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The Vale of Pickering: an initial summary of the Quaternary/superficial geology and data holdings

Geology & Regional Geophysics Programme

Open Report OR/15/064

BRITISH GEOLOGICAL SURVEY

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J R Ford, L Hughes, H F Burke and J R Lee

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British Geological Survey offices

BGS Central Enquiries Desk

Tel 0115 936 3143 Fax 0115 936 3276

email enquiries@bgs.ac.uk

Environmental Science 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

Maclean Building, Crowmarsh Gifford, Wallingford OX10 8BB

Tel 01491 838800 Fax 01491 692345

Geological Survey of Northern Ireland, Department of Enterprise, Trade & Investment, Dundonald House, Upper Newtownards Road, Ballymiscaw, Belfast, BT4 3SB

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

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Foreword

The British Geological Survey (BGS), together with a number of partners is undertaking an independent environmental monitoring programme to characterise baseline conditions across the Vale of Pickering in North Yorkshire, in the vicinity of a site close to Kirby Misperton (Third Energy, KM8) proposed for shale-gas exploration and production. The monitoring will include measurement of: water quality (groundwater and surface water), seismicity, ground motion, air quality including radon, and soil gas. The programme aims to establish the environmental baseline before any shale-gas explorations begin.

This report presents the results of a desk study to develop an initial summary of the Quaternary superficial geology across the Vale of Pickering. It is a component and specific deliverable of the environmental baseline project. The Quaternary deposits form a shallow aquifer that is used locally for drinking water supply and agriculture. A separate report considers the bedrock geology.

The geological information in this report will be used to identify aquifer dimensions and configurations, groundwater flow paths and potential contaminant migration pathways, as well as determining optimum locations for sampling and monitoring. It will also provide information to support the locating of new borehole infrastructure (suitable for groundwater sampling and seismometers) and will underpin the interpretation of acquired hydrogeochemical data.

1 Introduction

The Vale of Pickering (the Vale) is located in East Yorkshire, Eastern England, approximately 10 km to the southwest of Scarborough. During the Quaternary geological period, the Vale lay just to the south of the maximum limit of the Late Devensian glaciation (Figure 1) – the last major glaciation to affect the UK (Bowen *et al*., 1986; Clark *et al*., 2012; Böse *et al*., 2012).

The Vale forms a broadly west-east trending area of low-lying ground that is bounded to the north by the Tabular Hills, to the south by the Howardian Hills and Yorkshire Wolds (Figure 2). In contrast to the surrounding hills, the relief of the Vale is relatively flat with few notable hills or visible deep valleys. This distinctive landscape reflects a relatively complicated recent geological history that was produced by a range of geological processes. The latter stages of its geological development occurred when the Vale was impounded to the west (Vale of York ice) and east (North Sea ice) by lobes of the last British-Irish Ice Sheet and a vast glacial lake formed (Kendall, 1902; Murton and Murton, 2012; Bateman *et al*., 2015). This lake appears to have been linked to an adjacent glacial lake – Lake Flixton, situated to the east of the Vale (Candy *et al*., 2015; Palmer *et al*., 2015), with their water levels and patterns of sedimentation patterns apparently controlled by ice-damming and overspill (Murton and Murton, 2012).

The scope of this report is two-fold: firstly, to provide a brief and easily-understandable overview of the recent geological evolution of the Vale of Pickering (Section 2); and secondly, to summarise the various datasets that provide information about the Vale (Section 3-5).

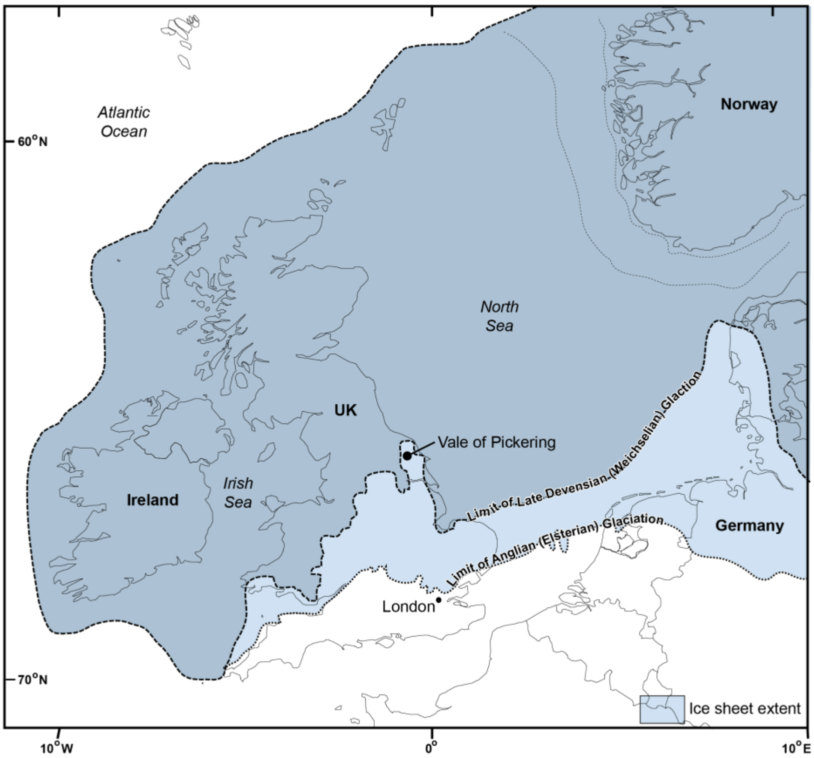


Figure 1 A map of the UK and adjacent areas showing the location of the Vale of Pickering and the extent of Quaternary glaciation (after Bowen *et al.*, 1986).

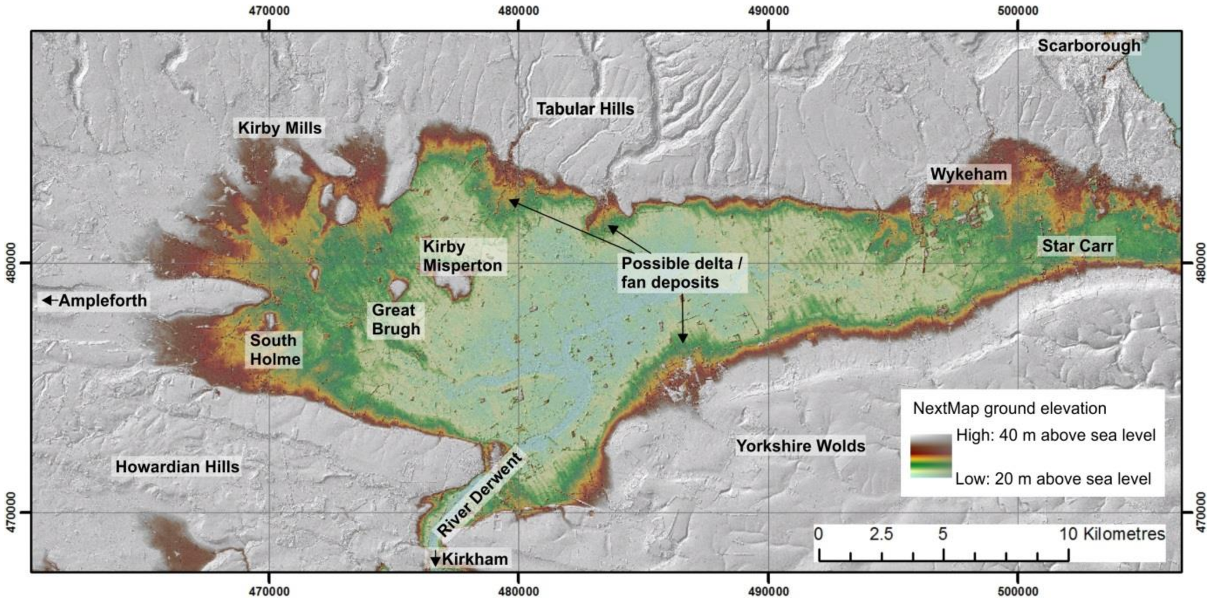


Figure 2 Digital elevation model showing the topography of the Vale of Pickering. Colour-ramped and shaded NextMap Britain elevation data from Intermap Technologies.

2 The Quaternary history of the Vale of Pickering

From the available evidence, including published maps, borehole records and various written accounts it is possible to piece together the geological evolution of the Vale of Pickering. Its recent geological evolution spans part of the Quaternary geological period which corresponds to the last 2.6 million years of Earth History.

2.1 THE EARLY EVOLUTION OF THE VALE OF PICKERING

The early geological history of the Vale of Pickering is poorly understood because recent geological events, including those that occurred during the last Ice Age, have either eroded or buried older deposits or features within the landscape. The term Ice Age refers to a period of geological time when the climate was much colder than the present day when frozen ground and glaciers – vast rivers of flowing ice, existed across much of northern Britain. Only limited geological evidence exists for events that may have shaped the Vale prior to the last Ice Age about 30,000 years ago. Evidence includes patches of strata called 'till' (or boulder-clay) which appear to cap several of the small hills within the Vale. A 'till' is a type of material that was deposited beneath a glacier and was probably laid down during a much older Ice Age. It is likely that the 'till' once spread widely across the area. However, erosion by rivers following its deposition has removed much of the deposit and scoured the underlying bedrock.

2.2 RIVERS AND HILLS IN THE VALE

The Vale of Pickering is underlain by relatively soft and erodible mud rocks (called the Kimmeridge Clay) and forms a natural low within the landscape between much harder and more durable rocks situated to the north and south. Prior to the last Ice Age, the Vale was probably a low-lying river valley with occasional small hills capped by 'till' deposited during the earlier Ice Age. Many of the modern river systems, like the River Derwent which now flows through the Howardian Hills, did not exist at this time. However, it is thought that a drainage pattern existed with rivers flowing west to east across the region into the North Sea. The history of these early river systems within the Vale of Pickering remains poorly-understood. However, borehole records reveal sand and gravel in places concealed at depth and these deposits may be related to these ancient rivers. One such river was a proto River Ure, which probably flowed eastwards through the Vale from its headwaters in the Yorkshire Dales (Reed, 1901).

2.3 THE LAST ICE AGE – ICE-DAMMED LAKES

During the last Ice Age, a large glacier moved southwards down the coast of eastern England encroaching inland as far as Wykeham about 10 km from the present day coastline. Meanwhile, to the west, a second glacier moved southwards through the Vale of York as far as Ampleforth. Both glaciers laid down tills and sculpted a series of subtle features within the landscape called moraines. These moraines record the maximum ice extent at either end of the Vale of Pickering and were formed by glaciers bulldozing materials into small ridges parallel to their margins. With both ends of the Vale effectively blocked by glaciers, meltwater from these glaciers and rivers flowing into the Vale caused a large glacial lake to form about 21,000 years ago. This glacial lake, which existed for about 6,000 years, is known as Glacial Lake Pickering and was one of several large glacier-dammed lakes that occurred in eastern England during the last Ice Age.

Glacial Lake Pickering was fed by meltwater and sediment derived from the nearby glaciers and rivers and streams flowing off the nearby hills. Coarse-grained sediment such as gravel and sand, represent deltas formed where these rivers and streams entered the lake. By contrast, finer-grained sediments, including silts and clays, were carried out further into deeper and quieter parts of the lake basin where they were laid down. These fine-grained sediments correspond to the ‘lacustrine deposits’ shown on the geological map.

Comparatively little detail is known about the history of Glacial Lake Pickering, although it could potentially provide important clues about how modern glaciers in places like Greenland and Antarctica may respond to future climates. Several major changes in lake level are believed to have occurred during the existence of Glacial Lake Pickering. These were perhaps controlled by seasonal changes in the input of water and sediment into the lake and by the position of the glaciers that impounded the Vale at each end. Both would have acted to regulate lake-level and have led to marked changes in the geography of the lake basin, causing the position of the shoreline, rivers and streams to migrate over time. This history is reflected within the complex pattern of sediments revealed by shallow boreholes in the Vale. For instance, sand and gravel that is shown on borehole logs to occur within fine-grained lake sediments may correspond to an abrupt lowering of lake level and the short-lived development of a small river-fed delta.

Around 17,000 years ago, the glaciers impounding Glacial Lake Pickering had begun to retreat. Water levels within the lake overtopped a low-point in the Howardian Hills to the south and began to drain into the Vale of York. As the water drained it eroded a distinctive steep-sided channel which can be observed at Kirkham, south of Malton. This channel became the main outlet pathway for water draining from the lake and the present-day River Derwent follows the same route.

2.4 THE RECENT LANDSCAPE

The end of the last Ice Age coincided with the removal of glaciers from the landscape and progressive warming of the climate. Glacial Lake Pickering had by this time drained and was succeeded by a much smaller and shallower lake basin located at the eastern margins of the Vale called Lake Flixton. The latter is of particular archaeological importance because at several important sites including Star Carr, it contains evidence for the first humans to colonise the landscape following the last Ice Age. The climate during this time-interval was probably still quite marginal with sand and silt laid-down by the glaciers being actively redistributed by wind.

Within the Vale of Pickering itself, a network of rivers has formed which have cut down into the lacustrine deposits to form channels. In addition to eroding older deposits, they have deposited ‘alluvium’ on the banks and floodplains of these rivers. The alluvium in this area consists predominantly of silt and clay, although sand and gravel is likely in areas where the rivers dissect older coarse-grained deposits or bedrock. Peat may be found alongside or within modern river or floodplain deposits, especially in low-lying areas where shallow water may have ponded to create marshy areas.

3 Relevant geological data

3.1 PUBLISHED GEOLOGICAL MAP DATA

Within this section of the report, the availability and type of geological data within the Vale of Pickering is reviewed. The Vale is largely covered by the Pickering 1:50,000 scale *provisional* series geological map sheet. The current map was published in 2000 and is based on the original survey published in 1882. It was updated for the 2000 publication through re-survey in the western margin and the consideration of borehole data.

Digital geological linework is available at 1:50,000 (Figure 3), however no digital 1:10 000 scale data exist.

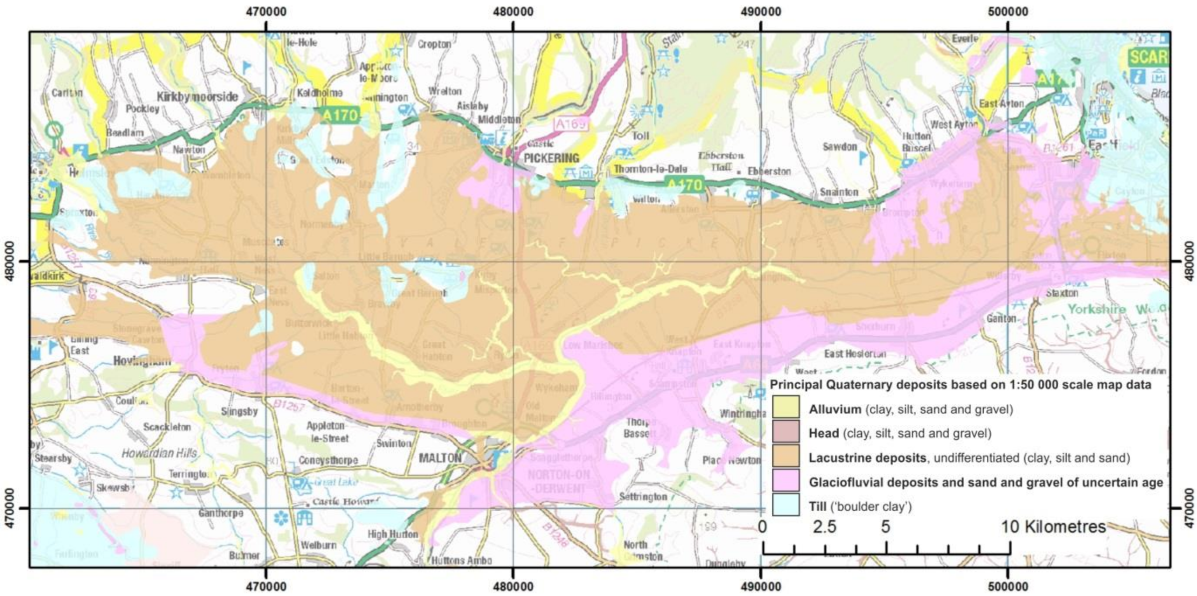


Figure 3 DiGMap50 superficial geology for the Vale of Pickering and surrounding area.

The range of superficial deposits shown on the Pickering 1:50,000 scale provisional map sheet is shown in Figure 4.

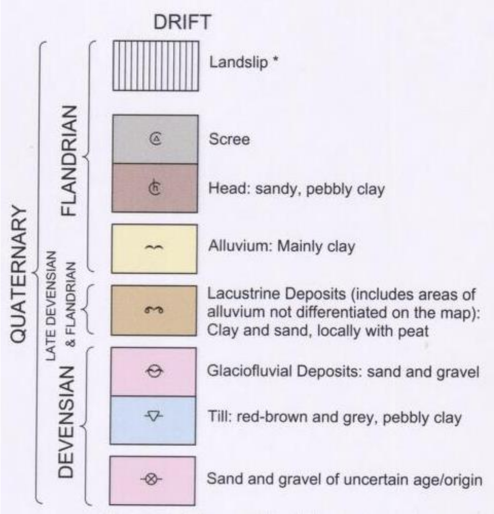


Figure 4 Key to the superficial deposits shown on the Pickering 1:50 000 scale provisional map sheet; not all of these units are recorded in the Vale area.

3.2 BOREHOLE DATA

BGS holds around 900 borehole records for the Vale (Figure 5). These range considerably in age, depth, detail and distribution. An initial assessment of selected boreholes (described below) indicates that only around 50% contain useful information on the superficial geology.

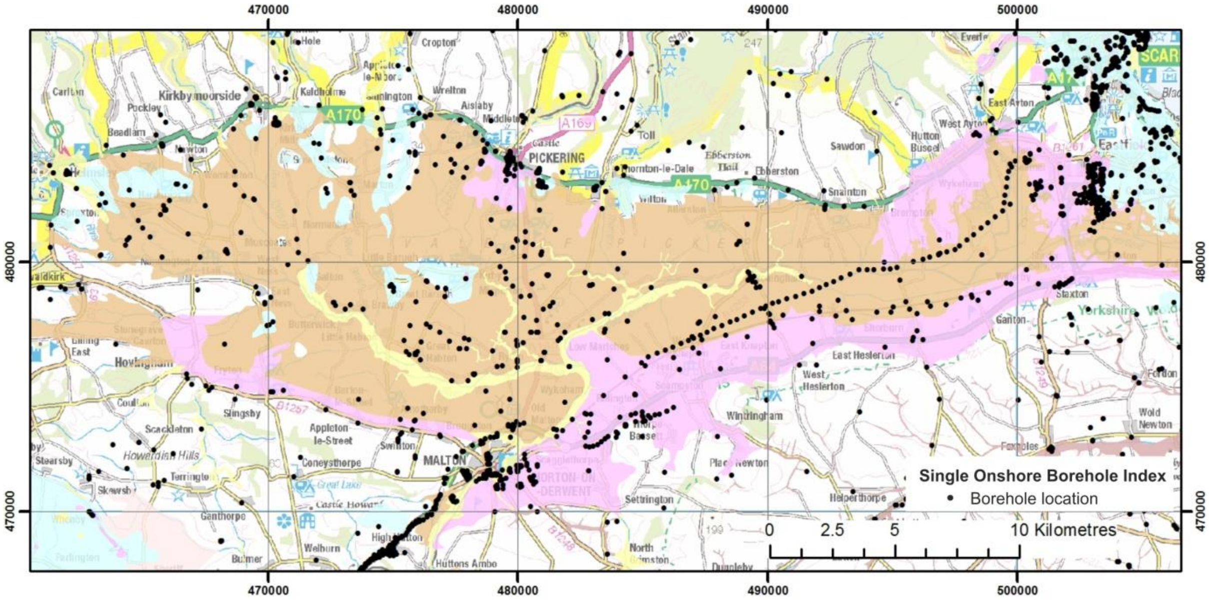


Figure 5 Borehole distribution based on BGS Single Onshore Borehole Index (SOBI).

3.3 ROCKHEAD SUPERFICIAL THICKNESS

The BGS Advanced Superficial Deposits Thickness Model (ASTM) (Lawley and Garcia-Bajo, 2009) offers coverage of the Vale. This model uses borehole thicknesses and Quaternary map limits; rather than interpolating superficial 'thickness', each data point is compared with a digital elevation model (DEM) and the elevation of the point of rockhead above sea-level is calculated. The rockhead 'elevations' from the boreholes and map margin are then interpolated across the entire map area to create a rockhead elevation model (Figure 6). This model is then subtracted from the DEM to derive a thickness model (Figure 7). Where no superficial deposits are present (i.e. where bedrock is mapped directly beneath the ground surface; white areas on Figure 6 and Figure 7) the rockhead elevation is equivalent to that of the ground surface.

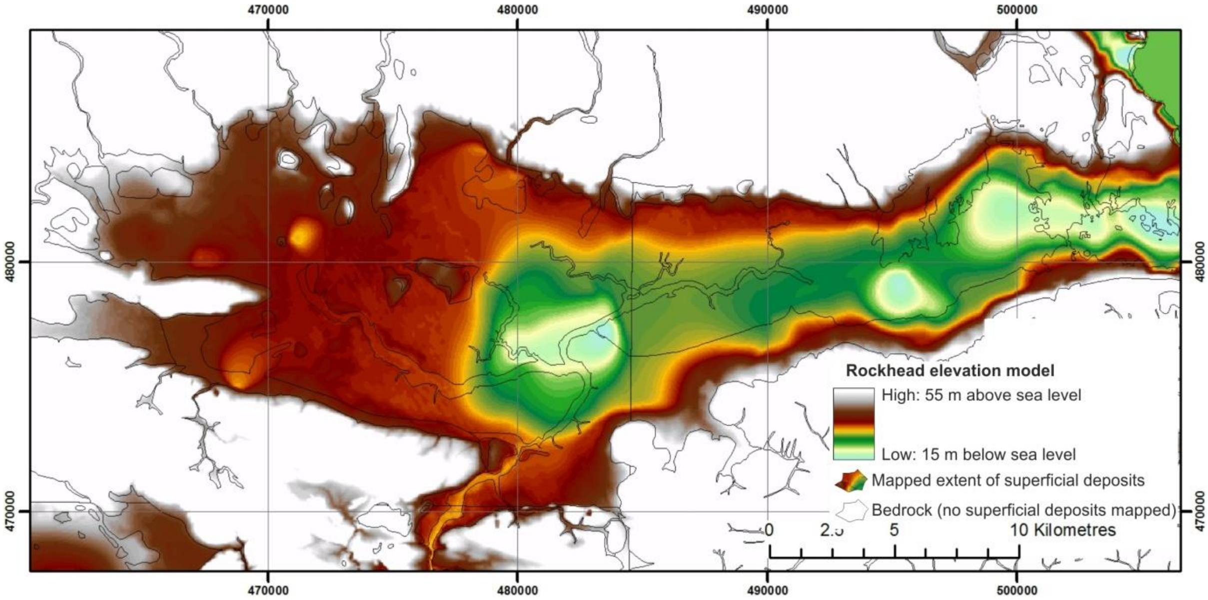


Figure 6 BGS rockhead elevation model; colour ramp ranged to highlight local variation.

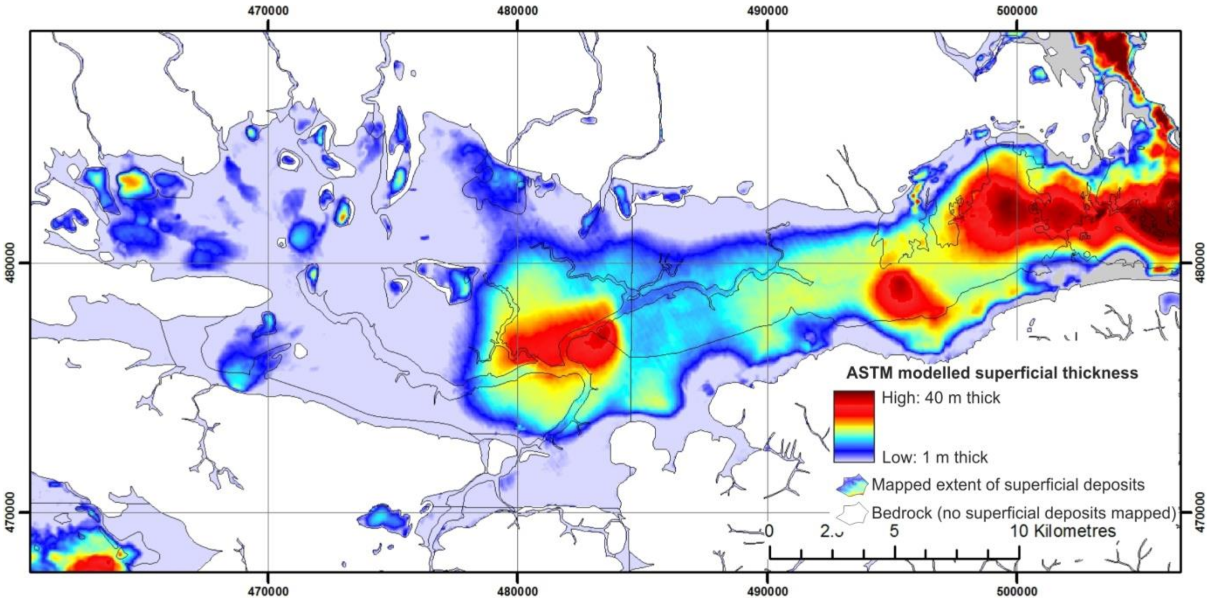


Figure 7 Advanced superficial thickness model (ASTM); colour ramp ranged to highlight local variation.

Both models indicate that the central axis of the Vale corresponds with the area of deepest/thickest superficial deposits, reaching a maximum modelled thickness of around 35 m. The model shows several prominent anomalies, including a large depression in the rockhead surface around 6 km to the southeast of Kirby Misperton. Such anomalies may be associated with a change in lithology (i.e. the possibility of coarse-grained saturated sediments) or the preservation of older (i.e. concealed) deposits that may not be represented by the surface geological map.

As noted above, a proportion of the borehole information available to BGS in the Vale contains useful information on the superficial succession or thickness. The distribution of borehole data used to constrain the ASTM and rockhead models is shown in **Error! Reference source not ound.**. The data includes boreholes that prove rockhead as well as those that terminate above rockhead and provide a minimum thickness to the superficial succession. The linear and clustered nature of these data points and gaps in data coverage highlight the relative level of confidence that should be associated with these models. Similarly, the provisional nature of the published geological linework indicates that the mapped extent of any superficial deposits may be locally uncertain. These factors should be taken into account when considering the rockhead and superficial thickness model outputs.

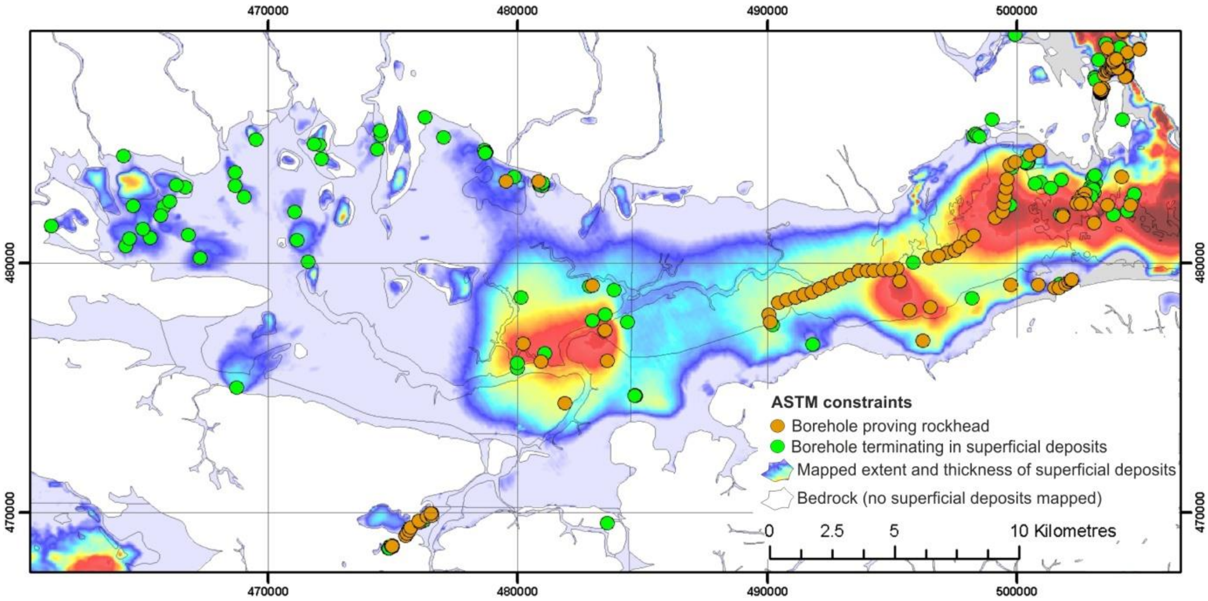


Figure 8 Map showing the distribution of borehole data used in the ASTM and rockhead models.

The cross-sections reported as part of this study have been constructed independently of the ASTM. The superficial thickness indicated by the cross sections, are based on a different set of borehole information to the ASTM (Figure 9). They incorporate a considerable amount of geological interpretation that is informed by the geologists' tacit knowledge and conceptual understanding of the local geology. Hence, the range of superficial thickness suggested by the cross-sections differs from that given in the ASTM model. Correspondingly, the depth and geometry of rockhead presented in the cross-sections (as red lines in the corresponding figure below) differs from the model in several areas. The construction of further cross-sections may allow a refined ASTM and rockhead model to be produced.

4 Review and interpretation of selected Single Onshore Borehole Index logs

A review of selected borehole logs available via the Single Onshore Borehole Index (SOBI) has been completed. Logs that contain potentially relevant information on the Quaternary succession have been prioritised. Lithological information has been codified in the BGS Borehole Geology database for the purpose of cross-section construction. Where possible, lithostratigraphical interpretations have been applied. Boreholes have been selected to provide a uniform coverage of the study area and to align with possible cross-section positions. A total of around 250 borehole logs have been considered, of which about 135 have provided usable information on the Quaternary succession (Figure 9).

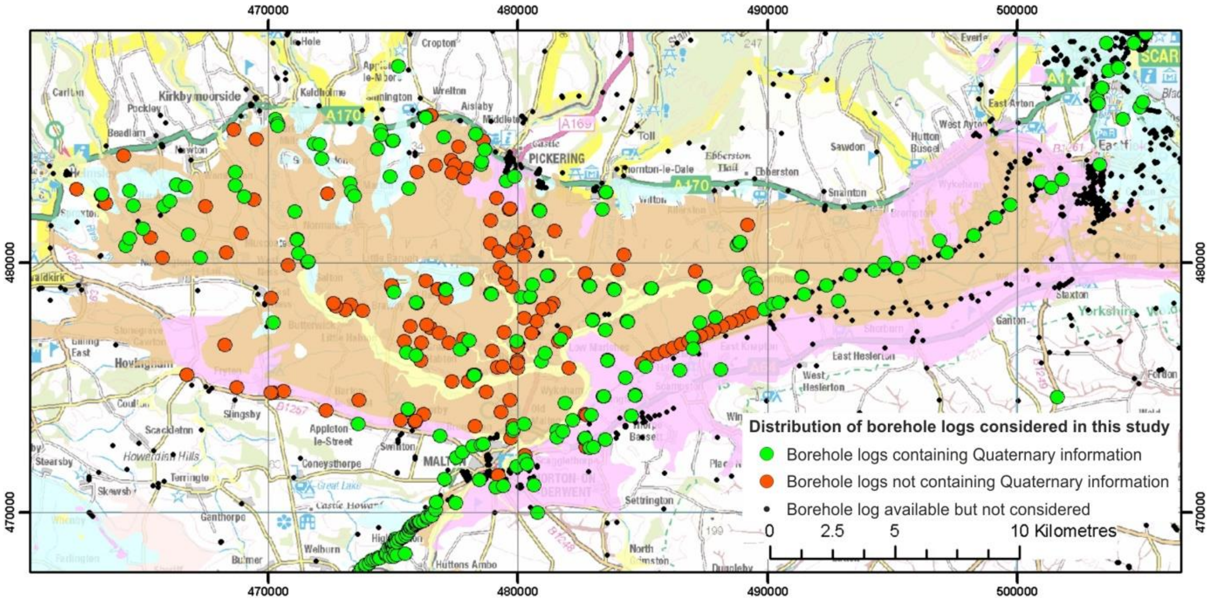
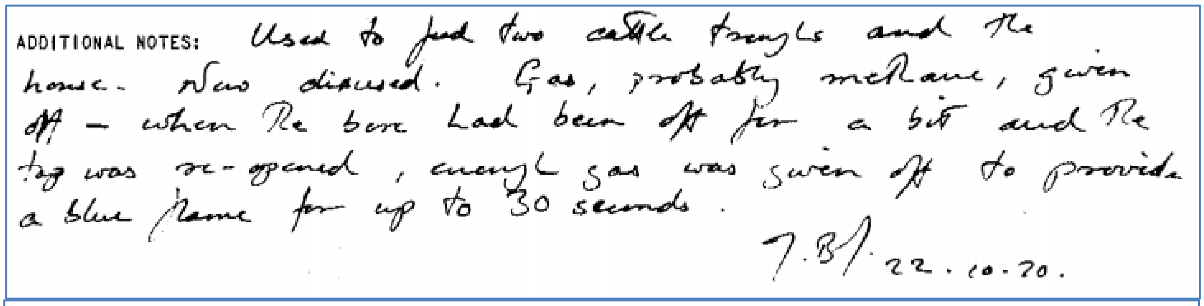


Figure 9 The distribution of borehole records considered as part of this study.

The lithostratigraphical interpretation of the information presented on the logs can involve a degree of subjectivity and a variable level of confidence in the corresponding cross-section correlation. For the study area, one of the greatest areas of uncertainty in the borehole information is the distinction between weathered rockhead (i.e. weathered mudstone - often reported as clay and including gravel that may be interpreted as drilled bands of more indurated material) and the clay-rich Quaternary succession (including primary clay and gravel sediments). As a rule, clay deposits that are described as “soft” have been interpreted as forming part of the Quaternary succession; clay deposits that are described as “hard” or “blue” are typically interpreted as weathered bedrock. Each log is considered in the context of surrounding information and some exceptions to these rules have been made where demanded by the weight of additional evidence and the geologists’ conceptual understanding of the succession.

When considering 3rd party borehole logs it is necessary to accept that the confidence in the data can vary considerably between logs. Examples of low-confidence/questionable borehole logs include those where: the same lithological description has been given for a number of boreholes (e.g. as noted on the logs for SE77NE54 [478040, 476890] and SE87NW15 [480580, 479130]); the location of the borehole is uncertain; the succession recorded on the log is based on verbal accounts rather than direct observation. Where data are deemed to be too low in confidence, they have been excluded from the study / superseded by the interpretations shown in the cross sections.

In addition to location, lithological and related geological information the logs available through SOBI can include a range of additional notes, often anecdotal. An example of a historical observation that may be relevant to the current study, in this case a recorded occurrence of “gas, probably methane…” during reopening of a borehole, is presented in Figure 10.


ADDITIONAL NOTES: Used to feed two cattle troughs and the house. Now disused. Gas, probably methane, given off – when the bore had been off for a bit and the tap was re-opened, enough gas was given off to provide a blue flame for up to 30 seconds. 7.B/. 22.10.70.

"Used to feed two cattle troughs and the house. Now disused. Gas, probably methane, given off – when the bore had been left off for a bit and the tap was re-opened, enough gas was given off to provide a blue flame for up to 30 seconds."

Figure 10 Extract and transcript from a log for a borehole located approximately 2 km to the east of Kirby Misperton.

5 Cross section interpretation

Borehole data, a DEM and 1:50 000 scale surface geological linework have been used to construct an interim set of schematic cross-sections through the Vale for the Quaternary succession (the software and methodology used in this study are described by Mathers & Kessler 2008). These cross-sections (located on Figure 11) are largely interpretative and should be considered as schematic representations of the superficial geology for the purpose of developing a conceptual (hydro-)geological understanding of the area for the Vale of Pickering environmental baseline monitoring project. Ongoing work will further increase the level of constraint and confidence in these sections and assess the viability of progressing to a 3D geological framework model.

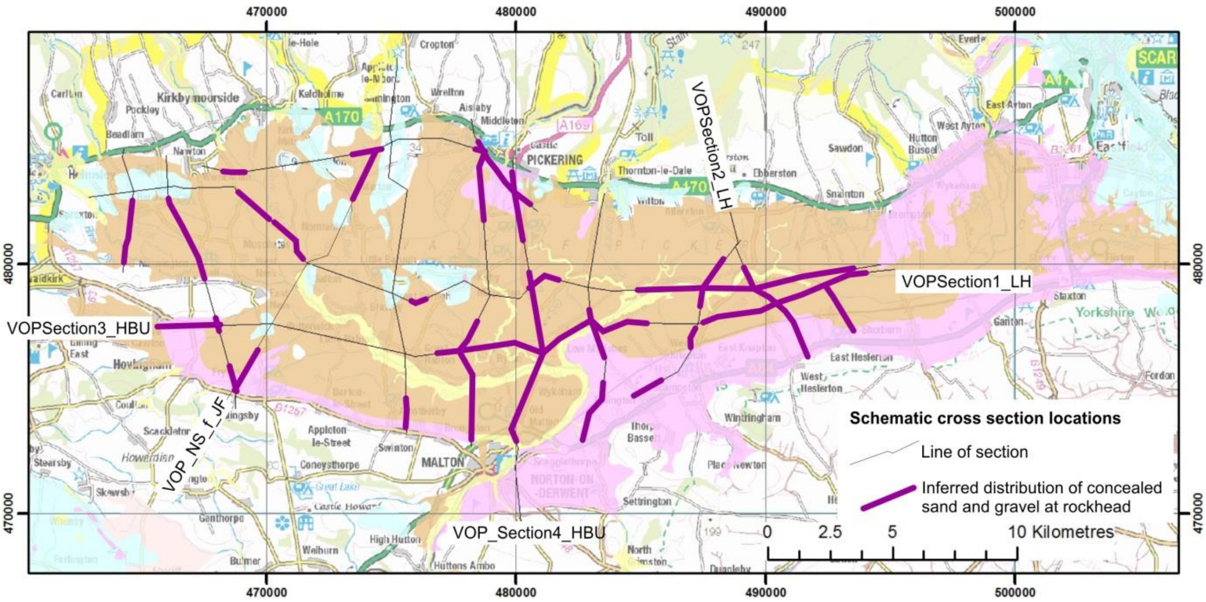


Figure 11 Map showing inferred distribution of concealed sand and gravel deposits at rockhead based on the schematic cross sections.

For the purpose of constructing the schematic cross-sections, the borehole logs have been hung from the DEM. In some cases, this has superseded the start height recorded on the log or shown in SOBI. Hence, the elevation of the Quaternary succession shown in the sections may differ slightly from that derived directly from the logs. A key to the interpreted Quaternary succession and corresponding lithological descriptions for the logs included in the cross-sections is shown in Figure 12.

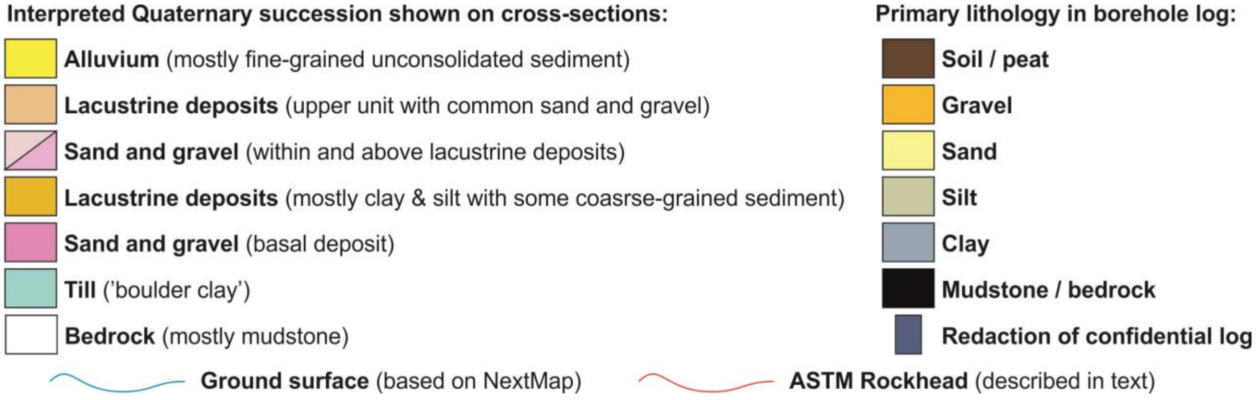


Figure 12 Key to the schematic cross-sections.

5.1 BRIEF EXPLANATION OF THE SUPERFICIAL GEOLOGY BASED ON THE BOREHOLE REVIEW AND SCHEMATIC CROSS SECTIONS

Alluvium – Mostly fine-grained poorly consolidated sediment associated with the modern-day drainage network, the precursor for which was established following the draining of 'Lake Pickering'. Due to the flat-lying nature of the Vale and the low-permeability substrate it is likely that the alluvium will locally contain organic deposits and although no isolated peat deposits are shown on the Pickering 1:50 000 scale map, it is likely that bodies of peat will be present. Close to the higher ground flanking the Vale, coarser-grained alluvial deposits should be expected.

A confident differentiation between alluvium and (the older) lacustrine deposits can be problematic in low-lying areas due to limited contrast in lithology and surface morphology. The Vale of Pickering shares many similarities with the Vale of York (Ford *et al.*, 2008), where observations indicate a continuum between alluvium and lacustrine deposits in some areas.

Blown sand (postulated occurrence, not shown on the cross-sections) – Although no blown sand deposits are shown on the published data, observations from the Vale of York suggest that such deposits may be present in the Vale of Pickering, having developed following the draining of Lake Pickering. If so, these deposits are likely to occur at surface as a thin (1-2 m max.) veneer of fine-grained, well-sorted sand.

Lacustrine deposits – During the Late Devensian, North Sea ice and corresponding glaciogenic deposits in the east, and similar restrictions in the west, impounded drainage within the Vale. This resulted in the inundation of the area and the formation of (Glacial) Lake Pickering. This lake was fed by corresponding meltwaters in the east and west and by active drainage from the Wolds to the south and the Tabular Hills to the north.

The lacustrine deposits are shown on the map as "clay and sand, locally with peat". Borehole data confirms that these deposits are predominantly fine-grained, composed of clay and silt. It is likely that the clay and silt are thinly interlaminated. The lower lacustrine unit shown in the sections represents this fine-grained 'facies' of the lacustrine deposits.

The lacustrine succession shows a coarsening of sediment in the upper part. This is most pronounced in the south and east of the area, where in the cross-sections, a body of interbedded clay, sand and gravel has been correlated over a large part of the Vale. The upper lacustrine unit shown on the cross-sections represents this interbedded fine- and coarse-grained facies of the lacustrine deposits. Borehole evidence suggests that several sand or gravel horizons within this unit may be correlated over distances in the order of several kilometres (e.g. as shown in the eastern-most part of the sections illustrated in Figure 13). This facies is thought to pass laterally into the fine-grained facies with smaller, discreet and possibly less continuous beds or lenses of sand and gravel.

In addition to the broadly defined facies described above, more localised lithological variation within the lake succession should be expected. It is likely that coarser-grained (silt- or sand-dominated) horizons will be present, possibly emanating from the contemporaneous drainage systems that fed the lake. These horizons may occur at several levels within the lake deposits and may be laterally persistent. Equivalent clay-dominated lacustrine deposits in the Vale of York contain saturated silty sand horizons up to 2.5 m in thickness that extend laterally in the subsurface for more than 10 km. In the present study, several 'lenses' of sand or gravel that have been inferred from borehole evidence and included in the cross sections (e.g. Figure 15).

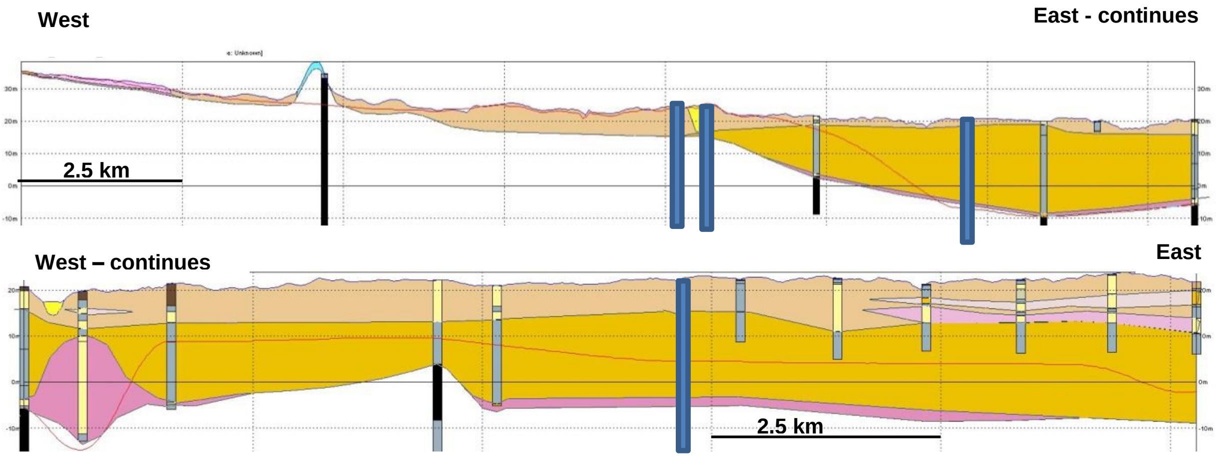


Figure 13 West-east oriented schematic cross section, split into two parts (VOPSection3_HBU and VOPSection1_LH; about 50 times vertical exaggeration; for section location and key see Figure 11 and Figure 12).

Sand and gravel deposits – Several areas of sand and gravel coincide with the opening of confined river valleys on the Vale's norther margin. These deposits are interpreted as delta/fan deposits (patches of sand and gravel shown on the northern edge of the Vale in Figure 3 and corresponding topographic features highlighted in Figure 2). It is likely that the rivers were active at times during the Late Devensian and that sand and gravel that is mapped at surface may extend into the lake succession at depth. Rivers that have little or no current expression at surface may have been active during the early stages of Lake Pickering. Such rivers may have deposited coarse-grained sediment that is now entirely concealed. Little is known about the lateral extent, continuity or orientation (i.e. if channel-like in form) of these rivers or any corresponding deposits.

The southern margin of the superficial deposits of the Vale is largely represented by "sand and gravel of uncertain age". The relative distribution of these deposits appears similar to those observed on the eastern flank of the Vale of York, and may represent sheets of gravel and shoreline deposits that were sourced from the limestone and chalk bedrock to the south. If analogous to the marginal sand and gravel deposits in the Vale of York, these deposits may be expected to interdigitate with the lacustrine deposits and form laterally persistent horizons within or below the lake sediments (see above).

Borehole evidence indicates that sand and gravel deposits occur at depth in the Vale. These deposits can be identified in adjacent borehole logs (e.g. Figure 14). In the absence of additional borehole evidence, they are interpreted in the schematic sections as having lateral continuity with the sand and gravel mapped at surface (e.g. Figure 14).

However, it should be noted that alternative interpretations could be made, for example to model the sand and gravel that is encountered at depth as a separate body to that mapped at the surface. In Figure 14 this would be shown as deposit of sand and gravel occupying the rockhead depression in the centre of the Vale, isolated by fine-grained lacustrine deposits from that on the edge of the Vale (for example, as shown in Figure 15 where the concealed sand and gravel deposits at depth in the centre of the Vale are inferred to be contiguous with those mapped at surface in the south but isolated from equivalent deposits in the north).

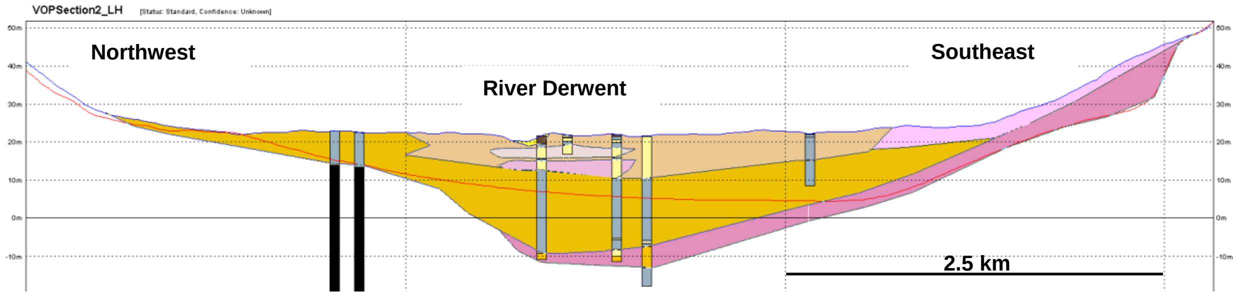


Figure 14 Northwest-southeast oriented schematic cross section (VOPSection2_LH; about 25 times vertical exaggeration; for section location and key see Figure 11 and Figure 12).

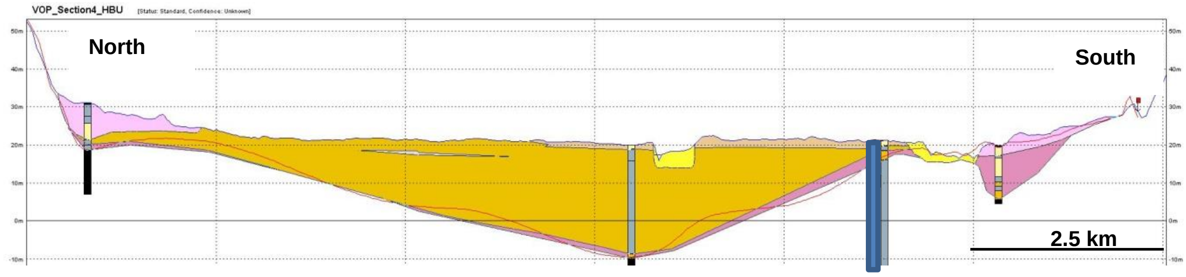


Figure 15 North-south oriented schematic cross section (VOP_Section4_HBU; about 50 times vertical exaggeration; for section location and key see Figure 11 and Figure 12).

The cross-sections show a schematic/simplified representation of the concealed sand and gravel. The inferred distribution of concealed sand and gravel deposits at rockhead based on the schematic cross sections is shown in Figure 11. The actual extent of these deposits may differ from that shown and additional bodies may be present that have not been depicted by this study.

Till – Till is a poorly-sorted sediment composed of clay, silt, sand and gravel that was deposited by a glacier. Isolated patches of till are shown on the map, occupying topographic highs within or at the margin of the Vale (Figure 3). These deposits are inferred to pre-date the formation of Lake Pickering. It is suggested that the till is discontinuous at depth and may not extend any great distance away from the topographic highs where it is preserved. The borehole and cross-section studies support this premise: no firm evidence was found to suggest that the till extends for any significant distance at depth beneath or within the lacustrine deposits adjacent to the hills such as those at South Holme, Great Barugh and Kirby Misperton (e.g. Figure 16). The 3D geometry of the till shows that it is caps and forms a drape on the flanks of these topographic highs – the material mapped as till on the flanks is likely to represent re-worked material (i.e. 'head', rather than insitu till). The till-capped topographic highs within the Vale may represent local sources of coarse-grained sediment within or beneath the lacustrine succession.

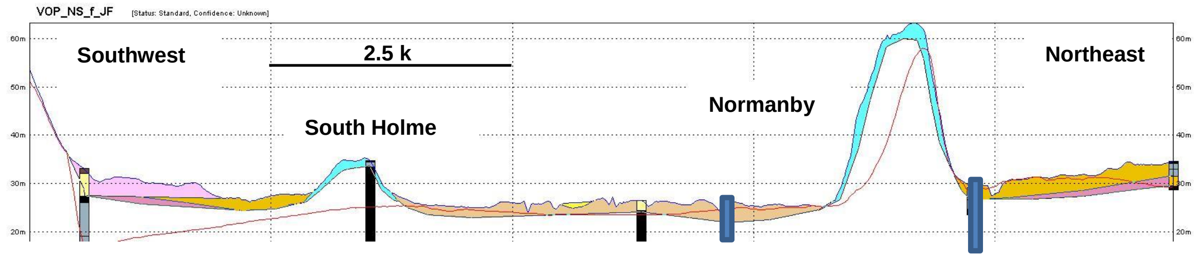


Figure 16 Southwest-northeast oriented schematic cross section (VOP_NS_f_JF; about 50 times vertical exaggeration; for section location and key see Figure 11 and Figure 12).

Borehole information in the north of the Vale, close to the limit of the lacustrine deposits and adjacent to an area where extensive areas of till have been mapped around Kirby Mills, indicate that till deposits may extend at depth in this area, concealed beneath the lacustrine succession. This suggestion is based on the recorded presence of boulders and gravelly clay at rockhead. Alternative genetic interpretations for these deposits also includes their classification as head deposits (i.e. soliflucted material), or an admixture of gravel and clay deposits, including weakened bedrock (formed by weathering, permafrost, drilling or sampling).

The till of the Vale was targeted by BGS-led drilling in recent years as part of ongoing research into the glacial evolution of the area. Results and interpretations based on these boreholes, including schematic cross sections and the geological evolution outlined above forms the basis of a draft paper on the region's Quaternary geology (Powell and Ford, in prep.)

6 Summary

This desk study of the Quaternary geology of the Vale of Pickering has considered a range of existing datasets held by the BGS, including maps, superficial thickness and rockhead models and selected borehole information. The latter has been synthesised as a series of interlocking schematic cross sections. This study has been undertaken to provide a 'conceptual geological' model for the area to support the selection of groundwater monitoring sites for the BGS-led Environmental Baseline Monitoring project.

The geological cross-sections presented in this study consider a variety of baseline data including borehole logs and surface geological mapping. The interpreted geology shown is informed by the geologists' tactic knowledge and conceptual understanding of the local geology.

Key outcomes of the work are as follows:

- The study has identified considerable lithological heterogeneity in the lacustrine deposits including: a lower fine-grained facies and an upper interbedded fine- and coarser-grained facies; the latter has been correlated primarily in the south and east part of the Vale.
- The interbedded facies is inferred to pass laterally into fine-grained facies.
- 'Lenses' of sand and gravel have been identified in the fine-grained facies. Although these are modelled as lenses in the cross-sections, they may represent bodies of sediment that are channelized and that extend for a greater distance away from the section.
- Beds of sand and gravel have been identified in the interbedded facies that have been correlated between boreholes for several kilometres.
- Basal sand and gravel is inferred to be present over a considerable part of the Vale. These deposits are in part inferred to be contiguous with equivalent deposits that are mapped at surface on the edges of the lacustrine deposits and at higher elevations on flanks of the Vale.
- The till deposits are inferred to be mostly restricted to highly dissected patches on the topographic highs and the mapped areas on the periphery of the Vale; the lacustrine deposits are believed to overlie the till. This study has not identified any large areas of concealed till at depth in the Vale.
- The subsurface / concealed Quaternary geology is likely to be locally heterogeneous, with a level of complexity that is not apparent in the published superficial mapping of the area nor captured by the current set of schematic cross sections.
- The thickness of superficial deposits depicted in the cross sections differs considerably from that shown in the SDTM model in some parts of the Vale.

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