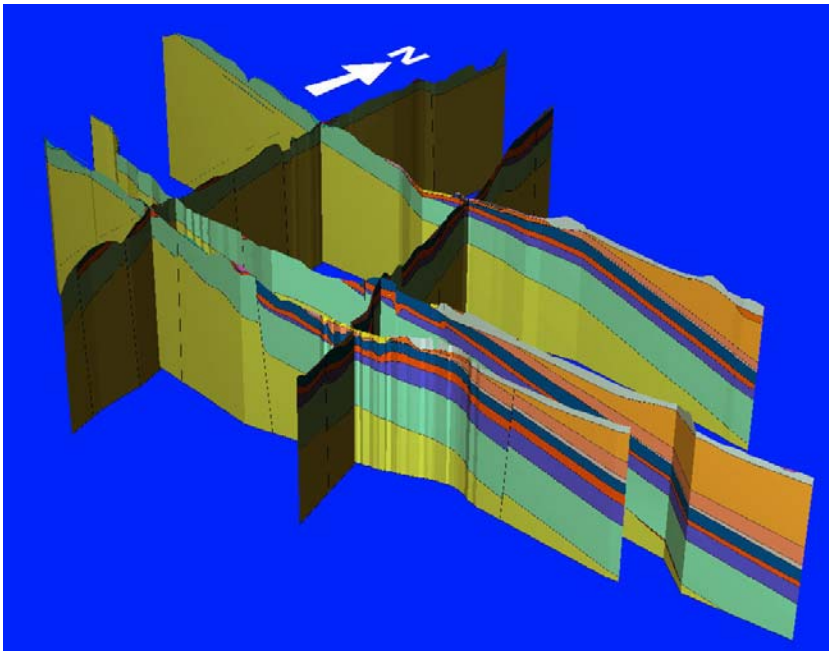
Tadcaster Magnesian Limestone 3-D Borehole Interpretation and Cross-sections Study

Geology and Landscape (South) Report

CR/06/256 N



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GEOLOGY AND LANDSCAPE (SOUTH) PROGRAMME

IN CONFIDENCE REPORT CR/06/256N

Tadcaster Magnesian Limestone 3-D Borehole Interpretation and Cross-sections Study

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Study undertaken for the Environment Agency

Keywords

Report;Permian, Quaternary, 3D cross-sections, Tadcaster, Yorkshire, hydrogeology.

Front cover

3-D model of the Permian strata and Quaternary deposits of the Tadcaster area.

Bibliographical reference

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Foreword

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

Acknowledgements

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The cross-sections and thematic maps are compiled from borehole information that varies considerably in distribution, age, quality, depth and content. The geological information has been compiled from these boreholes and digital map data at a scale of 1: 50,000. Use of the cross-section interpretations at scales larger than 1:50,000 is not recommended. The varied distribution of the borehole data means that in some places the sections are well constrained and in others the geological lines are considerably extrapolated. The cross-sections are the best interpretation that the geologist has been able to make from the existing information and new boreholes may require this interpretation to be modified.

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Summary

This report was prepared under contract to the Environment Agency and describes the geology of the area surrounding Tadcaster in North Yorkshire. The work was commissioned to investigate the local geology and construct 3-D cross-sections from borehole and surface information. Approximately 1200 boreholes were utilised for the work and these ranged in depth from a few metres to 350m. Five cross-sections were constructed; three WSW-ENE trending sections and two NNW-SSE trending sections all to a depth of 250m below OD.

In addition, a series of thematic maps were generated from the lithological component of the digital borehole data. Total superficial aquifer and superficial aquitard maps show how the lithological nature of the superficial sequence varies across the area. Rockhead elevation and superficial thickness maps indicate where the bedrock aquifers outcrop or are near to the ground surface.

The east side of the Vale of York in the vicinity of Tadcaster is underlain by a sequence of Permian and Triassic rocks overlain in part by thick superficial deposits dating mainly from the last Ice-Age. The Permian rocks comprise two magnesian limestone aquifers separated by sequences of gypsum/anhydrite and gypsiferous mudstones. The overlying Triassic rocks comprise the major Sherwood Sandstone aquifer. The western part of the area consists of mainly exposed bedrock (Permian dolostone and dolomitic limestone), but the eastern side where the Sherwood Sandstone Group is present has a thick cover of superficial deposits including moraines, glacial lake deposits and alluvial deposits.

1 Introduction and Scope of Study

This report has been produced in response to a request made by the Environment Agency (EA) to investigate the potential hydrogeological impact caused by the variability in thickness and composition of the bedrock and natural superficial deposits around Tadcaster in the west of the Vale of York. The west of this area is underlain by Carboniferous rocks overlain by the Cadeby and Brotherton formations, both aquifers in the Permian sequence. In the east, the area is underlain by the Sherwood Sandstone Group, one of the United Kingdom’s major aquifers. The Permian sequence yields water that is extensively utilised for the brewing industry. This water contains high amounts of dissolved calcium sulphate, a desired additive that makes the water naturally “Burtonised” for brewing.

By constructing digital regional scale cross-sections, the study aims to characterise the lithological properties of the bedrock and superficial deposits, their spatial distribution, geometry and thickness including the delineation of areas where these deposits are thin or absent.

The construction of the cross-sections was enabled by the interpretation, lithological coding and databasing of borehole data held within the National Geoscience Data Centre at BGS. The cross-sections and geological correlation were performed digitally within GSI3D (Geological Surveying and Investigation in 3-D) version 2, a proprietary 3-D modelling package developed by Dr Hans Sobisch at Insight Geologische Softwaresysteme GmbH .

2 Borehole Coding

Lithological interpretation of boreholes were derived from paper records held within the National Geoscience Data Centre at the British Geological survey and additional digital records provided by the Environment Agency. Boreholes for use in the project were selected based on their position within a 200m wide buffer zone around the previously agreed lines of section (Figure 1 and Figure 2).

2.1 CODING METHODOLOGY

Boreholes were coded according to the description of the down-hole lithology recorded on the paper records of the borehole. The quality of the original description varied according to the age of the record and the purpose for which the borehole was drilled (e.g. site investigation, water abstraction or coal exploration). In addition to lithological interpretation, the appropriate stratigraphic code was applied where the coder was confident of the interpretation. The stratigraphic codes used for the project were derived from the BGS Stratigraphic Lexicon (http://www.bgs.ac.uk/lexicon/lexicon.html).

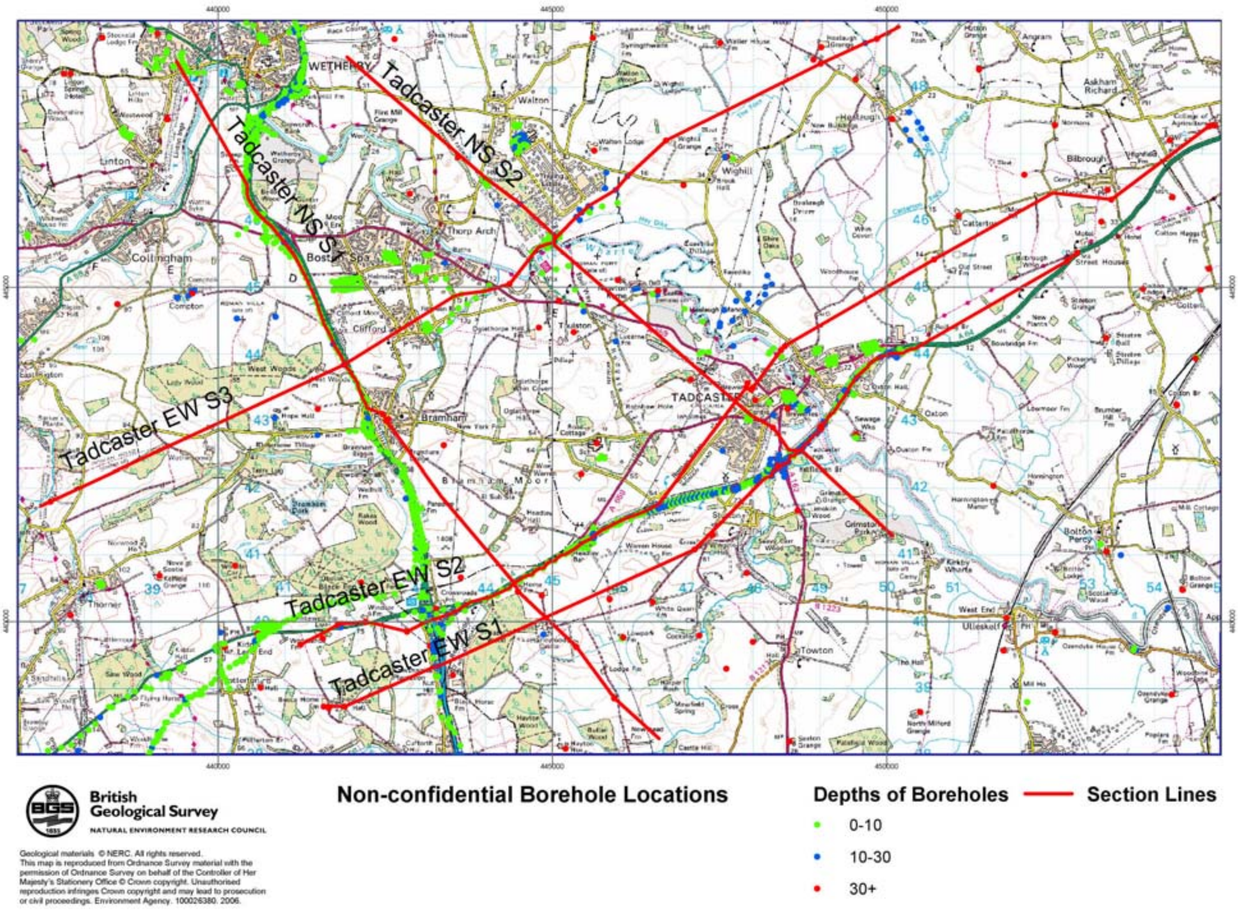

Figure 1. Locations of sections and boreholes used for the Tadcaster study, confidential boreholes are not shown.

Sites of all boreholes confidential and non-confidential can be obtained from the BGS website at http://www.bgs.ac.uk/geoindex/home.html Borehole logs can be purchased from the BGS through central enquiries and the internet: http://www.bgs.ac.uk/boreholes/home.html

The lithological codes for the superficial deposits were derived from the BGS Superficial Deposits Coding Scheme (Cooper et al., 2005). The scheme uses six letters to denote the primary lithology of a deposit and is shown below in Table 1.

Lithological Units	**Code**
Peat	P
Sand	S
Silt	Z
Clay	C
Gravel	V
Cobbles	L
Boulders	B
For Made Ground	FILLU

Table 1. Superficial deposit lithological coding scheme component codes

Where more than one lithological unit is present (for example a sandy clay) the letters can be combined to reflect the full lithology of the material. The coded lithological and stratigraphic information was added to the BGS Borehole Geology database to be retrieved subsequently for correlation.

2.2 BOREHOLE ELEVATION

Each borehole was referenced to an elevation with respect to Ordnance Datum. The presence of this information on a borehole log was variable. If the elevation was recorded on the borehole log it was used in the database. If the elevation was missing it was either derived manually from Ordnance Survey contours and spot heights or automatically from the NextMap digital terrain model.

3 Cross-Section Construction and Correlation

The five cross-sections were constructed along the agreed lines using a buffer zone of 200m wide to allow the best boreholes in the database near to those lines to be incorporated. In a few places the line of section was taken slightly outside of the buffer zone to allow the incorporation of a few deep boreholes that added considerably to the understanding of the local geology (for example on the NE end of section Tadcaster EW S2).

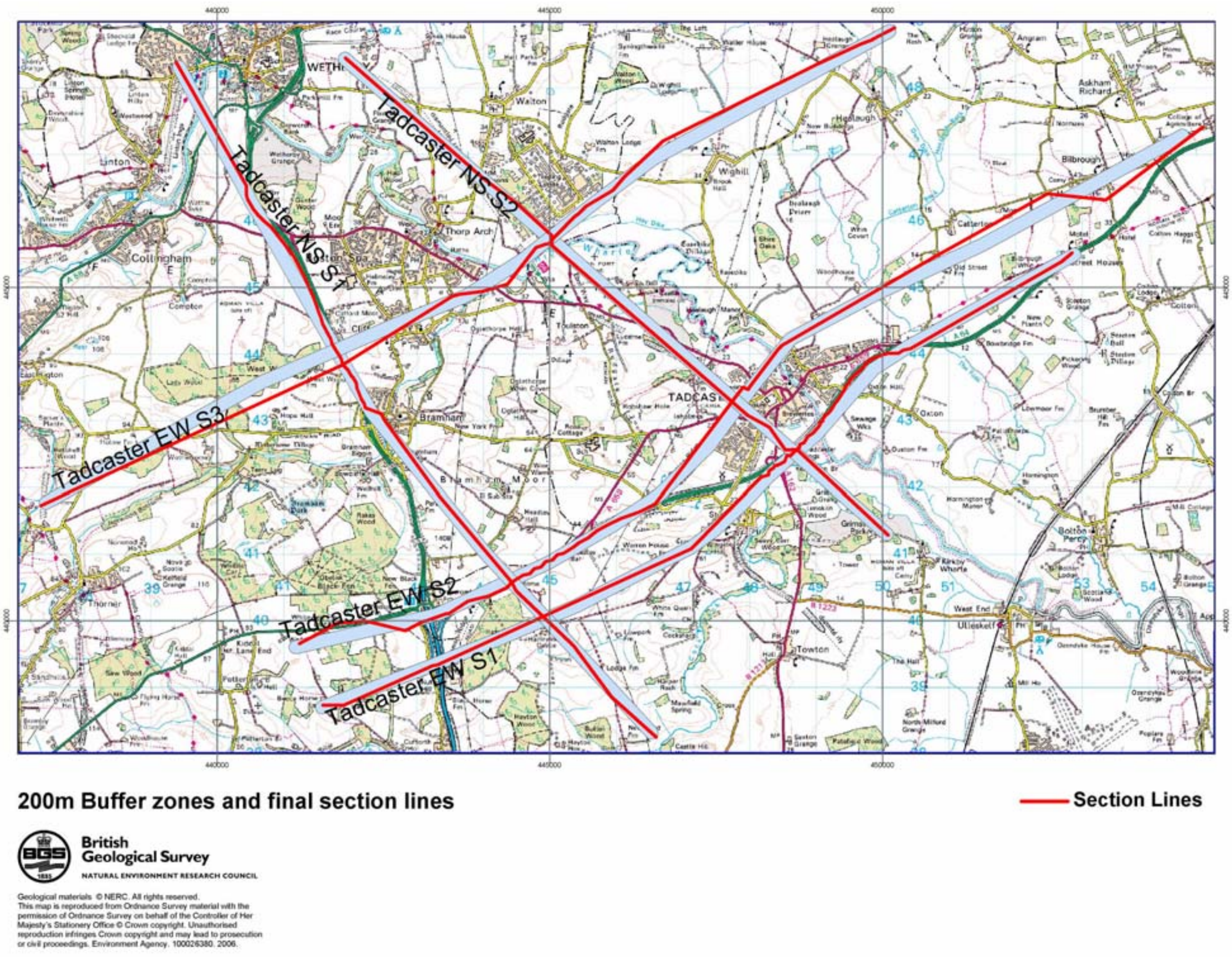

Figure 2. Buffer zones for the proposed sections and lines of final sections for the Tadcaster study area.

3.1 CROSS-SECTION CONSTRUCTION METHODOLOGY

The coded boreholes were imported into GSI3D from the BGS Borehole Geology database in their correct spatial positions. From the complete database of coded boreholes, the highest quality logs were selected for inclusion along the cross-section. The selection process was based a number of key criteria including depth (preferably boreholes reaching bedrock) and quality of description.

Each borehole added to the line of section defined a control point for subsequent geological correlation. Of the 1498 boreholes in the study area, approximately 1000 fully coded and attributed boreholes were available, but many of these along the A1/A1(M) and A64 roads were shallow in the range of 1-5 m. The deepest boreholes used were about 350 m deep, but most of these cannot be identified as they are held confidentially. The deep boreholes both on and off the lines of section were used to constrain the stratigraphy and thickness. The sections included the following number of boreholes in the lines of section:

Tadcaster EW_S1 – 53 boreholes

Tadcaster EW_S2 – 40 boreholes

Tadcaster EW_S3 – 19 boreholes

Tadcaster NS_S1 – 39 boreholes

Tadcaster NS_S2 – 10 boreholes

Lists of the boreholes used and their depths along with co-ordinates of section kinks where no boreholes are present are given in Appendix 1.

3.2 CORRELATION

The full lithological coding and partial stratigraphic coding was displayed on screen in GSI3D. These descriptions were used as data-rich anchor points to begin to build the correlation. The geological units correlated along the sections are shown in Tables 2 and 3. Correlation lines and the nodes that make up the lines were constructed manually on screen (Figure 3). Each line was then attributed with the corresponding correlation code (Table 2 and Table 3).

Existing 1:50,000 scale 2D digital geological map data (DigMap50 - Figure 16 and Figure 17) was used to aid correlation and define the limits and relationships of different geological units.

The cross-sections included data poor and data rich areas. Data rich areas, where the borehole density was high, resulted in increased confidence in the correlation. In data poor areas, lines of correlation were projected from data rich areas, or interpreted from an understanding of the local geology.

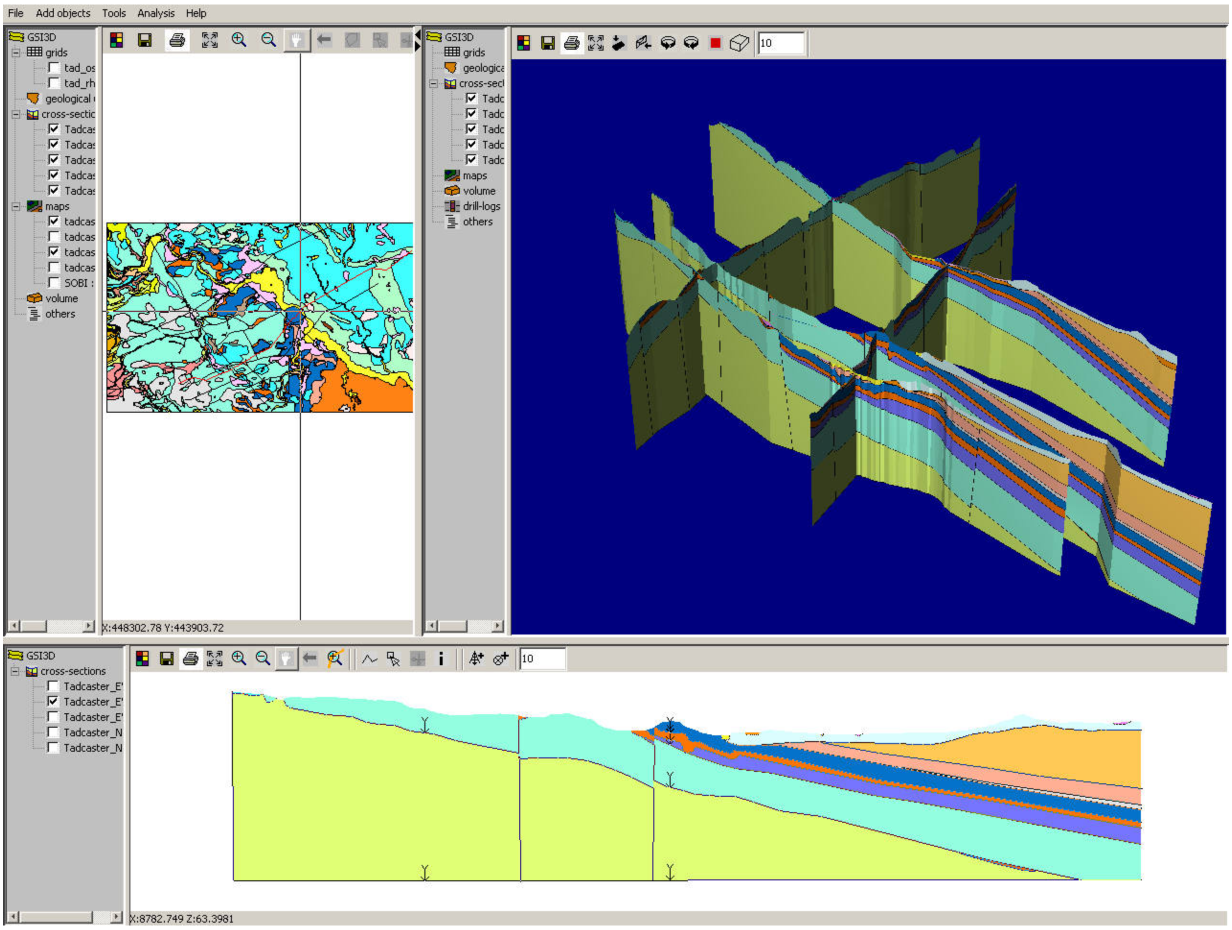

Figure 3. GSI3D windows showing the map view, section view and 3-D view for the Tadcaster area study

4 Aquifer and aquitard thickness modelling

4.1 OVERVIEW

1. The models represent a mathematical interpolation of BGS’s legacy borehole and map datasets, including new data supplied for this project by the EA. No third party data relating to Quaternary deposits has been used. A mathematical model does not take into account any conceptual modelling of the form of the superficial deposits.
2. The ‘Natural Neighbour’ modelling used with this data provides a smoothed, average-fit surface, Alternative modelling techniques will generate alternative models (see below).
3. The borehole data used to make the models is subject to a small degree of error; new borehole data lodged with BGS Offices in recent months may not have been incorporated within the models.
4. The map data used to make the models is based upon DigmapGB50 Version 3.14.
5. The models provide indicative values of thickness and elevation and not definitive values.

4.2 GRIDDING DETAILS

1. Grids are created using Vertical Mapper and MapInfo V8. Interpolation between data points was via Natural Neighbour analysis. Natural neighbour interpolation is a geometric estimation technique that uses natural neighbour regions generated around each point in the data. This technique is particularly effective for dealing with a variety of spatial data themes exhibiting clustered or highly linear distributions. Put simply, natural neighbour interpolation makes use of an area-weighting technique to determine a new value for every grid node. As shown in Figure 4, a natural neighbour region is first generated for each data point. Then, a new natural neighbour region is generated at every node in the new grid, which effectively overlies various portions of the surrounding natural neighbour regions defining each point. The new grid value is calculated as the average of the surrounding point values proportionally weighted according to the intersecting area of each point
2. The grids are generated with a cell spacing of 25m by 25m, and data is aggregated by a 25m radius (i.e. points located a cell spacing from their neighbours are averaged).
3. Grids are smoothed (Hermitian smoothing) with local minima and maxima honoured but extrapolation beyond these values limited. Hermitian smoothing is an area-weighting technique that assigns greater influence to datapoints that are closest to the grid nodes of the interpolated surface. I.e. if the grid cell lies mostly within the voronoi neighbourhood of one data point, the cell value is 'weighted' towards the value of the dominant datapoint. The overall result is a proximity-related smoothing effect across the entire interpolated surface.
4. Grids are nulled where DigmapGB50 indicates no superficial material to be present.
5. Gridding of data is iterative. Initially only boreholes proving the whole superficial thickness are processed; boreholes that terminate within the deposits are subsequently added where interpolation indicates they will affect the model (this provides a ‘minimum thickness model and is useful in areas of low borehole density).

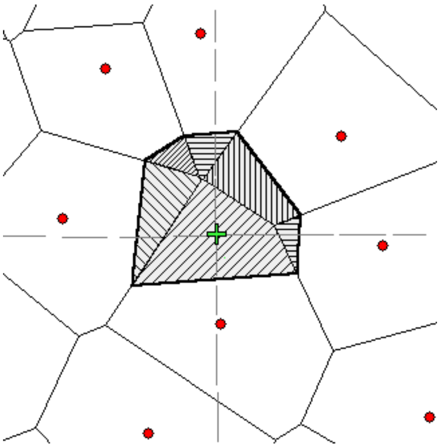

Figure 4. Natural Neighbour regions (white polygons) around the point file as well as those created around a grid node (hatched with green cross showing node)

The thematic maps are shown in section 8.

5 Bedrock Geology

Age	Geological Unit (Lithostratigraphy)	Code	Thick-ness (m)	Summary Lithology	Superficial Aquifer / Aquitard
TRIASSIC	Sherwood Sandstone Group	SSG	Up to 105 m present	Fine to medium-grained red-brown sandstone	Major Aquifer
PERMIAN	Roxby Formation	ROX	15-35 m	Calcareous and gypsiferous red-brown mudstone	Aquitard, but partial aquifer where collapse due to gypsum dissolution has occurred
	Billingham Anhydrite Formation (or gypsum)	BLA	0-8 m	Anhydrite which towards outcrop passes into gypsum, then gypsum with partial or severe dissolution	Minor Aquifer where it has been dissolved near outcrop
	Brotherton Formation	BTH	18-26 m	Dolostone and dolomitic limestone with a little mudstone, mainly thin bedded (and well jointed near outcrop)	Major Aquifer
	Edlington Formation	EDT	8-18 m	Calcareous and gypsiferous red-brown mudstone	Aquitard, but partial aquifer where collapse due to gypsum dissolution has occurred
	Hayton Anhydrite Formation (or gypsum)	HTA	0-25 m	Anhydrite which towards outcrop passes into gypsum, then gypsum with partial or severe dissolution	Minor Aquifer where it has been dissolved near outcrop
	Cadeby Formation	CDF	15-80 m	Dolostone with a porous texture due to dolomitisation. Relict ooliths are common and small patch reefs also occur. Traces of dissolution towards outcrop	Major Aquifer
	Marl Slate Formation	MLSL	0-2 m	Calcareous pyretic mudstone of very limited extent, becoming more prevalent to the east	Aquitard (impersistent and too thin to be modelled on sections)
	Yellow Sands Formation	YWS	0-20 m	Fine-grained slightly ferruginous sandstone with rounded grains forming lenticular and dune-shaped masses. Blue grey at depth becoming yellow at outcrop	Minor Aquifer
CARBONIFEROUS	Millstone Grit Group (undivided on cross-sections only)	MG		The code for Millstone Grit Group undivided has been used to represent a complex sequence of sandstone, mudstone and siltstone units that include the Millstone Grit Group and the Pennine Lower and Middle Coal Measures Groups on the cross-sections	The sandstone units for minor aquifers, the intervening siltstones and mudstones form aquitards

Table 2. The bedrock units modelled in cross-sections for the Tadcaster area

The regional lithostratigraphical units that have been correlated in the Tadcaster cross-sections have been defined on the basis of their lithology and mode of origin. The bedrock is Carboniferous in the west and at depth, unconformably overlain in the east by late Permian to Triassic strata. The Permo-Triassic rocks dip gently to the east and include the aquifers of the Permian Cadeby and Brotherton (Magnesian Limestone) formations and the regionally important Triassic Sherwood Sandstone Group aquifer. The description of the main geological units is based on outcrop (Figure 5) and borehole information from both within and outside of the Tadcaster area.

Non-confidential borehole SE54SW/9 at Colton (NGR 454693, 444965) provides the best publicly available section in the area proving the full Permian sequence. It is located within the study area about 1.9 km to the ESE of the end of section Tadcaster EW_S1. The description of the Triassic and Permian strata covers 3 pages and the Carboniferous another 3 pages. The borehole proved the following sequence:

Borehole SE54SW/9 at Colton (NGR 454693, 444965)		
Surface level 11.64 m		
Lithology	Depth below surface (m)	Thickness (m)
Brown and grey clay	12.00	12.00
Red sandstone with siltstone and marl layers (Sherwood Sandstone Group)	87.45	75.45
Red and grey-green marl with a little gypsum (Roxby Formation)	121.18	33.73
Grey marl, anhydrite and gypsum (Billingham Anhydrite Formation)	124.45	3.27
Light grey limestone (Brotherton Formation)	147.60	23.15
Red and grey marl with anhydrite, gypsum, limestone and salt (Edlington Formation)	175.55	27.95
Anhydrite and gypsum with marl (Hayton Anhydrite Formation)	184.40	8.85
Limestone with vughs, shells and ooliths (Cadeby Formation)	257.37	72.97
Hard grey and dark grey siltstone and silty mudstone with fish debris, limestone at base (Marl Slate Formation)	258.70	1.33
Soft dark and light blue-grey sandstone with rounded grains (Yellow Sands Formation)	278.25	19.55
Purple and brown stained siltstone and sandstone becoming grey (weathered Pennine Middle Coal Measures Formation)	286.97	8.72
Grey siltstone and mudstone with sandstones and numerous coals to bottom of borehole	366.70	79.73

While this borehole gives the full sequence it is also important to note that the Permian strata vary considerably across the area and this borehole lies to the east of the study area where the anhydrite sequences start to thin and salt beds appear. This borehole also shows a thick sequence of the Yellow Sands Formation.

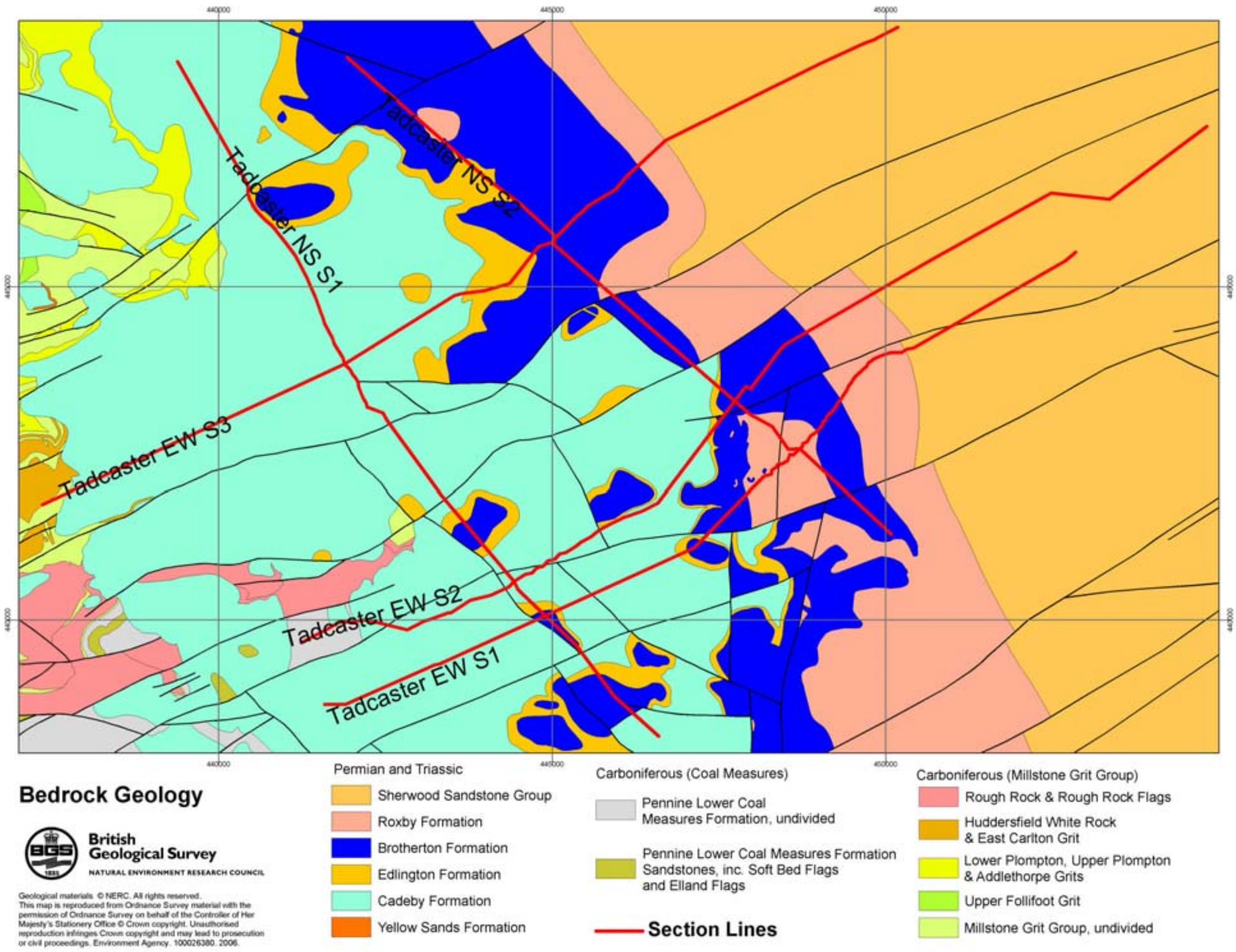

Figure 5. Bedrock geology of the Tadcaster area

5.1 CARBONIFEROUS STRATA

In the west of the district the Carboniferous rocks comprise strata ranging from the upper part of the Millstone Grit Group to the lower part of the Pennine Lower Coal Measures Formation. The Millstone Grit Group includes numerous thick coarse-grained sandstones dipping in a generally south-easterly and easterly direction and cut by numerous WSW-ENE trending faults (Figure 10 and Figure 16). The most notable sandstone in this sequence is the Rough Rock and the associated Rough Rock Flags. These two units are coloured pink on Figure 10 and Figure 16. They occur at outcrop and are in contact with the overlying Permian Cadeby Formation, consequently they may be in hydrological continuity with that unit. The Rough Rock forms the top of the Millstone Grit Group and is overlain by the Pennine Lower Coal Measures Formation. This comprises mainly siltstones and mudstones with subordinate sandstones and numerous coals. The main worked coal – The Barnsley Coal – enters the area in the very east of the district.

5.2 PERMIAN STRATA

The Variscan earth movements at the end of Carboniferous times caused faulting and folding with associated uplift. By early Permian times, the land surface took the form of a major land-locked basin extending from eastern England across to Germany and Poland. The Tadcaster area lay at the western margin of this basin in tropical palaeolatitudes (Smith, 1970, 1974, 1989, 1995, Smith et al., 1992; Aitkenhead et al., 2002). The newly uplifted areas were subject to intense, mainly subaerial erosion in a desert environment. Some areas, such as the resistant Carboniferous sandstones (ie the Rough Rock in the west of the study area) formed subdued hills (Cooper and Burgess, 1993). However, the majority of the Permian basin, especially over the soft Coal Measures (Westphalian) rocks, was worn down to a rocky pediment plain on which thin deposits of basal breccia developed. In the district, these breccias and the overlying desert sand dunes make up the Yellow Sands Formation of the Rotliegend Group. In the late Permian, the enclosed basin flooded rapidly and became a major enclosed evaporitic sea in which the cyclic Zechstein Group sequence was deposited (Smith, 1970, 1974, 1989, 1995; Tucker 1991).

5.3 YELLOW SANDS FORMATION

The sands are lenticular yellow aeolian sandstones with rounded wind-blown grains, (now named the Yellow Sands Formation they were formerly called the Basal Permian Sands). In boreholes the sands are a light bluish grey due to the oxidation state of the ferruginous pellicles that coat the sand (Smith, 1992). At outcrop, along the base of the Magnesian Limestone escarpment, they range from nothing up to a maximum thickness of about 6 m just south of the Tadcaster area. Similar thicknesses are proved in some of the Tadcaster area boreholes with a maximum of 20 m in the Colton borehole described above. At depth to the east beneath the Vale of York, they increase to a maximum of 46 m beneath York and thicker areas may be present beneath the Tadcaster district. The sands form SW-NE trending dune structures or draa. The nature of the deposits and the sparse number of boreholes that penetrate the sequence mean that it is probable that more lenticular bodies of the Yellow Sands Formation are present at the unconformity between the Carboniferous and Permian rocks. Where the sands are thick, the overlying Cadeby Formation tends to be correspondingly thinner.

5.4 MARL SLATE FORMATION

This formation comprises a lenticular and very thin (0 to 1 or 2 m) deposit of organic-rich argillaceous dolostone that was deposited extensively in the deeper parts of the basin, but is only likely to be sporadically present in the west of the basin beneath the Tadcaster area. Where it is seen at outcrop in the north of England it fills in low areas between sand dunes of the Yellow Sands Formation. The deposit represents the first sediments in the Zechstein basin after it flooded catastrophically and before the limestone seas became established.

5.5 ZECHSTEIN GROUP

Subsequent to the flooding and deposition of the Marl Slate Formation, the depositional basin underwent a series of cycles of flooding and evaporation, possibly caused by glacioeustatic changes. These have been called the five English Zechstein Cycles EZ1-EZ5 of Smith (1970, 1974, 1989 & 1995), but the current favoured view is that there are seven Sequence-Stratigraphic Cycles ZS1-ZS7 (Tucker, 1991). In both schemes, individual cycles show variable associations of evaporitic sedimentation. Tucker (1991) interpreted the cyclic sequences as a result of highstand (mainly carbonate) and lowstand (mainly evaporitic) cycles. The carbonate and sulphate phases are generally best developed near the margins of the basin, which approximate to the outcrop in the Tadcaster district. These two lithologies along with calcareous mudstone form most of the Permian rocks present in the Tadcaster district where the Permian is about 150m thick. The halite and sylvinite deposits occur toward the deeper parts of the basin and salt is present in the Colton borehole at the eastern limit of the Tadcaster study area.

5.6 CADEBY FORMATION

The Cadeby Formation, formerly called the Lower Magnesian Limestone (Smith et al., 1986), forms the wide outcrop of dolostone and dolomitic limestone at the west of the Permian sequence. The sea from which the formation was deposited inundated the Carboniferous topography and swamped the Permian sand dunes. Consequently the formation varies considerably in thickness from as little as 15 m over hills of Carboniferous sandstone to around

80m in the east of the district. This formation has a complex diagenetic history and locally includes vughs, some of which are mineralised, with haematite, galena and copper minerals at Newton Kyme (Marshall, 1856; Harwood and Smith, 1986;). The sequence also contains barite exposed in the road sections at Bramham. Most of this mineralization is probably related to a combination of fault reactivation and the susceptibility of the magnesian limestone to allow minerals to be deposited.

The formation is subdivided into a lower Wetherby Member and an upper Sprotbrough Member, these are separated by the Hampole discontinuity. The Wetherby Member is mainly bedded dolostone with local reef deposits, and broad algal stromatolite domes, such as those exposed at the south of the Tadcaster study area along the road cuttings at the A1-A64 junction (Cooper and Gibson, 2003). The Sprotbrough Member is mainly massively cross-bedded oolitic dolostones formed by deposition as sub-aqueous oolite dunes, which may also be seen in the cuttings at Aberford. These members can be recognised in exposures, separated by the Hampole Discontinuity (Smith, 1974; Smith, *et al.*, 1986), but are impossible to separate into mappable units and impossible to differentiate in the majority of boreholes unless they are cored and carefully logged. For modelling the Cadeby Formation had to be considered as one unit.

5.7 HAYTON ANHYDRITE (OR GYPSUM) FORMATION

The Hayton Anhydrite comprises up to 25 m of mainly grey-coloured anhydrite, which is bedded and massive. It is thickest near outcrop and thins towards the east of the area so that it is only around 9m thick in the Colton borehole (see above). Anhydrite is the anhydrous form of Calcium Sulphate ($CaSO_4$), but when it is subject to water it hydrates to gypsum ($CaSO_4.2H_2O$) and expands by about 40%, a process which provides fluids that inject the surrounding rock forming fibrous gypsum veins. Further contact with water then causes the gypsum to dissolve with cave development, collapse and ultimately complete dissolution. Consequently, this formation becomes difficult to separate from the overlying Edlington Formation, which at outcrop can contain dissolution residues of the anhydrite sequence. The zone of gypsum and dissolution is generally between 1 and 3 km wide along the Permian outcrop with the transition from anhydrite to gypsum occurring at a depth of around 80-120 m depending on water flow and factors such as jointing and faulting.

5.8 EDLINGTON FORMATION

The Edlington Formation at depth is up to 28 m thick and mainly comprises anhydritic and calcareous mudstone with numerous thin beds of anhydrite. At the eastern limit of the area salt beds also occur in the sequence. Near outcrop, any salt will have dissolved and most of the anhydrite hydrated to gypsum; very close to outcrop all the gypsum may be dissolved and the strata collapsed. At outcrop the collapsed and brecciated nature of the rock means that it is commonly present as 8-10 m of weathered red clay sandwiched between the Cadeby and Brotherton Formations.

5.9 BROTHERTON FORMATION

The Brotherton Formation (formerly Upper Magnesian Limestone – Smith et al., 1986) overlies the Edlington Formation and forms a narrow outcrop on the map with several outliers (Figure 16). The formation is generally between 18 and 26 m thick comprising a thin uniform sequence of dolomitic limestone, but where the underlying gypsum has dissolved the rock is frequently folded and slightly brecciated (Figure 11, Figure 12 and Figure 15)

5.10 BILLINGHAM ANHYDRITE (OR GYPSUM) FORMATION

The Billingham Anhydrite Formation is generally between 3 and 8 m thick; it behaves in a very similar way to the Hayton Anhydrite Formation described above. It forms a zone of dissolution and gypsum passing down dip into a zone of anhydrite. Like the sequence beneath it, the formation can be disrupted by the dissolution and collapse of both it and the underlying sequence.

5.11 ROXBY FORMATION

The Roxby Formation comprises the topmost formation of the Permian sequence. In the project area, it is dominantly composed of calcareous mudstone and gypsiferous mudstone with substantial units of gypsum and anhydrite towards the base of the formation. The formation underlies the Sherwood Sandstone Group aquifer and dips gently to the east. The formation is commonly thin at outcrop (approximately 20 m) where the gypsum is dissolved away, thickening to approximately 35 m in the east of the district.

5.12 SHERWOOD SANDSTONE GROUP

The Sherwood Sandstone Group is the main aquifer in the Vale of York. It comprises mainly fine to medium-grained red-brown sandstone with occasional mudstone beds and very sporadic pebble horizons, mainly in the south of the area. The group is approximately 380 m in thickness, dipping gently to the east. In boreholes and at outcrop, the upper part of the sequence is commonly heavily weathered producing sand that is difficult to differentiate from the overlying superficial deposits.

6 Superficial Geology

The superficial deposits are made up of a series of glacial sediments typically comprising: till (boulder clay and moraine deposits), laminated clay & silt, sand & gravel, and gravelly sand. The glacial units are variably overlain by a series of younger Holocene sediments that are associated with modern river systems comprising sand and rare gravel with common silt and clay.

An outline of the main geological superficial units and their relative age is given in Table 3 and a more detailed description of the geological units is given below.

6.1 GEOLOGICAL SETTING

The Tadcaster area has been glaciated at least twice and deposits from the two main events are preserved in the area. The earliest deposits appear to date from the Anglian Ice-Age and are represented in the western half of the district by thin dissected deposits of gravelly clay till (also referred to as diamicton) and some linear deposits of sand and gravel with till named the Linton-Stutton kame belt (Edwards, et. al., 1950).

During the last Ice Age, the Devensian ice covered most of northern Britain. The Pennines were glaciated as far south as Leeds and a tongue of ice occupied the Vale of York. Within the Tadcaster district, the Devensian ice retreated as recently as perhaps 14000 years ago, leaving extensive glacial and pro-glacial deposits behind. During the glaciation, the Vale of York ice advanced as far south as Escrick and the North Sea ice advanced to Norfolk, blocking the drainage out through the Humber gap. In front of the ice, fluvio-glacial outwash deposits and pro-glacial lake deposits were formed in the dammed pre-glacial valley system (Gaunt, 1976, 1994). The melting ice-front deposited the Escrick Moraine ice then retreated northwards where it deposited the lobate York Moraine across the vale. The lateral moraine to this ice-sheet and ends of these two moraines cross the north-eastern part of the Tadcaster district. Between and north of the moraines, a spread of glacial till with some glacial sand and gravel was deposited, these deposits are now assigned to the Vale of York Formation with the Escrick and York moraines referred to as members.

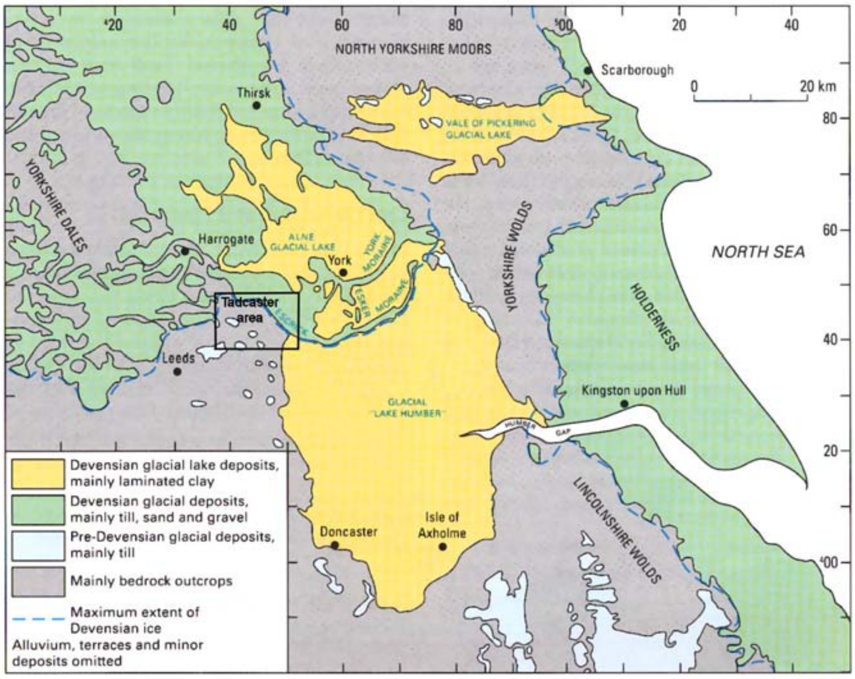

Figure 6. Outline of glacial geology of the Vale of York and Tadcaster area

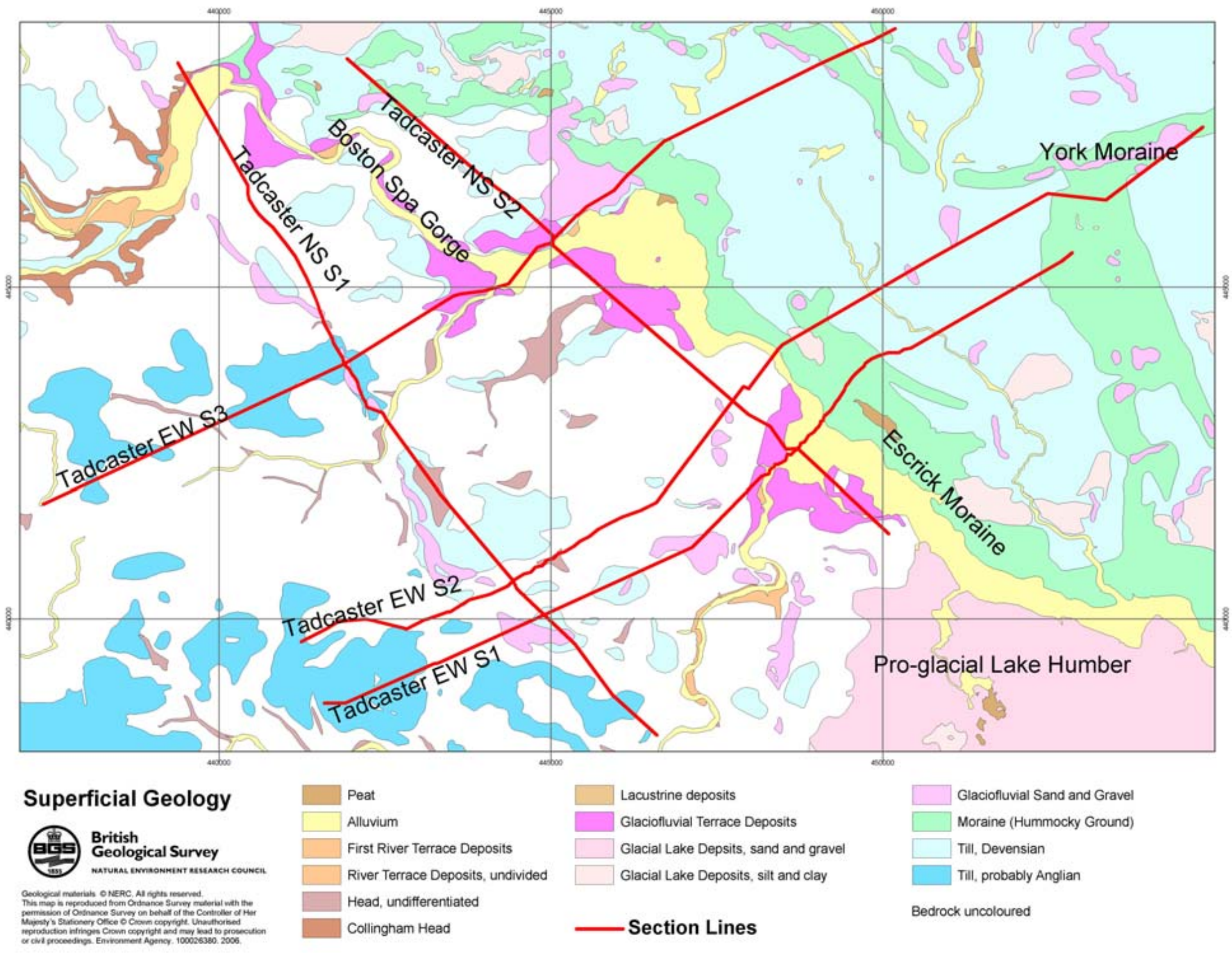

Figure 7. Superficial geology of the Tadcaster area

The ice in the Vale of York blocked the Pennine drainage and the river Wharfe diverted round to the south of the Escrick Moraine. As a result, the Wharfe valley is incised into a gorge between Wetherby and Boston Spa. Upstream of Linton, erosion of pre-existing till deposits resulted in erosional terraces, that were incised. At the wider points along the Wharfe valley, terraces of sandy gravel were deposited. These deposits grade eastwards into pro-glacial lake deposits formed in front of, and around, the glacial topography of the York-Escrick moraines. The Devensian ice limit and moraines with the diverted course of the River Wharfe form an important divide across the area between the west, which is largely free of superficial deposits, and the east, which is heavily covered by them.

The pro-glacial lake deposits comprise laminated silts and clays with interbedded and overlying sands, especially where drainage from the west entered the lake. Consequently, the covering sands are concentrated where the Wharfe entered the pro-glacial lake to the south-east of Tadcaster. Silt and clay glacial lake deposits are present to the south-east of the district southwards to Church Fenton. The sands, silts and clays were once referred to as the 25ft drift of the Vale of York, or alternatively the deposits of glacial Lake Humber. The clays and silts are now referred to as the Hemingbrough Formation, while the covering sands have been assigned to the Breighton Formation. In the non-glaciated areas, periglacial weathering and solfluxion have produced deposits of head. These include the Collingham Head deposits of the Wharfe valley and the later head deposits that are recognised in many places throughout the area.

6.2 TILL, MIDDLE PLEISTOCENE (POSSIBLY ANGLIAN)

The deposits possibly date from the Anglian glaciation and represent the oldest glacial deposits in the Tadcaster area. It generally comprises sandy clay with cobbles and boulders and is closely associated with sand and gravel deposits. The till forms isolated patches throughout the western half of the district to the west and south of the River Wharfe. A linear belt of sand and gravel approximately coincidental with the A1 has been referred to as the Linton Stutton kame belt (Edwards et al., 1950). The exact mode of origin of this feature is uncertain.

6.3 TILL, DEVENSIAN (VALE OF YORK FORMATION)

Thick till of Devensian age is present throughout the eastern part of the Tadcaster district to the east of the River Wharfe. The till commonly overlies silt and clay of the Devensian Glacial Lake Deposits (Hemingbrough Glaciolacustrine Formation) or directly overlies bedrock.

The till was deposited directly by ice and consequently displays a variable lithology ranging from sandy gravelly clay with common cobbles and boulders to slightly clayey sand and gravel. Clast composition, including Carboniferous lithologies and rare volcanic material supports a northern-England provenance for the till. This lithostratigraphical unit is interpreted as a superficial aquitard, reaching a maximum thickness of approximately 30 m in the Escrick and York members (see below), but the unit is more commonly around 10 m thick.

6.4 HUMMOCKY (MOUNDY) GLACIAL DEPOSITS (ESCRICK AND YORK MORAINE MEMBERS)

On the digital maps this sequence is referred to as Hummocky (Moundy) Glacial Deposits, on the published geological maps it is referred to as Moraine. More recently in the Selby district to the east it has been classified as the Escrick and York Moraine Members of the Vale of York Formation. Lithologically it is very similar to the general till formation, but the deposits are much thicker (up to 30 or so metres) and with a marked topographical form as lobate elongate ridges up to about a kilometre wide (Figure 7 and Figure 32). Deposits of sand and gravel are commonly mixed with the moraine and in places form mappable units of Glaciofluvial Deposits

Relative Age	Geological Unit (Modern Lithostratigraphy in parentheses)	Map Code	Summary Lithology	Superficial Aquifer / Aquitard
YOUNG	Alluvial Fan Deposits	ALF		Very small area, insignificant
	Alluvium	ALV	Common gravel base, fining upwards into SILT and CLAY. Interbedded peat horizons common throughout	Aquitard
	Peat	PEAT	PEAT	Aquifer
	Head	HEAD	CLAY, SILT, sand and gravel mixed	Aquitard
	Collingham Head	COHD	CLAY, SILT, sand and gravel mixed	Aquitard
	River Terrace Deposits, First terrace	RTD1	SAND and GRAVEL	Aquifer
	River Terrace Deposits (Undifferentiated)	RTDU	SAND and GRAVEL	Aquifer
	Glacial Lake Deposits - Sand and Gravel (Breighton Sand Formation)	GLLD	SAND and GRAVEL	Aquifer
	Glacial Lake Deposits - Devensian (Hemingbrough Glaciolacustrine Formation)	GLLDD	Thinly to thickly laminated SILT and CLAY with occasional sand beds or laminae (saturated “running sand”)	Aquitard
	Glaciofluvial Terrace Deposits - Devensian	GFTDD	SAND and GRAVEL, gravelly SAND, sandy GRAVEL	Aquifer
	Glaciofluvial Deposits (Undifferentiated) note this is used for both Devensian and probable Anglian deposits	GFDUD	SAND and GRAVEL, gravelly SAND, sandy GRAVEL	Aquifer
	Hummocky (Moundy) Glacial Deposits (Escrick and York Moraine members of the Vale of York Formation)	HMGDD	Variable gravelly, sandy CLAY with common cobbles and boulders	Aquitard
OLD	Till, Devensian (Vale of York Formation)	TILLD	Variable gravelly, sandy CLAY with common cobbles and boulders	Aquitard
	Till, Middle Pleistocene	TILLP	Variable gravelly, sandy CLAY with common cobbles and boulders	Aquitard

Table 3. Principal superficial geological units correlated in the Tadcaster cross-sections

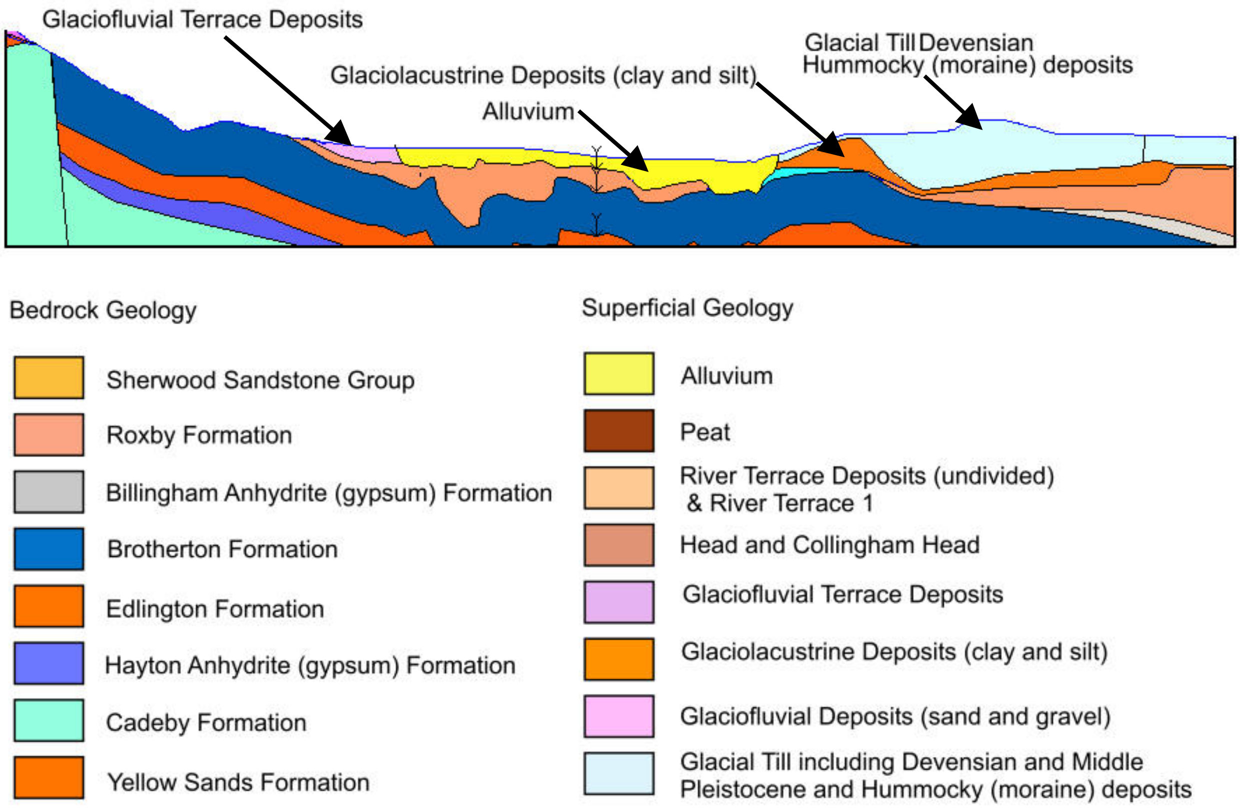

Figure 8. Detail from Tadcaster EW S1 showing the alluvial deposits, moraine and bedrock in at Tadcaster.

6.5 GLACIOFLUVIAL DEPOSITS (UNDIFFERENTIATED)

Undifferentiated Glaciofluvial Deposits have been mapped throughout the project area. In places the deposit is laterally persistent but in other areas forms discreet lenses. The Glaciofluvial Deposits comprise: sand & gravel, gravelly sand, and sandy gravel. Two categories of deposit are included within this name. In the west the linear belt of sand and gravel forming the "Linton-Stutton kame belt" of Edwards et al. (1950), and patchy sand and gravel associated with the glacial till are included. In the east sand and gravel associated with the Vale of York Formation is included; these sediments were deposited by glaciofluvial processes associated with Vale of York glacier. This lithostratigraphical unit is interpreted as a superficial aquifer.

6.6 GLACIAL LAKE DEPOSITS – DEVENSIAN (HEMINGBROUGH GLACIOLACUSTRINE FORMATION)

This Formation commonly overlies the Undifferentiated Glaciofluvial Deposits or lies directly on bedrock. The lower part of the unit passes beneath the Devensian till deposits of the Vale of York Formation, a situation caused when the ice-sheet overrode the glacial lake deposits (Figure 8, Figure 30 and east end of Figure 32). The unit has also been referred to as silts and clays of the 25 Foot Drift and the deposits of glacial Lake Humber (Gaunt, 1994).

The Glacial Lake Deposits generally comprise a sequence of thinly to thickly laminated, stiff clay and silt, with occasional to common sand beds. The enclosed sand beds in the upper part of the sequence are commonly completely saturated and tend to form "running sand" horizons. The elevation of the top of the unit is between 8 and 11 m above OD. This unit is an important superficial aquitard in the area, ranging from a featheredge up to a maximum thickness of approximately 25 m in the south-east corner of the district.

6.7 GLACIAL LAKE DEPOSITS – SAND AND GRAVEL (BREIGHTON SAND FORMATION)

These deposits comprise thin sands with subordinate gravels that overlie the silts and clays of the Glacial Lake Deposits. In the past, they have been referred to as Sands of the 25 foot Drift, but recent work on the Selby district to the east has named them the Breighton Sand Formation. They represent deposits washed into the glacial Lake Humber from the rivers including the River Wharfe and from drainage emanating from the front of the Devensian ice-sheet. They are continuous with terrace deposits in the Wharfe Valley and generally show an eastward fining in grain size. In many places they have been re-worked by aeolian activity and work from the Selby district just to the east has suggested that the deposits were re-worked by fluvial and aeolian activity when glacial Lake Humber drained. In general these deposits comprise a few metres of fine-grained sand in the south-east part of the district.

6.8 GLACIOFLUVIAL TERRACE DEPOSITS – DEVENSIAN

These deposits form elevated terraces along the River Wharfe both at the entrance to the Boston Spa Gorge and at its outfall in the Tadcaster area. The deposits comprise mainly sand and gravel, but around Thorpe Arch they overlie laminated clays that belong to the Glacial Lake Deposits (probably Hemingbrough Glaciolacustrine Formation). The terraces appear grade into the glacial lake deposits and probably represent delta-like deposition from the glacial River Wharfe as it entered glacial Lake Humber.

6.9 RIVER TERRACE DEPOSITS (UNDIFFERENTIATED)

Two small and relatively insignificant areas of undifferentiated River Terrace Deposits are present alongside the River Wharfe near Boston Spa and Thorpe Arch.

6.10 RIVER TERRACE DEPOSITS (TERRACE 1)

River Terrace Deposits mapped as Terrace 1 are present along the sides of the River Wharfe between Collingham and Wetherby. Similar deposits are also present as narrow terraces flanking Cock Beck in the south of the district. In general these deposits comprise sand and gravel, but there is not borehole information in them to confirm the thickness or nature of the deposits.

6.11 COLLINGHAM HEAD

Both sides of the Wharfe Valley and its tributaries west of Wetherby are covered by slope deposits of the Collingham Head. This comprises a mixture of local bedrock types in a matrix of clay, silt and sand derived by periglacial weathering during the last Ice-Age.

6.12 HEAD

Unnamed Head deposits are present in many of the western parts of the district especially on the Magnesian Limestone (Cadeby Formation) bedrock. The deposits comprise mainly local dolostone and dolomitic limestone (magnesian limestone) in a clay and silt matrix. Some of the deposits occupy narrow dry valleys, while other deposits fill depressions in the bedrock.

6.13 PEAT

Peat in the area is commonly associated with alluvium and modern river drainage systems (i.e. Holocene sedimentation). The peat is variably preserved but often forms persistent beds, less than 1 m in thickness. This lithostratigraphical unit is interpreted as a superficial aquitard, reaching approximately 3 m in thickness. Peat also occurs ponded in hollows within the hummocky glacial deposits.

6.14 ALLUVIUM

The alluvial deposits are mainly associated with the River Wharfe. South of Wetherby they form a moderately wide flood plain, but along the Boston Spa Gorge (Figure 17) they form a narrow strip that widens at he gorge exit. There are also minor deposits along Carr Beck, which drains through Bramham to join the Wharfe south of Boston Spa. Other alluvial deposits are present along the course of Cock Beck that drains the south of the district joining the River Wharfe near Tadcaster. The alluvial deposits typically comprise a basal gravel and sand lag with overlying flood deposits of silty sandy clay. The thickness of the deposits is variable. Along the Wharfe at Tadcaster over the dissolved gypsum area, they reach a thickness of about 10m (Figure 8).

6.15 ALLUVIAL FAN DEPOSITS

One very small Alluvial Fan Deposit has been mapped within the area adjacent to the Cock Beck south of Tadcaster. It is mentioned only for completeness.

7 Structural Geology

7.1 STRUCTURE IN CARBONIFEROUS ROCKS

The structure and sedimentation of the Tadcaster district has been largely influenced by major basement block, basin and fault structures that manifest themselves in the surface fault and fold pattern. To the north of the area, the Askrigg Block is underlain by exposed Lower Palaeozoic basement rocks faulted on the southern side by the Craven Faults. These bound the Harrogate Basin (Figure 9) that extends southwards onto the Tadcaster district (see Kirby et al., 2000 for details of the area and a full description of the regional structural and depositional setting).

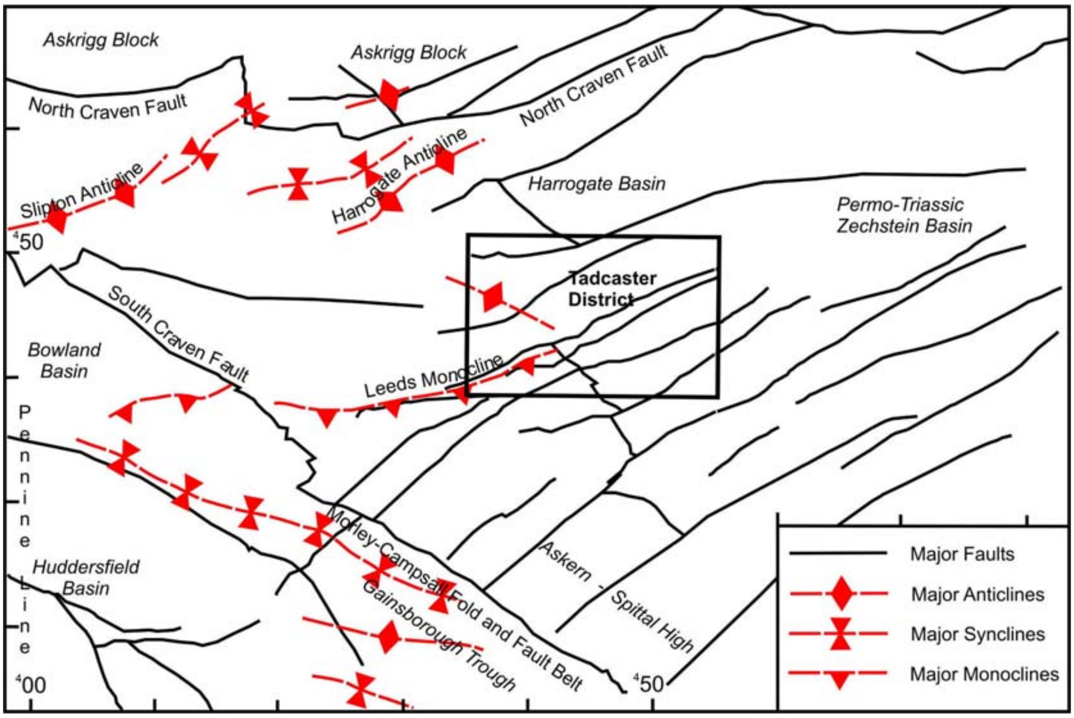

Figure 9. Outline of the general structure of the Tadcaster and surrounding areas.

In late Carboniferous times, the geological situation changed from passive to compressive tectonism, related to the Variscan earth movements. These were caused by the closure of the Rheic Ocean and the associated continental collision. This collision caused the inversion of the depositional basins and the reactivation of basement structures. Along the edges of the blocks and basins en-echelon folds developed to the northwest of the Tadcaster district against the Askrigg Block. The basement structures beneath the Tadcaster district were reactivated, folding the overlying strata into the Leeds monocline. This monocline and the underlying fault structure extends across the Pennines to the west and eastwards into the Tadcaster district (Kirby et al., 2000). This structure controls the northern boundary of the Yorkshire coalfield and is transacted by the Pennine Anticline, running approximately north-south up the middle of the Pennines. This fold was partly responsible for controlling the margins of the Permian Zechstein basin, and subsequently tightened to give the generally easterly dip of the strata east of the Pennines. The intersection of the Pennine structure and the Leeds monocline structure produced the acutely-angled termination of the Yorkshire coalfield just west of Bradford. A similar intersection between the monocline and approximately north-west trending anticline and NNW-SSE trending faults beneath the Tadcaster district cause the Carboniferous sequence strike to change from east-west to north-south (Figure 10). Thus it can be seen that if the Permian sequence is removed, there is a complex structure in the Carboniferous rocks. Figure 10 is only an approximation of the broad belts of strata that are present beneath the Permian. The figure does not attempt to model the strata in individual fault blocks as there is insufficient information to do so.

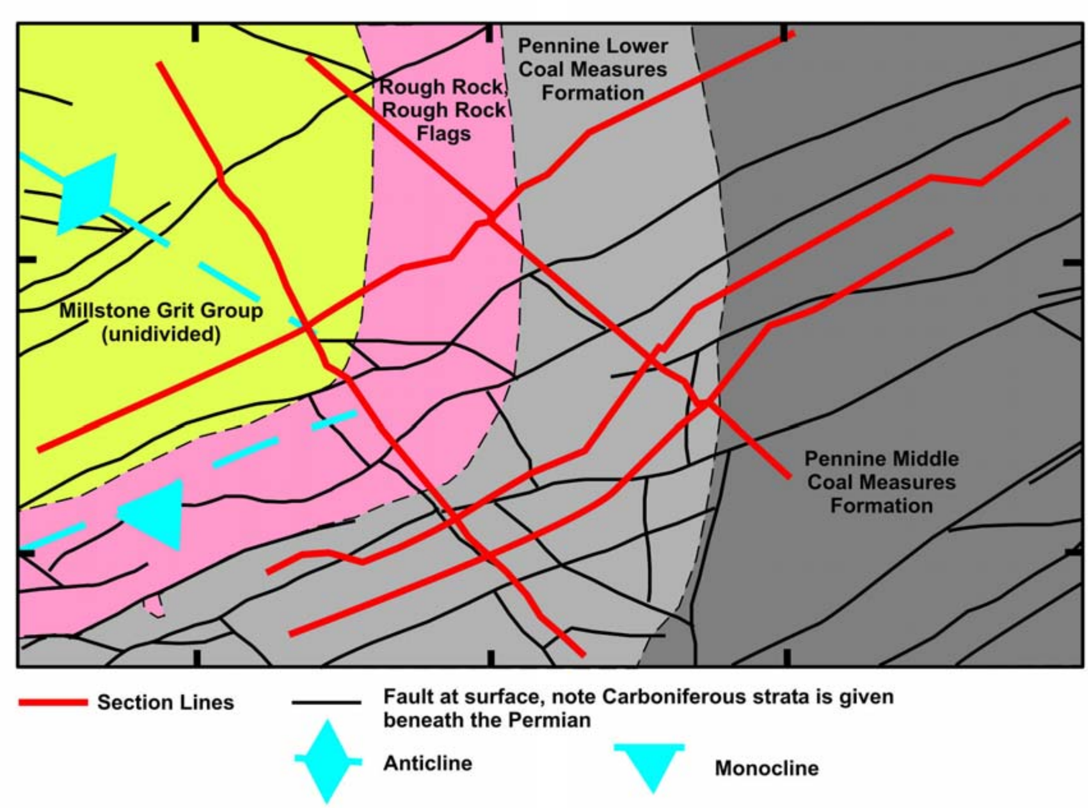

Figure 10. General disposition of the main stratigraphical units beneath the Permian sequence in the Tadcaster area. Note that the strata in individual fault blocks have not been modelled due to the lack of detailed seismic and borehole information that this requires.

7.2 STRUCTURE IN PERMIAN ROCKS

Subsequent to the deposition of the Permo-Triassic strata, the Tadcaster district has been subjected to mainly extensional events (probably Jurassic and Cretaceous), causing the widespread normal faulting pattern that is now preserved in all the rocks of the area. This fault pattern, with associated folding, has two main trends; NW-SE and SW-NE forming approximately conjugate sets of faulting (Figure 16). Over the basement structures, some minor mineralisation has occurred in the Permian dolostones and copper mineralisation was recorded at Newton Kyme (Marshall, 1856). This is a pattern repeated in several places along the Permian outcrop (Smith and Harwood, 1986).

7.3 STRUCTURE CAUSED BY GYPSUM DISSOLUTION AND COLLAPSE

Massive gypsum is present in the lower part of the Edlington Formation (Hayton Anhydrite Formation equivalent), where it may locally reach 20-30 m in thickness and in the lower part of the Roxby Formation (Billingham Anhydrite Formation equivalent) where it reaches about 8m thick. More gypsum is present in the middle to upper part of the Roxby Formation in the south of the district (Sherburn Anhydrite Formation equivalent). In both the Edlington and Roxby Formations, the gypsum is generally pale grey alabastrine and porhyroblastic with fibrous veins. The overlying red-brown calcareous mudstones generally contain thin beds and nodules of grey, pink and red gypsum plus abundant fibrous veins. Commonly these beds are severely contorted in the manner of those exposed at Ripon Parks (James et al., 1981). Where dissolution and collapse have taken place, collapse breccias are common in the gypsiferous and overlying parts of the sequence.

Gypsum is a very soluble rock and dissolves about one hundred times faster than limestone. A block of gypsum about 3 m square, which fell into the River Ure at Ripon Parks dissolved away in only 18 months. This was documented by James et al. (1981), who also presented formulae for calculating the gypsum dissolution rate provided the velocity and temperature of the dissolving water are known. In subsurface conditions, with suitable water flow, gypsum commonly dissolves, resulting in cave systems and a buried gypsum-karst topography. In cave environments, with dissolved gypsum in solution, the dissolution rate of gypsum may be less that that observed in surface situations (Klimchouk et al., 1996). Because gypsum dissolves rapidly, cave systems are also believed to evolve rapidly. The catastrophic collapse of the caverns so produced results in dramatic surface subsidence occurring in the area.

Much of the Tadcaster district is underlain by gypsum. In many circumstances, this rock can dissolve causing subsidence problems. Boreholes and exposures in the Tadcaster area suggest that dissolution has occurred in the past and is likely to in the future. Some areas of foundered Roxby Formation have been recorded preserved in subsidence areas. Such features are seen in the Brotherton Formation at outcrop in Copley Lane Quarry about 4 km south of the district near Sherburn in Elmet (Smith 1972). The subsidence features in this quarry have areas of Roxby Formation preserved within them (Figure 11, Figure 12). This formation no longer exists near the site so the implication is that the collapse here occurred prior to the last Ice-Age.

Figure 11. Breccia pipe of foundered Roxby Formation collapsed into the Brotherton Formation after the dissolution of gypsum in the underlying Edlington Formation (Hayton Anhydrite Formation equivalent) at Copley Lane Quarry, Sherburn in Elmet, just south of the study area.

Figure 12. Breccia pipes of foundered Roxby Formation collapsed into gently folded Brotherton Formation at Copley Lane Quarry, Sherburn in Elmet, just south of the study area.

The apparent cone-shaped nature of the subsidence pipes in Figure 12 is due to the sloping quarry face intersecting a vertical cylindrical collapse pipe. Similar, but much more active features in the equivalent rocks have been recorded extensively in the Ripon area by Cooper

(1986, 1998). The cross-sections through the Tadcaster area have a strong similarity with the sections through the Ripon area (Figure 13).

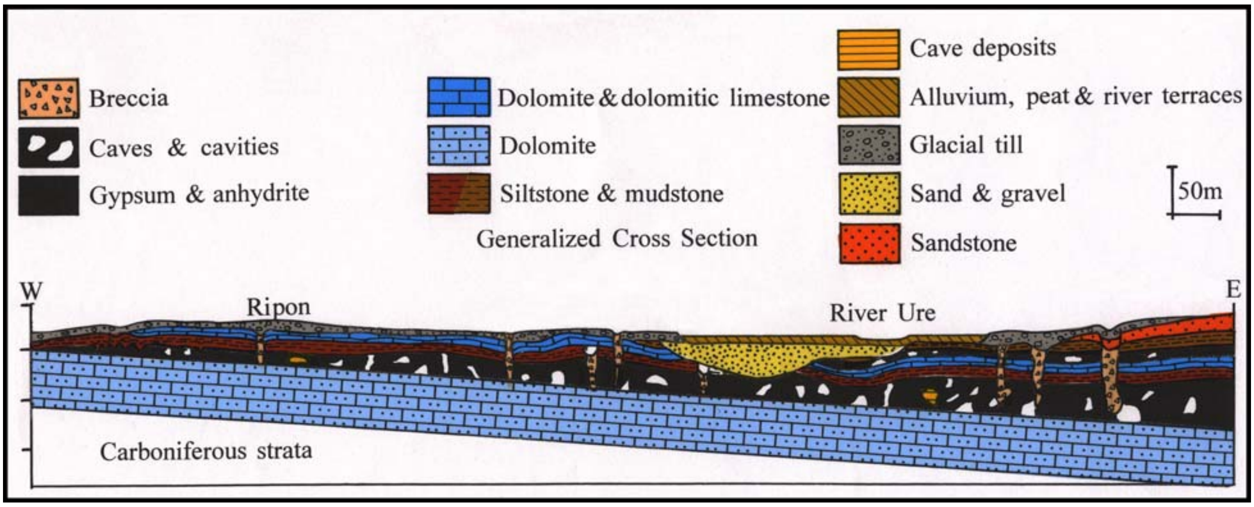

Figure 13. Cross-section through the Ripon area in North Yorkshire, showing the dissolution of gypsum and collapse of the overlying strata as breccia pipes and foundering. The pale blue dolostone is the Cadeby Formation, the dark blue the Brotherton Formation.

8 Hydrogeological considerations

8.1 GYPSUM DISSOLUTION AND BURTONISED WATER

The structural effects of gypsum dissolution are mentioned above. By comparison with Ripon (Cooper, 1988, 1998, Thompson et al., 1995) the natural groundwater movement is most likely from the high ground of the Cadeby Formation towards the River Wharfe. The escape route for the water into the river is most likely via the gypsiferous strata that is being actively dissolved and through the overlying collapsed or foundered materials.

Active and post-glacial subsidence features have been recorded in the south-east of the Tadcaster district in the vicinity of Church Fenton (Thomson et al., 1995). The main driving forces for the triggering of collapse are the presence of gypsum, water flow and water table fluctuations (Cooper 1988). The water abstracted in the Tadcaster area is rich in dissolved gypsum, it is naturally “Burtonised” a requirement for the brewing industry. The local geology is disposed such that the Cadeby Formation to the west of Tadcaster forms a natural catchment area. The water will flow from this to the valley of the River Wharfe passing up through the gypsum sequence as it goes. There is some poorly reported evidence of subsidence in the vicinity of the breweries next to River Wharfe.

The effect of gypsum dissolution and collapse is to perforate the geological sequence so that the Cadeby Formation aquifer can be in hydrological continuity with the Hayton anhydrite (as gypsum), the Brotherton Formation and the Billingham Anhydrite (as gypsum), plus in some cases the overlying Sherwood Sandstone Group. Within the outcrop belt of the gypsiferous formations severe dissolution can occur causing the overlying units to founder and fold into a monoclinal structure as shown in Figure 14 below. This structure is interpreted for the Tadcaster area with severe dissolution of the Hayton gypsum along the course of the River Wharfe (Figure 15). This explains the different depths to the base of the Brotherton Formation in the numerous brewery boreholes in Tadcaster at the intersection of cross-sections EW_S2 and NS_S2 (Figure 31 and Figure 34).

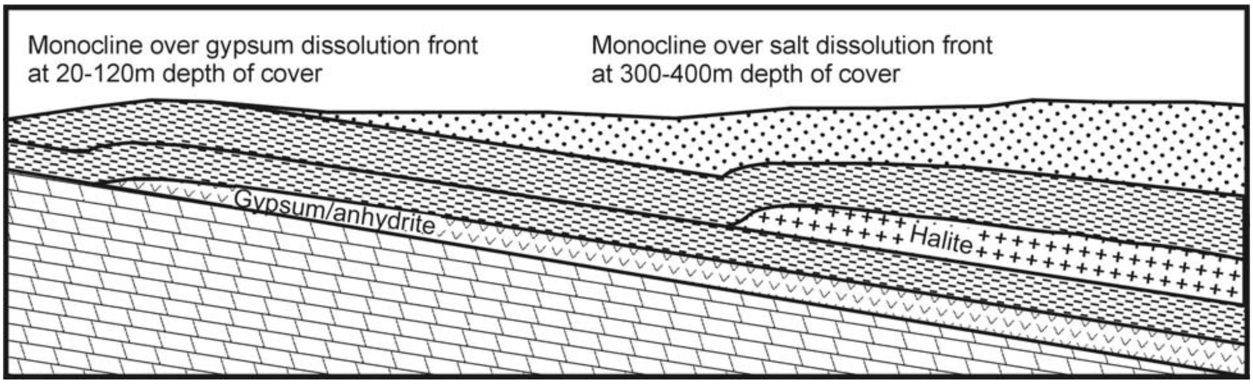

Figure 14. Simplified cross-section through the dissolution fronts of the Permian salt and gypsum/anhydrite in north-east England. In reality, there are several sequences of anhydrite and salt, which can each produce their own monoclinal structures. (after Cooper 2002).

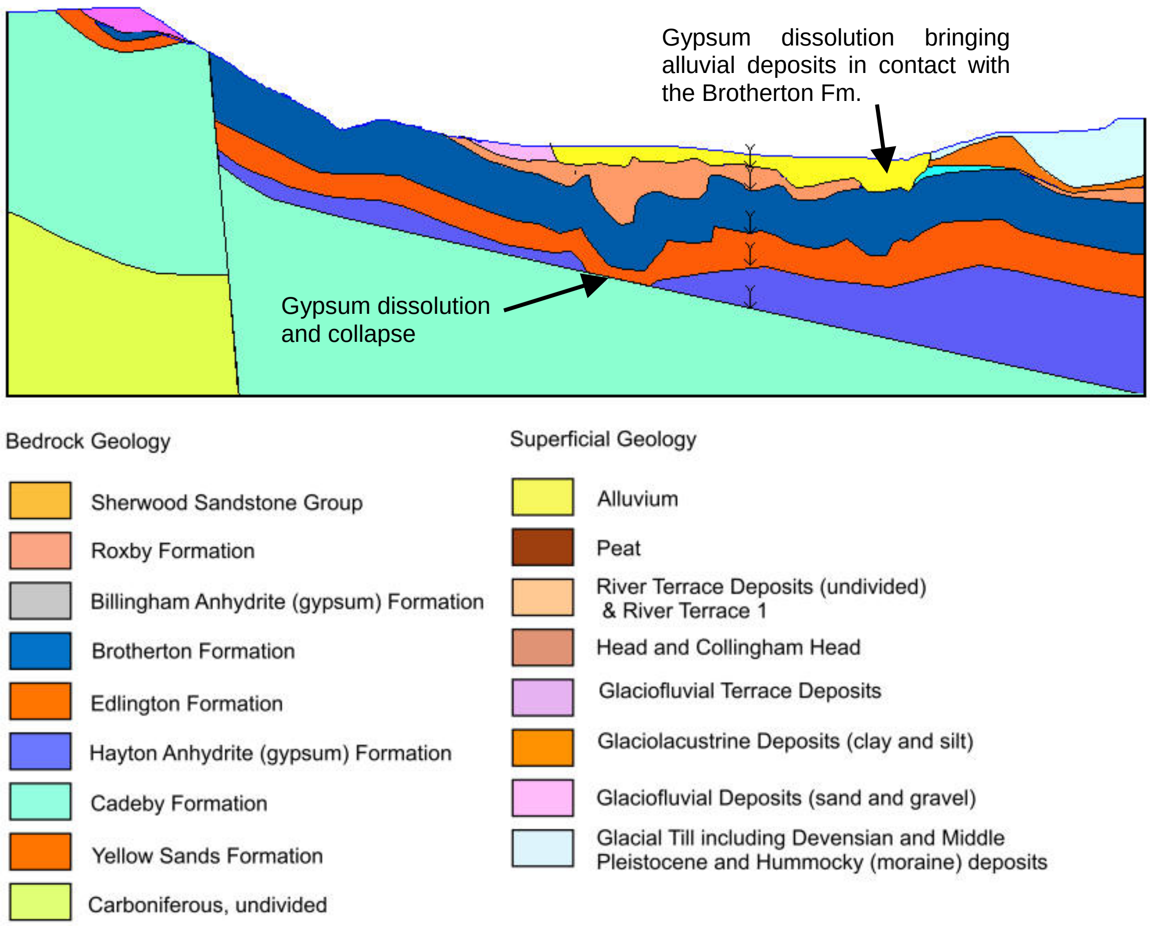

Figure 15. Extract from section EW_S1 for the Tadcaster area showing the dissolution of the gypsum and collapse of the overlying strata.

The effects of both the dissolution with its associated collapse and the faulting of the Permian sequence means that the Cadeby and Brotherton Formation aquifers are likely to be in hydrological continuity throughout much of the study area, especially along the River Wharfe, around Tadcaster itself and southwards. To the east, down dip, the connection will decrease as the amount of gypsum dissolution decreases and the presence of anhydrite increases. The cross-sections suggest that the glacial till deposits and associated lake clay deposits in much of the north-east of the area act as a cap preventing water infiltration into much of the Sherwood Sandstone Group. Consequently, it would appear that the limit of gypsum dissolution is approximately along the line of the Escrick Moraine and not further to the east in the sandstone as it is in the Ripon district (Cooper, 1986, 1988, 1998).

The maps of superficial aquifer and aquitard characteristics in section 9 (Figure 21 to Figure 26), indicate that the recharge from the River Wharfe may be directly into the Brotherton Formation concentrated just upstream of Tadcaster in the wide area of alluvium to the south-east of Thorpe Arch. This area was also the location of a landfill site [445287,446002] located to the east of the current sewage works. It is likely that the Brotherton Formation will be in hydrological continuity with the Cadeby Formation to the south either by connection across faulting or by connection through subsidence features and the karstified gypsum sequence. The presence of a wide area of alluvium coincidental with an area of gypsum dissolution and collapse is something that also occurs to the south of Ripon.

9 Thematic maps

9.1 BEDROCK GEOLOGY (Tadcaster_bedrock)

This map shows a mosaic of bedrock geology data and faults derived for the project area from the 1:50,000 scale digital geological map of the British Isles (DigMap50). The main units described by the codes shown in Table 4. Descriptions are given in the sheet explanation for the Leeds geological map (Cooper and Gibson, 2003).

LEX-ROCK CODE	DESCRIPTION
SSG-SDST	Sherwood Sandstone Group - Sandstone
ROX-CAMD	Roxby Formation – Calcareous Mudstone
BTH-DOLM	Brotherton Formation – Dolomitic Limestone
EDT-CAMD	Edlington Formation – Calcareous Mudstone
CDF-DOLO	Cadeby Formation – Dolostone
YWS-SDST	Yellow Sands Formation - Sandstone
PLCM-MDSS	Pennine Lower Coal Measures Formation – Mudstone Sandstone and Siltstone
SBF-SDST	Soft Bed Flags - Sanstone
MG-MDSS	Millstone Grit Group - Mudstone Sandstone and Siltstone
RR-SDST	Rough Rock - Sandstone
RF-SDST	Rough Rock Flags - Sandstone
HDW-SDST	Huddersfield White Rock – Sandstone
EC-SDST	East Carlton Grit - Sandstone
UPG-SDST	Upper Plompton Grit - Sandstone
LPG-SDST	Lower Plompton Grit - Sandstone
AD-SDST	Addlethorpe Grit - Sandstone
UF-SDST	Upper Follifoot Grit - Sandstone

Table 4. Principal bedrock units and corresponding codes

The “Lex” and “Rock” codes indicate the stratigraphy and primary lithology respectively. For example, the Sherwood Sandstone Group is predominantly composed of sandstone; the corresponding Lex-Rock code is SSG-SDST. Distinct lithological variants exist for several of the units considered here.

The full description shown above provides a reference to the attribution provided by the digital file. For presentation purposes, the printed version of this map is generally coloured by stratigraphy (“Lex” code”). Consequently, single colours may be used to represent more than one lithological variant of the same stratigraphy.

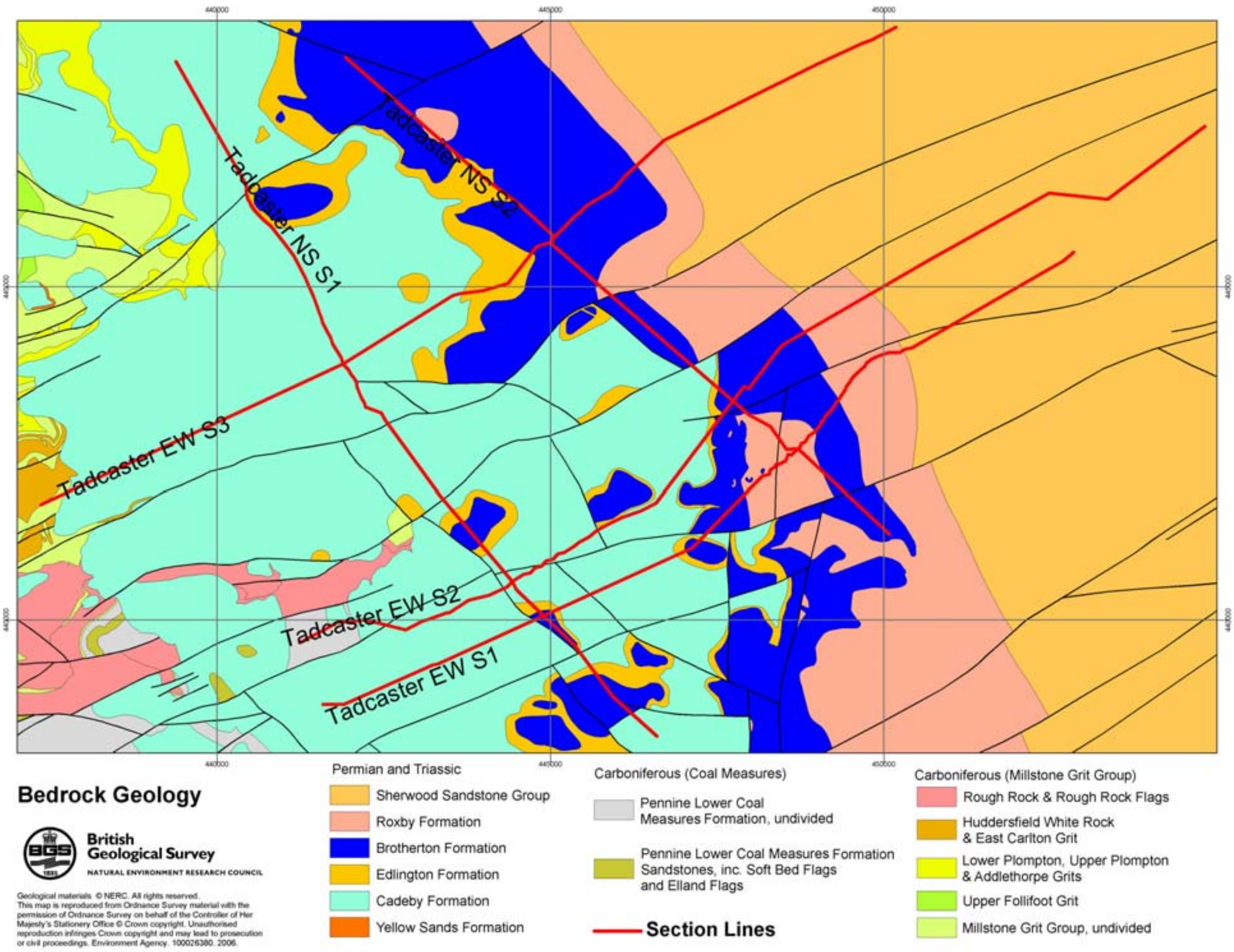

Figure 16. Bedrock geology and faulting in the Tadcaster area.

9.2 SUPERFICIAL GEOLOGY (Tadcaster_Superficial2)

This map shows a mosaic of superficial geology data derived from the 1:50,000 scale digital geological map of the British Isles (DigMap50). The main units described by the codes shown in Table 5.

LEX-ROCK CODE	DESCRIPTION
ALF-SAGR	Alluvial Fan deposits – Sand and Gravel
ALV-CSSG	Alluvium – Clay, Silt, Sand and Gravel
PEAT-PEAT	Peat
HEAD-CSSG	Head (Undifferentiated) – Clay, Silt, Sand and Gravel
COHD-CSSG	Collingham Head – Clay, Silt, Sand and Gravel
RTD1-SAGR	River Terrace Deposits, 1 – Sand and Gravel
RTDU-SAGR	River Terrace Deposits (Undifferentiated) – Sand and Gravel
GFTDD-SAGR	Glaciofluvial Terrace Deposits, Devensian – Sand and Gravel
GLLDD-CLSI	Glaciolacustrine Deposits, Devensian – Clay and Silt
GLLD-SAGR	Glaciolacustrine Deposits (Undifferentiated) – Sand and Gravel
GFDUD-SAGR	Glaciofluvial Deposits, Undifferentiated, Devensian – Sand and Gravel
HMGDD-DMTN	Hummocky (Moundy) Glacial Deposits, Devensian – Diamicton (Gravelly bouldery sandy clay)
TILLD-DMTN	Till, Devensian - Diamicton (Gravelly bouldery sandy clay)
TILMP-DMTN	Till, Middle Pleistocene - Diamicton (Gravelly bouldery sandy clay)

Table 5. Principal superficial deposits and corresponding codes

The “Lex” and “Rock” codes indicate the stratigraphy and primary lithology respectively. For example, Glaciofluvial Deposits Undifferentiated is predominantly composed of sand and gravel; the corresponding Lex-Rock code is GFDUD-SAGR. Distinct lithological variants exist for several of the units considered here.

The full description shown above provides a reference to the attribution provided by the digital file. For presentation purposes, the printed version of this map is generally coloured by stratigraphy (“Lex” code”). Consequently, single colours may be used to represent more than one lithological variant of the same stratigraphy.

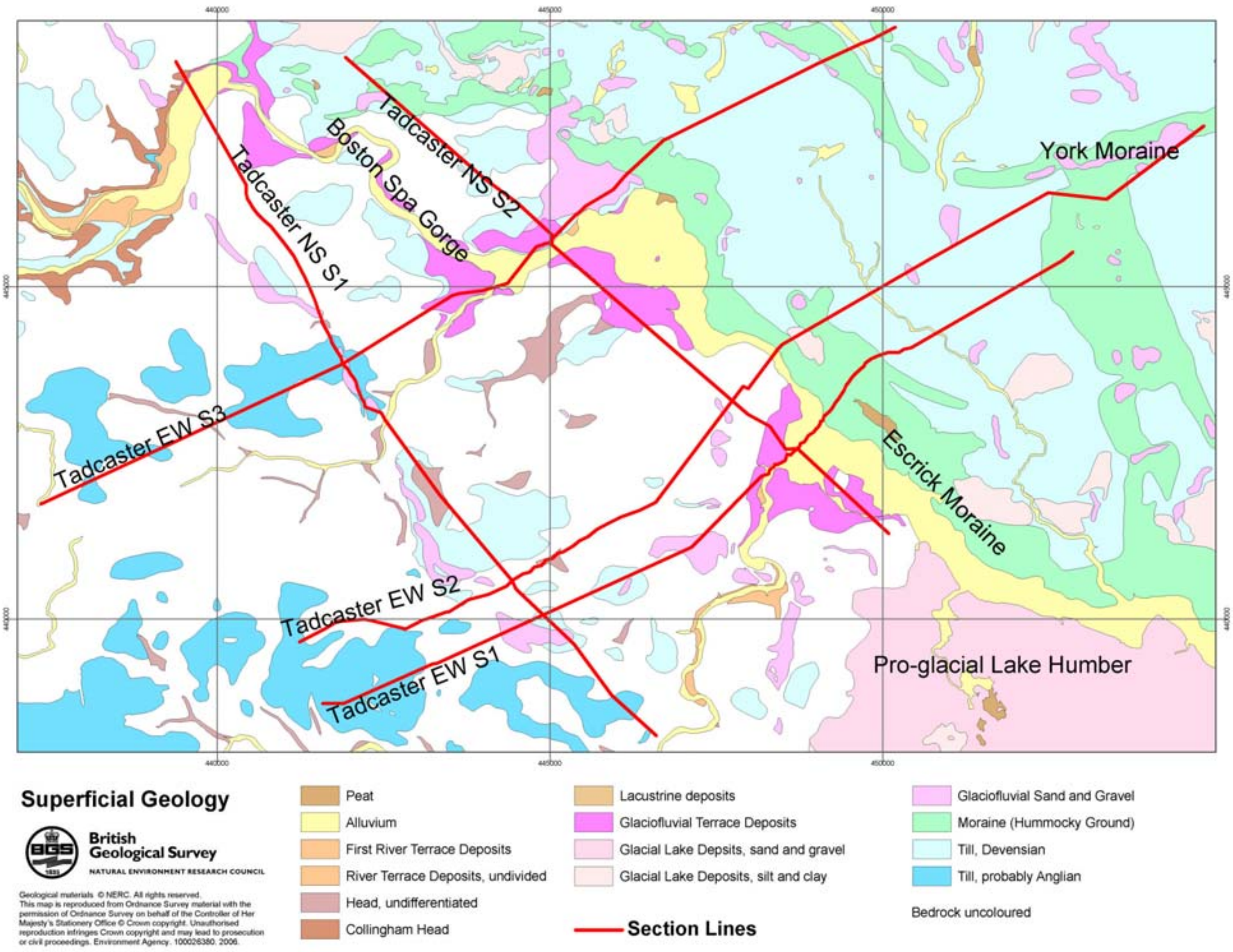

Figure 17. Superficial geology in the Tadcaster area.

9.3 TOPOGRAPHY OF THE TADCASTER AREA

This elevation model shows the high land underlain by the Carboniferous and Permian rocks in the west with the lobate moraines in the north east and east. The south-east corner is flat glacial lake deposits. The wide river Wharfe valley is constricted to a narrow gorge (north-west part of map) where the river was diverted during the Devensian glaciation. Note that the Ordnance Survey DTM shows slightly less detail than the Nextmap one, but that woods show as elevated areas on this Nextmap image.

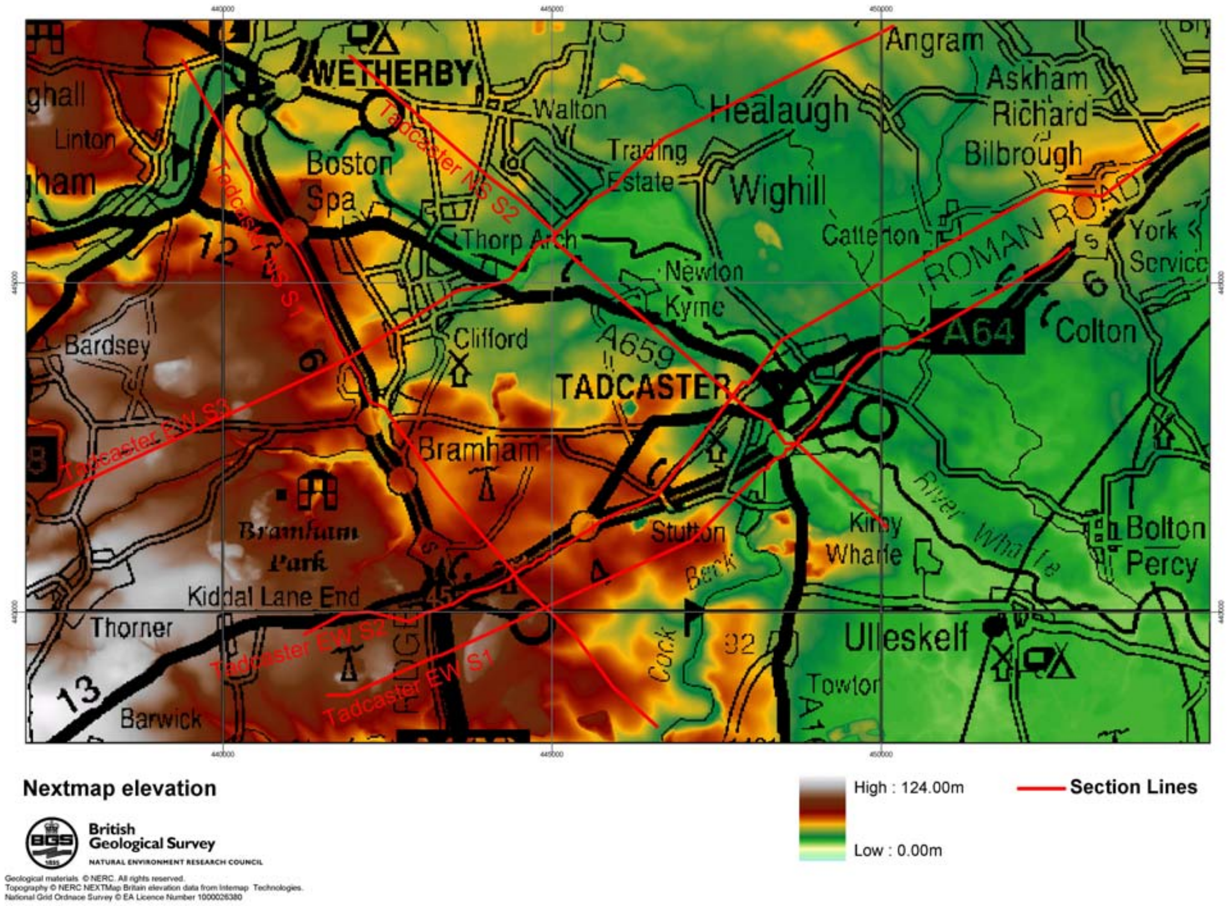

Figure 18. Topography of the Tadcaster area derived from NextMap Britain, elevation data in metres AOD from Intermap Technologies.

9.4 ROCKHEAD ELEVATION (tad_RHEM.asc)

This map shows a gridded surface representing the elevation of rockhead in the project area. The elevation data is shown as metres above or below OD.

This surface is a subset of a national dataset, and is based on a combination of digital downhole information and surface geological information. Rockhead is interpreted as the base of superficial deposits (i.e. base of Quaternary).

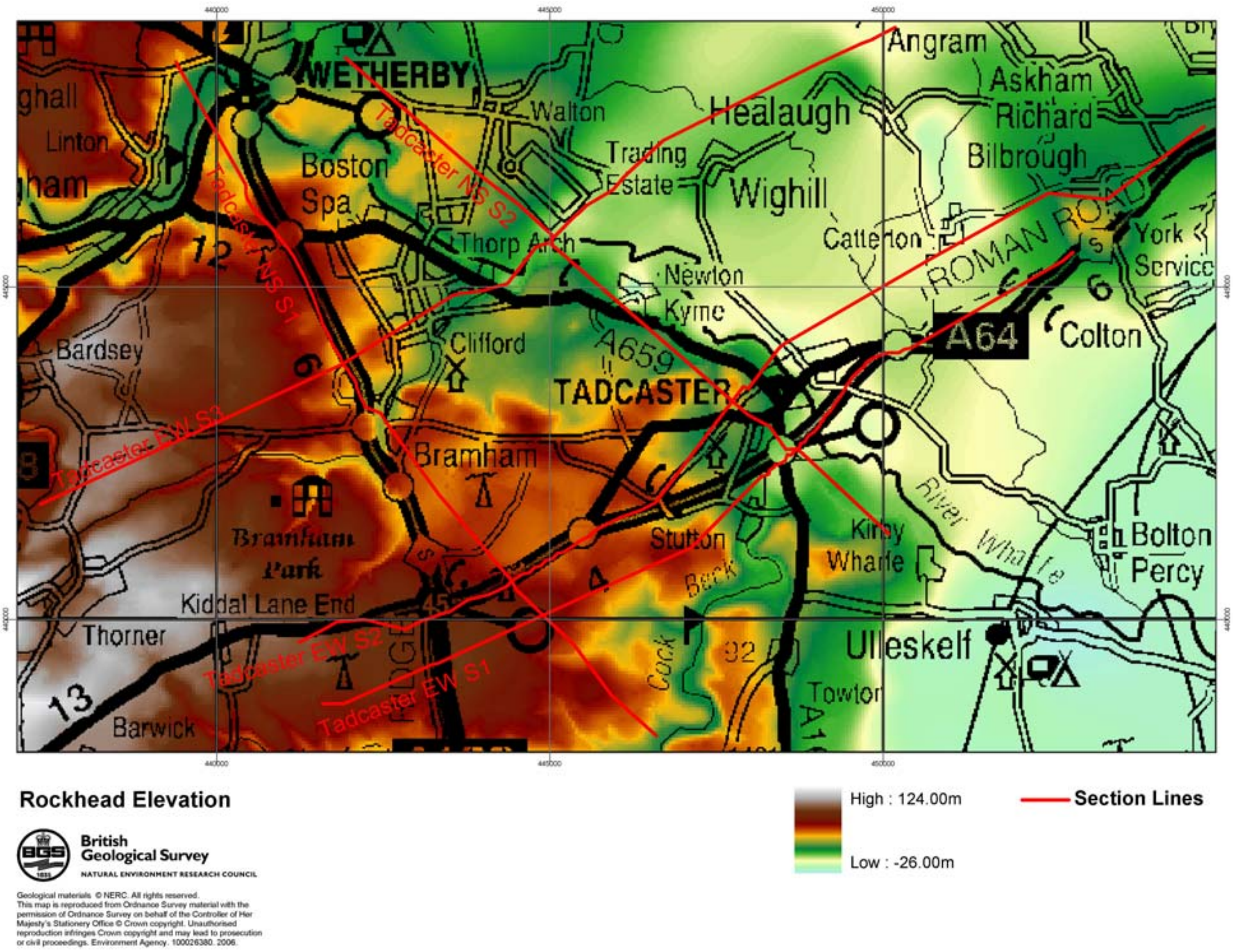

Figure 19. Rockhead elevation derived from NextMap digital elevation data and borehole data.

9.5 SUPERFICIAL THICKNESS (tad_astn.asc)

This map shows a grid of the total thickness in metres of superficial deposits in the project area. The thickness is independent of the lithological nature of the deposits, and includes all material (including Artificial Ground) above rockhead.

The thickness is calculated by subtracting the rockhead elevation surface from a digital elevation model of the land surface. The digital elevation model used in this study is based on the OS Landform Profile elevation data (contours and spot-heights), interpolated to a gridded surface with a 25m cell-size.

Both the rockhead elevation and drift thickness surfaces are based on an existing borehole database that includes only summary lithological data. This database is distinct to that used for the detailed lithological models described below. The distribution and density of data used in creating the rockhead elevation and drift thickness surfaces is generally greater than that used for the detailed lithological models.

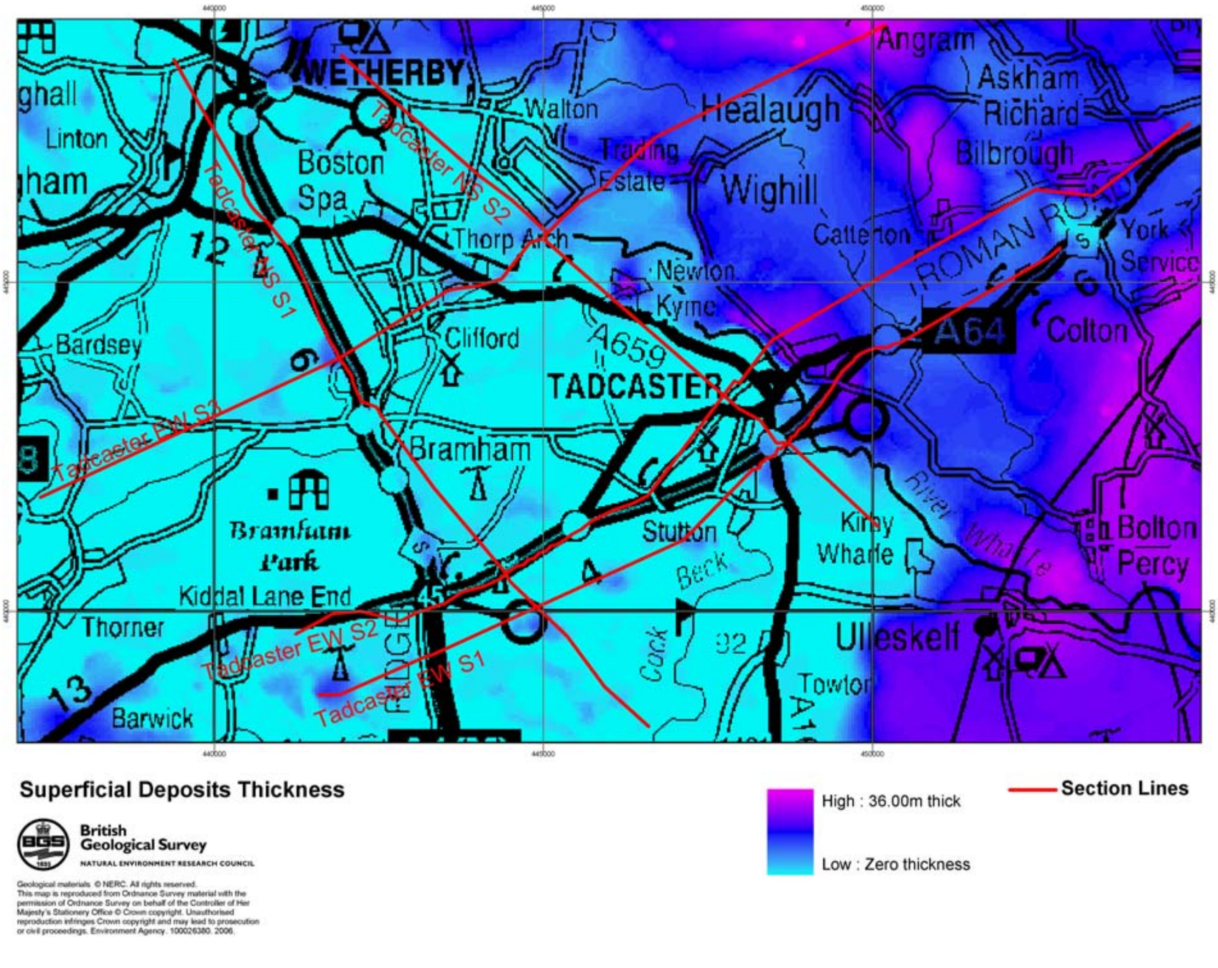

Figure 20. Thickness of superficial deposits in the Tadcaster area.

9.6 CONTINUOUS SUPERFICIAL AQUITARD GREATER THAN 5 METRES

This map shows areas where the superficial sequence includes continuous aquitard units of greater than 5 m thickness.

The classification of superficial lithologies by hydraulic character is described below.

All sand-dominated lithologies are considered as aquifers. This class includes all clean gravel, clean sand, fine sand and clean silt. Previous studies have indicated that these lithologies may have a hydraulic conductivity in the range 10^{-2} to $>10^{3}$ metres/day.

All clay-dominated lithologies are considered as aquitards. This class includes all clay, silt and mixtures of clay silt and sand. The corresponding hydraulic conductivity may be in the range 0 to $<10^{-2}$ metres/day.

All other data (unclassified or unrelated) are excluded from this study.

The interpretation is based on an appraisal of those boreholes described above. An automated gridding process has been used to interpolate between boreholes. This process produces a best estimate of the distribution of aquitard lithologies, but is dependent on the density and distribution of data. The thick aquitard coincides with the glacial deposits in the east of the area.

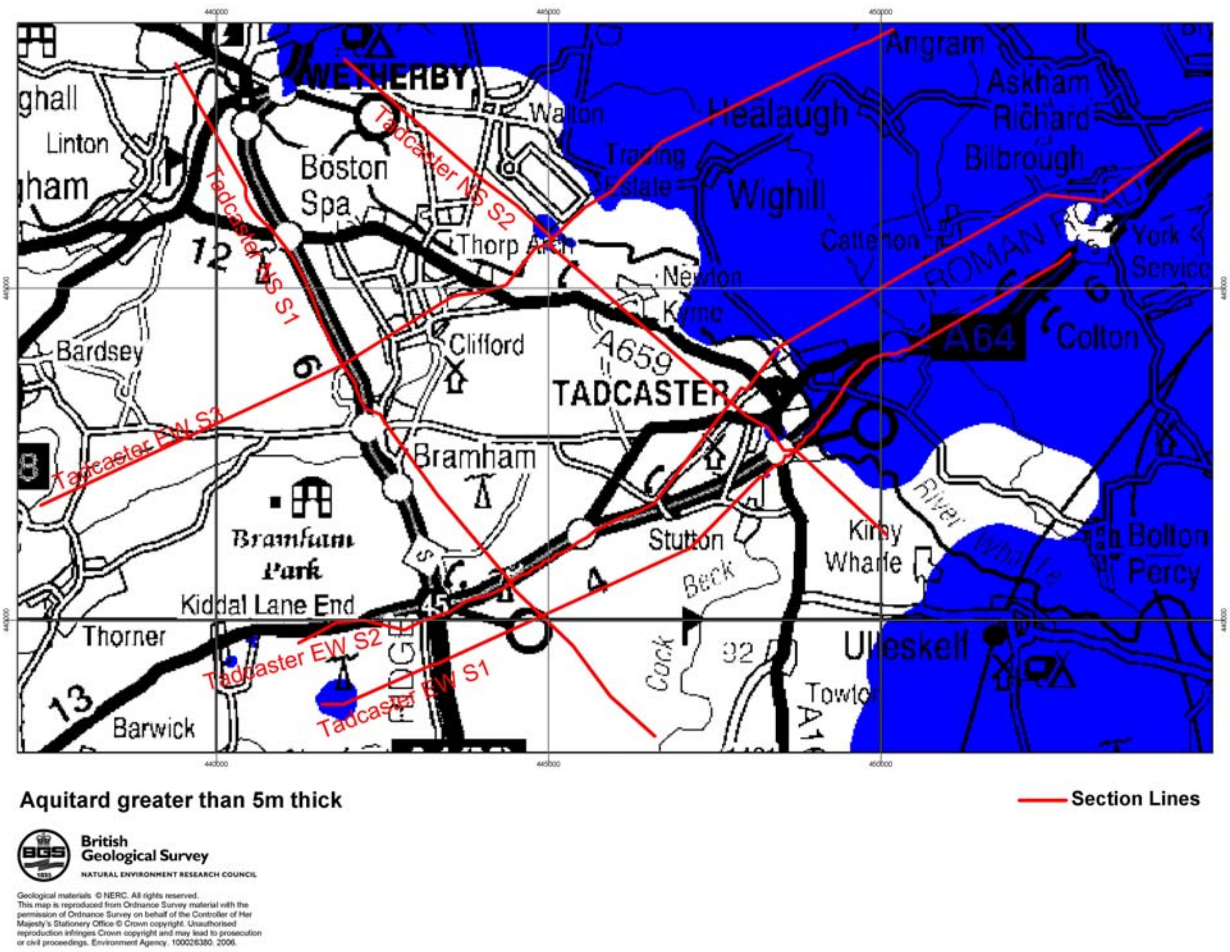

Figure 21. Distribution of superifical aquitard greater than 5 m thick in the Tadcaster area.

9.7 SUPERFICIAL AQUITARD TOTAL THICKNESS

This map shows a grid of the combined thickness of aquitard units recorded in each borehole. All aquitard units are included, independent of thickness. Total thicknesses range from 0 m (where no aquitard units are present) to >20 m (where many isolated or continuous aquitard units are present). The maximum-recorded total aquitard thickness is 22.58 m (i.e. corresponding to the greatest continuous aquitard). There are very few places where the aquitard is split by other deposits and a map showing the thickness of individual units is essentially the same.

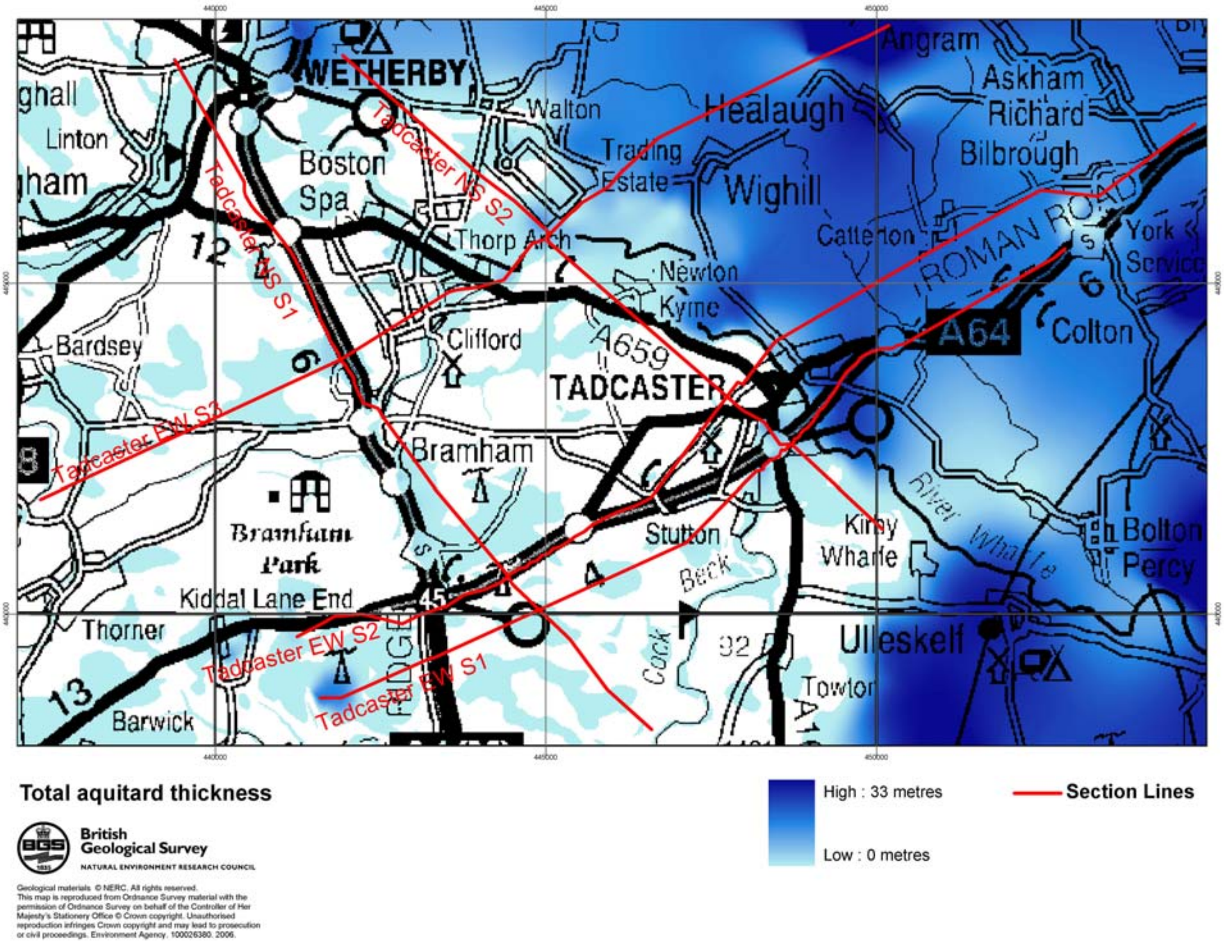

Figure 22. Total thickness of aquitard in the Tadcaster area.

9.8 CONTINUOUS SUPERFICIAL AQUIFER GREATER THAN 5 METRES

This map shows areas where the superficial sequence includes continuous aquifer units of greater than 5 m thickness.

The classification of superficial lithologies by hydraulic character is described below.

All sand-dominated lithologies are considered as aquifers. This class includes all clean gravel, clean sand, fine sand and clean silt. Previous studies have indicated that these lithologies may have a hydraulic conductivity in the range 10^{-2} to $>10^{3}$ metres/day.

All clay-dominated lithologies are considered as aquitards. This class includes all clay, silt and mixtures of clay silt and sand. The corresponding hydraulic conductivity may be in the range 0 to $<10^{-2}$ metres/day.

All other data (unclassified or unrelated) are excluded from this study.

The interpretation is based on an appraisal of those boreholes described above. An automated gridding process has been used to interpolate between boreholes. This process produces a best estimate of the distribution of aquifer lithologies, but is dependent on the density and distribution of data. The thick superficial aquifer coincides with the glacial deposits in the east of the area and the alluvial deposits of the lower reaches of the River Wharfe. It should be noted that this layer has not been clipped against the digital geological map and that some of the areas may not be as continuous as suggested.

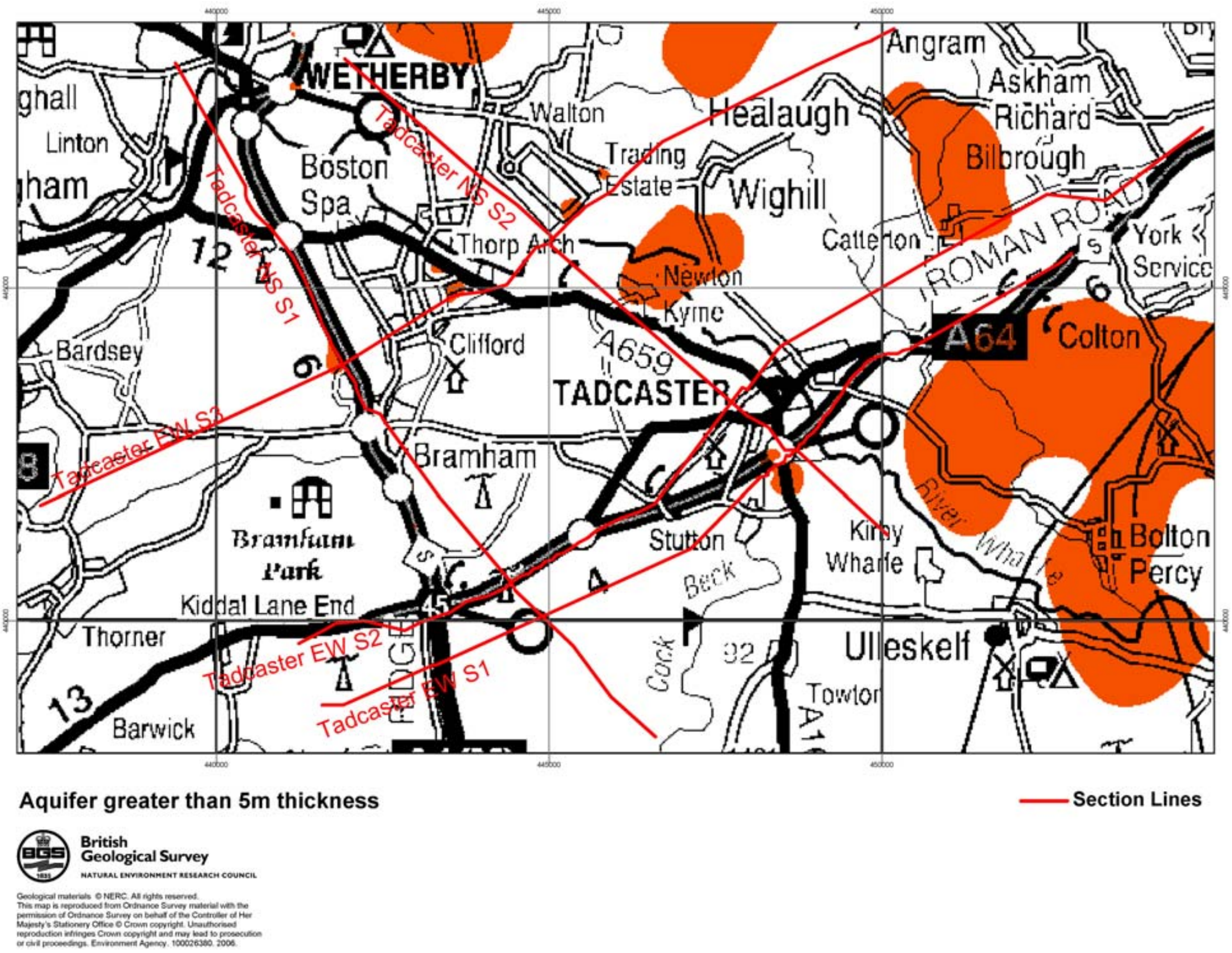

Figure 23. Continuous superficial aquifer greater than 5 m thick in the Tadcaster area.

9.9 SUPERFICIAL AQUIFER MAXIMUM THICKNESS

This map shows a grid of the thickness of the greatest continuous aquifer unit recorded in each borehole. Thicknesses range from 0 m (where no aquifer units are present) to >20 m (where extensive continuous aquifers units are present). The maximum-recorded aquifer thickness is 22.58 m.

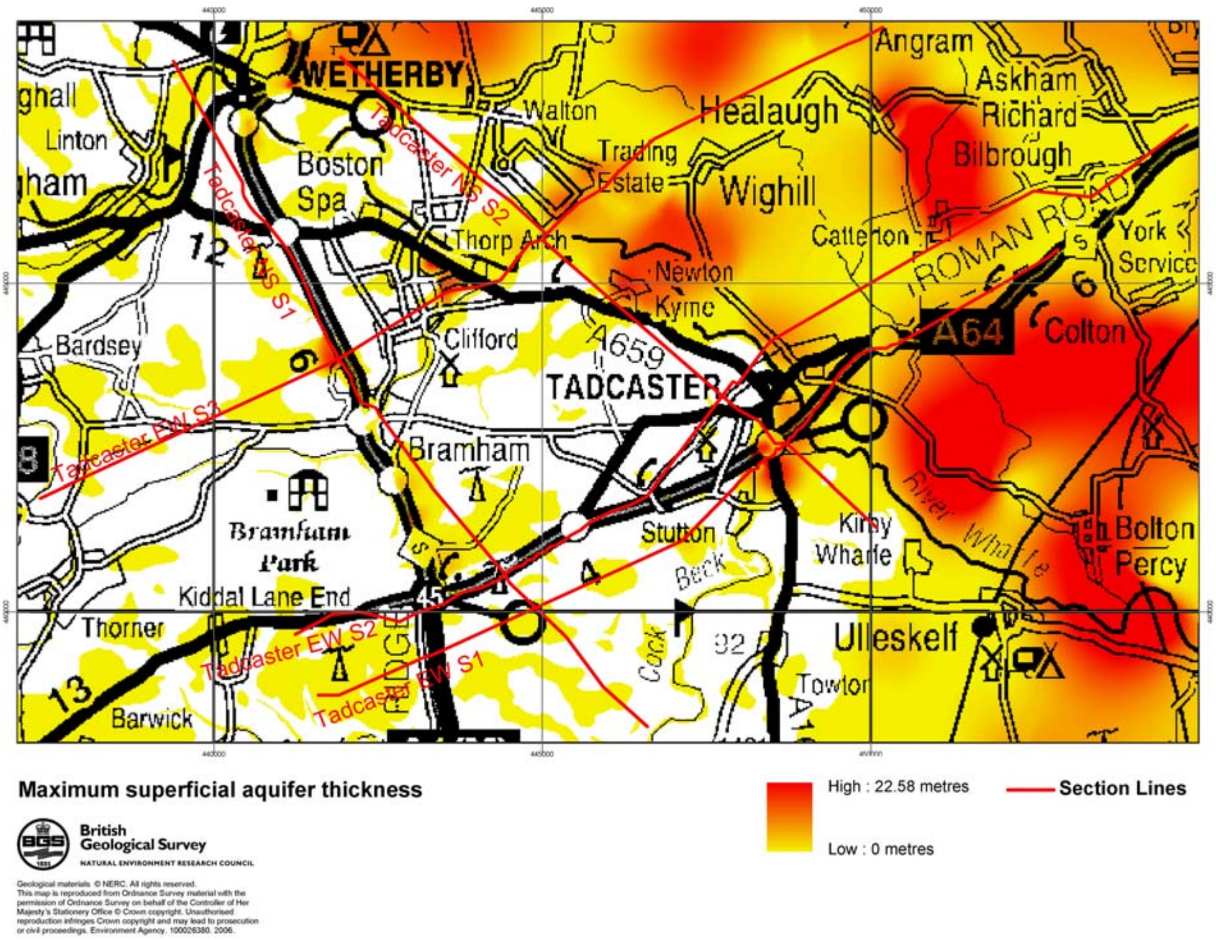

Figure 24. Maximum superficial deposits aquifer thickness in the Tadcaster area

9.10 SUPERFICIAL AQUIFER TOTAL THICKNESS

This map shows a grid of the combined thickness of aquifer units recorded in each borehole. All aquifer units are included, independent of thickness. Total thicknesses range from 0 m (where no aquifer units are present) to >20 m (where many isolated or continuous aquifer units are present). The maximum-recorded total aquifer thickness is 22.58 m (i.e. corresponding to the greatest continuous aquifer).

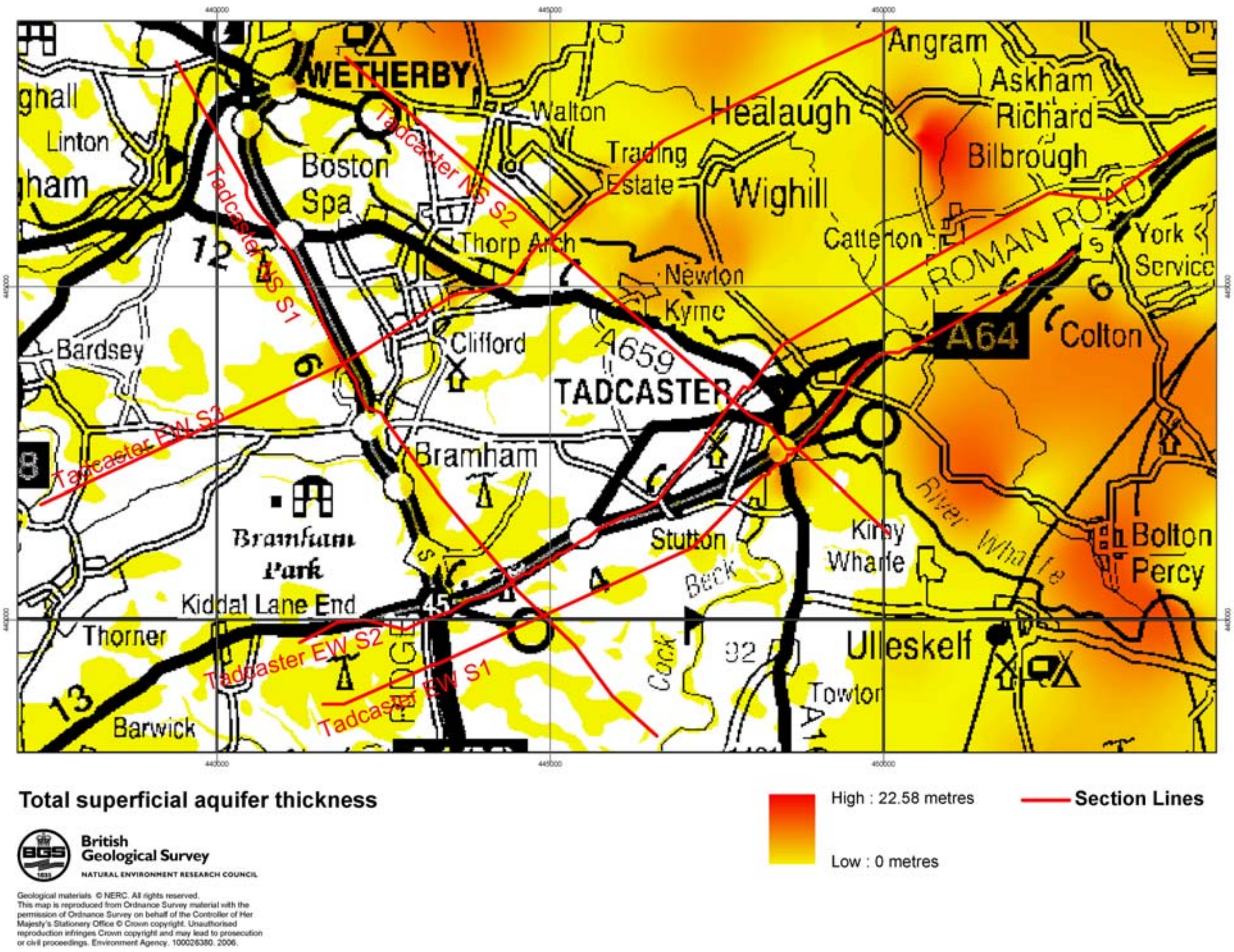

Figure 25. Total superficial deposits aquifer thickness in the Tadcaster area.

9.11 RATIO OF SUPERFICIAL TOTAL AQUIFER TO TOTAL AQUITARD

This map shows a grid of the ratio of the total aquifer thickness to total aquitard thickness recorded in each borehole. Values in the range 0 to 0.5 represent areas where the superficial sequence is dominantly composed of aquitard units (isolated or continuous). Values in the range 0.5 to 1 represent areas where the superficial sequence is dominantly composed of aquifer units (isolated or continuous). The gridded data has been cut against the geological map boundaries. In the far-west there was no gridded data and in the central to western part the information is patchy giving a rainbow effect, for this part of the map it is better to refer to the individual aquifer or aquitard maps.

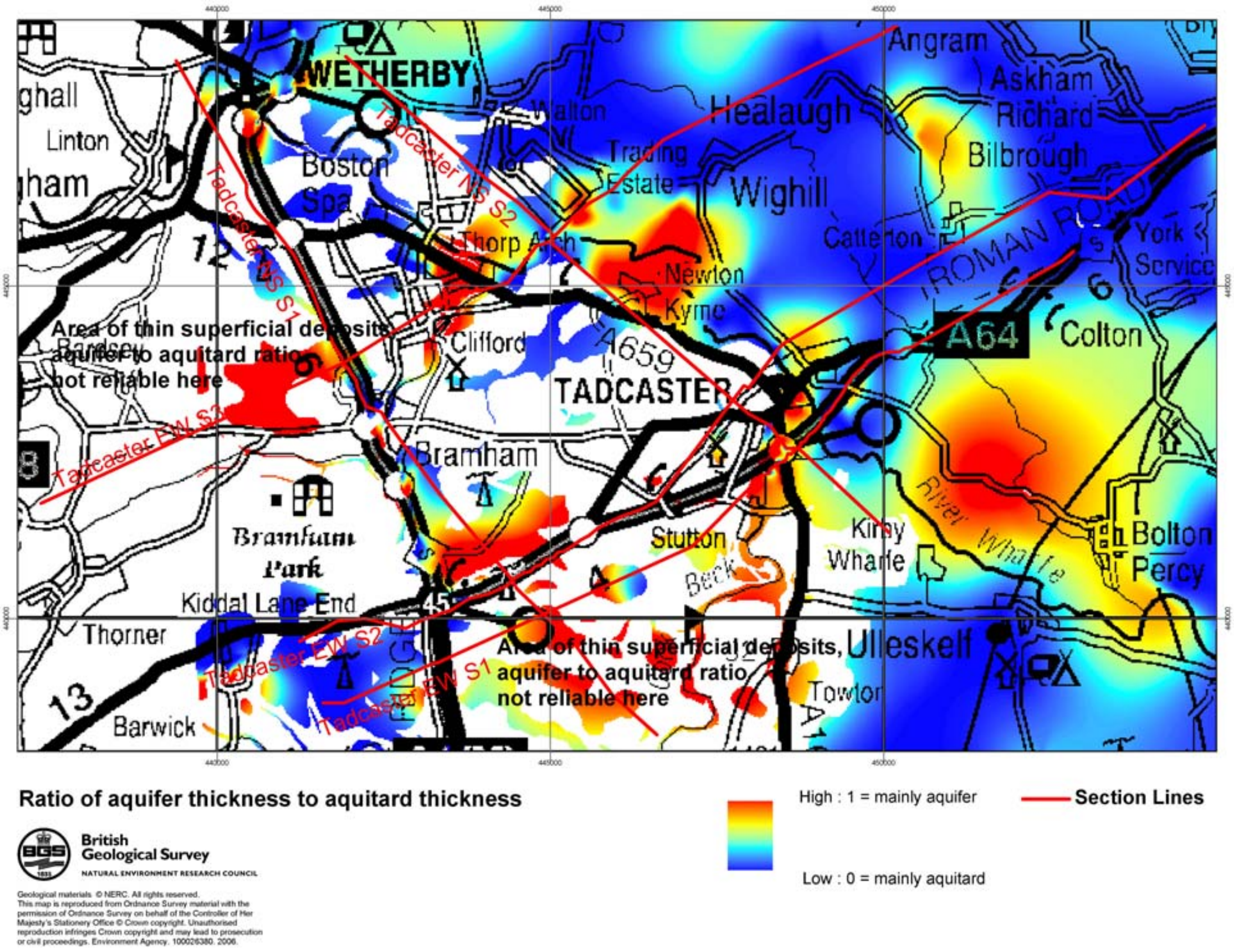

Figure 26. Map of the Tadcaster area showing the ratio of aquifer to aquitard.

10 Cross-sections

The sections are shown below at a small scale for completeness; large scale sections are included with the report.

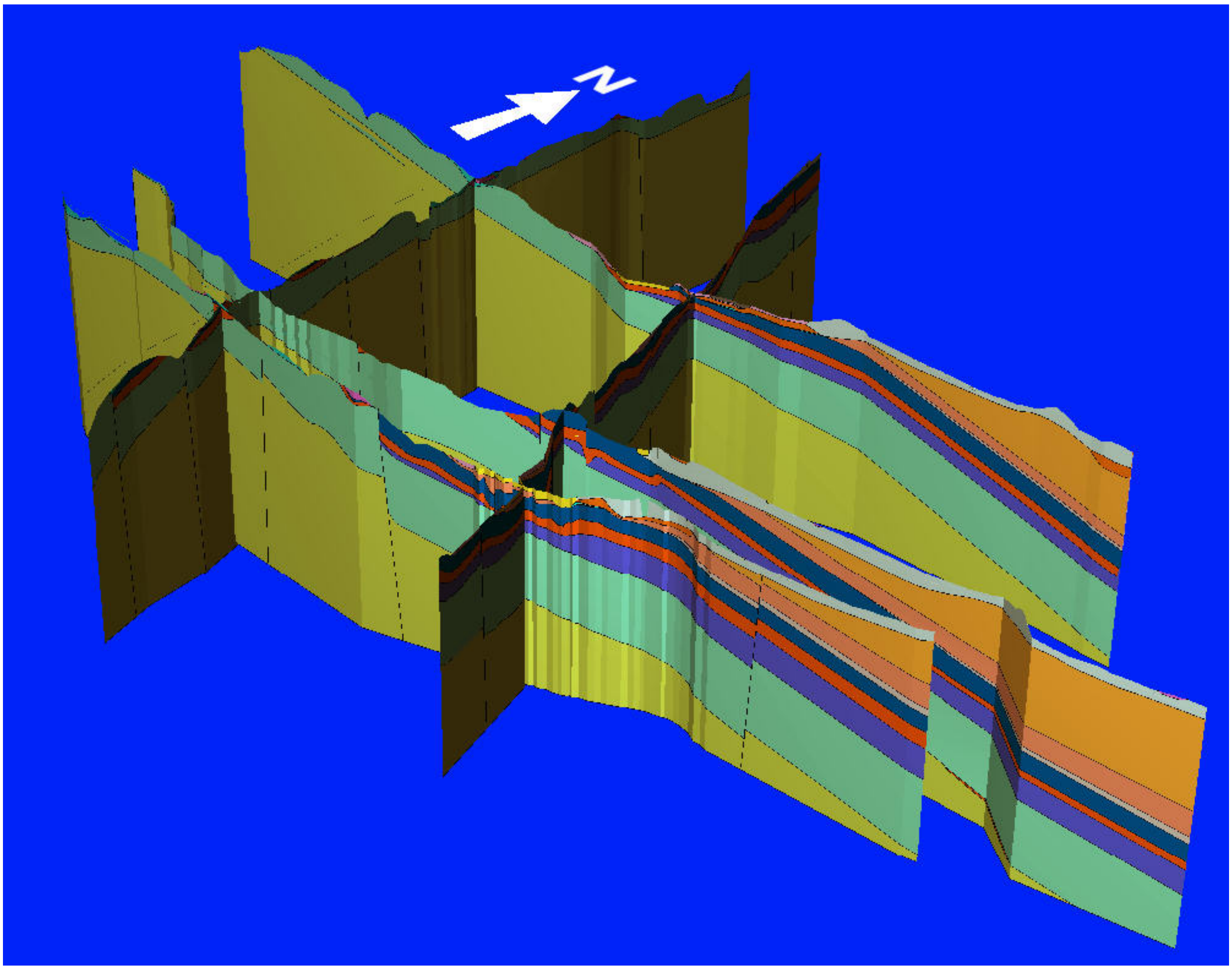

Figure 27. 3-D view of the five Tadcaster cross-sections, see Figure 1 for locations of section lines.

The 3-D model shows undivided Carboniferous strata in light green at the base. This is overlain by the Cadeby Formation in greenish blue dipping eastwards. The Hayton anhydrite/gypsum is shown in purple and the calcareous mudstone of the Edlington Formation in orange. Above this the Brotherton Formation is shown in dark blue and above this the Billingham Anhydrite/gypsum Formation in grey. The Roxby Formation is shown in pink and the Sherwood Sandstone Group in Orange. Above this the glacial till is shown in pale blue and alluvial deposits in yellow.

Note that all the sections are presented with a x10 vertical exaggeration.

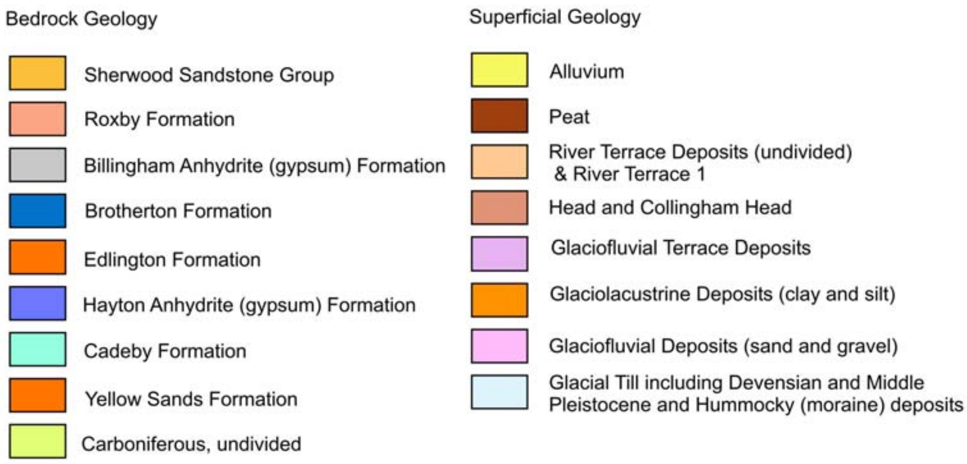

Figure 28. Legend for cross-sections through the Tadcaster area.

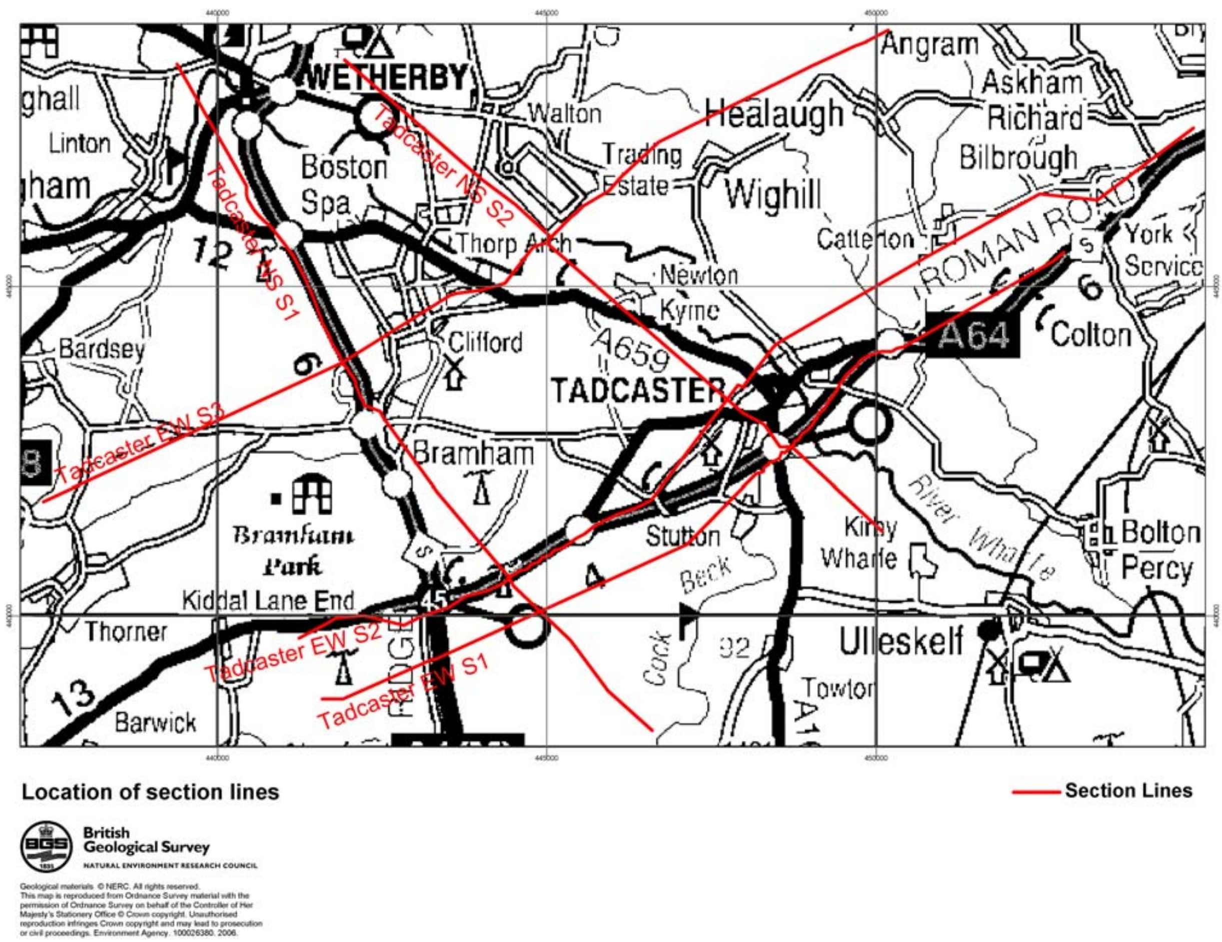

Figure 29. Location map for sections

Note about the cross-sections:

Detailed large scale sections are included with the report. The Carboniferous only shows faults that have been mapped in the Permo-Triassic rocks. It is likely that there is more faulting within the Carboniferous rocks with the faults not penetrating the overlying cover.

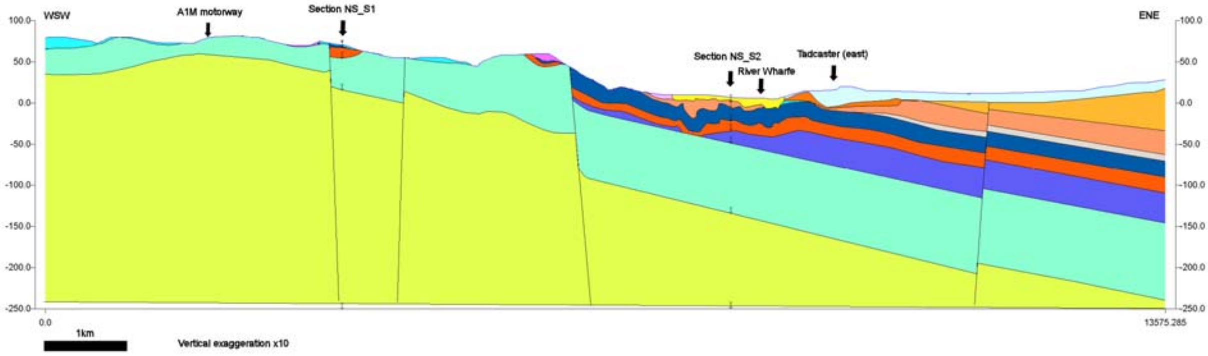

Figure 30. Cross-section Tadcaster_EW_S1 (0.0 m west NGR 441583,438732; 13575 m east NGR 452850,445520) vertical exaggeration x10.

Cross-section EW_S1 shows the easterly dipping Permian rocks with the effects of slight folding and the buried Carboniferous topography beneath the area of the A1 Motorway at the WSW end. The Cadeby Formation is thinner in the western part of the section than it is in the east due to deposition around buried hills of Carboniferous strata. The sequence is cut by numerous NW-SE trending faults, which delineate small grabens, dropping down the sequence and juxtaposing the Edlington, and in places the Brotherton Formation, with the Cadeby Formation. The Hayton Anhydrite (gypsum) formation shows considerable dissolution along the line of the River Wharfe valley (see also Figure 15). The collapse area will allow the escape of water under artesian pressure from the Cadeby Formation to the river. The eastern side of the district will have little influence on the supply of water towards the River Wharfe due to the thick covering of glacial till on the Sherwood Sandstone Group and the low-lying nature of the area.

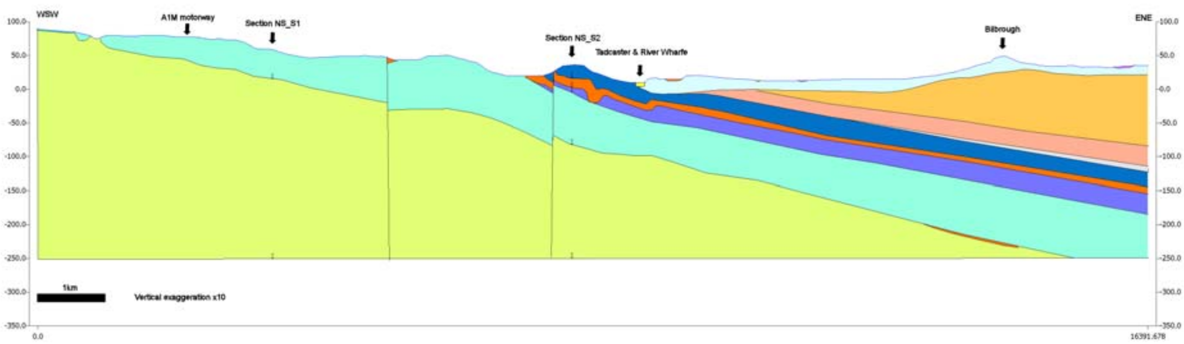

Figure 31. Cross-section Tadcaster_EW_S2, (0.0 m west NGR 441235,439659; 16391 m east NGR 454818,447415) vertical exaggeration x10.

Section EW_S2 is similar to EW_S1 with an overall easterly dip, but with a minor anticline formed within a faulted graben. A small area of Yellow Sands Formation is proved at the base of the Cadeby Formation and this is the only section on which it is proven. However, the Yellow Sands Formation forms lenticular ridges and may be present elsewhere. Like the section immediately to the south, there is considerable dissolution of the Hayton Anhydrite (gypsum) Formation in the vicinity of the River Wharfe and dissolution of the Billingham Anhydrite (gypsum) Formation towards outcrop. The superficial deposits blanket the eastern half of the section and the River Wharfe is constrained to a narrow gorge-like course between the Brotherton Formation dip slope and the Escrick Moraine. A morainic ridge is also present at Bilbrough. The thick superficial deposits blanket the outcrop of the Sherwood Sandstone Group and probably prevent recharge in this area.

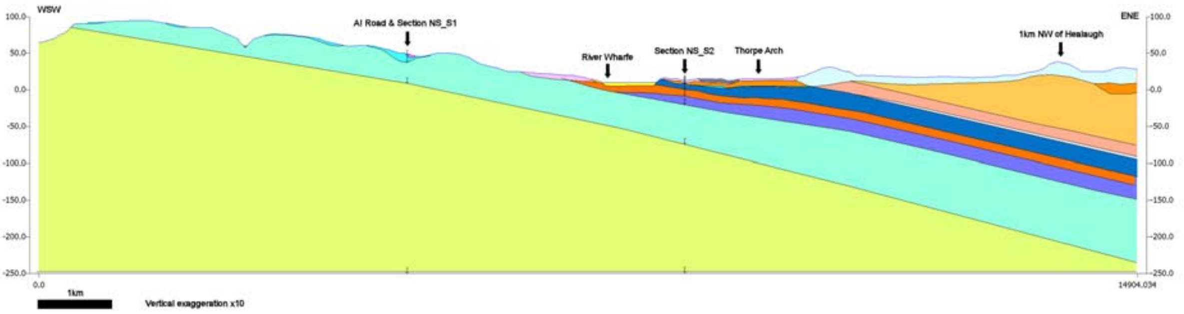

Figure 32. Cross-section Tadcaster_EW_S3 (0.0 m west NGR 437350,441733; 14904 m east NGR 450182,448904) vertical exaggeration x10.

Section EW_S3 also shows similar features to sections EW_S1 and S2, but it does not cross any mapped faults. Dissolution of the anhydrite and gypsum towards outcrop is evident. The superficial deposits show some variation not seen on the other sections and silt and clay Glaciolacustrine deposits are present beneath the glacial till both in the east of the area and in the vicinity of Thorpe Arch. Two morainic ridges are also present in the glacial till to the east of Thorpe Arch and to the NW of Healaugh.

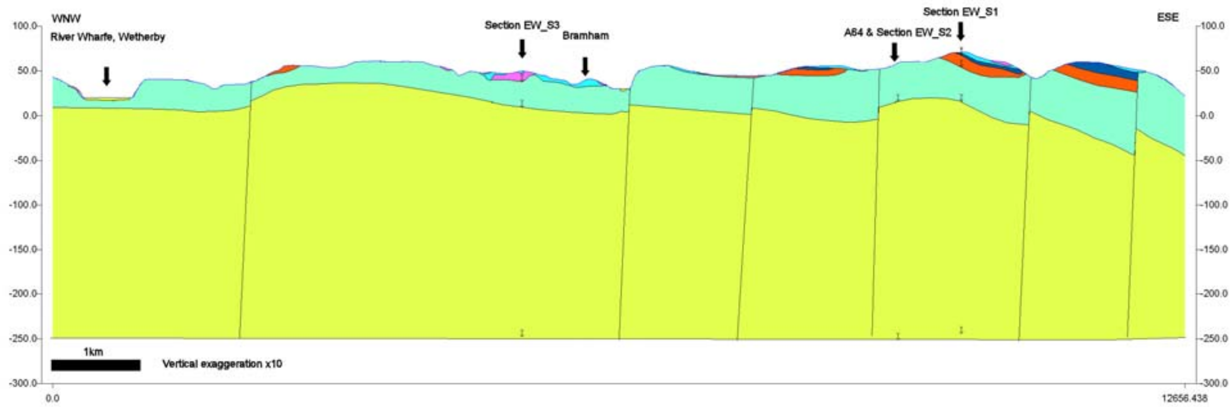

Figure 33. Cross-section Tadcaster_NS_S1 (0.0 m north NGR 439380,448387; 12656 m south NGR 446596,438250) vertical exaggeration x10.

North-south cross-section NS_S1 lies to the west of the study district where the Permian sequence is thin and where the Cadeby Formation drapes over and thickens around hills of weathered Carboniferous rocks at the Permian/Carboniferous unconformity. The section shows that the sequence is cut by numerous normal faults with a regular downthrow to the north. This is the situation across the whole of the Selby to York district to the east where it has been shown that the throw of the faults increases northwards.

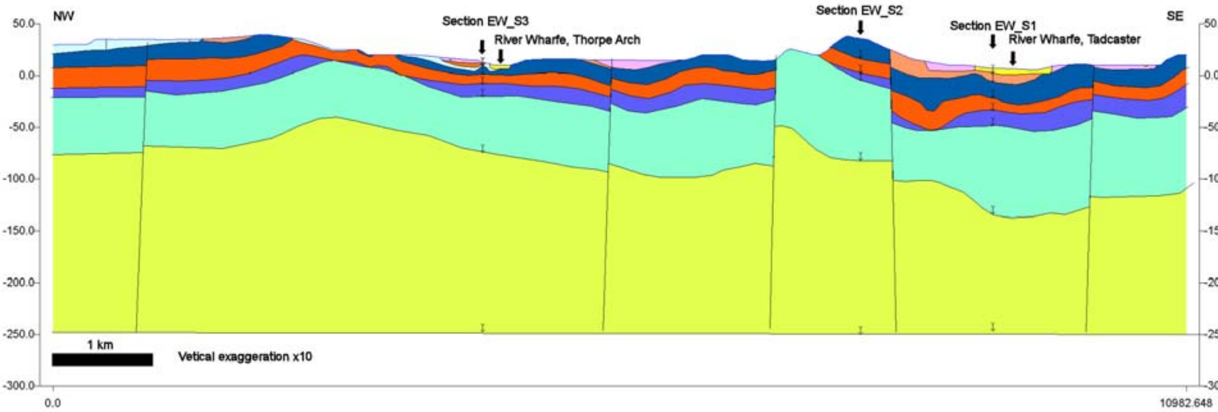

Figure 34. Cross-section Tadcaster_NS_S2 (0.0 m north NGR 441925,448449; 10982 m south 450085,441286) vertical exaggeration x10.

Section NS_S2 crosses the middle of the district. The section is cut by numerous normal faults, mainly with a downthrow to the north, but with one throwing to the south and bounding a narrow graben. The section shows some variation in the thickness of the Cadeby Formation and areas of dissolution in the Hayton Anhydrite (gypsum) Formation, where it comes near to outcrop and the River Wharfe.

Appendix 1 Non-confidential borehole numbers and co-ordinates used for the sections

Tadcaster EW_S1	x	y	Start height (m AOD)	Depth (m)
SE43NW9/A	441583	438732	77.7	42.67
SE43NW8	441897	438733	79	68.28
SE43NW68	443238	439329	72.2	15.00
SE43NW67	443303	439336	74.1	15.00
SE44SE2	447127	441087	59.8	112.78
SE44SE223	448173	442150	9.26	10.00
SE44SE225	448285	442184	6.34	17.00
SE44SE227	448291	442242	6.32	12.00
SE44SE229	448327	442270	6.25	15.00
SE44SE230	448361	442292	6.24	15.00
SE44SE330	448378	442331	6.75	35.00
SE44SE337	448417	442327	6.22	33.00
SE44SE342	448430	442340	6.81	28.00
SE44SE298	448465	442352	7.92	15.00
SE44SE232	448531	442390	6.27	20.00
SE44SE233	448560	442481	6.11	17.00
SE44SE235	448611	442469	7.7	10.00
SE44SE236	448674	442536	5.9	20.00
SE44SE239	448694	442546	5.74	18.00
SE44SE240	448715	442565	5.7	14.00
SE44SE241	448750	442601	5.79	13.00
SE44SE242	448756	442644	5.7	12.00
SE44SE243	448820	442670	5.92	15.00
SE44SE244	448874	442763	5.82	15.00
SE44SE245	448961	442818	6.48	12.00
SE44SE246	448991	442857	7.58	20.00
SE44SE348	449027	442891	8.54	33.00
SE44SE353	449063	442950	8.28	35.00
SE44SE349	449057	442975	8.37	35.00
SE44SE247	449097	442988	7.34	10.00
SE44SE248	449115	443054	8.14	9.00
SE44SE249	449206	443133	12.6	8.00
SE44SE250	449251	443200	11.92	6.00
SE44SE252	449286	443261	17.81	7.00
SE44SE254	449328	443313	16.1	5.00
SE44SE364	449417	443445	12.37	25.00
SE44SE261	449444	443513	14.14	4.00
SE44SE262	449487	443565	18.7	8.00
SE44SE265	449523	443623	22.3	11.00
SE44SE267	449553	443660	20.97	15.00
SE44SE269	449614	443718	18.99	8.00
SE44SE271	449665	443765	15.95	7.00
SE44SE273	449715	443805	14.9	4.00
SE44SE275	449736	443854	14.8	8.00
SE44SE276	449823	443917	14.15	5.00
SE44SE277	449917	443960	14.28	19.00
SE54SW22	450015	443992	13.9	20.00
SE54SW26	450073	444012	13.64	20.00
SE54SW30	450233	444012	12.35	10.00
SE54SW31	450315	444062	12.33	8.00
SE54SW15	450419	444083	12.23	6.00
SE54NW10	452693	445392	25.5	45.11

Tadcaster_EW_S2	x	y	Start height (m AOD)	Depth
SE43NW17	441235	439659	88.8	61.26
SE43NW167	441620	439860	85.6	4.00
SE43NW13/B	441793	439963	83.7	44.20
SE44SW16	442210	440000	79.24	42.67
SE43NW166	442310	439982	79.8	4.00
SE43NW15	442827	439852	79.2	36.58
SE43NW92	443097	439994	78.05	8.00
SE44SW39	443142	440002	77.3	12.00
SE44SW32	443436	440108	76.15	11.00
SE44SW31	443477	440107	76.2	8.00
SE44SW25	443771	440296	73.32	1.00
SE44SW167	444076	440375	69.23	8.00
SE44SW170	444353	440502	59.52	3.00
SE44SW171	444426	440580	58.39	2.00
SE44SW173	444593	440685	51.41	8.00
SE44SW174	444696	440707	51.58	1.00
SE44SW175	444762	440785	47.08	3.00
SE44SW176	444866	440808	46.28	4.00
SE44SW177	444935	440890	44.36	4.00
SE44SE78	445038	440916	44.24	4.00
SE44SE79	445109	440994	43.55	1.00
SE44SE80	445199	441015	46.48	8.00
SE44SE90	445348	441104	47.08	4.00
SE44SE97	445440	441178	47.34	12.00
SE44SE104	445573	441246	52.93	9.00
SE44SE308	445624	441288	51.99	21.00
SE44SE106	445708	441355	45.58	5.00
SE44SE108	445872	441443	37.9	10.00
SE44SE125	446064	441537	38.85	5.00
SE44SE130	446350	441640	46.99	10.00
SE44SE284	446586	441757	52.96	20.00
SE44SE19/C	447900	443500	27	46.63
SE44SE385	447980	443470	24.5	42.00
SE44SE19/A	448000	443500	23.3	38.71
SE44SE16/B	448420	444060	10	31.09
SE44SE16/A	448480	444120	16	193.24
SE54NW17	450708	445418	15	82.29
SE54NW11/B	453357	446318	37	118.57
SE54NW1/B	454818	447415	40	91.44
Coordinate	448474	444124	0	

Tadcaster_EW_S3	x	y	Start height (m AOD)	Depth (m)
Coordinate	437350	441733	0	
SE44SW120	441886	443839	49.5	12.00
SE44SW180	443530	444870	21.95	7.00
SE44SW181	443640	444900	21.27	7.00
SE44SW184	443980	444940	17.35	4.00
SE44NW28	444360	445050	10.6	130.00
SE44NW64	444790	445600	16.11	6.00
SE44NW65	444880	445630	15.78	6.00
SE44NW66	444920	445650	16.15	6.00
SE44NW70	444990	445660	15.49	6.00
SE44NE67	445030	445710	15.57	11.00
SE44NE63	445050	445740	15.88	6.00
SE44NE64	445110	445800	15.38	9.00
SE44NE73	445360	446060	17.65	15.00
SE44NE72	445440	446120	14.2	14.00
SE44NE69	445540	446220	16.25	22.00
SE44NE58	445945	446462	15.93	11.00
SE44NE56	446124	446669	17.25	14.00
SE44NE88	446700	447200	25	108.00
SE44NE12B	449010	448353	27	67.06
SE44NE25	449678	448662	21.3	15.00
SE44NE26	449853	448727	26.8	31.50
Coordinate	449848	448728	0	
Coordinate	450182	448904	0	

Tadcaster_NS_2	x	y	Start height (m AOD)	Depth (m)
Coordinate	441925	448449	0	
SE44NW303	444010	446630	25.61	13.00
SE44NW262	444520	446250	25.8	22.00
SE44NE61	445030	445780	16.16	12.00
SE44NE67	445030	445710	15.57	11.00
SE44NE68	445030	445690	15.84	11.00
SE44NE65	445030	445630	11.07	10.00
SE44SE47	447974	443079	23.9	4.00
SE44SE427	448300	442900	13	137.16
SE44SE234	448538	442557	6.06	8.00
SE44SE240	448715	442565	5.7	14.00
Coordinate	450085	441286	0	

Tadcaster_NS_S1	x	y	Start height (m AOD)	Depth (m)
Coordinate	439380	448387	0	
SE44NW175	440436	446530	36	6.00
SE44NW109	440438	446393	38.5	1.00
SE44NW166	440455	446327	40.9	1.00
SE44NW107	440540	446180	48.3	4.00
SE44NW73	440603	446101	52	6.00
SE44NW165	440715	445988	55.3	2.00
SE44NW106	440805	445910	56.9	4.00
SE44NW83	440899	445793	52.5	20.00
SE44NW82	440996	445668	53.2	20.00
SE44NW72	441149	445468	60.9	1.00
SE44NW161	441317	445140	61.3	1.00
SE44NW90	441379	445002	61	3.00
SE44SW127	441441	444861	59.7	3.00
SE44SW126	441476	444766	57.2	3.00
SE44SW144	441507	444676	56.9	2.00
SE44SW143	441528	444612	53.5	2.00
SE44SW142	441560	444540	51.8	2.00
SE44SW84	441581	444457	44.2	3.00
SE44SW124	441675	444282	47	1.00
SE44SW123	441703	444231	47.9	1.00
SE44SW83	441724	444155	50.2	11.00
SE44SW122	441760	444096	49.5	4.00
SE44SW121	441803	444024	47.2	6.00
SE44SW140	441858	443936	48.2	3.00
SE44SW120	441886	443839	49.5	12.00
SE44SW129	441960	443763	47.6	4.00
SE44SW139	442007	443678	45.7	1.00
SE44SW82	442040	443641	44.5	7.00
SE44SW119	442087	443566	41.8	3.00
SE44SW118	442098	443495	41.5	3.00
SE44SW81	442166	443323	34	4.00
SE44SW116	442208	443257	38	7.00
SE44SW115	442222	443192	40.1	8.00
SE44SW21	442463	443105	32.4	42.67
SE44SW9A	442517	443004	28.95	32
Coordinate	442513	443006	0	
Coordinate	443333	441877	0	
SE44SW171	444426	440580	58.39	2.00
SE44SW14	444487	440455	62.48	36.58
SE43NE5	445357	439626	52.5	55.17
SE43NE4	445928	438853	58.4	59.74
Coordinate	446596	438250	0	

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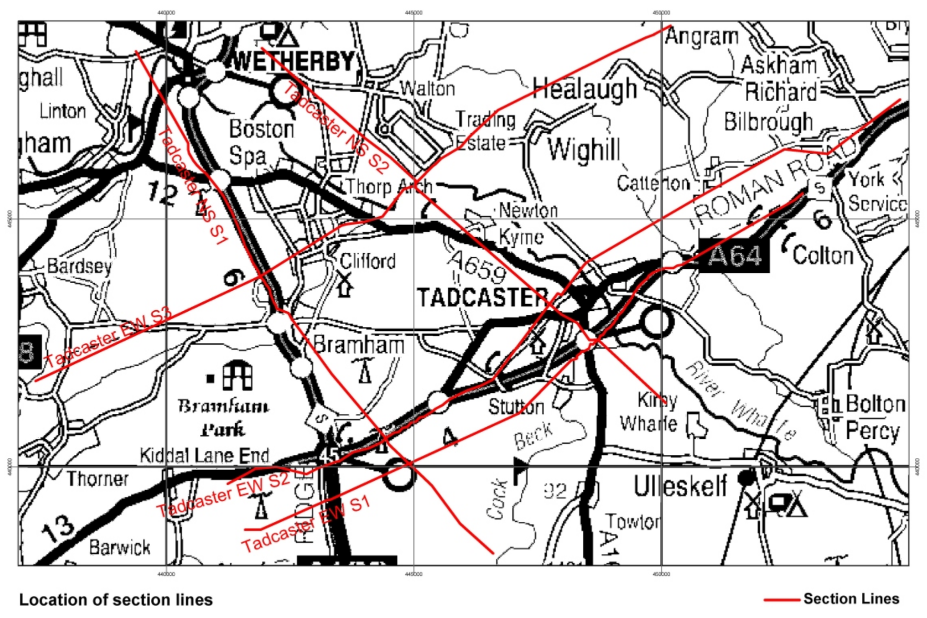
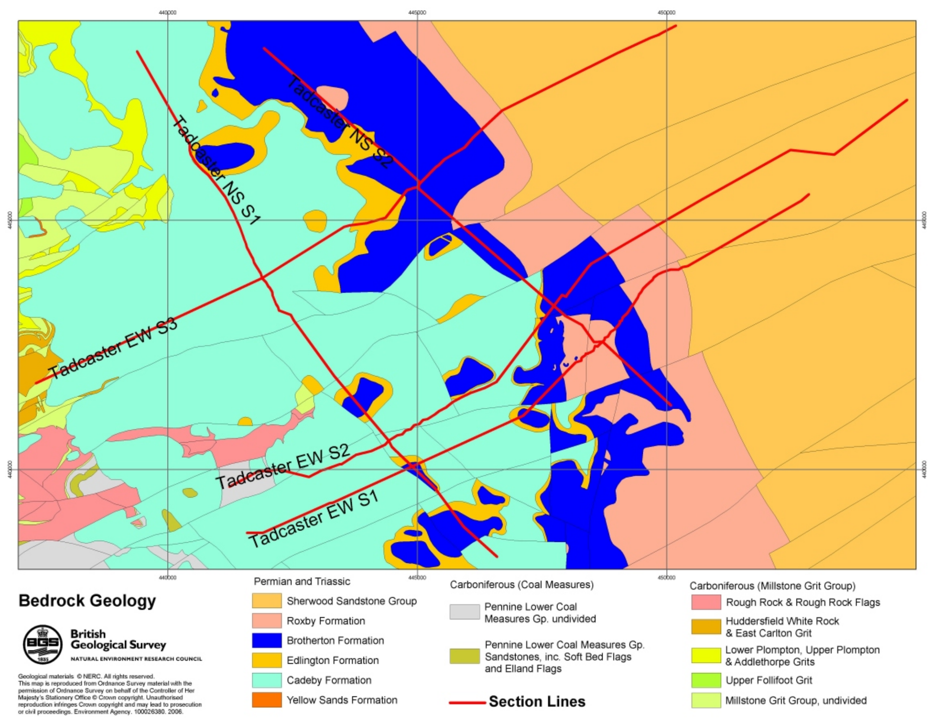
Tadcaster Magnesian Limestone 3D Borehole Interpretation and Cross-sections Study

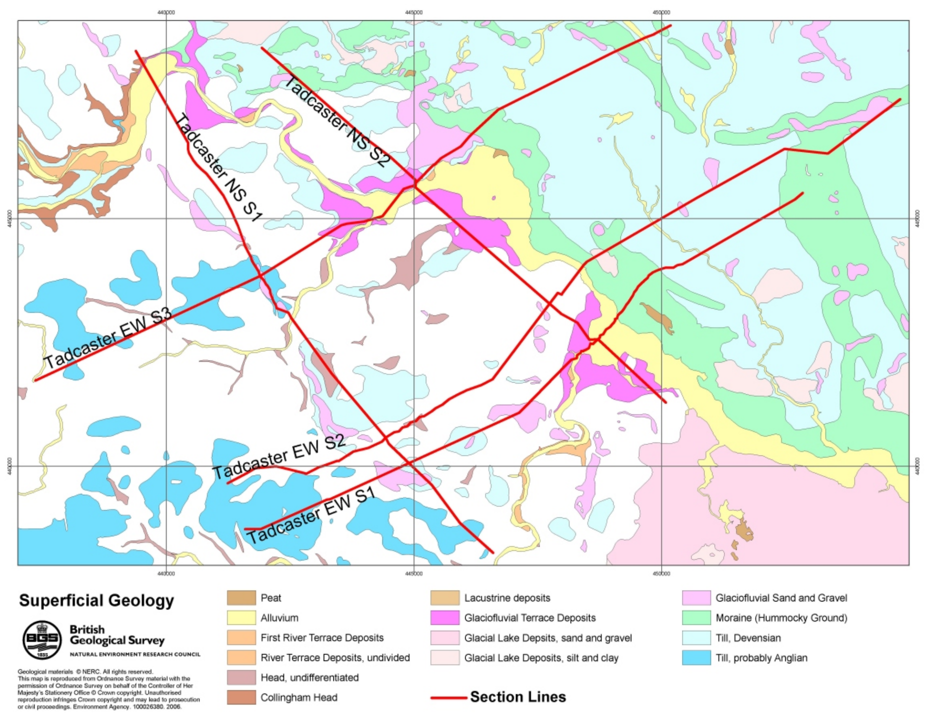
British Geological Survey
NATURAL ENVIRONMENT RESEARCH COUNCIL

Environment Agency

Geology and Landscape (South) Programme
In confidence report CR/06/256
By A H Cooper & R S Lawley, 2007.







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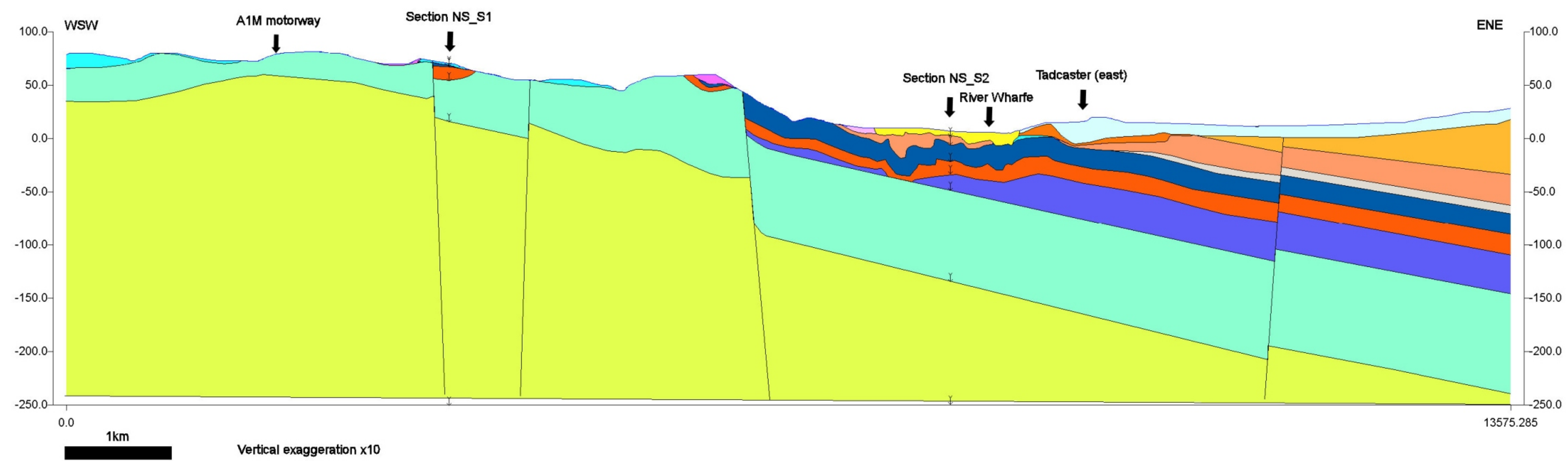


Legend for cross-sections which are shown at a horizontal scale of 1:50,000 and vertical exaggeration of x10

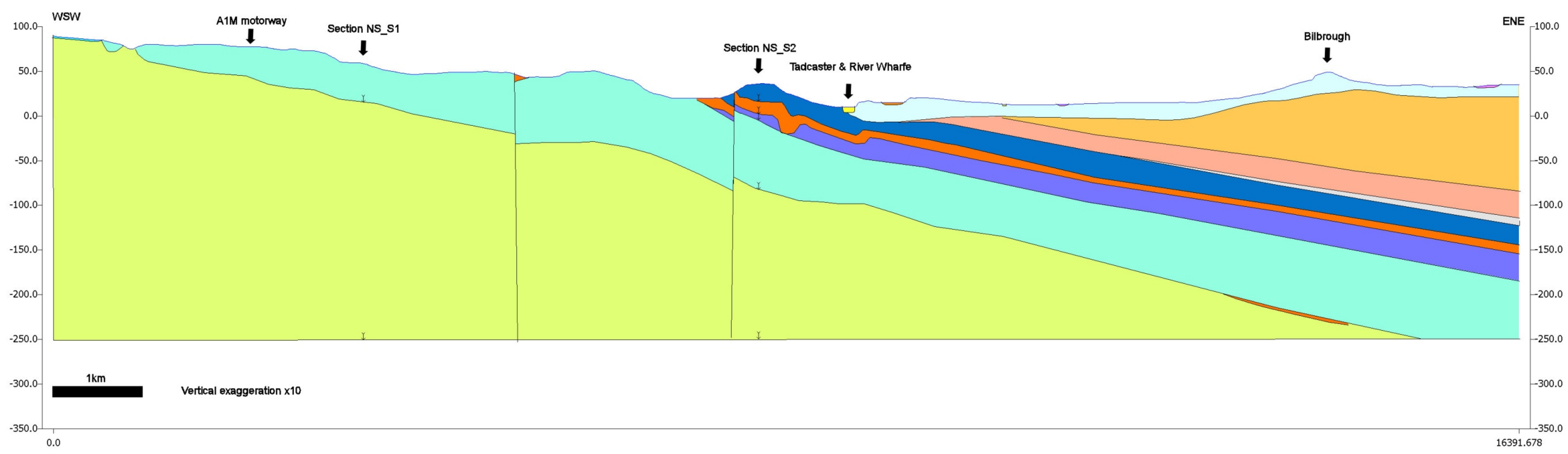
Bedrock Geology

- Sherwood Sandstone Group
- Roxby Formation
- Billingham Anhydrite (gypsum) Formation
- Brotherton Formation
- Edlington Formation
- Hayton Anhydrite (gypsum) Formation
- Cadeby Formation
- Yellow Sands Formation
- Carboniferous, undivided

Superficial Geology

- Alluvium
- Peat
- River Terrace Deposits (undivided) & River Terrace 1
- Head and Collingham Head
- Glaciofluvial Terrace Deposits
- Glaciolacustrine Deposits (clay and silt)
- Glaciofluvial Deposits (sand and gravel)
- Glacial Till including Devensian and Middle Pleistocene and Hummocky (moraine) deposits

Section EW_S2



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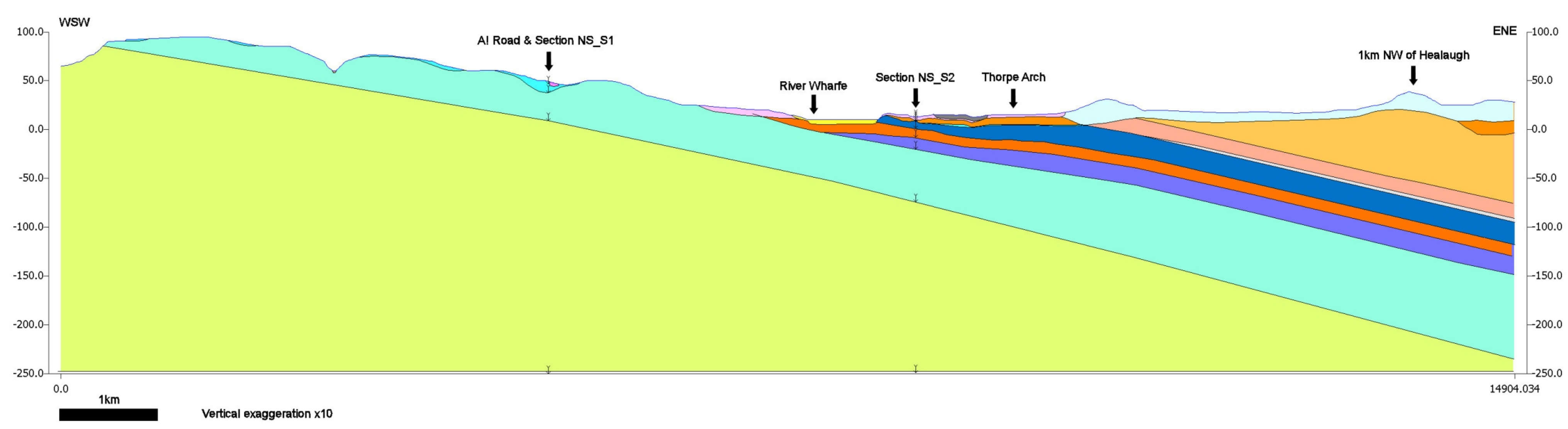
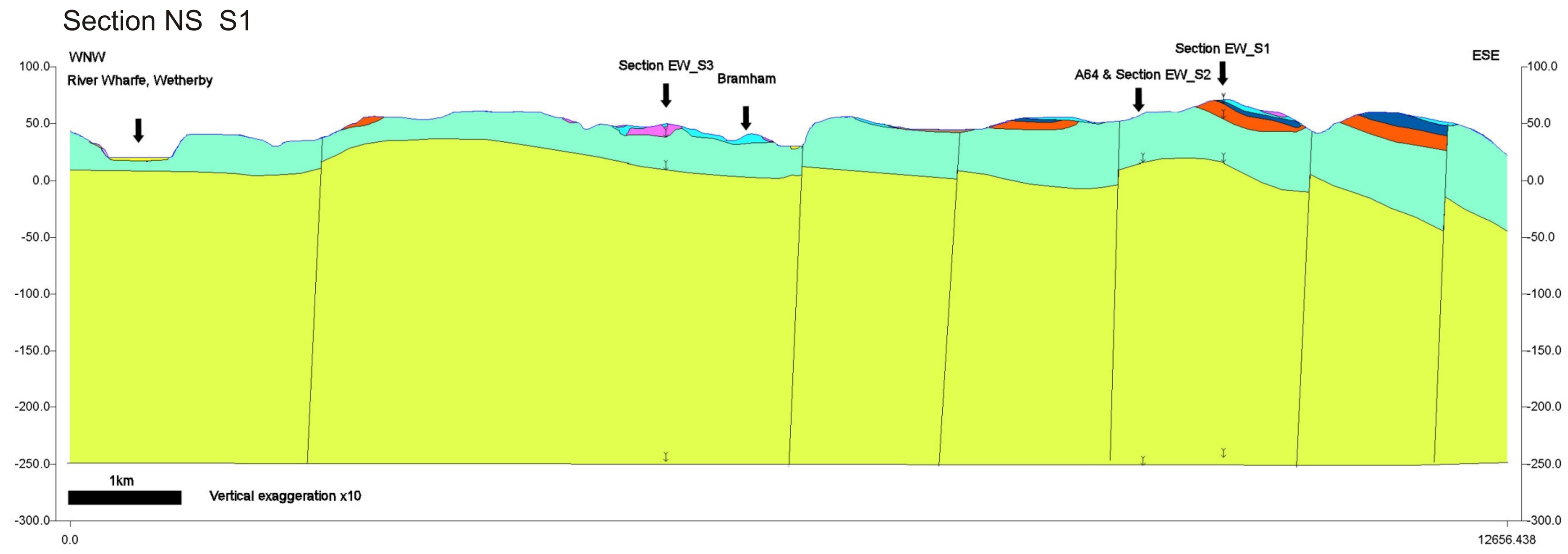


The cross-sections are compiled from borehole information that varies considerably in distribution, age, quality, depth and content. The geological information has been compiled from these boreholes and digital map data at a scale of 1: 50,000. Use of the cross-section interpretations at scales larger than 1:50,000 is not recommended. The varied distribution of the borehole data means that in some places the sections are well constrained and in others the geological lines are considerably extrapolated. The cross-sections are the best interpretation that the geologist has been able to make from the existing information and new boreholes may require this interpretation to be modified

Section NS S1



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