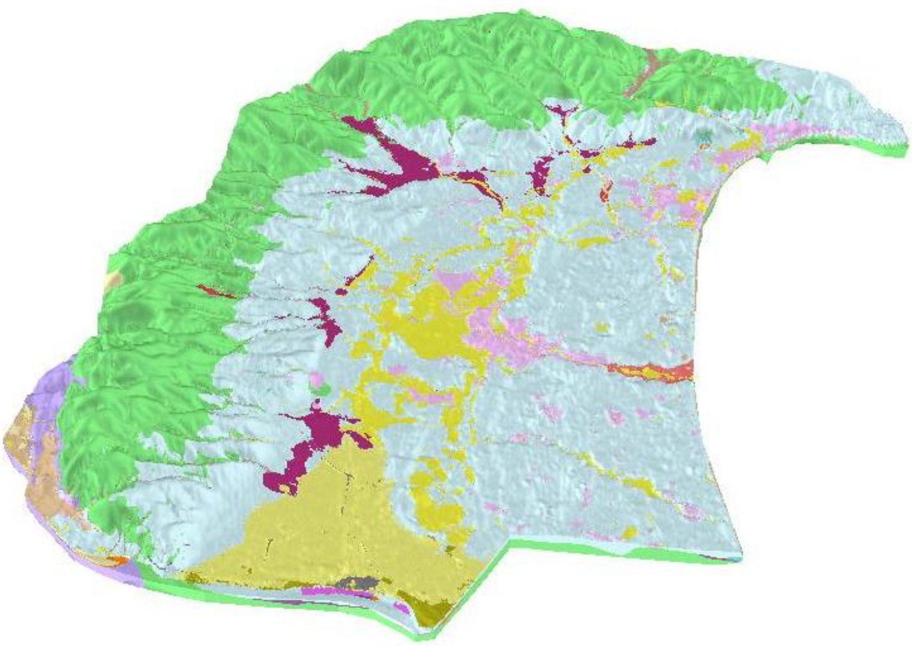
A 3D geological model of the superficial deposits of the Holderness area

Geology and Landscape Programme

Commissioned Report CR/09/132N



BRITISH GEOLOGICAL SURVEY

GEOLOGY AND LANDSCAPE PROGRAMME

COMMISSIONED REPORT CR/09/132

A 3D geological model of the superficial deposits of the Holderness area

H. F. Burke, D. J. Morgan, H. Kessler and A. H. Cooper

The National Grid and other Ordnance Survey data are used with the permission of the Controller of Her Majesty's Stationery Office. Licence No: 100017897/ 2015.

Keywords

Report; Holderness; 3D model; GSI3D; Environment Agency; Quaternary; Chalk.

National Grid Reference

SW corner 488722,424886
Centre point 506328,448157
NE corner 526348,474973

Map

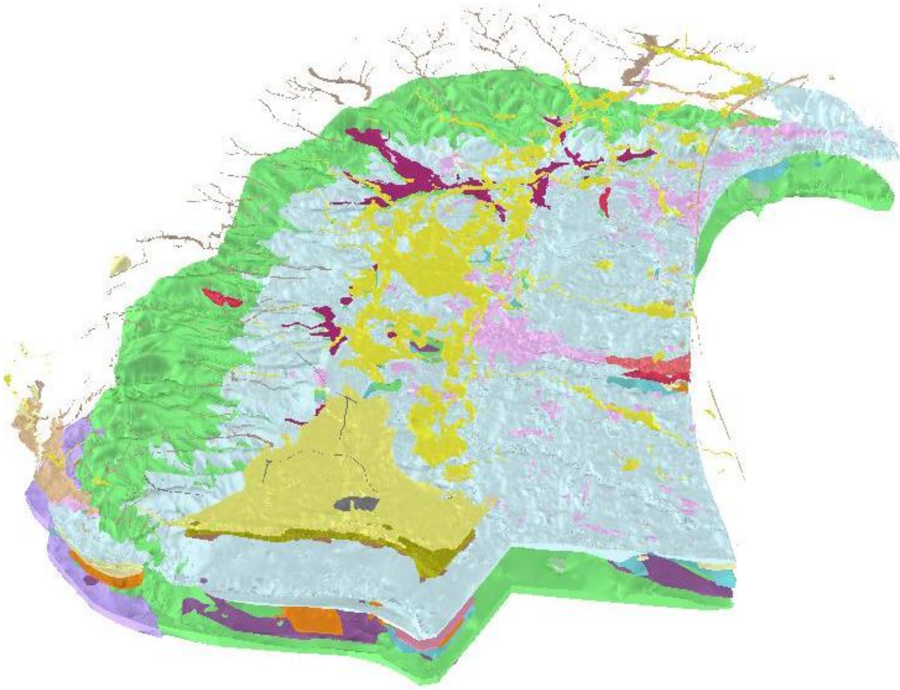
Front cover

Cover picture details, delete if no cover picture. *Bibliographical reference*

BURKE, H. F., MORGAN, D. J., KESSLER, H., AND A. H. COOPER. 2015. A 3D geological model of the superficial deposits of the Holderness area. *British Geological Survey Commissioned Report*, CR/09/132N. 58pp.

Copyright in materials derived from the British Geological Survey's work is owned by the Natural Environment Research Council (NERC) and/or the authority that commissioned the work. You may not copy or adapt this publication without first obtaining permission. Contact the BGS Intellectual Property Rights Section, British Geological Survey, Keyworth, e-mail ipr@bgs.ac.uk. You may quote extracts of a reasonable length without prior permission, provided a full acknowledgement is given of the source of the extract.

Maps and diagrams in this book use topography based on Ordnance Survey mapping.



© NERC 2015. All rights reserved

Keyworth, Nottingham British Geological Survey 2015

BRITISH GEOLOGICAL SURVEY

The full range of our publications is available from BGS shops at Nottingham, Edinburgh, London and Cardiff (Welsh publications only) see contact details below or shop online at www.geologyshop.com

The London Information Office also maintains a reference collection of BGS publications, including maps, for consultation.

We publish an annual catalogue of our maps and other publications; this catalogue is available online or from any of the BGS shops.

The British Geological Survey carries out the geological survey of Great Britain and Northern Ireland (the latter as an agency service for the government of Northern Ireland), and of the surrounding continental shelf, as well as basic research projects. It also undertakes programmes of technical aid in geology in developing countries.

The British Geological Survey is a component body of the Natural Environment Research Council.

British Geological Survey offices

BGS Central Enquiries Desk

Tel 0115 936 3143 Fax 0115 936 3276

email enquiries@bgs.ac.uk

Kingsley Dunham Centre, Keyworth, Nottingham NG12 5GG

Tel 0115 936 3241 Fax 0115 936 3488
email sales@bgs.ac.uk

Murchison House, West Mains Road, Edinburgh EH9 3LA

Tel 0131 667 1000 Fax 0131 668 2683
email scotsales@bgs.ac.uk

Natural History Museum, Cromwell Road, London SW7 5BD

Tel 020 7589 4090 Fax 020 7584 8270
Tel 020 7942 5344/45 email bgslondon@bgs.ac.uk

Columbus House, Greenmeadow Springs, Tongwynlais, Cardiff CF15 7NE

Tel 029 2052 1962 Fax 029 2052 1963

Forde House, Park Five Business Centre, Harrier Way, Sowton EX2 7HU

Tel 01392 445271 Fax 01392 445371

Maclean Building, Crowmarsh Gifford, Wallingford OX10 8BB

Tel 01491 838800 Fax 01491 692345

Geological Survey of Northern Ireland, Colby House, Stranmillis Court, Belfast BT9 5BF

Tel 028 9038 8462 Fax 028 9038 8461

www.bgs.ac.uk/gsni/

Parent Body

Natural Environment Research Council, Polaris House, North Star Avenue, Swindon SN2 1EU

Tel 01793 411500 Fax 01793 411501
www.nerc.ac.uk

Website www.bgs.ac.uk
Shop online at www.geologyshop.com

Foreword

This report is the published product of a study by the British Geological Survey (BGS) undertaken for the Environment Agency.

Acknowledgements

Helen Sharp and Rolf Farrell of the Environment Agency are thanked for instigating this project, providing additional data used in the model and for their encouragement throughout.

Special thanks are extended to Ben Wood for his assistance with GSI3D. The authors also wish to thank Dr Hans-Georg Sobisch from INSIGHT Geologische Softwaresysteme GmbH for developing GSI3D software.

The bathymetry data of the Humber Estuary was kindly supplied by ABP Marine Environmental Research and NEXTMap Digital Elevation Models are supplied by Intermap.

Contents

FIGURES

TABLES

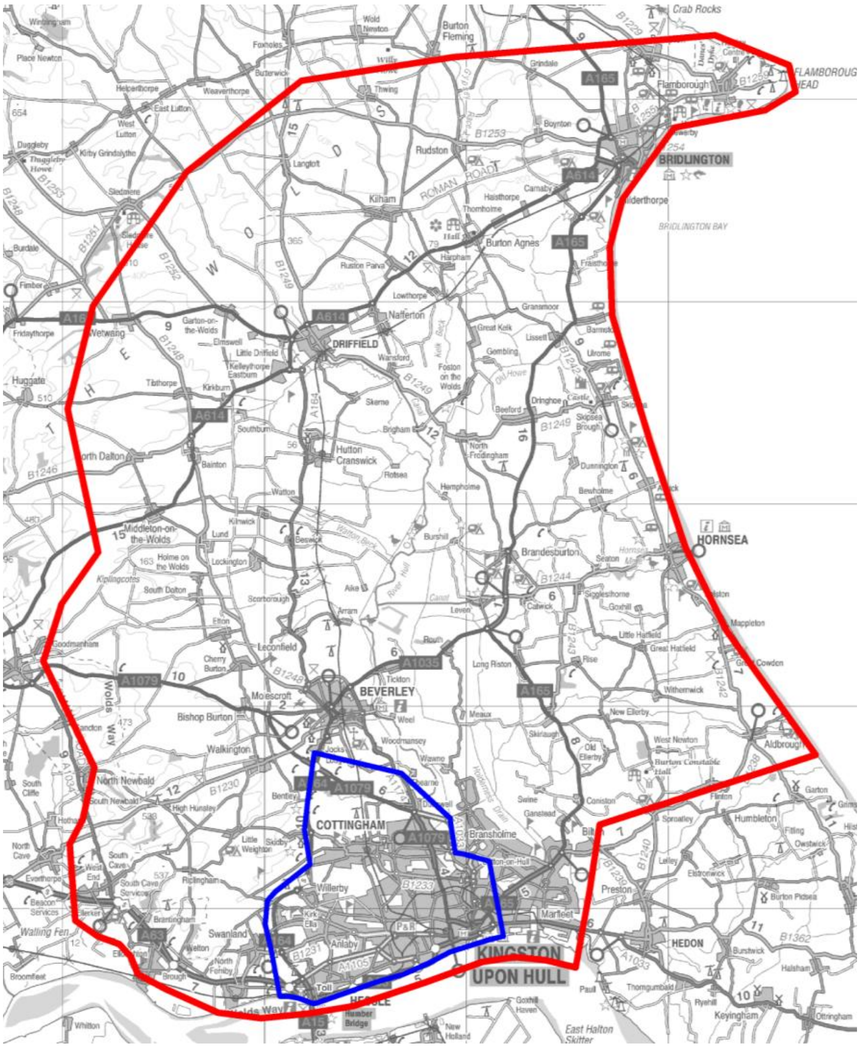
Summary

This report and accompanying 3D geological model were produced for the Environment Agency. The report describes the Quaternary geology of the study area, from Hull in the south to Flamborough Head in the north (Figure 1), and supersedes a previous study carried out in 2008 for the Hull area. The description and spatial distribution of each geological unit is based on interpretations from a 3D geological model, which was constructed using digital geological map data and 1398 boreholes taken from the BGS Borehole Geology database, plus borehole data supplied by the Environment Agency. The data from the EA were included in the 3D model where they fell along lines of cross-section and were particularly useful where gaps occurred in the BGS records. The 3D model was constructed using GSI3D® software and methodology (described in more detail at http://en.wikipedia.org/wiki/GSI3D). The 3D model comprises 74 cross-sections (plus additional 'helper sections), it includes 26 geological units and covers a total area of approximately 1280 km^2. A NEXTMap 100m cell size DTM was used to cap the 3D model, which was combined with bathymetry data of the Humber Estuary, supplied by ABP Marine Environmental Research.

The 3D model has revealed extensive sand and gravel units both beneath and within the main till sequence, plus a deep sand and gravel-filled buried channel that cuts into the Chalk bedrock in the Holderness coastal area. A morainic deposit, consisting of intermixed sand and gravel with till, in places extending down to bedrock, was identified in the previous study carried out for the Hull area. These more permeable units are likely to impact on groundwater in the area.

1 Introduction

The Environment Agency identified the need for an extension to the Hull 3D geological model of the Chalk aquifer and overlying superficial deposits to be extended to cover the Holderness area. This is required for aquifer and drainage modelling and groundwater protection in the region. This report and accompanying 3D geological model are intended to help the Environment Agency meet its regulatory requirements under the Water Framework Directive and Catchment Abstraction Management Strategy. It will provide a better understanding of the most vulnerable groundwater areas around public supply boreholes north of Hull, and allow for more targeted protection measures.

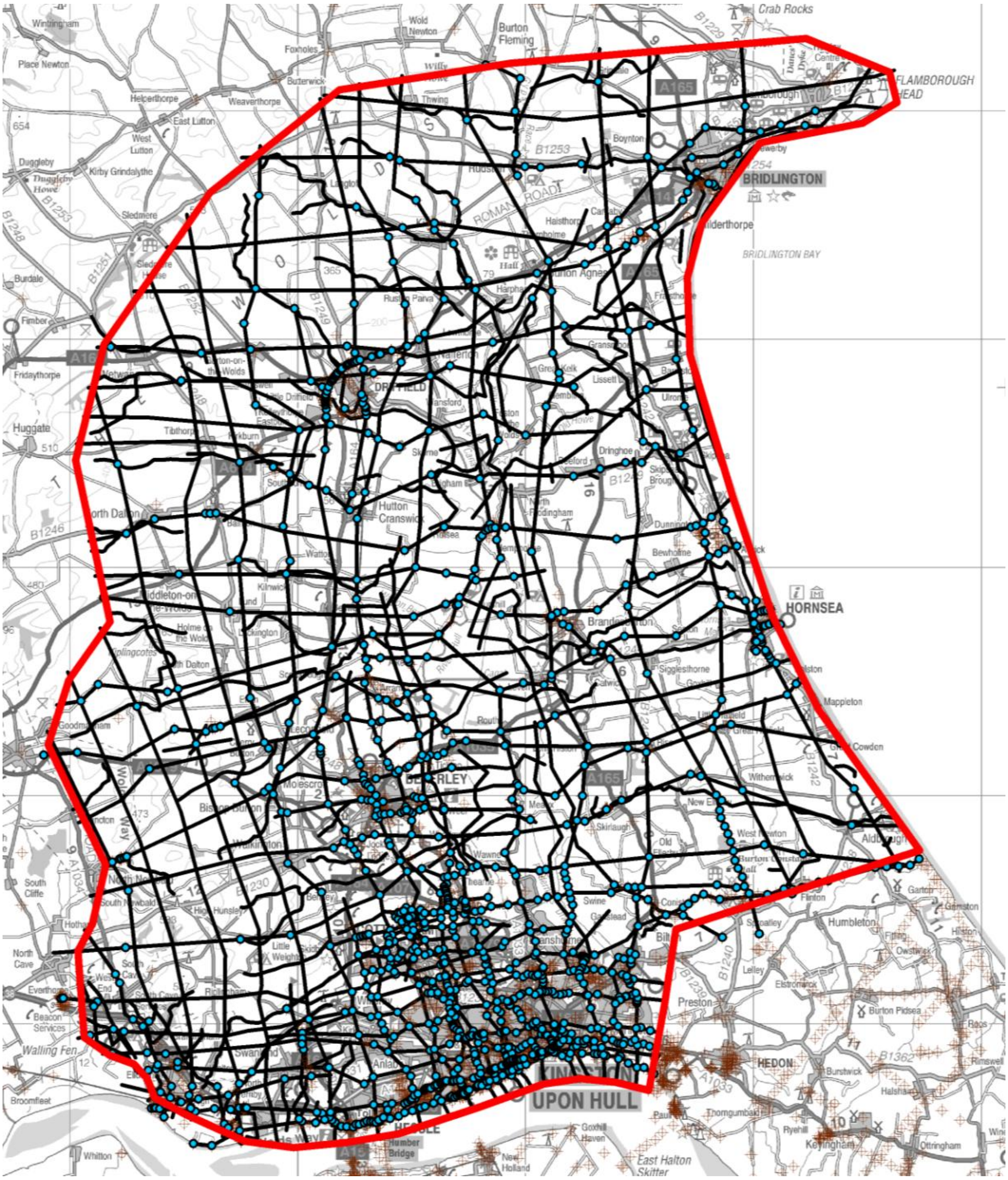


Based on OS topography © Crown Copyright. All rights reserved. BGS 100017897/2010. 10km grid squares.

Figure 1. 3D model study areas of Hull (blue) and Holderness (red)

The 3D geological model used 1398 BGS boreholes (including 525 used in the Hull model) and 74 cross-sections (including 32 created for the Hull model) to create an ‘egg crate’ model of the Holderness area, from which gridded surfaces were generated. The 3D model covers an area of approximately 1280 km^2, from Hull in the south to Flamborough Head in the north (Figure 2).

The ground surface elevation data, which caps the 3D model and provides start heights for borehole logs, was derived from NEXTMap data (sub-sampled to a 100m cell size). It is important to note here that there may be discrepancies with true depths of geological units recorded in borehole logs in areas where the land level has been artificially changed, such as along major transport routes. There may also be minor discrepancies between the NEXTMap DTM and the Ordnance Survey contour-derived DTM. It is important to point out that not every borehole used to construct the 3D model reaches as far as the chalk in the area where the superficial deposits are thicker.



Based on OS topography © Crown Copyright. All rights reserved. BGS 100017897/2010. 10km grid squares.

- Lines of section
- Boreholes used in cross-sections
- Borehole locations

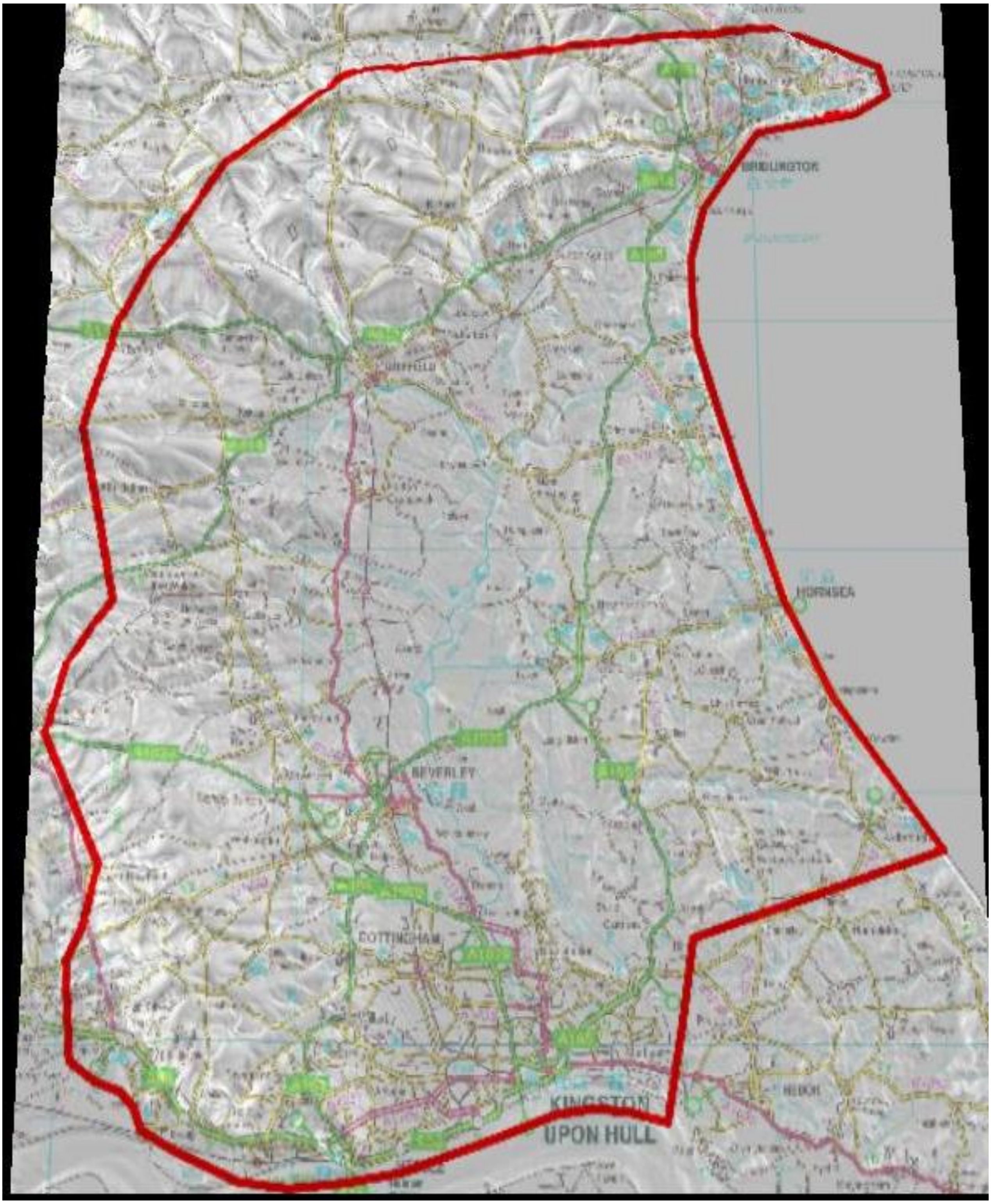
Figure 2. Cross-section positions and borehole locations

2 Location and Topography

The project area covers the whole of Hull and the northern edge of the Humber Estuary as far as Marfleet, northwards to Bilton; it includes the east Yorkshire coast from Aldbrough to Flamborough Head and extends westwards to Wetwang and Market Weighton (

Figure 3).

In general, the superficial deposits occupy the lower ground within the project area, with exposed bedrock occupying a higher plateau area to the north and west, where the ground rises to 150-160m above Ordnance Datum (OD). The dip slope of this escarpment leading up to this bedrock plateau is incised by head-filled valleys, which radiate from an east-west to a north-south trend, reflecting the curvature of the escarpment. Alluvial deposits associated with the Humber and its tributaries occupy the lowest ground (below 5m above OD) along the Humber estuary and extend northwards through the middle of the project area. This low ground is bounded to the east by a 20m high ridge, which slopes gently eastwards towards the coast.



Based on OS topography © Crown Copyright. All rights reserved. BGS 100017897/2010. 10km grid squares.

Figure 3. Topography and project boundary of the study area

3 3D modelling methodology

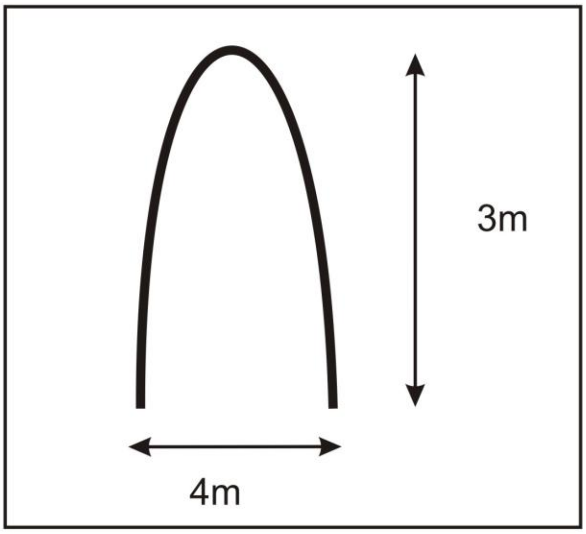
To integrate the revised project area with the pre-existing Hull model, a series of cross-sections from the Hull model were extended and additional sections were added to take into account specified areas of interest. As in the previous Hull work, the base of the model is cut off at 50m below OD. Given the extent of the additional study area, the cross-sections in the pre-existing Hull model are more closely spaced (500-1000m apart) than those for the additional area (1000-2000m spacing). The Hull model was not revised and 1:50,000 scale geological map data were used for the entire modelled area.

Artificial Ground was represented in the original Hull geological model as MADE_A, which is restricted to the original Hull project area in the 3D model. This comprises instances of artificially raised ground, such as the docks adjacent to the Humber. MADE_A was captured in the same was as other geological units, with cross-sections and ‘envelopes’. For continuity, the area of MADE_A representing the docks was extended eastwards to the edge of the Holderness project area.

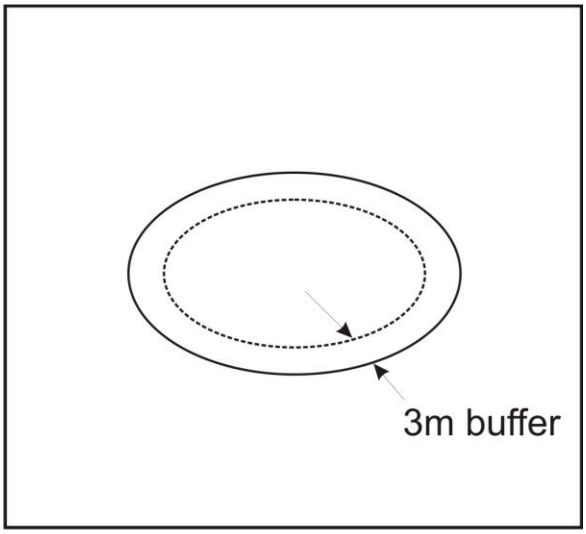
For the remainder of the Holderness project area, Artificial Ground was captured in a GIS using 1:10,000 and 1:50,000 scale Ordnance Survey Maps, NextMap surface model hillshade and aerial photographs. Four subdivisions of Artificial Ground were modelled: Made Ground, consisting of artificially raised areas such as road embankments (MGR in the 3D model); flood embankments along the River Hull and its tributaries (modelled as LEVEE); Worked Ground, e.g. pits and quarries (WGR in the model); and Worked and Made Ground, backfilled pits and quarries (WMGR in the model). Water-filled pits and ponds were also included in the WMGR category, as well as Hornsea Mere.

MGR and Levees were given a nominal thickness of 3m, and levees were given a nominal width of 4m (Figure 4a). Areas of WMGR were given a nominal thickness of 3m to enable their respective 2D polygons to be visualised as volumes in the 3D model. An internal buffer of 3m was applied to the outline of each WGR and WMGR polygon to give excavations a more realistic appearance, with sloping sides (Figures 4b and 4c). WGR was given a nominal thickness of 0.1m in order for excavations to display in the 3D model at the base of voids in the DTM (Figure 4d). Figure 34 shows the distribution of Artificial Ground in the 3D model. The bases of these units were generated by lowering the DTM by the nominal thickness values and extracting those areas using their modelled extents.

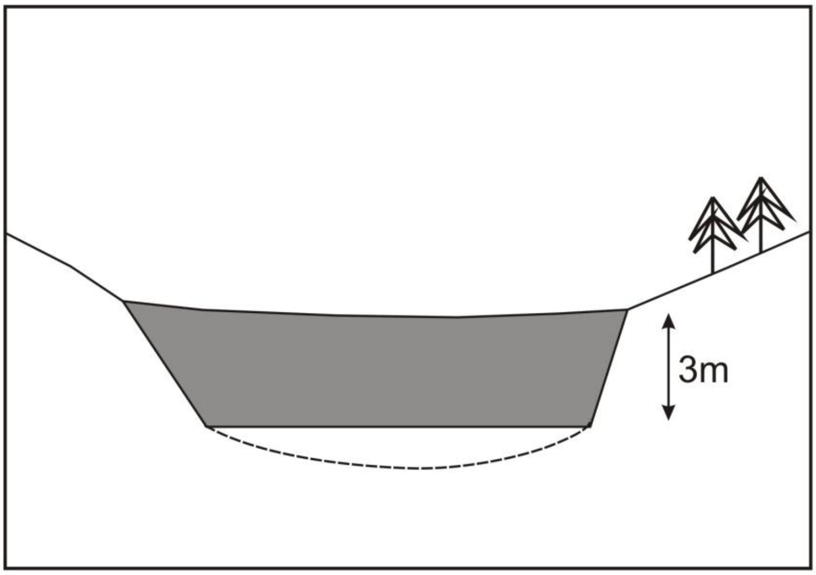
Other areas of made ground are modelled as MADE_A. MADE_A is modelled where made ground is indicated in existing DiGMap polygons and where recorded in borehole logs. For the Humber estuary area of Kingston-Upon-Hull, historic Ordnance Survey topographic maps were used to digitise areas where the foreshore has been extended into the estuary.



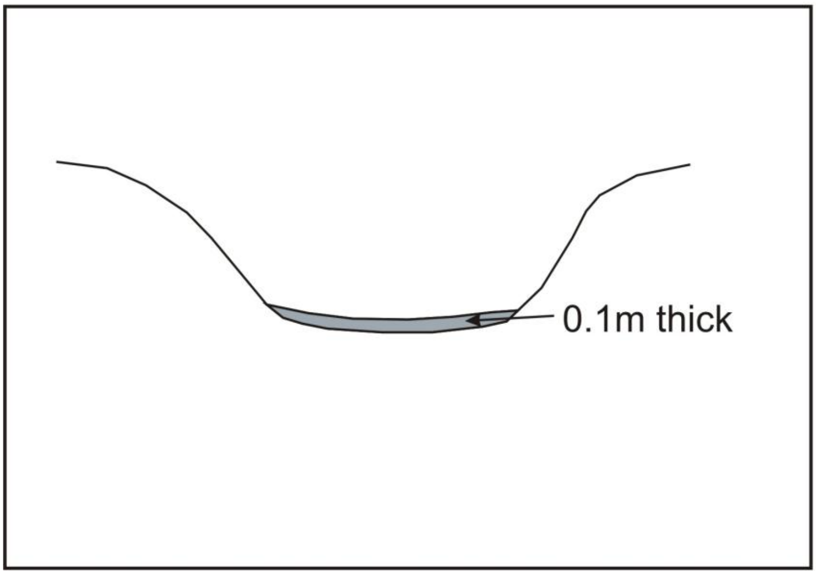
a) Construction of Levees



b) Buffering WMGR and WGR polygons



c) Modelling Worked and Made Ground (WMGR)



d) Modelling Worked Ground

Figure 4. Artificial Ground modelling methodology

4 Bedrock Geology

The investigation of the bedrock geology is not included in the project specification, but for completeness an outline of the strata are presented. Details of the local stratigraphy are contained in the BGS geological memoirs for the Hull area (Gaunt et al., 1992), and the Holderness area (Reid, 1885). However, many of the stratigraphical names and the ranks of the units have evolved over the years, the nomenclature in Table 1 is that used on the digital geological maps and detailed in the BGS online stratigraphical lexicon http://www.bgs.ac.uk/Lexicon/home.cfm

The majority of the project area is underlain by Chalk of Cretaceous age, with older Jurassic rocks outcropping in the south-west corner. According to geological map data, Jurassic rocks are also likely to occur beneath the Chalk throughout the study area. However, their eastern limit is represented in the model by an arbitrary line, which pinches out the Jurassic as the overlying base of the Chalk dips eastwards towards the 50m cut-off depth of the model. This contact honours borehole data where available. Contours of the surface of the chalk are shown in Figure 6.

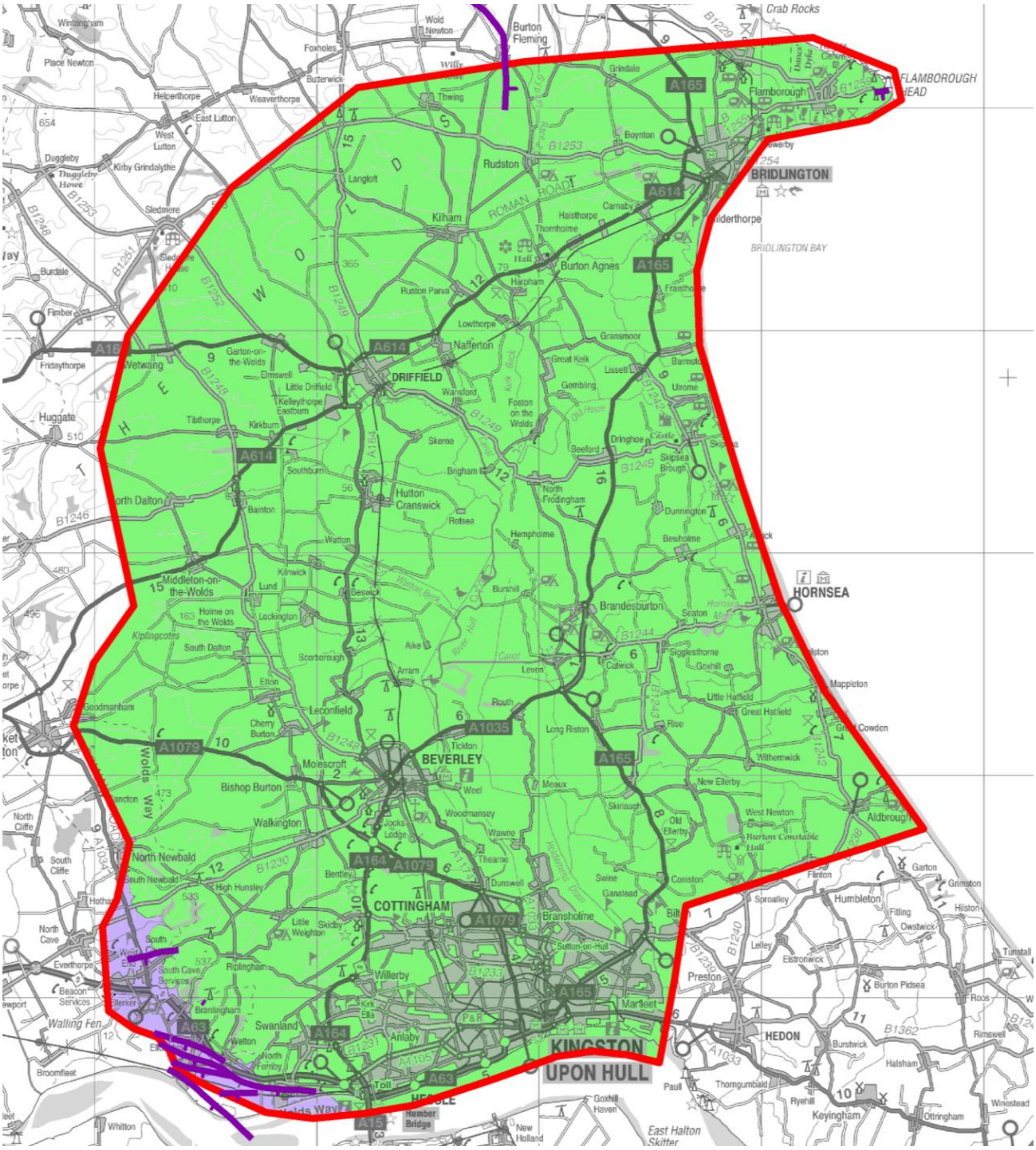
Seven normal geological faults derived from the 1:50,000 scale geological maps fall within the project area. Six of these only displace Jurassic rocks against themselves and one displaces both Chalk and Jurassic rocks. The maximum displacement on the fault in the Hull area (at NGR: 498080 425920) that offsets the Chalk and Jurassic rocks is only 4.3m and was deemed to be too insignificant to affect to have any bearing on the end use of the model. These faults have not been included in the 3D model because of limitations of the Lithoframe Viewer to be able to display them. The positions of the faults are shown in the bedrock geology map (Figure 5).

Deep basement structures in the project area are shown on the Tectonic Map of Britain, Ireland and Adjacent Areas (British Geological Survey, 1996). There are likely to be other geological faults in the area that have not been mapped. A paper on a seismic study by Kirby and Swallow (1987), for example, concludes that a fault zone exists in the Flamborough Head, rather than the single fault shown on the geological map. The 1:100,000 scale hydrogeological map of East Yorkshire (Institute of Geological Sciences and Yorkshire Water Authority, 1980) has a structure contour plot for the base of the chalk. This shows the chalk dipping gently eastwards curving to dip to the south east as it approaches the Flamborough Fault Zone and Flamborough Head.

The Chalk and Jurassic have not been subdivided in the 3D model, but are summarised in Table 1 for reference (listed from youngest at the top to oldest at the bottom).

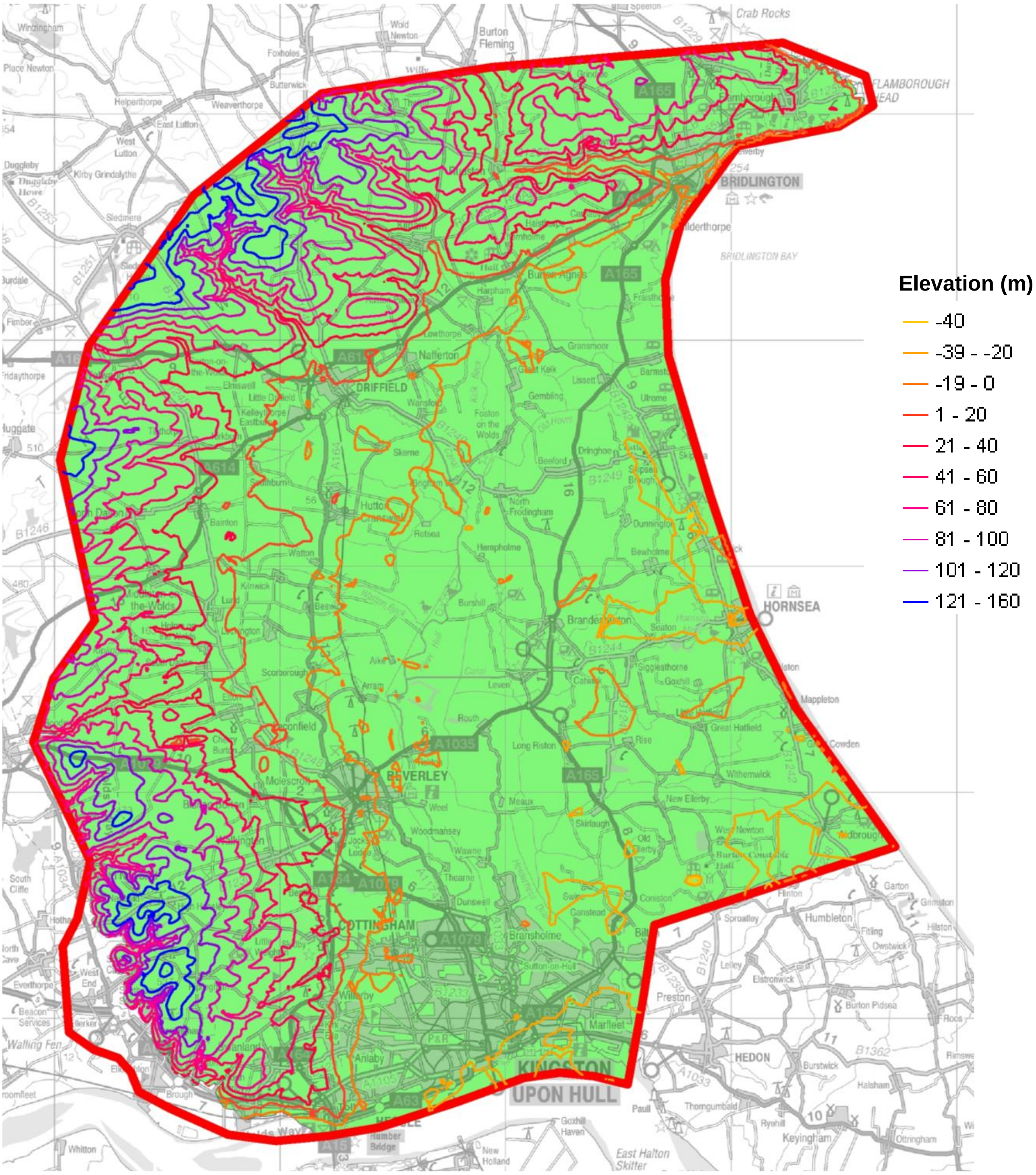
Table 1. Bedrock geology of the study area

Formation	*Description*	*Group*	*Age*
Rowe Chalk Formation	White flinty chalk with sporadic marl bands	Chalk Group	Cretaceous Not subdivided, modelled as CHLK
Flamborough Chalk Formation	White, well-bedded flint-free chalk with common marl seams (typically about 1 m)		
Burnham Chalk Formation	White, thinly bedded chalk with common tabular and discontinuous flint bands, sporadic marl seams		
Welton Chalk Formation	White, massive or thickly bedded chalk with common flint nodules, generally lacking tabular flint bands. Sporadic marl seams		
Ferriby Chalk Formation	Grey, soft, marly, flint-free chalk. Locally includes some pinkish bands, harder, gritty shell-rich beds and thin marl seams		
Hunstanton Chalk Formation	Rubbly to massive chalk with marl bands, typically pink to brick red, locally grey		
West Walton Formation	Calcareous mudstone, silty mudstone and siltstone with subordinate fine-grained argillaceous limestone or siltstone nodules	Ancholme Group	Jurassic Not subdivided, modelled as JUR
Undivided Ancholme Group	Grey marine mudstones and silty mudstone, beds of argillaceous limestone nodules, siltstone and sandstone		
Kellaways Formation	Grey mudstone, commonly silty or sandy, with beds of calcareous silty sandstone		
Rutland Formation	Grey marine mudstone, passing up into non-marine siltstone, with a green-grey rootlet bed at the top. Local subordinate sandstones, shelly marine limestones and calcareous mudstones	Great Oolite Group	
Lincolnshire Limestone Formation	Limestone and grey ooidal, shelly grainstones. Commonly includes sandy limestone and substantial mudstone units	Inferior Oolite Group	
Whitby Mudstone Formation	Medium and dark grey fossiliferous, locally laminated and bituminous mudstone and siltstone, with silty mudstone and rare sandstone beds.	Lias Group	
Marlstone Rock Formation	Sandy, shelly, ooidal, ferruginous limestone, interbedded with ferruginous calcareous sandstone beds		
Charmouth Mudstone Formation	Dark grey, laminated shales and blue-grey mudstones		
Scunthorpe Mudstone Formation	Grey, often calcareous and silty mudstone with thin argillaceous limestone and calcareous siltstone beds		



Based on OS topography © Crown Copyright. All rights reserved. BGS 100017897/2010. 10km grid squares.

Figure 5. Bedrock in the study area: undivided Chalk (green); undivided Jurassic (lilac); faults (purple lines). Fault ticks indicate downthrown side.



Based on OS topography © Crown Copyright. All rights reserved. BGS 100017897/2010. 10km grid squares.

Figure 6. Contours of Chalk rockhead surface, taken from the 3D model (20m intervals)

5 Superficial Geology

5.1 INTRODUCTION

The superficial geology was discussed in the report relating to earlier work for the Environment agency, in the Hull area (Kessler et al., 2008). As the discussion relates closely to the whole of the Holderness area, it is reproduced here with some additions.

This description is based largely on local borehole records and published BGS reports on the Hull district. It also incorporates the broader knowledge of the geology of eastern England derived from other geological investigations in the region, and from additional information gained during this project.

The bedrock geology of the Holderness area is part of the Chalk Group, of Late Cretaceous age, with Jurassic rocks in the southwest, as described above. The low-lying terrain of the study area is bounded by the Yorkshire Wolds to the west and north, by the Humber estuary to the south and the North Sea to the east. Apart from where the Chalk is exposed on the Yorkshire Wolds, it entirely covered by superficial deposits of Quaternary age, mostly glacial till, but locally together with artificial (man-made) deposits.

The Quaternary deposits lie on a landscape composed of a network of valleys created during a period of prolonged denudation. This was a time of low sea level, before the onset of the Devensian glaciation, a major ice age which occurred throughout north-western Europe between 120,000 and 12,000 years ago. The pre-glacial sands and gravels would have been deposited by the rivers that had incised this landscape. There is evidence of an older (Wolstonian) Basement Till in the area (Catt, 1991, 2007), but the majority of the till is presumed to be predominantly of Devensian age.

The published literature (e.g. Catt, 2007) identifies three distinct layers of till, but the level of detail in the borehole logs used in this study usually makes it impossible to distinguish between them. Consequently, the till has been modelled as a single unit over much of the study area; but in places where there is a layer of gravel, sand, silt or clay within the till sequence, the till has been sub-divided (**Table 2** below). Even here, one must be cautious interpreting these as different till formations, as these intervening layers can lie within an individual till (see Catt 2007, fig.5).

An extensive buried cliff in the chalk bedrock runs through the study area, west of Hull towards Bridlington and sweeps round to the coast, where it is exposed at Sewerby (Bateman & Catt, 1996). This palaeocliff formed during the Ipswichian (128,000 to117,000 years ago, Catt 2007) an interglacial period prior to the Devensian glaciation, and can clearly be seen in the 3D model (Figure 6 and Figure 7). The palaeocliff provides evidence that the pre-Devensian landscape was a marine erosion surface or 'wave-cut platform' in the Chalk, which represents the shoreline during a period when the inferred relative sea level was approximately 2m above present OD (Catt, 2007).

Figure 7 shows the correlation between the mapped palaeo-cliff line and a bench in the top of chalk surface in some areas. This can clearly be seen in the 3D model, marked by a topographic bench-like feature, to the east of which the overlying superficial deposits thicken substantially.

The palaeocliff is incised by several deep channels. Although outside the project area, a similar channel in the Immingham area, reaching 80m below OD, is documented in the Grimsby and

Partington memoir (Berridge and Pattison, 1994). These channels are likely to have formed during the major sea level lowering at the onset of the last or previous glaciations and pre-date the glacial deposits in the area.

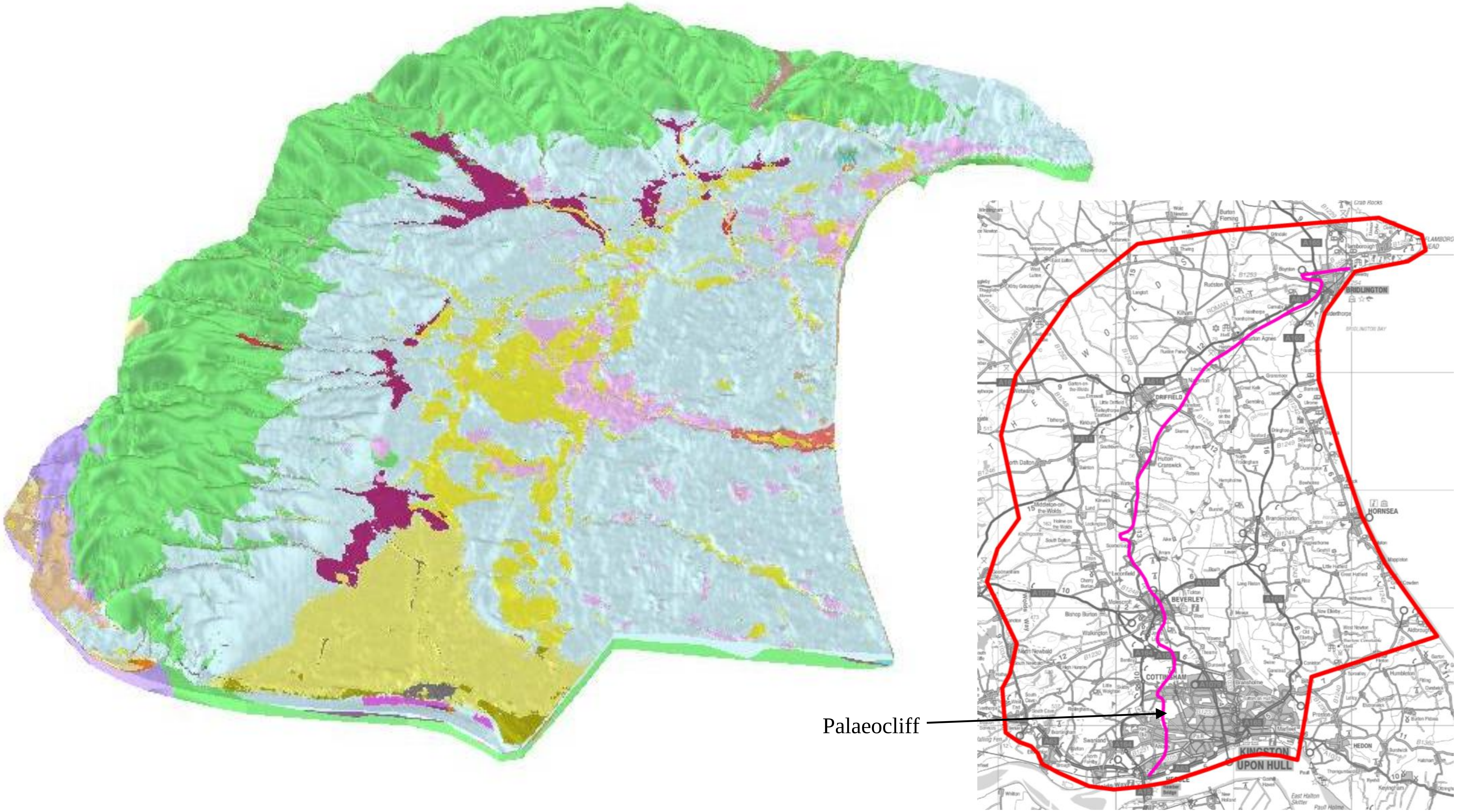


Figure 7. Location of the buried cliff line (topographic bench feature) as shown in the 3D model

The Devensian ice front is known to have been just to the east of the Yorkshire Wolds at the time of the Dimlington Stadial (Catt, 1991, 2007), between 22,000 and 13,000 years ago. This ice front may be responsible for the deposition of the moraine seen in the model (see MORAINE_B). Ponding of water by the ice and/or the moraine would have created conditions for the deposition of the lacustrine sediments in the area. In the model these have been correlated as CLAY_BAS (sub-till) and GLLD (intra-till). Interbedding of the clay with the till could indicate that the two units were deposited more or less contemporaneously (cf. Catt, 1991) or sequentially as to the west of the area in the Vale of York where laminated clays in proglacial Lake Humber underlie the till and gravels that form the Escrick Moraine, while later proglacial lake deposits sit above the moraine (Ford et al., 2008). The modelling work suggests that the Hull area moraine was formed where the glacier terminated in a proglacial lake, which was dammed by the ice blocking the Humber. In addition, small lakes were impounded by the Devensian ice in some valleys, often with interconnecting overflow channels. The unit SAND_A might represent deposits formed in such overflow channels.

The complex glacigenic sequence seen in the Holderness area records abrupt spatial and temporal changes in geological processes; these range between glaciolacustrine (glacial lake deposits), glaciofluvial (glaciofluvial deposits) and subglacial (till) environments. Similar sediment assemblages and rapid geographic changes in environment can be observed at the margins of many present-day glaciers and ice sheets. (Aldiss et al., 2004).

Upon deglaciation, differential compaction and settlement of the Quaternary deposits is likely to have occurred, particularly where bodies of buried ice gradually melted, leaving an uneven land surface. River valleys across the coastal plain typically follow channels that were probably cut through the glacigenic deposits by meltwater emanating from the ice sheet, perhaps following those already established by subglacial streams.

The Hull area features upper deposits of clays, silts and peat that form a fining-upwards tidal-flat sequence following the deglaciation and sea-level rise during the Holocene. As the sea rose to its present level, alluvium and the lower-level peat initially filled the channels. Later, the deposits were spread thinly over the adjacent low ground, with expanses of peat followed by the silts and clays. Some of the fine-grained sediments include ‘warp’, an artificially deposited silt and clay sequence formed in the last two or three centuries by controlled flooding to raise the land level and improve the quality of agricultural land. This deposit is difficult to separate from the underlying natural deposits and is therefore included in the Tidal Flat Deposits in the 3D model.

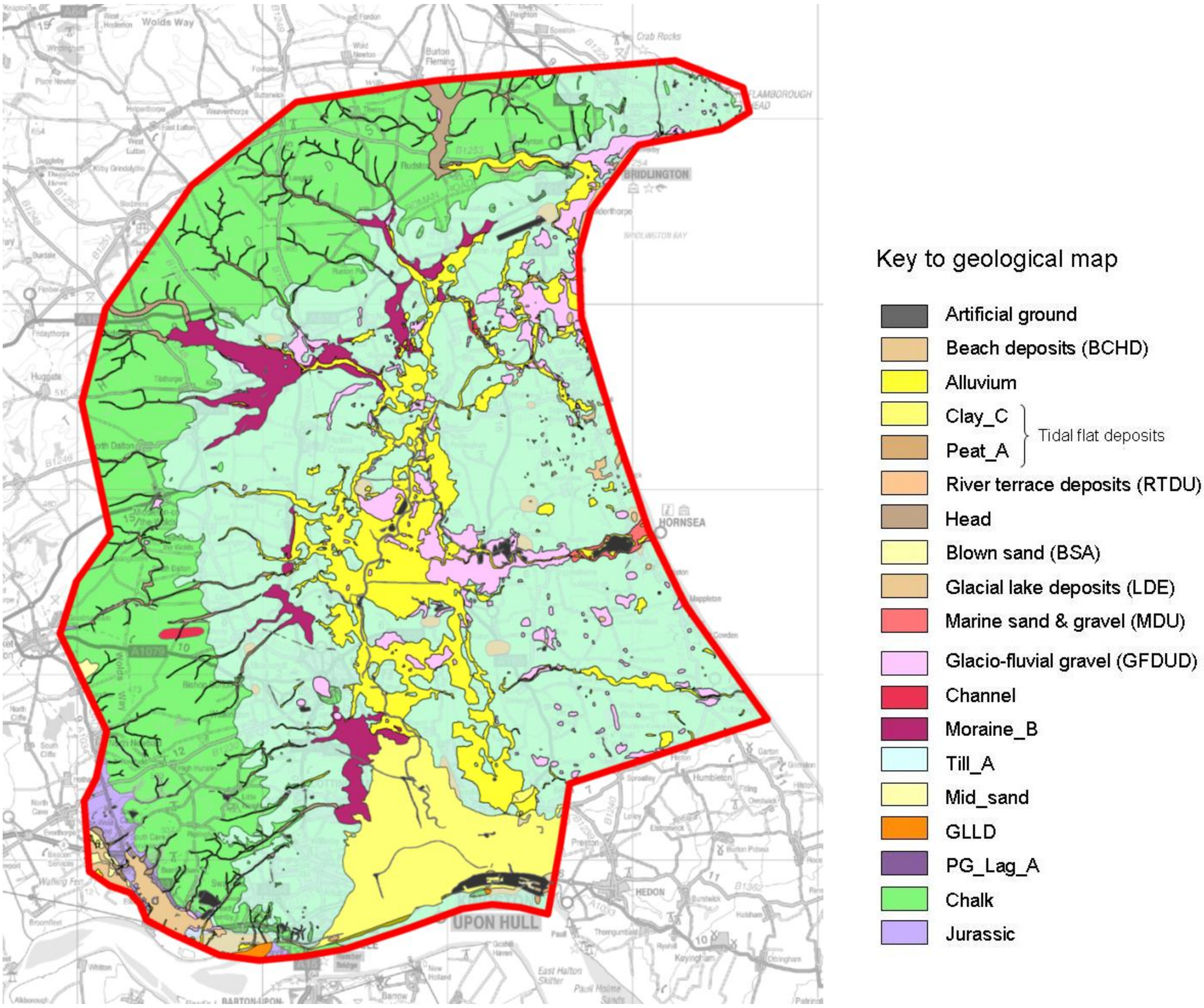
Running north to south from Burton Agnes, through Cottingham, towards Hull is a broad strip of alluvial deposits associated with the River Hull and other small rivers.

The generalised sequence modelled in the area and codes used to designate the units of the model is summarised in Table 2 with the youngest deposits at the top.

Table 2. Artificial and Superficial geology of the study area

Unit	Subdivision	Model code	General lithological characteristics and comments
Artificial Ground	Made Ground	MGR	Artificially raised deposits above the surrounding area (not including levees). See Modelling Methodology for details.
	Made Ground	LEVEE	Flood embankments along the River Hull and its tributaries. See Modelling Methodology for details.
	Worked Ground	WGR	Excavations which have not been backfilled. See Modelling Methodology for details.
	Worked and Made Ground	WMGR	Excavations which have been backfilled, includes water-filled ponds. See Modelling Methodology for details.
	Made Ground	MADE_A	Only modelled in the Hull project area. Comprises man-made deposits raised above the surrounding area or filling excavations. Captured as polygons and cross-sections.
Beach Deposits		BCHD	Sand and gravel. Modern and interglacial shoreline deposits.
Alluvium		ALV	Clay, silt, sand and gravel
Peat		PEAT	Peat
Tidal Flat Deposits	Clay	CLAY_C	Soft clay, peaty and silty
	Silt	SILT_B	Soft silt and sandy silt
	Peat	PEAT_A	Soft peat
Basal Clay		CLAY_A	Soft clay, often laminated
River Terrace Deposits		RTDU	Sand and gravel
Blown Sand Deposits		BSA1	Sand, mainly dune forms. Age relationships with other Holocene deposits uncertain
Head		HEAD	Clay, silt, sand and gravel
Glaciolacustrine Deposits at or near surface		LDE	Laminated clay, silt, sand and gravel
Marine Deposits		MDU	Sand and gravel
Glaciofluvial Deposits		GFDUD	Sand and gravel
Channel		CHANNEL	Sand and gravel
Glaciofluvial sand and gravel at surface – morainic deposits		MORAINE_B	Sand and gravel with till and clay in places.
Glacial Till (upper)		TILL_A	Firm to stiff sandy, silty clay with gravel and boulders
Glaciofluvial sand and		SAND_A	Lenses of sand and gravel, silty sand

gravel lenses in Glacial Till			in parts
		MID_SAND	Intra-till deposits of sand with some gravel and silt
		MID_GRAVEL	Intra-till deposits of gravel with some sand and silt
Glaciolacustrine Clay near middle of glacial sequence		GLLD	Laminated clay and silt; sand in places
Glacial Till (lower)		TILL_B	Firm to stiff sandy, silty clay with gravel and boulders
Glaciolacustrine Clay near base of glacial sequence		CLAY_BAS	Laminated clay and silt
Glaciofluvial Sand and Gravel at base of glacial sequence		PG_LAG_A	Clayey sand and gravel
Weathered bedrock (marl and putty chalk)		MARL_A	Weathered chalk that reduces to a clayey chalk (marl) or soft chalk (putty chalk)



Based on OS topography © Crown Copyright. All rights reserved. BGS 100017897/2010. 10km grid squares.

Figure 8. Composite geological map of the study area (derived from the 3D model)

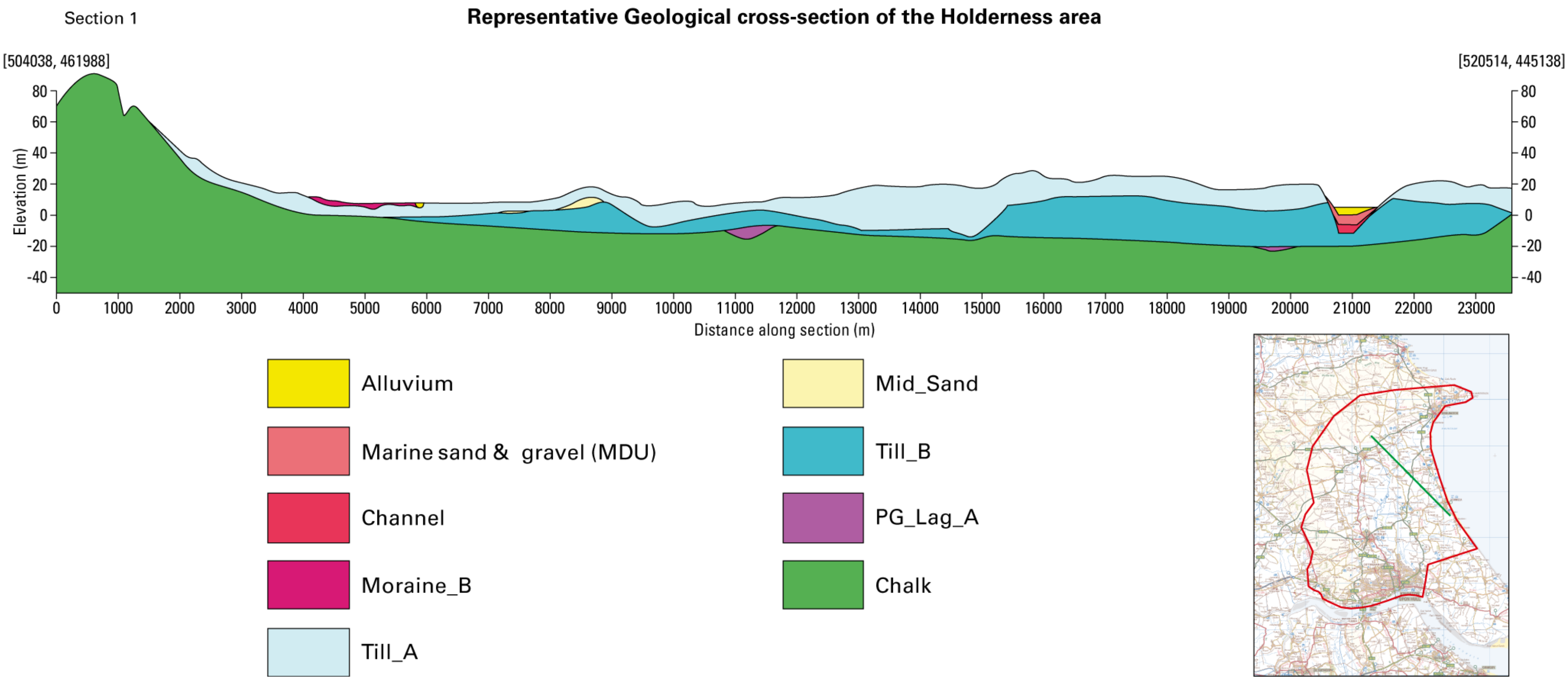


Figure 9. Geological cross-section oriented NW-SE, from the palaeocliff to the channel in the Holderness area

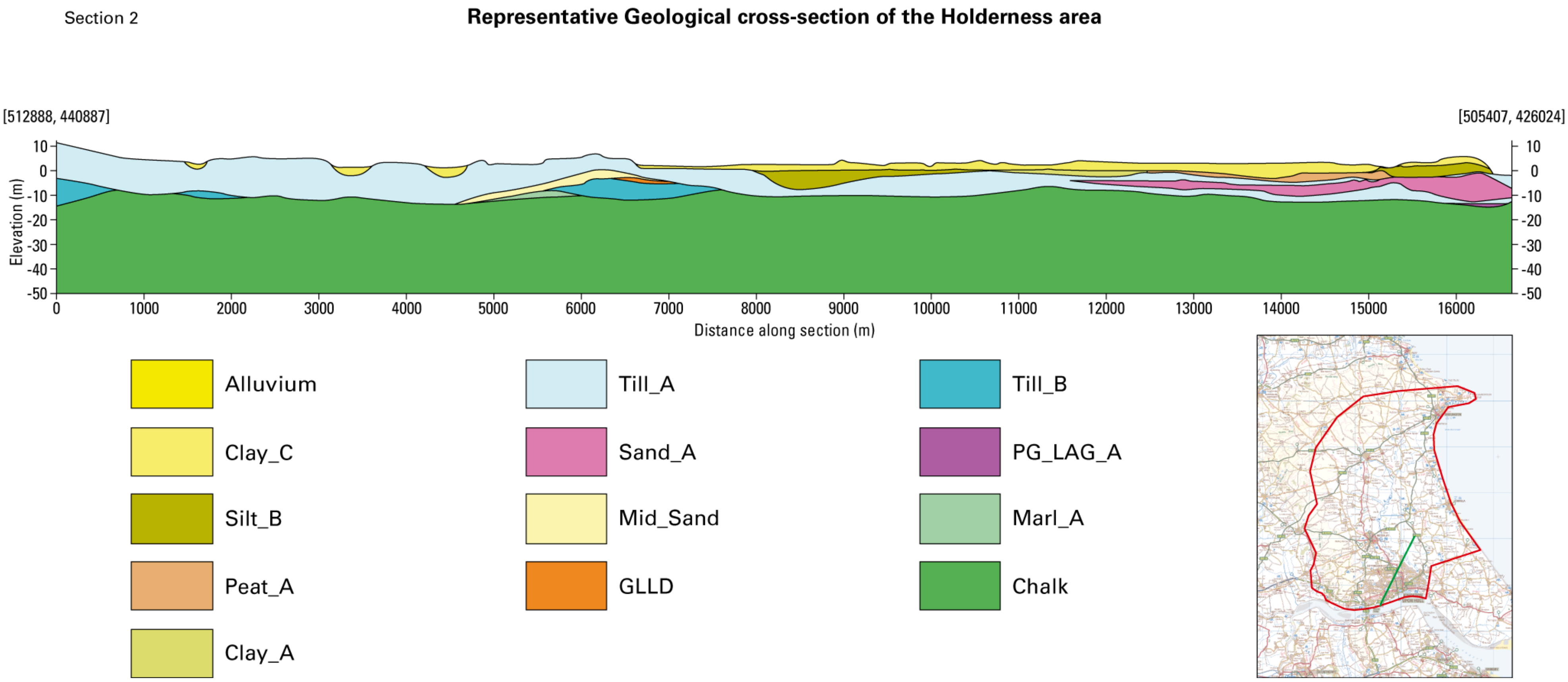


Figure 10. Geological cross-section oriented NE-SW through the alluvium and tidal flat deposits of the Hull area

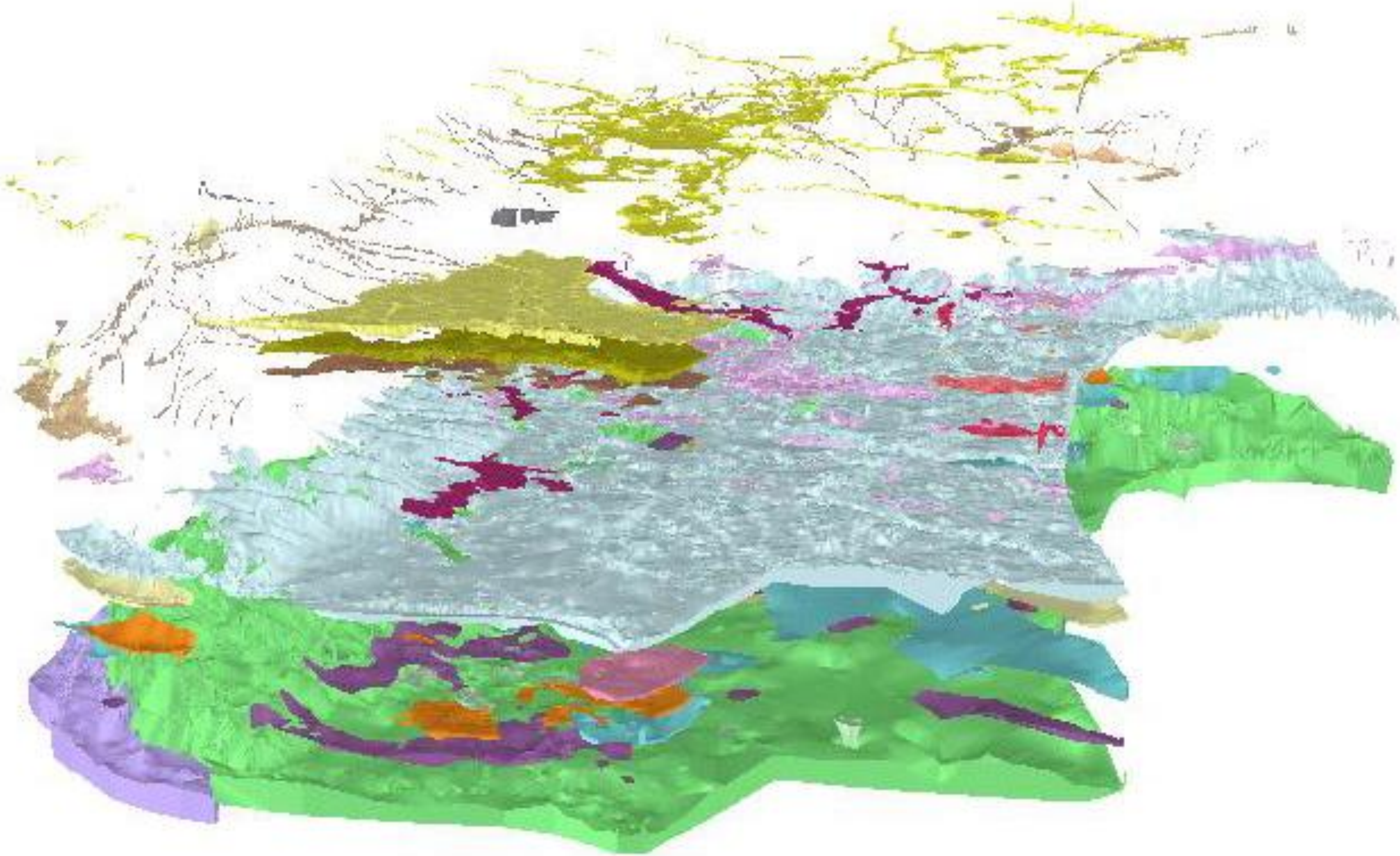


Figure 11. Exploded view of the Holderness 3D model

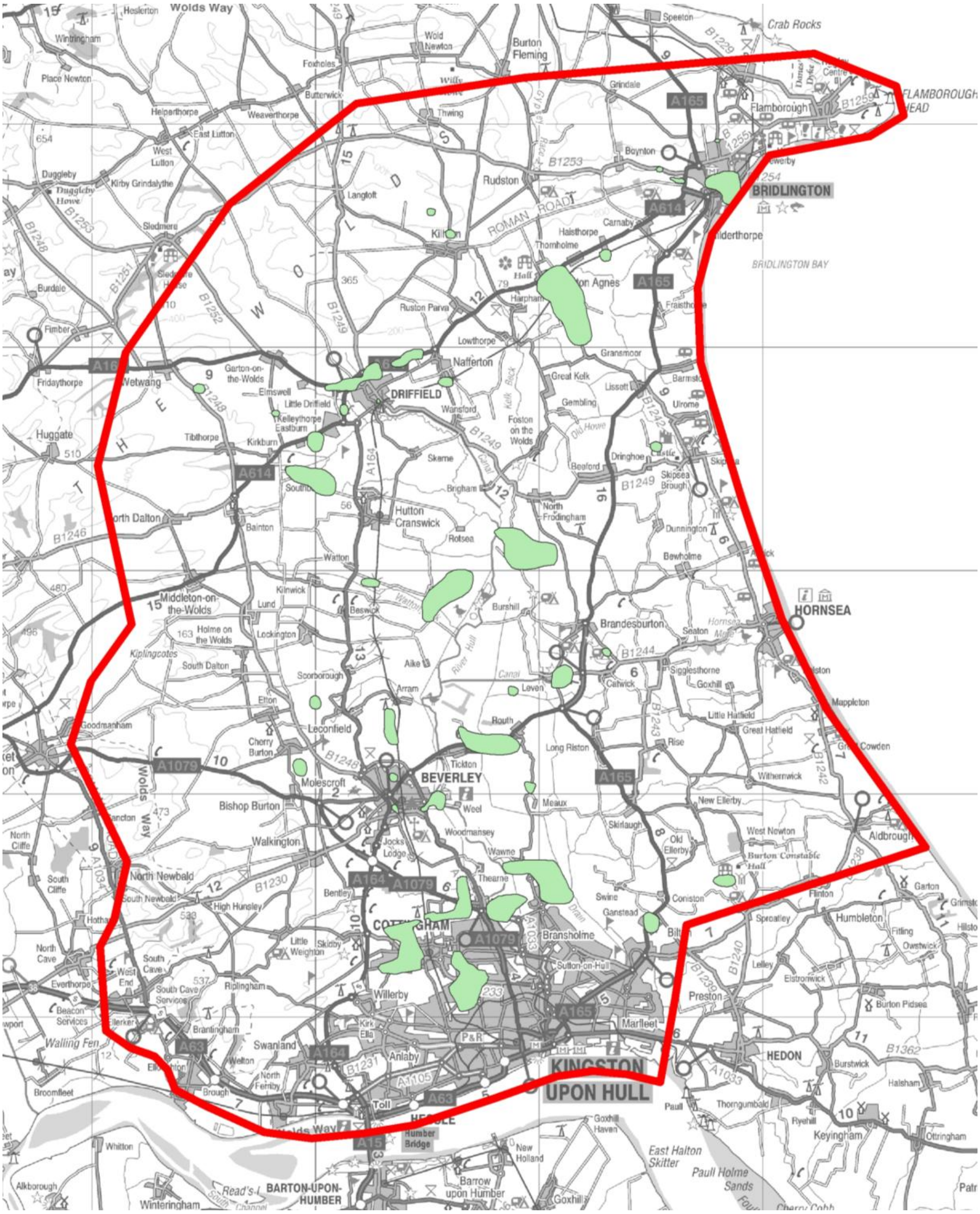
DESCRIPTION OF LITHOLOGICAL UNITS

Many of the borehole records used in this study have only a very brief description of the lithologies. For example, a unit described as "Clay" could be alluvium, tidal flat deposits, head, till or glaciolacustrine. In interpreting this, a good deal of judgment had to be used, based on the likely stratigraphy at that location and depth. This obviously has an effect on the uncertainty within the model.

In the Hull model, CLAY_C, SILT_B and PEAT_A were characterised as Tidal Flat Deposits. These are confined to the low-lying tidal-flat area around the city of Hull.

5.1.1 Weathered bedrock (marl and putty chalk)

Patchy areas of weathered bedrock are present at the contact between the superficial deposits and the underlying bedrock. In boreholes these are variably described by drillers as marl or putty chalk and they may include flint fragments depending on whether or not the underlying Chalk formation contains flint. The marl and putty chalk are weathered chalk bedrock which generally reaches a thickness of up to a few metres, but can be up to 5m thick.

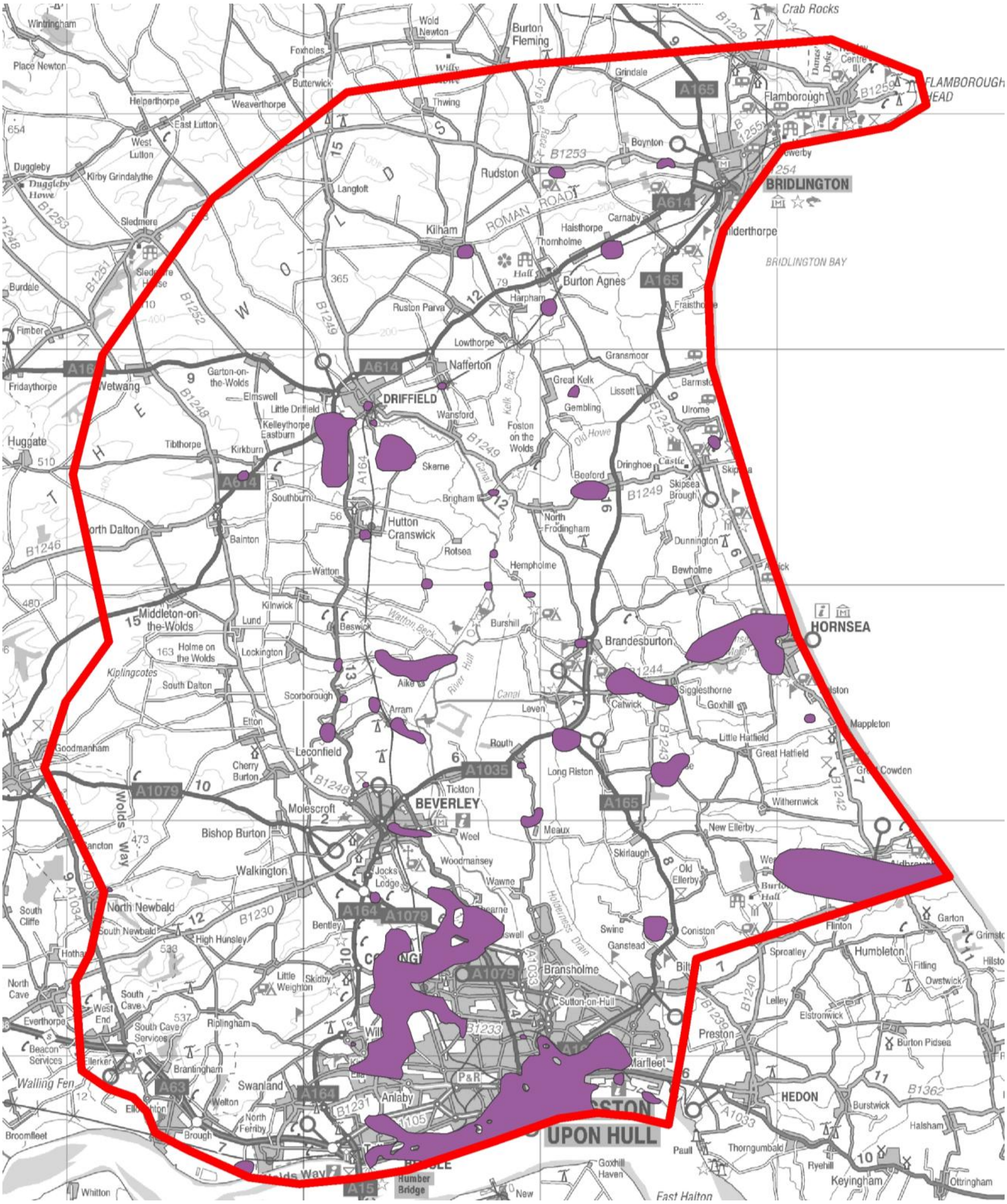


Based on OS topography © Crown Copyright. All rights reserved. BGS 100017897/2010. 10km grid squares.

Figure 12. Distribution of weathered chalk (MARL_A)

5.1.2 Glaciofluvial Sand and Gravel (base of the glacial sequence)

The base of the glacial sequence is marked by a deposit of clay-free sand and gravel, which may also include some gravel derived from weathered bedrock. This unit occurs in patches scattered over much of the study area, particularly in the south and west. Its thickness ranges from a few centimetres to more than 7m. Glaciofluvial deposits are typically derived from glacial meltwater streams.



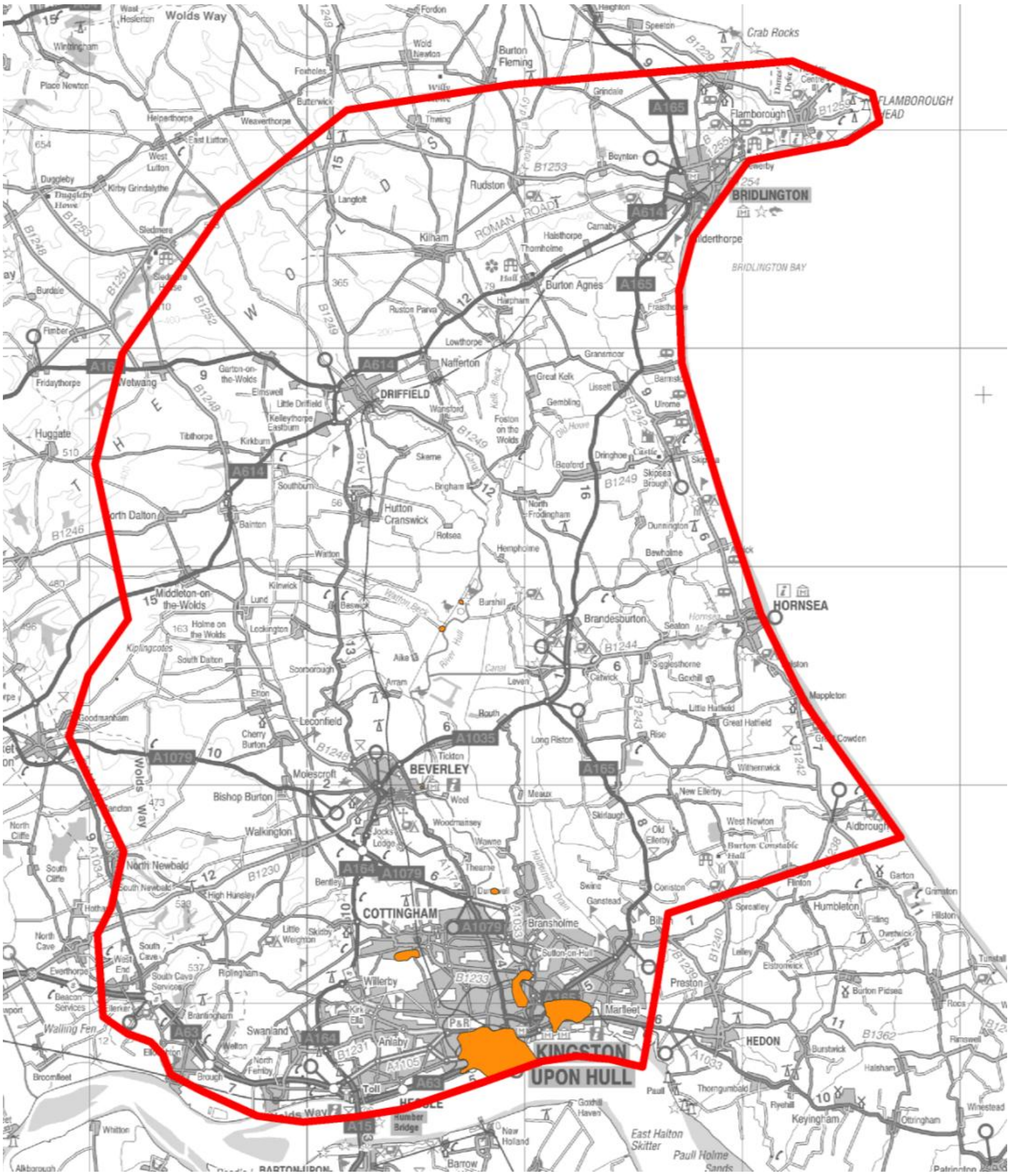
Based on OS topography © Crown Copyright. All rights reserved. BGS 100017897/2010. 10km grid squares.

Figure 13. Distribution of basal glacial sand and gravel (PG_LAG_A)

5.1.3 Glaciolacustrine Clay

Patchy clay, some of which is laminated, is present at the base of the glacial sequence, and is sometimes seen within the Till. The deposit is often silty, sandy and gravelly. It appears to represent glaciolacustrine deposits formed marginal to the ice as it advanced during the Devensian cold stage. It ranges in thickness from about 2m, thickening southwards up to about 8m. Glaciolacustrine clays typically consist of laminated clay, silt and fine sand, and accumulate in low-energy glacial lake-bed environments.

CLAY_BAS is a basal laminated clay unit, inferred to be glaciolacustrine in origin, which was modelled beneath both till units and rests on chalk, MARL_A or, PG_LAG_A. There is a degree of uncertainty where the boreholes do not penetrate the full superficial sequence, where CLAY_BAS may in fact be underlain by TILL_B. This was addressed by correlating GLLD where two till units were interpreted from the borehole records (see section 5.1.6). It is possible that these actually represent the same geological unit in some areas.



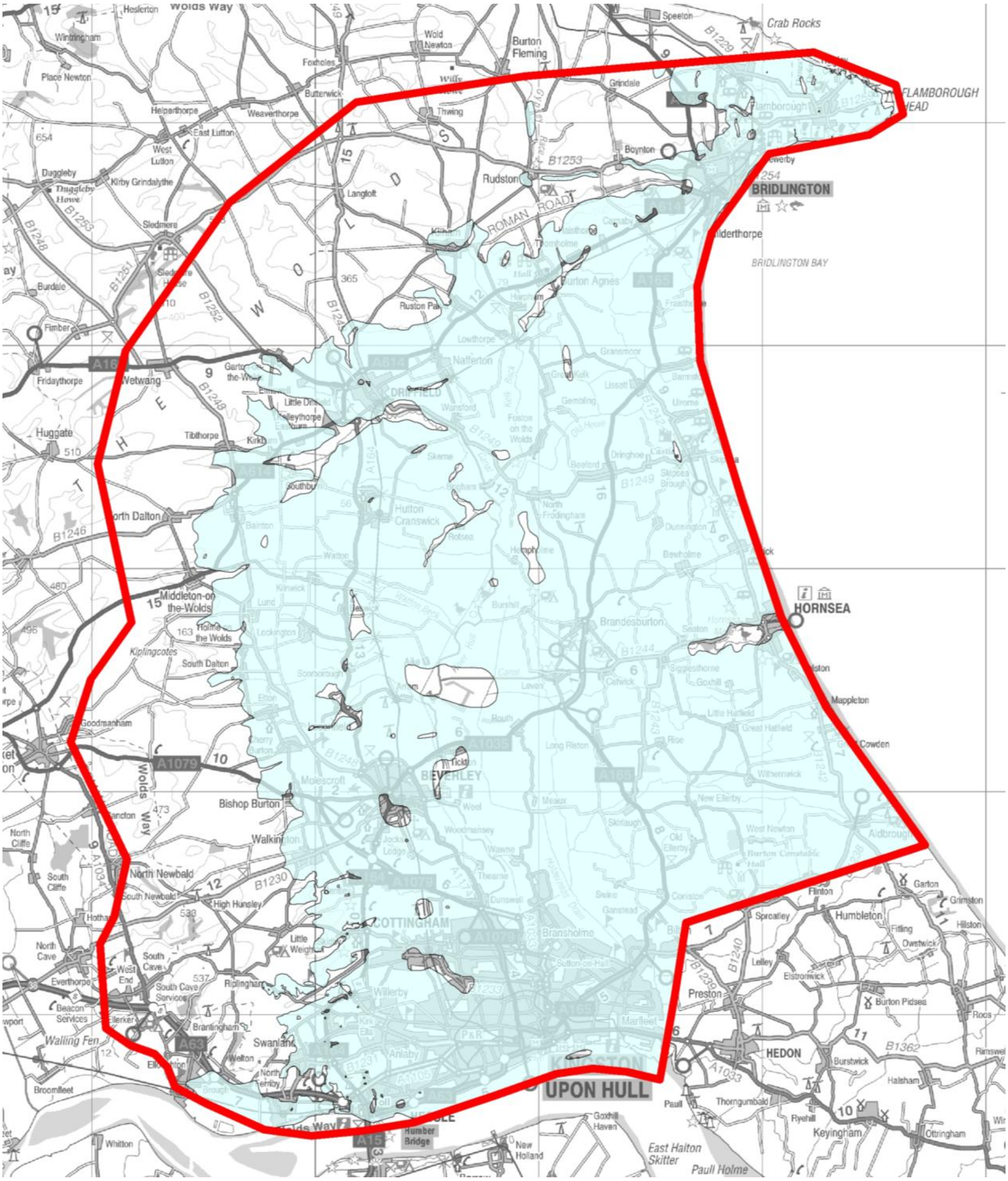
Based on OS topography © Crown Copyright. All rights reserved. BGS 100017897/2010. 10km grid squares.

Figure 14. Distribution of basal laminated glacolacustrine clay (CLAY_BAS)

5.1.4 Glacial Till deposits

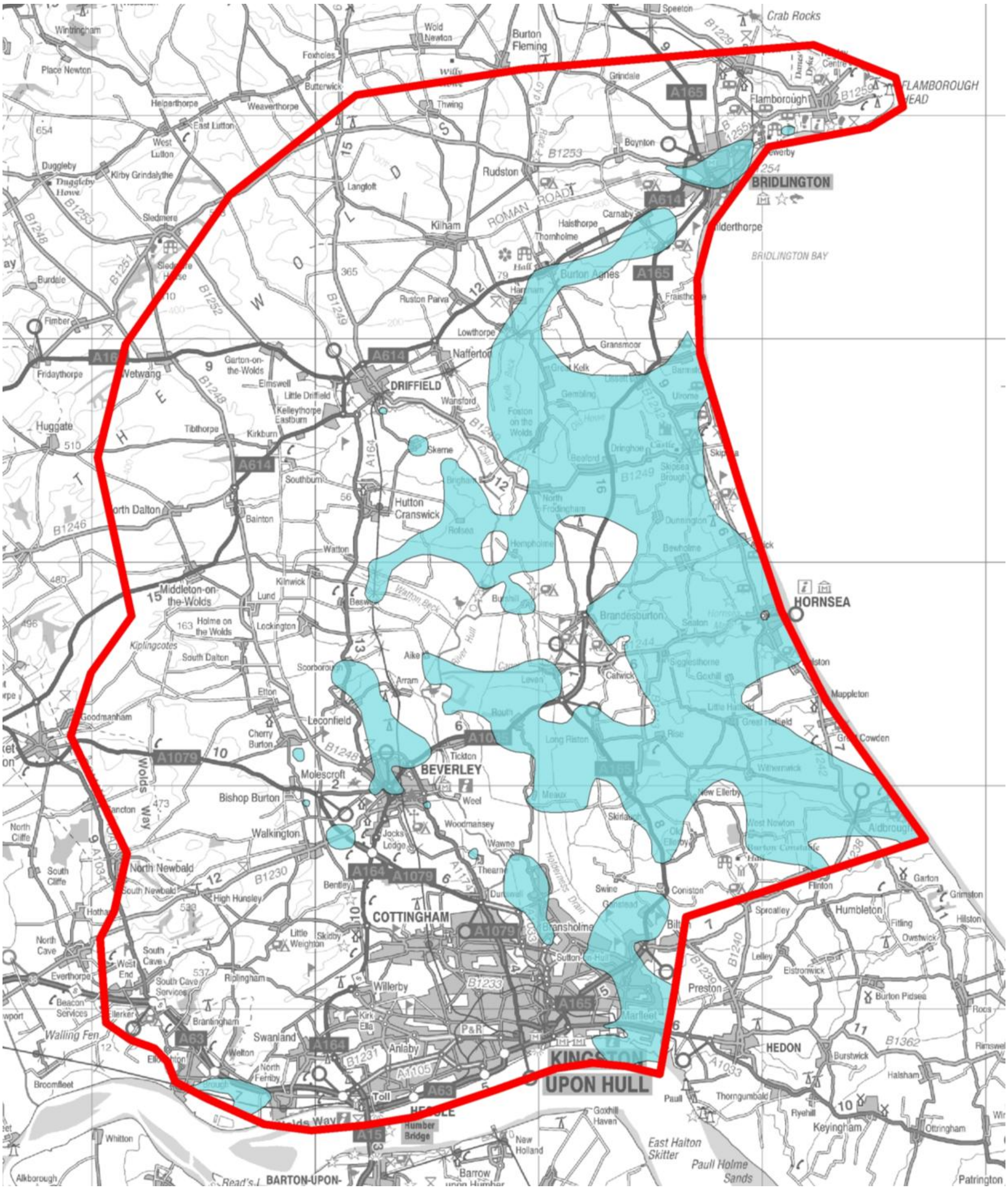
The glacial till is the main deposit from the last (Devensian) cold stage. Till is deposited by glacial ice, either at the glacier base or derived from material within and on the ice. It comprises gravelly sandy silty clay with boulders and contains numerous lenses of sand and gravel. The till is also likely to contain interdigitating units of glaciolacustrine clay, plus sand and gravel formed during ice advance and retreat. The more significant sand and gravel lenses have been mapped out from the boreholes and included in the sequence noted below in section 5.1.5. The till is 5-10m thick, reaching over 40m in places, and thickens towards the east. *Note: The sand and gravel; lens (SAND_A) has not been subtracted from the till thickness.* An intra-till glaciolacustrine clay unit has also been identified in the borehole records. This is described in section 5.1.6.

In the 3D model, two tills have been defined, separated by layers of gravel, sand and/or clay The published literature (Catt, 2007) identifies three separate till units in the region. However, the borehole data used in this project were not sufficiently detailed to distinguish between them. Where intervening layers of clay, sand and/or gravel are recorded in boreholes, the till has been split into two layers (TILL_A and TILL_B below), but this does not necessarily represent two temporally distinct tills, as these layers may have been deposited contemporaneously. Where there is no evidence of intervening lithologies, a single layer of till has been modelled.



Based on OS topography © Crown Copyright. All rights reserved. BGS 100017897/2010. 10km grid squares.

Figure 15. Distribution of the upper, main till unit (TILL_A)



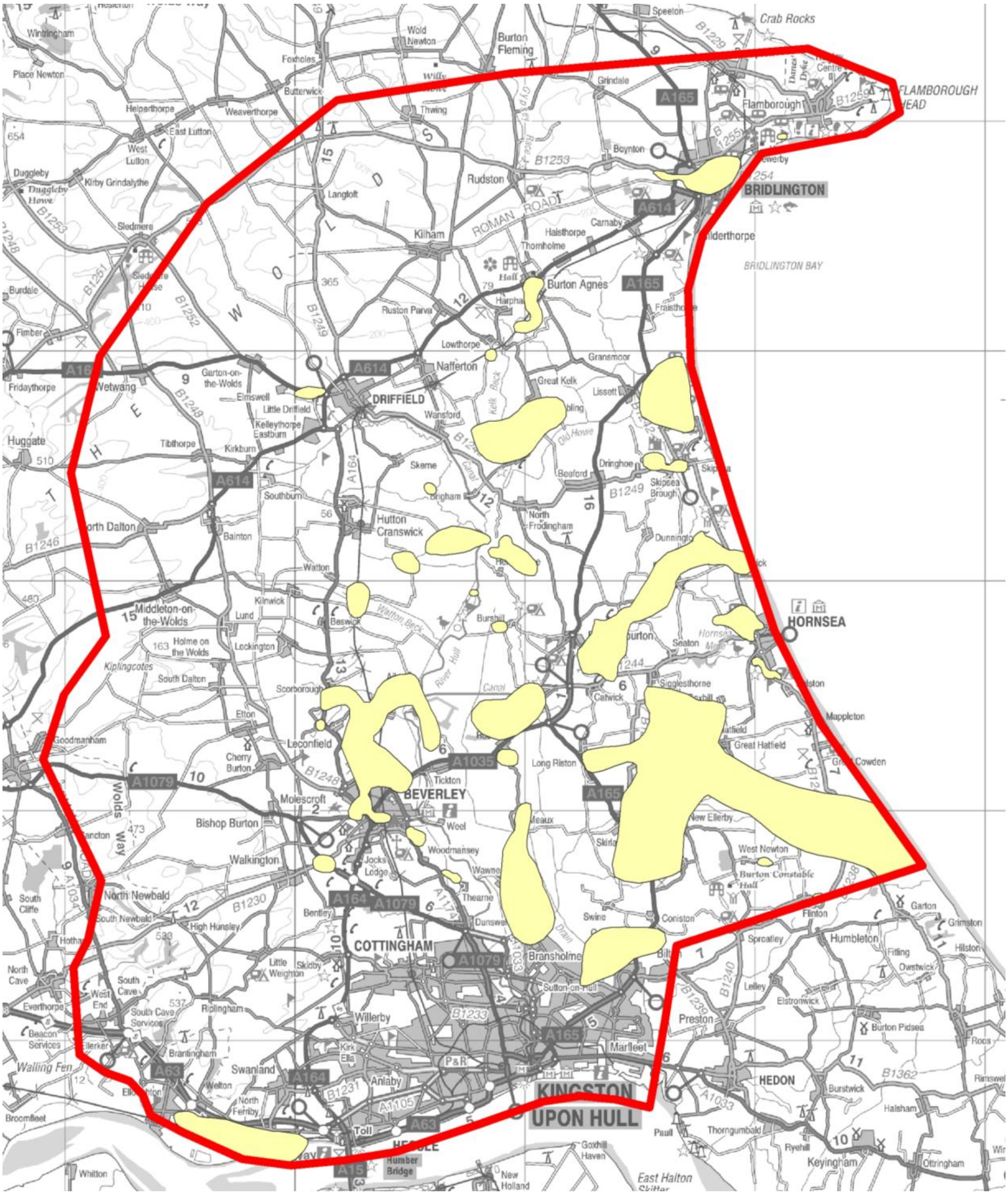
Based on OS topography © Crown Copyright. All rights reserved. BGS 100017897/2010. 10km grid squares.

Figure 16. Distribution of lower till unit (TILL_B)

5.1.5 Glaciofluvial Sand and Gravel deposits within the till

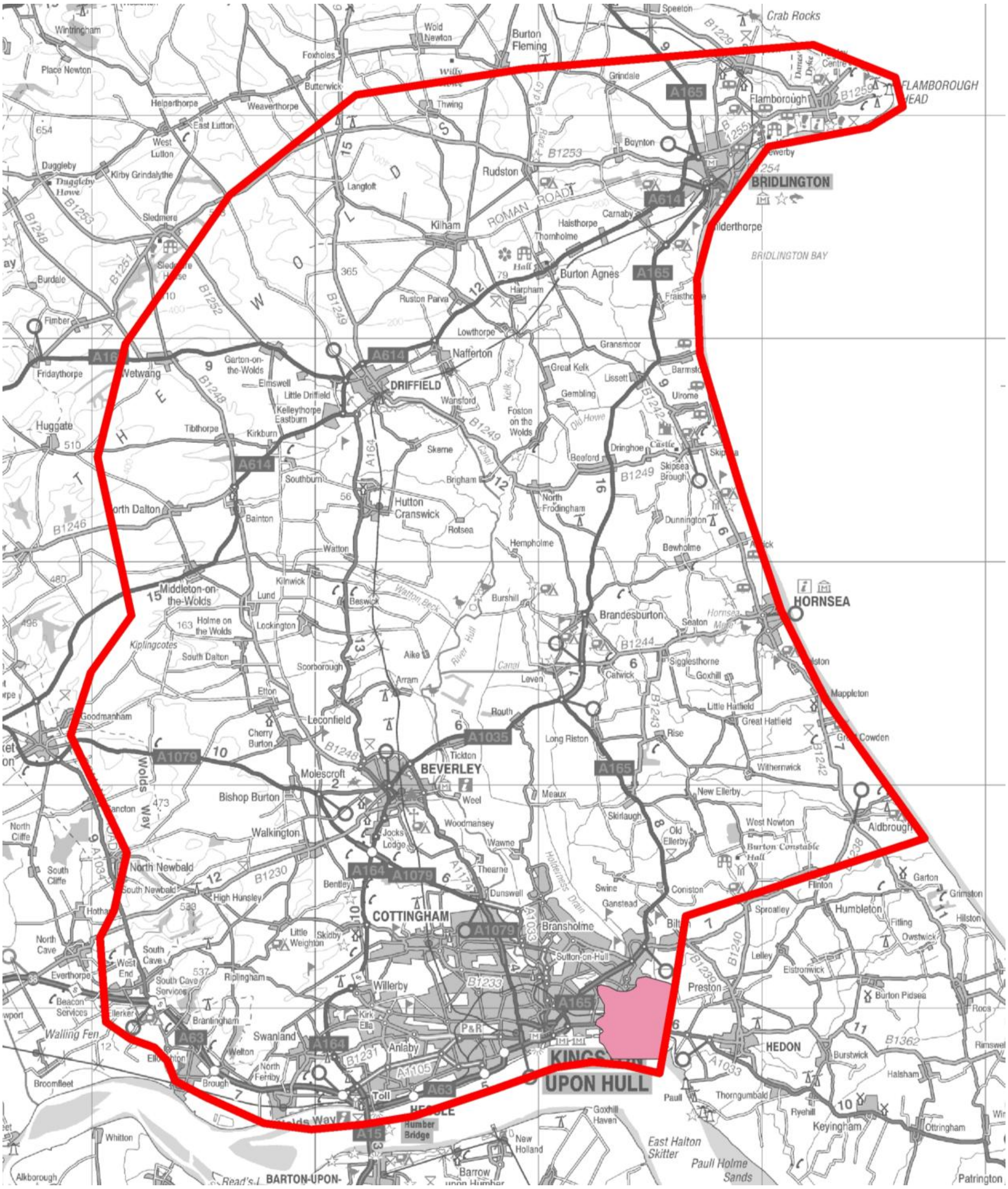
The areas of Glaciofluvial Sand and Gravel are restricted to the larger areas of sand and gravel proved by boreholes to be closely associated with the till deposits. They generally have a lower clay content and correspondingly greater proportions of sand and gravel, compared with the till. They are quite variable in thickness and composition, even over very short distances (a few tens of metres) ranging up to 18 metres, but with an average thickness is around 3 metres.

The deposits have been modelled as lenses within the till in the city of Hull area (SAND_A), and in the other areas as a layer of sand (MID_SAND) separating TILL_A and TILL_B. To the east of Hull, a layer of sand and gravel 5-7m thick, modelled as MID_GRAVEL, lies above the lacustrine clay, GLLD, over the basal TILL_B.



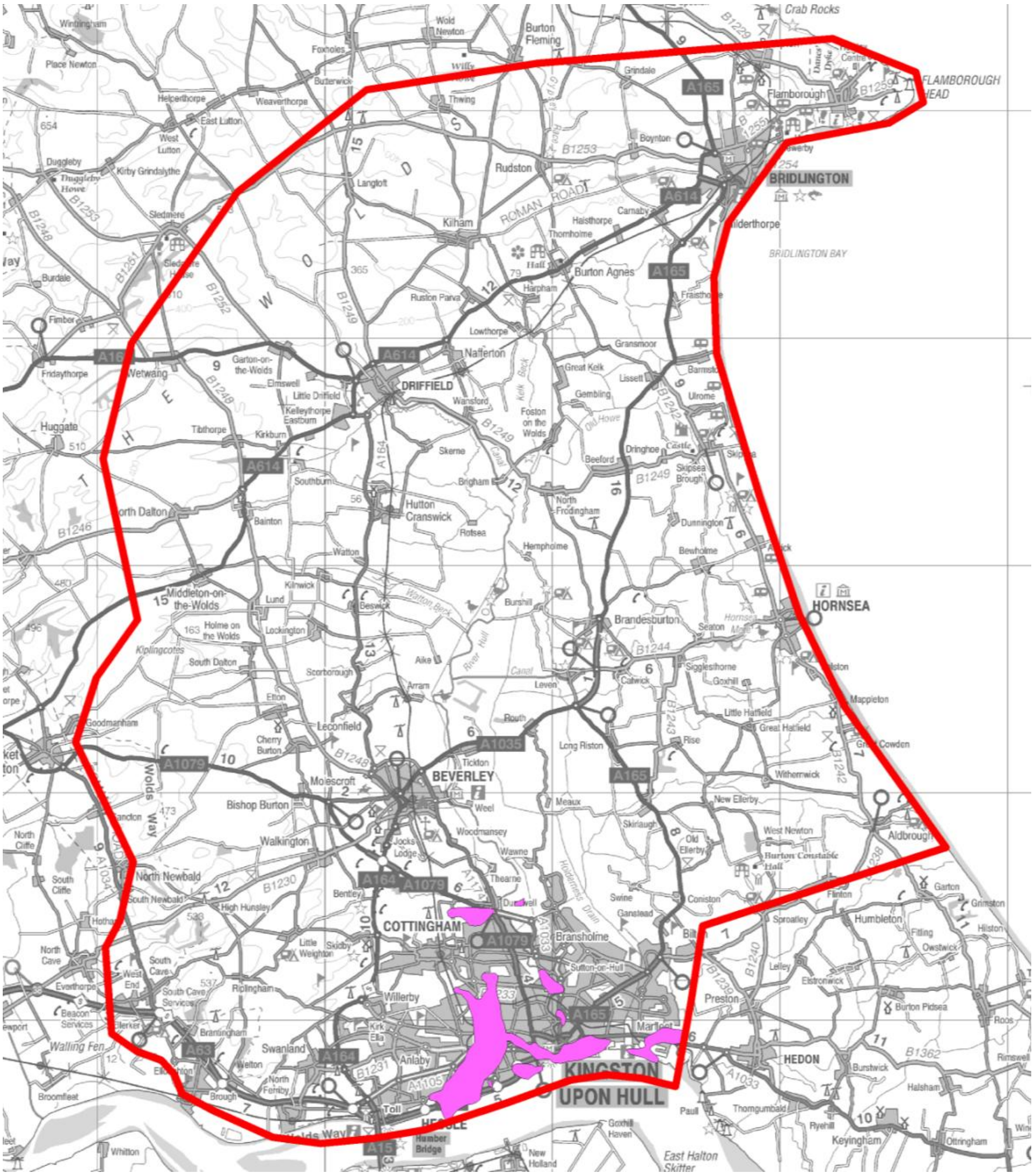
Based on OS topography © Crown Copyright. All rights reserved. BGS 100017897/2010. 10km grid squares.

Figure 17. Distribution of intra-till sand unit (MID_SAND)



Based on OS topography © Crown Copyright. All rights reserved. BGS 100017897/2010. 10km grid squares.

Figure 18. Distribution of intra-till gravel (MID_GRAVEL)

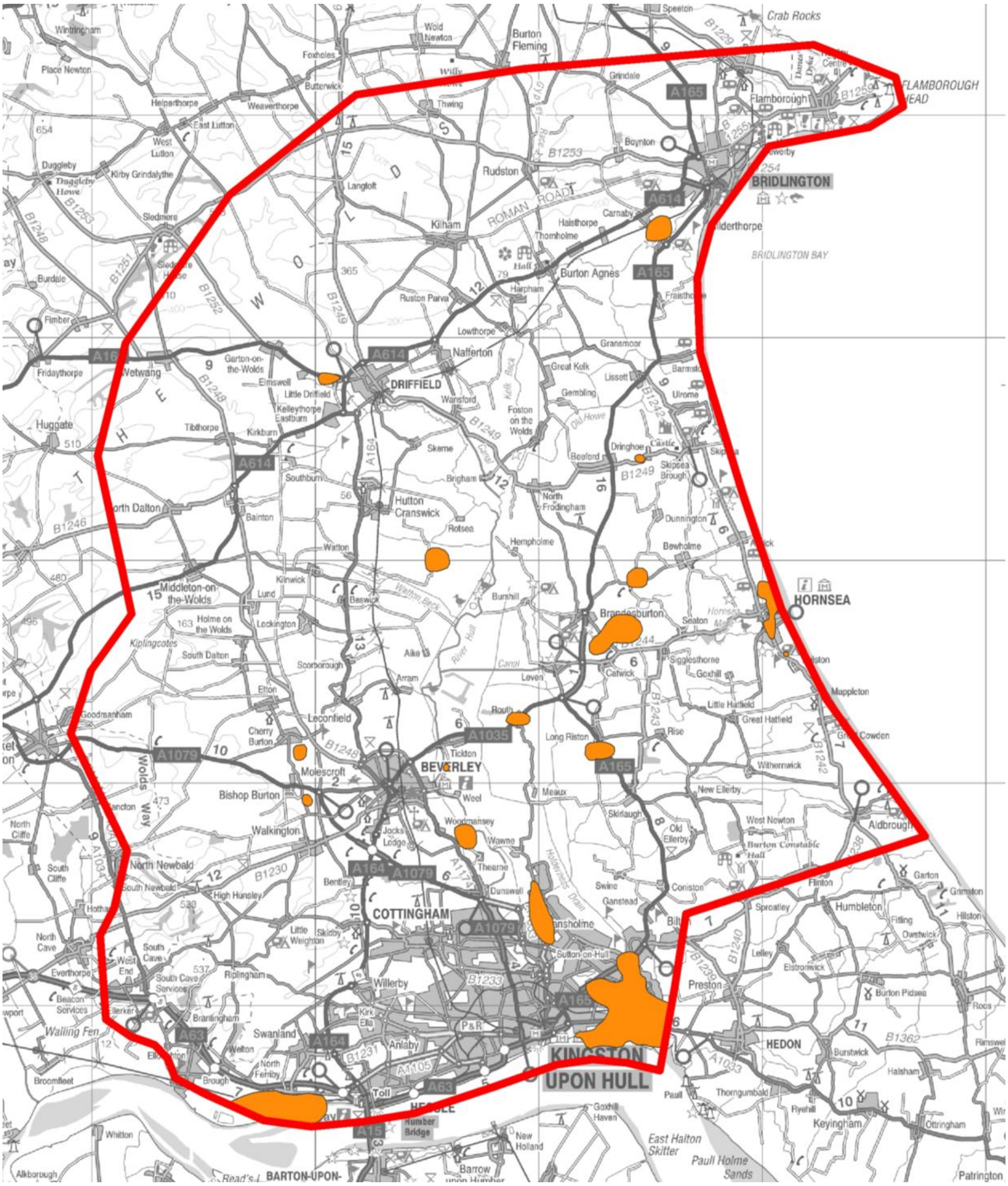


Based on OS topography © Crown Copyright. All rights reserved. BGS 100017897/2010. 10km grid squares.

Figure 19. Distribution of intra-till sand lens, SAND_A.

5.1.6 Intra-till glaciolacustrine clay deposits (GLLD)

Intra-till glacio-lacustrine deposits (GLLD) were identified in boreholes where a laminated clay is sandwiched between till units, Till A and Till B. These glaciolacustrine deposits represent temporary glacial lakes that form in topographic lows on the till surface. The laminated clay became incorporated into the till deposits when they were overridden during a later ice advance. GLLD was only correlated where there was clear evidence in the borehole logs.

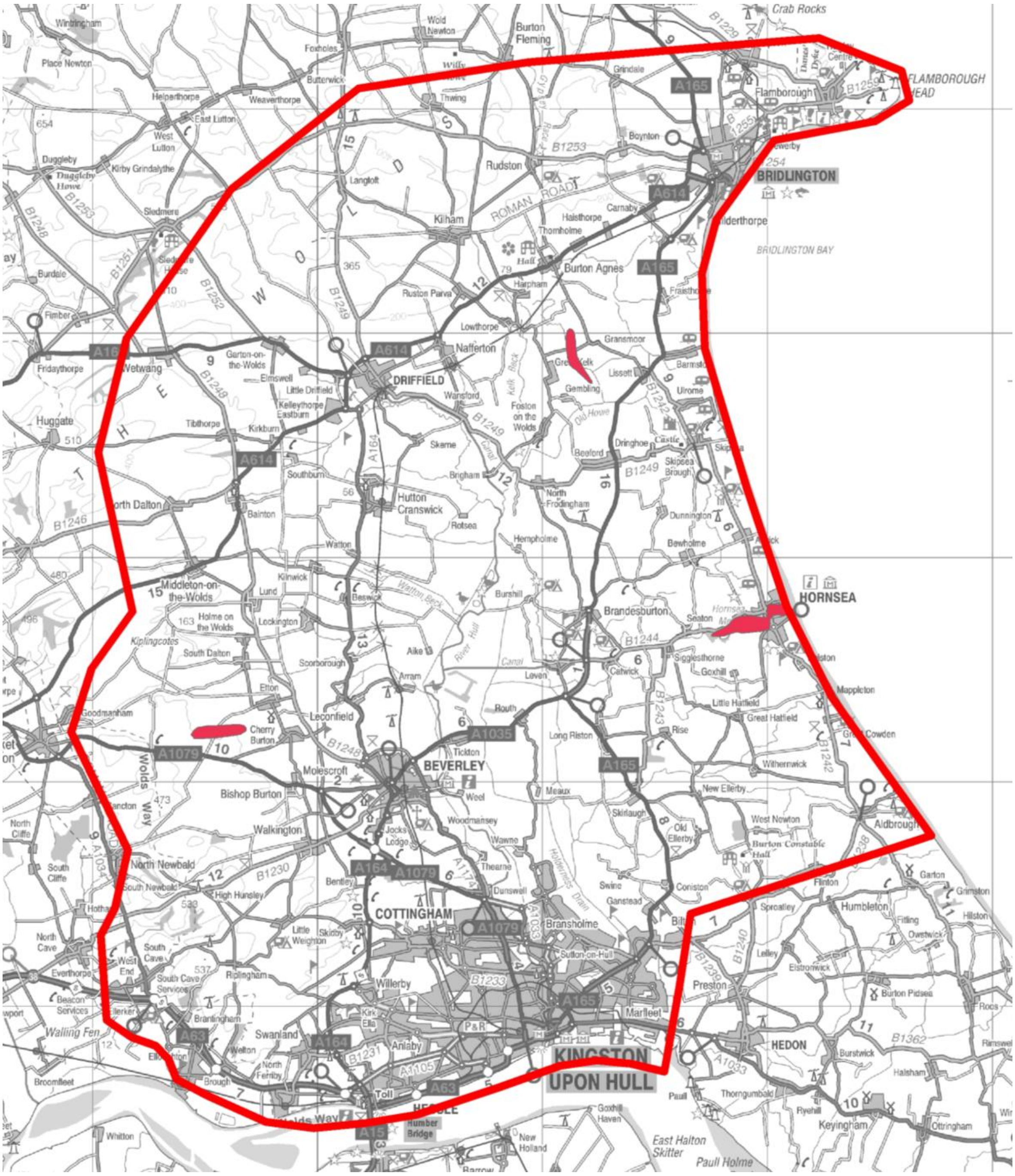


Based on OS topography © Crown Copyright. All rights reserved. BGS 100017897/2010. 10km grid squares.

Figure 20. Distribution of intra-till glacio-lacustrine clay (GLLD)

5.1.7 Channel deposits

Channels have been modelled where sand and gravel extends to a significantly greater depth than in the surrounding area. There are three such areas in the model, the most notable of which forms part of a complex deposit extending westwards from Hornsea. The channel at Gardham Farm, to the west of Cherry Burton is 40m deep, but is only constrained by a single borehole that shows 38m thickness of superficial deposits in an area where chalk is otherwise near the surface.



Based on OS topography © Crown Copyright. All rights reserved. BGS 100017897/2010. 10km grid squares.

Figure 21. Distribution of channel deposits (CHANNEL)

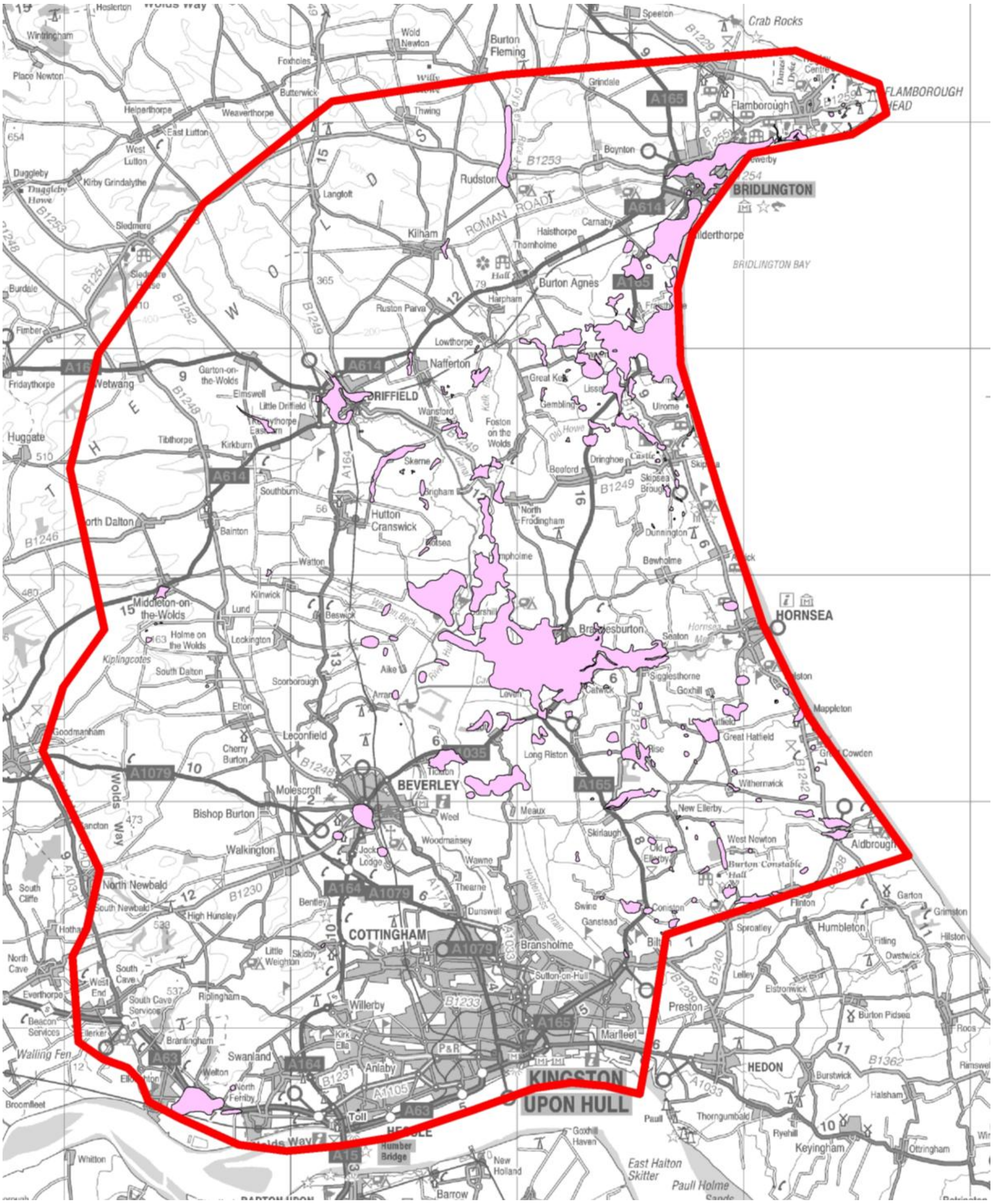
5.1.8 Glaciofluvial Sand and Gravel Deposits at or near surface

These deposits of sand and gravel are present at the surface to the northwest of Hull, and in places extend all the way down to bedrock, where they form in a permeable ‘window’ through the till. They are interbedded with clay or gravelly clay in some of the boreholes and they extend into the Glacial Till sequence in some places around the margins of the deposit. This area approximately coincides with the sand and gravel mapped at the surface, and is the most significant of such surface deposits within the area. The average moraine thickness is 3 metres reaching up to 12 metres in the centre.

Similar lithologies are mapped at surface further north and are modelled as part of this moraine complex (MORAINE_B). However, in many places there is insufficient borehole control to determine whether the unit forms a permeable window into the bedrock.

To the centre and northeast of the study area the sands and gravels are mapped and modelled as GFDUD (glaciofluvial deposits – undivided), where they tend to cap subtle topographic highs. They have a patchy distribution, with some extensive sheets in the region between Beverley and Bridlington. Thicknesses are quite variable, and range from 3m to 20m.

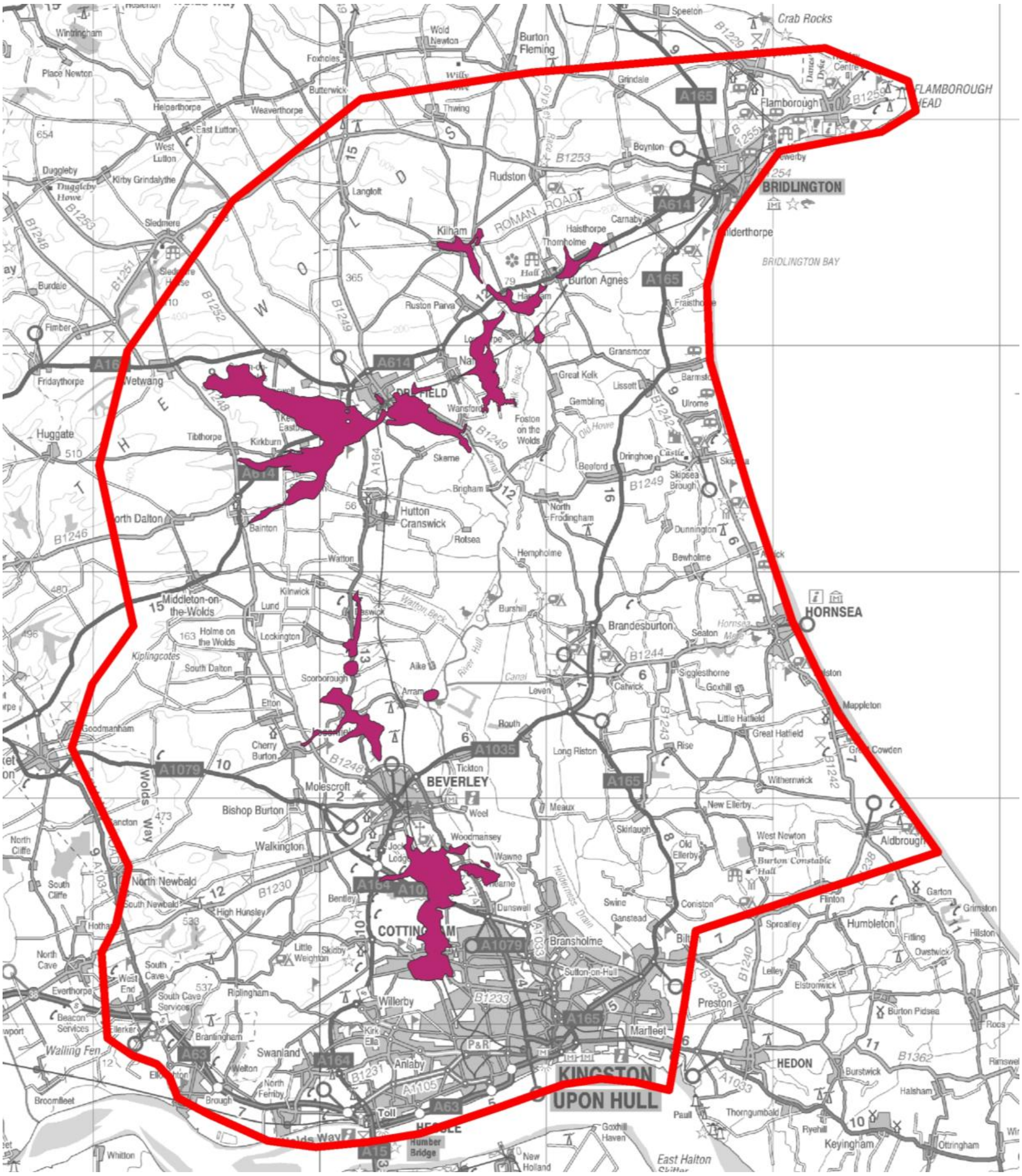
To the northwest and north, the sand and gravel deposits appear to be infilling valleys on the edge of the chalk wolds, so are more likely to be fluvial (periglacial or glaciofluvial) rather than part of the moraine.



Based on OS topography © Crown Copyright. All rights reserved. BGS 100017897/2010. 10km grid squares.

Figure 22. Distribution of surface glacial sand and gravel deposits (GFDUD)

The unit named MORAINE_B in the 3D model is actually mapped as glacial sand and gravel. However, this was interpreted as a glacial moraine in the Hull model, based on its raised topography in relation to the surrounding deposits. This moraine feature is present on the western perimeter of the till sheet throughout the Holderness study area. MORAINE_B consists of sand and gravel, interbedded with clay or gravelly clay, and occasionally forms a permeable 'window' directly through to bedrock. The term 'moraine' relates to material that has been transported and deposited by a glacier.

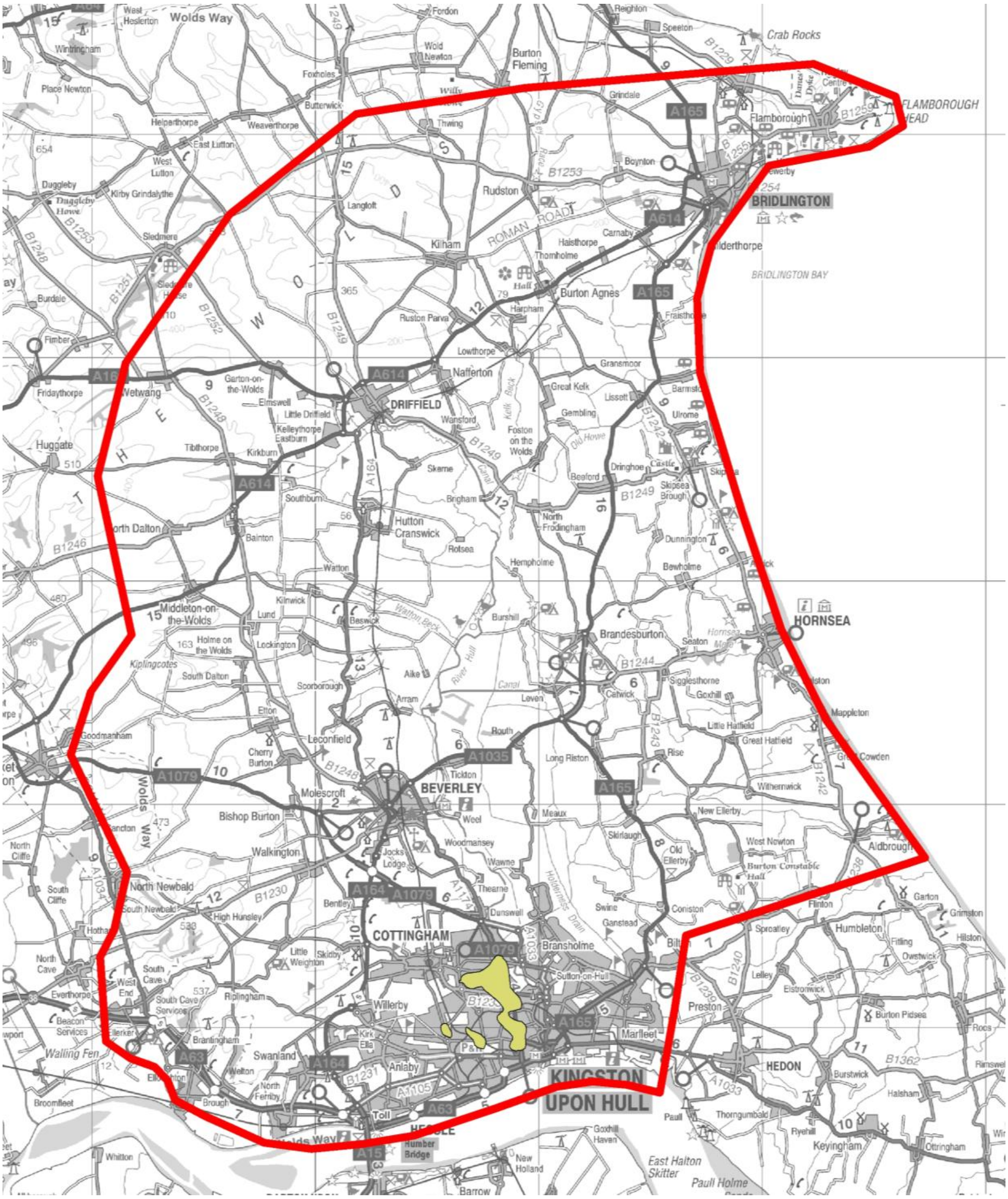


Based on OS topography © Crown Copyright. All rights reserved. BGS 100017897/2010. 10km grid squares.

Figure 23. Distribution of MORAINE_B

5.1.9 Basal Clay

The area of clay (CLAY_A) is of limited extent, normally between 1 and 3m in thickness, but locally reaching to 9m, and underlies the Holocene Tidal Flat deposits. It may have been deposited in small ponds formed after the deglaciation of the ice sheet.

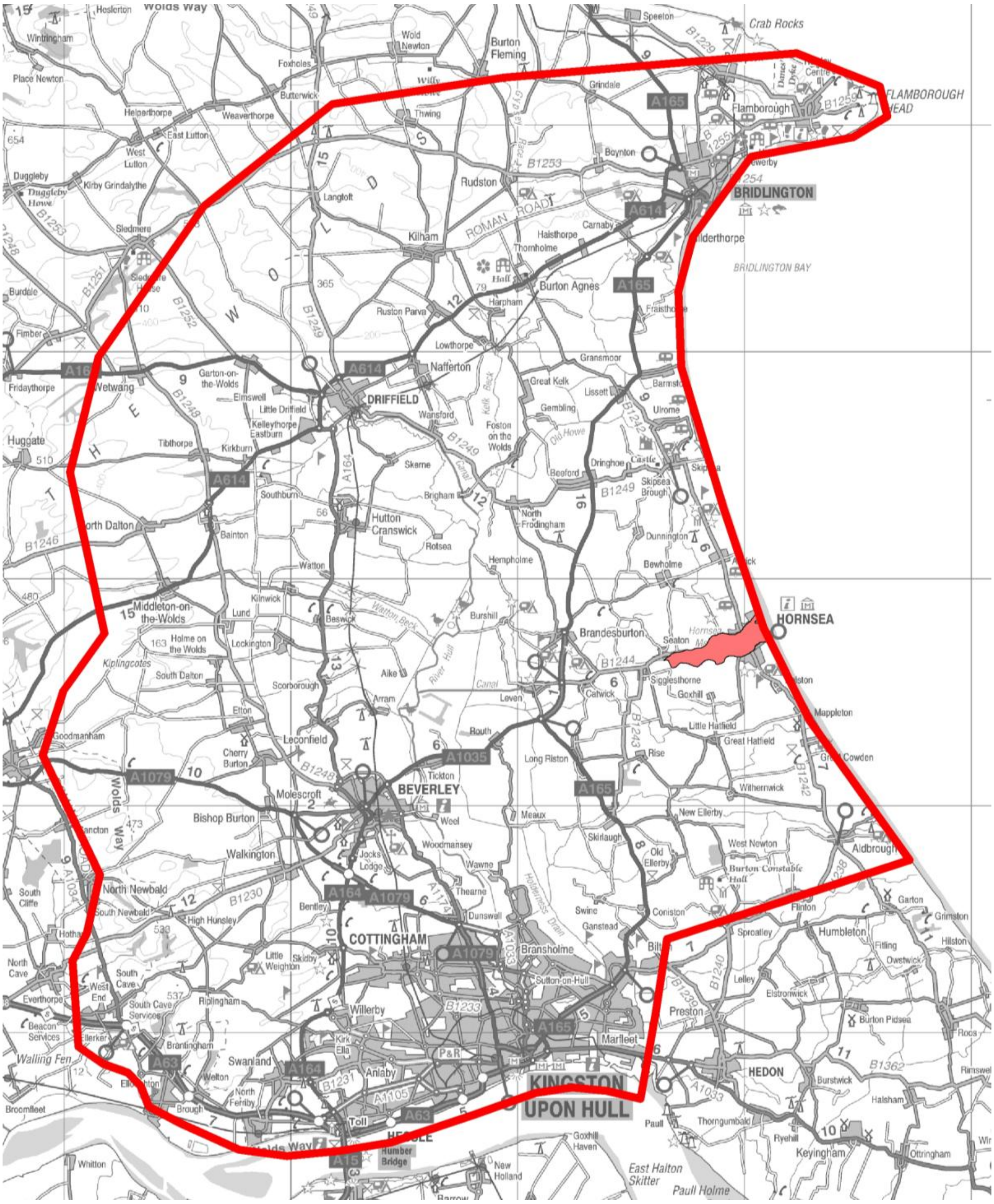


Based on OS topography © Crown Copyright. All rights reserved. BGS 100017897/2010. 10km grid squares.

Figure 24. Distribution of basal clay unit of the Tidal Flat Deposits (CLAY_A)

5.1.10 Marine Deposits

Sands and gravels of marine origin (MDU), deposited in a channel to the west of Hornsea. They are generally around 6m thick, up to a maximum of 15m thickness. Borehole information in the area has revealed a deep glacial channel beneath the marine sand and gravel.

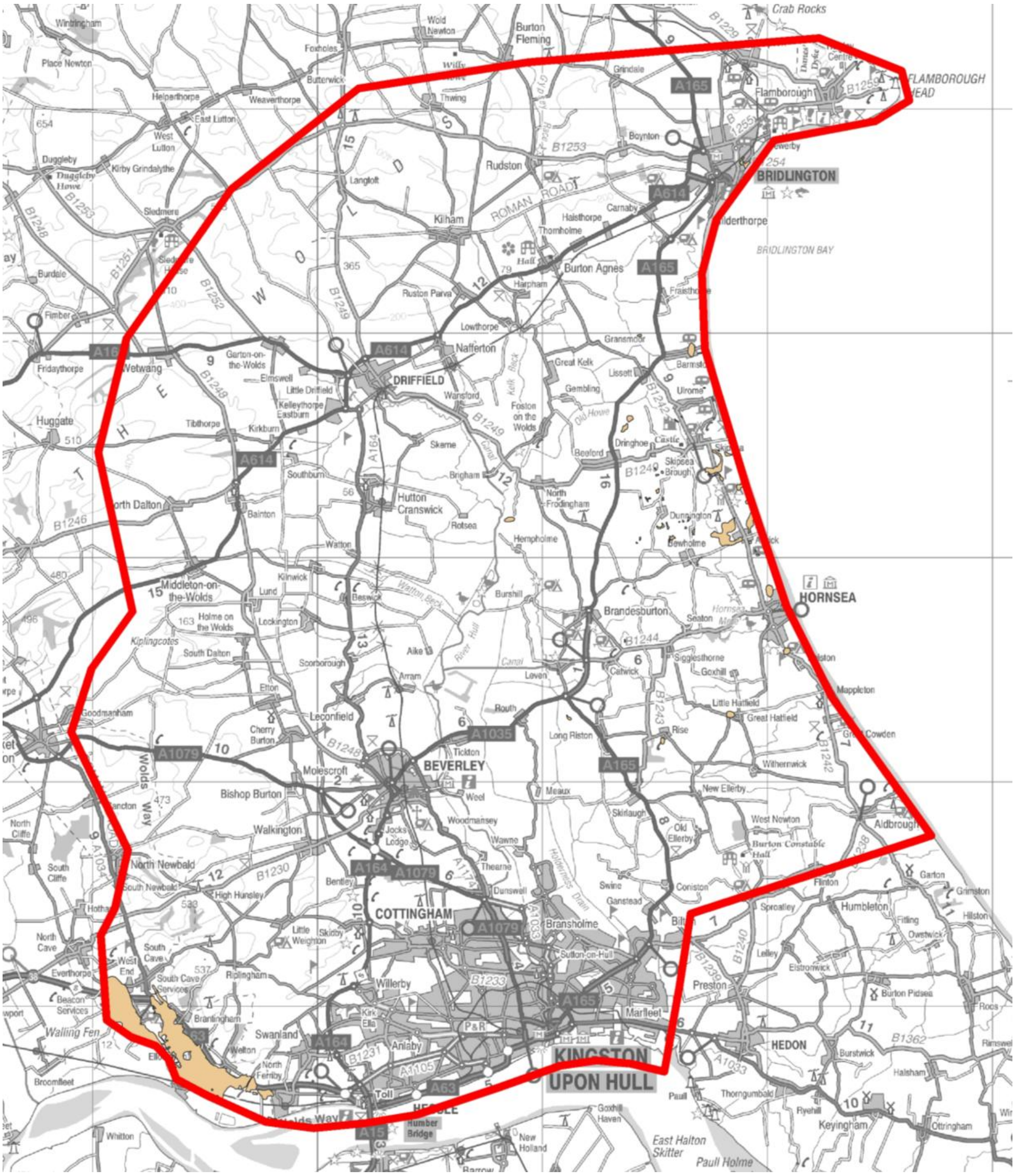


Based on OS topography © Crown Copyright. All rights reserved. BGS 100017897/2010. 10km grid squares.

Figure 25. Distribution of marine sand and gravel (MDU)

5.1.11 Glaciolacustrine Deposits at or near surface

In the south-west, the Glaciolacustrine Deposits at or near surface form part of a much more extensive and continuous sheet of deposits. They encroach into the extreme southwest of the study area where they are composed mainly of sand and gravel. Deposits in this category also occur as isolated patches of clay, silt and sand near the coast between Hornsea and Bridlington. Generally the deposits are 1 to 5m thick, but locally reach upwards of 8m. These represent episodes of surface ponding and the build-up of low-energy sand, silt and clay in hollows in the till topography.



Based on OS topography © Crown Copyright. All rights reserved. BGS 100017897/2010. 10km grid squares.

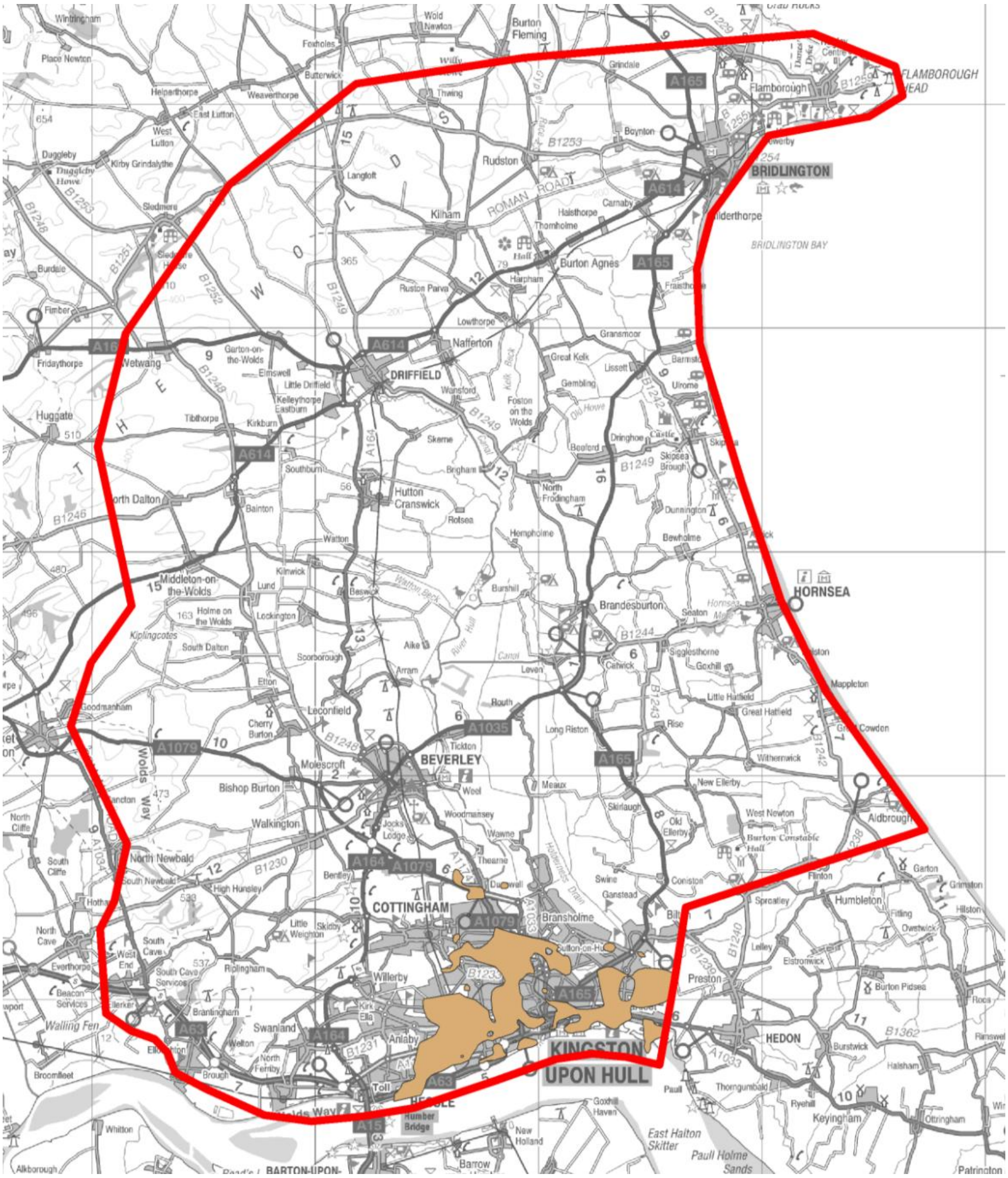
Figure 26. Distribution of surface glacial lake deposits (LDE)

5.1.12 Tidal Flat Deposits

The tidal flat deposits comprise four layers: a basal peat unit, overlain by silt, which is in turn overlain by clay. The upper clay unit (CLAY_C) extends across a considerable area around the low-lying regions of Hull, whereas the lower units are less extensive. The Tidal Flat Deposits are described from base to top below:

5.1.12.1 PEAT

Peat (PEAT_A) within the Tidal Flat deposits forms a significant compressible layer beneath the surface silts and clays. The peat is commonly water-saturated, and is normally 0.5m to 1.0m thick, but in places can be up to more than 5m thick. The lower level peat is thought to have been localised in the channels before the more widespread deposition seen across the area.

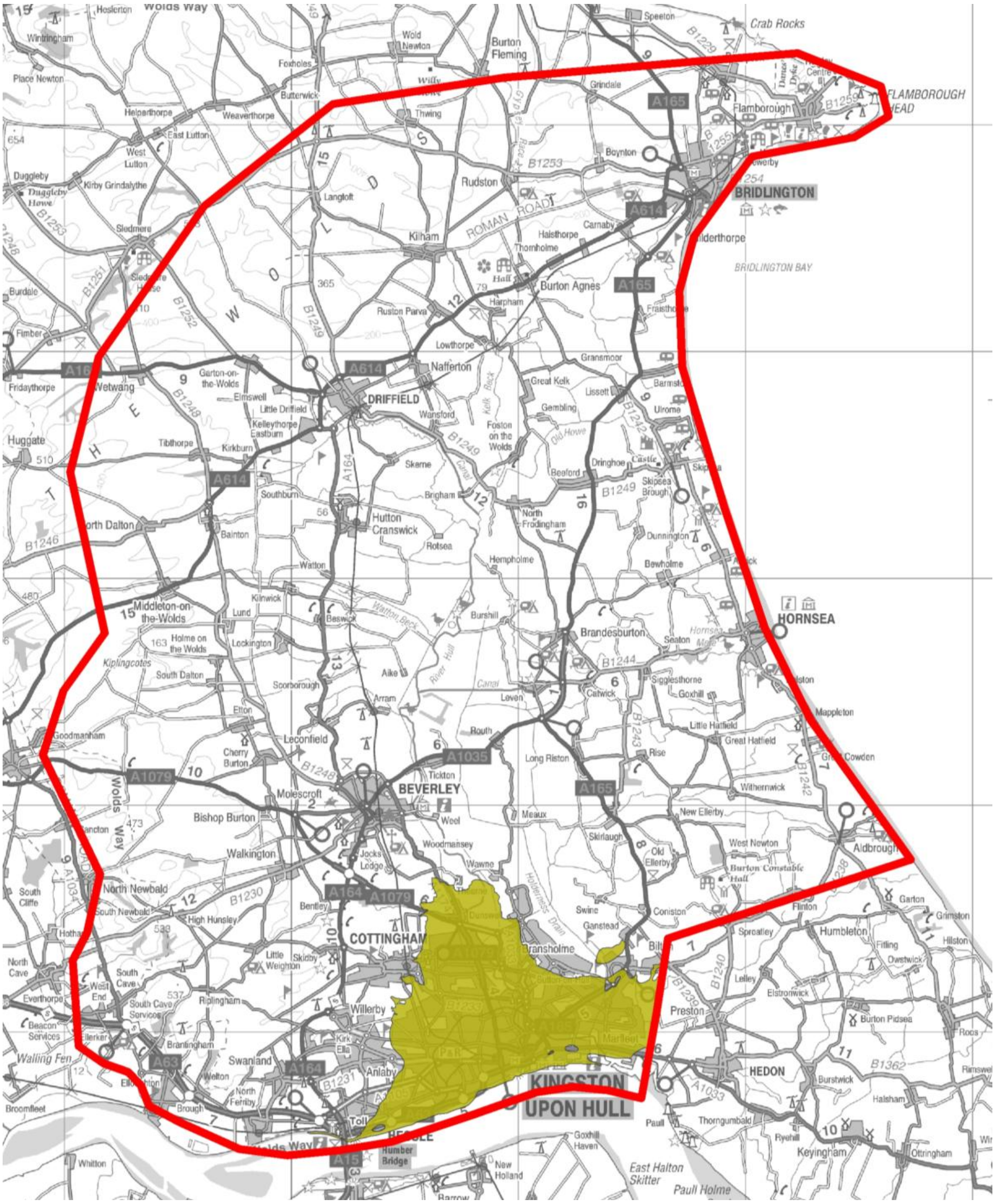


Based on OS topography © Crown Copyright. All rights reserved. BGS 100017897/2010. 10km grid squares.

Figure 27. Distribution of peat within the tidal flat deposits (PEAT_A)

5.1.12.2 SILT

The silt sequence in the Tidal Flat Deposits (SILT_B) lies beneath the surface clay deposit and above the peat deposits. It represents a change from a marginal marine bog to an estuarine environment. Its composition varies from silty clay to gravelly sand; and thickness increases to the south and east from 0.5m to more than 8m with an average thickness of 3 metres.

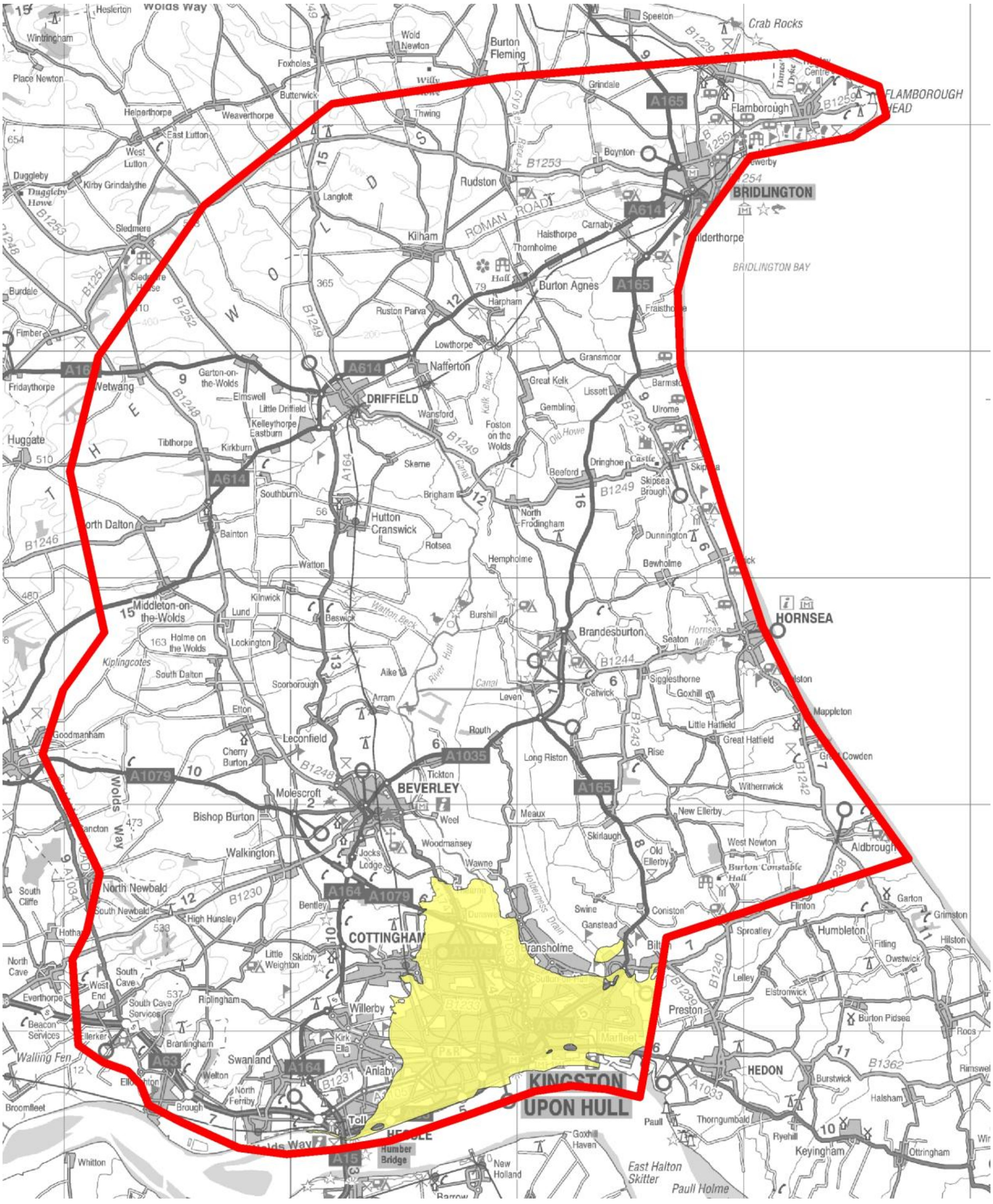


Based on OS topography © Crown Copyright. All rights reserved. BGS 100017897/2010. 10km grid squares.

Fi gure 28. Distribution of silt within the Tidal Flat Deposits (SILT_B)

5.1.12.3 CLAY

All the low-lying part of the Hull district is covered by a level sequence of clay (CLAY_C) that was deposited in a tidal mud flat environment. This area is still prone to flooding in severe storm events. The thickness increases from less than 1m at the fringes of the mud flats, to up to 10m towards the south of the area with an average thickness of 2.5m.

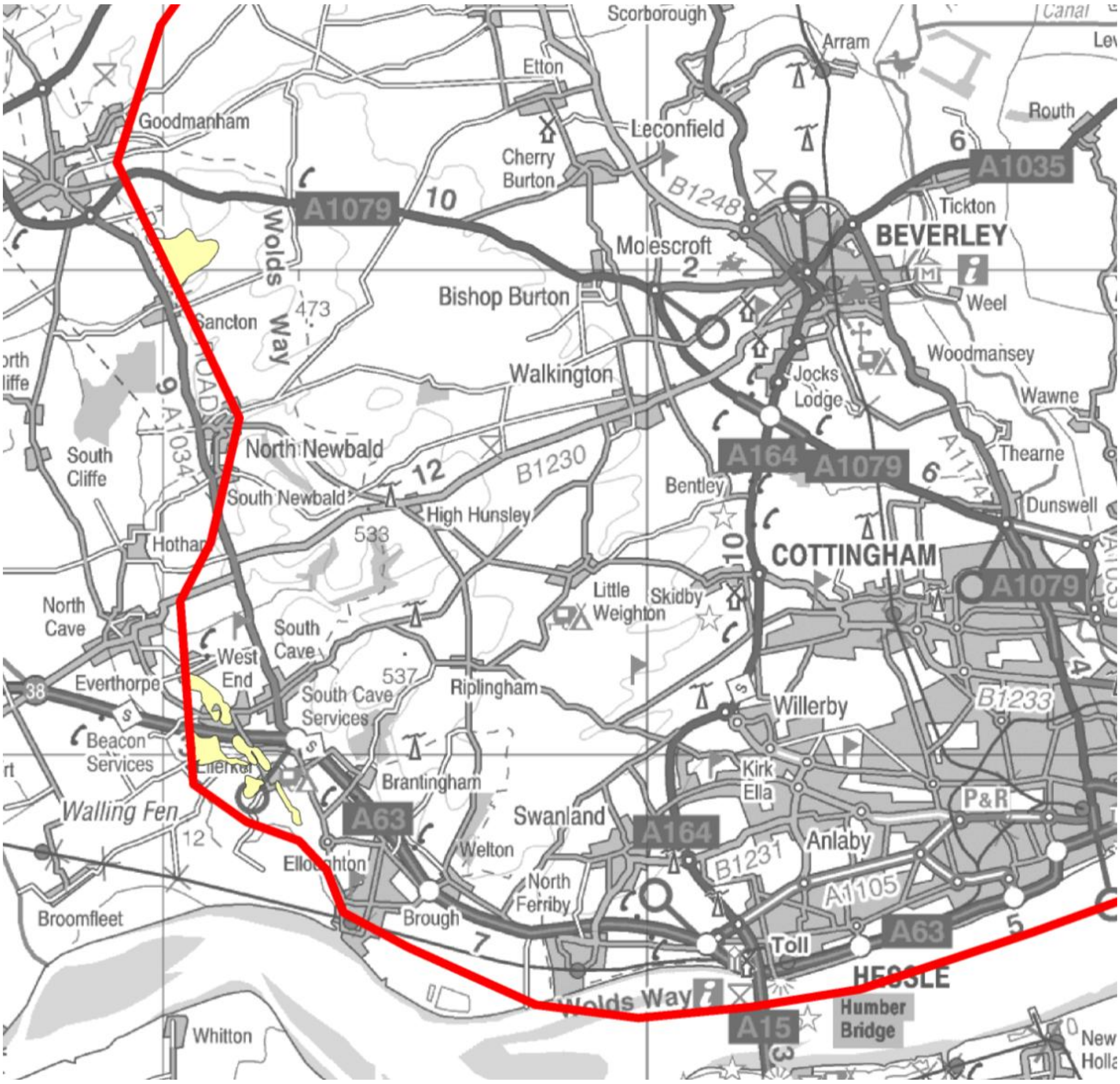


Based on OS topography © Crown Copyright. All rights reserved. BGS 100017897/2010. 10km grid squares.

Figure 29. Distribution of clay within the Tidal Flat Deposits (CLAY_C)

5.1.13 Blown Sand

Deposits of blown sand (BSA) are mapped in the extreme southwest of the study area; they are composed of fine sand and silt, deposited on the eastern side of the former glacial lake. These deposits are often associated with periglacial conditions, after the ice had retreated, and fine material was picked up by strong winds. Borehole data does not confirm the depth of the blown sand, but it has been modelled with a thickness of 2-3m.

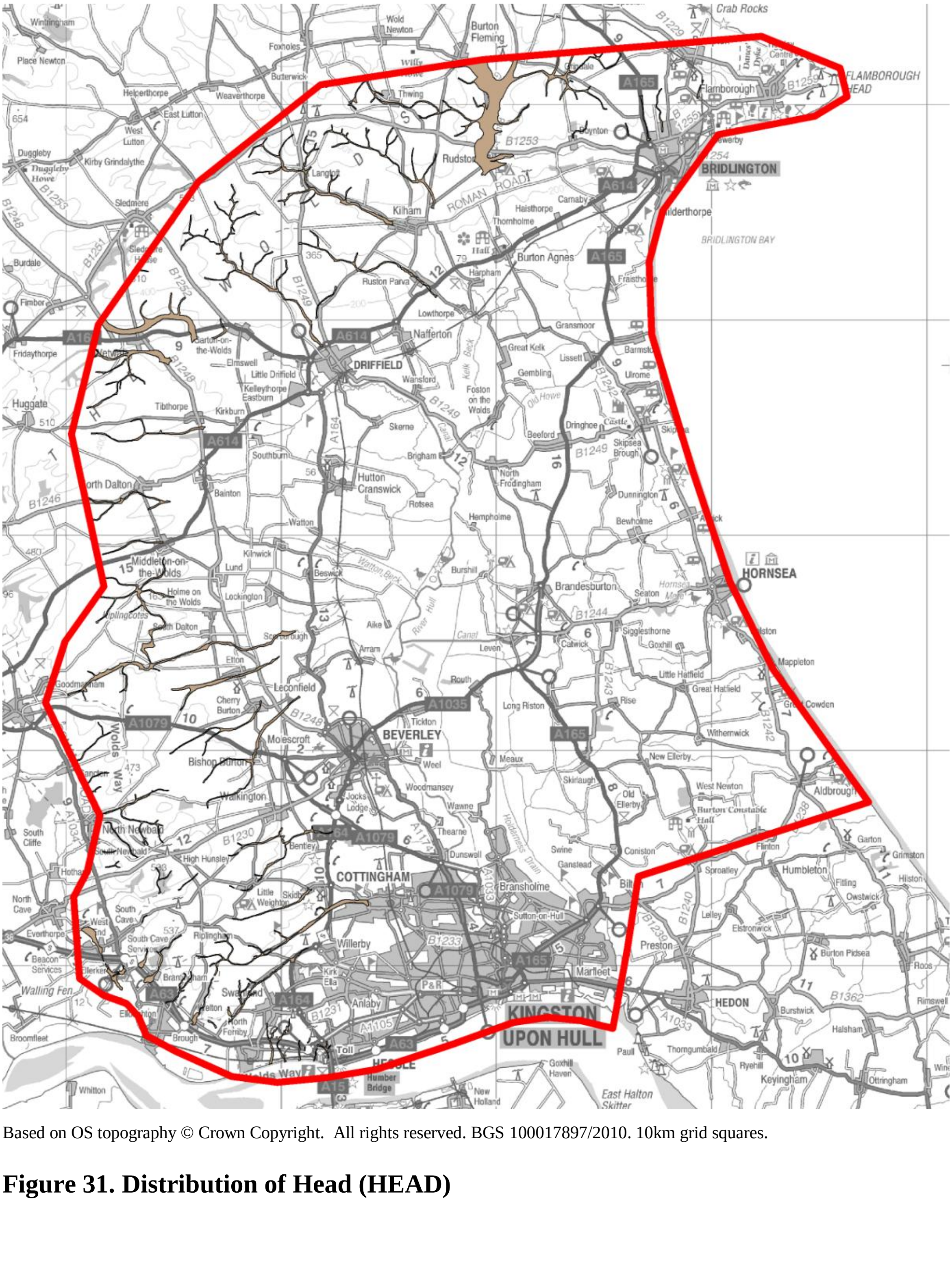


Based on OS topography © Crown Copyright. All rights reserved. BGS 100017897/2010. 10km grid squares.

Figure 30. Distribution of Blown Sand (BSA)

5.1.14 Head

This occurs as a thin superficial deposit confined to the valleys of the chalk wolds. Head typically forms at the base of slopes, where material accumulates through down-slope soil creep processes. It is therefore a poorly sorted mixture of sand and gravel, locally with lenses of silt, clay or peat and organic material. The modelled thickness is usually 2-5m, but can be up to 9m.

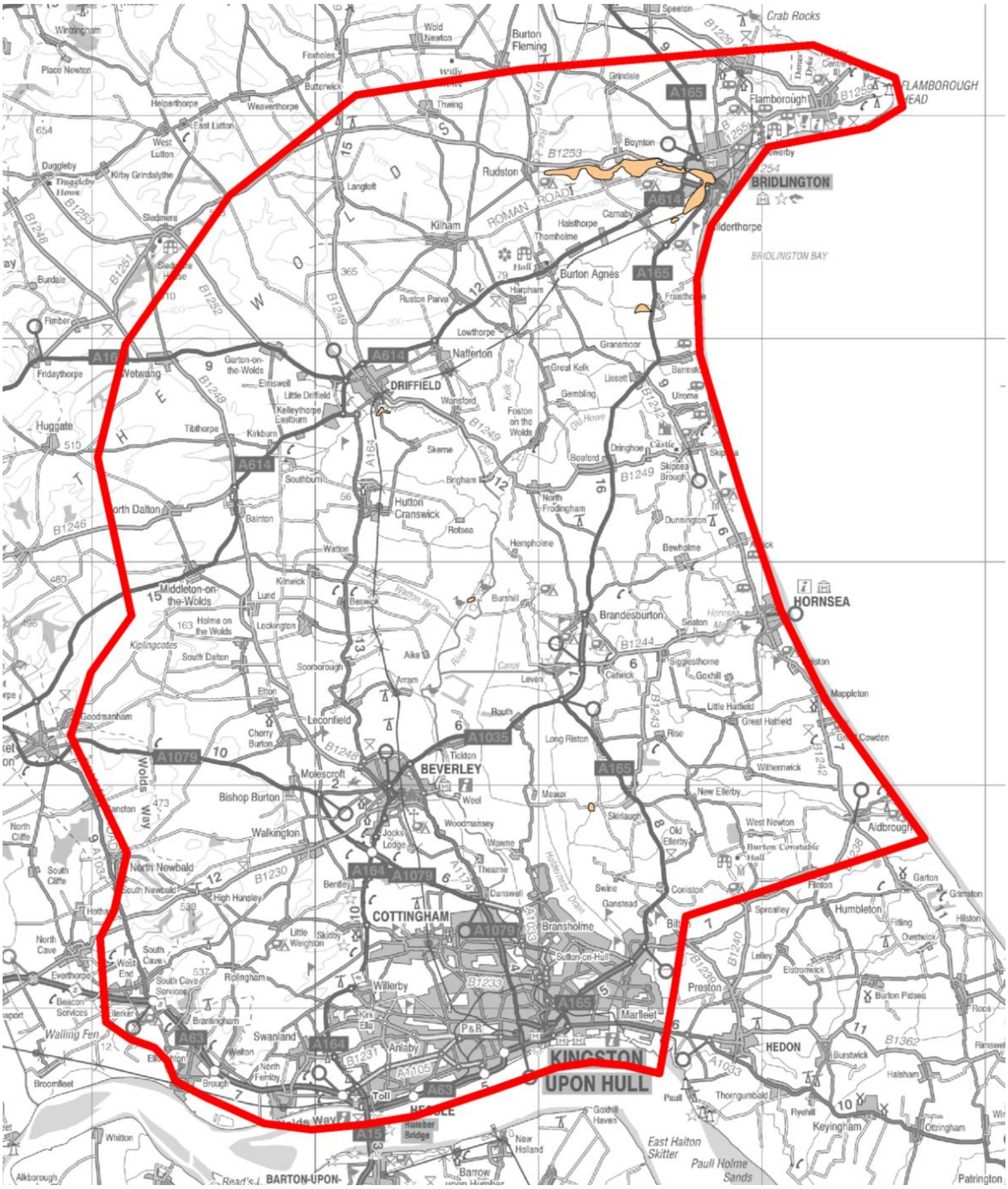


Based on OS topography © Crown Copyright. All rights reserved. BGS 100017897/2010. 10km grid squares.

Figure 31. Distribution of Head (HEAD)

5.1.15 River Terrace Deposits

Sand and gravel, 3-7m thick, forming an extensive deposit under the alluvium of Gypsy Race to the west of Bridlington, and a few small, isolated patches elsewhere. These are included in the River Terrace Deposits (RTDU).



Based on OS topography © Crown Copyright. All rights reserved. BGS 100017897/2010. 10km grid squares.

Figure 32. Distribution of River Terrace Deposits (RTDU)

5.1.16 Beach deposits

Modern beach deposits (BCHD) composed of sand and gravel form a continuous strip lying on the till along the coast from Aldbrough to Bridlington. Its thickness ranges from less than 1m to 3-4m.

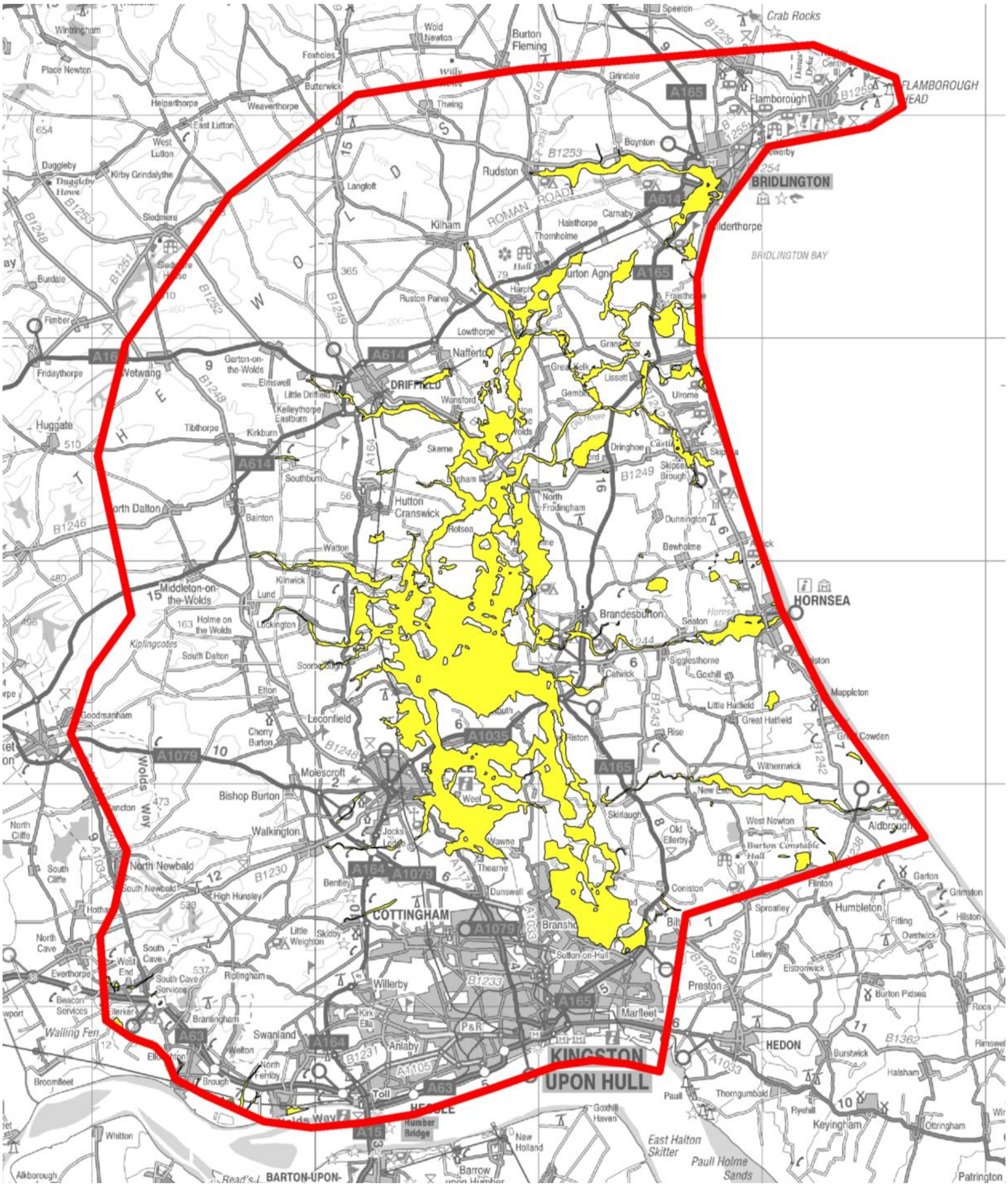
There are two isolated small patches of beach deposit mapped in the extreme south west of the study area. As these sit at some 30m above OD, they probably date from when glacial Lake Humber was impounded in the Vale of York with a water level of 30m above OD during the Devensian Glaciation. For simplicity these have been included with the modern day beach deposits in the 3D model.

5.1.17 Peat

Within the study area there are two small, isolated patches of peat (PEAT) associated with alluvial deposits. These are 2 to 4m thick.

5.1.18 Alluvium

The alluvium (ALV) in the area consists of silt, sand and clay, along with some gravel and peat. A gravel lag beneath the alluvium was modelled as RTDU (River Terrace Deposits) where proven in the boreholes. The average thickness is 2-4 m, reaching a maximum of 7-10 m in places.

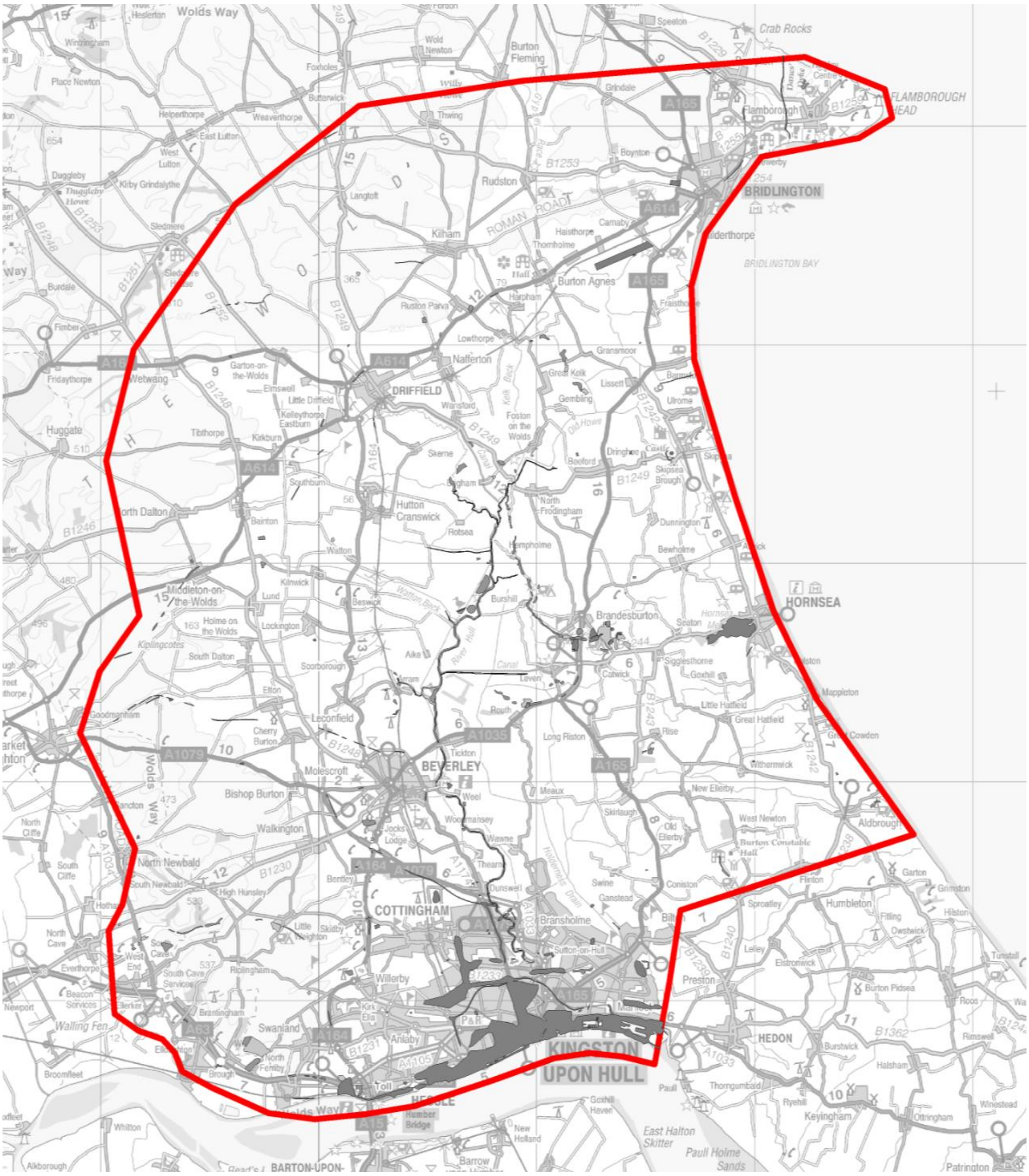


Based on OS topography © Crown Copyright. All rights reserved. BGS 100017897/2010. 10km grid squares.

Figure 33. Distribution of Alluvium (ALV)

5.1.19 Artificial Ground

Artificial Ground consists of areas of artificially raised or excavated ground, such as embankments and cuttings. Artificial Ground is subdivided into Made Ground, Worked Ground, Made and Worked Ground and Levees in the Holderness project area and MADE_A in the Hull project area. All instances of Artificial Ground in the model are shown in Figure 34 below.



Based on OS topography © Crown Copyright. All rights reserved. BGS 100017897/2010. 10km grid squares.

Figure 34. Distribution of Artificial Ground

6 Limitations of the 3D model

- In general, uncertainty in 3D models is greatest in areas of high geological complexity. In the Holderness model, the greatest geological complexity occurs where the glacial sequence is at its thickest. Added to this is the nature of the superficial deposits themselves, which vary considerably over short distances.
- Areas of low data density are also an issue with 3D models. In these areas, a greater degree of manual interpretation was used to construct the model. (Figure 2 shows the borehole distribution across the study area).
- The quality of the available data has a bearing on the reliability of the finished 3D model. Where possible, the deepest boreholes and those with the most detailed lithological descriptions were used to construct the Holderness model. Some of the geological mapping in the project area dates from the 1880s and did not always match up with modern mapping across sheet boundaries. In these cases, the newer, more detailed geological map was given precedence. To address discrepancies between the geological map and borehole data, priority was usually given to the borehole.
- Cross-section spacing also has a bearing on confidence in finished model. In the Holderness model, cross-sections were generally 1-2km apart, and were more closely spaced in areas of higher geological complexity.
- It is important to note that this 3D model represents just one interpretation of the data available; other interpretations may be just as valid.
- Some generic uncertainties in GSI3D modelling methodology are documented in Kessler et al., (2009): The capture and dissemination of integrated 3D geospatial knowledge at the British Geological Survey using GSI3D software and methodology. *Computers & Geoscience*. Vol 35, pt 6, pp 1311-1321.

Conclusions and Recommendations

The project revealed two items of particular interest:

- The revelation of extensive higher permeability sand and gravel units above, within and beneath the till sheet, which in areas extend to the chalk bedrock, create permeable 'windows' through the superficial deposits into the chalk. These deposits were initially identified during the previous Hull project and seem to extend over a significant part of the Holderness study area.
- Deep channels infilled with sand and gravel near Hornsea, Great Kelk, and Cherry Burton could also act as permeable pathways into the chalk.

This project has led to a greater understanding of the detail within the glacial deposits of the area; and an appreciation of their complexity and heterogeneity.

One of the most difficult areas for modelling was the area of Glaciofluvial Sand and Gravel Deposits at or near surface. More detailed modelling and the gathering or drilling of some additional boreholes are essential to gain greater confidence in the model in this area. A fuller understanding of the till sequence and glacial stratigraphy may also be possible with more detailed borehole information.

Apart from the Victoria Docks area and major embankments for main roads and railway, modelling of Made Ground was not attempted due to the lack of resources and the uncertainties associated with the Digital Terrain Model. An approximately 1 kilometre wide strip along the river Hull has been raised due to human development. The true thickness of the Tidal Flat deposits will be slightly overestimated here.

References

British Geological Survey holds most of the references listed below, and copies may be obtained via the library service subject to copyright legislation (contact libuser@bgs.ac.uk for details). The library catalogue is available at: http://geolib.bgs.ac.uk.

ALDISS, D T, KESSLER, H, LAWRENCE, A R, LEE, J R, WHITEHEAD, E J, BUCKLEY, D K, AND COBBING, J E. 2004. An investigation of potential pathways for subsurface water movement in the Little Coates area of Grimsby, Lincolnshire. *British Geological Survey Commissioned Report, CR/04/248*

BATEMAN, M.D. and CATT, J.A. 1996. An absolute chronology for the raised beach and associated deposits at Sewerby, East Yorkshire, England. *Journal of Quaternary Science.* Vol. 11, pp 389-395.

BERRIDGE, N. G. and PATTISON J. 1994. Geology of the country around Grimsby and Partington. pp 38-44 *Memoir of the Geological Survey of England and Wales, London.*

CATT, J. A. 1991. The Quaternary history and glacial deposits of East Yorkshire. In EHLERS, J., GIBBARD P. L., and ROSE J. (eds.): *Glacial deposits in Great Britain and Ireland*, pp 185-191. Balkema, Rotterdam.

CATT, J.A. 2007. The Pleistocene glaciations of eastern Yorkshire: a review. *Proceedings of the Yorkshire Geological Society.* Vol. 56, pp 177-207.

FORD, J R, COOPER, AH, GIBSON, A, PRICE, S, PHARAOH, TC and KESSLER, H. 2008. Geology of the Selby district – a brief explanation of the geological map. *Sheet Explanation of the British Geological Survey.* 1:50 000 Sheet 71 Selby (England and Wales)

GAUNT, G D. 1992. Geology of the country around Kingston upon Hull and Brigg. *Memoir for 1:50 000 geological sheets 80 and 89 (England and Wales).*

KENT, P. and GAUNT, G. D. 1980. British Regional Geology guide: *Eastern England, from the Tees to the Wash*. pp 118-127

KESSLER, H., MATHERS, S. and SOBISCH, H-G. 2009 The capture and dissemination of integrated 3D geospatial knowledge at the British Geological Survey using GSI3D software and methodology. *Computers and Geosciences*, 35 (6). 1311-1321. 10.1016/j.cageo.2008.04.005 and digitally on http://nora.nerc.ac.uk/7207/

KIRBY, G. A. and SWALLOW, P. W. 1987. Tectonism and sedimentation in the Flamborough Head region of north-east England. *Proceedings of the Yorkshire Geological Society* Vol. 46, pp 301-309.

REID, C. 1885. The Geology of Holderness and the adjoining parts of Yorkshire and Lincolnshire. *Memoir of the Geological Survey of England and Wales, London.*

BRITISH GEOLOGICAL SURVEY 1:50,000 scale geological map sheet 55/65 (Flamborough and Bridlington). Compiled in 1985 with amendments, based on original 6" scale survey in 1873-80.

BRITISH GEOLOGICAL SURVEY 1:50,000 scale geological map sheet 64 (Driffield). Compiled in 1993 with amendments, based on an original survey at 6" scale in 1873-1884

BRITISH GEOLOGICAL SURVEY 1:50,000 scale geological map sheet 72 (Beverley). Compiled in 1995 from a 6" mapping survey carried out in 1880-81.

BRITISH GEOLOGICAL SURVEY 1:50,000 scale geological map sheet 80 (Kingstone Upon Hull). Based on original geological surveyed at 6" scale in 1964-77.

BRITISH GEOLOGICAL SURVEY. 1996.1:1 500,000 scale Tectonic Map of Britain, Ireland and Adjacent Areas,.

INSTITUTE OF GEOLOGICAL SCIENCES AND YORKSHIRE WATER AUTHORITY. 1980. 1:100,000 scale Hydrogeological Map of East Yorkshire,