British Geological Survey

Project Groundwater Northumbria

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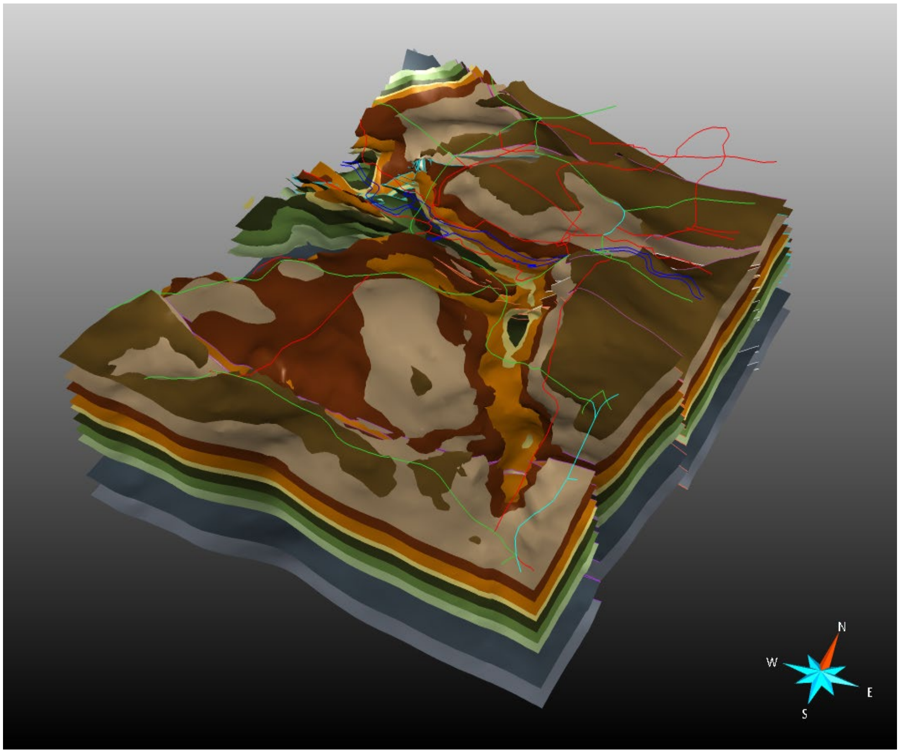
3D geological model report of the bedrock geology underlying the Gateshead area - Project Groundwater Northumbria

National Geoscience Programme

Commercial Report CR/24/123



BRITISH GEOLOGICAL SURVEY

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Front cover

Image of the Gateshead 3D bedrock model, looking northwest.

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Keyworth, Nottingham British Geological Survey 2025

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Summary

This report has been produced by the British Geological Survey (BGS) on behalf of Project Groundwater Northumbria, the Flood and Coastal Resilience Innovation Programme (FCRIP) project led by Gateshead Council. It provides background and methodological information on the development of a 3D geological model of the bedrock strata and of major faults in the Gateshead area.

The model covers an area approximately 13 km by 18 km and has a vertical accuracy of +/- 1 to 10 m. The 3D geological model described here uses historical subsurface data including borehole records and geological maps held by the BGS and seam plan data held by the Mining Remedation Authority / Coal Authority (CA) and represents our current understanding of the bedrock and coal seam geometry.

The model will be used to understand both spatial variations in recharge to the bedrock aquifers and highlight areas where outflow from coal seams or historic mine workings may increase risks of groundwater flooding and/or interact with surface water systems and shallow superficial aquifers.

1 Introduction

1.1 PURPOSE AND SCOPE OF THE WORK

The British Geological Survey (BGS) has created a 3D geological model of the bedrock strata and major faults in the Newcastle-Gateshead area as part of commissioned work for Project Groundwater Northumbria (PGN), the Flood and Coastal Resilience Innovation Programme (FCRIP) project led by Gateshead Council. The bedrock model shows the 3D structure of the major coal seams; formational boundaries; selected faults and generalised worked coal seams. The model will aid understanding of the movement of groundwater in the subsurface and provide input to hydrological models.

The PGN project work is intended to help project partners including the Environment Agency and Gateshead Council understand both spatial variations in recharge to the bedrock aquifers and highlight areas where outflow from sandstone units or historic mine workings may increase risks of groundwater flooding and/or interact with surface water systems and shallow superficial aquifers.

This report details background information and the methodology used for the development of the 3D bedrock geological model underlying the Gateshead project area, see **Figure 1**. The model has been developed using Aspen SKUA™ software which was developed by the oil industry and academia, it provides a highly customizable, integrated software suite for geological modelling and reservoir characterization, bridging the gap between interpretation and simulation.

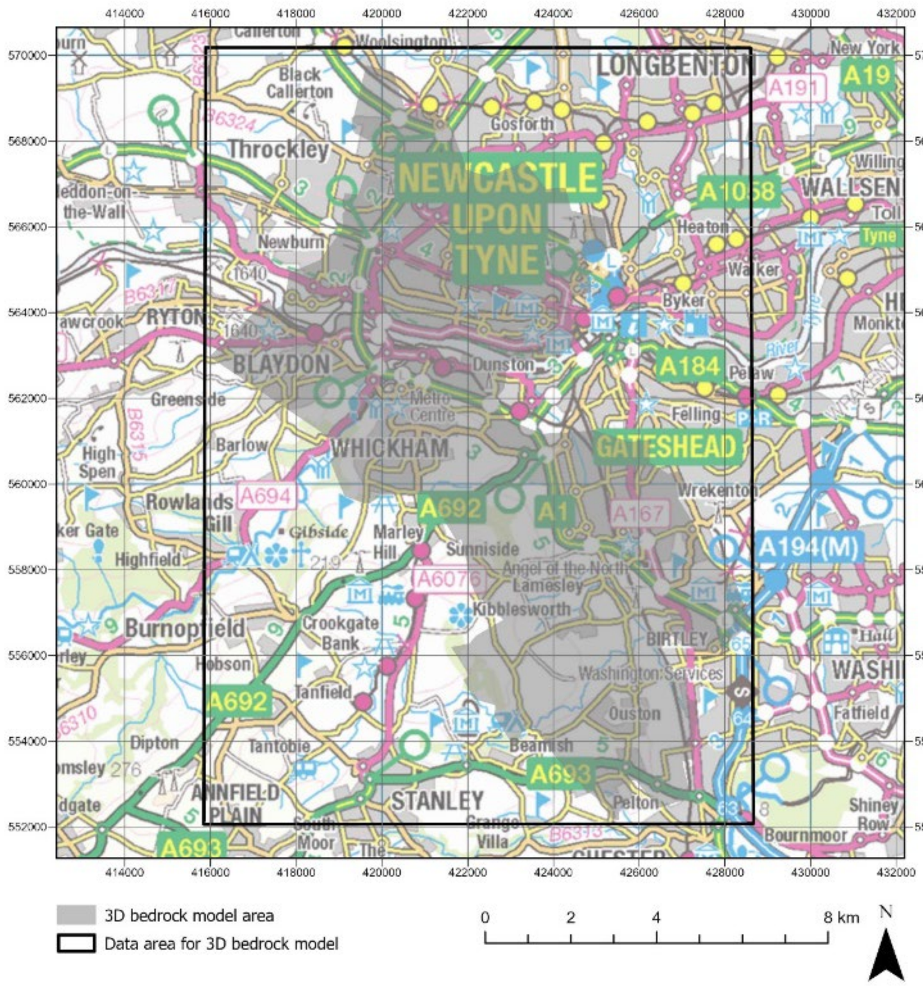

Figure 1: Area covered by the 3D bedrock geology model for Project Groundwater Northumbria. Contains OS data © Crown copyright and database rights 2024.

The model produces a 3D representation of the bedrock geology comprising of key stratigraphical horizons, major coal seams within the geological sequence and selected faults. It is based on 1:50 000 scale geological map data, but the modelling process sub-samples that information, so the final model is at a coarser scale. Also, the modelling software has geological rules built in so if there are geometric errors in the mapping the model will not honour them.

The stratigraphic horizons included in the model are:

- Topography
- Geological rockhead (base of superficial deposits)
- Base of the High Main Seam (E)
- Base of the Maudlin (Bensham) Seam (H)
- Base of the Durham Low Main Seam (J)
- Base of the Hutton Seam (L)
- Base of the Middle Coal Measures Fm/Vanderbeckei Marine Band
- Base of the Harvey (Beaumont) Seam (N)
- Base of the Busty Seam (Q) or Bottom Busty Seam (Q2)
- Base of the Brockwell Seam (S)
- Base of the Lower Coal Measures Fm/Subcrenatum Marine Band
- Base of the Millstone Grit Group

Various datasets have been interpreted to produce the model, including historical borehole records and geological maps held by the BGS and Mining Remedation Authority / Coal Authority datasets, these are described in more detail in Section 3.1. It is noted that whilst in-seam contours and spot elevations from mine plans are used to inform the construction of the 3D model, inclusion of the mine working extents (e.g. as worked parts of seams or similar) as part of the model output is not currently possible due to Mining Remedation Authority / Coal Authority licensing constraints.

The report will detail established BGS model Quality Assurance procedures, methodology, limitations of the model and uncertainty of the modelled surfaces. Derived model outputs are provided in the form of elevation grids in GIS format and complemented by 3D views (images), taken from the 3D modelling software platform.

2 Bedrock geology

The model area is underlain by a thick sequence of interbedded sedimentary rocks, belonging largely to the Pennine Coal Measures Group of Carboniferous, Westphalian A to C age (Ramsbottom et al., 1978), **Figure 2**. The Coal Measures Group strata are underlain at depth by rocks belonging to the Millstone Grit Group (of Namurian age) and in the northeastern corner of the project area are mapped to be unconformably overlain by strata of Permian age (Yellow Sands Formation), where the Yellow Sands Formation has been shown to form ridges of various heights (Smith and Francis, 1967). The regional dip of the strata across the model area is at a low angle towards the east, **Figure 3**, therefore the strata present at rockhead generally becomes younger towards the east. Localised folding and faulting of the strata means the dips vary locally. Numerous faults are recorded on the BGS geological maps to cut the bedrock strata (**Figure 2**); although most of these faults are thought/known to have a small amount of throw, others are large regional features, for example the Ninety Fathom Fault and the Tantobie Fault.

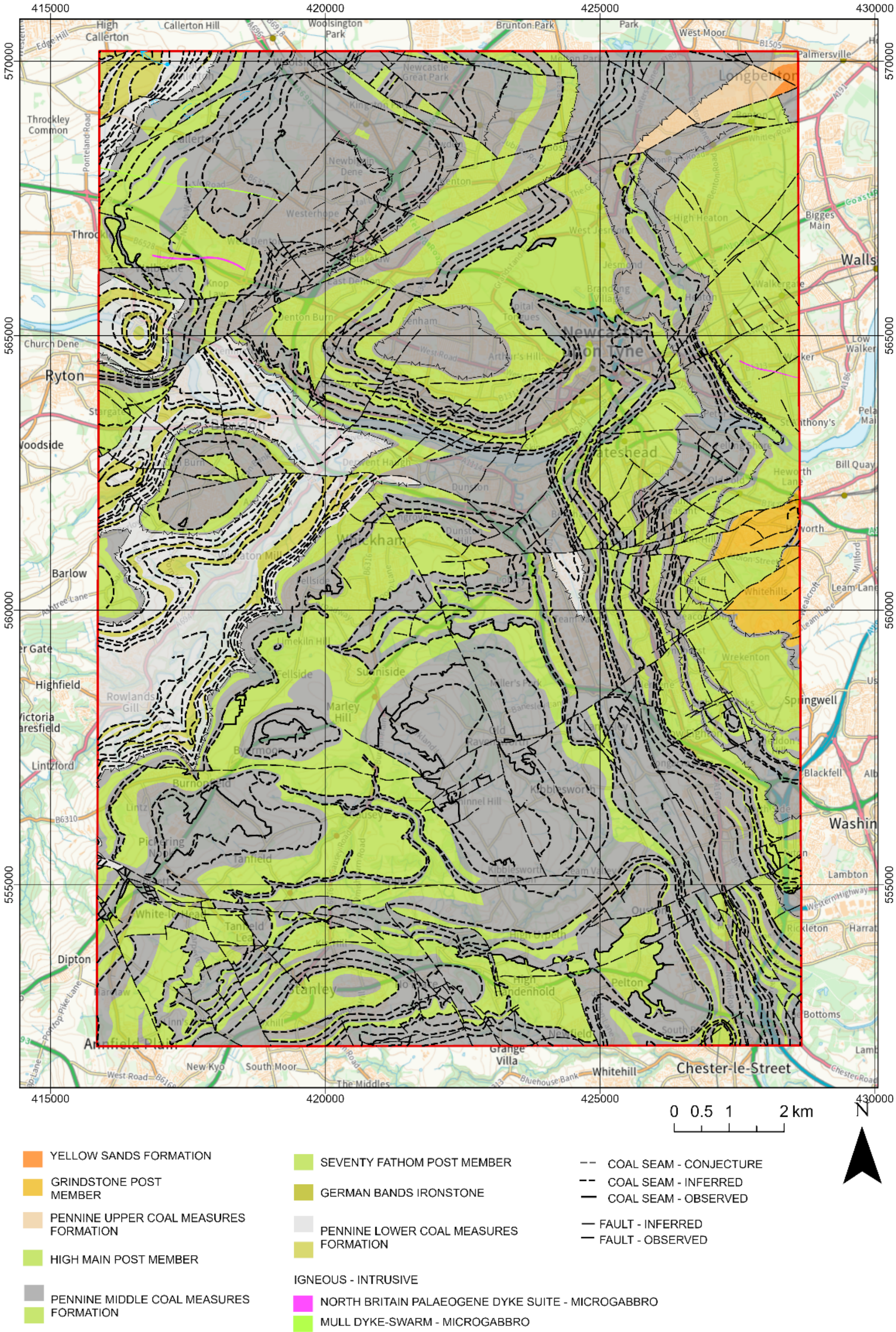

Figure 2: Bedrock geological map (1:50 000 scale) of the model area. BGS © UKRI 2024. Contains OS data © Crown copyright and database rights 2024.

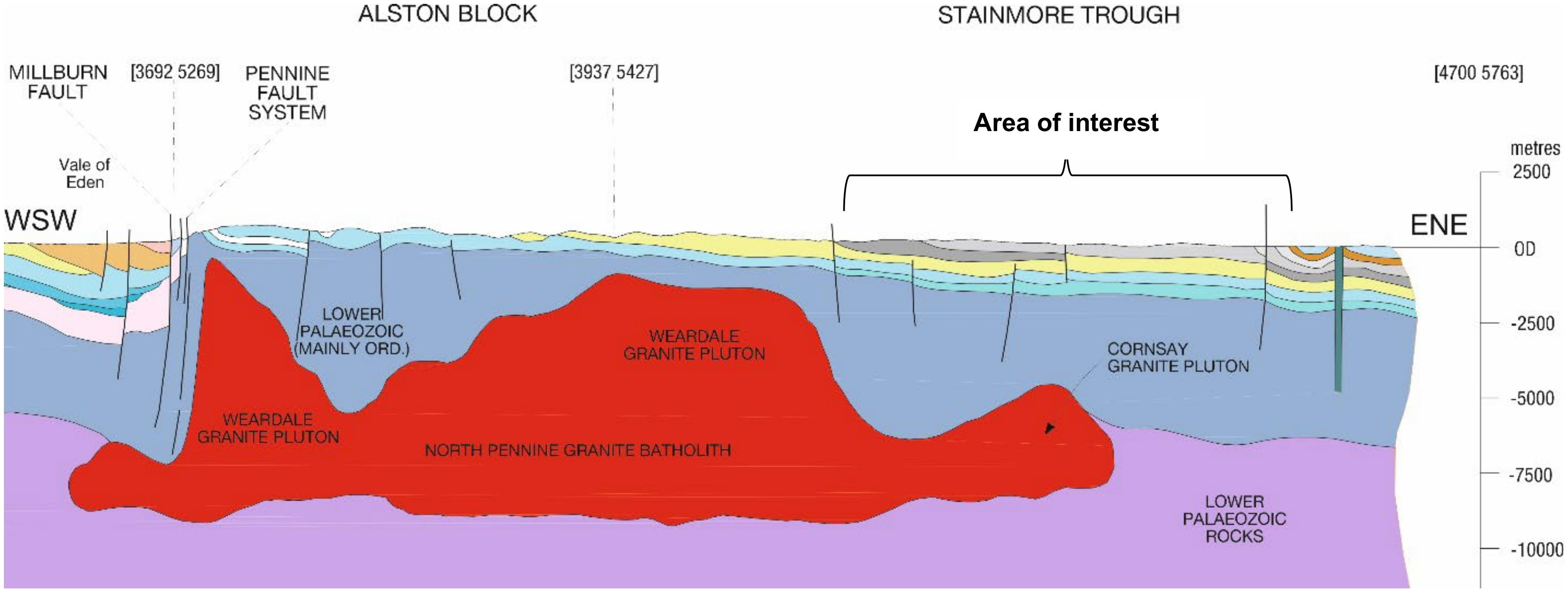

Figure 3: Part of the BGS 1:625 000 scale geological cross-section through northeast England. Illustrating a regional dip towards the east, with local variations due to folding and faulting. Lower Palaeozoic strata (purple and greyish blue), Carboniferous strata (mid blue, green, grey and brown) and Permian strata (pale blue). BGS © UKRI 2024.

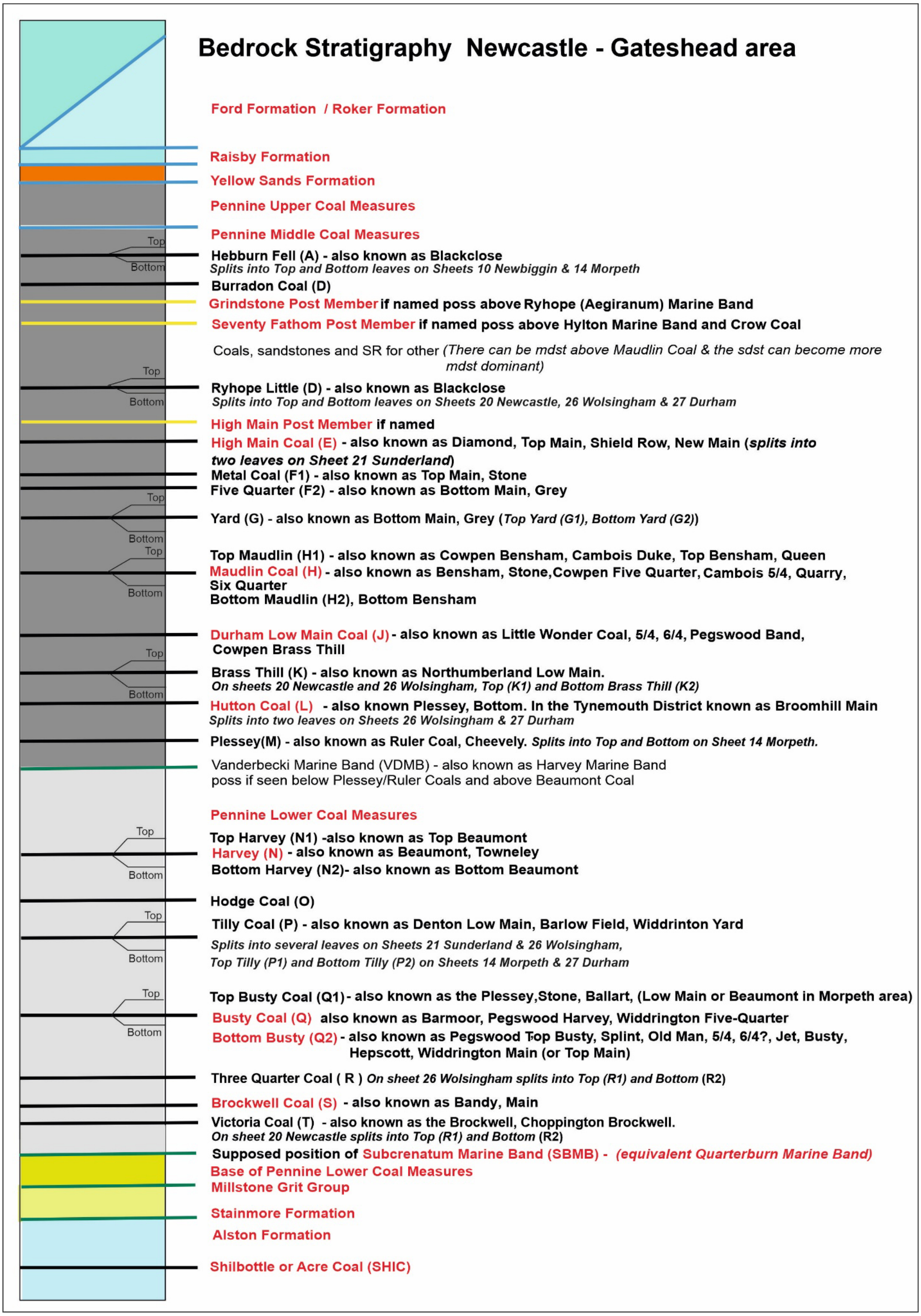

Figure 4: Bedrock stratigraphy in the model area. BGS © UKRI 2024

2.1 MILLSTONE GRIT GROUP

The Millstone Grit Group is Namurian in age and is the oldest geological unit in the bedrock model; the 'base of the Millstone Grit' forms the lowest horizon in the model. The unit does not crop out anywhere within the model but has been recorded at depth in borehole logs. The published BGS bedrock maps of the model area do not divide the Millstone Grit Group as a separate unit, rather subsume it into the Stainmore Formation (see the BGS Rothbury 1:50 000 sheet 9, 2009). However, Waters, Millward and Thomas (2014) revise this understanding and highlight the presence of the Millstone Grit Group under the Newcastle-Durham area. This is further confirmed by Kearsey et al. (2019) who traced the unit further out into the North Sea. In the model area, the borehole named '3/4 Mile SE of Morwick' (BGS ID 703083) near Amble contains 30 m of Millstone Grit under the Coal Measures Group. In the Newcastle Science Centre Geothermal borehole (BGS ID 18946180) the Millstone Grit is 58 m thick and in the Harton Dome 1 borehole (BGS ID 923323) in South Shields, it is 56 m thick. The Millstone Grit Group consists of broadly upward-coarsening cyclic sequences of sandstone, siltstone and grey mudstone, with subordinate and typically thin coal seams and seatearth (palaeosol) horizons. The Millstone Grit Group is conformably overlain by the Pennine Lower Coal Measures Formaton.

2.2 PENNINE MIDDLE AND LOWER COAL MEASURES FORMATIONS

The base of the Pennine Lower Coal Measures Formation across northeast England is the inferred position of the Subcrenatum Marine Band, which defines the base of the Westphalian Series (Mills and Hull, 1968, 1976; Land, 1974; Ramsbottom et al., 1978). Locally, in the Newcastle-Gateshead area, this horizon is more typically known as the Quarterburn Marine Band (**Figure 4**). The Pennine Lower Coal Measures Formation is approximately 170 m thick in the Newcastle-Gateshead area (Mills and Holliday, 1998) and is conformably overlain by the Pennine Middle Coal Measures Formation.

The base of the Pennine Middle Coal Measures Formation is the base of the Harvey Marine Band, the local correlative of the Vanderbeckei Marine Band (Ramsbottom et al., 1978), see **Figure 4**. The Pennine Middle Coal Measures Formation is approximately 310 m thick in the Newcastle-Gateshead area (Mills and Holliday, 1998).

Both the Pennine Lower Coal Measures Formation and Pennine Middle Coal Measures Formation consist of cyclic sequences of mudstone, siltstone, sandstone and seatearth with numerous coal seams (many of former economic importance and the reason multiple subsurface datasets exist for the area). An analysis of all the borehole data coded for the project shows that 41% of the rock seen in boreholes were sandstone in these formations and 5% coal (**Figure 5**: Kearsey et al., 2024).

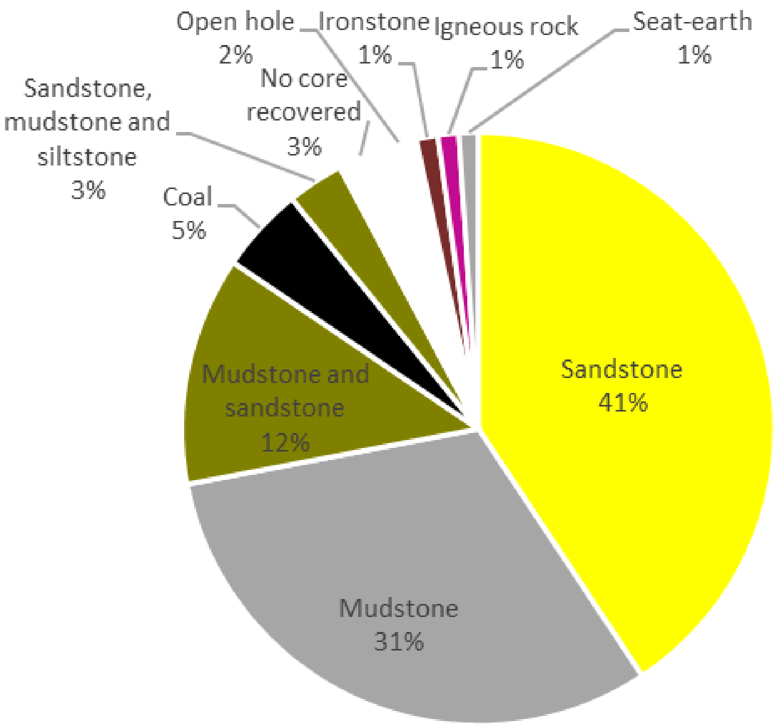

Figure 5: Bulk analysis of all the simplified lithologies found in the boreholes that pass through the Pennine Middle and Lower Coal Measures Formation in the model area. (from Kearsey et al., 2024). BGS © UKRI 2024.

2.2.1 Coals

The BGS 1:50 000 scale geological maps show 54 named coal seams in the model area, and borehole records show many additional thinner unnamed seams. However, correlation of coal seams from one colliery or borehole to the next is challenging; seams can change in thickness, change in character, split into upper and lower leaves or pinch out altogether, or faulting can bring together seams from higher or lower in the sequence. Many coal seams are simply not laterally continuous or distinctive enough to be recognised in boreholes across km's with any certainty, so cannot be modelled in the subsurface. Therefore, the bedrock model only contains 7 coal seams:

- Base of the High Main Seam (E)
- Base of the Maudlin (Bensham) Seam (H)
- Base of the Durham Low Main Seam (J)
- Base of the Hutton Seam (L)
- Base of the Harvey (Beaumont) Seam (N)
- Base of the Busty Seam (Q) or Bottom Busty Seam (Q2)
- Base of the Brockwell Seam (S)

These seams are known to be of significant thickness and laterally continuous across the model area, they are all shown on the BGS geological maps, are generally named in boreholes records (although often with local names), and have been worked extensively both at the surface and underground, so mine plan information (held by the Mining Remedation Authority / Coal Authority) is available. Note: The software used to generate the bedrock model cannot currently model splits in a coal seam. Therefore, the modelled surface representing the base of a coal seam is either the base of the whole seam or the base of the bottom leaf of the seam, where applicable.

The Mining Remedation Authority / Coal Authority seam plans include information on the thickness of coal seams across the model area (**Figure 6**). Most seams average about 1 m thick, although, seams can be >2 m thick and the High Main is recorded up to 4.5 m thick.

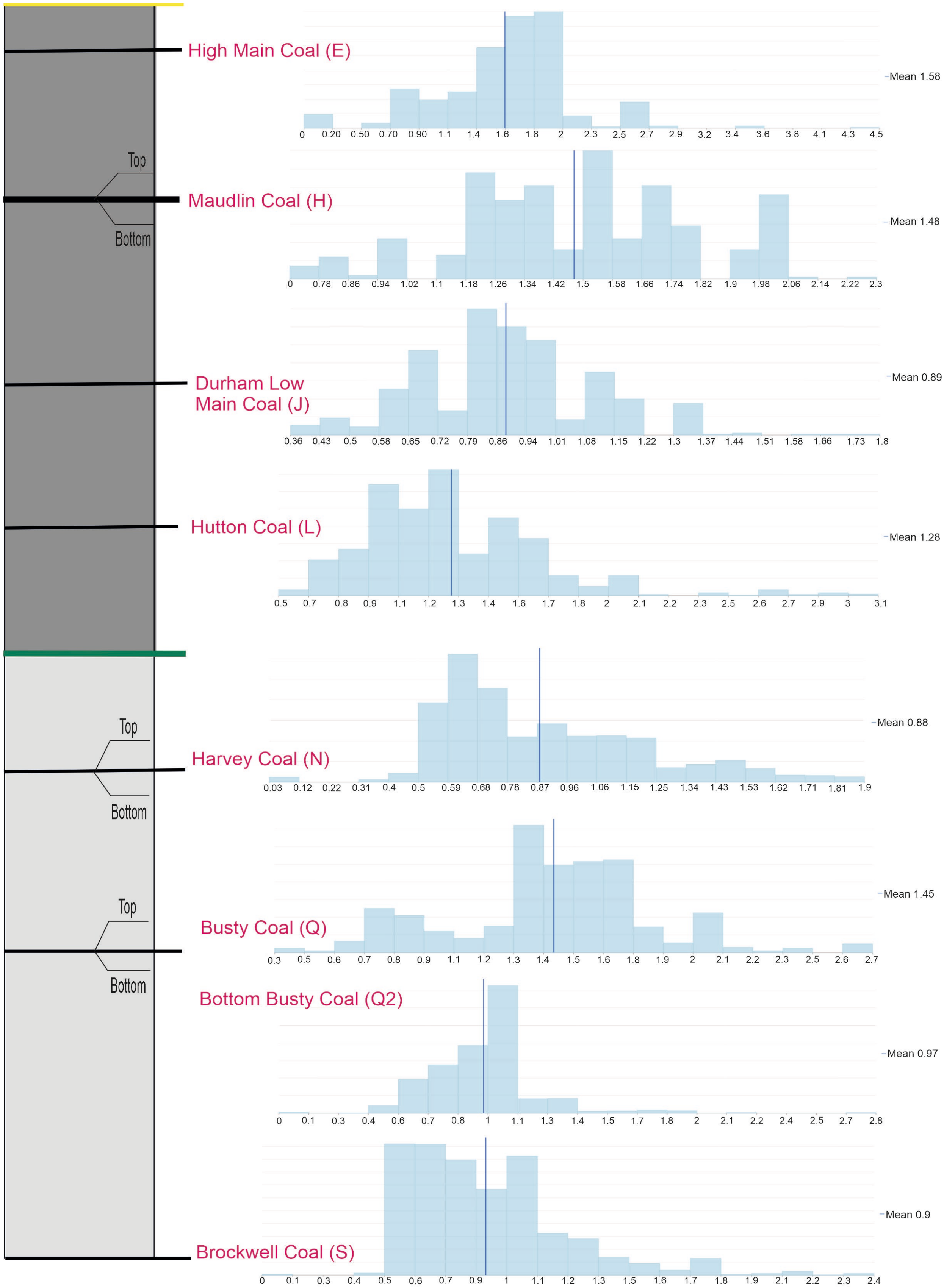

Figure 6: Variation in thickness (in meters) for each of the modelled coal seams across the model area, calculated using seam plan data provided by the Mining Remedation Authority / Coal Authority. BGS © UKRI 2024

2.3 PENNINE UPPER COAL MEASURES FORMATION AND YELLOW SANDS FORMATION

The base of the Pennine Upper Coal Measures Formation is recorded as the base of the Down Hill Marine Band (see the BGS Sunderland 1:50 000 sheet 21, 1978).

The BGS 1:50 000 scale geological maps show an area of Pennine Upper Coal Measures Formation strata and Permian strata (Yellow Sands Formation) in the northeast corner of the model area, between Gosforth and Longbenton (**Figure 7**). This outlier of younger strata is mapped as approximately 4 km long, up to 700 m wide and is bound to the south by the Ninety Fathom Fault. However, there appears to be little hard evidence to support its presence; no bedrock exposures have been found on any of the BGS maps or fieldslips viewed in this area to indicate it is exposed at the surface and only one borehole record has been found within the area which penetrates the strata more than a few metres; the Red House Close borehole (BGS ID 879790) was drilled in 1749 to a depth of 87 m below the surface. The precise location of the borehole is uncertain and although the log describes a detailed sedimentary sequence containing some coal seams, none of the seams are named and no marker horizons are shown to indicate the position of the strata in the stratigraphy. Although a note at the top of the borehole log does state that “This bore penetrates higher Coal Measure strata than any other in Northumberland. The coal at 55’6” may be the Clousden Hill”. Not having any solid evidence of its presence, thickness or extent makes modelling the unit very difficult.

The Tynemouth memoir (Land, 1974) states that the younger strata has been inserted on the geological map on “structural grounds”; available data and geological understanding of the area at that time suggested that there is room for 900 feet of strata above the Killingworth Seam on the north side of the Ninety Fathom Fault.

As there are no borehole logs recording the base of the Pennine Upper Coal Measures Formation in the model area and there is some uncertainty to whether Pennine Upper Coal Measures Formation strata is present in the wider area, the base of the Pennine Upper Coal Measures Formation has not been included in this model.

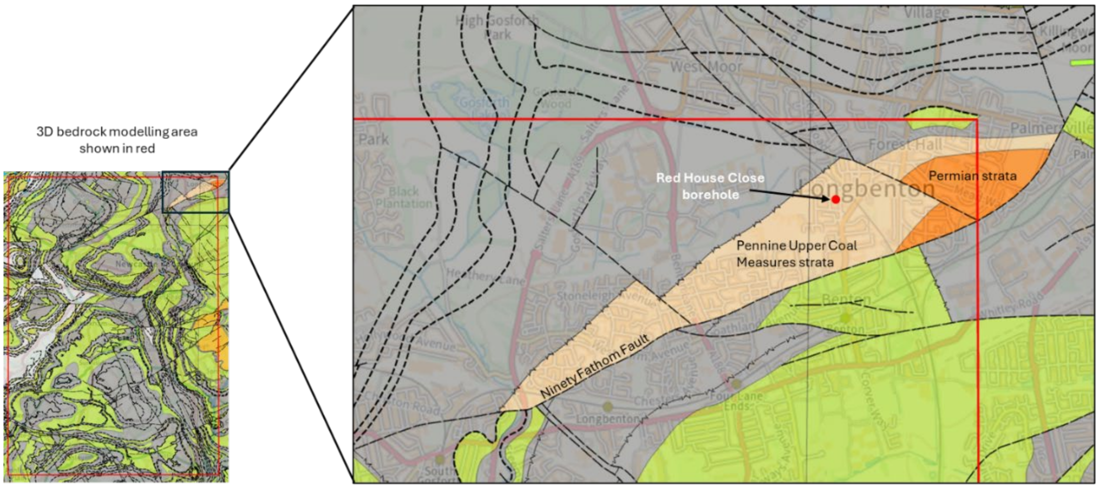

Figure 7: Mapped extent of Permian strata (orange) and Pennine Upper Coal Measures strata (beige) within the 3D model area, surrounded by Middle Coal Measures strata (grey and green). BGS © UKRI 2024. Contains OS data © Crown copyright and database rights 2024.

2.4 IGNEOUS INTRUSIONS

The thick sequence of Carboniferous rocks present across northeast England, and beneath the model area, was intruded by igneous sills and related dykes belonging to the Whin Sill suite during late Carboniferous to early Permian times, and by more dykes during the Palaeogene. All the intrusions in the model area are thought to have a basaltic or microgabbroic (doleritic) composition and exploited existing planes of weakness within the strata; magma intruding between the layers of sedimentary strata formed sub-horizontal sheets known as sills, whilst magma that exploited cracks and fractures cutting through the strata, formed sub-vertical sheets called dykes.

The Whin Sill does not crop out in the model area and is not penetrated by boreholes in the model area. However, it is thought to be present everywhere at depth; the Throckley Borehole (BGS ID 724700) located approximately 1 km west of the model area, proved the Whin Sill to be 38.5 m thick at a depth of 543.8 m and it is possible to identify the sill elsewhere in the region on seismic sections (Chadwick, 1995). Stratigraphically, the sill intruded near the base of the Stainmore Formation in the Throckley Borehole, but it is not at the same level throughout the Newcastle-Gateshead area and more than one sill may be present locally (Mills and Holliday, 1998). The metamorphic effects of the sill on the Carboniferous country rocks can be significant; Owens (1972) found that organic matter was thermally altered more than 200 m above the sill.

During the Palaeogene a series of west- to west-north-west-trending dykes, emanating from the igneous centre of Mull in western Scotland, intruded across northern England and the model area. Three microgabbro dykes are shown cutting through the Carboniferous strata in the northern part of the model area on the 1:50 000 scale geological map (**Figure 2**). These include the Hebburn Dyke (at the eastern edge of the model) and the Walbottle Dyke (towards the western edge of the model). None of the dykes are thought to be currently visible at outcrop, although some have been formerly observed in quarries or encountered in underground coal workings. All these dykes are thought to be less than 15 m thick and either vertical or steeply subvertical (Mills and Holliday, 1998). The metamorphic effects of the dykes on the Carboniferous country rocks are described as restricted in extent, although noticeable in coals and other organic matter; locally coal has been reduced to cinders more than 50 m from a dyke and contacts are commonly brecciated with considerable intermingling of cindered coal and altered basalt (Mills and Holliday, 1998).

Units of ‘whin’ are described in some borehole records and could indicate that additional unrecorded intrusions exist within the model area. Although present in the model area, igneous rocks have not been modelled in the BGS 3D bedrock model.

2.5 STRUCTURAL GEOLOGY

Tectonic movements during the late-Carboniferous both faulted and gently folded the Carboniferous rocks of the Newcastle-Gateshead area, additional earth movements in Tertiary times reactivated some of these faults and gently tilted the strata eastwards (Land, 1974). Most of the faults in the model area (**Figure 2**) trend roughly E-W, NW-SE or NE-SW. The largest of these, the Ninety Fathom Fault, strikes roughly ENE-WSW across the northern part of the model and divides the model into two structural areas; the area south of this fault forms part of the Alston Block, while the area to the north forms a structural hingeline between the Alston Block and the Northumberland Trough (Chadwick et al, 1995) (**Figure 8 and 9**). Underlying the block and giving it structural stability is the Weardale Granite of Devonian age, which is in the form of a batholith with several interconnected bosses (**Figure 8**). Because of the granite, the Block was relatively buoyant with a lower rate of subsidence than the Trough. This was specially marked in the Lower Carboniferous where some 500 m of strata were deposited on the Block compared with around 4000 m in the Trough (BGS 1:50 000 sheet 20, Newcastle, 1989). This differential effect was less marked in the Namurian and almost died away in the Westphalian. A few conjugate faults are also of importance in the model area, having both sizeable throws and lateral persistence, for example, the Tantobie Fault is a number of parallel and interconnected faults trending in a WNW direction through the Breamish Burn to Tantobie and then splitting before joining the Ninety Fathom Fault north of Leadgate.

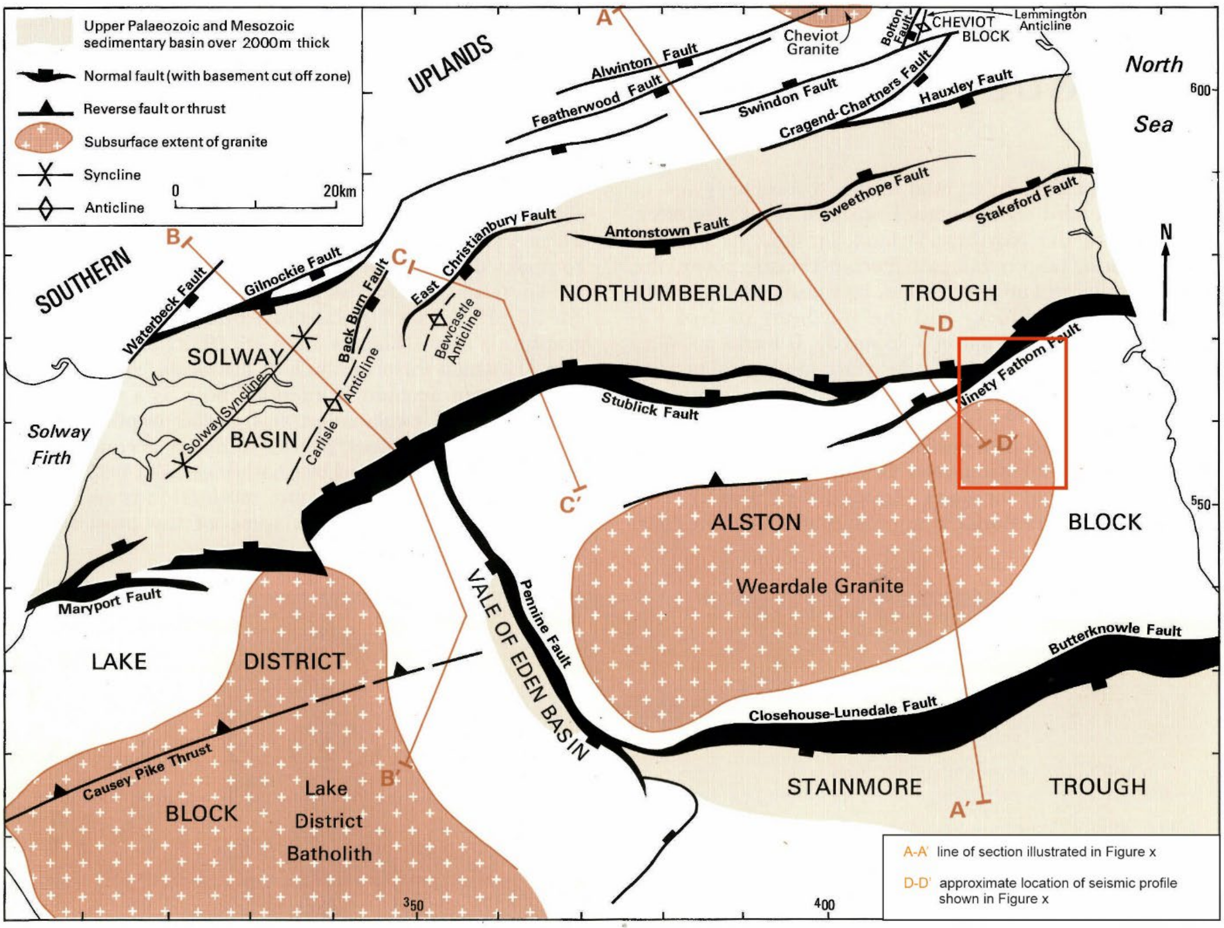

Figure 8: Principal subsurface structures influencing Carboniferous sedimentation in the region (Chadwick et al, 1995). 3D Bedrock model area is shown in red. BGS © UKRI 2024.

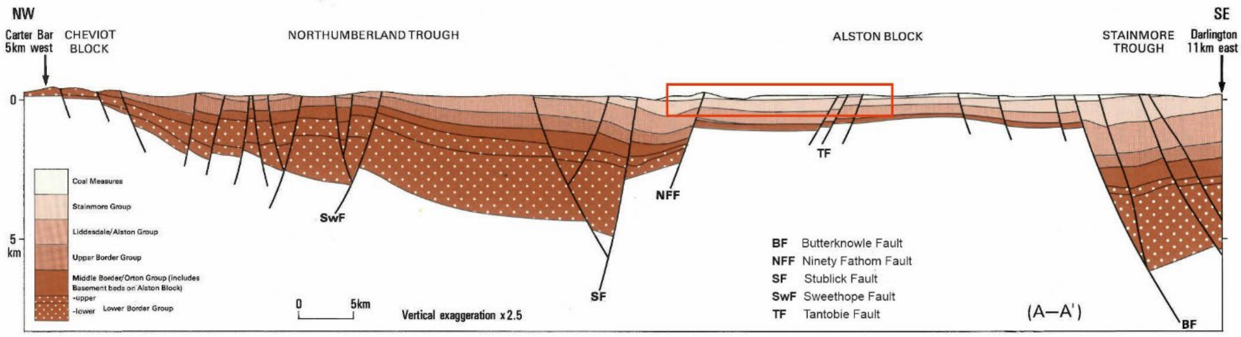

Figure 9: Section A-A' on Figure 8, cross-section illustrating the much thicker sequence of Carboniferous strata that was deposited within the Northumberland Trough (north of the Ninety Fathom Fault) than on the Alston Block (south of the Ninety Fathom Fault). (Chadwick et al, 1995). 3D Bedrock model area is shown in red. BGS © UKRI 2024.

2.5.1 The Ninety Fathom Fault

It has been confirmed by seismic reflection surveys that the Ninety Fathom Fault defines the boundary between the Alston Block and the Northumberland Trough, and is part of the regional Maryport–Stublick–Ninety Fathom fault system (Chadwick *et al*, 1995). It is one of the principal subsurface structures influencing Carboniferous sedimentation in the region (**Figure 8**) and in the area of the bedrock model. The Ninety Fathom Fault throws down the strata to the north by a significant amount (**Figure 9**); estimated to be up to 280 m in the Longbenton area (BGS map sheet NZ26NE, 1983). Seismic data suggests that the fault dips at a moderate angle (45-60 degrees) towards the north (**Figure 10**).

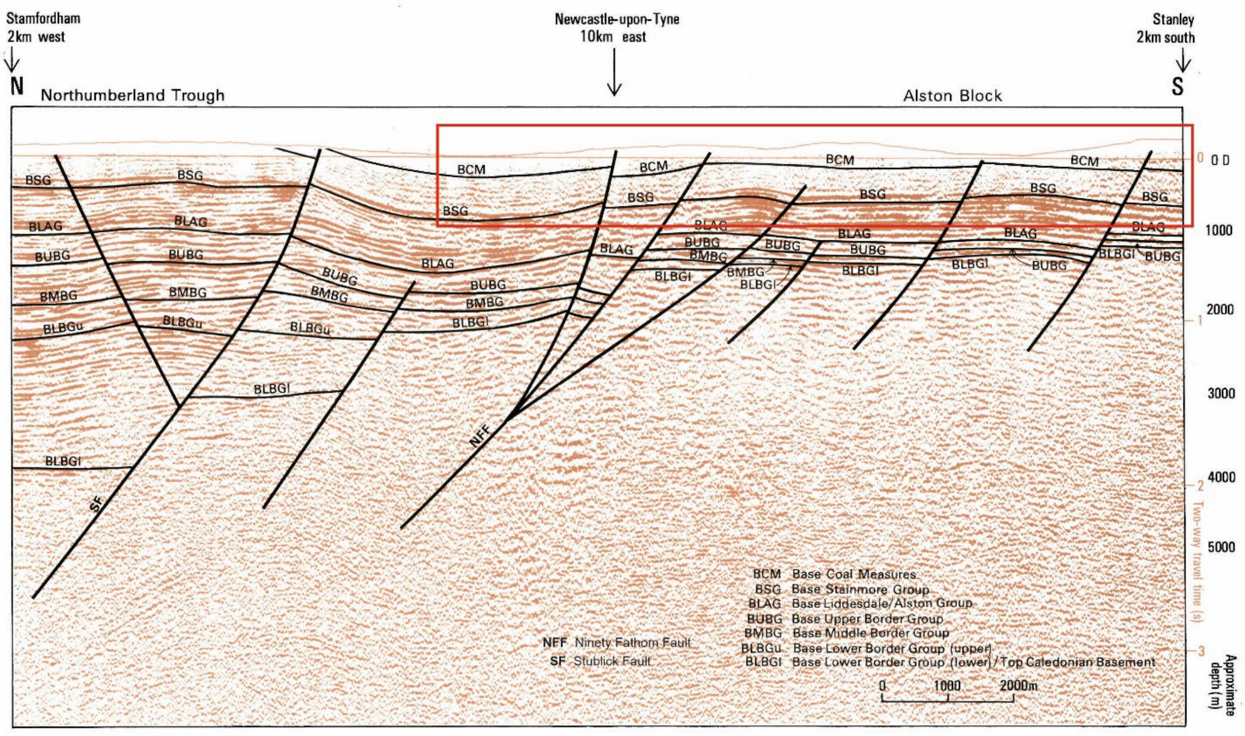

Figure 10: Section D-D' on Figure 8. Seismic reflection across the Stublick-Ninety Fathom fault system, which forms the southern margin of the Northumberland trough. SF Stublick Fault; NFF Ninety Fathom fault. Seismic data suggests that the Ninety Fathom fault dips at a moderate angle (45-60 degrees). (Chadwick et al, 1995). 3D Bedrock model area is shown in red. BGS © UKRI 2024.

2.5.2 Damage zones around modelled faults

The strata adjacent to faults is typically broken and disrupted because of movement along the fault plane. These 'damaged zones' were difficult/dangerous for miners to work and so were typically left unworked. These narrow linear unworked areas can be seen in the coal seam plans and inferred to represent fault damage zones; narrow zones may indicate a steep single fault plane; wider zones may indicate a fault zone with multiple sub parallel faults. The unworked width was measured from the gaps in the mine plans to get an indication of the damage zone on each of the modelled faults (**Figure 10**). Where possible measurements were taken along the length of the faults and across a range of coal seams to see what variation is present. Measurements were taken using the Mining Remedation Authority / Coal Authority mine plans.

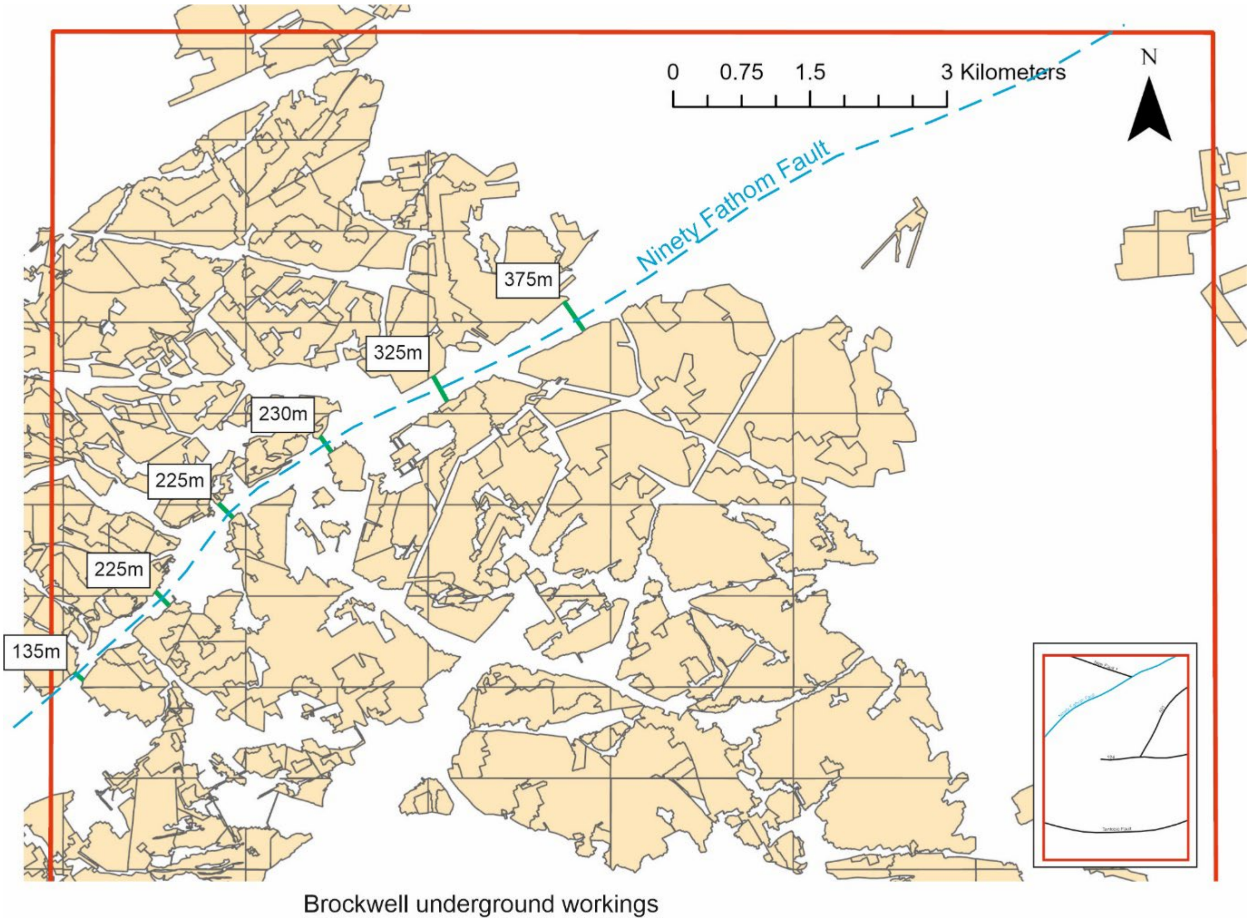

Figure 11: Mining Remedation Authority / Coal Authority seam plan showing areas (in beige) where the Brockwell Coal has been worked underground in the northern part of the modelled area. An ENE-WSW trending linear zone which has not been worked, highlights the position and approximate width of the 'damage zone' associated with the Ninety Fathom Fault. Reproduced with the permission of © Mining Remedation Authority / Coal Authority Coal Authority. All rights reserved.

Modelled Fault	Seam plan							
	High Main	Maudlin	Durham Low Main	Hutton	Harvey	Busty	Brockwell	Mix of seams
Ninety Fathom Fault	265m-410m				260m - 300m		135m-375m	
Tantobie Fault			225m - 510m	170m-500m		55m-330m		
Fault 3					355m-735m			670m-965m
Fault 1		60m-300m		25m-260m			45m-120m	
Fault 2	No evidence for fault				235m-310m		205m	

Table 1: Summary table showing the width of the damage zones associated with faults in the modelled area. BGS © UKRI 2024.

The results from the seam plans (**Table 1**) indicates that in general a damage zone of up to 500 m wide was observed. Faults with larger displacements which have undergone multiple phases of movement (e.g. the Ninety Fathom Fault) showed a wider damage zone, as do faults which are known to have a number of sub-parallel interconnected faults in a zone of weakness (e.g. the Tantobie Fault).

It is worth noting that an absence of workings could also be due to:

- The coal being washed out at the time of deposition by a river channel and replaced by a sandstone body. Typically seen in different places on different seams
- An igneous intrusion, e.g. a sill (intruding parallel to the strata) or a dyke (cutting through the strata); although relatively rare in this area ‘whin’ is recorded in borehole logs and can thermally and chemically alter the coal to make them worthless.
- An irregular rockhead surface, e.g. a deep valley or buried valley which has removed part of the coal seam. Typically seen in the same place through different seams (although lower seams should be intact) and are larger broader features

3 Methodology

3.1 LIST OF DATASETS USED IN THE BGS 3D GEOLOGICAL BEDROCK MODEL

The following section describes the main datasets used to inform the BGS Gateshead 3D geological bedrock model. Key datasets were:

- Digital Terrain Model
    - OS Open 50 DTM
- BGS borehole records
    - 126 BGS boreholes (see Appendix 1)
- Mining Remedation Authority / Coal Authority datasets
    - Underground workings
    - Seam Levels
- BGS geological maps
    - 1:50 000 scale bedrock geology map linework (British Geological Survey, 2009)

Initial observations of the base of the Pennine Lower Coal Measures Formation horizon and the associated fault geometries were taken from the Northumberland and Solway Basin regional 3D geological model (Terrington and Thorpe, 2013), which is based on the seismic interpretations in the Northumberland and Solway Basin Regional Subsurface Memoir (Chadwick *et al*., 1995).

3.1.1 Borehole data

Lithological and stratigraphical information from 173 boreholes were digitally coded and entered into BGS databases to build the 3D bedrock model (**Figure 12**). Borehole selection was based on three criteria; 1) borehole ideally penetrated more than 100 m of strata so it passed through multiple marker horizons, 2) coal seams were already identified and named on the scanned log, and 3) boreholes were spread across the model area to give an even distribution of data points. Of the 173 boreholes, 126 were used in the final model; 47 boreholes were excluded due to their proximity to faults and/or uncertainty about the identification of the coal seams.

It should be noted that; many of these boreholes were logged in fathoms, feet and inches, so the depth values were converted to metric and rounded to the nearest metre; hand written borehole logs could be difficult to read and often used mining terms which were unique to the local area, these were interpreted and converted into modern rock types found in the BGS Rock Classification Scheme. Some coal seams and marine bands were identified with local names in borehole logs and were correlated using published tables to determine the regional seam name. The stratigraphic markers present in each borehole, and used in the construction of the model, can be seen in Appendix 1.

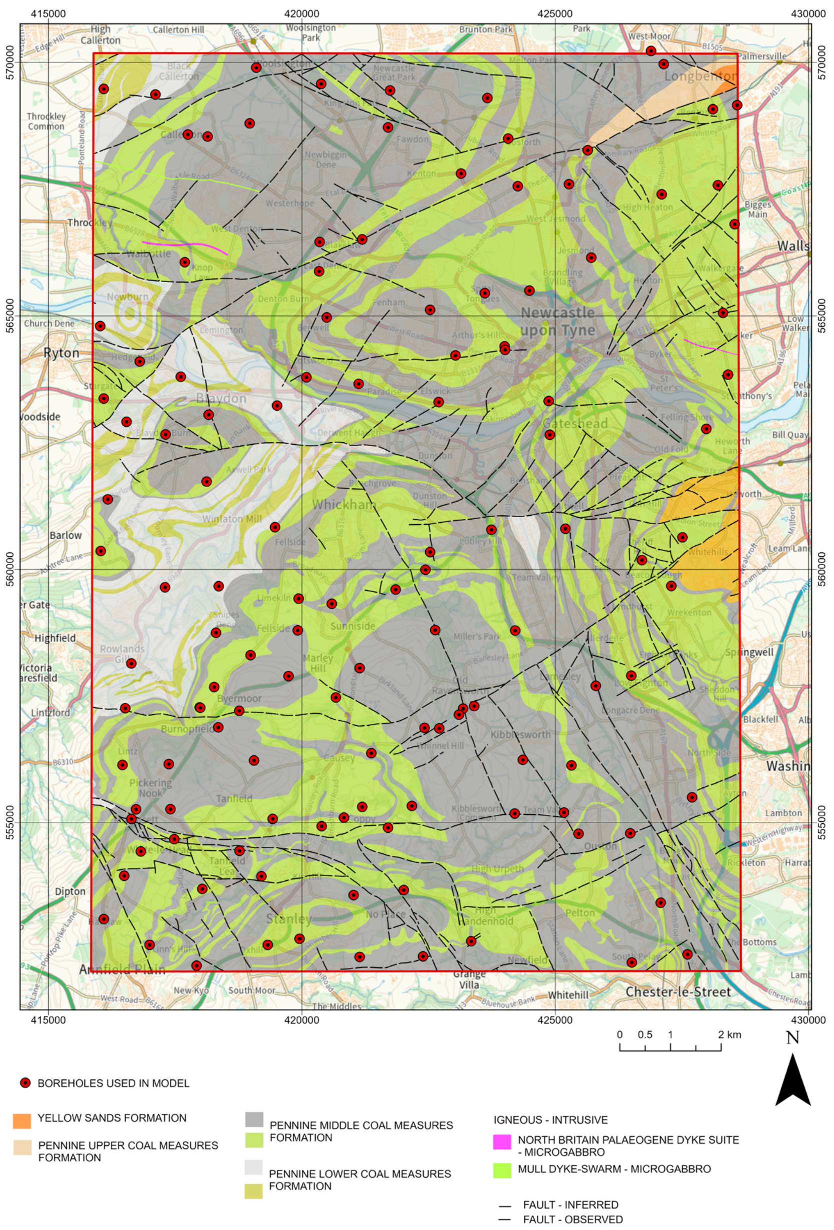

Figure 12: Location of boreholes used in the construction of the 3D bedrock model. Contains OS data © Crown copyright and database rights 2024. BGS © UKRI 2024.

3.1.2 Mine Plan data

The digital mine plan data was supplied by the Mining Remedation Authority / Coal Authority on 29/06/23 and included:

- Underground Working v0.5
- Seam Table v0.5
- Mine Entries v0.5
- In Seam Level v0.5
- In Seam Level Contours v0.5

The 'In Seam Level' and 'In Seam Level Contours' were used as an input into the 3D bedrock model.

3.1.3 Geological maps

Selected 'observed' (but no 'inferred') linework from the 1:50 000 scale BGS Digital Geological Map of Great Britain (v8) was used in the construction of some of the coal seam horizons.

3.2 MODELLING PROCESS

The BGS 3D bedrock model for the Newcastle-Gateshead area was constructed using Aspen SKUA™ (v14.2) using the Structure & Stratigraphy workflow. Due to the complexity of the geology and the variable spatial distribution of the control points (from borehole and mine plan data), an implicit geological modelling method (e.g. Cowan et al., 2003) was used where all geological units were modelled simultaneously using all the available data held and interpolated within a 3D scalar field. Rules were applied to ensure that stratigraphic relationships such as onlap and truncation at unconformities were honoured.

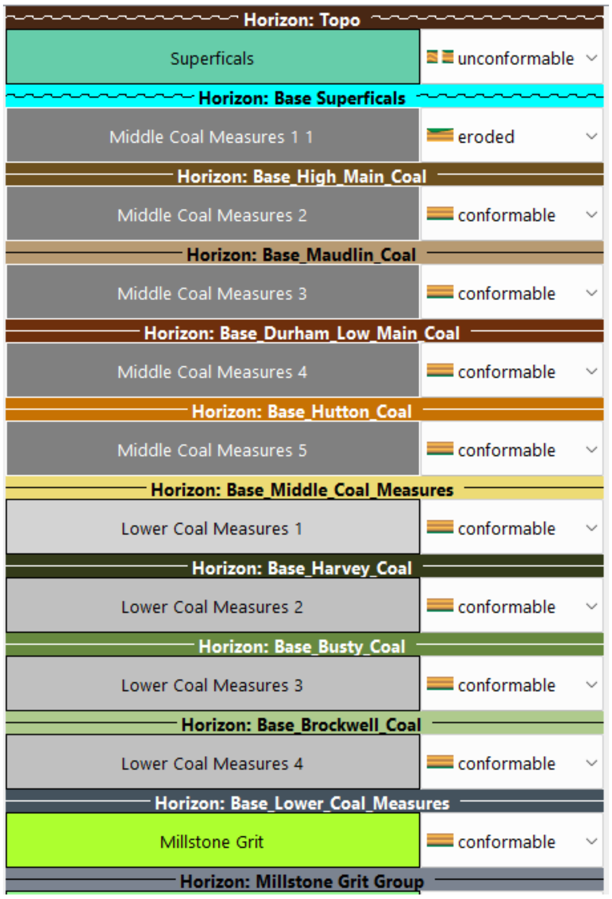

Figure 13: Stratigraphic column from the model showing the conformable and unconformable relationships of units. BGS © UKRI 2024.

The implicit model was constructed using a continuous 3D scalar field with a variable cell-size with an area equal to 127 m^2. The model extends down to -700 m OD.

3.3 FAULT MODELLING

The 1:50 000 scale BGS Digital Geological Map shows 230 mapped faults in the model area. However, the direction of throw, the amount of throw and the dip of the fault plane is not recorded on the digital map. It is good practice to only model faults that significantly displace strata in the model. To determine this, we used an iterative approach to identifying those to be included in the model. We started with the faults identified on seismic (**Figure 10**) which are the Ninety Fathom and Tantobie faults. We then used the borehole mismatch table to identify those areas where faults may be needed in the model and the relevant mapped faults were then added to the model.

4 Results

The implicit bedrock model contains volumes representing the Pennine Middle Coal Measures Formation, Pennine Lower Coal Measures Formation and Millstone Grit Group(**Figure 14**) and surfaces indicating the base of all the stratigraphic units (formations and coal seams) included in the model (**Figure 15**). The generalised underground mine working was also derived from the model which shows the predicted depths that recorded workings may be in the subsurface (**Figure 15**).

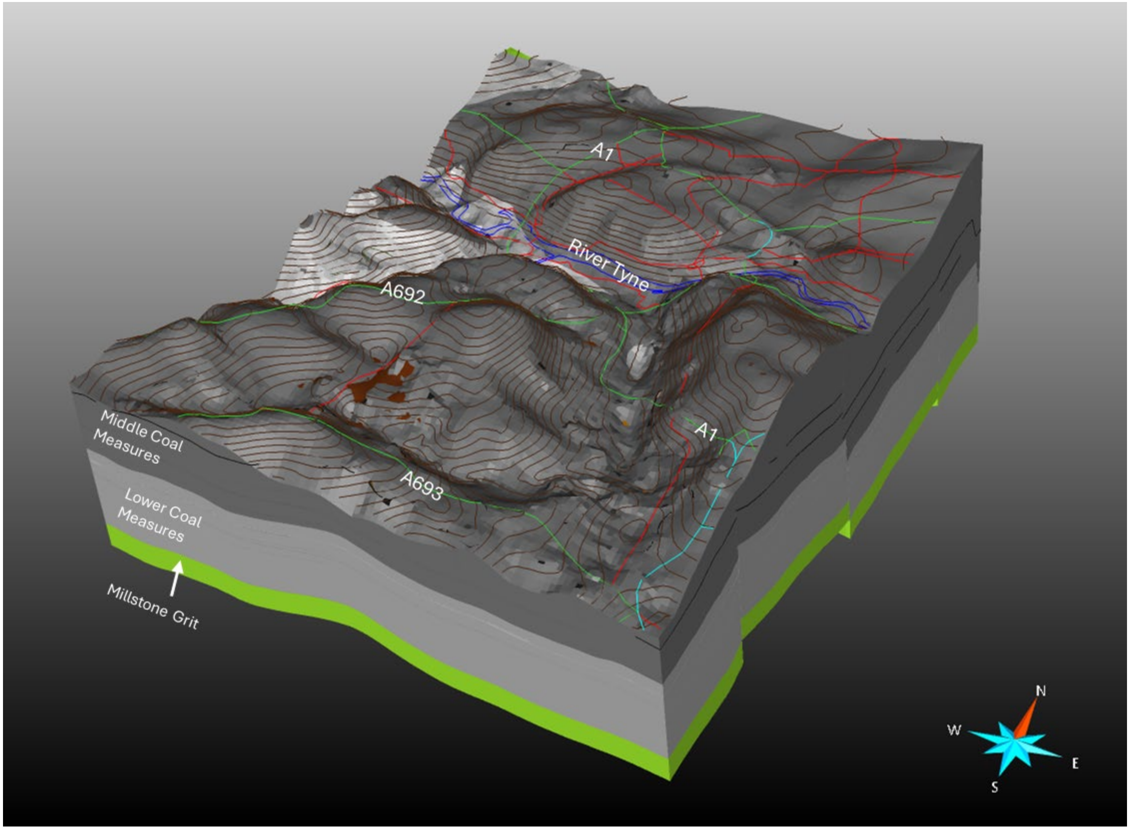

Figure 14: Image of the 3D volumes from the model with a vertical exhaduation of x5. BGS © UKRI 2024.

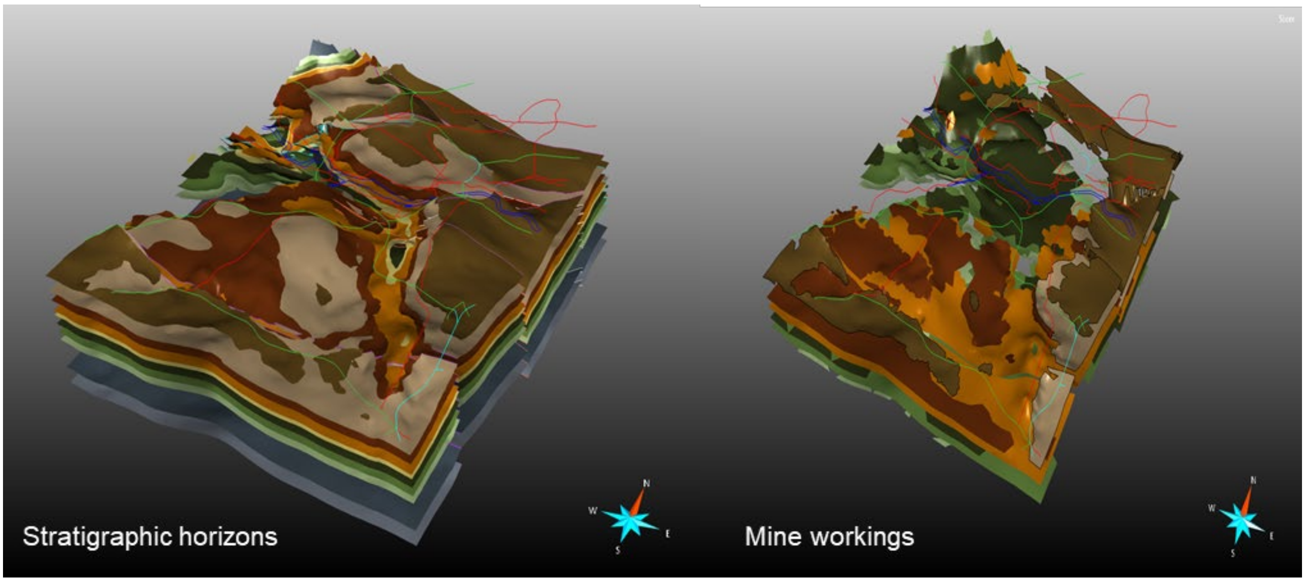

Figure 15: The stratigraphic horizons and the underground mine workings in 3D. BGS © UKRI 2024.

The final model contains five faults (**Figure 16**) all with an average displacement greater than 20 m for the strata modelled. This may be less than the published displacement for these faults (e.g. Ninety Fathom fault) because the model is only considering the displacement in the area of the model. The model does show increasing thickness variation across the Ninety Fathom Fault with younger strata – strata above the High Main Coal is 62 m thick north of the fault but 56 m in the footwall, whereas thickness difference is not present in the strata in Lower Coal Measures Formation and Millstone Grit Group. This suggests that the fault became increasingly active in the Pennine Middle Coal Measures Formation and affected the thickness of the sediment deposited.

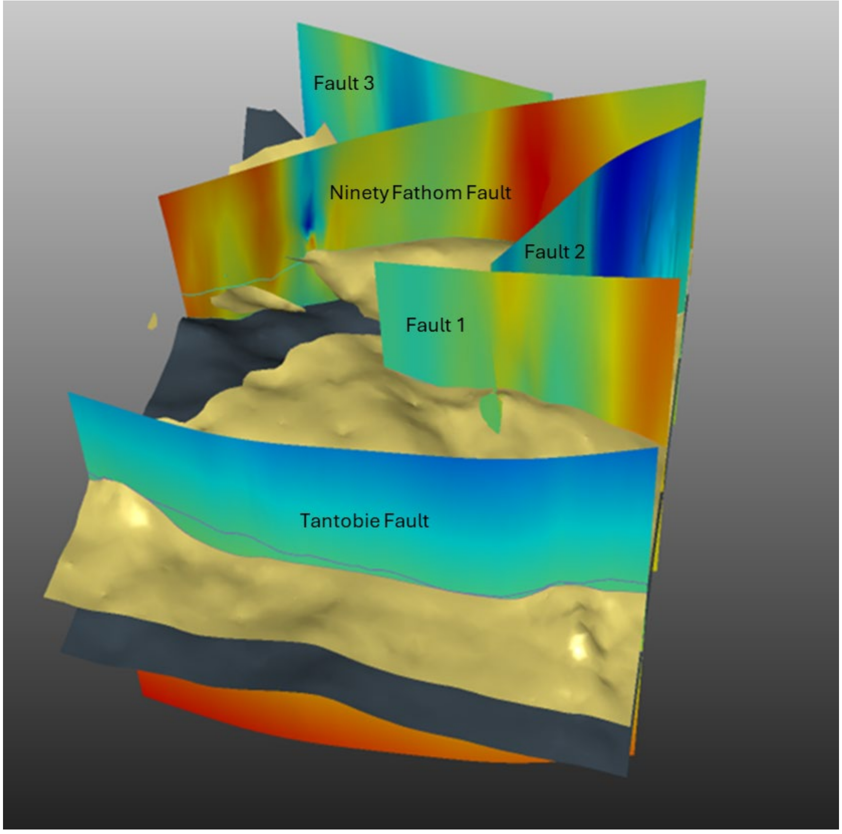

Figure 16: The modelled faults from the 3D model. The colour ramps on the faults is the displacement measured in the model BGS © UKRI 2024.

	Min (meters)	Mean (meters)	Max (meters)
Ninety Fathom	-103	60	143
Tantobie	-48	32	97
Fault 1	-20	22	99
Fault 2	-105	-38	52
Fault 3	-84	-25	36

Table 2: Amount of displacement across each of the five modelled faults. Displacement is calculated using the modelled surfaces on each side of the fault. BGS © UKRI 2024.

5 Model accuracy and limitations

Users should note that a 3D geological model is a generalisation of reality constrained by the data available at the time of the model construction. Users of the 3D geological model outputs do so at their own risk.

The 3D geological model is an interpretation only and actual ground conditions encountered may be different from those shown in the Gateshead 3D bedrock model.

5.1 GENERAL MODELLING LIMITATIONS

Geological modelling is an empirical approach. Interpretations are made according to the prevailing understanding of the geology at the time of survey. The quality of such interpretations may be affected by:

- availability of new data
- subsequent advances in geological knowledge
- improved methods of interpretation
- improved modelling software
- better access to sampling locations

In the BGS Gateshead 3D bedrock model, all faults have been modelled as discrete planes. However some of these faults can have zones up to several tens of metres wide containing several fractures, each one of which accommodates some displacement and associated fracture or damage zones that can extend tens of metres away from the main fault. In some strata, such as the Carboniferous, it is more common for a fault to be a zone of fractures rather than a single, discrete plane. The portrayal of such faults as a single line on a map or 3D geological model is therefore a generalisation. The position of a fault may be based on the interpretation of topographical features, surface outcrops, site investigation data and underground mining records, but the evidence is rarely sufficient to locate a fault or the extent of a fault zone precisely. In an area of thick and extensive superficial deposits, the positioning of faults at surface relies almost entirely on projection from subsurface data.

It is important to note that this 3D geological model represents an individual interpretation of the available data; other interpretations may be valid. The full complexity of the geology will not be represented by the model due to the spatial distribution of the data at the time of model construction and other limitations, including those set out elsewhere in this report. Best endeavours (detailed quality-checking procedures) are employed to minimise data entry errors but, given the diversity and volume of data used, it is anticipated that occasional erroneous entries will still be present (e.g. boreholes locations; elevations, etc). Any raw data considered when building geological models may have been transcribed from analogue to digital format; such processes are subject to quality control to ensure reliability, but undetected errors may exist.

Borehole ground levels are obtained from the original records, Ordnance Survey mapping or a DTM. Where borehole ground levels look unreasonable, they are checked and amended, if necessary, in the index file. In some cases, the borehole start height may be different from the ground surface of the DTM, if for example, the ground surface has been raised or lowered since the borehole was drilled, or if the borehole was not originally drilled at the ground surface.

5.2 MODEL UNCERTAINTY

The model was not forced to fit stratigraphical well markers because this ‘over fitted’ the model to the shallower data and at the target depths (i.e. caused local highs/lows not representative of the wider model). However, it is possible to use the difference between the observed position of a horizon and the modelled position of a horizon as an approximation of vertical error for each surface in the model. The average and maximum vertical errors, for each horizon are shown in

	Base Superficial	Base High Main Coal	Base Maudlin Coal	Base Durham Low Main Coal	Base Hutton Coal	Base Middle Coal Measures	Base Harvey Coal	Base Busty Coal	Base Brockwell Coal	Base Lower Coal Measures	Millstone Grit Group
Average (m)	4.2	5.1	9.9	10.1	5.3	1.0	1.3	1.1	-0.2	0.0	0.1
Maximum (m)	22.0	29.3	24.2	27.0	23.6	29.9	29.1	18.3	21.9	3.7	3.5

Table 3: Average and Maximum vertical error for all horizons in the model. BGS © UKRI 2024.

The modelling process also affects the horizontal accuracy (the geographical extent) of the modelled surfaces, as it simplifies the topography and the rockhead (base of the superficial deposits) surface. So, even though the 1:50 000 scale geological map linework (which shows where a horizon is known or expected to outcrop at rockhead) is used as an input to the model, the final modelled surfaces may show a significantly different outcrop pattern. The High Main Coal (**Figure 17A**) shows a good match between the geological map linework and the modelled outcrop of the coal, showing where the surface reaches rockhead or terminates against a fault. However, the modelled surfaces of the Maudlin Coal and Durham Low Main Coal match less well with linework on the geological map (**Figure 17B**). The difference in the mapped and modelled outcrop pattern is due largely to significant down sampling of the rockhead surface created by Whitbread et al. (2024) because of the reduced number of data points controlling the surface construction. Because the connections between the coal seams and superficial deposits is a key aim of the project, we will provide all the horizons with a version that come directly from the model and then those with the areas that project above the Whitbread et al. (2024) surface removed.

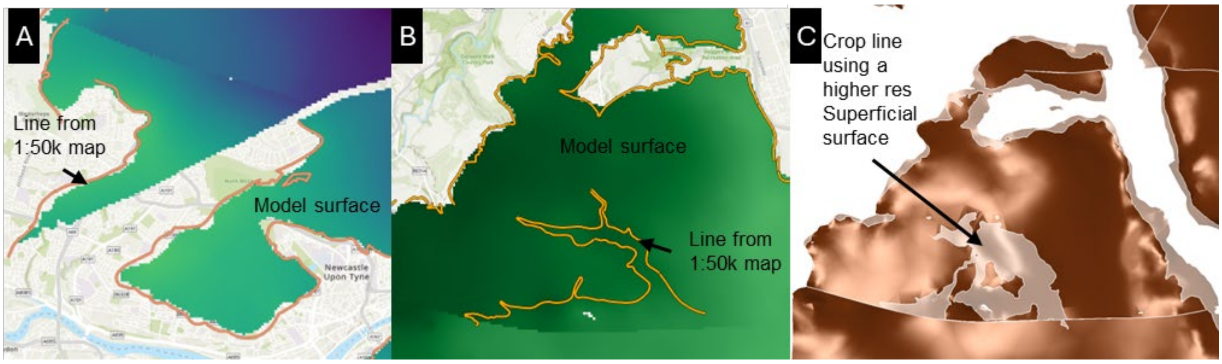

Figure 17: A) High Main Coal; the extent of the modelled surface matches well with the linework shown on the 1:50 000 scale geological map. B) The modelled extent of the Durham Low Main Coal differs significantly from the linework shown on the 1:50 000 scale geological map. C) the areas that are removed when the model is cut by Whitbread et al. (2024) rock head model. BGS © UKRI 2024.

Outcrop lines of the bedrock geology in the geological model may also differ from the geological map as only significant faults have been modelled and the geological map additionally shows many more minor faults. Due to the thick cover of superficial deposits across the area most of the outcrop lines on the geological map are inferred, as more data points become available, and our geological understanding of the area evolves the position of these crop lines will change.

6 Outputs from the model

The model surfaces have been outputted as .asc grids which are suitable for importing into ArcGIS.

Surfaced from the model:

- Base_High_Main_Coal_from_model_grid.asc
- Base_Maudlin_Coal_from_model_grid.asc
- Base_Durham_Low_Main_Coal_from_model_high_grid.asc
- Base_Hutton_Coal_from_model_grid.asc
- Base_Middle_Coal_Measures_grid.asc
- Base_Harvey_Coal_from_model_grid.asc
- Base_Busty_Coal_from_model_grid.asc
- Base_Brockwell_Coal_from_model_grid.asc
- Base_Lower_Coal_Measures_from_model_grid.asc
- Base_Millstone_Grit_Group_grid.asc

Surfaced from the model re-trimmed to Whitbread et al.(2024) rock head model:

- Base_High_Main_Coal_from_model_high_res_rh_grid.asc
- Base_Maudlin_Coal_from_model_high_res_rh_grid.asc
- Base_Durham_Low_Main_Coal_from_model_high_res_rh_grid.asc
- Base_Hutton_Coal_from_model_high_res_rh_grid.asc
- Base_Harvey_Coal_from_model_high_res_rh_grid.asc
- Base_Busty_Coal_from_model_high_res_rh_grid.asc
- Base_Brockwell_Coal_from_model_high_res_rh_grid.asc

Simplified underground mine workings:

- Worked_Base_High_Main_Coal_from_model_grid.asc
- Worked_Base_Maudlin_Coal_from_model_grid.asc
- Worked_Base_Durham_Low_Main_Coal_from_model_grid.asc
- Worked_Base_Hutton_Coal_from_model_grid.asc
- Worked_Base_Harvey_Coal_from_model_grid.asc
- Worked_Base_Busty_Coal_from_model_grid.asc
- Worked_Base_Brockwell_Coal_from_model_grid.asc

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Appendix 1 List of boreholes

Borehole data:

Old boreholes were drilled primarily for mineral exploration and extended deep into the subsurface to verify the presence and quality of mineral seams prior to mining. These borehole typically pass through multiple horizons and are extremely valuable for the modelling process. However, the location of the borehole can be imprecise, start heights can be approximate and the measurements averaged to the nearest foot or even fathom. Also the terminology and handwriting can be a challenge to decipher.

Recent boreholes are typically drilled for ground investigation work and although strata is often described in detail and measurements are accurate, they generally only penetrate into the shallow subsurface.

A few deep boreholes have been drilled regionally which help our regionally understanding of the geology for hydrocarbon exploration.

BGS ID	BNG_EASTING	BNG_NORTHING	START_HEIGHT (mOD)	DRILLED_LENGTH (m)	Stratigraphic horizon	Depth to base (m)
789482	420390	0554930	101.25	117.3	Base Superficals	32
789482	420390	0554930	101.25	117.3	Base_Middle_Coal_Measures	54
789482	420390	0554930	101.25	117.3	Base_Harvey_Coal	62
789482	420390	0554930	101.25	117.3	Base_Busty_Coal	96
789486	421020	0553570	179	256.72	Base Superficals	6
789486	421020	0553570	179	256.72	Base_High_Main_Coal	38
789486	421020	0553570	179	256.72	Base_Durham_Low_Main_Coal	128
789486	421020	0553570	179	256.72	Base_Hutton_Coal	145
789486	421020	0553570	179	256.72	Base_Harvey_Coal	194
789486	421020	0553570	179	256.72	Base_Middle_Coal_Measures	207
789486	421020	0553570	179	256.72	Base_Busty_Coal	221
789486	421020	0553570	179	256.72	Base_Brockwell_Coal	251
789518	422010	0553670	149	115.52	Base Superficals	4
789518	422010	0553670	149	115.52	Base_High_Main_Coal	19
789518	422010	0553670	149	115.52	Base_Durham_Low_Main_Coal	97
789518	422010	0553670	149	115.52	Base_Middle_Coal_Measures	114
789530	421700	0554900	183	122.84	Base Superficals	7
789594	421140	0552350	164.66	170.69	Base Superficals	10
789594	421140	0552350	164.66	170.69	Base_Hutton_Coal	107
789594	421140	0552350	164.66	170.69	Base_Middle_Coal_Measures	138
789594	421140	0552350	164.66	170.69	Base_Harvey_Coal	152
789607	422390	0552360	143	221.95	Base Superficals	33
789607	422390	0552360	143	221.95	Base_Durham_Low_Main_Coal	82
789607	422390	0552360	143	221.95	Base_Hutton_Coal	102
789607	422390	0552360	143	221.95	Base_Harvey_Coal	149
789607	422390	0552360	143	221.95	Base_Busty_Coal	187
789609	423340	0552660	109.73	116.87	Base Superficals	8
789609	423340	0552660	109.73	116.87	Base_Durham_Low_Main_Coal	92

789609	423340	0552660	109.73	116.87	Base_Hutton_Coal	115
813572	417300	0559644	55.09	79.04	Base Superficals	34
813578	418359	0559665	74.01	68.28	Base_Brockwell_Coal	44
813592	419936	0559420	147.22	60.96	Base Superficals	5
813592	419936	0559420	147.22	60.96	Base_Durham_Low_Main_Coal	10
813592	419936	0559420	147.22	60.96	Base_Hutton_Coal	33
813598	416459	0556139	192.94	143.64	Base Superficals	6
813598	416459	0556139	192.94	143.64	Base_Durham_Low_Main_Coal	30
813598	416459	0556139	192.94	143.64	Base_Hutton_Coal	38
813598	416459	0556139	192.94	143.64	Base_Middle_Coal_Measures	68
813598	416459	0556139	192.94	143.64	Base_Busty_Coal	111
813598	416459	0556139	192.94	143.64	Base_Brockwell_Coal	141
813600	416514	0557258	122.65	67.06	Base Superficals	7
813600	416514	0557258	122.65	67.06	Base_Harvey_Coal	9
813600	416514	0557258	122.65	67.06	Base_Busty_Coal	33
813600	416514	0557258	122.65	67.06	Base_Brockwell_Coal	63
813623	417373	0556155	219.05	199.74	Base_Durham_Low_Main_Coal	75
813623	417373	0556155	219.05	199.74	Base_Hutton_Coal	87
813623	417373	0556155	219.05	199.74	Base_Middle_Coal_Measures	113
813623	417373	0556155	219.05	199.74	Base_Harvey_Coal	134
813623	417373	0556155	219.05	199.74	Base_Busty_Coal	163
813623	417373	0556155	219.05	199.74	Base_Brockwell_Coal	193
813637	417983	0557274	185.14	100.58	Base Superficals	5
813637	417983	0557274	185.14	100.58	Base_Durham_Low_Main_Coal	26
813637	417983	0557274	185.14	100.58	Base_Hutton_Coal	34
813637	417983	0557274	185.14	100.58	Base_Middle_Coal_Measures	66
813637	417983	0557274	185.14	100.58	Base_Harvey_Coal	82
813638	417995	0557267	185.5	140.51	Base Superficals	0
813638	417995	0557267	185.5	140.51	Base_Durham_Low_Main_Coal	20
813638	417995	0557267	185.5	140.51	Base_Hutton_Coal	35
813638	417995	0557267	185.5	140.51	Base_Middle_Coal_Measures	66
813638	417995	0557267	185.5	140.51	Base_Harvey_Coal	80
813638	417995	0557267	185.5	140.51	Base_Busty_Coal	112
813638	417995	0557267	185.5	140.51	Base_Brockwell_Coal	138
813656	418350	0556880	183	68.86	Base Superficals	1
813656	418350	0556880	183	68.86	Base_Hutton_Coal	52
813656	418350	0556880	183	68.86	Base_Middle_Coal_Measures	55
813657	418305	0558747	124.39	101.19	Base Superficals	0
813657	418305	0558747	124.39	101.19	Base_Middle_Coal_Measures	10
813657	418305	0558747	124.39	101.19	Base_Harvey_Coal	28
813657	418305	0558747	124.39	101.19	Base_Busty_Coal	57
813657	418305	0558747	124.39	101.19	Base_Brockwell_Coal	86
813661	418269	0557676	177.7	100.58	Base Superficals	5
813661	418269	0557676	177.7	100.58	Base_Durham_Low_Main_Coal	18

813661	418269	0557676	177.7	100.58	Base_Hutton_Coal	34
813661	418269	0557676	177.7	100.58	Base_Middle_Coal_Measures	64
813661	418269	0557676	177.7	100.58	Base_Harvey_Coal	78
813663	418763	0557206	183	160.35	Base_Durham_Low_Main_Coal	35
813663	418763	0557206	183	160.35	Base_Middle_Coal_Measures	52
813663	418763	0557206	183	160.35	Base_Hutton_Coal	53
813663	418763	0557206	183	160.35	Base_Harvey_Coal	102
813663	418763	0557206	183	160.35	Base_Busty_Coal	126
813663	418763	0557206	183	160.35	Base_Brockwell_Coal	147
813665	418987	0558305	174.13	171.68	Base Superficals	6
813665	418987	0558305	174.13	171.68	Base_Durham_Low_Main_Coal	33
813665	418987	0558305	174.13	171.68	Base_Hutton_Coal	45
813665	418987	0558305	174.13	171.68	Base_Middle_Coal_Measures	71
813665	418987	0558305	174.13	171.68	Base_Busty_Coal	114
813665	418987	0558305	174.13	171.68	Base_Brockwell_Coal	146
813670	419918	0558794	172.67	100.15	Base Superficals	6
813670	419918	0558794	172.67	100.15	Base_Durham_Low_Main_Coal	45
813670	419918	0558794	172.67	100.15	Base_Hutton_Coal	52
813670	419918	0558794	172.67	100.15	Base_Middle_Coal_Measures	83
813670	419918	0558794	172.67	100.15	Base_Harvey_Coal	96
813694	416727	0555263	210.62	111.25	Base Superficals	4
813694	416727	0555263	210.62	111.25	Base_Durham_Low_Main_Coal	52
813694	416727	0555263	210.62	111.25	Base_Hutton_Coal	63
813694	416727	0555263	210.62	111.25	Base_Middle_Coal_Measures	101
813696	417406	0555265	216.19	198.68	Base Superficals	7
813696	417406	0555265	216.19	198.68	Base_Durham_Low_Main_Coal	68
813696	417406	0555265	216.19	198.68	Base_Hutton_Coal	78
813696	417406	0555265	216.19	198.68	Base_Middle_Coal_Measures	108
813696	417406	0555265	216.19	198.68	Base_Harvey_Coal	125
813696	417406	0555265	216.19	198.68	Base_Busty_Coal	150
813696	417406	0555265	216.19	198.68	Base_Brockwell_Coal	179
813709	419423	0555073	146	138.17	Base_Durham_Low_Main_Coal	22
813709	419423	0555073	146	138.17	Base_Hutton_Coal	31
813709	419423	0555073	146	138.17	Base_Middle_Coal_Measures	53
813709	419423	0555073	146	138.17	Base_Harvey_Coal	76
813709	419423	0555073	146	138.17	Base_Busty_Coal	108
813775	416636	0555073	236.28	115.37	Base Superficals	2
813775	416636	0555073	236.28	115.37	Base_Durham_Low_Main_Coal	22
813775	416636	0555073	236.28	115.37	Base_Middle_Coal_Measures	72
813881	416634	0558141	43.11	242.89	Base_Lower_Coal_Measures	57
813881	416634	0558141	43.11	242.89	Millstone Grit Group	111
813881	416634	0558141	43.11	242.89	Stainmore Formation	243
817821	416090	0569480	124.97	121.92	Base Superficals	4

817821	416090	0569480	124.97	121.92	Base_Lower_Coal_Measures	73
817842	417750	0568580	75	103.63	Base_Maudlin_Coal	20
817842	417750	0568580	75	103.63	Base_Durham_Low_Main_Coal	50
817844	418140	0568540	76	129.85	Base_Maudlin_Coal	42
817844	418140	0568540	76	129.85	Base_Durham_Low_Main_Coal	75
817849	418970	0568800	77.85	133.78	Base_Maudlin_Coal	67
817849	418970	0568800	77.85	133.78	Base_Durham_Low_Main_Coal	89
817849	418970	0568800	77.85	133.78	Base_Hutton_Coal	107
817857	417690	0566060	87	160.33	Base_Durham_Low_Main_Coal	30
817857	417690	0566060	87	160.33	Base_Harvey_Coal	93
817857	417690	0566060	87	160.33	Base_Brockwell_Coal	158
843248	426890	0570230	50.99	509.83	Base Superficals	11
843248	426890	0570230	50.99	509.83	Base_High_Main_Coal	229
843248	426890	0570230	50.99	509.83	Base_Maudlin_Coal	288
843248	426890	0570230	50.99	509.83	Base_Durham_Low_Main_Coal	317
843248	426890	0570230	50.99	509.83	Base_Middle_Coal_Measures	376
843248	426890	0570230	50.99	509.83	Base_Harvey_Coal	396
843248	426890	0570230	50.99	509.83	Base_Busty_Coal	440
843248	426890	0570230	50.99	509.83	Base_Brockwell_Coal	477
852708	416091	0553097	254	131.47	Base Superficals	5
852708	416091	0553097	254	131.47	Base_High_Main_Coal	48
852708	416091	0553097	254	131.47	Base_Middle_Coal_Measures	130
852760	416821	0554431	259	76.5	Base Superficals	2
852760	416821	0554431	259	76.5	Base_High_Main_Coal	56
852766	416493	0553951	256.03	142.29	Base Superficals	7
852766	416493	0553951	256.03	142.29	Base_High_Main_Coal	49
852774	418035	0553692	158	106.91	Base Superficals	20
852774	418035	0553692	158	106.91	Base_Durham_Low_Main_Coal	94
852774	418035	0553692	158	106.91	Base_Middle_Coal_Measures	100
852774	418035	0553692	158	106.91	Base_Hutton_Coal	101
852783	418769	0554443	152	232.41	Base Superficals	20
852783	418769	0554443	152	232.41	Base_Durham_Low_Main_Coal	105
852783	418769	0554443	152	232.41	Base_Hutton_Coal	112
852783	418769	0554443	152	232.41	Base_Middle_Coal_Measures	146
852783	418769	0554443	152	232.41	Base_Harvey_Coal	161
852783	418769	0554443	152	232.41	Base_Busty_Coal	191
852823	416994	0552588	196.54	235.86	Base Superficals	11
852823	416994	0552588	196.54	235.86	Base_Durham_Low_Main_Coal	92
852823	416994	0552588	196.54	235.86	Base_Hutton_Coal	99
852823	416994	0552588	196.54	235.86	Base_Middle_Coal_Measures	136
852823	416994	0552588	196.54	235.86	Base_Harvey_Coal	156
852823	416994	0552588	196.54	235.86	Base_Busty_Coal	186
852823	416994	0552588	196.54	235.86	Base_Brockwell_Coal	216

852825	417922	0552177	234.09	309.63	Base Superficals	15
852825	417922	0552177	234.09	309.63	Base_High_Main_Coal	52
852825	417922	0552177	234.09	309.63	Base_Durham_Low_Main_Coal	145
852825	417922	0552177	234.09	309.63	Base_Hutton_Coal	152
852825	417922	0552177	234.09	309.63	Base_Middle_Coal_Measures	182
852825	417922	0552177	234.09	309.63	Base_Harvey_Coal	205
852825	417922	0552177	234.09	309.63	Base_Busty_Coal	240
852827	419954	0552708	229	316.38	Base Superficals	5
852827	419954	0552708	229	316.38	Base_Maudlin_Coal	155
852827	419954	0552708	229	316.38	Base_Durham_Low_Main_Coal	171
852827	419954	0552708	229	316.38	Base_Hutton_Coal	180
852827	419954	0552708	229	316.38	Base_Middle_Coal_Measures	216
852827	419954	0552708	229	316.38	Base_Harvey_Coal	227
852827	419954	0552708	229	316.38	Base_Busty_Coal	256
852828	419326	0552587	227	303.12	Base_Middle_Coal_Measures	220
852828	419326	0552587	227	303.12	Base_Harvey_Coal	225
852828	419326	0552587	227	303.12	Base_Busty_Coal	267
852828	419326	0552587	227	303.12	Base_Brockwell_Coal	298
852995	417482	0554674	230.83	137.97	Base Superficals	6
868096	425800	0557700	21.34	53.44	Base Superficals	26
868096	425800	0557700	21.34	53.44	Base_Hutton_Coal	50
868100	427290	0559670	155.45	224.59	Base Superficals	8
868100	427290	0559670	155.45	224.59	Base_High_Main_Coal	122
868100	427290	0559670	155.45	224.59	Base_Durham_Low_Main_Coal	196
868100	427290	0559670	155.45	224.59	Base_Middle_Coal_Measures	223
868100	427290	0559670	155.45	224.59	Base_Hutton_Coal	225
868102	426500	0557900	90.22	127.22	Base Superficals	8
868102	426500	0557900	90.22	127.22	Base_High_Main_Coal	23
868102	426500	0557900	90.22	127.22	Base_Maudlin_Coal	99
868102	426500	0557900	90.22	127.22	Base_Durham_Low_Main_Coal	117
868177	427700	0555500	61	248.11	Base Superficals	8
868177	427700	0555500	61	248.11	Base_Durham_Low_Main_Coal	20
868177	427700	0555500	61	248.11	Base_Middle_Coal_Measures	49
868177	427700	0555500	61	248.11	Base_Hutton_Coal	50
868177	427700	0555500	61	248.11	Base_Harvey_Coal	63
868177	427700	0555500	61	248.11	Base_Brockwell_Coal	173
868183	425320	0556130	30.48	69.49	Base Superficals	14
868183	425320	0556130	30.48	69.49	Base_Maudlin_Coal	54
868183	425320	0556130	30.48	69.49	Base_Durham_Low_Main_Coal	55
868318	425172	0555200	49.04	66.45	Base_Durham_Low_Main_Coal	54
873857	420670	0557470	176.81	161.56	Base Superficals	4
873857	420670	0557470	176.81	161.56	Base_Durham_Low_Main_Coal	46
873857	420670	0557470	176.81	161.56	Base_Hutton_Coal	61
873857	420670	0557470	176.81	161.56	Base_Harvey_Coal	104

873857	420670	0557470	176.81	161.56	Base_Middle_Coal_Measures	104
873857	420670	0557470	176.81	161.56	Base_Busty_Coal	135
873858	420590	0559320	123.35	78.46	Base Superficals	14
873858	420590	0559320	123.35	78.46	Base_Middle_Coal_Measures	45
874046	421140	0558050	187.66	168.81	Base Superficals	5
874046	421140	0558050	187.66	168.81	Base_Durham_Low_Main_Coal	70
874046	421140	0558050	187.66	168.81	Base_Hutton_Coal	82
874046	421140	0558050	187.66	168.81	Base_Middle_Coal_Measures	114
874046	421140	0558050	187.66	168.81	Base_Harvey_Coal	126
874057	422420	0556870	162.27	214.81	Base Superficals	12
874057	422420	0556870	162.27	214.81	Base_Durham_Low_Main_Coal	76
874057	422420	0556870	162.27	214.81	Base_Hutton_Coal	88
874057	422420	0556870	162.27	214.81	Base_Middle_Coal_Measures	126
874057	422420	0556870	162.27	214.81	Base_Harvey_Coal	135
874057	422420	0556870	162.27	214.81	Base_Busty_Coal	166
874060	422630	0558800	149.81	192.02	Base Superficals	8
874060	422630	0558800	149.81	192.02	Base_Maudlin_Coal	47
874060	422630	0558800	149.81	192.02	Base_Durham_Low_Main_Coal	55
874060	422630	0558800	149.81	192.02	Base_Middle_Coal_Measures	71
874060	422630	0558800	149.81	192.02	Base_Hutton_Coal	74
874060	422630	0558800	149.81	192.02	Base_Harvey_Coal	125
874060	422630	0558800	149.81	192.02	Base_Busty_Coal	149
874060	422630	0558800	149.81	192.02	Base_Brockwell_Coal	174
874074	424210	0558790	26	100.42	Base Superficals	10
874074	424210	0558790	26	100.42	Base_Durham_Low_Main_Coal	13
874074	424210	0558790	26	100.42	Base_Middle_Coal_Measures	33
874074	424210	0558790	26	100.42	Base_Hutton_Coal	35
874074	424210	0558790	26	100.42	Base_Harvey_Coal	83
874118	424200	0555180	69	85.75	Base Superficals	18
874118	424200	0555180	69	85.75	Base_Maudlin_Coal	54
874118	424200	0555180	69	85.75	Base_Durham_Low_Main_Coal	76
874118	424200	0555180	69	85.75	Base_Hutton_Coal	85
874122	420830	0555100	115.28	109.42	Base_Middle_Coal_Measures	62
874122	420830	0555100	115.28	109.42	Base_Harvey_Coal	72
874122	420830	0555100	115.28	109.42	Base_Busty_Coal	105
874126	421190	0555310	128.28	116.74	Base Superficals	6
874126	421190	0555310	128.28	116.74	Base_Durham_Low_Main_Coal	34
874126	421190	0555310	128.28	116.74	Base_Hutton_Coal	41
874126	421190	0555310	128.28	116.74	Base_Middle_Coal_Measures	78
874126	421190	0555310	128.28	116.74	Base_Harvey_Coal	86
874126	421190	0555310	128.28	116.74	Base_Busty_Coal	115
874130	421850	0559600	99.79	94.84	Base Superficals	5
874130	421850	0559600	99.79	94.84	Base_Hutton_Coal	13

874130	421850	0559600	99.79	94.84	Base_Middle_Coal_Measures	49
874130	421850	0559600	99.79	94.84	Base_Harvey_Coal	66
874130	421850	0559600	99.79	94.84	Base_Busty_Coal	93
874146	423400	0557300	94.73	188.21	Base Superficals	7
874146	423400	0557300	94.73	188.21	Base_Maudlin_Coal	47
874146	423400	0557300	94.73	188.21	Base_Durham_Low_Main_Coal	62
874146	423400	0557300	94.73	188.21	Base_Hutton_Coal	73
874146	423400	0557300	94.73	188.21	Base_Harvey_Coal	121
874146	423400	0557300	94.73	188.21	Base_Middle_Coal_Measures	121
874146	423400	0557300	94.73	188.21	Base_Busty_Coal	154
874150	422710	0556860	149.2	195.68	Base Superficals	9
874150	422710	0556860	149.2	195.68	Base_Durham_Low_Main_Coal	71
874150	422710	0556860	149.2	195.68	Base_Middle_Coal_Measures	82
874150	422710	0556860	149.2	195.68	Base_Hutton_Coal	84
874150	422710	0556860	149.2	195.68	Base_Busty_Coal	162
874150	422710	0556860	149.2	195.68	Base_Brockwell_Coal	192
874151	423180	0557250	115.82	183.49	Base Superficals	11
874151	423180	0557250	115.82	183.49	Base_Maudlin_Coal	35
874151	423180	0557250	115.82	183.49	Base_Durham_Low_Main_Coal	53
874151	423180	0557250	115.82	183.49	Base_Hutton_Coal	71
874151	423180	0557250	115.82	183.49	Base_Harvey_Coal	116
874151	423180	0557250	115.82	183.49	Base_Middle_Coal_Measures	116
874151	423180	0557250	115.82	183.49	Base_Busty_Coal	148
874152	423100	0557130	124.33	184.86	Base Superficals	11
874152	423100	0557130	124.33	184.86	Base_Maudlin_Coal	39
874152	423100	0557130	124.33	184.86	Base_Durham_Low_Main_Coal	61
874152	423100	0557130	124.33	184.86	Base_Middle_Coal_Measures	78
874152	423100	0557130	124.33	184.86	Base_Hutton_Coal	80
874152	423100	0557130	124.33	184.86	Base_Harvey_Coal	125
874152	423100	0557130	124.33	184.86	Base_Busty_Coal	157
874163	422170	0555330	106.86	123.44	Base_Middle_Coal_Measures	95
874163	422170	0555330	106.86	123.44	Base_Harvey_Coal	105
874228	424360	0556240	73.43	225.17	Base Superficals	9
874228	424360	0556240	73.43	225.17	Base_Durham_Low_Main_Coal	92
874228	424360	0556240	73.43	225.17	Base_Middle_Coal_Measures	104
874228	424360	0556240	73.43	225.17	Base_Hutton_Coal	105
874228	424360	0556240	73.43	225.17	Base_Harvey_Coal	150
875452	426480	0554790	32	166.99	Base Superficals	36
875452	426480	0554790	32	166.99	Base_Middle_Coal_Measures	68
875452	426480	0554790	32	166.99	Base_Hutton_Coal	69
875452	426480	0554790	32	166.99	Base_Busty_Coal	144
875454	427080	0553420	35.3	88.39	Base Superficals	35
875454	427080	0553420	35.3	88.39	Base_Durham_Low_Main_Coal	76

875464	426510	0552240	56	190	Base Superficals	18
875464	426510	0552240	56	190	Base_Maudlin_Coal	82
875464	426510	0552240	56	190	Base_Durham_Low_Main_Coal	98
875464	426510	0552240	56	190	Base_Middle_Coal_Measures	112
875464	426510	0552240	56	190	Base_Hutton_Coal	114
875464	426510	0552240	56	190	Base_Harvey_Coal	178
875464	426510	0552240	56	190	Base_Busty_Coal	190
875472	427610	0552400	24.99	85.34	Base Superficals	12
875472	427610	0552400	24.99	85.34	Base_Hutton_Coal	84
875576	425460	0554780	60	109.11	Base Superficals	19
875576	425460	0554780	60	109.11	Base_Maudlin_Coal	55
875576	425460	0554780	60	109.11	Base_Durham_Low_Main_Coal	68
875576	425460	0554780	60	109.11	Base_Middle_Coal_Measures	108
879722	427140	0569970	52	225.9	Aegiranum Marine Band	113
879723	428590	0569160	40	166.52	Base_High_Main_Coal	166
879733	425640	0568270	48	333.78	Base_High_Main_Coal	65
879733	425640	0568270	48	333.78	Base_Maudlin_Coal	118
879733	425640	0568270	48	333.78	Base_Durham_Low_Main_Coal	155
879733	425640	0568270	48	333.78	Base_Hutton_Coal	161
879733	425640	0568270	48	333.78	Base_Harvey_Coal	230
879733	425640	0568270	48	333.78	Base_Busty_Coal	267
879733	425640	0568270	48	333.78	Base_Brockwell_Coal	296
879737	425710	0566150	50	191.87	Base_Maudlin_Coal	124
879737	425710	0566150	50	191.87	Base_Durham_Low_Main_Coal	165
879747	427100	0567400	61	145.74	Base_High_Main_Coal	142
879748	428210	0567580	-168	176.48	Base_Durham_Low_Main_Coal	27
879748	428210	0567580	-168	176.48	Base_Hutton_Coal	39
879748	428210	0567580	-168	176.48	Base_Harvey_Coal	101
879748	428210	0567580	-168	176.48	Base_Busty_Coal	142
879748	428210	0567580	-168	176.48	Base_Brockwell_Coal	176
879752	428540	0566810	36	353.23	Base_High_Main_Coal	174
879752	428540	0566810	36	353.23	Base_Maudlin_Coal	230
879752	428540	0566810	36	353.23	Base_Durham_Low_Main_Coal	253
879752	428540	0566810	36	353.23	Base_Hutton_Coal	267
879752	428540	0566810	36	353.23	Base_Harvey_Coal	329
879752	428540	0566810	36	353.23	Base_Brockwell_Coal	343
879789	428110	0569080	61	149.35	Base_High_Main_Coal	149
879814	428310	0565060	34	219.61	Base_High_Main_Coal	150
879814	428310	0565060	34	219.61	Base_Maudlin_Coal	215
883203	416090	0563370	85	151.18	Base_Durham_Low_Main_Coal	15
883203	416090	0563370	85	151.18	Base_Hutton_Coal	44
883203	416090	0563370	85	151.18	Base_Harvey_Coal	94
883203	416090	0563370	85	151.18	Base_Busty_Coal	123
883204	416020	0564800	8	84.05	Base_Busty_Coal	42
883204	416020	0564800	8	84.05	Base_Brockwell_Coal	67

883241	418160	0563050	62	87	Base_Hutton_Coal	9
883241	418160	0563050	62	87	Base_Harvey_Coal	59
883241	418160	0563050	62	87	Base_Busty_Coal	87
883249	416800	0564100	8	86.97	Base_Harvey_Coal	25
883249	416800	0564100	8	86.97	Base_Brockwell_Coal	81
883262	417610	0563800	13	85.42	Base_Busty_Coal	26
883262	417610	0563800	13	85.42	Base_Brockwell_Coal	47
883271	417310	0562660	103.02	107.28	Base_Hutton_Coal	8
883271	417310	0562660	103.02	107.28	Base_Harvey_Coal	54
883271	417310	0562660	103.02	107.28	Base_Busty_Coal	84
883271	417310	0562660	103.02	107.28	Base_Brockwell_Coal	107
883325	416170	0561380	133	66.7	Base_Harvey_Coal	17
883325	416170	0561380	133	66.7	Base_Busty_Coal	47
883325	416170	0561380	133	66.7	Base_Brockwell_Coal	67
883333	416030	0560360	157	91.44	Base_Harvey_Coal	37
883333	416030	0560360	157	91.44	Base_Busty_Coal	74
883333	416030	0560360	157	91.44	Base_Brockwell_Coal	91
883349	418120	0561730	109	93.27	Base_Harvey_Coal	42
883349	418120	0561730	109	93.27	Base_Busty_Coal	69
883365	419470	0560830	81	65.56	Base_Harvey_Coal	17
883365	419470	0560830	81	65.56	Base_Busty_Coal	42
883365	419470	0560830	81	65.56	Base_Brockwell_Coal	66
924342	420380	0569580	64.45	257.98	Base_High_Main_Coal	117
924342	420380	0569580	64.45	257.98	Base_Durham_Low_Main_Coal	207
924345	421740	0569450	57.91	322.22	Base_High_Main_Coal	79
924345	421740	0569450	57.91	322.22	Base_Middle_Coal_Measures	232
924345	421740	0569450	57.91	322.22	Base_Harvey_Coal	254
924345	421740	0569450	57.91	322.22	Base_Busty_Coal	290
924345	421740	0569450	57.91	322.22	Base_Brockwell_Coal	318
924347	423660	0569300	53.34	102.56	Base_High_Main_Coal	102
924355	420340	0565880	79.24	174.62	Base_Durham_Low_Main_Coal	39
924355	420340	0565880	79.24	174.62	Base_Middle_Coal_Measures	84
924355	420340	0565880	79.24	174.62	Base_Busty_Coal	143
924355	420340	0565880	79.24	174.62	Base_Brockwell_Coal	166
924359	421700	0568720	70.71	130.75	Base_High_Main_Coal	58
924370	424070	0568500	62	393.82	Base_High_Main_Coal	172
924370	424070	0568500	62	393.82	Base_Maudlin_Coal	226
924370	424070	0568500	62	393.82	Base_Durham_Low_Main_Coal	270
924375	424260	0567560	70.1	93.92	Base_Maudlin_Coal	93
924379	421190	0566510	92.65	64	Base_Durham_Low_Main_Coal	64
924387	422530	0565120	103	127.88	Base_High_Main_Coal	26
924387	422530	0565120	103	127.88	Base_Maudlin_Coal	80
924387	422530	0565120	103	127.88	Base_Durham_Low_Main_Coal	121
924388	423610	0565450	79.24	104.51	Base_Maudlin_Coal	56
924389	424490	0565500	66.45	113.46	Base_Maudlin_Coal	38

969689	422530	0560340	62.87	96.55	Base_Hutton_Coal	42
969733	420490	0564970	86	141.15	Base_Durham_Low_Main_Coal	82
969733	420490	0564970	86	141.15	Base_Hutton_Coal	113
969733	420490	0564970	86	141.15	Base_Harvey_Coal	141
969735	420090	0563790	5.18	93.37	Base_Harvey_Coal	59
969735	420090	0563790	5.18	93.37	Base_Busty_Coal	92
969739	421120	0563660	18	112.01	Base_Durham_Low_Main_Coal	33
969739	421120	0563660	18	112.01	Base_Harvey_Coal	108
969742	423030	0564220	99	192.94	Base_High_Main_Coal	24
969742	423030	0564220	99	192.94	Base_Maudlin_Coal	76
969742	423030	0564220	99	192.94	Base_Durham_Low_Main_Coal	125
969742	423030	0564220	99	192.94	Base_Harvey_Coal	187
969745	424000	0564400	61	236.62	Base_High_Main_Coal	9
969745	424000	0564400	61	236.62	Base_Maudlin_Coal	63
969745	424000	0564400	61	236.62	Base_Durham_Low_Main_Coal	112
969745	424000	0564400	61	236.62	Base_Harvey_Coal	172
970090	424870	0563320	0.54	61.5	Base_Durham_Low_Main_Coal	17
970090	424870	0563320	0.54	61.5	Base_Hutton_Coal	43
971039	424892	0562654	69.85	106.65	Base_High_Main_Coal	5
979470	427980	0562770	23	229.69	Base_High_Main_Coal	120
979470	427980	0562770	23	229.69	Base_Maudlin_Coal	180
979470	427980	0562770	23	229.69	Base_Durham_Low_Main_Coal	227
979478	425200	0560800	30	89.78	Base_Harvey_Coal	88
979484	426710	0560180	163	245.06	Base Superficals	0
979484	426710	0560180	163	245.06	Base_High_Main_Coal	96
979484	426710	0560180	163	245.06	Base_Maudlin_Coal	162
979484	426710	0560180	163	245.06	Base_Durham_Low_Main_Coal	178
979484	426710	0560180	163	245.06	Base_Middle_Coal_Measures	196
979484	426710	0560180	163	245.06	Base_Hutton_Coal	198
979484	426710	0560180	163	245.06	Base_Harvey_Coal	245
979565	428410	0563840	41	291.08	Base_High_Main_Coal	139
979565	428410	0563840	41	291.08	Base_Maudlin_Coal	201
979565	428410	0563840	41	291.08	Base_Durham_Low_Main_Coal	235
979565	428410	0563840	41	291.08	Base_Hutton_Coal	247
18946180	424010	0564330	60.49	1820	Base_Middle_Coal_Measures	161
18946180	424010	0564330	60.49	1820	Base_Lower_Coal_Measures	318
18946180	424010	0564330	60.49	1820	Millstone Grit Group	376
18946180	424010	0564330	60.49	1820	Stainmore Formation	644