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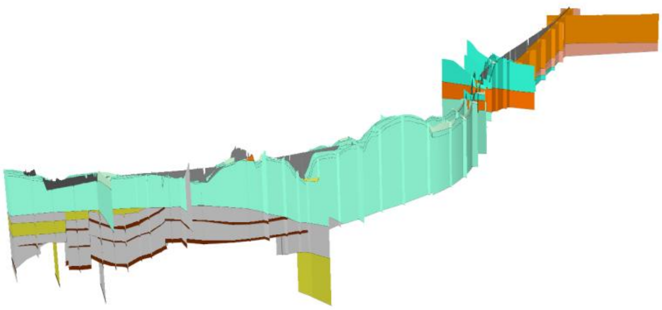
A 3D geological model for B90745 North Trans Pennine Electrification East between Leeds and York

Geology and Regional Geophysics Programme

Commissioned Report CR/15/04N



BRITISH GEOLOGICAL SURVEY

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A 3D geological model for B90745 North Trans Pennine Electrification East between Leeds and York

Burke, H. F., Hughes, L., Wakefield, O. J. W., Entwisle, D. C., Waters, C. N., Myers, A., Thorpe, S., Terrington, R., Kessler, H. and Horabin, C.

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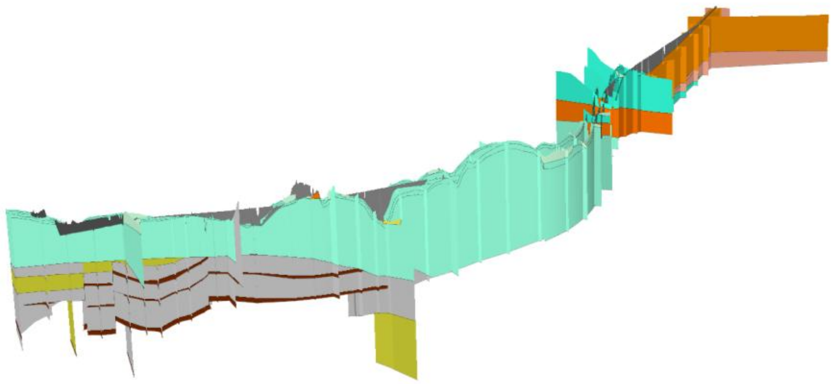

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Foreword

This report accompanies the Leeds-York 3D geological model, which was created by the British Geological Survey (BGS) under commission by Tata Steel Projects.

Acknowledgements

The authors of this report wish to thank Gerard McArdle of Tata Steel Projects for commissioning the work and Network Rail for allowing us to use their data in the model.

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Summary

This report and accompanying 3D geological model were produced for Tata Steel Projects. The report describes the bedrock and Quaternary geology of the study area, comprising 28 km (17.5 miles) of railway line between Leeds and York. The description and spatial distribution of each geological unit is based on the 3D geological model, which was constructed using 1:10,000 scale digital geological map data and 102 borehole logs from the British Geological Survey's national archive. All boreholes located within the modelled area were considered in the construction of the geological model, together with key boreholes that fall outside the area of study. The top and base of weathered rock as defined is depicted as layers within the model.

1 Introduction

To enable the geology to be better understood and incorporated into their Building Information Modelling (BIM) system of the railway line between Leeds and York, Tata Steel Projects commissioned BGS to produce a detailed 3D geological model of the route. This report accompanies the modelled surfaces supplied to Tata Steel Projects, describing the methodology used to construct the geological model and describes the geology of the route. The work began on 5th January 2015 and was completed on 30th January 2015.

2 Aim of Study

The study aimed to create a 3D conceptual ground model for the TransPennine Electrification (TPE) linear route. The model had to be designed within the following specifications:

- - Conceptual Ground Model (CGM) must extend the width of the LiDAR data provided by Tata Steel Projects, covering OLE zones 2, 3 and 4.
- - CGM must extend a minimum of 30m below track level.
- - Fence Diagrams are to be produced showing geological layers as defined by the strata along the centre of the alignment.
- - CGM must include surfaces that represent the top and bottom of the geological strata.
- - The CGM model output must be in Bentley (.dgn) 3D model file format.
- - The models produced by the BGS will comply with the project BIM execution plan and CAD standards.
- - The coordinate system to be used within the files will be the REAL Alliance snake grid.
- - Each model will use the Microstation seed file provided.
- - TSP are having a DTM (Digital Terrain Model) created separately to this subcontract enquiry but the lidar information has been included to assist in the creation of the CGM.

The model should include the following:

- A 0.5m deep 3.8m wide channel along the route of each track alignment should be included in the DTM to allow the track formation to be referenced. A separate channel will be created for each track and combined where there is less than 1m between the channels. The track alignment was provided in .dgn drawing format.
- For the CGM a separate model file is required for each track unit (e.g. Y18). Where multiple DTMxyz files are used to create a track unit model the boundary between them must not be visible. This also applies when the track units are referenced in the same model and combined model files are viewed together (e.g. MOD 3 and MOD 4).
- Each model file should be named as per the OLE Track Unit Index Plan e.g. MOD 4.
- The MOD files will comprise 2 or 3 track unit models
- An additional layer to the top of the weathered rock as defined to be included in all the models

2 Model location and data used

The Leeds-York 3D Conceptual Ground Model (CGM) covers an 80m wide, 28km long stretch of railway line between Leeds and York (Figure 1). The model is constrained by BGS's 1:10,000 scale geological map data and 102 boreholes held in BGS's national archive, plus one additional borehole supplied by Tata Steel Projects, located at a bridge in Bolton Percy.

The CGM comprises 117 correlated cross-sections and 57 geological units. This includes 11 coal seams, which are not modelled as volumes or surfaces (Table 3).

Coal Authority records held in the National Geoscience Data Centre have been considered in the geological model.

Table 1 lists the datasets supplied by Tata in snake Grid. The model is capped by LiDAR elevation data provided by Tata Steel Projects. This LiDAR data was originally supplied at

0.25m resolution, but was sub-sampled to 1m as the 3D modelling software struggles to calculate high resolution terrain models. The terrain model is lowered by 0.5m along the railway track. All datasets supplied by Tata Steel Projects that were used in the model were projected into British National Grid to fit BGS's data. The model has a cut-off depth of 30m below track level. All delivered exports from the model are projected into Snake Grid.

Table 1. List of datasets provided by Tata Steel

Aerial photographs	20 x TIF files	Used for reference only
DTM	93 x XYZ files	Converted to BNG and sub-sampled from 0.25m to 1m resolution for GSI3D modelling
Example of DTM file	1 x prototype DGN	Not used
Mapping	71 x DGN files	Used for reference only
PointCloud	92 x .LAS and .POD	Not used
Excel file	1 x XLSL	Not used
Pdf	1 x PDF	Used for referencing OLE and MOD areas
DGN	3 x DGN	Programme MOD areas

2.1 GEOLOGICAL MAP DATA

1:10,000-scale geological map data is available for the entire route, and was used to inform the model (Figure 1). The entire route falls on the Leeds 1:50,000 map sheet, which was published in 2003. Recent amendments have been made to the 1:10,000-scale geological maps in this area, focusing on the representation of opencast coal mines and their effect on coal seam outcrops etc. These modifications are not yet corporately approved, but were represented in the model. In addition to showing the surface geology, the 1:10,000-scale geological maps include sub-surface mining information, notable depths to worked coal seams and the subsurface position of faults. Additional information on subsurface data, including throw values on geological faults, are presented on the earlier series of 1:10,560-scale geological maps (Figure 1).

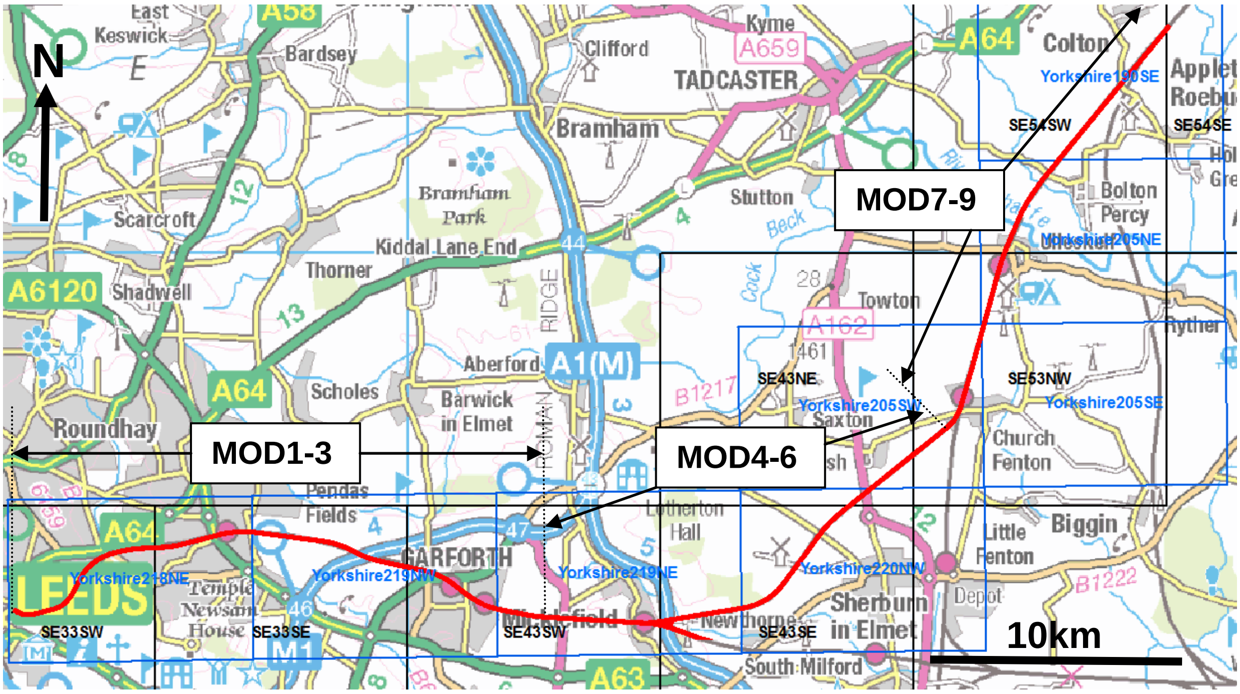

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Figure 1. Location map of the alignment, shown in red. 1:10,560 scale map sheet areas (blue) and 1:10,000-scale map sheet areas are also shown (black)

2.2 BOREHOLE DATA

BGS holds 333 borehole records within 80m either side of the TPE route. 102 boreholes were used to constrain the model because not all of those considered were suitable for coding, as some borehole logs were drilled to assess underground coal resources and the logs start below ground, and many only record the top 5m. A list of boreholes used to constrain the model is provided in Appendix 1.

Where possible an even spread of borehole data was used along the route. However, these boreholes are concentrated in the western third of the route (MOD 1 to MOD 3), where the Pennine Coal Measures Group occurs at outcrop (Figure 2). Priority was given to boreholes that lie within the area covered by LiDAR data, and those that reach a depth of 20m or more below ground level.

Where data gaps occur, boreholes outside the model area were used to constrain the geological units. Additional borehole data owned by Network Rail could not be supplied during the construction of the CGM.

3 Geological (CGM) modelling

The three-dimensional structure of the bedrock and superficial geology of the Leeds to York railway route was modelled using GSI3D software (Geological Surveying and Investigation on 3D) using an established workflow (Kessler and Mathers, 2004), which consists of four main stages: coding boreholes, constructing cross-sections, constructing coverages for the distribution of geological units, and calculating the model to generate surfaces. The 3D modelling workflow consists of three stages: borehole coding, cross-section correlation and envelope construction. These are discussed in turn below.

3.1 BOREHOLE CODING

Borehole records held in the British Geological Survey's National Geoscience Data Centre underpin the model. The start heights of these boreholes were compared to the LiDAR DTM during the correlation of cross-sections. The borehole start heights were honoured where possible, but in some cases it was necessary to adjust the start height of the borehole to match the LiDAR elevation data where considered appropriate and on the evidence of modelled geology.

All boreholes that fall within the modelled area were assessed, and in data poor areas, the boreholes that fall closest to the alignment were considered. To enable these boreholes to be viewed in the 3D modelling software, these borehole records were 'coded' in BGS's Borehole Geology database. A total of 102 BGS held borehole logs along the route were coded for this model, 19 of which are confidential. These confidential records were considered in the construction of the model, but details of the logs cannot be presented. One borehole record supplied by Tata Steel Projects was used in the model, located at Bolton Percy (Figure 5).

Scans of non-confidential boreholes used to construct the model are available to view via the BGS web site at:
http://mapapps.bgs.ac.uk/boreholescans_mobile/MobileBoreholeScans.html#/boreholescans_mobile/MobileBoreholeScans.html&ui-state=dialog

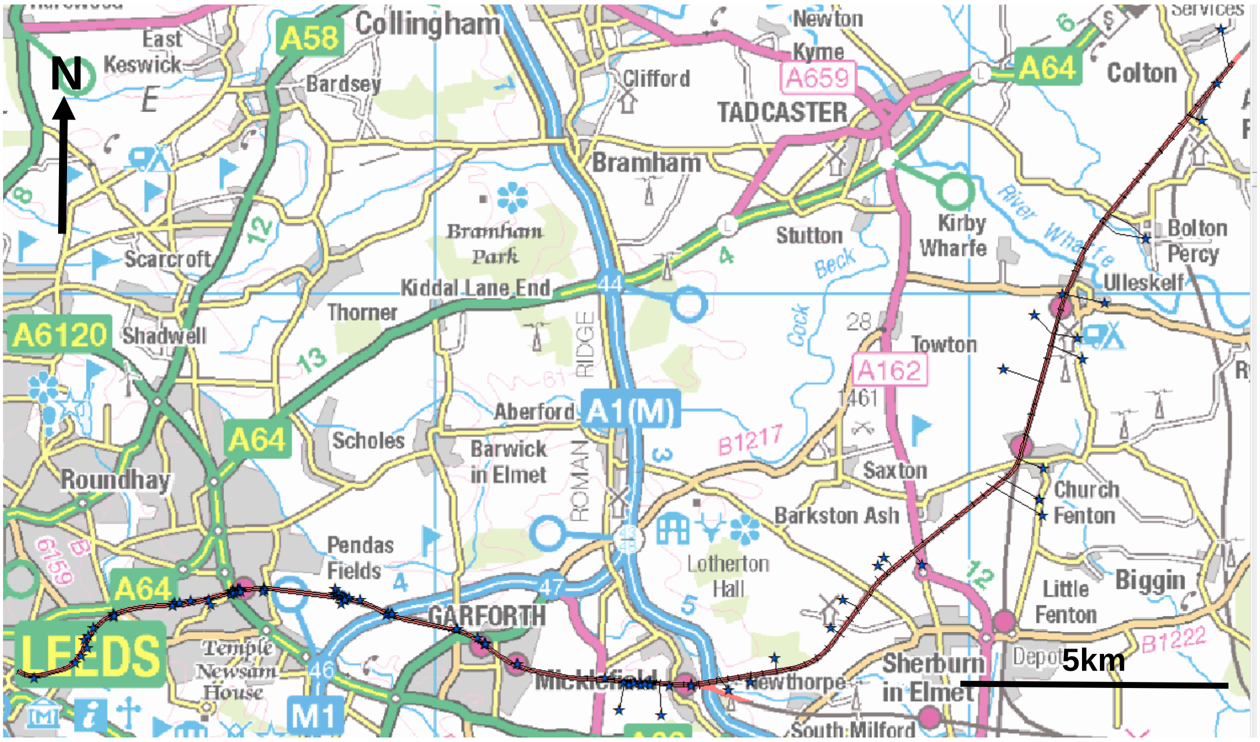

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Figure 2. Location of cross-sections (black lines) and borehole logs (blue stars) used to constrain the model

3.2 CROSS-SECTION CONSTRUCTION

The modelled linear route was divided into three sections, each consisting of three MOD areas, to enable three geologists to construct the model simultaneously. Each modeller correlated a series of short ‘rung’ sections, which cross the track and use borehole data to constrain the depths of the geological units. The spacing of the rungs is determined by the distribution of borehole data and the complexity of the geology, and are therefore closer together where the geology is more complex. Every available borehole within the modelled area has been used. Three parallel sections were also constructed, one along the centre of the alignment and one 36m spaced either side. The rung sections were constructed first and were used inform the parallel sections (Figure 2).

The model area includes 29 mapped geological faults, the vast majority of which affect the Coal Measures in the west of the model. These faults are supplied as planes, each of which is assigned a generic dip value of 70 degrees. The bases of the affected units are stepped down across these faults to show the displacement.

3.3 UNIT DISTRIBUTION AND MODEL CALCULATION

The spatial extent of the modelled geological units uses the mapped distribution for units at outcrop, as indicated in the 1:10,000-scale geological maps. Subcrops are determined by their distribution in the cross-sections. Railway embankments are classed as made ground, and their coverage was digitised from the LiDAR DTM. Borehole data was also used to determine the presence and thickness of made ground, as well as DigMapGB-10 artificial ground polygons.

The only automated part of the 3D model construction process is the calculation. The 3D modelling software triangulates between the edges of polygons, nodes along correlation lines and the digital terrain model to calculate top and base surfaces and volumes for each geological unit.

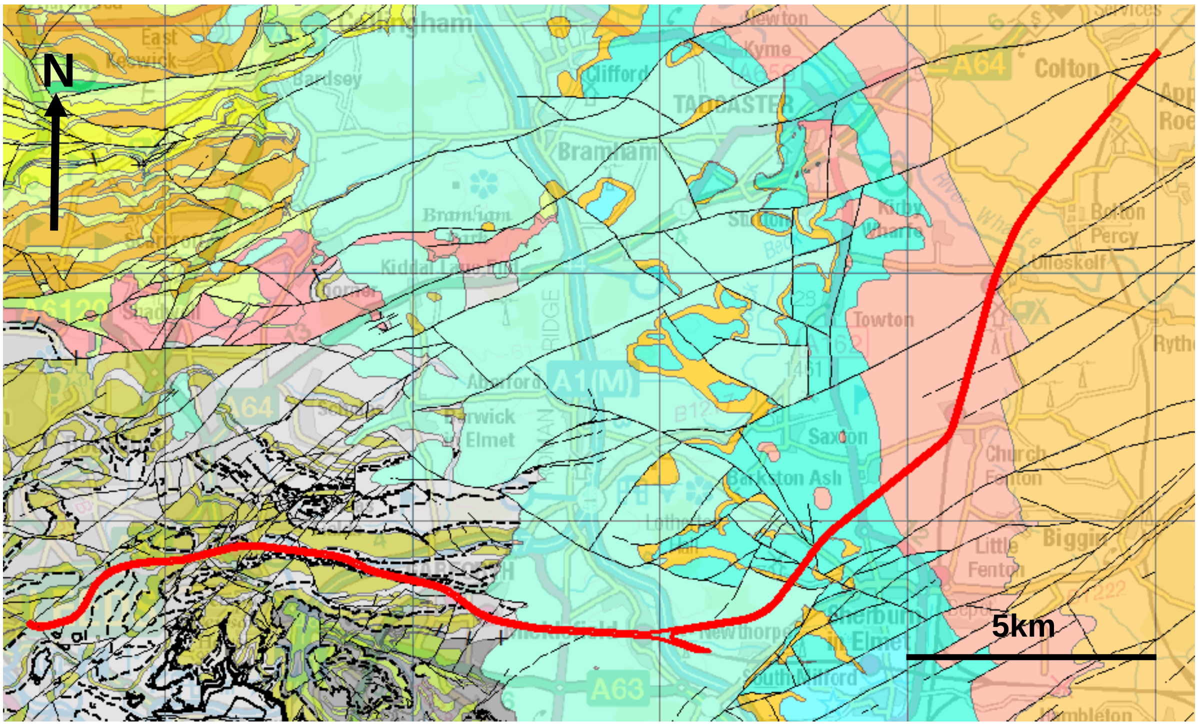
4 Geology

The geology along the route is described below according to the units that occur in the CGM. More detail can be found in the geological maps, memoirs and reports listed in the reference section at the end of this report.

The bedrock geology along the route comprises late Carboniferous aged Pennine Coal Measures Group, which are unconformably overlain by Permian and Triassic rocks of the Zechstein and Sherwood Sandstone groups, respectively. These rocks are mapped at surface in the western part of the route as far as Sherburn in Elmet, with isolated patches of Quaternary cover. East of Sherburn in Elmet the bedrock is entirely concealed beneath a thick sequence of predominantly glacial Quaternary sediments. The modelled bedrock and Quaternary geological units are described in turn below.

4.1 BEDROCK GEOLOGY

Tables 2 to 5 list the artificial, superficial and bedrock units modelled along the route in stratigraphic order. Where possible, the modelled bedrock units are consistent with the corresponding 1:10,000 scale geological maps (Figure 3). The bedrock geology is summarised here, but a more detailed account can be found in the Leeds 1:50,000 scale map sheet explanation (Cooper and Gibson, 2003) and in the Leeds geological memoir (Edwards, et al, 1950).



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Key to bedrock geology map:

- Pennine Lower Coal Measures
- Pennine Lower Coal measures sandstone
- Cadeby Formation
- Edlington Formation
- Brotherton Formation
- Roxby Formation
- Sherwood Sandstone Group
- Route
- Fault
- Coal seam

Figure 3. Bedrock geology of the route

The oldest rocks in the model are Late Carboniferous aged Pennine Lower Coal Measures Formation, which outcrop between Leeds and Garforth and are exposed in a railway cutting at Killingbeck (Figure 4). The formation is up to 530m thick in the area, though only the upper part of the formation- at or above the level of the Beeston Coal- is present within the CGM. The Coal Measures include a number of coal seams, which together with some intervening unnamed seams, are displayed on the 1:10,000 scale geological maps. These seams are displayed in the cross-sections, but have not been modelled as individual units. Similarly, a number of mapped sandstone units also occur in the modelled area. These mapped sandstone units, some of which are named and some unnamed, have been modelled.

It is important to realise that additional thin sandstone units that have been identified in the boreholes have not been modelled; these have been included with the intervening undifferentiated Pennine Lower Coal Measures Formation mudstones, siltstones and sandstones. The mudstones are typically black to grey, fissile to massive. Marine bands, soft, organic/carbonaceous and commonly pyritous shales, are not recognised in Pennine Lower Coal Measures encountered within the model. The non-marine marker band Low 'Estheria' Band, which occurs between the Top Beeston and Blocking Coals has not been recorded in the boreholes or published maps along the route and hence is not incorporated into the cross-sections or in the model. Ironstone within the mudstone successions and fireclay (seatclay) commonly developed beneath coal seams are not know to have been worked independent of the coal workings in this area.

Outside of areas of borehole control the Coal Measures succession was inferred from known elevations of coals seams which provide good laterally persistent markers. The interseam thicknesses and maximum thickness of sandstones were estimated using the Generalised Vertical Sections present on the published 1:10,000-scale geological maps. Table 2 lists the subdivision of the Coal Measures in the model.

The Pennine Lower Coal Measures Formation has been subdivided in the model using a schematic Generalised Vertical Section to enable the sandstones and coal seams to be represented (Table 2).

Figure 4. Railway cutting (north side) at Killingbeck, Leeds [NGR 434680 434150] in the Slack Bank Rock, Pennine Lower Coal Measures Formation. The sandstone comprises ~6m of fine-grained sandstone which tends to be massive in lower parts and cross-bedded above. Photograph taken in 1991. BGS GeoScenic archive no. P213856.

The Permian rocks along the route form a tripartite sequence of an upper and lower dolostone unit, separated by a mudstone unit (Table 3). These Permian rocks unconformably overlie the Pennine Coal Measures Group and occur at outcrop between Garforth and Sherburn in Elmet. A basal Permian sandstone unit named Yellow Sands Formation is recorded on the geological maps, but is not proven in boreholes considered in the model and is therefore not modelled. The basal Permian unit in the model is the Cadeby Formation which consists of grey to yellowish dolostone. The Cadeby Formation is overlain by the Edlington Formation, a red-brown mudstone unit that includes siltstone, gypsum and anhydrite. The Brotherton, overlies the Edlington Formation, and consists of dolomitic grey limestone.

Triassic aged rocks occur in the eastern section of the route from Sherburn in Elmet, and are concealed beneath Quaternary sediments (Table 3). The oldest Triassic unit is the Roxby Formation, which overlies the Brotherton Formation, and consists of mudstone with sandstone and evaporites. Thin gypsum bands are recorded in the Roxby Formation in some of the boreholes used to inform the model, but being around 1.5m thick, these are considered too thin to model as individual units. Borehole 118060 records 5.5m of gypsum at the top of the Roxby Formation, which is likely to be the Sherburn Anhydrite. However, this borehole is located approximately 700m east of the route, and is considered too great a distance to infer across to the modelled area.

Triassic aged Sherwood Sandstone Group overlies the Roxby Formation in the eastern part of the route and is concealed beneath Quaternary sediments. The Sherwood Sandstone Group is composed of red, yellow and brown sandstone, which weathers to sand. It can be difficult to distinguish between completely weathered Sherwood Sandstone and glacial sand and gravel at the base of the Quaternary sequence in borehole logs.

Table 2 List of Pennine Lower Coal Measures units in the model

Unit code	Unit name	Group	Age	Description
PLCM-MDSS	Pennine Lower Coal Measures Formation	Pennine Coal Measures Group	Late Carboniferous (Langsettian)	Interbedded mudstone, siltstone and pale grey sandstone, commonly with mudstones containing marine fossils in the lower part and thicker coal seams in the upper part
FTKC-COAL	Flockton Thick Coal	Pennine Coal Measures Group	Late Carboniferous (Langsettian)	Coal seam
PLCM1-MDSS	Pennine Lower Coal Measures Formation	Pennine Coal Measures Group	Late Carboniferous (Langsettian)	As PLCM-MDSS
ER-SDST	Emley Rock	Pennine Coal Measures Group	Late Carboniferous (Langsettian)	Sandstone
PLCM1A-MDSS	Pennine Lower Coal Measures Formation	Pennine Coal Measures Group	Late Carboniferous (Langsettian)	As PLCM-MDSS
FTNC-COAL	Flockton Thin Coal	Pennine Coal Measures Group	Late Carboniferous (Langsettian)	Coal seam
PLCM2-MDSS	Pennine Lower Coal Measures Formation	Pennine Coal Measures Group	Late Carboniferous (Langsettian)	As PLCM-MDSS
BNM1-COAL	1st Brown Metals	Pennine Coal Measures Group	Late Carboniferous (Langsettian)	Coal seam

PLCM3-MDSS	Pennine Lower Coal Measures Formation	Pennine Coal Measures Group	Late Carboniferous (Langsettian)	As PLCM-MDSS
BRSR-SDST	Birstall Rock	Pennine Coal Measures Group	Late Carboniferous (Langsettian)	Sandstone
BNM2-COAL	2nd Brown Metals	Pennine Coal Measures Group	Late Carboniferous (Langsettian)	Coal seam
PLCM3A-MDSS	Pennine Lower Coal Measures Formation	Pennine Coal Measures Group	Late Carboniferous (Langsettian)	As PLCM-MDSS
UN-SDST	Pennine Lower Coal Measures Formation	Pennine Coal Measures Group	Late Carboniferous (Langsettian)	Unnamed sandstone unit
PLCM4-MDSS	Pennine Lower Coal Measures Formation	Pennine Coal Measures Group	Late Carboniferous (Langsettian)	As PLCM-MDSS
BNM3-COAL	3rd Brown Metals	Pennine Coal Measures Group	Late Carboniferous (Langsettian)	Coal seam
PLCM5-MDSS	Pennine Lower Coal Measures Formation	Pennine Coal Measures Group	Late Carboniferous (Langsettian)	As PLCM-MDSS
MDLC-COAL	Middleton Little Coal	Pennine Coal Measures Group	Late Carboniferous (Langsettian)	Coal seam
PLCM5A-MDSS	Pennine Lower Coal Measures Formation	Pennine Coal Measures Group	Late Carboniferous (Langsettian)	As PLCM-MDSS
SA-SDST	Pennine Lower Coal Measures Formation	Pennine Coal Measures Group	Late Carboniferous (Langsettian)	Unnamed sandstone unit
PLCM6-MDSS	Pennine Lower Coal Measures Formation	Pennine Coal Measures Group	Late Carboniferous (Langsettian)	As PLCM-MDSS
SA1-SDST	Pennine Lower Coal Measures Formation	Pennine Coal Measures Group	Late Carboniferous (Langsettian)	Unnamed sandstone unit
PLCM7-MDSS	Pennine Lower Coal Measures Formation	Pennine Coal Measures Group	Late Carboniferous (Langsettian)	As PLCM-MDSS
MDMC-COAL	Middleton Main Coal	Pennine Coal Measures Group	Late Carboniferous (Langsettian)	Coal seam
PLCM8-MDSS	Pennine Lower Coal Measures Formation	Pennine Coal Measures Group	Late Carboniferous (Langsettian)	As PLCM-MDSS
WHLC-COAL	Wheatley Lime Coal	Pennine Coal Measures Group	Late Carboniferous (Langsettian)	Coal seam
SBR-SDST	Slack Bank Rock	Pennine Coal Measures Group	Late Carboniferous (Langsettian)	Sandstone

PLCM9-MDSS	Pennine Lower Coal Measures Formation	Pennine Coal Measures Group	Late Carboniferous (Langsettian)	As PLCM-MDSS
BLBC-COAL	Blocking Coal	Pennine Coal Measures Group	Late Carboniferous (Langsettian)	Coal seam
SA2-MDSS	Pennine Lower Coal Measures Formation	Pennine Coal Measures Group	Late Carboniferous (Langsettian)	Unnamed sandstone unit
UN-COAL	Pennine Lower Coal Measures Formation	Pennine Coal Measures Group	Late Carboniferous (Langsettian)	Unnamed coal seam
PLCM10-MDSS	Pennine Lower Coal Measures Formation	Pennine Coal Measures Group	Late Carboniferous (Langsettian)	As PLCM-MDSS
SA3-MDSS	Pennine Lower Coal Measures Formation	Pennine Coal Measures Group	Late Carboniferous (Langsettian)	Unnamed sandstone unit
PLCM11-MDSS	Pennine Lower Coal Measures Formation	Pennine Coal Measures Group	Late Carboniferous (Langsettian)	As PLCM-MDSS
BSNT-COAL	Top Beeston	Pennine Coal Measures Group	Late Carboniferous (Langsettian)	Coal seam
SA4-SDST	Pennine Lower Coal Measures Formation	Pennine Coal Measures Group	Late Carboniferous (Langsettian)	Unnamed sandstone unit
PLCM12-MDSS	Pennine Lower Coal Measures Formation	Pennine Coal Measures Group	Late Carboniferous (Langsettian)	As PLCM-MDSS

Table 3 List of Permian and Triassic aged bedrock units in the model

Unit code	Unit name	Group	Age	Description
SSG-SDST	Sherwood Sandstone Group	Sherwood Sandstone Group	Triassic	Sandstone, red, yellow and brown, part pebbly, with subordinate red mudstone and siltstone. Not subdivided into individual formations
ROX-CAMDST	Roxby Formation	Zechstein Group	Early Triassic	Mudstone and siltstone, red-brown, with subordinate sandstones. Sulphates (gypsum, anhydrite) common towards base
BTH-DOLMST	Brotherton Formation	Zechstein Group	Permian	Limestone, dolomitic, grey, with abundant *calcinema* algae. Formerly named Upper Magnesian Limestone
EDT-CAMDST	Edlington Formation	Zechstein Group	Permian	Mudstone, red brown, with subordinate siltstone and sandstone. Dolostone and gypsum/anhydrite are locally common.
CDF-DOLMST	Cadeby Formation	Zechstein Group	Permian	Dolostone, grey to buff grey, commonly oolitic or granular, with subordinate mudstone, dolomitic siltstone and sandstone. Formerly named Lower Magnesian Limestone

4.2 GEOLOGICAL FAULTS

The bedrock units in the model are displaced by 31 normal geological faults. These faults are modelled as planes with a generic dip angle of 70 degrees (typical of coalfields in Yorkshire) to a cut-off depth of 30m below Ordnance Datum. Displacements are represented in the bases of the affected geological units as steps down towards the downthrown side of the faults. Where a fault displaces a thicker unit against itself, such as the Sherwood Sandstone Group, the fault is not represented in the cross-section.

Underground data recorded on the 1:10,000-scale geological maps was used to identify the subsurface position of geological faults. These help in determining the direction and magnitude of dip of the fault plane. In certain examples the 1:10,560-scale geological maps record throws (vertical displacements) on some of the faults. For example, the Osmondthorpe Fault (Leeds_Tata_21 in model) is shown to have a throw of 30m (105 feet) down to the south-east; Leeds_Tata_1 with a throw of 3m (10 feet) down to the north-west, Leeds_Tata_2 with a throw of 9m (30 feet) down to the south-east. All of these faults are recorded in the Beeston Coal within MOD 1 and were used in construction of the model. Underground faults that are not mapped at the ground surface are assumed to only affect the Coal Measures and are not modelled through the overlying Permian rocks.

Correlated cross-section Tata_Leeds_York_HBU_Track is shown in Figure 5. This cross-section runs along the centre of the alignment from Roman Ridge Bridge, approximately 1km east of Garforth to Church Fenton. The rocks have a regional dip to the east, with local variation caused by faulting. In this area the Coal Measures are concealed beneath the Cadeby Formation. Faults that are mapped at the ground surface are modelled through all geological units. Two underground faults are mapped in the west of this cross-section, modelled as U1 and U2. These are recorded where they intercept coal seam extents and these faults are only modelled in the Coal Measures. Two additional faults, named Inf1 and Inf2, were inferred through the modelling process. Fault Inf1 is modelled up to the base of the Cadeby Formation. Fault Inf2 is modelled up to rockhead because the base of the Cadeby Formation deepens in boreholes east of fault.

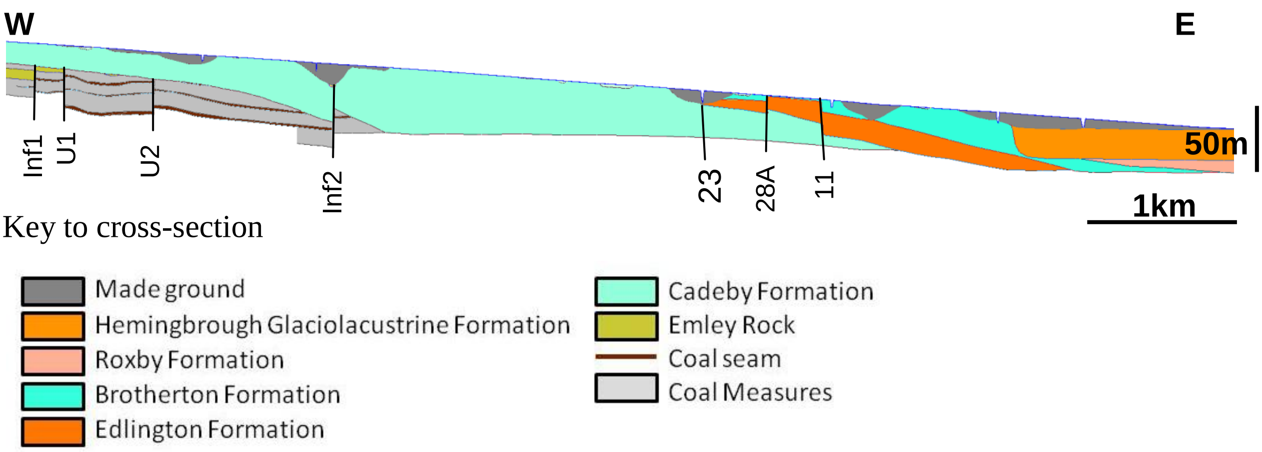
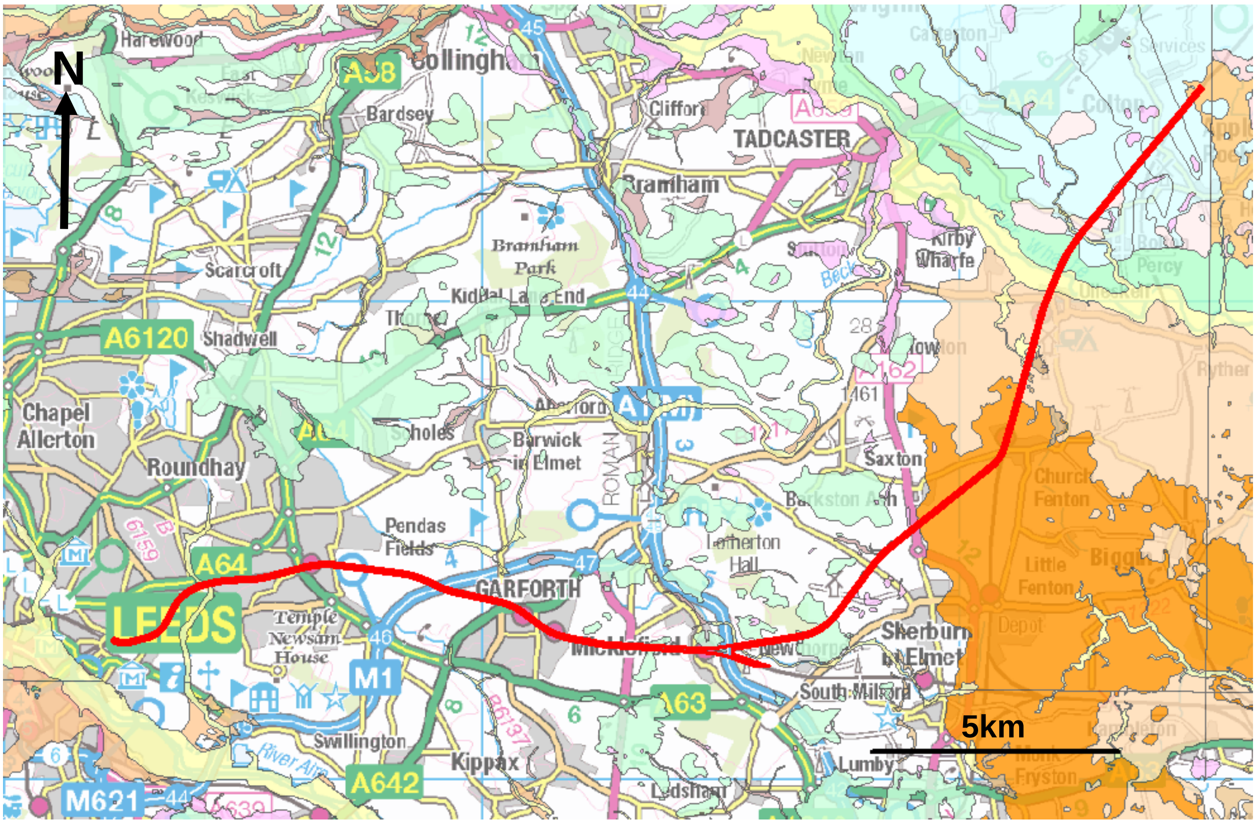


Figure 5. Cross-section along the centre of the alignment from Garforth to Church Fenton showing the Coal Measures beneath the Cadeby Formation and modelled faults

5 Superficial geology

The modelled superficial units along the route are pictured in Figure 6 and listed in relative stratigraphic order in Table 4. The Quaternary succession is summarised in this report; a more detailed account can be found in the sheet explanation for the Leeds 1:50,000 scale map sheet (Cooper and Gibson, 2003).



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Main superficial units:

Route	Escrick Moraine Member
Alluvium	Glacial sand and gravel
Breighton Sand Formation	Hemingbrough Glaciolacustrine Formation
Vale of York Formation till	Harrogate Till Formation

Figure 6. Superficial geology of the route

The oldest Quaternary unit in the model is the Anglian aged Harrogate Till Formation (boulder clay), which occurs as isolated patches through the middle of the route. This is associated with an Anglian aged glacial sand and gravel unit, which overlies the Harrogate Till Formation.

A sequence of Devensian aged Quaternary deposits dominates in the eastern part of the route, reaching over 30m in thickness. These deposits comprise a basal sand and gravel unit, which rests on Sherwood Sandstone bedrock. It is uncertain whether this unit is entirely composed of glacial sand and gravel, or whether it includes weathered Sherwood Sandstone bedrock where the sandstone has degraded to sand. This unit does not outcrop at the ground surface and is described in several boreholes near the model zone, namely non-confidential logs 118961 and 118951. These logs have varying lithological descriptions (Table 4).

The Hemingbrough Glaciolacustrine Formation consists of laminated silt, clay and sand and outcrops along the route from Sherburn in Elmet to Church Fenton and underlies the Breighton Sand Formation. The Vale of York Formation is predominantly composed of till (gravelly sandy clay) and underlies the route from Bolton Percy to Colton. It also forms the Escrick Moraine Member, which pushed southwards into the Hemingbrough Glaciolacustrine Formation. A lens of sand and gravel within the till of the Vale of York Formation was identified in borehole logs. This lens is only modelled where proven in boreholes, but could be more extensive. A patch of older till is present in one borehole underlying the Hemingbrough Glaciolacustrine Formation, which contains limestone gravel and might be the Harrogate Till Formation.

Small patches of glacial lake sediments overlie the till of the Vale of York Formation between Boulton Percy and Colton Junction, which consist of laminated clay and silt. Patches of glacial sand and gravel are present overlying the bedrock to the north of Sherburn in Elmet.

Alluvium occurs along the floodplains of the River Aire and its tributaries, the river Wharfe and its tributaries and along Newthorpe Beck. It consists of mainly silt and clay with some horizons of sand. The maximum modelled thickness is 8m, interpreted from the Selby sheet explanation (Ford et al, 2009).

Table 4. Quaternary geological units modelled

Unit code	Unit name	Group	Age	Description
ALV-CZ	Alluvium	Britannia Catchments Group	Holocene	Alluvium, composed of silty clay
BREI-SZ	Breighton Sand Formation	Caledonide Glacigenic Group	Devensian-Holocene	Aeolian sand
GLLD-XCZ	Glacial lake sediments	Caledonide Glacigenic Group	Devensian	Silty clay, often laminated
ELV-CZ	Elvington Glaciolacustrine Formation	Caledonide Glacigenic Group	Devensian	Silty clay
ESKM-CSV	Escrick Moraine Member	Caledonide Glacigenic Group	Devensian	Till (boulder clay)
VYORK-SV	Vale of York Formation	Caledonide Glacigenic Group	Devensian	Glacial sand and gravel
VYORK-CSV	Vale of York Formation	Caledonide Glacigenic Group	Devensian	Composed of gravelly, sandy clay
HEM-CZ	Hemingbrough Glaciolacustrine Formation	Caledonide Glacigenic Group	Devensian	Composed of silty clay
OUT-CSV	Older unnamed till unit	Uncertain	Devensian or Anglian	Identified in boreholes beneath the Hemingbrough Formation
GFDMP-XSV	Glacial sand and gravel	Albion Glacigenic Group	Anglian	Forms isolated patches
HRT-CSV	Harrogate Till Formation	Albion Glacigenic Group	Anglian	Forms isolated patches
GFOSS-SV	Basal sand and gravel unit	Uncertain	Devensian or Anglian	Basal sand and gravel beneath the Vale of York Till/Hemingbrough Formation. Described in boreholes logs as glacial sand and gravel, gravelly sand or sandy gravel. Uncertain whether this is glacial sand and gravel or weathered Sherwood Sandstone.
VYORK-SV _LENS1	Vale of York Till Formation	York Till Formation	Devensian	Sand and gravel lens within the Vale of York Till Formation, identified from boreholes

A correlated cross-section along the centre of the alignment in the eastern part of the route is shown in Figure 7. This shows the Quaternary sequence, with thick glacial lake sediments of the Hemingbrough Formation (orange), which have been overridden by the Vale of York till (pale blue) and Escrick Moraine (pale green). A sand and gravel lens is shown in the Vale of York till (pink). Railway embankments are modelled as made ground (grey).

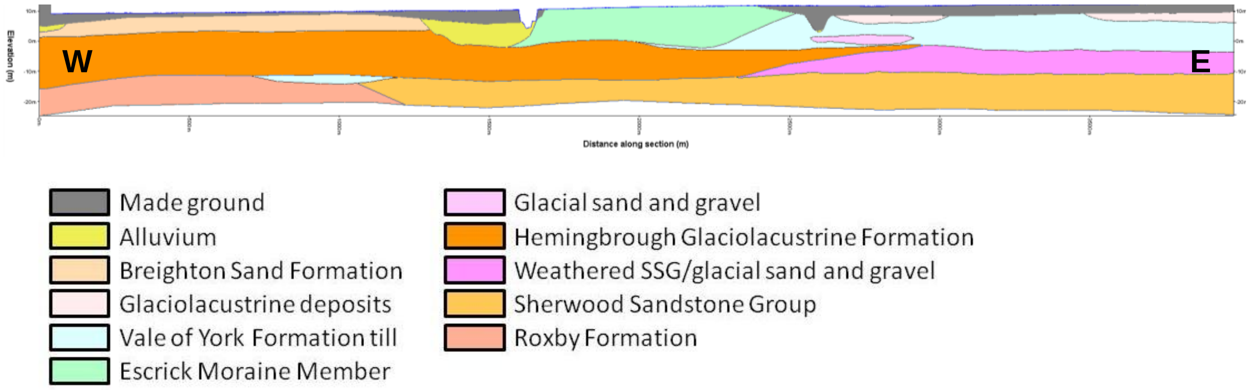

Figure 7. Cross-section along the centre of the alignment, showing the geometries of the Quaternary units

6 Artificially modified ground

Artificially modified ground is modelled according to the standard classification scheme on BGS maps. Four categories of artificially modified ground occur within the modelled area (Table 5). Areas where the ground surface has been artificially raised, such as railway embankments, are modelled as *made ground*. The LiDAR terrain model was assessed for the distribution of made ground within the modelled area, which proved to be more accurate than the 1:10,000 scale geological maps. Borehole logs that record made ground were used to provide thickness information and to identify areas of made ground that are not apparent in the LiDAR data or recorded on the BGS maps.

The route crosses areas of former opencast coal workings, particularly around Garforth. These backfilled opencast sites are modelled as *infilled ground*, where material has been removed and the site has subsequently been backfilled. The route crosses a small area of mapped *disturbed ground* on the western side of Garforth. This term is used for areas of shallow disused workings, such as bell pits. The survey geologist records the presence of ‘old shallow pits’ adjacent to the railway cutting at this locality. Areas of *worked ground*, where the ground surface has been artificially lowered through the removal of material, have not modelled as these are clearly visible in the Digital Terrain Model.

Table 5. Artificial ground units modelled

Unit code	**Unit name**	**Group**	**Age**	**Description**
WMGR-FILL	Infilled ground		Holocene	Backfilled workings/cuttings
MGR-FILL	Made ground		Holocene	Areas where the land surface has been raised. Variable composition and thickness
DDGR	Disturbed Ground		Holocene	Areas of disused shallow mineral workings, such as bell pits

7 Engineering geology descriptions

The engineering geological descriptions of the different lithostratigraphical units are summaries of borehole descriptions from civil engineering projects for bedrock in Table 6 and Quaternary deposits in Table 7. The bedrock descriptions include extra detail on weathered materials as identified in the boreholes and Lake et al. (1992). Some of the descriptions confirm to BS5930 of the time (BSI 1981, 1999) and its predecessor CP2001 (BSI, 1957). Although many of the more recent site investigations provide detailed descriptions that can be used in this project, many are not of sufficient quality. The older site investigations for major roads are often not suitable. Boreholes outside of the area were used to supplement the understanding of the weathering characteristics of the bedrock eastern part of the area where borehole coverage is poor.

Table 6. Engineering description of the bedrock units with additional notes on weathering

Lithostratigraphical unit		Engineering geology description	Weathered (soil)
Sherwood Sandstone Group		Generally very weak to moderately strong, orange, yellowish, brownish orange, orangish brown, yellow, sometimes gravelly SANDSTONE with a few mudstones and siltstones	Moderately dense to very dense fine to coarse SAND or gravelly SAND, gravel of sandstone. Depth of weathering to sand highly variable; can have sandstone above sand. In this area the upper weathered zone and glaciofluvial sand and gravels cannot be easily distinguished from borehole logs
Roxby Formation		Generally stiff to very stiff becoming extremely weak to weak, red brown occasionally grey green thinly to thickly bedded CLAY, MUDSTONE or SILTSTONE. Gypsum beds up to 7m thick are described in boreholes near Sherburn in Elmet	Stiff to very stiff red-brown CLAY sometimes described to the base of the formation, Alternatively description of stiff to 'hard'
Brotherton Formation		Weak to medium strong, sometimes strong, grey or light grey LIMESTONE	Brown sandy CLAY with many limestone fragments typically to 0.5 to 1.5m below ground level or below superficial deposits. Just above the Edlington Formation: stiff clay with limestone fragments occurs to about 4.0m, this may be partly head. Weathered material thins away from the Edlington Formation
Edlington Formation		Extremely weak to medium strong, red-brown MUDSTONE with subordinate siltstone and moderately weak to strong sandstone. Anydrite/gypsum occurs locally. SILTSTONE SANDSTONE	Stiff to very stiff red brown CLAY with some mudstone lithorelicts. Where gypsum dissolution has occurred softer clay might occur at depth beneath stiffer clay or mudstone
Cadeby Formation		Weak to medium strong occasionally strong, thinly to thickly bedded, light brownish yellow, fine to coarse dolomitic LIMESTONE. Nearer surface extremely weak to very weak, jointed, more likely to be more thinly bedded	Top 0.5 to 1.5m often completely weathered to calcareous clay with limestone sand and gravel or limestone sand and gravel. Or red brown, slightly gravelly silty SAND, Gravel is fine to coarse limestone
Pennine Lower Coal Measures Formation	Mudstone and siltstone	Very weak to medium strong, thinly to thickly bedded MUDSTONES and SILTSTONES. Weak to strong, thinly to thickly bedded, fine to medium	Mudstones and Siltstones: Firm to stiff, mottled clay or silt of low to high plasticity within 2 to 6m of the ground surface, possibly deeper in

PLCM-MDSS		grained, sometimes coarse grained SANDSTONE	fault zones. Clay matrix with mudstone clasts might occur to depths of 10 to 15m in fault zones. The thickness of the clay zone varies between and on mudstones and siltstones
	Sandstone (Not mapped separately)	Weak to strong, thinly to thickly bedded, fine to medium grained, sometimes coarse grained SANDSTONE	Loose to dense orange brown fine to medium or coarse SAND or extremely to very weak SANDSTONE. Interbedded SAND and SANDSTONE occurs. General depth of weathering between 1 and 3 m. Deeper in faults
Pennine Lower Coal Measures Formation PLCM-SDST and named sandstone units	Sandstone	Very weak to strong, occasionally very strong SANDSTONE	Loose to dense orange brown fine to medium or coarse SAND or extremely to very weak SANDSTONE. Interbedded SAND and SANDSTONE occurs. General depth of weathering between 1 and 3m. Deeper in faults

Notes Gypsum occurs within the Edlington and Roxby formations. Their presence is somewhat unpredictable due to dissolution. In the Edlington Formation the gypsum/anhydrite in this area does not form a persistent bed, whereas the Upper (Sherburn Anhydrite) of the Roxby Formation, is a 4 to 7m thick bed and has been identified in boreholes in the area. It was formerly mined at Sherburn in Elmet.

Table 7. Engineering descriptions of the superficial deposits.

Unit name	**Unit code**	**Description**
Alluvium	ALV-XCZ	**River Wharfe and the east**: Firm to stiff sandy CLAY or loose brown SAND becoming soft organic/peaty CLAY with occasional lenses of sand **Leeds river**: Very soft to soft, sometimes firm in the top metre or so, grey SILT or sandy CLAY, sometimes bottom 0.5m gravelly
Breighton Sand Formation	BREI-SZ	Loose to medium dense, brown, or light orange brown, or light grey and orange brown, CLAY, sometimes silt, sporadically interlaminated with fine reddish brown sand. in part fine to medium SAND with very clayey SAND or very sandy CLAY beds
Glacial lake sediments	GLLD-XCZ	Soft to firm or stiff, often thinly laminated grey-brown, or grey and brown CLAY or SILT, may contain layers of loose to medium dense brown medium SAND
Elvington Glaciolacustrine Formation	ELV-CZ	Soft to firm or stiff, often thinly laminated grey-brown, or grey and brown CLAY or SILT, might contain layers of loose to medium dense brown medium SAND
Escrick Moraine Member	ESKM-CSV	Stiff, firm to stiff, sometimes soft at surface, light brown or brown gravelly sandy clay to slightly gravelly CLAY with a little to much gravel and cobbles
Vale of York Formation	VYORK-SV	Medium dense to dense red brown silty or clayey SAND or gravelly SAND or sandy GRAVEL
Vale of York Formation	VYORK-CSV	Firm to stiff or very stiff, and sometimes soft at and near surface, sometimes indistinctly laminated, brown, reddish brown sometimes mottled grey, slightly gravelly or gravelly, slightly sandy or sandy CLAY with rare boulders
Hemingbrough Glaciolacustrine Formation	HEM-CZ	Soft to firm or stiff generally at or near surface, often laminated, medium grey brown or dark or light brown, clayey SILT or CLAY

Unit name	Unit code	Description
Older unnamed till unit	OUT-CSV	Gravelly sandy CLAY. Gravel is of limestone
Glacial sand and gravel	GFDMP-XSV	Loose to dense light brown or brown clayey SAND, SAND, gravelly SAND and sandy GRAVEL
Harrogate Till Formation	HRT-CSV	Firm to very stiff, light to dark brown, yellowish brown or grey brown sandy CLAY with some gravel and cobbles of sandstone and limestone and occasional limestone or sandstone boulders
Unnamed basal sand and gravel unit	GFOSS-SV	Loose to dense, brown or orange-brown fine or medium coarse SAND

8 Weathering profiles

8.1 REQUIREMENTS

As part of this project an extra surface was requested that represents a weathering description to inform potential foundation design and possible depth. Correlation lines were digitised where the principal material was described as an engineering soil that is clay, silt, sand or gravel, above the bedrock. This includes clay with coarser grained material, such as gravel, for instance, clay with mudstone gravel from the weathering of mudstone, clay with sandstone gravel from the weathering of mixed lithologies of the Pennine Lower Coal Measures Formation or clay with limestone gravel from the weathering of Cadeby and Brotherton formations. Sand and gravel where no superficial deposits are mapped are considered to be from the weathering of sandstone (Pennine Lower Coal Measures Formation or the Sherwood Sandstone Group.

After consideration of the borehole descriptions and their distribution two weathering guidelines were digitised. The upper line represents a shallow weathering guideline (W_Bedrock_T), and a lower line represents the deep weathering guideline (W_Bedrock_B). The different bedrock units have different weathering characteristics as indicated in Table 6. The unnamed sand and gravel deposit that might comprise fluvioglacial sand and gravel deposits and the weathered Sherwood Sandstone Group (GFOSS) falls above the upper weathering guideline.

8.2 IDENTIFICATION OF THE DEPTH OF WEATHERINGS

Identifying the base of materials that are principally soil as opposed to rock is relatively simple in most of the good quality borehole logs for civil engineering purposes. Rock-like materials in this area are limited to bedrock units. However, rock-like materials might occur in anthropogenic deposits, such as concrete or other man-made materials, are not considered for the purposes of the ‘weathering line’.

To aid the understanding of the depth to the base of engineering soil, the base of classified soil-like behaviour, as described in section 8.1, was extracted from borehole data used for this project. The bases of each of the soil-like materials and those boreholes that contain engineering rock were imported into a GIS and displayed. The depth to the base of the engineering soil was displayed in the GIS as a label. The two datasets were compared and those that did not contain engineering rock were ignored, as the borehole or trial pit did not encounter engineering rock. The depths, shown in the labels, were used as a guide to the depth of the base of soil and top of rock along the line of the sections. As there was little data in the eastern half of the project area further borehole data were extracted from the National Geotechnical Properties Database for the geographical squares SE33, SE43 and SE44. There were no data in SE34, SE53 and SE54. The advantage of this data was that it included tops and bases, as opposed to just bases in the project data. This allowed for the identification of the base of engineering soil but also the top of 'engineering rock' as defined for this project. The data were manipulated to provide top 'engineering rock' and base 'engineering soil'. These were added to the GIS as layer files.

Those data closest to the section lines were used in preference to those further away. As noted in Lake et al (1992), the depth of weathering is likely to be deeper in fault zones, most notably in the mudstone and siltstones of the Pennine Lower Coal Measures. It is assumed that this information in primarily based on the descriptions of sections and not boreholes, as boreholes are unlikely to intercept faults, particularly if they are narrow structures. However, those boreholes nearest or that might be on faults were used as guides. Some of the data in this dataset were ignored, that is those identified as 'Drift' over 'Rock' as this data was used to identify the geological rockhead and does not take into consideration weathering and the alteration of bedrock to an engineering soil.

8.3 DATA INTERPRETATION

The 'weathering guidelines' produced are judgements using the available data and information. Changes in the depth of weathering might be related not only to lithology and faulting, but also to place in the landscape (i.e. top of slope, mid slope or base of slope) and other local factors. The bedrock might also be weathered to different depths beneath different superficial deposits, such as at the edge of lower permeability superficial deposits where there might be greater water flow increasing local weathering of the dolomitic limestones of the Cadeby and Brotherton formations. The upper part of the Roxby Formation contains anhydrite or gypsum beds, and these beds might have been removed by dissolution leaving a collapse breccia, which might be of clay or mudstone. These factors have to be taken into consideration. As with the 3D geological model, data is sparse in some areas and there is little data to assess depth of weathering to an engineering soil near the line beneath the thick superficial deposits in the east of the model. Here, the weathering line has been informed by other data not included or considered in the 3D modelling and were extracted from the National Geotechnical Properties Database for geographical area SE43.

Some boreholes in the dataset were drilled for mineral or hydrogeological purposes and the drilling methods and descriptions might not be suitable or relevant. If these boreholes are considered to be important they are checked against others in a similar geological and geographical setting.

The modelled upper and lower weathering guidelines within the Pennine Lower Coal Measures Formation (PLCM-MDSS) are generally more widely spaced than in other parts of the model as the different rock types present, mudstone, siltstone and sandstone, have different weathering characteristics and tend to weather to different depths.

8.4 WEATHERING MODELLING CONSTRAINTS

There are a number of constraints on the weathering model as listed below;

- Lack of borehole information in some areas, most notably in the centre and east of the area, particularly at depth
- Quality of information: poor borehole descriptions make interpretation of the soil/rock interface difficult, ambiguous or impossible. These boreholes were not described to a suitable standard.
- Possible effects of drilling disturbance when using inappropriate drilling methods may affect some descriptions
- The variability of weathering of different materials classed together e.g. PLCM-MDSS, or the effects of possible dissolution of anhydrite/gypsum in the Roxby Formation
- Potential removal of weathered materials, particularly beneath anthropogenic deposits

9 Weathering profile

The weathering profile is an interpreted line using constructed in the three longitudinal sections. Each surface was generated from the calculated geological unit and then output as a GoCad Tsurf. As with all other geological units, the resulting surface is an interpretation and not a precise boundary between physical properties.

10 Karst features

The BGS karst database and corresponding GIS layer records a cluster of sink holes in the Church Fenton area, which are displayed in Figure 8. These sink holes and related subsidence are associated with the dissolution of three named anhydrite units: Hayton Anhydrite (0-30m thick) at the base of the Edlington Formation, Sherburn Anhydrite (3-8m thick) within the Roxby Formation, and Billingham Anhydrite (3-7m thick) at the base of the Roxby Formation. An assessment of these sink holes by Thompson et al (1996) concluded that the susceptibility of future subsidence is relatively low, but cannot be ruled out (Cooper, 2015). Gypsum, ranging from 1.5 to 5.1m in thickness, is recorded in the Roxby Formation in three boreholes located between c. 700 and 1km east of the modelled area (borehole IDs: 118062, 118059 and 118060).

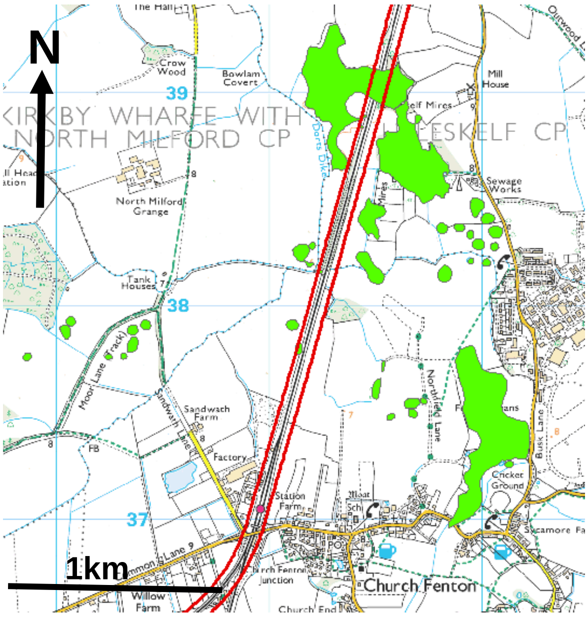

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Figure 8. Dolines recorded in the BGS karst database/GIS at Church Fenton

11 Distribution of Coal Workings

Several BGS boreholes used to construct the model record voids in the shallow subsurface. All of these boreholes are located in the Austhorpe area, and four fall within the modelled area. These boreholes are listed in Appendix 2 and are shown alongside the map of quarrying and shallow mining map in the Leeds planning and development report (Lake et al, 1992). As can be seen in Figure 9, these boreholes are located in areas of known or inferred workings.

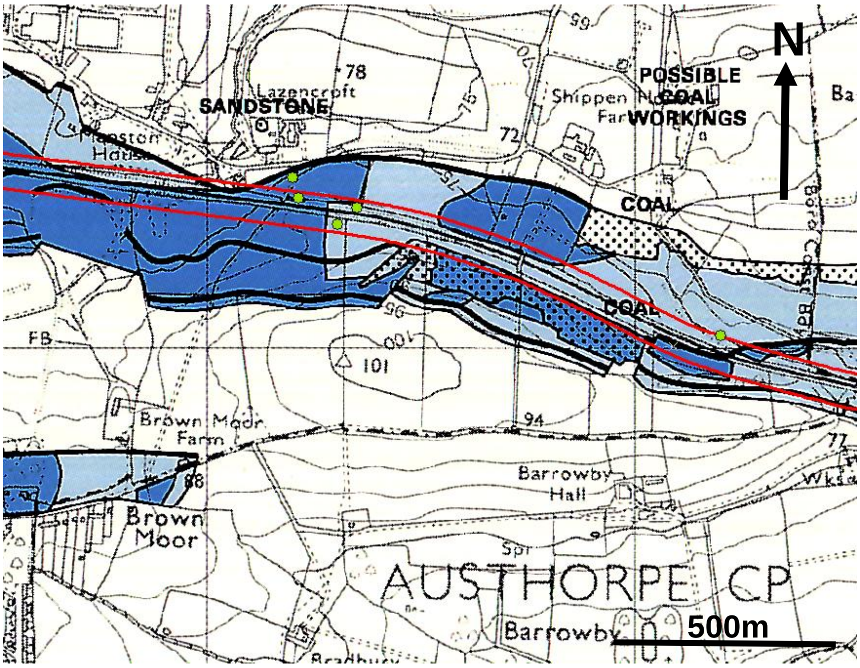

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Figure 9. Plot of borehole logs (green) recording voids in the shallow subsurface. These correspond with areas of known (dark blue) and inferred (light blue) coal workings in the Leeds planning and development report (Lake et al, 1992)

12 Model QA

All cross-sections that include Coal Measures were checked by Colin Waters at key stages during the construction of the model. The Quaternary in the Modules 7-9 was checked by Holger Kessler.

The weathering information provided in this report was compiled by an engineering geologist, Dave Entwisle, who assessed the cross-sections and boreholes data used and added a line to the parallel cross-sections to represent the base of the weathered zone. These lines were used to generate a surface.

The model calculation was checked by examining to calculated surfaces in the cross-sections in the 3D modelling software. Extra nodes were added where needed to improve the calculation of the model.

13 Confidence

Confidence in the model is primarily constrained at the ground surface by observed sections noted on the geological maps and field slips. Confidence is also influenced by the number and spread of borehole logs available, the level of detail recorded in them and the complexity of the geology. The Leeds-York CGM uses 102 boreholes, 47 of which are located in the western third part of the model. The Pennine Coal Measures Group are the most geologically complex part of the model, where the units are thin and highly faulted. Although numerous boreholes constrain the Coal Measures, the geology is inferred where gaps occur in the borehole data.

Wherever possible the borehole start heights have been honoured during cross-section correlation. However, where a borehole start height is anomalous in comparison to adjacent boreholes, it has been rendered to the digital terrain model. Borehole data has been honoured in preference to the geological maps where discrepancies occur. For example, the geological map has Cadeby Formation mapped in a railway cutting at Micklefield, where the railway runs beneath the A1(M) (Figure 10).

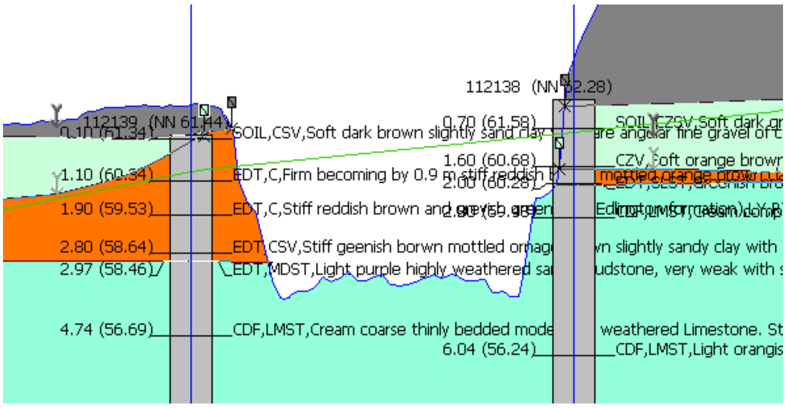

Figure 10 Cross-section Tata_Leeds_York_HBU_Rung_10. Cadeby Formation is mapped on both sides of the railway cutting at Micklefield, but the boreholes record Edlington Formation. The boreholes were honoured in the model

Faults that are recorded on the geological map have been modelled with a dip direction of the fault plane of 70 degrees, unless evidence proved otherwise. It is likely that the Coal Measures are offset by more faults than those displayed on the geological maps. However, only mapped faults are shown in the model.

Coal Authority records were considered to ascertain the dip direction and magnitude of both coal seams and geological faults in the Coal Measures in Modules 1-4. As a rule, subsurface faults not mapped at the ground surface are assumed to only affect the Coal Measures. For example, two underground faults displayed on 1:10,000 scale map sheet SE43SW are modelled up to the base of the Cadeby Formation. Several additional subsurface faults have been inferred in this area, one of which has been projected through the Cadeby Formation up to the base of alluvium where the railway crosses Newthorpe Beck, as the Cadeby Formation thickens to the east (Figure 11).

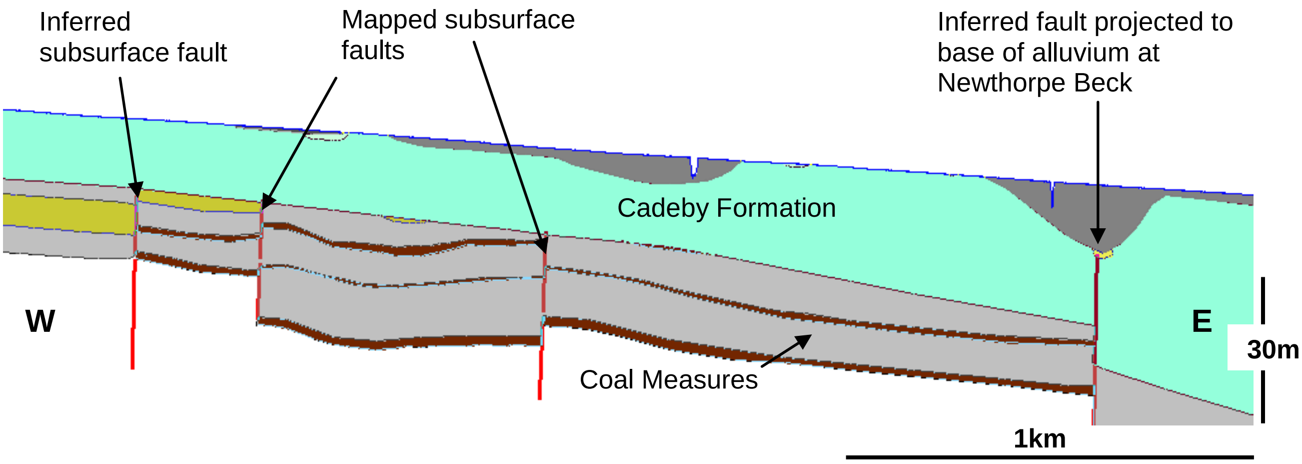

Figure 11. Cross-section Leeds_York_HBU_Track showing subsurface faults that affect the Coal Measures, one of which has been projected through the Cadeby Formation to the base of alluvium at Newthorpe Beck

Only the coal seams and sandstone units picked out on the geological maps have been modelled. Additional thin sandstone bands and coal seams are recorded in the boreholes, but these have not been modelled as separate units and are therefore included with the background mudstones, siltstones and sandstones.

14 Recommendations

Additional borehole data belonging to Tata Steel Projects would have improved the accuracy of the model, particularly where BGS borehole data is sparse. In order to increase efficiency for future 3D modelling contracts commissioned by Tata Steel Projects, it would be useful if all available borehole data could be provided at the costing up stage, ideally in digital AGS format, so that these boreholes can be assessed at the very beginning.

During a progress meeting at BGS the client highlighted specific issues along the route, such as embankment failures. It would be useful for BGS to know in advance where such areas of interest are in order to concentrate the modelling effort.

The use of use of Coal Authority data in the 3D modelling process needs investigating and whether Tata Steel Projects or Network Rail already has a licence to use their data.

The model can be updated as new information becomes available. This could be additional borehole logs or geophysical data, for example. Additional attributes can also be applied to the model as required, such as engineering properties.

The 3D vector data supplied does not cover the full width of the LiDAR DTM supplied and could therefore not be used as a capping surface to the model (Figure 12).

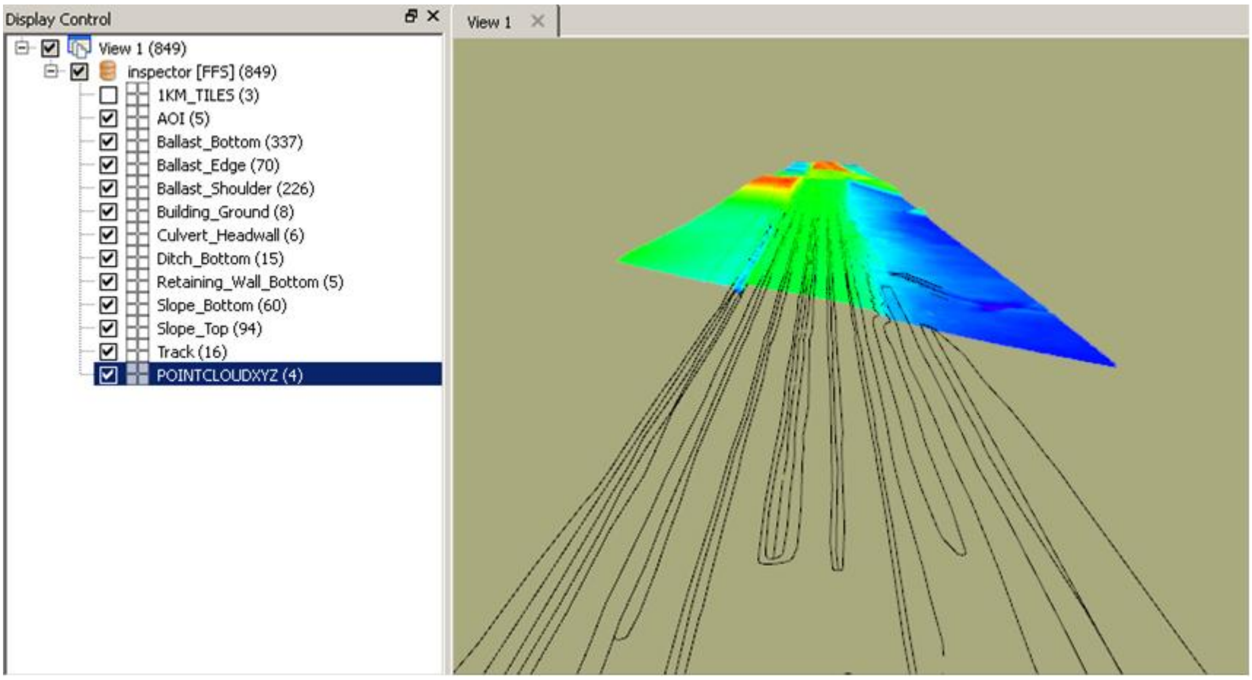

Figure 12. 3D vector data displayed as lines, with the LiDAR DTM shows as a blue to red colour ramped surface

15 Model Delivery

The model is delivered in segments according to track MOD numbers 1-9, as referenced in the data supplied to BGS. The delivery files comprise Adobe 3D pdf format for visualisation and Bentley Microstation V8 DGN files for faults, shells, weathering surface and cross-sections along the centre of the alignment. It is recommended that the Master files are opened first, e.g. Master_MOD4.dgn.

Appendix 1

List of all 102 BGS boreholes used to constrain the model. Scans of non-confidential logs are available from the BGS web site at: http://mapapps.bgs.ac.uk/boreholescans_mobile/MobileBoreholeScans.html#/boreholescans_mobile/MobileBoreholeScans.html&ui-state=dialog

Borehole ID	Easting	Northing	Start Height	Confidential
91736	436807	434518	73.60	N
91737	436812	434488	75.32	N
91738	438401	434329	79.61	N
91742	438600	434300	78.21	N
91817	438112	434400	71.57	N
91818	438200	434400	73.91	N
91819	438300	434342	78.64	N
91844	438134	434492	71.28	N
91847	438172	434381	73.99	N
91848	438242	434356	77.61	N
91849	438269	434358	77.94	N
91851	438214	434352	76.84	N
92002	436182	434438	71.27	N
92003	436200	434403	71.65	N
92004	436228	434452	73.43	N
92006	436314	434480	74.72	N
92007	436242	434419	71.66	N
92009	436315	434438	70.95	N
92010	436346	434470	73.43	N
92011	436379	434451	68.11	N
92153	438330	434300	79.52	N
92250	438302	434340	78.64	N
92278	438250	434209	81.51	N
92279	438304	434292	80.15	N
92280	438286	434296	79.88	N
92281	438328	434290	80.10	N
92282	438349	434330	79.15	N
92360	435099	434176	59.78	N
92361	435105	434204	59.62	N
92362	435134	434231	61.30	N
92363	435236	434239	63.93	N
92366	435426	434275	68.86	N
92383	435814	434197	74.94	N
92404	435764	434284	71.72	N
92414	436780	434441	77.25	N
92415	436805	434488	75.69	N
94731	436220	434470	75.26	N
94733	436310	434500	74.99	N
94734	436240	434430	67.33	N
94736	436320	434450	66.55	N
94737	436350	434490	74.30	N

94755	439097	434006	76.80	N
94756	439131	434040	74.80	N
94758	439198	434032	71.50	N
94826	439087	434006	76.18	N
94827	439182	434022	75.03	N
95819	432504	432829	39.72	N
96731	433621	433769	51.18	N
96746	433497	433401	45.51	N
96748	433387	433236	45.26	N
96750	433276	433109	44.81	N
97426	433985	433970	44.27	N
97428	433983	434030	44.54	N
97429	434010	433990	43.27	N
111434	448400	435074	23.99	Y
111628	446339	433198	57.48	N
111629	445485	432607	39.60	N
111660	447625	434285	50.56	Y
111700	445900	432750	46.43	N
111778	449110	434940	13.90	N
111779	447390	433760	29.24	N
111816	444220	432140	77.35	N
111817	443440	432220	76.62	N
111889	444380	432670	55.87	N
112020	440430	433740	73.23	N
112021	440410	433740	72.73	N
112058	443180	432820	70.88	N
112138	444782	432674	62.28	N
112139	444783	432719	61.44	N
112292	440800	433580	76.93	N
112314	443930	432720	63.16	N
112320	443830	432730	63.86	N
112321	443730	432730	64.69	N
112325	443630	432700	69.59	N
112327	443530	432740	67.20	N
112390	440920	433460	77.08	Y
112391	440940	433460	77.23	Y
112392	440950	433460	77.25	Y
112393	440920	433470	77.16	Y
112394	440930	433480	77.25	Y
112404	443850	432700	64.73	N
118031	452520	439850	9.75	N
118038	451379	436742	9.09	N
118059	451293	436170	8.26	Y
118060	451360	435869	7.98	Y
118071	452010	439183	9.40	N
118094	450629	438606	8.10	Y
118095	451196	439608	9.14	Y
118098	452100	438800	9.00	N
118961	453288	441051	9.91	N

118963	454693	444965	11.64	N
118968	451725	440019	9.58	Y
118986	454330	443250	13.05	N
118988	454620	443940	12.90	N
15622740	441550	433090	77.06	Y
15622741	441520	433100	77.72	Y
15630590	448280	434930	26.60	Y
18016847	433447	433535	44.75	Y
18016896	433513	433621	47.60	Y
18761124	436190	434390	72.41	N
18900773	444018	432700	63.09	Y
18900774	444020	432761	61.60	Y

Appendix 2

List of boreholes recoding voids and shallow coal workings

Borehole ID	Easting	Northing	Depth (m)	Confidential	
91754	439000	434101	15.5-16	N	VOID
91851	438214	434352	9.5-10	N	VOID
92279	438304	434292	18.6-19.7	N	VOID
92282	438349	434330	8.05-8.75 and 10.2-10.5	N	VOID
98308	430744	433630	4.5-4.8	N	VOID
94758	439198	434032	16.3-19.5	N	VOID
91818	438200	434400	1.4-2.8	N	Possible backfilled workings (clay)

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