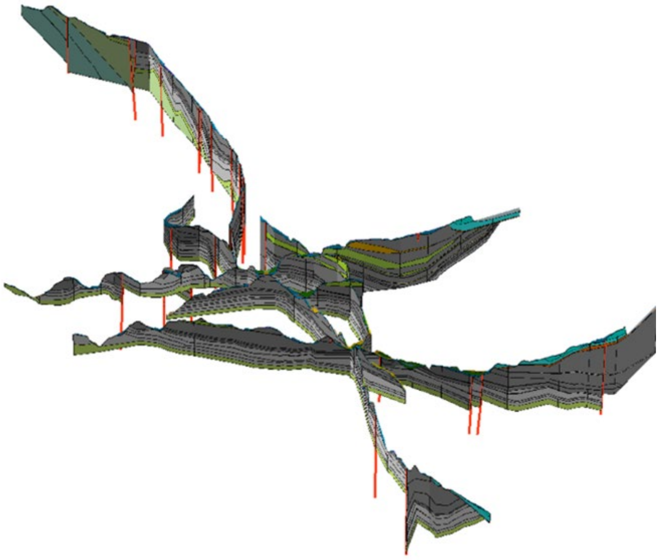
Project Groundwater Northumbria (FCRIP) - Phase 1 Geological Cross-sections

National Geoscience Programme

Commissioned Report CR/22/136



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Project Groundwater Northumbria (FCRIP) - Phase 1 Geological Cross-sections

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Editor

A Monaghan

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Front cover

3D view of the cross-sections (Cross-section interpretation BGS©UKRI 2023, incorporating BGS and Coal Authority data. Reproduced with the permission of ©The Coal Authority. All rights reserved)

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Coal Authority in-seam contour data provided under licence has been incorporated with BGS datasets in the geological cross-section interpretations described here.

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Summary

The British Geological Survey (BGS) has interpreted nine cross-sections to underpin the Conceptual Hydrogeological Model for the Project Groundwater Northumbria. This 'Task 1' work has been delivered to the Environment Agency (EA) for Project Groundwater Northumbria, the Flood and Coastal Resilience Innovation Programme (FCRIP) project led by Gateshead Council. This report is intended as brief accompanying text and describes the data used, the geological units included, and the constraints and limitations of the interpretations. The outputs are summarised. The cross-section interpretations are planned to be followed by more detailed 3D geological modelling work in future tasks. This report and the outputs described in section 5 are provided by BGS to EA under the terms of a non-commercial Government licence. The cross-section interpretation is BGS©UKRI 2023, incorporating BGS and Coal Authority data. Reproduced with the permission of © The Coal Authority. All rights reserved.

1 Introduction

1.1 PURPOSE AND SCOPE OF THE WORK

The British Geological Survey has interpreted nine cross-sections to underpin the Conceptual Hydrogeological Model for the Northumbria Groundwater Flooding Project. This 'Task 1' work has been delivered to the Environment Agency (EA) as part of a larger FCRIP innovation project run by Gateshead Risk Management Authority.

The geological cross sections have been produced to aid understanding of the complexity of the subsurface in the study area, help steer the identification of new monitoring points, and as a building block towards a hydrogeological conceptual model. The main study area covered a large area of the north-east England from south of Durham to Alnwick and covering the coalfield area. A small area to the south of Berwick-upon-Tweed near the Scottish border was also included. EA provided the location of the cross-section lines to BGS.

Figure 1: Overview map of the nine cross-sections. Contains Ordnance Survey data © Crown Copyright and database rights 2023.

The cross-sections (Figure 1) provide a regional overview of the geological units within the superficial deposits and bedrock, to a few hundred metres depth. As the purpose of the work is to support a mine water/groundwater flood monitoring and warning system, identification of recharge and discharge areas, pathways and confining layers is a priority. Thus, the superficial geological units have been subdivided based on lithological characteristics that are likely to affect hydrogeological behaviour (e.g. sand, clay dominant); bedrock units include regionally mapped sandstones and extensively mined coals.

The following units were planned to be included (Table 1):

Regional cross-sections	Detailed cross-sections
Superficial/ made ground hydrodomain classification, include buried valleys, Pelaw Clay	• Clay dominant units • Sand & gravel dominant units • Pelaw Clay • Buried valleys • Made ground
• Brockwell (S) • Harvey(N) • Hutton(L) • High Main(E) • Shilbottle Coal Measures sandstones • Grindstone Post Member, • Main Post Member • 70 fathom sandstone	• High Main Seam (E) • Maudlin (Bensham) Seam (H) • Durham Low Main Seam (J) • Hutton Seam (L) • Harvey (Beaumont) Seam (N) • Busty Seam (Q) or Bottom Busty Seam (Q2) • Brockwell Seam (S • Shillbottle • Fawcett Coal • Blackhill Coal • Bulman Main Coal • Cooper Eye Coal Coal Measures sandstone units • Grindstone Post Member, • Main Post Member • 70 fathom sandstone • *Maudlin Sandstone* • *Hutton Sandstone* • *Harvey Sandstone* • *Busty Sandstone* • *Brockwell Sandstone*

Table 1 Summary of geological units planned to be included in the cross-sections, as provided by the EA. During the work it was agreed that all units in the detailed list were included in all sections (where present), with the exception of sandstones in italics that are not currently included in any section.

As described below, mine plan depth data distribution meant that the same coals and level of detail were included in the regional and detailed cross-sections. Also as discussed below it did not prove possible to interpret the sandstones shown in italics in Table 1. A summary of the stratigraphy and equivalent coal names is given in Figures 6, 7 and Appendix 1.

1.2 OUTLINE OF ACTIVITIES

Task 1 comprised the following activities:

- Data compilation, borehole coding. Assessment of mine plan in seam spot height and contour information from the Coal Authority.
- Superficial cross-sections to 10 m below geological rockhead, lithostratigraphical subdivision/generalisation relevant to hydrogeological conceptualisation. Short accompanying text.
- Bedrock cross-sections from geological rockhead. Main units, coal seams and faults. Two types: regional cross-sections and local, detailed cross-sections. Short accompanying text.
- 3D fly through: draped geology in 3D with cross-sections. To include selected information supplied by EA and others.
- QC/management. Including informing focus of Stage 2 work

2 Data compilation

2.1 BOREHOLE SELECTION

Boreholes used in the project include non-confidential records held in the BGS Single Onshore Borehole Index (SOBI), for which suitable log records are available. Scanned pdfs of the log record required digital coding in the BGS Borehole Geology database (BoGe) to create a baseline dataset to constrain the cross-sections.

Some of the SOBI boreholes have already been coded in BoGe through previous project activities. These existing BoGe records were reviewed to highlight suitable pre-existing data and prioritise both superficial and bedrock boreholes for new coding as part of the project.

The cross-section lines have been provided by the EA, and boreholes were projected onto the line for correlation.

2.1.1 Superficial boreholes

Boreholes were selected for coding to constrain the superficial deposits in cross-sections according to the following criteria:

- Suitable boreholes that lie as close to a cross-section line as possible are preferred, within a maximum limit of 500 m
- Boreholes that penetrate to rockhead *and* have a detailed log of the superficial deposits
- Target an initial maximum spacing of boreholes at 1 km intervals along the section line where possible, based on the borehole distribution
- Include boreholes that penetrate areas of particular interest such as buried valleys
- Additional boreholes may be added to densify the lines or target areas of interest depending on time available.

2.1.2 Bedrock boreholes

Boreholes were selected for coding to constrain the bedrock geology according to the following criteria:

- Boreholes with lengths greater than 100 m
- Boreholes that had named coal seams in the logs rather than just identifying ‘coals’
- Priority was given to those boreholes in areas where there were no mine plan data.

2.2 BOREHOLE CODING

2.2.1 Superficial deposits borehole coding

A total of 5161 boreholes were identified within the 500 m buffer zone of the superficial deposits cross-sections. Superficial geological materials recorded in borehole logs have been assigned lithological codes following the BGS coding scheme for unlithified deposits (Cooper et al., 2006). This scheme uses letter codes to represent grain size classes. Where the deposit comprised of more than one grain size, letter codes are combined with the primary lithology listed first (e.g. a sandy, gravelly clay is coded as ‘CVS’) (Table 2). Descriptive text, interval thicknesses and depths, and lithostratigraphic interpretations (where possible) were also entered during coding of the scanned records.

Lithological Unit	Code
Peat	P
Clay	C
Silt	Z
Sand	S
Gravel	V
Cobbles	L
Boulders	B

Table 2: Letter codes used for lithology coding in the superficial deposits.

The position of geological rockhead (RH) was marked at the relevant interval base (where possible) for boreholes that were drilled to bedrock. This is taken at the base of superficial deposits and includes weathered rock. The total depth (TD) of the borehole log is also recorded.

In addition to the unit lithology and stratigraphy, thickness and depth, further information from the scanned log record is captured during coding, including descriptive information that is useful for geological correlation and interpretation (e.g. notes about the colour, clast composition, presence of laminations, or frequency of occurrence of boulders).

Start heights were honoured where stated on the borehole logs; where no start height was recorded NextMap elevation data was entered. Geologists undertaking interpretation take into account that where anthropogenic activities have altered the ground level (e.g. opencast coal sites), borehole start heights when drilled maybe different than the current ground level.

2.2.1.1 Coding the detailed cross-sections

As stated in 2.1.1 a criterion was followed to code at least one borehole within a 1 km gridded square to generate an even spread of boreholes along each detailed cross-section. The aim was to code boreholes lying as close to the cross-sections as possible and code boreholes that penetrate geological rockhead.

2.2.1.2 Coding the regional cross-sections

The methodology for coding the regional cross-sections followed the coding criteria for the detailed cross-sections except that a 2 km grid was used instead of a 1 km grid. The aim was to have at least one borehole coded per grid square. In areas where the BGS Buried Valleys database highlighted deep superficial deposits boreholes occurring, these were coded if the information was available. Figure 2 indicates the boreholes chosen within the project area for the detailed and regional cross-sections.

In total for the project area, a total of 354 boreholes were investigated and 209 were coded at January 2023.

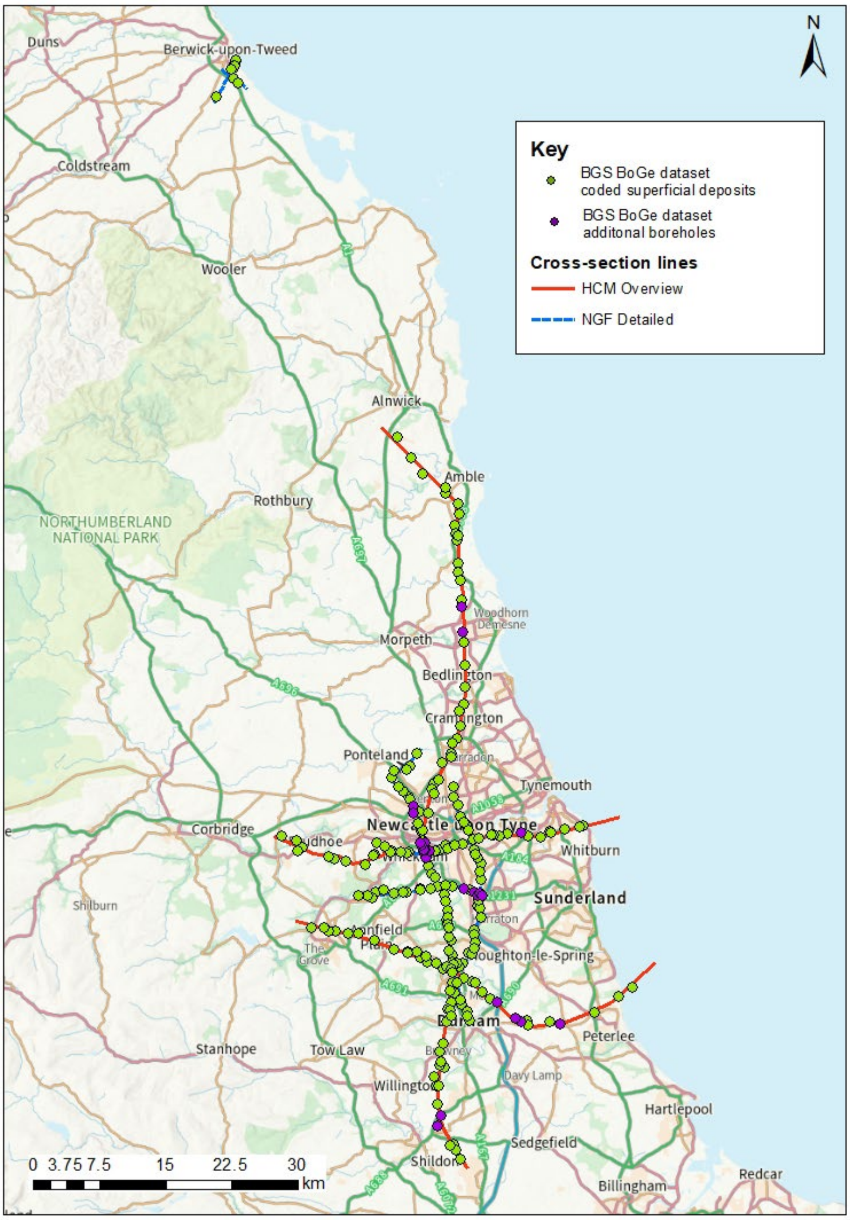

Figure 2: Superficial deposits coded boreholes: BGS borehole dataset indicating boreholes coded for this project (green) and additional boreholes interrogated to aid interpretation within Groundhog modelling (purple). Contains Ordnance Survey data © Crown Copyright and database rights 2023.

Some of the reasons for not coding the boreholes once viewed are:-

- No or poor log
- Geological rockhead not reached
- No detail of superficial deposits recorded ('drift' is written in the borehole log)
- Borehole starts underground

2.2.2 Bedrock borehole coding

A total of 89 boreholes were identified within the 500 m buffer zone of the regional cross-sections, with a depth of more than 100 m. In areas lacking boreholes greater than 100 m, boreholes identifying named coals were used., and were entered in the BGS Borehole Geology (BoGe) database, Figure 3.

The methodology for selecting boreholes included evaluating the mine abandonment plan coal seam data distribution, as licenced from The Coal Authority. The areas where there was sparse coal seam data were targeted for boreholes that required coding.

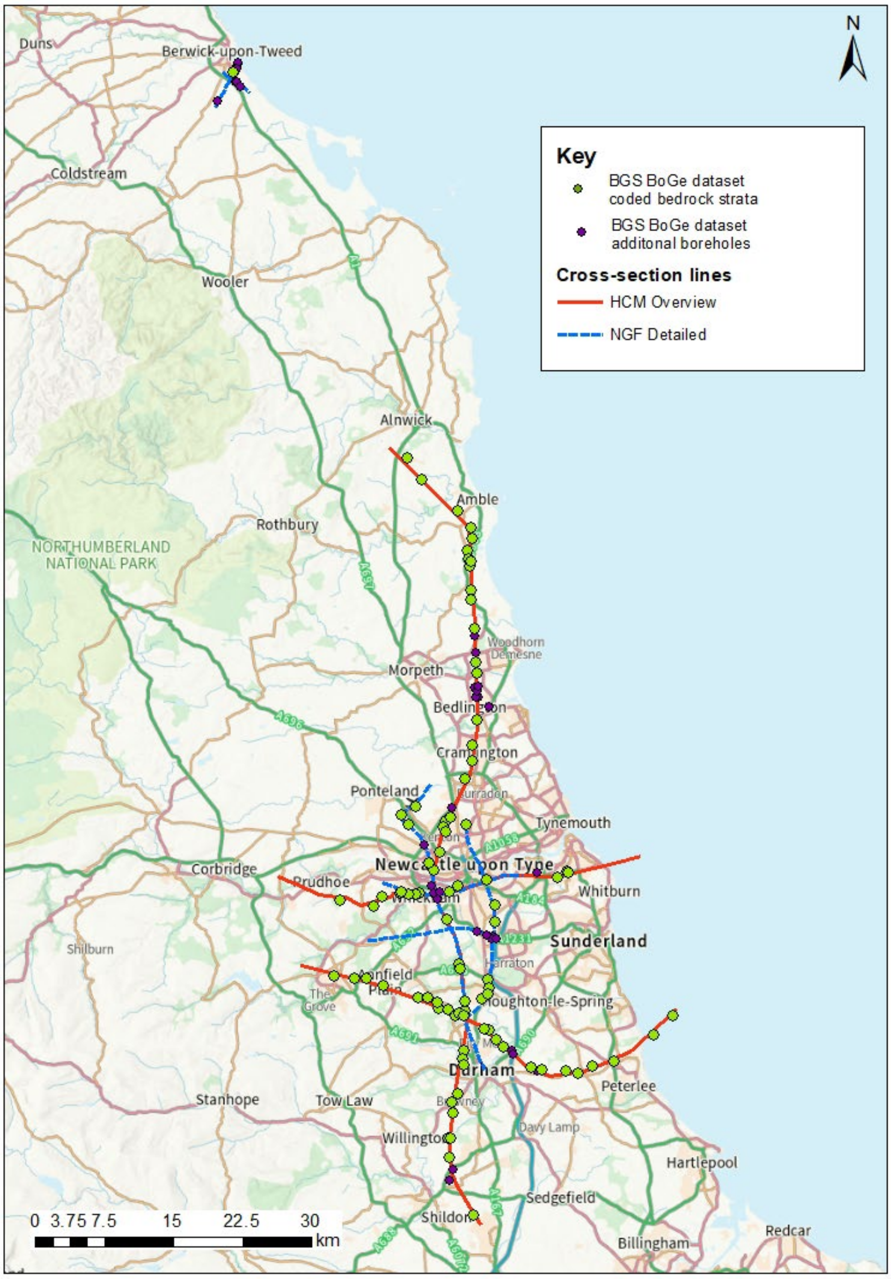

Figure 3: Bedrock geology coded boreholes: BGS borehole dataset indicating boreholes coded for this project (green) and additional boreholes interrogated to aid interpretation within modelling (purple). Contains Ordnance Survey data © Crown Copyright and database rights 2023.

Bedrock geology recorded in borehole logs has been assigned lithological and lithostratigraphical codes following the BGS LEX RCS (Lexicon and Rock Classification Schemes; Table 3). For the purposes of this project, the lithological codes used were generalised to 'sedimentary rock' within interbedded sequences without marker coals, sandstones or marine bands to allow more boreholes to be coded in the time allowance.

Lithology	
SR	Sedimentary Rock – used to class interbedded mudstone, sandstone, fireclay, ironstone
MDST	Mudstone – used particularly when a marine band had been identified
SDST	Sandstone – used when a required sandstone body had been identified e.g., High Main Post Member or a thickness of sandstone had been identified overlying a named coal.
COAL	Coal – used when coals were identified including old workings and goaf.
LMST	Limestone – used when important stratigraphic boundaries had been identified e.g., the base of the Permian

Lithostratigraphy	
RML	Raisby Formation
MLSL	Marl Slate
YWS	Yellow Sands
PUCM	Pennine Upper Coal Measures
PMCM	Pennine Middle Coal Measures
PMLM	Pennine Lower Coal Measures
SMGP	Stainmore Formation
AG	Alston Formation

Table 3 Summary of lithological and lithostratigraphical codes used in the BGS bedrock borehole coding, in addition to named coals and sandstones listed in Table 1

2.3 MINE PLANS

The mine working data within the 500 m buffer zone of the cross-section lines was licensed from the Coal Authority. This data included mine extents, in seam levels, in seam contours and geological disturbances. Of these only the seam contours were used in the cross-section construction software. These were available for parts of the following coal seams:

- High Main
- Top Maudlin
- Maudlin
- Btm Maudlin
- Low Main
- Hutton
- Harvey
- Top Busty
- Busty
- Btm Busty
- Brockwell
- Shillbottle

2.4 ADDITIONAL DATA SOURCES

BGS 50K map data and the BGS buried valleys dataset was incorporated into the interpretation.

3 Superficial cross-sections

3.1 CROSS-SECTION CONSTRUCTION

The regional and detailed cross-sections have been interpreted based on BGS 50K map data and projection of coded boreholes on to the lines of section from up to 500 m either side of the line.

Whilst care has been taken to prioritise boreholes closest to the line of section and to identify those providing the most representative example of conditions, local variability in the land surface and superficial deposits means that the ground surface elevation, rockhead elevation and geological units penetrated by the borehole are typically somewhat different from those expected at the line of section.

As such, the correlation reflects an interpretation of inferred conditions at the line of section based on a combination of information from coded boreholes, the geological map, terrain data, and regional understanding. Additional boreholes that have not been coded as part of this project were also consulted during section construction to provide broader understanding of the nature and interactions of the deposits in regions of complexity, particularly in areas to the south and east of Chester-le-Street (427000,551200).

The sections have been correlated using a generalised 'hydrostratigraphy' designed to highlight key features of the superficial succession that relate to recharge and discharge of groundwater to/from the underlying bedrock (Table 4; sections 3.2, 3.3).

A nominal thickness of 5 m is taken as a threshold for representing aquifer/aquitard units. This was based on discussions with the client, who reported that recharge and discharge to the aquifer is more likely to occur where superficial deposits are less than 5 m thick regardless of the lithology.

In many parts of the study area, thick and complex superficial deposits sequences comprising intercalated layers of till, clay, sand and sand and gravel on sub-metre to metre scales are present. In such sequences, the cross-sections have been constructed by generalising to identify the predominant lithology present over a 5 m scale.

Water bodies, including the River Tyne, minor lakes and the sea are represented by "water" polygons where they intersect cross-sections. Minor streams are not shown in the cross-sections.

3.2 SUPERFICIAL DEPOSITS AND HYDROSTRATIGRAPHY

3.2.1 General context for the superficial and artificial deposits

The general relationship of geological units across the study area is shown in Figure 4. The succession comprises an upper and lower till with intervening glaciolacustrine and/or glaciofluvial deposits (Tyne and Wear Glaciolacustrine Formation and Peterlee Sand and Gravel Formation) (Stone et al., 2010).

Artificial ground is included where this has been mapped on BGS 1:50 000 artificial geology maps. The thickness of artificial ground is defined according to depths proved in boreholes where possible. In the absence of boreholes, the base is estimated based on the nature of the made ground e.g., spoil heap or infilled excavation. For larger infilled open cast sites, the depth of the original workings is unknown and the base of the artificial ground has been estimated to lie 5 – 10 m below rockhead. However, it is possible that artificial ground is considerably thicker in these areas.

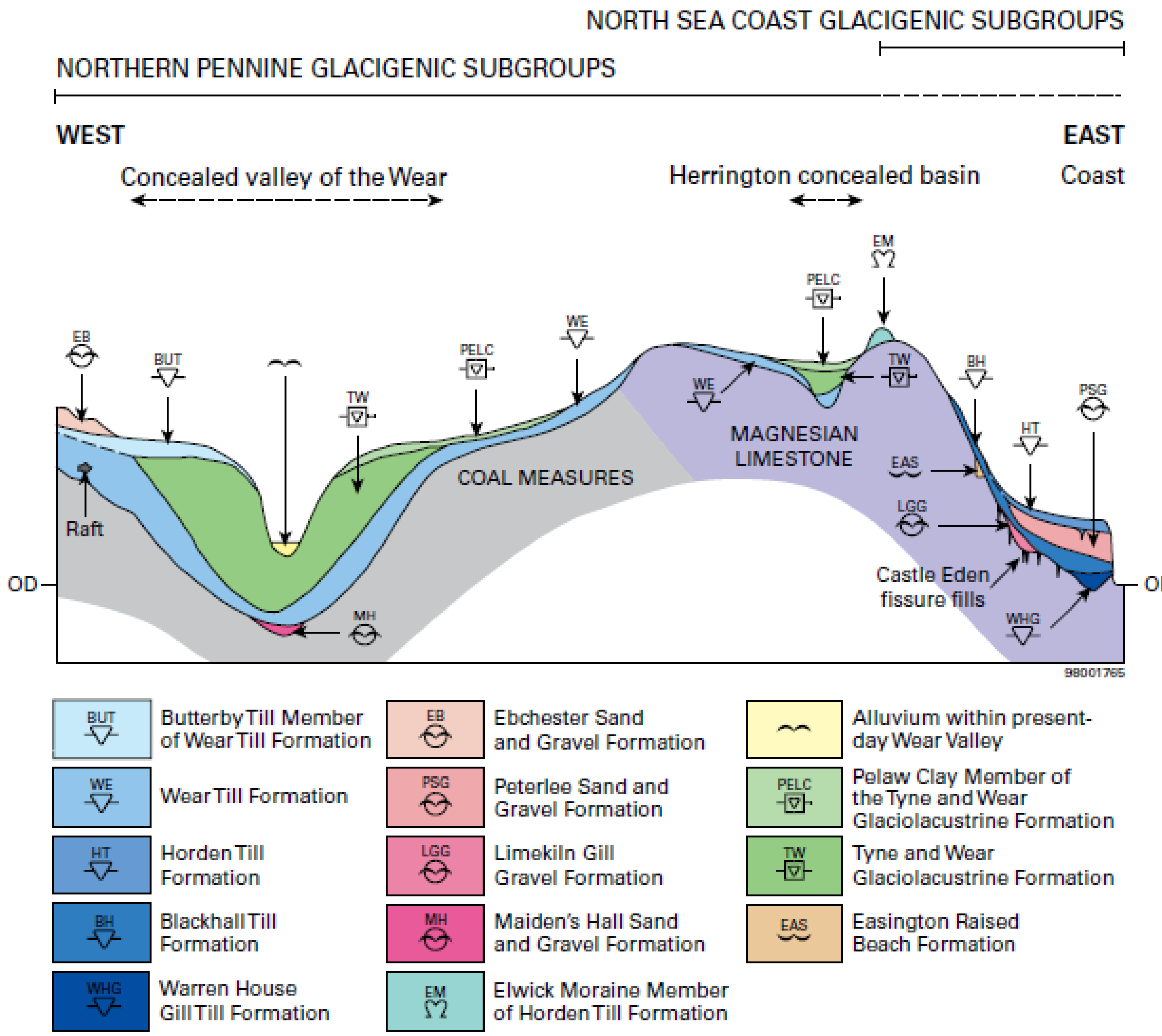

Figure 4 Schematic transect to the south of Sunderland from Stone et al. (2010) showing the general relationships of geological units across the study area. BGS©UKRI

3.2.2 Stratigraphy for the Newcastle – Sunderland AOI

The superficial deposits in the region of the study area include a complex sequence of glacial deposits overlain by postglacial (Holocene) deposits associated with hillslope, river and coastal processes.

The glacial deposits have been previously described by Price et al. (2007) and Whitbread et al. (2013). The complexity of the deposits within the study area is related to the interaction of glaciers sourced from the Pennines (onshore), and Southern Scotland / Northern England (offshore).

A simplified hydrostratigraphy has been developed for use in this study to distinguish units comprising predominantly clay (e.g. laminated glaciolacustrine clay and silt, glacial till (boulder clay), and clay-dominated alluvium), from units composed largely of sand or sand and gravel (e.g. glaciofluvial deposits, sandy moraine deposits, and sand-dominated alluvium). Clay-dominated units are inferred to be aquitards and sand-dominated units represent aquifers.

Table 4 Geological and hydrostratigraphic succession used in the Newcastle-Sunderland AOI

Geological stratigraphy (after Price et al. 2007)		Hydro-stratigraphy	
Artificial Ground		Anthropogenic	
Made Ground		MADE GROUND	Unknown
Holocene deposits		**Holocene**	
Marine deposits Sand, gravel and boulders		MDU-SAND	Aquifer
Alluvium Sand, sand and gravel, silty clay		ALV-CLAY	Aquitard
Alluvium Sand, sand and gravel, silty clay		ALV-SAND	Aquifer
River terrace deposits Sand, sand and gravel		RTD-SAND	Aquifer
Lacustrine deposits Clay, silt, sand, peat		LAC-CLAY	Aquitard
North Pennine Subgroup	**North Sea Coast Subgroup**	**Late Devensian**	
Ebchester Sand and Gravel Formation Sand, sand and gravel		EBSG-SAND	Aquifer
Un-named moraine Clay, boulders, gravel	**Elwick Moraine Member** Sand, sand and gravel, clay, silt	(Not intersected)	
Butterby Till Member Silty clay, sand, gravel	**Horden Till Formation** Silty clay, gravel	TILL2-CLAY	Aquitard
Butterby Till Member / **Tyne and Wear Glaciolacustrine Formation**	**Horden Till Formation** / **Peterlee Sand and Gravel Formation**	PELC-CLAY	Aquitard
Tyne and Wear Glaciolacustrine Formation Clay, Silt, Sand, (thin till)	**Peterlee Sand and Gravel Formation** Sand, silt, clay, gravel	TYWE-CLAY	Aquitard
Tyne and Wear Glaciolacustrine Formation Clay, Silt, Sand, (thin till)	**Peterlee Sand and Gravel Formation** Sand, silt, clay, gravel	TYWE-SAND	Aquifer
Wear Till Formation Silty, sandy clay, gravel, cobbles, boulders	**Blackhall Till Formation** Silty clay, sand, gravel, cobbles	TILL1-CLAY	Aquitard
Wear Till Formation Silty, sandy clay, gravel, cobbles, boulders	**Blackhall Till Formation** Silty clay, sand, gravel, cobbles	TILL1-SAND_BLDR	Aquifer
Maiden's Hall Sand and Gravel Formation Sand, sand and gravel	**Limekiln Gill Gravel Formation** Sand, sand and gravel	MHSG-SAND	Aquifer

3.2.3 Stratigraphy for the Berwick AOI

Cross-sections NGF_Detailed_8 and NGF_Detailed_9 are located just to the south of Berwick-upon-Tweed. The superficial deposits on these cross-sections comprise thin glacial till overlying bedrock. Borehole logs in the area indicate that the upper 1 – 2 m of the bedrock are highly weathered in places, with thin deposits of sand or sand with sandstone fragments described overlying weathered sandstone bedrock.

3.3 NOTES ON THE INTERPRETATION OF SUPERFICIAL DEPOSITS

3.3.1 Holocene deposits

Thin **alluvial deposits** (ALV-SAND and ALV-CLAY) are found along many of the stream courses in the area, with thicker deposits interpreted in association with the larger rivers, particularly the River Tyne. **River terraces** (RTD-SAND), comprising sand or sand and gravel deposits are also locally developed along the larger river systems, although these are rarely intersected by the cross-section lines.

Minor **lacustrine deposits** (LDE-CLAY) occur locally but are rarely intersected by the sections. These were formed during Holocene times in association with small lakes developed in hollows in the till surface.

Marine deposits (MDU-SAND) are recorded in boreholes in the Spittal area, on the southern edge of the Tweed Estuary (400550,651800) (Section NGF_Detailed_8). These comprise approximately 20 m of predominantly sand, gravel and boulders in an area mapped as marine beach and storm beach deposits.

Small developments of marine deposits are also intersected at the coast in cross-sections HCM_Overview_1 and HCM_Overview_3. Marine deposits are not interpreted in the offshore area of these sections due to a lack of data. It is possible that sub-tidal deposits of variable thickness are present at the seabed.

3.3.2 Till deposits

Glacial till is the most extensive deposit in the study area. It typically comprises a firm to stiff silty sandy clay with gravel and cobbles. The colour of the till varies from brown to grey as recorded in borehole records, with grey till typically associated with lower till unit (Wear Till Formation / TILL1-CLAY).

However, in areas where the glaciolacustrine and glaciofluvial deposits are not present it can be difficult to distinguish the upper and lower tills from many borehole records due to a lack of detail regarding the colour and clast content of the till. Due to this, the upper till (TILL2-CLAY) is only correlated where it is proved in boreholes to overlie glaciofluvial and glaciolacustrine deposits.

3.3.3 Glaciolacustrine deposits (clay and silt)

The glaciolacustrine deposits comprise laminated clay, silt and sand deposited in extensive glacial lakes during deglaciation at the close of the Late Devensian stadial (Stone et al., 2010). The most extensive glaciolacustrine deposits are associated with the Tyne and Wear Glaciolacustrine Formation. This was deposited in the largest of the lakes, Glacial Lake Wear, which occupied the Tyne and Team valleys and extended across a large area of low ground in the region of Newcastle, Gateshead, and Sunderland (Figure 5). Smaller glacial lakes were developed south of Durham, and in the area west of Peterlee (Glacial Lake Edderacres, cf. Stone et al., 2010).

The Tyne and Wear Glaciolacustrine Formation is locally up to 40 – 50 m thick where it infills parts of the Team Valley, but typically 5 – 20 m thick in the Sunderland area. It is mostly underlain by till but may locally rest on bedrock or overlie sandy deposits (possibly channel fills or moraines). Where developed predominately as laminated clay and silt these deposits are likely to be impermeable, with reduced recharge to the underlying aquifer and potential for perched aquifers to form in overlying sand deposits.

Around the margins of Glacial Lake Wear, and particularly towards the southern end of the Team valley around the junction with the modern Wear valley in the region of Chester-le-Street, the laminated clays are intercalated with and overlain by sandy deposits. South of Chester-le-Street, the deposits are predominantly sandy and may be associated with recharge to the underlying aquifer where they overlie sandier till deposits that are recorded in boreholes in this area. The relationship between the glaciolacustrine deposits and glaciofluvial deposits in this area is poorly known and requires further investigation (see section 3.3.5). The dominance of sand along the southern edge of Glacial Lake Wear may be reflect the presence of a delta system depositing coarser material at the margin of the lake.

3.3.4 Pelaw clay

In the area of Newcastle and Sunderland, the Glaciolacustrine deposits of Glacial Lake Wear (the Tyne and Wear Glaciolacustrine Formation) and adjacent slopes mantled in glacial till are overlain by an extensive unit of stony clay known as the Pelaw Clay. The unit is typically less than 5 m thick but may be locally up to 10 m. In marginal areas, and in places where the Pelaw Clay overlies till it may be difficult to distinguish from the Butterby Till Member. The origin of the Pelaw Clay is enigmatic, but it is believed to have been formed by periglacial processes following deglaciation of the region (Smith, 1994; Stone et al. 2010), and it is currently included as a member of the Tyne and Wear Glaciolacustrine Formation (Figure 4).

3.3.5 Glaciofluvial sand and gravel

Localised deposits of sand and gravel overlie till throughout the study area, with larger developments along the Tyne valley to the west of Newcastle, and to the east of the Team valley between the region south of Gateshead (421000,557300) to the vicinity of Durham (427150,542450). The latter area is discussed in more detail below. Where glaciofluvial deposits have been deposited above the till, they have been classed as the Ebchester Sand and Gravel Formation (Table 4).

3.3.5.1 Deposits between Gateshead and Durham

An extensive tract of glaciofluvial sand and gravel deposits occur on the lower slopes of the North Pennine hills, to the west of the Team valley between the region south of Gateshead (421000,557300) to the vicinity of Durham (427150,542450) (Figure 5). These deposits appear to form spreads overlying till and bedrock, but also infill a series of buried and active valleys draining into the Team valley, and within the Wear valley near the confluence with the River Browney.

In some areas the glaciofluvial deposits are overlain by thin upper till, such as in a buried valley along the valley of the River Browney (Figure 5). But towards the margin of the Team valley, and in the region between Durham and Chester-le-Street (427000,551200), they appear to be associated with the glaciolacustrine deposits of Glacial Lake Wear. Thus, it is possible that the glaciofluvial deposits have formed, or been reworked, as sandy delta systems bringing coarser sand and gravel into the edge of Glacial Lake Wear.

Several boreholes in areas mapped as till in the region of Chester-le-Street appear to show the presence of lacustrine clay, sand and gravel, and “sand and boulders” (cf. NGF_Detailed_5, chainage 18,000 – 20,000 m. The latter deposit is tentatively interpreted as a locally developed sandy till, or moraine deposit (TILL1-SAND-BLDR).

Thick sand and gravel units may have importance in relation to recharge to the underlying aquifer and the presence of perched aquifers. Thus, further investigation is needed to characterise the extent of glaciofluvial sand and gravel deposits and the nature of their association with the lacustrine deposits of Glacial Lake Wear.

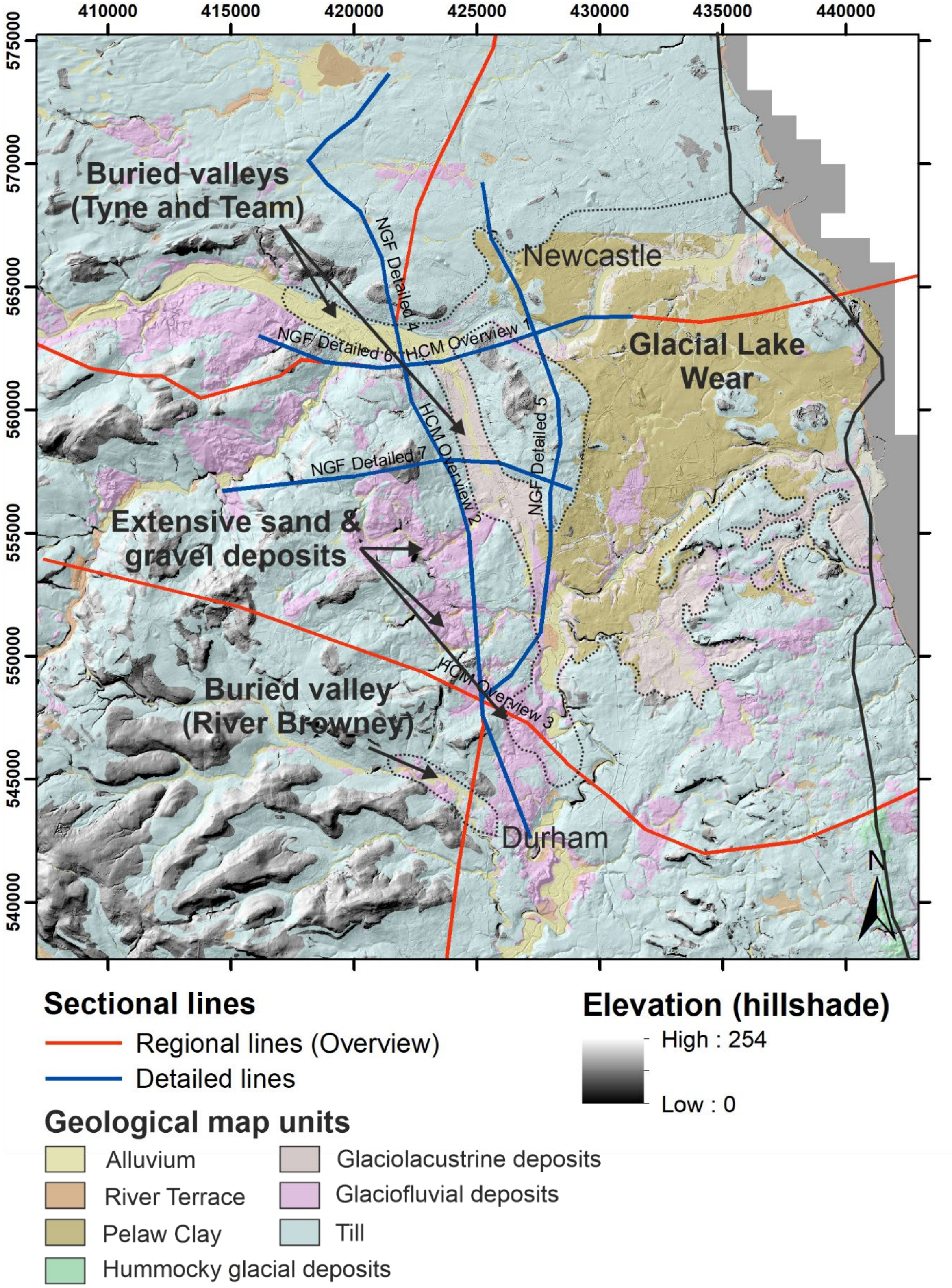

Figure 5 Superficial geology of the study area, focused on the area covered by the detailed sections. Geological map data (1:50 000 scale) is overlain on the PGA hillshade elevation model (5 m resolution). An approximate outline of Glacial Lake Wear is defined by the black dashed line, with the approximate limit of the North Sea ice lobe shown by the thick black line (after Stone et al., 2010). Highlighted features are discussed in the text. BGS© UKRI. Elevation data © Getmapping: Licence Number UKP2006/01

4 Bedrock

The regional and detailed cross-sections have been interpreted based on BGS 50K map data, mine seam plan contours and boreholes. In most cases the dip and geometry of units was constrained by the in-seam plan contours. Boreholes were used to calculate the thicknesses to those units without mine seam data. Only the major faults were included in the cross-sections (see section 4.6 for more details). In total, 30 bedrock units were included.

4.1 CROSS-SECTION STRATIGRAPHY

The stratigraphy used in the bedrock cross-sections is from the current BGS Geology 50K digital maps, with the exception of the Millstone Grit Group. This is included in the cross-sections but is not currently shown on the maps (see Section 4.4). The coal seam names used are those shown on the BGS 50K digital maps.

Figure 6 shows the bedrock stratigraphy used in the Spittal cross-sections (NGF_Detailed_8 and NGF_Detailed_9) and Figure 7 shows the stratigraphy in the Newcastle – Gateshead area cross sections (HCM_Overview_1, HCM_Overview_2, HCM_Overview_3, NGF_Detailed_4, NGF_Detailed_5, NGF_Detailed_6 and NGF_Detailed_7).

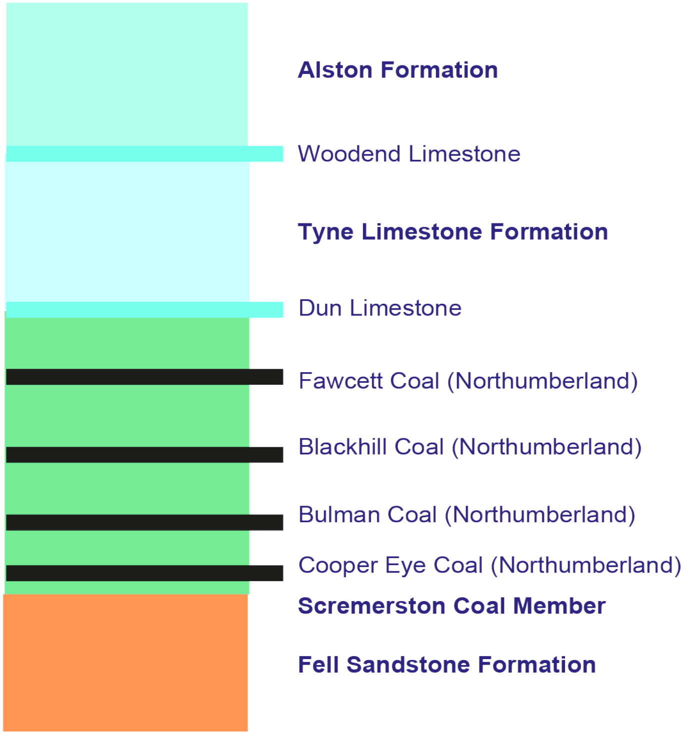

Figure 6 Bedrock stratigraphy used in the Spittal cross-sections (NGF_Detailed_8 and NGF_Detailed_9).

Figure 7 Bedrock stratigraphy used in the Newcastle and Gateshead area cross sections (HCM_Overview_1, HCM_Overview_2, HCM_Overview_3, NGF_Detailed_4, NGF_Detailed_5, NGF_Detailed_6, NGF_Detailed_7. More detail on equivalent coal seam names is given in Appendix 1.

4.2 FELL SANDSTONE FORMATION AND SCREMERSTON COAL MEMBER

The Fell Sandstone Formation and Scremerston Coal Member are only found in the Berwick-upon-Tweed and Spittal sections. Recent remapping that was completed as part of the EA project on the Fell Sandstone Formation was incorporated. In the area of the cross-sections, the mapped boundary of the Fell Sandstone Formation has not changed as a result of this recent remapping. However, the thickness of the Fell Sandstone Formation shown in the cross-sections was informed by the new mapping.

The Scremerston Coal Member is known to have at least six major sandstone channel bodies with thicknesses up to 30 m in the Berwick-upon-Tweed and Spittal area (Jones 2007). However, these are not included on the BGS 50K map dataset and so are not included in cross sections. Additional mapping and 3D modelling would be needed to translate the understanding held in Jones (2007) on to the map and cross-sections.

4.3 TYNE LIMESTONE FORMATION, ALSTON FORMATION & STAINMORE FORTMATIONS

The Tyne Limestone, Alston and Stainmore formations are all part of the Yoredale Group in the study area. These are upward coarsening sequences of mudstones and sandstones often capped by a coal and/or a limestone (Stone et al. 2010). Limestones in these units are normally 1–10 m thick and make up a minor component of the rock mass. Sandstone channels are present in this succession ranging from 8–22 m thick (Booth et al. 2020). However, these sandstones have not been mapped in the areas cut by the regional cross sections and thus locations at which they intersect the section line cannot be determined.

The Dun Limestone and Woodend Limestones are drawn on BGS 50K maps and were included in NGF_Detailed_8 and NGF_Detailed_9.

4.4 MILLSTONE GRIT GROUP

The published bedrock maps of the study 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 Newcastle and Durham. This is further confirmed by Kearsey et al. (2019) who trace it further out into the North Sea. In the study area, the borehole named '3/4 Mile SE of Morwick' (BGSID – 703083) near Amble contains 30 m of Millstone Grit under the Coal Measures Group. In the Newcastle Science Centre Geothermal borehole (BGSID – 18946180) it is 58 m thick and in the Harton Dome 1 borehole (BGSID – 923323) in South Shields, the Millstone Grit is 56 m thick.

4.5 COAL MEASURES GROUP

The Pennine Lower and Middle Coal Measures formations are similar in lithological composition to the Yoredale Group strata, although they lack the limestones and contain more coal seams. The BGS 50K maps show both named sandstone units (such as the High Main Post Member) and unnamed sandstones. The area in between the sandstone channels comprises of thin sheet sandstones and mudstones. These grade into each other in upward-coarsening cycles grading from mudstones into sandstones (Stone et al. 2010). The Pennine Upper Coal Measures only exists on cross-section line 1 and appears to be fault bounded. In this area near Jarrow, it is described as dominated by sandstones and mudstone, with occasional very thin coals (Stone et al. 2010).

4.5.1 Coals

Only the coals marked in Figure 6 and Figure 7 were included in the cross sections; there are more coal seams within this sequence that have not been included here. The names given are those used on the BGS 50K digital map. They are similar to those used by the Coal Authority, although some have been given local modifiers such at the 'Low Main Coal' which is referred to as the 'Durham Low Main Coal'. The equivalence of coal seam names is detailed in Appendix 1.

In the cross-sections all the coals were given a thickness of 1 m based on the average thickness of coal from the digital seam plans (1.13 m), although some of the coals can thicken up to as much as 4 m in some areas. There was not enough data to resolve the top and bottom leaves in the Busty and Maudlin Coal so they were modelled as a single unit. The thickness was modified by up to 10 m where there was evidence of multiple leaves.

In Gateshead e.g. [422000 561000] there is some disagreement between BGS 50K map and the Coal Authority seam plan data. The Maudlin and Five Quarter coals on the BGS 50K map appears to be confused with the Five Quarter coal / Main / Yard based on the Coal Authority data. Further work is needed to resolve the inconsistency.

4.5.2 Major named sandstones

The Pennine Coal Measures Group strata were deposited on a broad flat, delta plain and slope. Sandstones are therefore deposited by a range of mechanisms such as major and minor distributary channels and lobes created by crevasse splay or delta progradation (Fielding 1984). This means that unlike the coals, which are laterally extensive, the sandstones thicken and thin and disappear throughout the sequence (Figure 8).

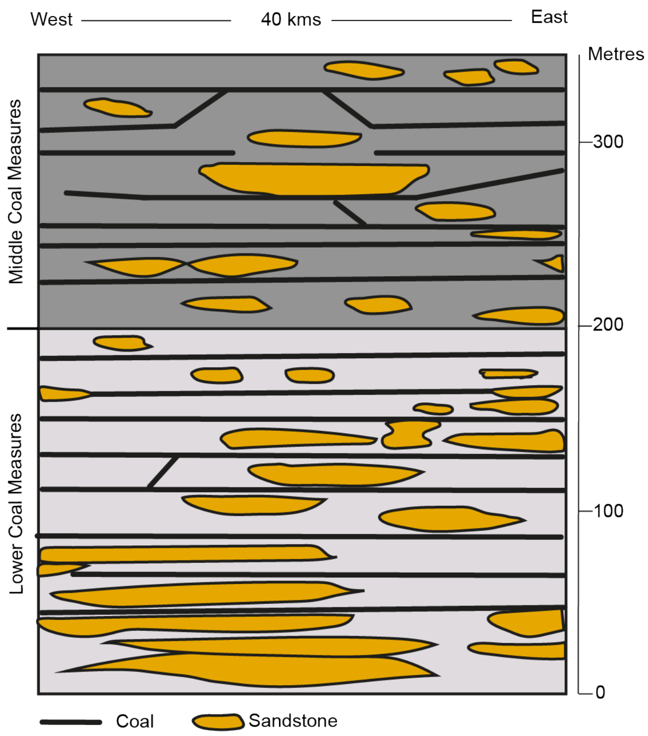

Figure 8 The architecture of the major sand bodies in Lower and Middle Coal Measures in the Durham Coalfield. Re-drawn from Fielding (1984 © Geological Society of London).

The Grindstone Post Member, Seventy Fathom Post Member and High Main Post Member are all named on the BGS 50K maps and in some boreholes, so were able to be correlated in the cross sections. The geometries in the cross-sections were based on the shape of the outcrop and the understanding from the literature (Fielding 1984).

4.5.3 Minor sandstones

Minor sandstones such as the Hutton Sandstone, Harvey Sandstone, Busty Sandstone, and the Brockwell Sandstone are not separated out on BGS 50K maps. Furthermore, they are not named in boreholes and this initial phase of the study did not have access to the mine plan washout data. Therefore, it proved challenging to project and correlate them into the cross sections without the relevant 3D information to resolve their geometry. So, for instance the Brockwell Coal often is overlain by a mudstone not a sandstone and when it is overlain by a sandstone those sandstones are 500 m – 2000 m wide and not a continuous sand bed (Figure 9).

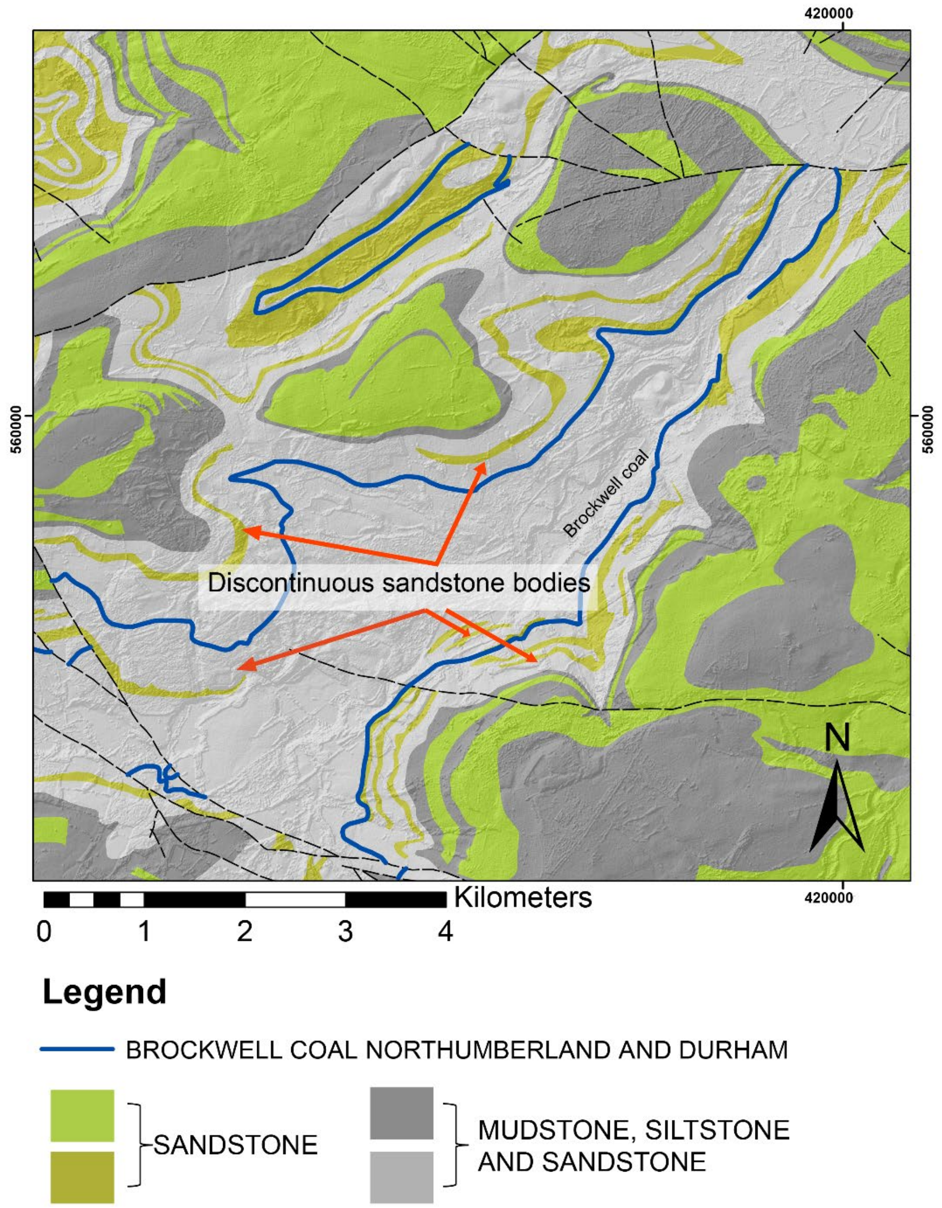

Figure 9 Extract of BGS 1:50,000 scale map in the Winlaton area, near the western end of NGF_Detailed_6 section showing the Brockwell Coal and the discontinuous sandstone channels above it BGS©UKRI

4.6 FAULTS

There are over 100 mapped faults that cut the cross-section lines. It was not possible to include all of those in this study. Therefore, only those faults with stratigraphic throws of >100 m were drawn in the cross sections including the following named faults:

- Ninety Fathom Fault
- Stakeford Fault
- Causey Park Dyke fault
- Hett Dyke fault
- Butterknowle Fault
- Stakeford South Fault

Some other minor faults were also included where the line of section and the geometry of the units necessitated a fault. The fault dips and stratigraphic offsets were primarily determined using mine contour data either side of the faults. Where mine contour data was not present, stratigraphic offsets were projected in from other sections with data.

The omission of minor faults is one of the reasons that there are thickness changes between coal seams shown on the cross-sections. There is also some evidence of beds changing thickness and pinching out due to sedimentary processes, as well as those thickness changes controlled by faulting.

5 Outputs

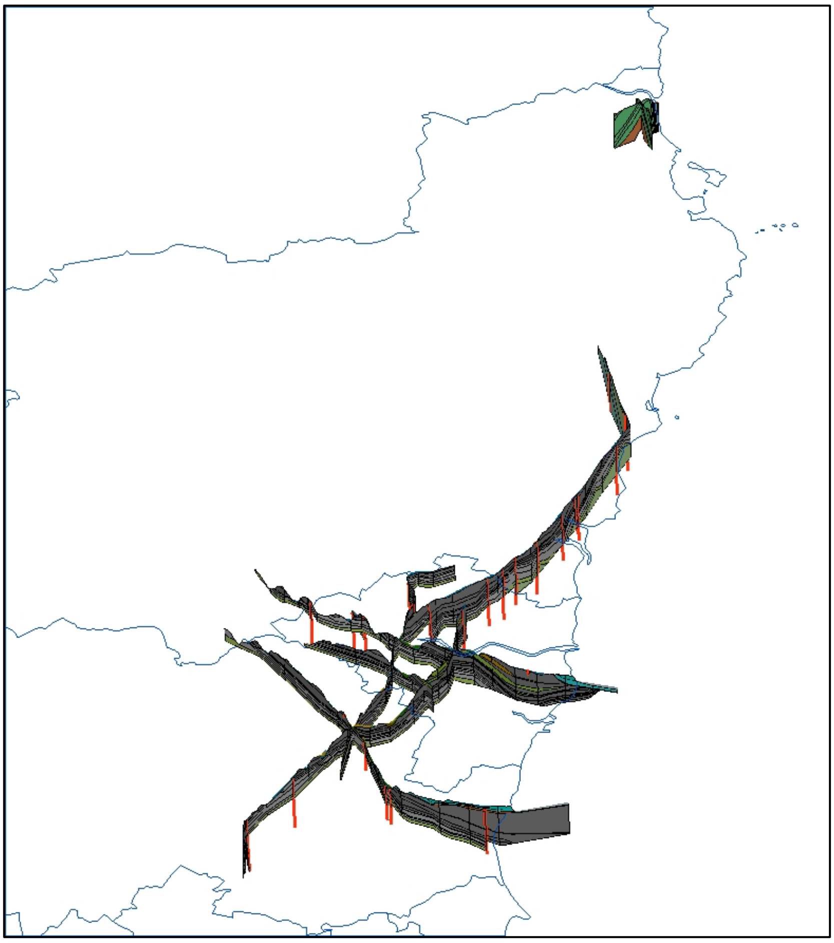

Figure 10 Overview image of the cross-sections, looking north with unitary/county boundaries shown. Contains Ordnance Survey data © Crown Copyright and database right 2023. Cross-section interpretation BGS©UKRI 2023, incorporating BGS and Coal Authority data. Reproduced with the permission of © The Coal Authority. All rights reserved.

Description	File naming convention
3D shapefiles of the cross-sections for specialist users (e.g. EA)	• final_section_polys_3d_new.shp (the geological polygons) • section_faults_3d.shp (the faults) • BGS cross sections .lyr (layer file to add into Arcscene with correct colouring)
PDF's of cross sections	For each cross-section there are two files: one at x5 and one x10 vertical exaggeration clipped 10 m beneath base of superficial deposits. e.g. HCM_Overview_1x5.pdf and HCM_Overview_1_x10.pdf (18 files in total) Note that bedrock sections were drawn at x3 vertical exaggeration and are not intended for use at x10 exaggeration, these plots are to visualise the superficial deposits. Labels and the simplified 'aquifer/aquitard' classification can be switched on and off by the user of the PDF (using menu on left hand side)
3D visualisation fly-through of sections, boreholes etc.	GWNE-_2023-03-23_17-26-06.wmv (for EA and project partners technical use) Using the same dataset, a separate fly-through is being prepared for public audiences under Year 2 BGS work on this project.
Spreadsheets of borehole coding	Northumbria_GroundWater_BH_BEDROCK_DOWNHOLEV2_February2023.csv Northumbria_GroundWater_BH_BEDROCK_INDEX_February2023.csv Northumbria_GroundWater_BH_SUPERFICIAL_DOWNHOLE_February2023.csv Northumbria_GroundWater_BH_SUPERFICIAL_INDEX_February2023.csv These sheets comprise a file of borehole locations and a file of the downhole geology. These are the boreholes that were coded specifically for this project during FY2022-2023.

Table 5 List of digital outputs provided.

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Appendix 1

					BGS 50K Geology Maps	2	6	9	10	14	15	20	21	26	27
Regional Name	**BGS 50K Linear All DigMap**	**BGS Lexicon Code**	**CA Seam Index**	**Alternative Names***		**Berwick Upon Tweed**	**Alnwick**	**Rothbury**	**Newbiggin**	**Morpeth**	**Tynemouth**	**Newcastle Upon Tyne**	**Sunderland**	**Wolsingham**	**Durham**
Pennine Middle Coal Measures															
HIGH MAIN	HIGH MAIN COAL (NORTHUMBERLAND AND DURHAM)	HMN	E	Diamond, Top Main, New Main, Shield Row				Y	Y	Y	Y	Y, Top High Main	Y, splits into two leaves	Y, Top High Main	Y
TOP MAUDLIN	TOP MAUDLIN COAL (DURHAM)	MAUDT	H1	Top Bensham, Cowpen Bensham, Cambois Duke, Bensham, Queen				Y, Top Bensham	Y, Top Bensham	Y, Top Bensham					Y
MAUDLIN	MAUDLIN COAL (DURHAM)	MAUD	H	Bensham				Y, Bensham	N, Bottom Bensham	Y, Bensham	Y, Bensham	Y	Y	Y	Y
LOW MAIN	DURHAM LOW MAIN COAL (NORTHUMBERLAND AND DURHAM)	DLO	J	Little Wonder Coal (Rothbury), 5/4, 6/4 Pegswood Band, Cowpen Brass Thill				Y	N, Top and Bottom Durham Low Main	Y	Y	Y	Y	Y	Y
HUTTON	HUTTON COAL (NORTHUMBERLAND AND DURHAM)	HUCO	L	Plessey, Bottom. The Broomhill Main is the Hutton in the Tynemouth district				Y, Broomhill Main	Y, Broomhill Main	Y, Broomhill Main	Y	Y	Y	Y, splits into Top and Bottom	Y, splits into Top and Bottom
Pennine Lower Coal Measures															
HARVEY	HARVEY COAL (NORTHUMBERLAND AND DURHAM), BEAUMONT COAL (NORTHUMBERLAND)	HARV, BMNT	N	Beaumont, Pegswood Tilly, Towneley				Y, Beaumont	Y, Beaumont	Y, Beaumont, including Top Beaumont	Y, Beaumont	Y	Y	Y	Y, splits into Top and Bottom
BUSTY	BUSTY COAL (NORTHUMBERLAND AND DURHAM)	BUS	Q										Y, splits into three leaves	Y	Y
BOTTOM BUSTY	BOTTOM BUSTY COAL (NORTHUMBERLAND AND DURHAM)	BBU	Q2	Pegswood Top Busty, Splint, Old Man, Hepscott, Widdrington Main (or Top Main), 5/4, 6/4?, Jet, Busty				Y	Y	Y	Y	Y		Y	Y
BROCKWELL	BROCKWELL COAL (NORTHUMBERLAND AND DURHAM)	BROC	S	Bandy, Main				Y	Y	Y	Y	Y	Y, splits into Top and Bottom	Y	Y, splits into Top and Bottom
Alston Formation															
SHILBOTTLE	SHILBOTTLE COAL (NORTHUMBERLAND)	SHIC		Acre		Y, Acre	Y								

* Sources for alternative names include: EA Hydrological Conceptual Model Introduction draft report, BGS Report WA/90/14, Memoir of the British Geological Survey, Sheet 20 (England and Wales) Table 2 and BGS BoGe Borehole log interpretations.

Table 6 Summary of equivalent coal seam names used by BGS and Coal Authority across different parts of the study area