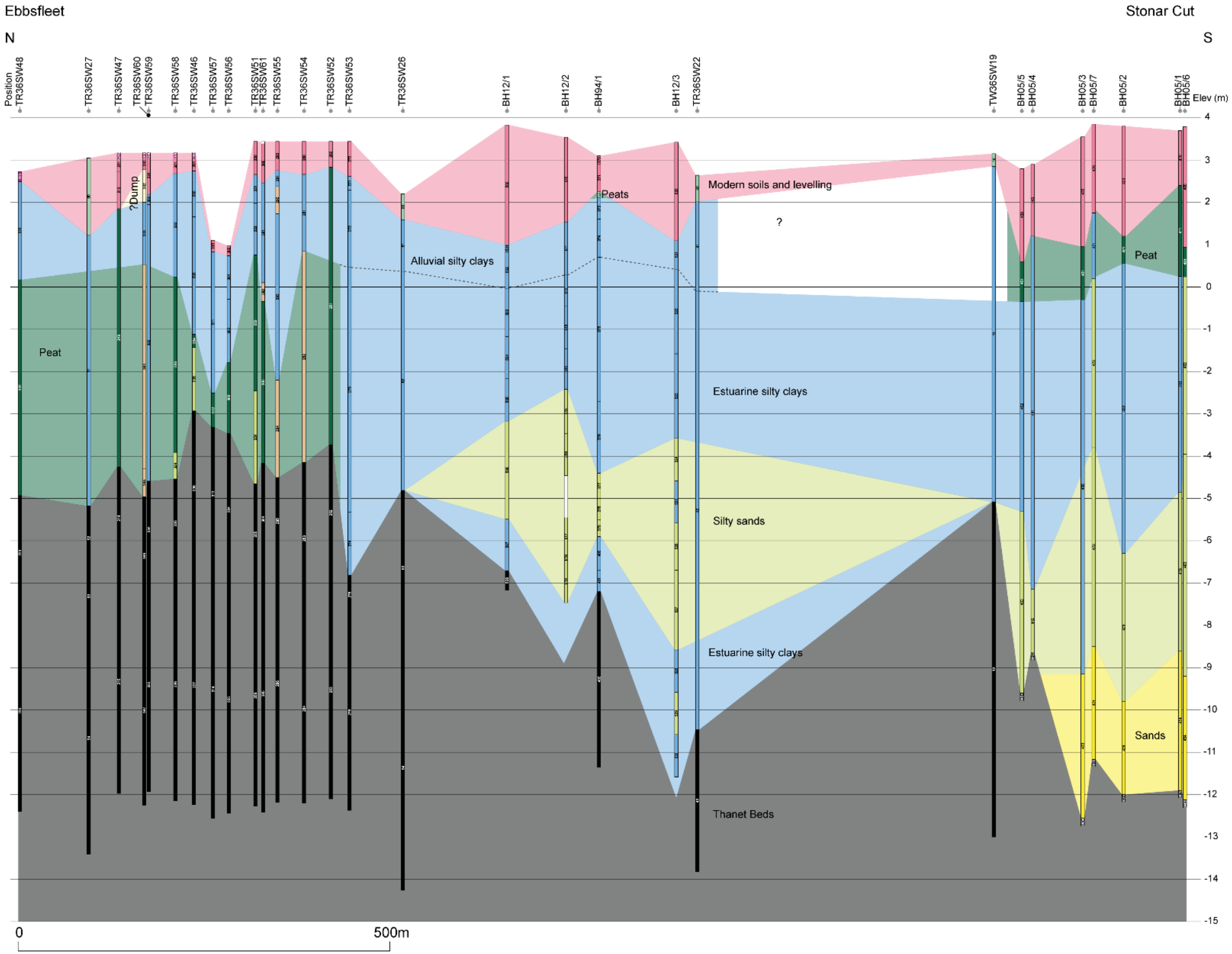

Figure 5: North-South borehole transect of boreholes from Ramsgate Road, Richborough (Green *et al.*, 2011), Sandwich Campus (Pratt *et al.*, 2000), Brown and Mason Yard (Spurr, 2005; 2006), Astra Pyrotechnics factory (Mills, 1994) and BGS boreholes available online (http://www.bgs.ac.uk/data/boreholescans/) (reproduced from Green *et al.*, 2011).

5. HISTORICAL BACKGROUND

The Wantsum Channel was an important seaway in Roman times as indicated by the presence of Roman forts close to both the northern end at Reculver (Regulbium) and the eastern end at Richborough (Rutupiae). In Saxon and early medieval times the higher level (5.0m OD) shingle outcrop to the south of the present site of investigation was occupied by the town of Stonar, first mentioned in documentary records in 1087, but thought to have been already in existence in the 8th century. This town was severely damaged by storms in the winter of 1365/6 and was later sacked and burned by the French in 1385, after which it went into rapid decline. No above-ground remains of the medieval settlement survive. There is some debate, summarised by Moody (2008), about whether the Wantsum Channel reached Sandwich Bay through one or two openings, with the possibility that there was a northern channel between Ebbsfleet and Stonar and a narrower southern channel passing to the south of the shingle accumulation at Stonar. The growth of the port of Sandwich adjacent to the putative southern channel and the location of the Roman fort at Richborough suggest that throughout the Roman and later historic period the principal opening lay in the south. If this interpretation is correct, the present site of investigation would have been near the southern edge of the broad northern channel.

Spurr (2006 Fig.5) suggests a possible sequence of landscape evolution at the eastern end of the Wantsum Channel for the period from pre-6000BC (Mesolithic) to the Middle Ages. He shows progressive encroachment of salt marsh from both north and south into the Wantsum Channel from the Neolithic onward, leading in his opinion to closure of the seaway between Thanet and mainland Kent by Saxon times, and development of the present course of the Stour before the end of the medieval period. Other reviews of the historical evidence (e.g. Moody (2008) suggest that closure of the seaway occurred rather later in the Middle Ages. The seaway was evidently silting up by the 11th century when the earliest schemes of reclamation are recorded and by the mid-16th century the whole of the former seaway appears to have been reclaimed (Figure 6), forming in its eastern arm, Minster Marshes and the Ash Levels. Between the 16th and the 18th centuries various engineering attempts were made to sustain the port of Sandwich, all of them eventually ineffectual.

The present site of investigation remained in agricultural use as reclaimed marshland until late in the 19th century when the impact of local industrialisation began to affect the site. At this time the ground level was raised within the site and light railway tracks were laid. Industrial land-use increased rapidly during the First World War in association with the development of the nearby port of Richborough which handled large volumes of military traffic destined for the western front. Within the site these developments led to the construction of warehouses and other industrial and commercial premises and additional railway sidings. Attempts to sustain the port of Richborough as a commercial enterprise in the years immediately following the First World War were largely unsuccessful but during the 1920s and 1930s further industrial premises were constructed and railway sidings associated with the extraction of sand and gravel from the deep quarry immediately to the south of the present site. Commercial premises (mainly the pharmaceutical firm Pfizer) continued to occupy large parts of the site throughout the rest of the 20th century.

Figure 6: Cotton's Map of 1548 (reproduced from CgMs Consulting, 2013)

6. METHODS

6.1 Field investigations

Four geoarchaeological boreholes were put down in early October 2016, monitored by Quest with a view to (1) obtaining continuous cores, down to bedrock, for detailed examination and recording in the laboratory, and (2) to recover material suitable for analysis of contained flora and fauna (forams, ostracods, etc.), and for dating using Optically Stimulated Luminescence (OSL) to date the sediment itself and/or radiocarbon assay to date contained organic material. The borehole locations (see Figure 2) were determined with reference to existing archive borehole records and their interpretation as set out above. The boreholes were located to sample both the gravel and gravelly sand of Unit 3 of the present account (see above) and the fine-grained sediments of the overlying Unit 4. Two of the geoarchaeological boreholes were put down to the east of the gravel ridge recorded in boreholes KB-8 and TR35NW79 in transect A-A and boreholes KB-9, MW79-R and MW84-R in transect B-B. The geoarchaeological boreholes QBH1 and QBH2 were put down close to the locations of, respectively, borehole KB-11 and borehole TR35NW80. Proximity to these boreholes was chosen because in both of them evidence of a palaeosol was recorded in the upper part of the fine-grained sediments of Unit 4. In addition, in borehole KB-11 an organic horizon was recorded in the gravel and gravelly sand of Unit 3 – the only record of an organic sub-unit in Unit 3 in any of the archive boreholes examined within or close to the Biomass site. The other two geoarchaeological boreholes (QBH3, QBH4) were put down to the west of the gravel ridge where the greatest thicknesses of Holocene sediment have been recorded.

6.2 Sampling methodology

The boreholes were put down by a geotechnical drilling team using a rotary sonic rig, with a geoarchaeologist in attendance. Samples were recovered in 1.5m lengths of 100mm transparent plastic lining tube. It was recognised prior to drilling that it might be difficult to recover undisturbed cores of the gravel and gravelly sand known to form the bulk of the sediment sequences of interest, using standard geoarchaeological drilling techniques (e.g. window sampling or cable percussion techniques). The rotary sonic rig was therefore proposed as a viable method for the collection of the samples, following discussions between the archaeological consultant, geotechnical engineers and Quaternary Scientific. In selected samples recovery was poor, specifically in at least nine of the 29 1.5m cores. These cores were mainly in the lower part of boreholes QBH2, QBH3 and QBH4. There was incomplete recovery in QBH4 9.0-10.5m bgs and 12.0-13.5 bgs which consisted of small amounts of sand obviously no longer in situ, and in QBH2 6.0-7.5m bgs, QBH3 9.0-10.5m bgs and QBH4 7.5-9.0m bgs where the sediment was free to move up and down in the tube as the core was handled. In QBH3 12.0-15.0m bgs and QBH2 9.0-12.0m bgs sediment arising from 3.0m of drilling was recovered in single 1.5m cores; and in QBH3 10.5-12.0m bgs and QBH4 13.5-15.0m bgs the sandy matrix of the gravel was redistributed in the core as a result of the flushing effect of large water volumes associated with the extraction method. There was minor evidence of water flow in some other cores, but insufficient to alter the structure or fabric of the sediment.

6.3 Lithostratigraphic descriptions

The lithostratigraphy of the core samples was described in the laboratory using standard procedures for recording unconsolidated sediment and organic sediments, noting the physical properties (colour), composition (gravel, sand, clay, silt and organic matter) and inclusions (e.g. artefacts). The procedure involved: (1) cleaning the sample using a scalpel; (2) recording the physical properties, most notably colour using a Munsell Soil Colour Chart; (3) recording the composition; e.g. gravel, fine sand, silt and clay; (4) recording the degree of peat humification; (5) sieving (0.25mm, 0.125mm) of sub-samples (10-20g) of organic fine-grained sediment to record microscopic flora and fauna (foraminifera, ostracoda, etc.) and (6) recording the unit boundaries e.g. sharp or diffuse. The results of the geoarchaeological descriptions of the boreholes are displayed in Tables 1 to 29.

6.4 Chronology

As outlined above, not all samples displayed evidence of disturbance. It was possible therefore to select from secure horizons within QBH1 and QBH4 marine Mollusca and plant remains for radiocarbon dating. Whilst these remains may be derived rather than *in situ*, they should provide a maximum age for the deposition of each major stratigraphic unit. Furthermore, the results will provide an initial set of dates for infilling sediments of the Wantsum Channel against which new and existing sequences can be tested.

Marine Mollusca (*Neptunea antiqua* & *Buccinum undatum*) were extracted from between -8.25 and -9.00m OD in QBH4 and *Scrobicularia plana* at -0.91m OD in QBH1 during lithostratigraphic description. In addition, three 750ml samples were processed from between -2.70 and 3.00m OD in QBH4 for the recovery of suitable dating material. Ostracoda and foraminifera were recorded, but not in sufficient concentrations for radiocarbon dating. Whilst not ideal for radiocarbon dating, unidentified marine bivalve fragments were selected instead. The chosen specimens had sharp edges suggesting they must have originated relatively close to source; derived material would more likely have blunt edges having been rolled around.

The results have been calibrated using OxCal v4.2 Bronk Ramsey (1995, 2001 and 2007) and Marine13 calibration curve (Reimer et al., 2013). Delta R values were ascertained from http://intcal.qub.ac.uk/marine/ as follows:

Delta R value location & reference	Delta R value	Latitude	Longitude
Dunkerque Tisnérat-Laborde, 2010	134 ± 60	50.3300	0.6200
Dunkerque Tisnérat-Laborde, 2010	-46 ± 60	51.0333	2.3833
English Channel Harkness, 1983	-31 ± 56	51.0333	2.3833

Due to the large variance in values, the weighted mean of all three was calculated to derive a single calibrated Delta R value of 17 ± 98 (calculated by Beta Analytic).

Twig wood was also dated from -5.84m OD in QBH1. All samples were submitted for AMS radiocarbon dating to Beta Analytic INC, Radiocarbon Dating Laboratory, Florida, USA. The results have been calibrated using OxCal v4.0.1 Bronk Ramsey (1995, 2001 and 2007) and IntCal13 atmospheric curve (Reimer et al., 2013). The results are displayed in Table 30.

As a result of the flushing effect of large water volumes associated with the extraction method, the core samples were considered compromised for Optically-Stimulated Luminescence.

7. RESULTS AND INTERPRETATION OF THE GEOARCHAEOLOGICAL INVESTIGATIONS

The sediment sequences are described in Tables 1 to 29 and illustrated in Figures 7 to 9. In describing below the sediment sequences recovered from the boreholes, the broad stratigraphy identified from the archive boreholes and outlined above can be adopted as the basis for the descriptions.

7.1 Unit 1 - Chalk and Unit 2 - Thanet Sand Formation

Bedrock was not penetrated in any of the geoarchaeological boreholes. Boreholes QBH1 and QBH2 were put down to 12.0m bgs, equivalent to about -8.3m OD, in an area where the bedrock surface is probably between -8.0 and -12.0m OD. Boreholes QBH3 and QBH4 were put down to 15.0m bgs, equivalent to between -11.6m and -12.0m OD, in an area where the bedrock surface is probably below -15.0m OD.

7.2 Unit 3 – Gravel and Gravelly Sand

This unit was recognised in all four boreholes. The surface of the gravel appears to slope down on both sides of the gravel ridge noted above. To the east of the ridge the gravel surface in borehole QBH1 was at -1.1m OD falling eastward to -2.26m OD in borehole QBH2. To the west of the ridge, the gravel surface in borehole QBH3 was at -1.1m OD falling westward to -3.0m OD in borehole QBH4. In boreholes QBH2, QBH3 and QBH4, the lowest recovered sediment was gravel, but in all cases it is unlikely to be *in situ* due to the difficulties encountered in drilling and recovering the sediment. However if the recovered sediment is assumed to indicate the presence of Unit 3 throughout the depth to which it is present in the borehole, then a thickness of at least 10.5m of Unit 3 was present in borehole QBH3 and a thickness of at least 9.0m in borehole QBH4. These values are consistent with the thicknesses recorded from the archive boreholes illustrated in transects A-A and B-B on the west side of the gravel ridge. In QBH2, on the east side of the gravel ridge sediment assessed on the same basis represents a thickness of at least 4.5m of gravel and gravelly sand. In borehole QBH1 a thickness of 4.16m of gravel was present, down to -5.26m OD, but below this level a thickness of 3.0m of sand was present to the bottom of the borehole at -8.26m OD.

Most of the sediment that can be assigned to Unit 3 in the four boreholes is gravel. Apart from the thick (3.0m) bed of sand in borehole QBH1, recorded beds of gravelly sand and sand are few in number and thin, but it is possible that thicker beds of sand were not recovered in parts of boreholes QBH2, QBH3 and QBH4. The gravel is almost entirely clast supported and in the larger fractions (>11.2mm) consists almost entirely of flint (up to c.100mm long axis), mainly sub-round but with smaller amounts of sub-angular clasts and some well-rounded flint pebbles. In the smaller gravel and granule fractions, clasts of quartz and sandstone are also present. In boreholes QBH1 and QBH2 at levels between -3.8m OD and -4.3m OD a distinctive fine to medium gravel is present in which a major component of the matrix is finely divided (<5mm) angular/sub-angular flint grit.

Throughout Unit 3, remains of mollusc shell was present, usually as small pieces (<5mm, often much smaller) but in a few places identifiable species were present including cf. *Neptunea antiqua* (Red

Whelk), *Buccinum undatum* (Common Whelk) and *Scrobicularia plana.* In sand sub-units within Unit 3, in addition to mollusc shell, remains of ostracods, forams and diatoms were present together with detrital plant remains, recorded in sub-samples retained in 0.5mm and 0.25mm separations. In general in sand sub-units in Unit 3 there were few recognisable primary depositional structures and organic remains were not visible to the naked eye. However in borehole QBH1 between -5.52m OD and -7.67m OD a sequence of nine organic sub-units was present incorporating visible plant remains including pieces of ?bark (up to 35mm) and other wood debris as well as complete mollusc shells, and remains of ostracods, diatoms, forams and ?bryozoans, together with detrital plant remains and seeds. This organic material seems likely to be equivalent to the 'organic clay' recorded in the nearby archive borehole KB-11 at about -7.0m OD.

7.3 Unit 4 – Fine-grained Alluvium

In all four boreholes fine-grained alluvium overlies the gravel and gravelly sand of Unit 3. The surface of the alluvium is at 0.74m OD in boreholes QBH1 and QBH2, and at -0.64 and -0.45 respectively in boreholes QBH3 and QBH4. In all four boreholes, these levels represent the base of Made Ground or of sediment disturbed and compromised during drilling and recovery. In the upper part of the surviving alluvium there is no evidence of soil formation, which may indicate truncation of the natural sediment prior to the emplacement of Made Ground; nor is there any evidence of buried soils horizons at depth within the fine-grained alluvial sequences. The thickness of the alluvium ranges from 0.46m in borehole QBH3 to 2.55m in borehole QBH4 (QBH1: 1.84m, QBH2: 2.45m). In all four boreholes part of the alluvial sequence is characterised by well-preserved horizontal bedding with alternating beds of silty fine sand and silt, with individual beds ranging in thickness from <2mm up to c.25mm. Well bedded sub-units form the bulk of the alluvial sequence in boreholes QBH1 (58%), QBH2 (100%) and QBH3 (100%) but less than a third of the sequence in borehole QBH4 (29%). Although these alluvial sediments were generally dark in colour, they contained few visible organic remains. However, 0.5mm and 0.25mm separations from some sub-units, e.g. QBH2 -0.11 to -0.76m OD contained small gastropods and bivalves, ostracods and forams, together with mollusc shell, detrital plant remains and charcoal. In other sub-units, e.g. borehole QBH4 -0.45 to -0.60m OD, only a few grains of quartz were retained in 0.25mm separations. These mainly well-bedded, fine-grained, predominantly sandy sediments are probably almost entirely of marine intertidal origin. However in QBH4, the surviving upper part of the sequence down to -1.5m OD is massive and lacks any indication of marine influence. It may therefore represent terrestrial accumulation on the floodplain of the River Stour on the landward side of the Stonar Bank.

7.4 Unit 5 – Made Ground

Between 3.0m and 4.5m of made or disturbed ground was present in the upper part of all four boreholes. It was generally recognisable due to the presence of extraneous debris visible to the naked eye or observed in 0.5mm or 0.25mm separations, including clinker, coal and glass in borehole QBH2, concrete, road metal and CBM in borehole QBH4 and a scaffolding clamp in borehole QBH3 at a depth of 4.5m below the ground surface.

8. RESULTS AND INTERPRETATION OF THE RADIOCARBON DATING

As outlined in section 6.4, marine Mollusca and plant remains from secure horizons within QBH1 and QBH4 were selected for radiocarbon dating. The results are displayed in Table 30 and Figure 8. The marine Mollusca were calibrated using the weighted mean of three different delta R values ascertained from http://intcal.qub.ac.uk/marine/,

Two separate dates were obtained from different points in Unit 3 (i) from marine Mollusca in QBH4 between -8.25 and -9.00m OD: 2650-2280 cal BP and (ii) from twig wood in QBH1 at -5.84m OD: 3380-3230 cal BP. It is highlighted, however that the twig wood from QBH1 has been calibrated using INTCal13 which is for samples of terrestrial origin, whilst the 13C value of the sample may indicate a tree growing in a brackish origin. As such, the twig wood should probably not have been calibrated against a terrestrial curve, and its uncertain origin makes the date obtained for this sample less reliable (Marshall & Corcoran pers. comm.). Unfortunately further material was not available from the same point for additional radiocarbon dating.

Nevertheless, the results broadly indicate that the middle to upper part of the gravel and gravelly sand of Unit 3 must date to, or post-date the late Bronze Age / early Iron Age period, and it can be inferred that on both the landward and seaward flanks of the Stonar Bank, shingle deposition was taking place in the Late Bronze Age/ Early Iron Age. The stratigraphic and sedimentological evidence is not sufficiently detailed to allow an interpretation of the exact depositional setting and process, i.e. whether it was primary accumulation associated with longshore movement of shingle along the Stonar Bank; or was reworking of material up or down its flanks. Nevertheless, the dates do suggest that open water was present in the Late Bronze age/Early Iron Age on both sides of the Stonar Bank with sufficient depth to allow wave action energetic enough to result in the movement of shingle size material. As sea level in the period indicated by the dates was already close to the present-day sea level, the evidence in QBH4 and QBH1 of shingle emplacement at -8.25 to -9.0m OD and -5.84m OD respectively, indicates water depths at this time of at least 9.0m on the landward side of the Stonar Bank and at least 6.0m on the seaward side. These findings can be compared with evidence from the Dungeness Foreland of shingle movement at similar depths in the historic period (Plater et al 2007).

Two separate dates were also obtained from marine Mollusca towards the base of the fine-grained alluvium forming Unit 4 (1) at -0.91m OD in QBH1: 650-300 cal BP and (ii) between -2.90 and -3.00 in QBH4: 1660-1250 cal BP. The results therefore suggest a ca. 1000 year age difference between accumulation of the fine-grained alluvium on the eastern landward side of the Stonar Bank (QBH4) which commenced during the early Medieval period and on the seaward side of the where, intertidal conditions were still present in the medieval/post-medieval period.

Table 1: Lithostratigraphic description of borehole QBH1, 0.0-3.0m

Depth (m OD)	Unit	Description
3.74 to 2.37	n/a	Loose clayey gravel
2.37 to 0.74	5	Poorly sorted clayey sandy gravel of sub-round, sub-angular and well-rounded flint (up to 85mm long axis)

Table 2: Lithostratigraphic description of borehole QBH1, 3.0-4.5m

Depth (m OD)	Unit	Description
0.74 to -0.32	4	5Y3/2 dark olive grey; beds of well-sorted silt and fine to medium sand, becoming more sandy downward; horizontal bedding – individual beds defined by texture and of variable thickness from <2mm to c.25mm; strong acid reaction; gradual transition to:
-0.32 to -0.76	4	Black; well-sorted silty fine sand; massive with infrequent partings; weak acid reaction.

Table 3: Lithostratigraphic description of borehole QBH1, 4.5-6.0m

Depth (m OD)	Unit	Description
-0.76 to -1.10	4	5Y4/1 dark grey; well-sorted slightly silty fine to medium sand; massive; scattered broken mollusc shell, two complete juvenile specimens of *Scrobicularia plana* at -0.91m; moderate acid reaction; sharp contact with:
-1.10 to -1.22	3	5Y4/1 dark grey; poorly sorted clayey sandy gravel of sub-angular, sub-round and well-rounded flint (up to 30mm long axis); massive; very scattered small (<5mm) pieces of broken mollusc shell; weak acid reaction; sharp contact with:
-1.22 to -1.45		5Y4/2 olive grey; well-sorted slightly silty fine to medium sand; massive; very scattered small (<5mm) pieces of broken mollusc shell; weak acid reaction; sharp contact with:
-1.45 to -2.26		5Y4/2 olive grey passing down to 7.5YR5/6 strong brown and back again to olive grey; very poorly sorted slightly clayey sandy gravel of sub-angular, sub-round and well-rounded flint (up to 60mm long axis); massive; very scattered small (<5mm) pieces of broken mollusc shell; weak acid reaction

Table 4: Lithostratigraphic description of borehole QBH1, 6.0-7.5m

Depth (m OD)	Unit	Description
-2.26 to -2.52	n/a	Loose gravel
-2.52 to -3.76	3	2.5Y5/3 light olive brown; poorly sorted sandy gravel of sub-angular, sub-round and well-rounded flint (up to 45mm long axis); massive.

Table 5: Lithostratigraphic description of borehole QBH1, 7.5-9.0m

Depth (m OD)	Unit	Description
-3.76 to -3.93	n/a	Loose gravel
-3.93 to -5.26	3	2.5Y5/4 light olive brown; gritty sandy gravel of sub-angular, sub-round and well-rounded flint (up to 25mm long axis); massive. [*Sub-sample >0.5mm*: mainly angular/sub-angular flint grit with scattered broken mollusc shell *Sub-sample 0.25-0.5mm*: coarser grains mainly angular/sub-angular flint grit; main component well-rounded quartz; scattered broken mollusc shell; very scattered detrital plant remains.]

Table 6: Lithostratigraphic description of borehole QBH1, 9.0-10.5m

Depth (m OD)	Unit	Description
-5.26 to -5.52	3	2.5Y4/2 dark greyish brown; well-sorted slightly silty fine to medium sand with very scattered clasts of flint (up to 12mm); massive; very scattered very small <1mm) pieces of mollusc shell; strong acid reaction; well-marked transition to:
-5.52 to -5.64		2.5Y4/1 dark grey; well sorted clayey/silty fine to medium sand; massive; common detrital plant remains; common broken mollusc shell (<5mm); moderate acid reaction; well-marked transition to:
-5.64 to -5.80		5Y4/1 dark grey; well-sorted slightly silty fine to medium sand; massive; common finely divided detrital plant remains; weak acid reaction; well-marked transition to:
-5.80 to -5.88		2.5Y4/1 dark grey; well sorted clayey/silty fine to medium sand; massive; common detrital plant remains; wood debris ?bark (up to 35mm); moderate acid reaction; well-marked transition to:
-5.88 to -6.27		2.5Y4/2 dark greyish brown; well-sorted slightly silty fine to medium sand; massive; common finely divided detrital plant remains; scattered small (<5mm) pieces of wood; common broken mollusc shell (up to 15mm); weak acid reaction; well-marked transition to:
-6.27 to -6.40		2.5Y4/1 dark grey; well sorted clayey/silty fine to medium sand; massive; common detrital plant remains; wood debris ?bark (up to 35mm); moderate acid reaction. [*Sub-sample >0.5mm*: mineral sediment, detrital plant remains, seeds, broken mollusc shell, bivalve shells, forams, diatoms, bryozoa remains] well-marked transition to:
-6.40 to -6.76		2.5Y4/2 dark greyish brown; well-sorted slightly silty fine to medium sand; massive; common finely divided detrital plant remains; scattered small (<5mm) pieces of wood; common broken mollusc shell (up to 15mm); weak acid reaction. [*Sub-sample 0.25-0.5mm*: detrital plant remains, broken mollusc shell, ostracod remains, forams, diatoms]

Table 7: Lithostratigraphic description of borehole QBH1, 10.5-12.0m

Depth (m OD)	Unit	Description
-6.76 to -6.82	n/a	void
-6.82 to -7.00	3	5Y4/1 dark grey; well-sorted silty/clayey fine to medium sand with very scattered flint clasts (up to 25mm); massive; common detrital plant remains; common finely divided mollusc shell remains; strong acid reaction; well-marked transition to:
-7.00 to -7.20		5Y4/1 dark grey; very well sorted slightly silty fine to medium sand; massive; finely divided (<1mm) detrital plant remains; finely divided (<2mm) broken mollusc shell; strong acid reaction; well-marked transition to:
-7.20 to -7.67		5Y4/1 dark grey; moderately sorted clayey fine to medium sand and slightly silty fine to medium sand; irregular mixture; common detrital plant remains in clayey sediment, scattered finely divided detrital plant remains in sandy sediment; common finely divided mollusc shell; moderate to srong acid reaction; well-marked transition to:
-7.67 to -8.26		Gley 4/4/1 dark greenish grey; well sorted slightly silty fine to medium sand; massive; finely divided detrital plant remains; finely divided broken mollusc shell; strong acid reaction.

Table 8: Lithostratigraphic description of borehole QBH2, 3.0-4.5m

mOD	unit	Description
0.74 to 0.37	4	5Y4/1 dark grey oxidising to 2.5Y5/4 light olive brown; very well sorted fine

		sandy silt; some discontinuous horizontal partings in upper part, otherwise massive; well-marked transition to:
0.37 to 0.19		5Y4/1 dark grey; well-sorted silty fine sand; massive with some discontinuous horizontal partings; moderate acid reaction. [*Sub-sample >0.25mm*: very little retained on sieve – quartz, flint, detrital plant remains, coal, clinker] Gradual transition to:
0.19 to -0.11		5Y4/1 dark grey; alternating beds of silt and fine sand; horizontal bedding defined by variations of texture with individual beds from <5mm to c.25mm; moderate acid reaction; gradual transition to:
-0.11 to -0.76		5Y4/1 dark grey; alternating beds of silt and fine sand; horizontal bedding defined by variations of texture with individual beds from <5mm to c.25mm, becoming more sandy downward with few silt beds below -0.46m; weak to moderate acid reaction. [*Sub-sample >0.25mm*: quartz, few flint, detrital plant remains, mollusc shell debris, complete gastropods and bivalves, ostracods, forams, charcoal]

Table 9: Lithostratigraphic description of borehole QBH2, 4.5-6.0m

Depth (m OD)	Unit	Description
-0.76 to -1.04	4	5Y3/1 very dark grey; well-sorted silty fine to medium sand; weakly defined bedding marked by horizontal partings; finely divided mollusc shell debris; moderate acid reaction; gradual transition to:
-1.04 to -1.45		5Y3/1 very dark grey; alternations of well sorted silt and fine to medium sand; horizontal bedding; finely divided mollusc shell debris; moderate acid reaction; well-marked transition to:
-1.45 to -1.77		2.5Y4/1 dark grey very well sorted fine to medium sand; massive; finely divided mollusc shell debris; moderate acid reaction; gradual transition to:
-1.77 to -2.26		2.5Y4/1 dark grey to black; moderately sorted gritty fine to medium sand with widely spaced silt beds; horizontal bedding; mollusc shell debris (up to 10mm); moderate acid reaction. [*Sub-sample >0.5mm*: small mineral component of flint quartz and sandstone; mainly mollusc shell debris with a few complete small marine gastropods and very scattered detrital plant remains. *Sub-sample 0.25-0.5mm*: mainly quartz sand with flint, mollusc shell debris, forams and very scattered detrital plant remains]

Table 10: Lithostratigraphic description of borehole QBH2, 6.0-7.5m

Depth (m OD)	Unit	Description
-2.26 to - 3.76	3	2.5YR6/2 light brownish grey; poorly sorted sandy gravel (up to 90mm long axis); massive; common mollusc shell debris (up to 5mm). *About 1.25 m of gravel free to slide up and down in tube.*

Table 11: Lithostratigraphic description of borehole QBH2, 7.5-9.0m

Depth (m OD)	Unit	Description
-3.76 to -5.26	3	2.5Y6/4 light yellowish brown; gritty sandy gravel of sub-angular, sub-round and well-rounded flint (up to 50mm long axis but mainly <25mm); massive; common broken mollusc shell (up to 5mm).

Table 12: Lithostratigraphic description of borehole QBH2, 9.0-12.0m
n.b. 3.0m of drilling in 1.5m tube

Depth (m OD)	Unit	Description
-5.26 to -5.59	3	Poorly sorted fine to coarse gravel of sub-angular, sub-round and well-rounded flint (up to 60mm long axis); massive; common broken mollusc

		shell (up to 15mm); well-marked junction with: *?sandy matrix washed out during drilling*
-5.59 to -6.49		Poorly sorted gritty sandy gravel of sub-angular, sub-round and well-rounded flint (up to 40mm long axis but mainly <25mm); massive; common broken mollusc shell (mainly <2mm); well-marked junction with:
-6.49 to -6.76		Poorly sorted fine to coarse gravel of sub-angular, sub-round and well-rounded flint (up to 85mm long axis); massive; common broken mollusc shell (up to 15mm) *?sandy matrix washed out during drilling*

Table 13: Lithostratigraphic description of borehole QBH3, 1.5-3.0m

Depth (m OD)	Unit	Description
1.90 to 0.40	n/a	Made Ground with clinker, coal and glass

Table 14: Lithostratigraphic description of borehole QBH3, 3.0-4.5m

Depth (m OD)	Unit	Description
0.40 to -0.05	n/a	Void
-0.05 to -0.15	n/a	Loose sediment
-0.15 to -0.64	5	Made ground – steel scaffolding clamp at -0.64
- 0.64 to -1.10	4	2.5Y4/1 dark grey; alternating beds of well-sorted silt and fine sand; horizontal bedding defined by variations of texture with individual beds from <5mm to c.25mm.

Table 15: Lithostratigraphic description of borehole QBH3, 4.5-6.0m

Depth (m OD)	Unit	Description
-1.10 to -1.41	3	2.5Y4/2 dark greyish brown; well-sorted ; clayey/silty very fine sand with scattered flint clasts (up to 30mm); massive; moderate acid reaction; very sharp contact with:
-1.41 to -1.58		Medium to coarse gravel of sub-angular, sub-round and well-rounded flint (up to 50mm long axis); massive. ? sandy matrix washed out during drilling sharp contact with:
-1.58 to -1.89		5Y5/2 olive grey; poorly to moderately sorted clayey sandy gravel of sub-angular, sub-round and well-rounded flint (up to 30mm long axis); massive; very scattered broken mollusc shell; weak acid reaction; sharp contact with:
-1.89 to -2.09		2.5Y5/6 light olive brown; well-sorted slightly silty fine to medium sand with scattered flint clasts (up to 25mm); massive; moderate acid reaction; sharp contact with:
-2.09 to -2.26		5Y5/2 olive grey; poorly to moderately sorted clayey sandy gravel of sub-angular, sub-round and well-rounded flint (up to 30mm long axis); massive; very scattered broken mollusc shell; weak acid reaction; sharp contact with:
-2.26 to -2.34		2.5Y5/6 light olive brown; well-sorted slightly silty fine to medium sand with scattered flint clasts (up to 25mm); massive; moderate acid reaction; sharp contact with:
-2.34 to -2.60		2.5Y5/6 light olive brown; gritty slightly gravelly sand becoming more gravelly downward (flint clasts up to 40mm); weakly developed horizontal bedding defined by colour and texture variations; common broken mollusc shell (up to 5mm).

Table 16: Lithostratigraphic description of borehole QBH3, 6.0-7.5m

Depth (m OD)	Unit	Description
-2.60 to -4.10	3	10YR 5/4 yellowish brown; poorly sorted sandy gravel of sub-angular, sub-round and well-rounded flint (up to 60mm long axis); massive; common broken mollusc shell.

Table 17: Lithostratigraphic description of borehole QBH3, 7.5-9.0m

Depth (m OD)	Unit	Description
-4.10 to -5.60	3	2.5Y5/2 greyish brown; moderately sorted sandy gravel of sub-angular, sub-round and well-rounded flint (up to 50mm long axis); massive; common broken mollusc shell (up to 5mm).

Table 18: Lithostratigraphic description of borehole QBH3, 9.0-10.5m

Depth (m OD)	Unit	Description
-5.60 to -7.10	3	10YR5/4 yellowish brown; poorly sorted sandy gravel of sub-angular, sub-round and well-rounded flint (up to 20mm long axis) with loose sand at 6.45-6.60m OD; massive; abundant broken mollusc shell. Sediment loose in tube; evidence of fines washing through gravel during drilling

Table 19: Lithostratigraphic description of borehole QBH3, 10.5-12.0m

n.b. Sand washed out to settle as a horizontal layer in tube

Depth (m OD)	Unit	Description
-7.10 to -7.15	n/a	Sand washed out during drilling
-7.15 to -7.56	3	2.5Y5/6 light olive brown; well-sorted fine to medium sand; massive; very finely divided mollusc shell debris; moderate acid reaction; sharp contact with:
-7.56 to -7.64		2.5Y5/6 light olive brown; fine to medium sandy gravel of sub-angular, sub-round and well-rounded flint (up to 25mm long axis); massive; common broken mollusc shell;moderate acid reaction; well-marked transition to:
-7.64 to -7.89		2.5Y5/3 light olive grown; gravelly sand with flint clasts up to 30mm; common broken mollusc shell; strong acid reaction; gradual transition to:
-7.89 to -8.60		Medium to coarse sandy gravel of sub-angular, sub-round and well-rounded flint (up to 50mm long axis); massive; common broken mollusc shell

Table 20: Lithostratigraphic description of borehole QBH3, 12.0-15.0m

n.b. 3.0m of drilling in 1.5m tube; evidence of water flowing through sediment during drilling

Depth (m OD)	Unit	Description
-8.60 to -11.1	3	2.5Y5/6 light olive brown; slightly silty fine to medium sand; scattered small (<2mm) pieces of mollusc shell; weak acid reaction. [*Sub-sample >0.25mm*: mineral sediment, mollusc shell debris, detrital plant material, ostracods, forams, diatoms]
-11.1 to -11.6		2.5Y5/6 light olive brown; poorly sorted sandy gravel of sub-angular, sub-round and well-rounded flint (up to 60mm long axis); massive; scattered mollusc shell debris (<5mm)

Table 21: Lithostratigraphic description of borehole QBH4, 0.0-3.0m
n.b. 3.00m of drilling in 1.5m tube

Depth (m OD)	Unit	Description
3.00 to 1.96	5	Upper 1.04 m of tube - void
1.96 to 0.00		Remainder of tube – clayey sandy gravel with concrete, road metal and CBM

Table 22: Lithostratigraphic description of borehole QBH4, 3.0-4.5m

Depth (m OD)	Unit	Description
0.00 to -0.35	n/a	void
-0.35 to -0.45	n/a	10YR5/4 yellowish brown; slightly gravelly clay - ?spoil/made ground
-0.45 to -0.60	4	10YR5/4 yellowish brown passing down to 2.5Y4/2 dark greyish brown; very well sorted fine sandy/silty clay; massive; moderate acid reaction. [*Sub-sample >0.25mm*: a few grains of quartz sand and a few pieces of detrital plant material] Gradual transition to:
-0.60 to -0.77		2.5Y4/1 dark grey; very well sorted silty fine sand; massive; weak acid reaction; gradual transition to:
-0.77 to -1.50		2.5Y4/2 dark greyish brown oxidising to 10YR5/4 yellowish brown; very well sorted fine sandy silt; massive – slight variations of sand content suggest weakly developed horizontal bedding; moderate acid reaction.

Table 23: Lithostratigraphic description of borehole QBH4, 4.5-6.0m

Depth (m OD)	Unit	Description
-1.50 to -3.00	3	2.5Y4/1 dark grey; alternating beds of very well sorted silt and fine sand – raging from sand with mud drapes to silt with sand partings; horizontal bedding; finely divided detrital plant remains; finely divided mollusc shell; weak to moderate acid reaction. [*Sub-sample >0.25mm*: mineral sediment, detrital plant material, mollusc shell debris; forams, diatoms]

Table 24: Lithostratigraphic description of borehole QBH4, 6.0-7.5m

Depth (m OD)	Unit	Description
-3.00 to -3.87	3	2.5Y5/2 greyish brown; moderately sorted slightly sandy gravel of sub-angular, sub-round and well-rounded flint (up to 55mm long axis); massive; common broken mollusc shell. n.b sand content has settled horizontally in tube as a result of washing through the gravel. Sharp contact with:
-3.87 to -3.97		2.5Y5/2 greyish brown; gravelly sand; sharp contact with:
-3.97 to -4.06		2.5Y5/2 greyish brown; slightly gravelly sand; sharp contact with:
-4.06 to -4.50		2.5Y5/2 greyish brown; sandy gravel.

Table 25: Lithostratigraphic description of borehole QBH4, 7.5-9.0m
Sediment loose in tube and free to move up and down

Depth (m OD)	Unit	Description
-4.50 to -4.55	n/a	void
-4.55 to -4.91	3	2.5Y5/2 greyish brown; poorly sorted gravelly sand with flint clasts up to 40mm; massive; common finely divided mollusc shell; moderate acid reaction; sharp contact with:

-4.91 to -5.03		2.5Y5/2 greyish brown; well-sorted slightly silty medium to coarse sand; massive; common finely divided mollusc shell; moderate acid reaction; sharp contact with:
-5.03 to -5.88		2.5Y5/2 greyish brown; poorly sorted sandy gravel of sub-angular, sub-round and well-rounded flint (up to 50mm); massive; common finely divided mollusc shell; sharp contact with:
-5.88 to -6.00		5Y4/2 dark grey; well-sorted slightly silty fine to medium sand; massive; very scattered small pieces (<2mm) of mollusc shell.

Table 26: Lithostratigraphic description of borehole QBH4, 9.0-10.5m

Depth (m OD)	Unit	Description
-6.00 to -7.50	?3	*Small amount of loose sand moving freely in tube*

Table 27: Lithostratigraphic description of borehole QBH4, 10.5-12.0m

Evidence of water washing down through tube during drilling

Depth (m OD)	Unit	Description
-7.50 to -7.78	3	2.5Y5/2 greyish brown; well sorted fine to medium sand; massive; finely divided detrital plant remains; finely divided mollusc shell; sharp contact with:
-7.78 to -8.25		2.5Y5/2 greyish brown; sandy gravel of sub-angular, sub-round and well-rounded flint (up to 45mm); massive; finely divided detrital plant remains; finely divided mollusc shell; well-marked transition to:
-8.25 to -9.00		Moderately sorted slightly sandy gravel of sub-angular, sub-round and well-rounded flint (up to 100mm); massive; two incomplete shells of marine gastropods (cf Red Whelk *Neptunea antiqua*; Common Whelk *Buccinum undatum*), scattered broken mollusc shell.

Table 28: Lithostratigraphic description of borehole QBH4, 12.0-13.5m

Depth (m OD)	Unit	Description
-9.00 to -10.5	3	Sand settled horizontally in tube

Table 29: Lithostratigraphic description of borehole QBH4, 13.5-15.0m

Depth (m OD)	Unit	Description
-9.00 to -10.5	3	Sandy gravel of sub-angular, sub-round and well-rounded flint (up to 80mm); massive. n.b. Sand content has settled horizontally in tube as a result of washing through the gravel

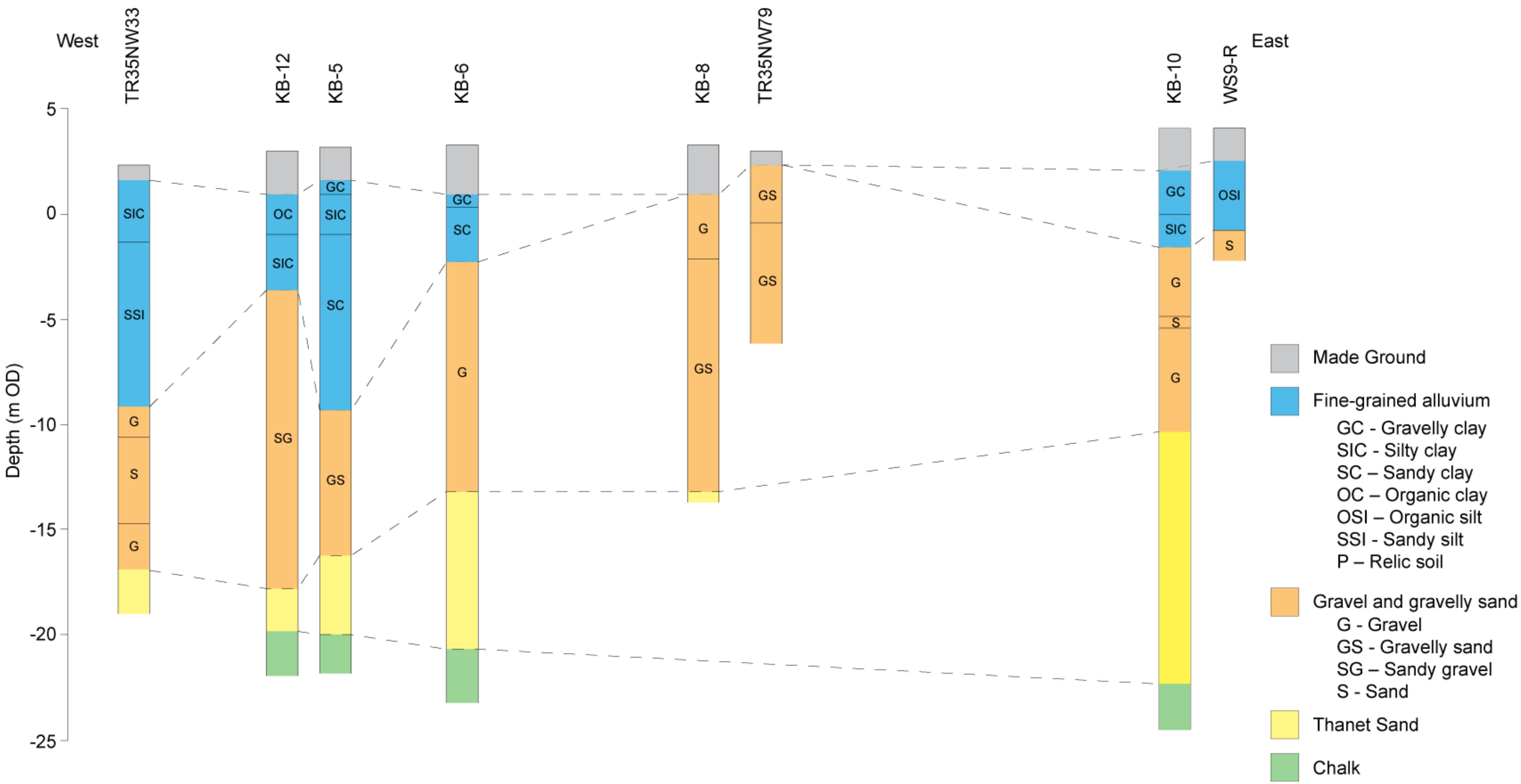

Figure 7: East-west transect of boreholes 'A-A' across the Biomass Combined Heat and Powerplant site (see Figure 2 for location)

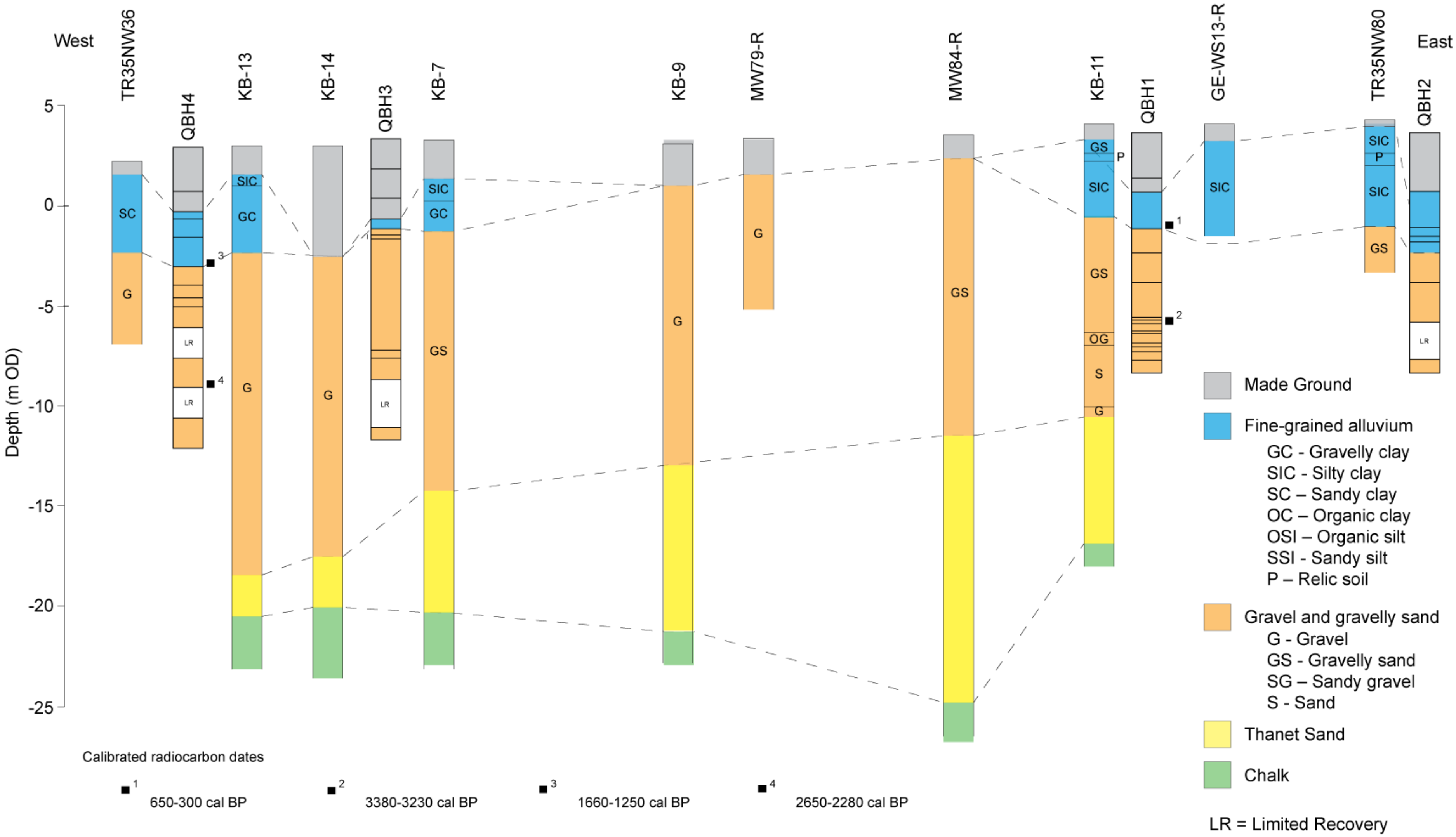

Figure 8: East-west transect of boreholes B-B across the Biomass Combined Heat and Powerplant site, including the four new geoarchaeological boreholes (see Figure 2 for location)

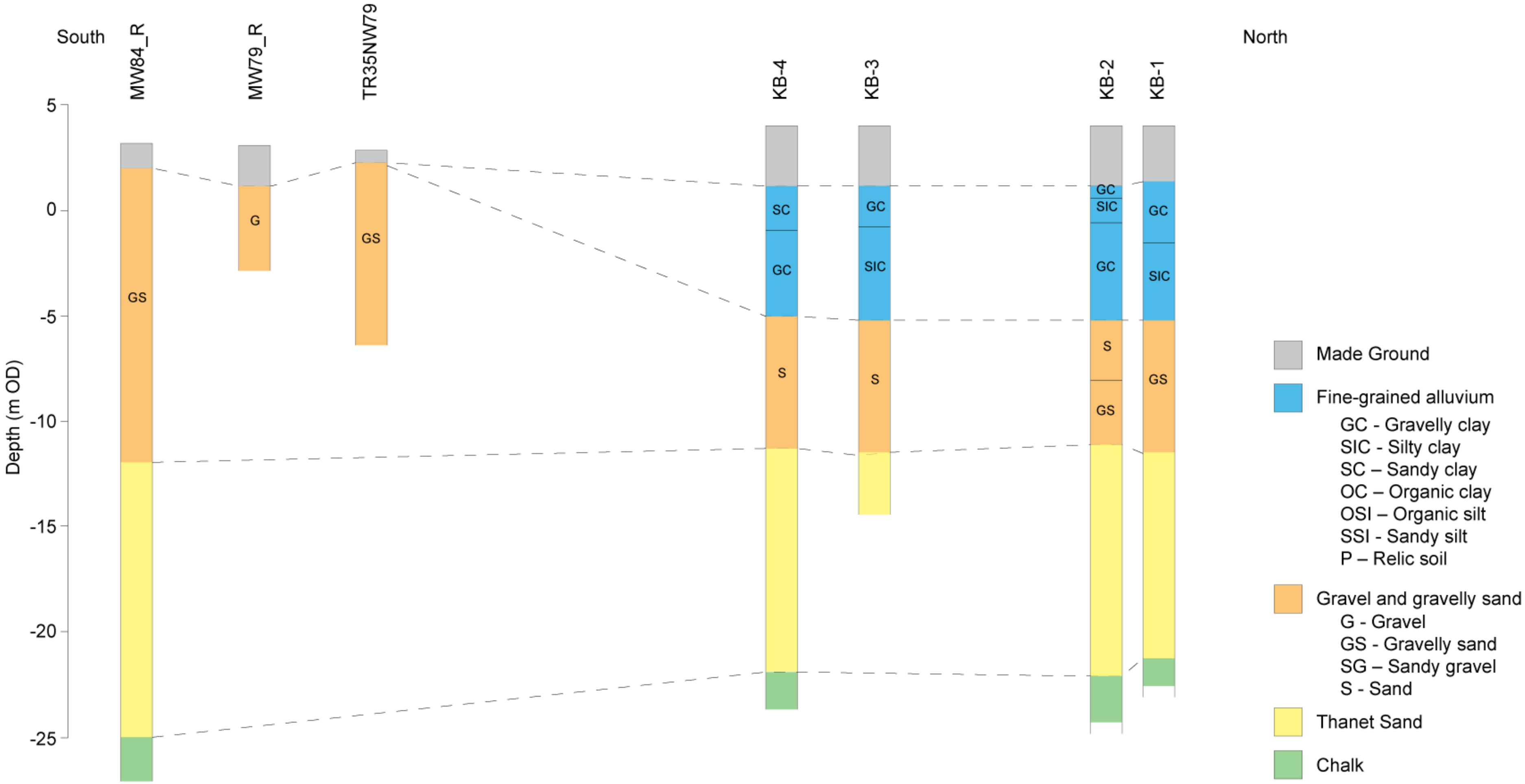

Figure 9: North-south transect of boreholes 'C-C' across the Biomass Combined Heat and Powerplant site (see Figure 2 for location)

Table 30: Results of the QBH1 & QBH4 radiocarbon dating, Biomass Combined Heat and Powerplant site

Laboratory code / Method	Material and location	Depth (m OD)	Uncalibrated radiocarbon years before present (yr BP)	Weighted mean Delta R value	Calibrated age BC/AD (BP) (2-sigma, 95.4% probability)	**δ**13C (‰)
BETA-461846	QBH4; Unit 4; unidentified Mollusca fragments	-2.90 to -3.00	1890 ± 30	17 ± 98	300 to 710 cal AD 1660-1250 cal BP	-1.1
BETA-455397 AMS	QBH4; Unit 3; marine mollusca (*Neptunea antiqua* & *Buccinum undatum)*	-8.25 to -9.00	2830 ± 30	17 ± 98	700-330 cal BC 2650-2280 cal BP	1.3
BETA-455395 AMS	QBH1; Unit 4; marine mollusca (*Scrobicularia plana*)	-0.91	890 ± 30	17 ± 98	1310-1660 cal AD 650-300 cal BP	0.7
BETA-455396 AMS	QBH1; Unit 3; waterlogged plant remains	-5.84	3100 ± 30	-	1440-1280 cal BC 3380-3230 cal BP	-15.9

9. DISCUSSION

The findings of the present investigation were limited by the difficulties encountered in the recovery of undisturbed cores and by the scarcity of sample material suitable either for OSL or radiocarbon dating. In addition little could be learned from the cores about the structural arrangement of the sand and shingle (Unit 3) forming the Stonar Bank, or therefore about its depositional history. However from the radiocarbon dates obtained from detrital organic material incorporated the shingle it can be inferred that relatively deep water (6.0-9.0m) was present on both sides of the Stonar Bank during or after the Late Bronze Age/Early Iron Age and that shingle was being actively redistributed by wave action on the Stonar Bank at that time. This finding is broadly consistent with evidence that the Wantsum Channel was still an open waterway in the Roman period, when the Roman port of Rutupiae was reached on an arm of the Wantsum Channel and stood in a position on the opposite side of that channel to the present site of investigation.

The level of the dated material within the body of sand and shingle (Unit 3) forming the Stonar Bank, indicates that accumulation of shingle in the vicinity of the Biomass site probably began at a date earlier than the Late Bronze Age. The dated material in QBH4 was probably about 10.0m above the base of gravel presumed to be equivalent to Unit 3 which was recorded in the nearby borehole KB-13 at a depth of c.-18.0m OD. Shingle accumulation may therefore have begun here earlier in the Holocene at a time when the sea level was below its present level.

Accumulation of the fine-grained alluvium (unit 4) on the landward side of the Stonar Bank commenced during the early medieval period. By comparison the late to post-medieval date obtained from intertidal Mollusca in the alluvium on the seaward side of the Stonar Bank shows that intertidal marine conditions were still present there at that time. This finding is consistent with the visible evidence in this area of a sand and shingle spit that has been extending northward from the vicinity of Deal during the historic period.

10. CONCLUSIONS

The results of the field and laboratory investigations confirm the broad stratigraphic scheme identified in earlier investigations of the Sandwich/Stonar/Ebbsfleet area. Within the Biomass site, well-bedded fine-grained alluvial sediments are present overlying the sloping flanks of a gravel (marine shingle) ridge representing part of the northward extent of the so-called Stonar Shingle. Sand sub-units within the gravel body are few in number and mainly thin. Undisturbed sediment was recovered however from a thick (3.0m) body of sand in the lower part of borehole QBH1, and sub-units within this sand provided material suitable for radiocarbon dating. The results of radiocarbon dating suggest that the middle-upper part of Unit 3 accumulated from no later than the late Bronze Age, and it can be inferred that open water was present in the Late Bronze Age/Early Iron Age on both the seaward and landward sides of the Stonar Bank with shingle movement at that time in water depths of between 6.0m and 9.0m on the flanks of the shingle accumulation.

Late to post-medieval dates obtained from intertidal Mollusca in alluvium on the seaward side of the Stonar Bank shows that marine conditions were still present there at that time. On the landward side of the Stonar Bank, the alluvial sequence began accumulating during the early medieval period; whilst the lower part of the alluvial sequence appears to be of marine origin the upper part may represent deposition on the terrestrial floodplain of the River Stour.

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12. APPENDIX 1: OASIS

OASIS ID: quaterna1-271877

Project details

Project name	Proposed Biomass Combined Heat and Power Plant, Discovery Park
Short description of the project	Following the results of previous archaeological and geoarchaeological desk-based assessments, a programme of geoarchaeological investigation was undertaken at the site of the Proposed Biomass Combined Heat and Power Plant in order to (1) recover sediment from Unit 3 (gravel and gravelly sand) for dating and the recovery of micro-fauna and flora; and (2) to explore the sequences of the fine-grained and potentially organic sediment of Unit 4 (fine-grained alluvium), in particular the deeper sequences underlying the western part of the site, with a view to radiocarbon dating. The results of the investigations confirm the broad stratigraphic scheme identified in earlier investigations of the Sandwich/Stonar/Ebbsfleet area. Within the Biomass site, well-bedded fine-grained alluvial sediments are present overlying the sloping flanks of a gravel (marine shingle) ridge representing part of the northward extent of the so-called Stonar Shingle. Sand sub-units within the gravel body are few in number and mainly thin, although undisturbed sediment was recovered from a thick (3.0m) body of sand in the lower part of borehole QBH1, along with fine-grained alluvium (Unit 4) overlying the gravel body in this borehole. The results of radiocarbon dating suggest that the middle-upper part of Unit 3 accumulated from no later than the late Bronze Age, and Unit 4 from no later than the Medieval period.
Project dates	Start: 01-09-2016 End: 21-12-2016
Previous/future work	Yes / Not known
Type of project	Environmental assessment
Survey techniques	Landscape

Project location

Country	England
Site location	KENT DOVER SANDWICH Proposed Biomass Combined Heat and Power Plant
Postcode	CT13 9FP
Site coordinates	TR 33467 59911 51.289734474674 1.348826244956 51 17 23 N 001 20 55 E Point

Project creators

Name of Organisation	Quaternary Scientific (QUEST)
Project brief originator	CgMs Consulting
Project design originator	Dr C.P. Green
Project director/manager	C.R. Batchelor
Project supervisor	D.S. Young
Type of sponsor/funding body	Developer

Project archives

Physical Archive Exists?	No
Digital Archive Exists?	No
Paper Archive recipient	Kent
Paper Contents	"Environmental"
Paper Media available	"Report"
Entered by	Daniel Young (d.s.young@reading.ac.uk)
Entered on	21 December 2016