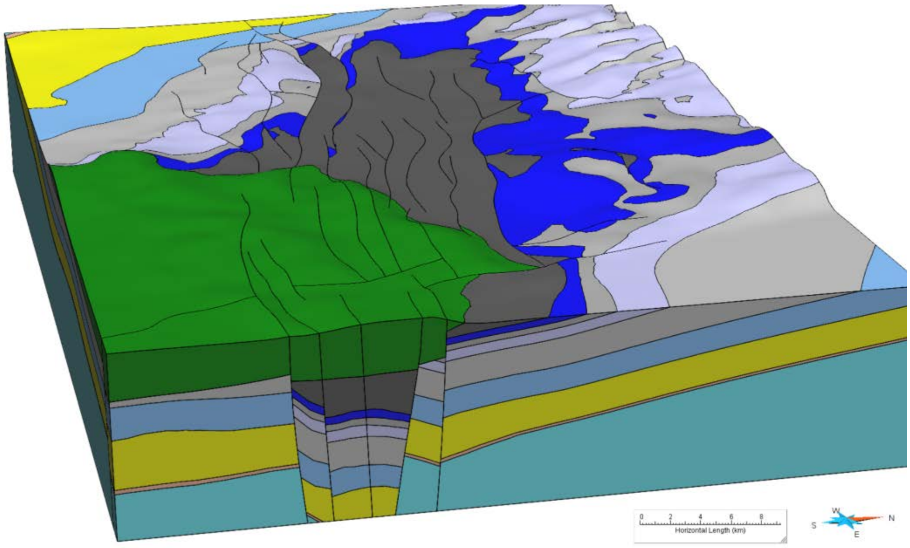
OR/15/068

British Geological Survey
NATURAL ENVIRONMENT RESEARCH COUNCIL

A preliminary 3D model of post-Permian bedrock geology in the Vale of Pickering, North Yorkshire, UK

Groundwater Programme

Open Report OR/15/068



BRITISH GEOLOGICAL SURVEY

GROUNDWATER PROGRAMME

OPEN REPORT OR/15/068

A preliminary 3D model of post-Permian bedrock geology in the Vale of Pickering, North Yorkshire, UK

Andrew J. Newell, Robert S. Ward & Mark W. Fellgett

Contributor/editor

J F Ford

Keywords

Vale of Pickering, bedrock geology, structure

Front cover

Bedrock geological model of the Vale of Pickering

Bibliographical reference

ANDREW J. Newell, Robert S, Ward & Mark W. Fellgett. 2016. A preliminary 3D model of post-Permian bedrock geology in the Vale of Pickering, North Yorkshire, UK. *British Geological Survey Open Report*, OR/15/068. 23pp.

Keyworth, Nottingham British Geological Survey 2016

BRITISH GEOLOGICAL SURVEY

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

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

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

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

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

British Geological Survey offices

BGS Central Enquiries Desk

Tel 0115 936 3143 Fax 0115 936 3276
email enquiries@bgs.ac.uk

Environmental Science Centre, Keyworth, Nottingham NG12 5GG

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

Murchison House, West Mains Road, Edinburgh EH9 3LA

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

Natural History Museum, Cromwell Road, London SW7 5BD

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

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

Tel 029 2052 1962 Fax 029 2052 1963

Maclean Building, Crowmarsh Gifford, Wallingford OX10 8BB

Tel 01491 838800 Fax 01491 692345

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

Tel 028 9038 8462 Fax 028 9038 8461

www.bgs.ac.uk/gsni/

Parent Body

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

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

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

Contents

FIGURES

TABLES

Foreword

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

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

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

1 Introduction

1.1 GEOGRAPHICAL AND STRATIGRAPHICAL LIMITS OF THE MODEL

This report summarises the location, input data and methods that were used in the construction of a three-dimensional (3D) geological model of the Vale of Pickering, North Yorkshire, England. The geological modelling was undertaken in 10 days, with the bulk of this time being used in the compilation and organisation of input data. The model and any geological conclusions based upon it should therefore be regarded as preliminary and liable to change as additional work is undertaken and the model is refined or expanded geographically or stratigraphically.

The geographical extent of the geological model is covered by a rectangle approximately 70x40 km centred on the Vale of Pickering and covering an area of 2701 km^2 (Figure 1). The boundaries of the area were set to maximise the quantity of well data (see Figure 8) around the Vale of Pickering. Throughout the report the area indicated by the blue rectangle in Figure 1 is referenced as the Vale of Pickering (VoP) area.

The geological units included in the model only include bedrock formations and groups above the Permian Zechstein Salt. Superficial deposits or Permian and Carboniferous and older strata below the top of the Zechstein were not included. Information on the superficial geology of the Vale of Pickering can be found in Ford et al. (2015).

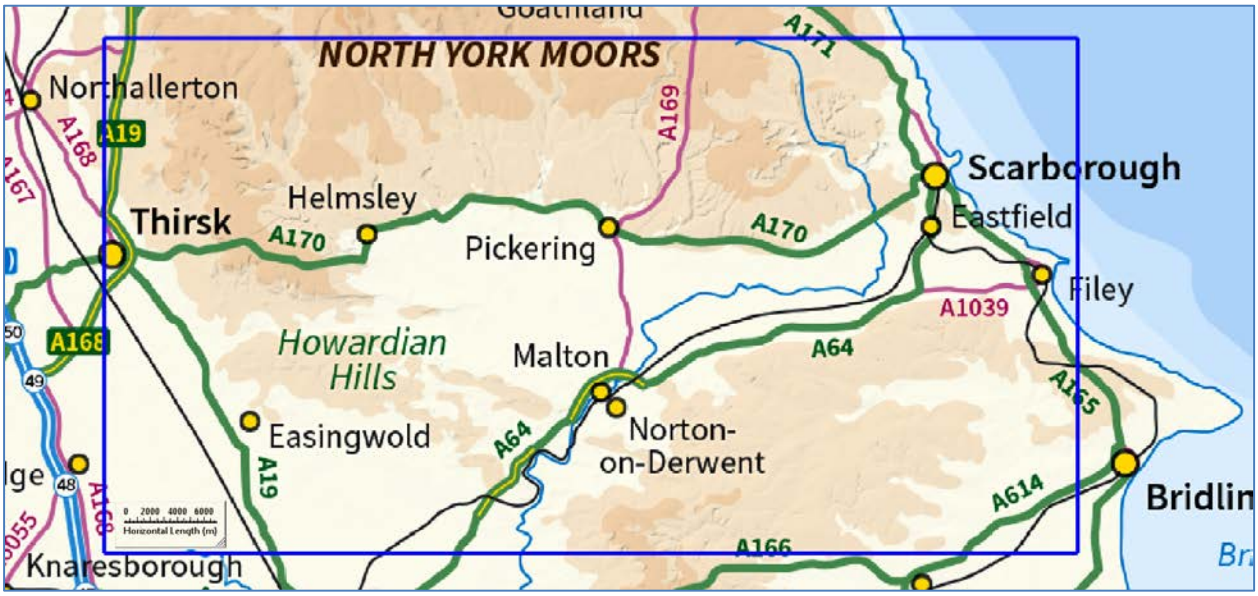


Figure 1 Boundary of the model shown by blue rectangle

1.2 TOPOGRAPHY, QUATERNARY EVOLUTION AND DRAINAGE

The elevation of the VoP area ranges from 0-420 mAOD, although the Vale of Pickering itself is an area of low relief that mostly lies at an elevation of 15-35 mAOD (Figure 2). This low-lying basin is bounded to the north by the North York Moors and to the south by the Howardian Hills and the chalk downlands of the Yorkshire Wolds. The fault-controlled Coxwold-Gilling Gap forms a conspicuous topographic break in the western part of the Vale of Pickering (Figure 2). A low topographic sill formed from Quaternary glacial deposits separates the Vale of Pickering from the North Sea (Figure 3).

The Vale is drained by the River Derwent and its tributaries which exit through the incised Kirkham Gorge between the Howardian Hills and the Yorkshire Wolds (Figure 2). This drainage system results from Quaternary glacial events that are well documented elsewhere (Ford et al., 2015; Foster, 1985) and are not covered in detail by this report. In summary, the pre-glaciation course of rivers draining the Vale of Pickering was through the Coxwold-Gilling Gap and along the west-east axis of the valley. This was disrupted by North Sea ice-sheets and their deposits which blocked the river exit into the North Sea (Figure 3) and transformed the Vale of Pickering into the site of a glacially-dammed lake (Lake Pickering). Blockage of the Coxwold-Gill Gap by ice sheets in the Vale of York forced the river to cut a new exit through the Kirkham Gorge. Inflows to the glacial lake included rivers diverted southward across the North York Moors which deposited deltaic sands and gravels where they entered the lake, most notably at Pickering (Figure 3).

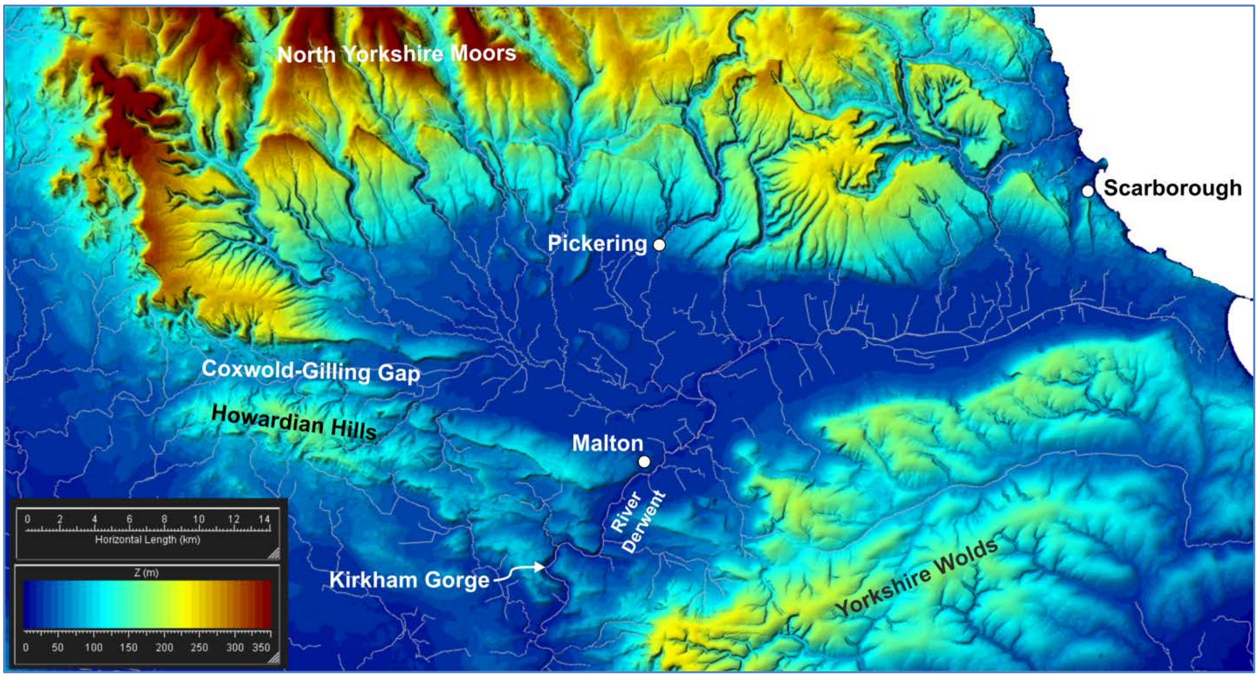


Figure 2 Topography and drainage of the Vale of Pickering. Terrain model based on Ordnance Survey OSTerrain50 (OpenData).

Prior to river diversion through the Kirkham Gorge, the Vale of Pickering was deepened by rivers adjusting to lowered base levels during Quaternary sea-level lowstands. The depth of scouring generally increases from west to east, with rockhead lying at around sea-level across much of the Vale of Pickering and exceptionally at -30 mOD at the coast (Foster, 1985). The scoured valley was subsequently infilled with glacial till, fluvial sand and gravel, and lacustrine silt and lacustrine clay.

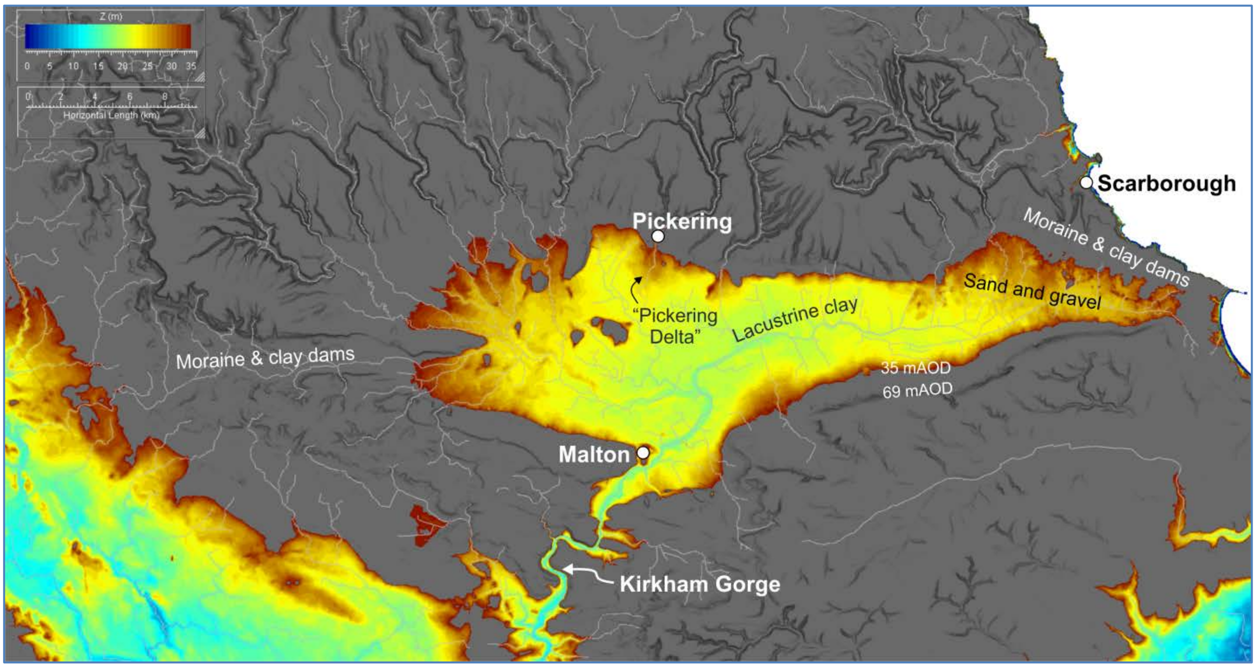


Figure 3 Terrain model (OSTerrain50) with the colour ramp clipped to elevations between 0-35 m. All elevations greater than 35 m are shown as grey. The area highlighted by the colour ramp broadly approximates to the area of the glacial Lake Pickering, although at maximum this may have reached an elevation of 69 mAOD (Foster, 1985). The clipped colour ramp clearly shows the topographic sill formed from glacial till along the North Sea coast, the sands and gravels of the Pickering delta and the flat low relief central part of the Vale of Pickering that is underlain by lacustrine clay.

1.3 SURFACE BEDROCK GEOLOGY AND TOPOGRAPHY

The VoP area exposes bedrock formations that range from the Triassic Sherwood Sandstone Group to the Cretaceous Chalk (Figure 4).

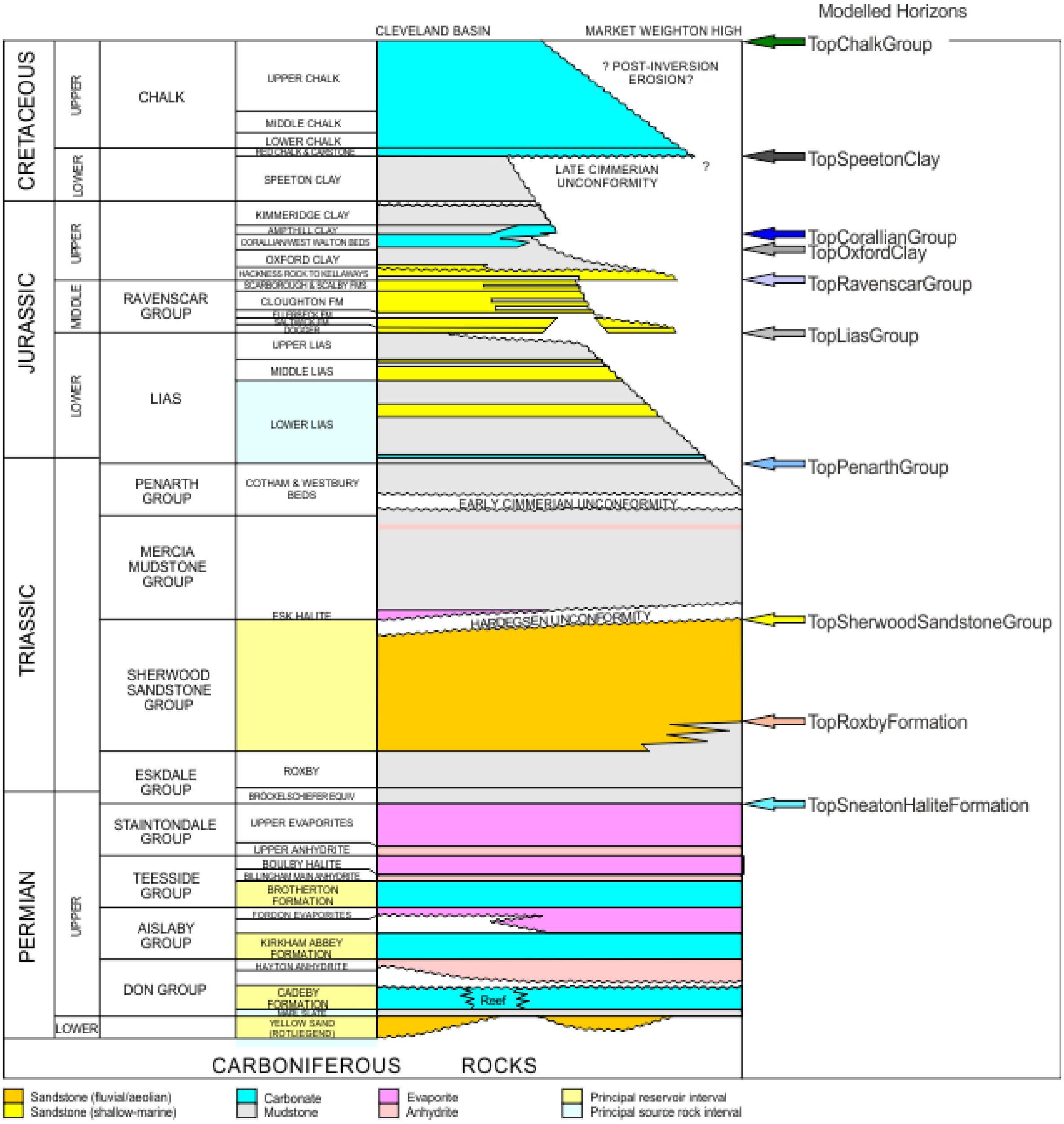


Figure 4 Chronostratigraphy and lithostratigraphy of Permian to Cretaceous bedrock units in Yorkshire (DECC, 2013) with arrows showing the ten horizons that have been included in the geological model.

The Triassic formations of the Sherwood Sandstone, Mercia Mudstone and Penarth groups and the Jurassic Lias Group underlie the low-relief terrain of the Vale of York in the southwest part of the VoP area. Here they form outcrop belts with a NW-SE strike which are disrupted by the numerous cross-cutting faults of the Howardian Hills Fault Belt (Figure 5) (Kent, 1980). Marine mudstones of the Lias Group also floor the bottom of deep valleys on the southern flank of the North York Moors (Figure 5).

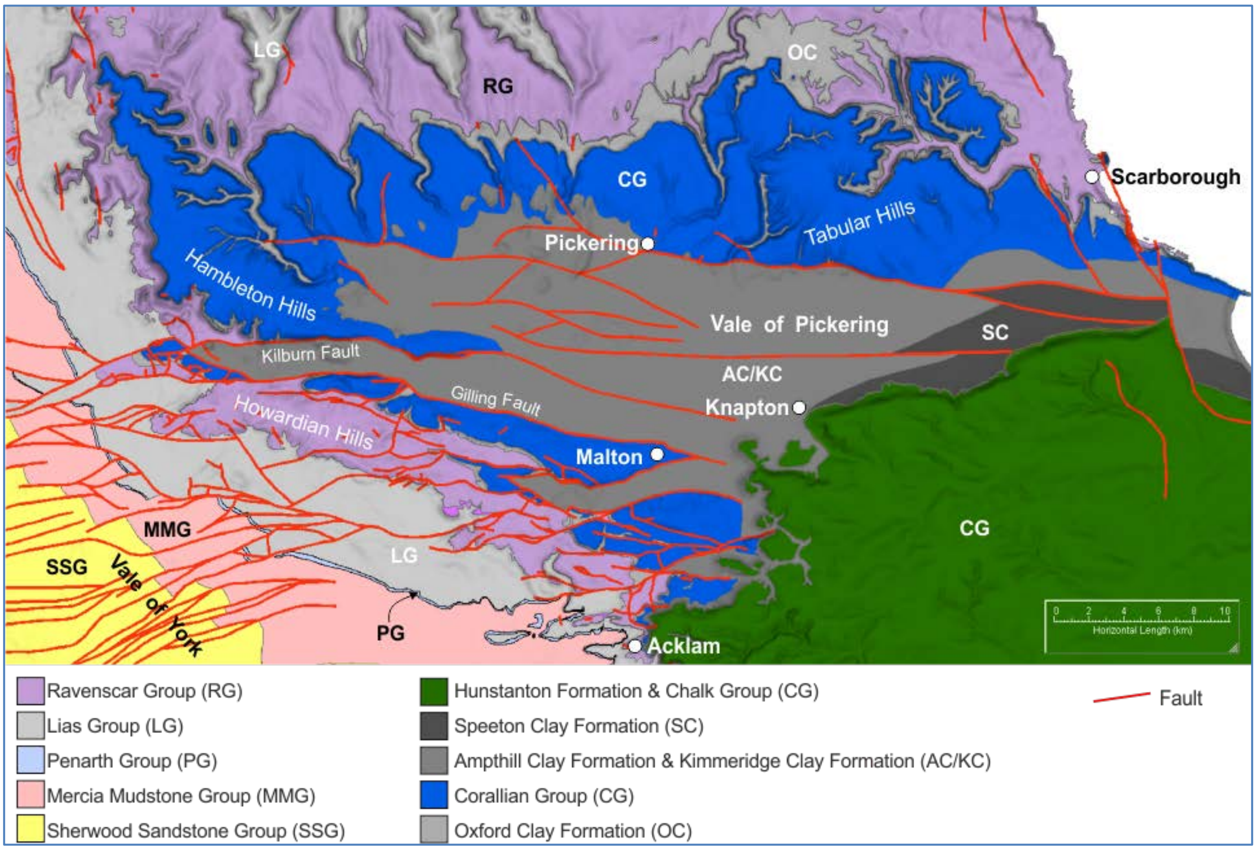


Figure 5 Outcrop bedrock geology of the VoP. Map based on BGS DiGMapGB-50 simplified by dissolving most units into their lithostratigraphical groups.

The Jurassic Ravenscar Group and overlying Osgodby Formation are made from sandstones, mudstones and thin limestones (see Powell (2010) for a detailed description) which rise above the Vale of York to form the Howardian Hills and they also have an extensive outcrop along the southern flanks of the North York Moors (Figure 5). Above the intervening Oxford Clay Formation, the limestones of the Corallian Group have a major impact on the topography of the region, in particular by forming the Tabular Hills which flank the North York Moors (Figure 6). The Tabular Hills have a steep scarp slope to the north and a gentle southward inclined dip slope formed from the southerly tilted limestone units (Figure 6). The Lockton Anticline cause local reversal of the structural dip on the eastern part of the Tabular Hills (Figure 6). The dip of the Corallian Groups swings toward the east in the Hambleton Hills, which form the western boundary of the Vale of Pickering, and then toward the north along the northern flank of the Howardian Hills. Here the northward trajectory of the Corallian limestones under the Vale of Pickering is offset by the Gilling Fault, which together with the opposing Kilburn Fault, downthrow a linear block of Ampthill Clay and Kimmeridge Clay into the graben-like structure of the Coxwold-Gilling Gap (Figure 6). To the east of the Coxwold-Gilling gap the area of Ampthill Clay and Kimmeridge Clay expands to occupy much of the floor of the Vale of Pickering before narrowing to the east of Malton toward the North Sea. A wedge of Speeton Clay occurs on the floor of the Vale of Pickering to the east of Knapton. To the south of Knapton, across the Gilling Fault, the Speeton Clay rapidly thins and disappears onto the Market Weighton High (Jeans, 1973; Underwood and Mitchell, 1999). A comparable thinning and disappearance of Jurassic strata (down to the level of the Lower Lias) onto the Market Weighton High occurs slightly further south around Acklam (Kent, 1955) on the southern boundary of the VoP model area (Figure 5). East of Acklam, the southern limits of the Corallian, Ravenscar and other Jurassic units are concealed beneath the Hunstanton Formation and Chalk Group which crop as a near continuous block in the southeast part of the VoP model area. The boundary of the

Chalk of the Yorkshire Wolds with the Vale of Pickering is marked by an abrupt and steep escarpment (Figure 6).

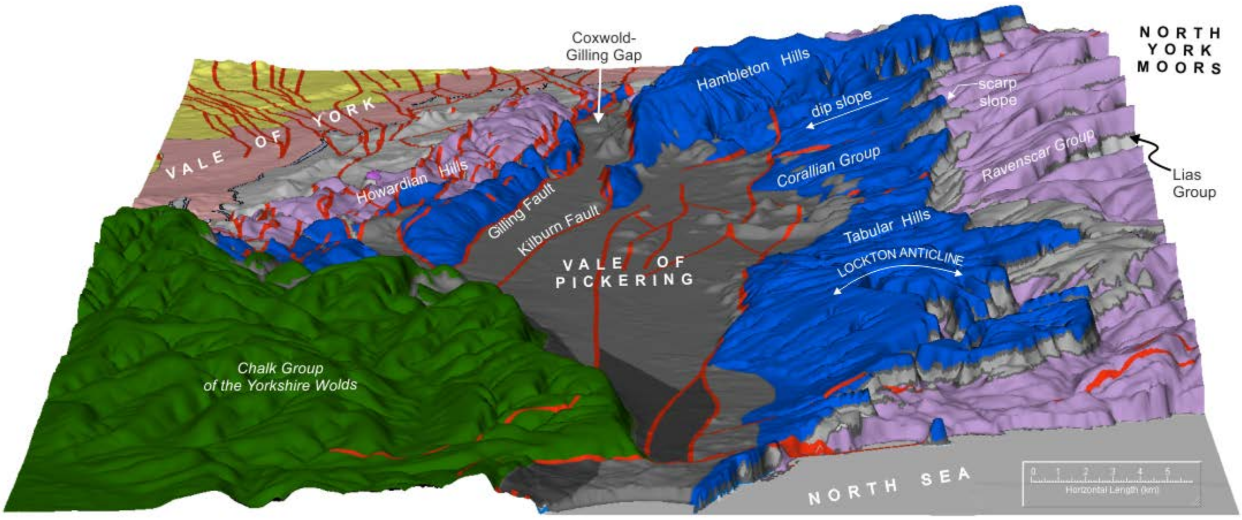


Figure 6 Perspective view across the western end of the Vale of Pickering from the NW. See Figure 5 for key to colours of geological units. Note the prominent step in the topography formed by the limestones of the Corallian Group shown in blue.

2 Development of a Subsurface Geological model

2.1 SOFTWARE AND OVERVIEW OF METHOD

The model was produced using Paradigm® SKUA-GOCAD™ 15.5 which provides a unified environment for well analysis, cross-section construction and 3D geological modelling (Paradigm, 2015). The modelling followed conventional methods starting with the analysis of individual wells and the identification of stratigraphic markers, followed by the construction of well-sections and cross-sections to check stratigraphic correlations and build structural constraints for the modelling process. The area is intensely faulted and structural control for the model was provided by the subsurface structure maps of Kirby et al. (1985) who undertook a detailed geological analysis of the Vale of Pickering and surrounding area using boreholes and seismic interpretation. No new seismic interpretation was undertaken as part of this work.

2.2 MODELLED HORIZONS AND CONFIGURATION OF THE STRATIGRAPHIC COLUMN

Ten horizons were modelled with the base horizon located at the top of the Permian Zechstein Salt (Top Sneaton Halite Formation). Figure 7 shows the configuration of the SKUA-GOCAD stratigraphic column used in the modelling process. All horizons are modelled as conformable with the exception of Top Speeton Clay and Top Chalk.

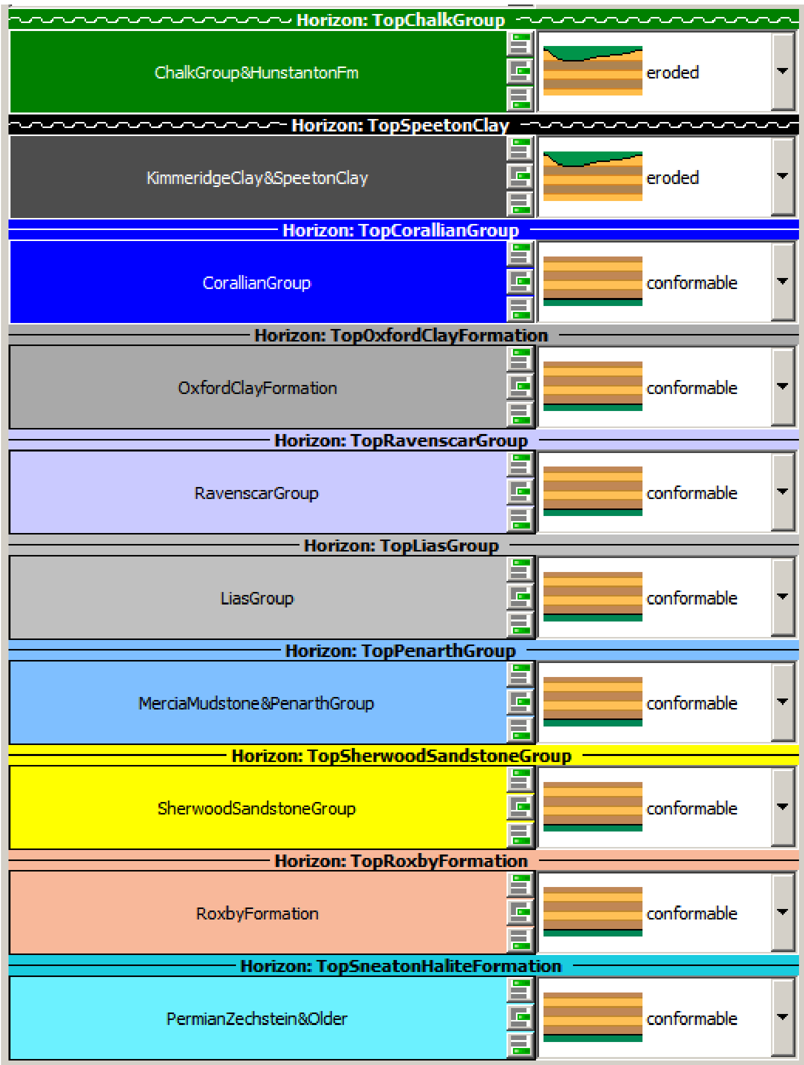


Figure 7 Configuration of the SKUA-GOCAD stratigraphic column used in the modelling showing modelled horizons, geological units and stratigraphic contacts.

2.3 MODEL INPUT DATA

2.3.1 Well data

The Vale of Pickering has a long history of hydrocarbon exploration (DECC, 2013; Kirby et al., 1985) which provides a substantial number of deep wells, most of which have borehole geophysical logs, descriptions of cutting returns and interpreted well stratigraphy. Fifty wells were used in the construction of the geological model, Figure 8 shows their distribution relative to geological units at crop and Table 1 lists the wells used in the study. This list by no means represents every potentially useful borehole in the area. In the construction of the model wells were considered to be vertical if the hole deviation did not exceed 10 degrees from vertical at any point. For the wells where the hole deviation was greater than 10 degrees the gyroscopic deviation surveys were taken from the end of well reports. Where there was no deviation information available the wells are considered to be vertical. The digital geophysical logs used to define the stratigraphic horizons in the model are stored in Landmark Recall software, the minimum requirement for the geophysical logs from a well to be incorporated into the model was a Gamma Ray curve.

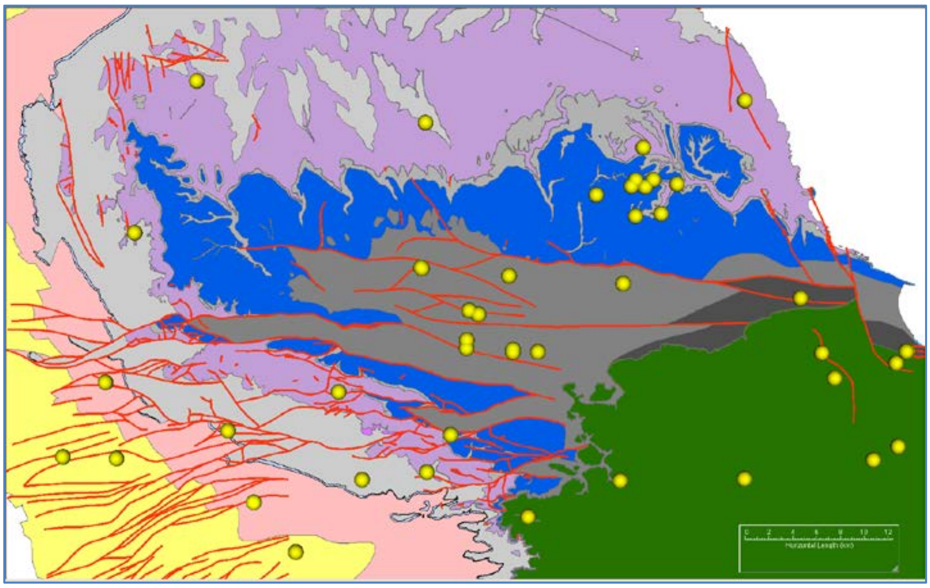


Figure 8 Distribution of wells (yellow spheres) used in the geological model. See Figure 7 for key to geological units.

SOBI	X	Y	START HEIGHT	LENGTH	NAME	BGS ID
SE46NE7	446824	466891	19.2	929.6	THOLTHORPE 1	114101
SE46NW7	442340	467030	18.3	1096.7	ELLENTHORPE 1	114169
SE47SE26	445902	473250	29.0	1676.0	SESSAY 1	114731
SE48NE2	448350	485760	186.9	299.2	FELIXKIRK	114793
SE56NE7	456158	469212	49.1	1379.8	CRAYKE 1	119734
SE56SE10	458308	463229	20.4	1109.3	WOODHOUSE	119800
SE59NW1	453540	498440	389.8	1915.1	CLEVELAND HILLS 1	119943
SE65NW23	461824	459071	13.2	1198.0	TOWTHORPE	123204
SE66NE8	467366	465119	62.5	1159.8	THORNTON-LE-CLAY 1	124205
SE67SE7	465409	472457	110.6	1831.9	WHENBY 1	124355
SE76NW14	474782	468872	52.1	2743.2	HIGH HUTTON 1	125667
SE76NW8	472780	465760	73.5	2008.3	WHITWELL ON THE HILL 1	125660
SE77NE13	479982	475778	27.9	1935.5	MALTON 1	125945
SE77NE14	476100	476100	27.9	1590.7	MALTON 2	125946
SE77NE15	479990	475992	21.5	1721.8	MALTON 3	125947
SE77NE16	476127	476797	25.6	2072.0	MALTON 4	125948
SE77NE17	477105	478933	36.0	3421.0	KIRBY MISPERTON 1	125949
SE77NE18	476331	479261	28.4	1761.7	KIRBY MISPERTON 2	125950
SE77NE19	477108	478943	35.2	1837.0	KIRBY MISPERTON 3	125951
SE78SE14	479658	482158	32.6	2046.4	PICKERING 1	126173
SE78SW3	472300	482850	52.6	212.2	MARTON	126205
SE78SW4	472376	482773	34.7	193.0	MARTON 2	126206
SE79SW1	472673	494960	163.2	1642.9	ROSEDALE 1	126224
SE86NE3	488950	465049	205.1	3058.7	DUGGLEBY 1	132562
SE86SW4	481260	462030	170.0	289.0	BROWN MOOR	132580
SE87NW30	482070	475803	22.9	1878.9	MARISHES 1	132690
SE87NW45	482070	475803	21.9	1728.8	MARISHES 2Z	19204460
SE88NE2	486960	488924	207.6	2025.7	LOCKTON 4	132749
SE88NE5	489900	489645	245.7	2179.3	EBBERSTON MOOR 1	19403922
SE88SE8	489199	481505	22.4	235.0	EBBERSTON 1A	132782
SE88SE9	489210	481506	22.4	237.5	EBBERSTON 1B	132783
SE96NE4	499340	465196	140.7	1993.4	LANGTOFT 1	135324
SE98NW14	490240	487149	223.2	2185.4	EBBERSTON SOUTH 1	19487756
SE98NW4	491060	489590	249.3	2081.8	LOCKTON 8	135423
SE98NW5	492380	487344	221.9	2014.7	WYKEHAM 1	135424
SE98NW6	493711	489826	87.2	1898.5	LOCKTON EAST 1	135425
SE99NE5	499391	496802	174.7	3078.5	CLOUGHTON 1	135474
SE99SW3	490890	492880	122.7	2208.0	LOCKTON 3	135484
SE99SW4	490258	490140	240.2	2048.6	LOCKTON 2	135485
SE99SW5	491730	490178	225.0	2135.1	LOCKTON 7	135486
TA07NE1	505830	475710	130.8	2303.0	FORDON 1 (WOLD NEWTON)	460083
TA07SE19	506890	473604	67.7	2444.5	FORDON 2	460181
TA08SW23	504038	480291	26.4	348.6	FLIXTON 1	460542
TA16NW12	510122	466771	52.1	2460.0	RUDSTON 2	463902
TA16NW13	512200	467899	27.4	2316.5	CAYTHORPE 2	463903
TA16SE5	515455	460622	18.3	1973.6	BARMSTON 1	463913
TA17NW10	513010	475880	80.8	2252.5	HUNMANBY 1	463974
TA17NW12	514650	475810	49.3	163.0	REIGHTON	463976
TA17NW13	512885	475830	79.1	223.0	REIGHTON 2	463977
TA17SW24	512027	474868	115.6	2405.0	WILLOWS 1	18126679

Table 1 List of wells used in the geological modelling

The subsurface elevation of horizon tops based on borehole evidence is a key component of the model. These were determined through the construction of well sections (Figure 9) and the picking and correlation of stratigraphic markers based on evidence from geophysical logs (principally gamma-ray and sonic velocity) and borehole drilling returns information shown on composite logs.

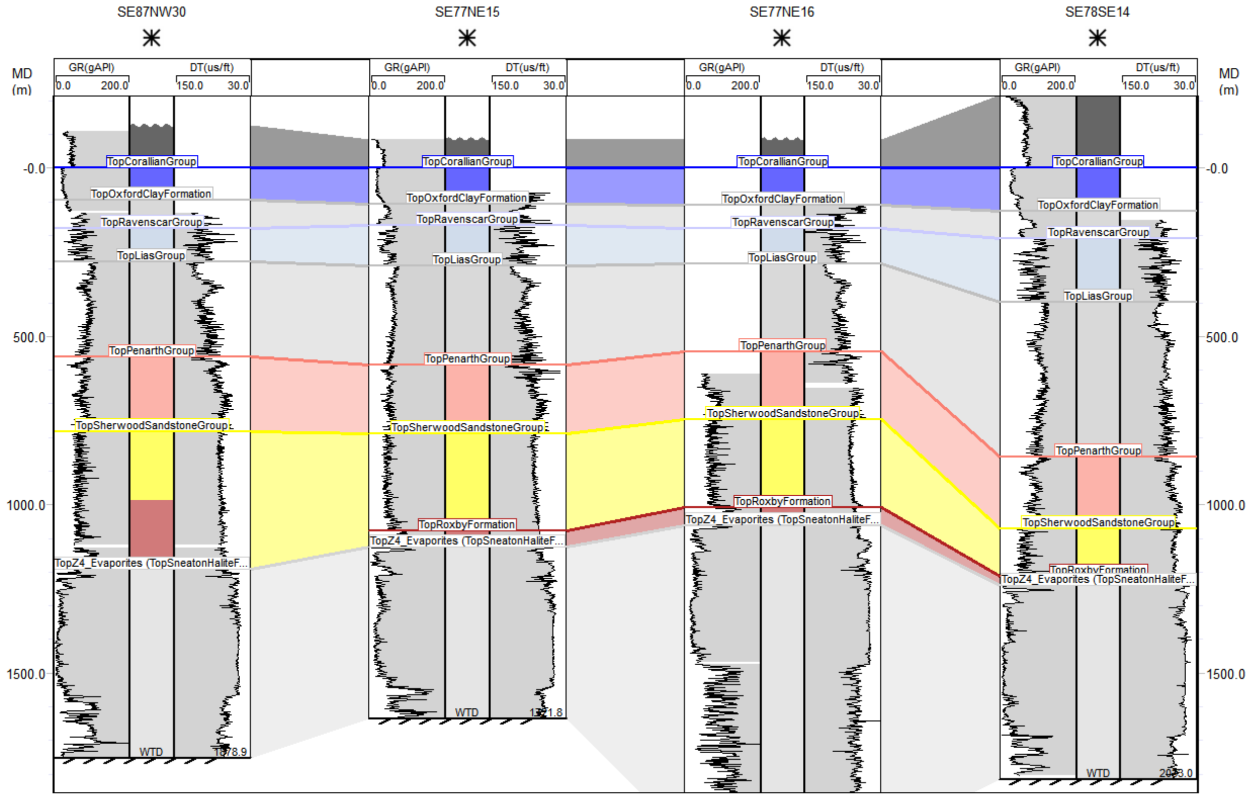


Figure 9 Example of a well section used to place and correlate well stratigraphic markers (formation tops) by using evidence from geophysical logs and borehole cutting returns. Section is flattened on the top of the Corallian Group.

2.3.2 Seismic data

Structural interpretation of the Vale of Pickering based on seismic reflection data of varying age and quality was undertaken by Kirby et al. (1985) and Kirby and Swallow (1987). Kirby et al. (1985) mapped nine horizons using seismic picks which were tied into well and outcrop controls wherever possible. For the purposes of making the VoP geological model, two of the structure maps contained within Kirby et al. (1985) were georeferenced and digitised: Top Corallian and Top Upper Magnesian Limestone (Enclosures 13 and 15 of Kirby et al., 1985). The Top Upper Magnesian Limestone map was depth converted by Kirby et al. (1985) and was used to guide the construction of the fault network and control the elevation of overlying horizons. The Top Corallian map (Figure 10) was only available as isochrons in milliseconds. This map requires depth conversion, however, as an interim solution borehole control points show the two-way travel time (in ms expressed as a negative value) approximates to the depth below surface in metres (Kirby and Swallow, 1987) (Figure 11). This is consistent with sonic velocity logs which show that the typical sonic transit time of the Kimmeridge Clay and Speeton Clay which overlies the Corallian Group in the Vale of Pickering is around 0.5 ms/m.

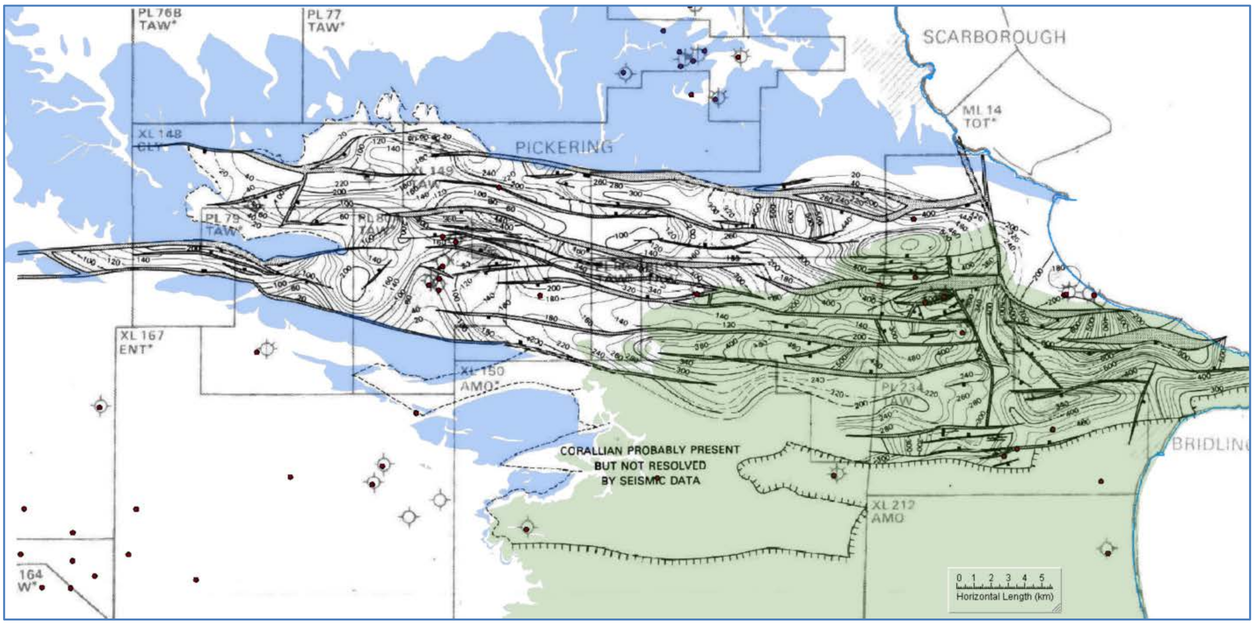


Figure 10 Example seismic interpretation map modified from Kirby et al. (1985). This map shows structure contours on the top of the Corallian Group. Contours are isochrons in 20 ms intervals. Blue-shaded areas show the crop of the Corallian Group and green-shaded areas show the crop of the Chalk Group.

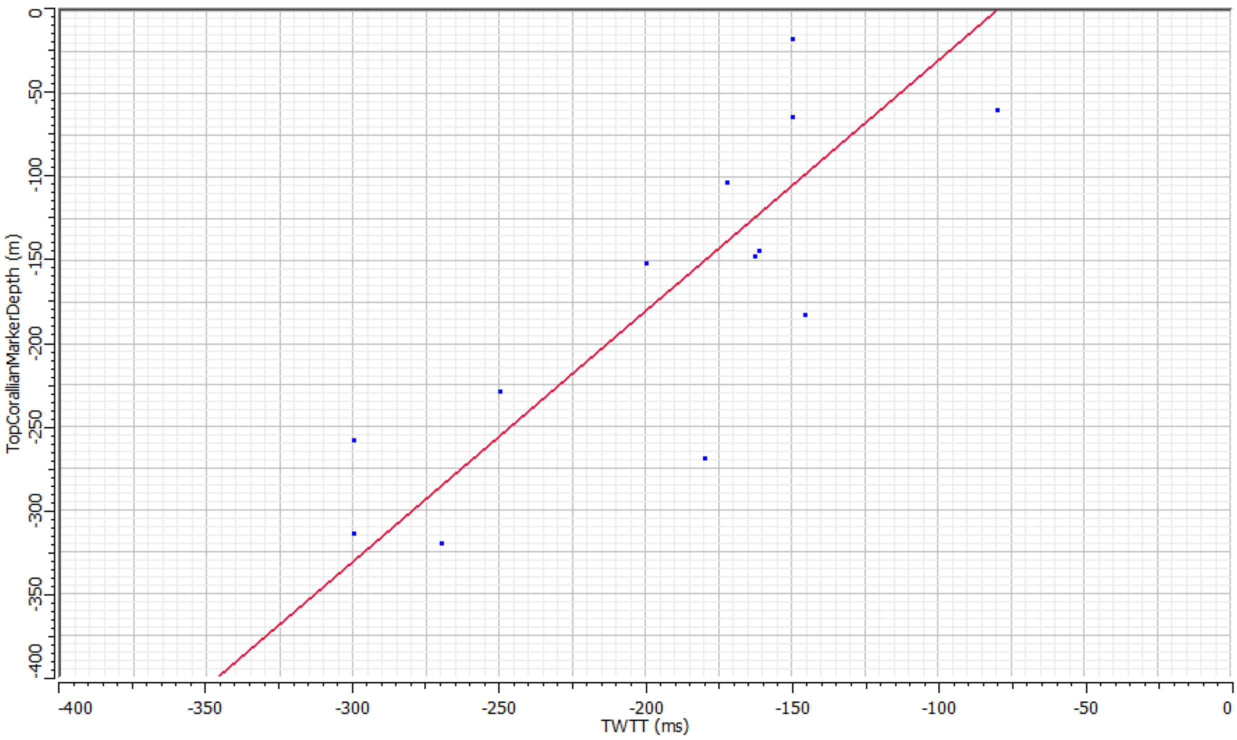


Figure 11 Plot of two-way travel time (taken from Top Corallian map of Kirby et al. 1985) against co-located well marker depth (m) for top of the Corallian Group.

The structure maps of Kirby et al. (1985) were the primary control on the development of the model fault network. Fault traces were digitised at three levels: Top Magnesian Limestone, Top Corallian Group and the land-surface intersection of faults as shown on BGS DiGMapGB-50. Differences in the fault map at Top Magnesium Limestone and Top Corallian Group are clearly apparent and reflect the discontinuity of structures across the Permian Zechstein Salt. While many of the faults in the Magnesium Limestone are hard-linked to basement, some faults within the post-salt cover have a strongly listric form, curving downward and detaching within the salt (Kirby and Swallow, 1987).

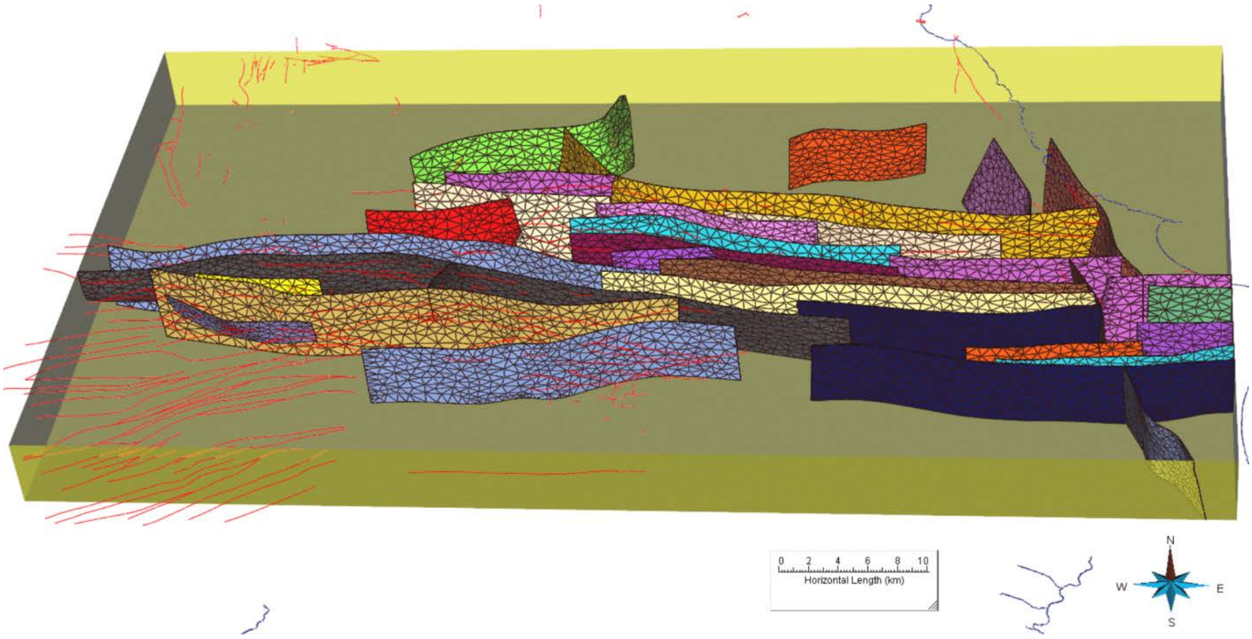


Figure 12 Fault network used in the model shown inside the model bounding box. Red lines show faults on BGS 1:50000 geological maps.

Faults were simplified, merged and extended to water-tight intersections where required (Figure 12). Many of the minor faults shown on BGS 1:50000 geological maps were omitted, particularly in the Vale of York, where most cause only minor displacements of stratigraphic horizons.

2.3.3 Geological outcrop linework

BGS DiGMapGB-50 geological linework were processed to provide a set of polylines defining the outcrop location of stratigraphic tops and then projected vertically (Z-attributed) onto the Ordnance Survey OSTerrain50 digital elevation model.

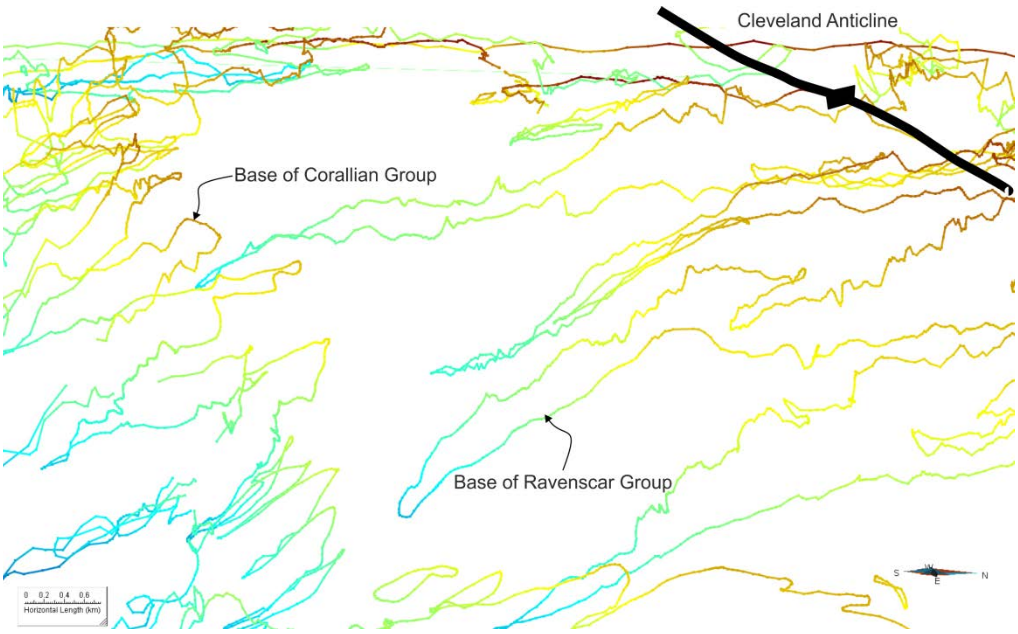


Figure 13 Example of BGS DiGMapGB-5 geological linework fitted to Ordnance Survey OSTerrain50 digital elevation model on the southern flanks of the Nork York Moors.

The Z-attributed linework, while showing the general form of the underlying geological structure, also displays considerable ‘noise’ (high frequency oscillations in elevation) largely caused by projection of the polylines onto a digital elevation model which differs from that originally used to construct the map (Figure 13). Partly for this reason the modelled horizons were not force-fitted to the geological linework along their entire length. Geological linework was used only as a guide to where subsurface horizons picked on cross-sections should intersect the terrain. Horizons were thus allowed to create their own modelled outcrop trace by intersecting the topography. The modelled outcrop trace will differ from the mapped outcrop trace depending on the form and resolution of the digital terrain model. However, comparison of modelled outcrop lines versus the observed provides a general means of checking the accuracy of the modelled geological horizons.

2.3.4 Manually-digitised horizon picks

In most subsurface 3D modelling tasks there are insufficient hard data to build an accurate model and some additional manually-digitised polylines are required. These were created using a grid of cross-sections onto which polylines were digitised using the elevation control offered by wells, outcrop intersects and the position of horizons based on seismic interpretation (Kirby et al., 1985). Cross-sections were largely orientated N-S or W-E, perpendicular and parallel to the structural grain of the Vale of Pickering (Figure 14).

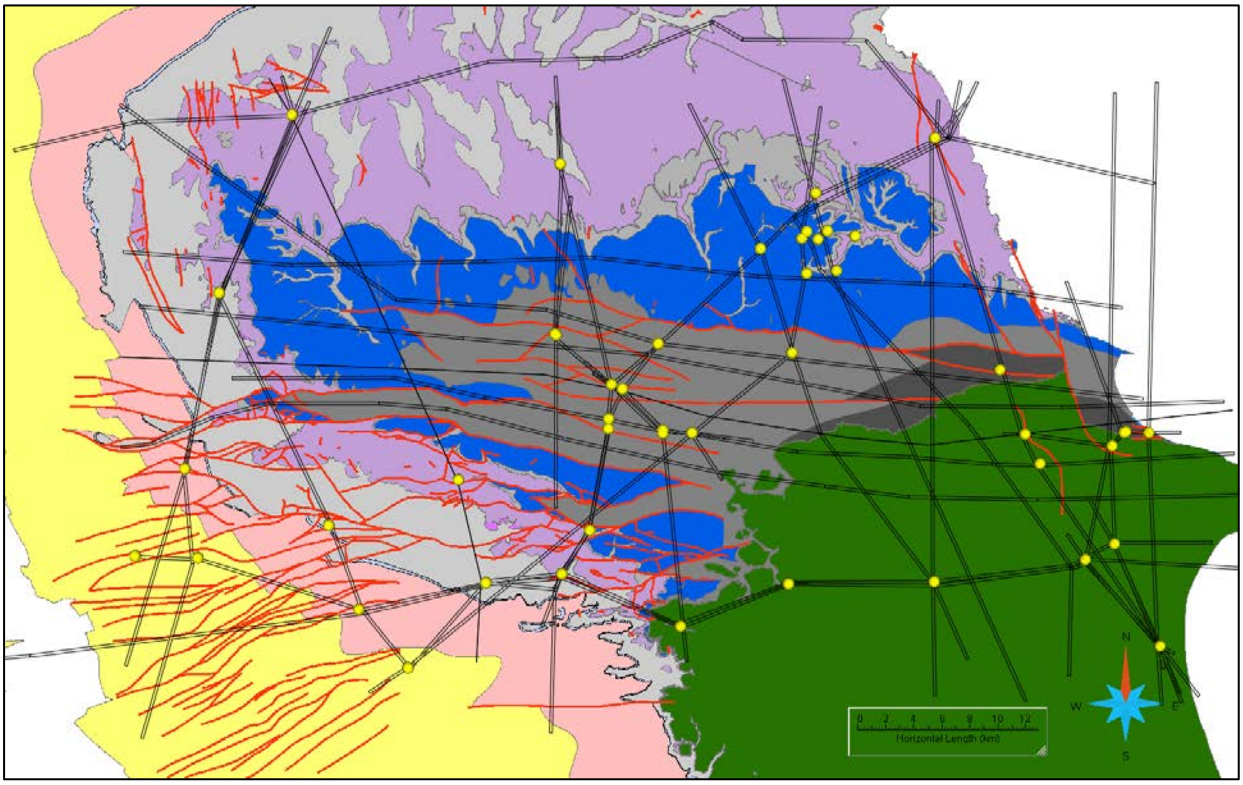


Figure 14 Map showing the distribution of cross-sections (black lines) used in the construction of the geological model. Yellow dots are well locations. For colour key to bedrock geology map see Figure 5.

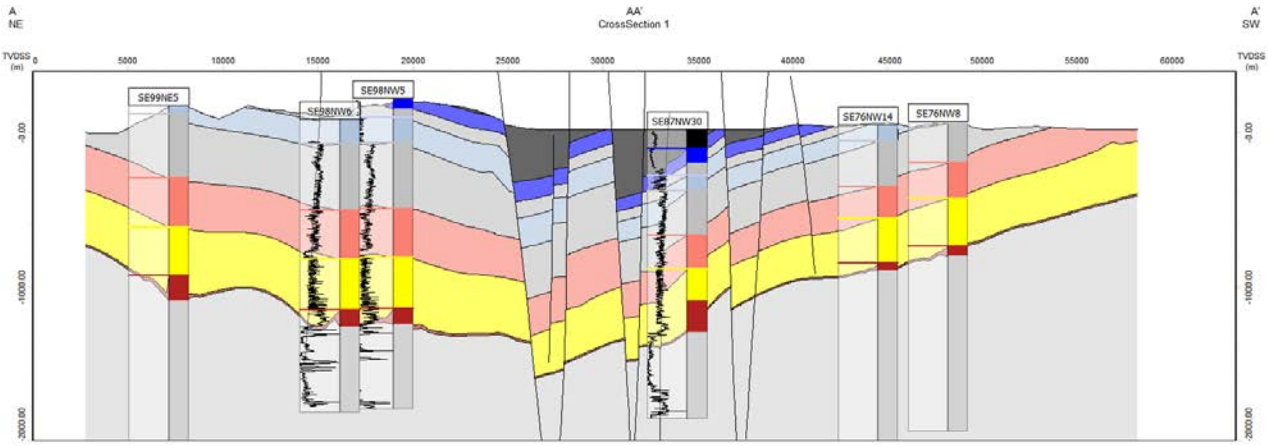


Figure 15 Example of a cross-section showing wells, faults and stratigraphic horizons. See Figure 7 for key to geological units.

The building of cross-section and stratigraphic and structural modelling is a highly iterative process with each generation of a new model being displayed within the cross-section window and used to refine and modify the digitised horizon picks (Figure 15).

2.4 GEOLOGICAL MODELLING PROCESS AND OUTPUT

Geological modelling was undertaken using Paradigm's SKUA-GOCAD™ 15.5 Integrated Earth Modelling application. This is an implicit 3D geological modelling approach which automates all fault network and stratigraphic horizon construction (Paradigm, 2015). The resulting geological model (Figure 16) honours horizon well markers precisely and provides a user-specified fit to other input data, such as polylines that were manually-digitised on cross-sections. All horizons and geological units within a model are built simultaneously and follow the stratigraphic rules of conformity or erosional unconformity contained within the geological column (Figure 7) in addition to fitting a thickness model derived from well and other input data.

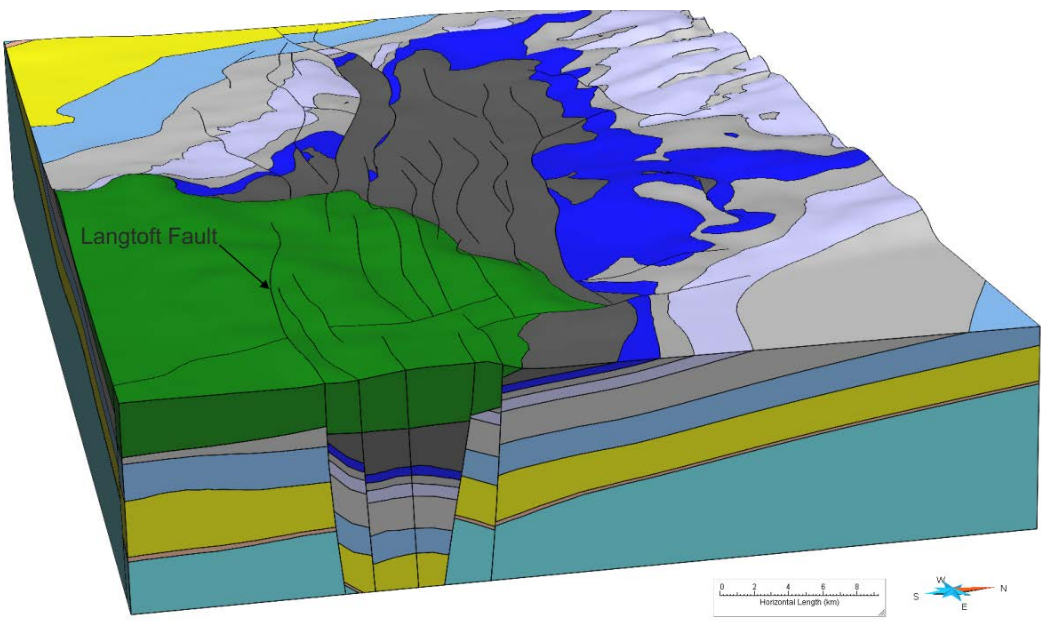


Figure 16 Geological model shown with five times vertical exaggeration. Vertical dimension covers approximately 2.5 km. Note the deep graben structure to the north of the Langtoft Fault and the unconformity at the base of the Chalk Group & Hunstanton Formation (shown in green). See Figure 7 for key to geological units.

The SKUA-GOCAD geological model is a 3D geological grid with stratigraphically-aligned cells that are truncated at faults and unconformities (Figure 17). Cells (of any user-specified dimensions) can be attributed with properties such as rock type, porosity or hydraulic conductivity allowing refinement of the model beyond the current broad formation-level subdivisions. Grids can be exported in many formats suitable for flow modelling and other dynamic simulations.

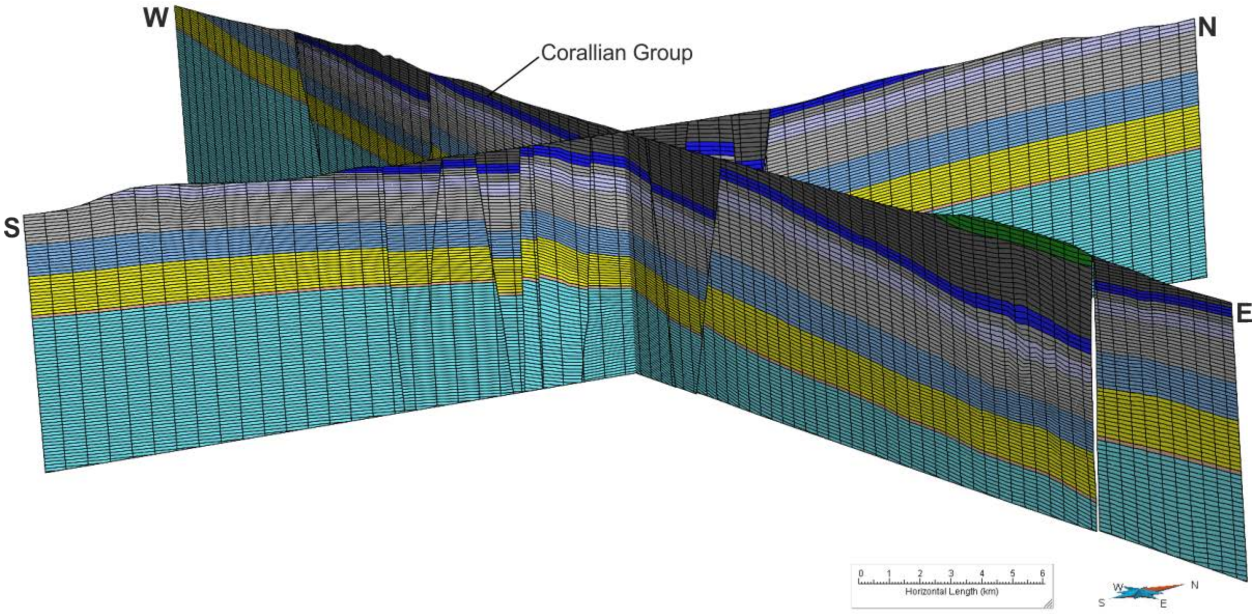


Figure 17 Two intersecting sections through the model showing stratigraphic alignment and faulting of grid cells. Note the west to east dip of the Corallian Group along the axis of the Vale of Pickering. See Figure 7 for key to geological units.

A primary purpose of the model is to determine how the complex geological structure of the Vale of Pickering will influence the hydraulic connectivity of aquifer units such as the Corallian Group. Many of the faults are of sufficient displacement to offset the relatively thin Corallian Group aquifer producing compartments with poor connectivity, particularly in a north-south direction (Figure 18). For example, previous work by Reeves et al. (1978) has shown limited hydraulic connectivity in the Corallian Group across the Coxwold-Gilling Trough (Bearcock et al., 2015).

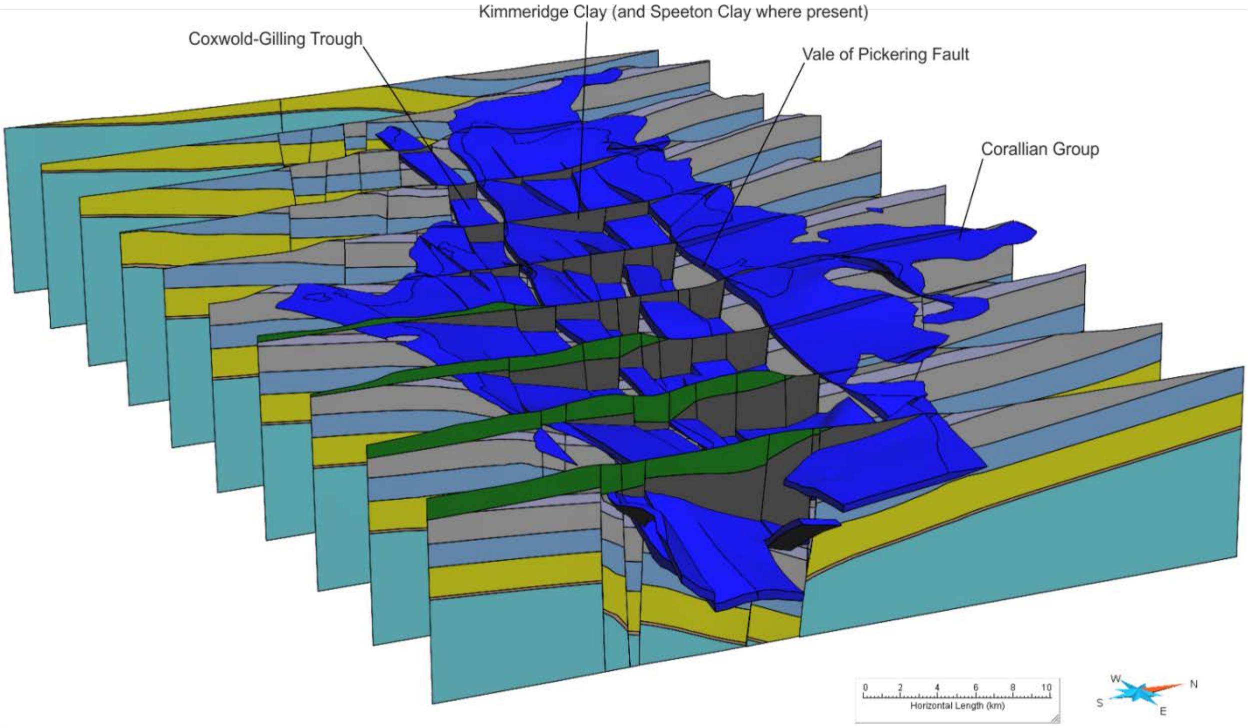


Figure 18 Regularly-spaced sections through the geological model and the Corallian Group (dark blue) extracted as a single unit. Note how closely-spaced west-east trending faults break the continuity of the Corallian Group (dark blue) under the Vale of Pickering. See Figure 7 for key to geological units.

3 Conclusions and further work

This study has shown that sufficient subsurface data exist in the Vale of Pickering to build a robust geological model. The present model was built in a relatively short time and requires refinement and further checking by the insertion of additional borehole control and checking and depth conversion of existing seismic maps (Kirby et al., 1985).

At present the model extends to the top of the Permian Zechstein. Further work to model lateral thickness and facies variations within the Zechstein would be important for understanding the sealing capacity of the salt. Modelling of the underlying Carboniferous would also be desirable to understand the relative position of hydrocarbon source rocks.

Faults are currently modelled as relatively simple planes and further work is required to differentiate and accurately model listric faults which sole out into Permian salt from planar faults which hard link into Carboniferous basement. Work could also be undertaken to model the sealing capacity of faults and identify where they may act as a transmitter or a barrier to fluid flow.

Geological units are currently modelled as groups or formations which in reality comprise a large number of rock types which interbed and change laterally (Powell, 2010). There are sufficient geophysical logs and other well data to capture some of this heterogeneity through stochastic modelling of the various lithologies.

References

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

Bearcock, J.M., Smedley, P.L., Milne, C.J., 2015. Baseline groundwater chemistry: the Corallian of the Vale of Pickering, Yorkshire. British Geological Survey Internal Report, OR/15/048.

DECC, 2013. The Hydrocarbon Prospectivity Of Britain's Onshore Basins. https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/367284/UK_onshore_2013.pdf.

Ford, J.R., Hughes, L., Burke, H.F., Lee, J.R., 2015. The Vale of Pickering : an initial summary of the Quaternary/superficial geology and data holdings (Open file report OR/15/064). BGS, Nottingham, UK, http://nora.nerc.ac.uk/512437/.

Foster, S.W., 1985. The Late Glacial and Early Post-Glacial History of the Vale of Pickering and Northern Yorkshire Wolds. Unpublished PhD Thesis, University of Hull http://core.ac.uk/download/pdf/2731925.pdf.

Jeans, C.V., 1973. The market weighton structure: Tectonics, sedimentation and diagenesis during the cretaceous. Proceedings of the Yorkshire Geological and Polytechnic Society 39, 409-444.

Kent, P.E., 1955. The Market Weighton Structure. Proceedings of the Yorkshire Geological and Polytechnic Society 30, 197-227.

Kent, P.E., 1980. British Regional Geology – Eastern England from the Tees to The Wash. British Geological Survey. HMSO, London.

Kirby, G.A., Swallow, P.W., 1987. Tectonism and sedimentation in the Flamborough Head region of north-east England. Proceedings of the Yorkshire Geological Society 46, 301-309.

Kirby, G.A., Swallow, P.W., Holliday, D.W., Holloway, S., Penn, I.E., Smith, K., 1985. Hydrocarbon prospectivity of North Yorkshire and Humberside. BGS Unpublished Report WA/KB/85/2C.

Paradigm, 2015. SKUA-GOCAD™ Integrated Earth Modeling. http://www.pdgm.com/resource-library/brochures/skua-gocad/skua-gocad/.

Powell, J.H., 2010. Jurassic sedimentation in the Cleveland Basin: a review. Proceedings of the Yorkshire Geological Society 58, 21-72.

Reeves, M.J., Parry, E.L., Richardson, G., 1978. Preliminary evaluation of the groundwater resources of the western part of the Vale of Pickering. Quarterly Journal of Engineering Geology and Hydrogeology 11, 253-262.

Underwood, C.J., Mitchell, S.F., 1999. Mid-Cretaceous onlap history of the Market Weighton structural high, northeast England. Geological Magazine 136, 681-696.