Superficial hydrogeological domains for the Gateshead area - Project Groundwater Northumbria

National Geoscience Programme

Commercial Report CR/24/066

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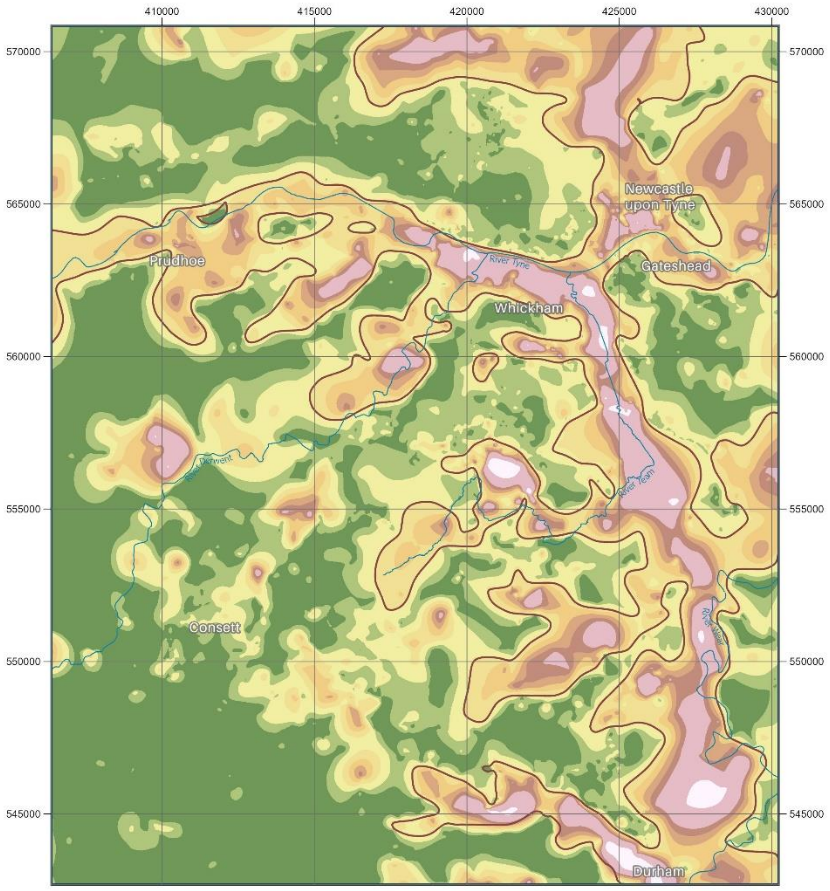

BRITISH GEOLOGICAL SURVEY

NATIONAL GEOSCIENCE PROGRAMME

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Superficial hydrogeological domains for the Gateshead area - Project Groundwater Northumbria

K Whitbread, N Dewald, V Banks, B Murphy, T Reeves

Keywords

Superficial deposits, hydrogeology, hydrogeological domains.

Front cover

Superficial thickness and the buried valley domain for the Gateshead area. BGS © UKRI 2024. Contains Ordnance Survey data © Crown copyright and database rights 2024

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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 superficial hydrogeological domains for the Newcastle-Gateshead area and accompanies the delivery of datasets including a superficial hydrogeological domains map and a new superficial thickness model for the study area.

The development of the domains was undertaken through analysis of 409 digitally coded boreholes including over 220 coded for this project. The boreholes were attributed for permeability according to previously used schemes and analysed to characterise the vertical succession of superficial deposits for classification as hydrogeological domains.

Superficial hydrogeological domains have been mapped for the area based on a classification scheme defined through consultation with the clients and intended for a qualitive characterisation of areas of preferential vertical and lateral groundwater flow such as recharge and discharge from underlying bedrock aquifers. The domains have been characterised from a superficial thickness model using thickness thresholds as well as the attributed borehole distribution, the 1:50,000 scale geological map of the area and wider geological understanding of the region and associations of deposits.

Five primary domains were identified in the area. Domain 1 reflects regions with less than 2 m of superficial deposits (including areas where no deposits have been mapped). Domain 2 reflects regions with only aquifer (permeable deposits) present, regardless of the thickness of deposits. Domain 3 covers areas with 2 – 10 m thickness of aquitard (low permeable deposits) within the succession, and domain 4 covers areas with 10 – 30 m of aquitard in the succession. The primary domains are further broken down into subdomains to highlight differences in the vertical sequence of aquifer and aquitard units. Note that domain 5 was included within the original classification scheme but all areas meeting the criteria (aquitard >30 m) fall within buried valleys and are therefore included in domain 6.

Domain 6, defined as buried valleys, comprises elongate regions with more than 10 m of superficial deposits that form a contiguous network or buried-valley system. The architecture of sediments within the buried valleys was assessed using targeted cross-sections and inspection of borehole data. This process was used to define subdomains based on assemblages of deposit types within the buried valley system.

Future work to improve understanding of the extent and lateral connectivity of buried sand bodies within domain 6 would enhance the mapping of the domains. Targeted coding of existing borehole records would help to locally improve the data coverage and take advantage of areas with denser borehole distributions (particularly in urban areas of Newcastle-Gateshead along the River Tyne). Furthermore, the capture of new borehole data down to rockhead (base of the superficial deposits), ideally with core suitable for high-resolution geological logging, is really needed for more accurate assessment of the range of material properties and geological interpretation of the deposits, and for direct quantification of the hydrogeological properties of the materials. The latter would also be improved by logging and analysis of exposed sections through key deposits in the field.

1 Introduction

1.1 BACKGROUND AND SCOPE

The British Geological Survey (BGS) has interpreted a set of superficial deposit hydrogeological domains (otherwise known as superficial hydrogeological domains) for the Newcastle-Gateshead area as part of commissioned work for Project Groundwater Northumbria (PGN), part of the Flood and Coastal Resilience Innovation Programme (FCRIP) project led by Gateshead Council. These hydrogeological domains reflect spatial variations in the lithological and structural properties of superficial deposits that are likely to influence the movement of groundwater into and out of bedrock aquifers within the underlying Coal Measures strata (cf. McMillan et al., 2000; Price et al., 2007).

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 raise risks of groundwater flooding and/or interact with surface water systems and shallow superficial aquifers.

This report details the methodology for the development of the revised superficial thickness model and superficial hydrogeological domains and accompanies the delivery of these datasets as grids and shapefiles. Work on the bedrock aquifers within the region is being undertaken as a separate task within the PGN project, hence consideration of bedrock lithologies and structures is not included within this report. Integration of the superficial hydrogeological domains with bedrock could be undertaken in a future phase of work.

1.2 THE DOMAINS APPROACH

Characterisation of superficial hydrogeological domains is an approach that has been developed to help understand the influence of complex superficial deposit sequences on groundwater recharge and on discharge from potential bedrock aquifers. The approach is particularly suited to complex Quaternary glacial successions which exhibit high structural and lithological variability arising from glacial and postglacial depositional environments (McMillan et al., 2000).

Superficial domains reflect areas with distinct vertical lithological profiles related to the distribution of permeable (typically sand and gravel dominated) and low permeability (typically clay dominated) deposits. Domains may be distinguished by the thickness, presence/absence and relative position of units (e.g. Price et al., 2007). For example, areas of till deposits that are overlain by glaciofluvial sand or sandy alluvium would be considered as distinct from areas of till deposits with buried sand lenses.

Although the focus of the domains approach is on characterising vertical successions, horizontal flow along channel structures and through sand and gravel lenses can also occur within superficial deposit sequences. This may be particularly important for buried valley structures where thick superficial fill sequences may be present. The Newcastle-Gateshead study area (**Figure 1**) has a network of deep buried valleys with complex fill and could include sandy channel deposits along the base of the valley and within valley fill sequences. In this study the buried valleys are recognised as a separate domain to better characterise their complex deposits and potential contexts for lateral flow within them.

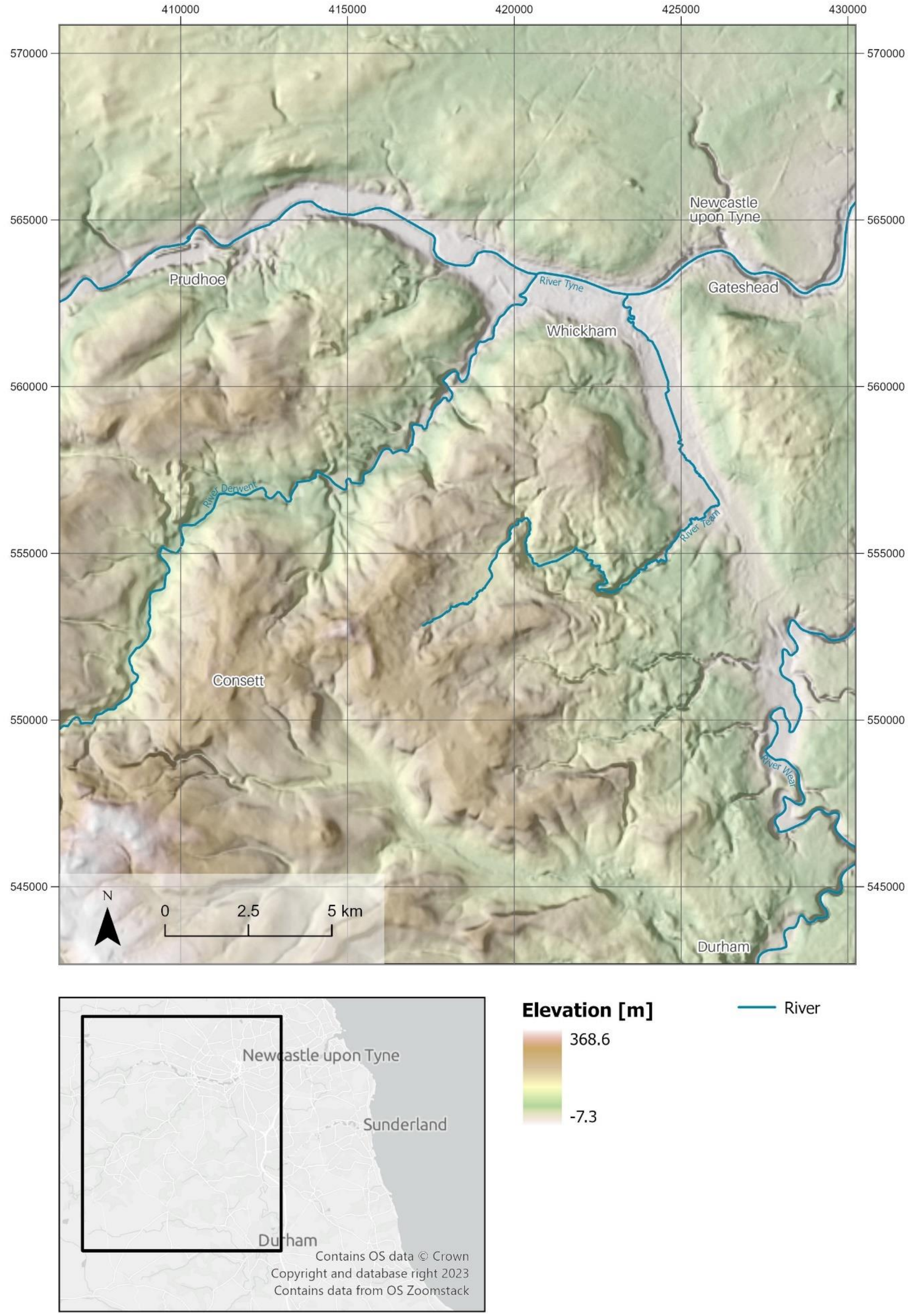

Figure 1 – Location map of the Project Groundwater Northumbria Gateshead area for superficial hydrogeological domains classification. Contains Ordnance Survey data © Crown copyright and database rights 2024.

1.3 GEOLOGICAL HISTORY OF THE AREA

The superficial geology in the study area comprises a suite of glacial and postglacial sediments deposited during and after the development and retreat of the British-Irish Ice-Sheet (BIIS) in the Late Devensian. These include extensive cover of glacial till, glaciofluvial (typically sand & gravel), and glaciolacustrine (typically silt and clay) deposits. The glacial deposits are overlain by modern river terraces and alluvium along river courses (**Figure 2**).

The distribution and architecture of superficial deposits reflects the geological evolution of the area, particularly the processes and events occurring during deglaciation of the BIIS. At the height of the BIIS (c. 22 - 20 ka), northeast England was overridden by ice flowing approximately eastwards along the Tyne Gap and from local ice centres on the Pennines flowing down Weardale and Teesdale. At the same time, ice sourced from Southern Scotland was deflected southwards along the current North Sea Coast (e.g. Davies et al., 2019) (**Figure 3**).

As deglaciation progressed, the Tyne glacier and local ice on the North Pennines retreated rapidly north and westwards across the area between c. 20 – 19 ka (Davies et al., 2019; Livingstone et al., 2012, 2015). During this time a large glacial lake – Glacial Lake Wear – developed in the Tyne-Wear lowlands as drainage was blocked to the east by the presence of ice in the North Sea (**Figure 3**).

During and following the glacial retreat, glaciofluvial sands and gravels were deposited at the margins of the Tyne and North Pennines glaciers (Yorke et al., 2007, 2012), and laminated glaciolacustrine silts and clays were deposited within Glacial Lake Wear. This lake extended inland along a network of deep buried valleys along the rivers Tyne, Team and Wear (cf. Mills and Holliday, 1998). These valleys are thought to have been carved into the underlying bedrock by glacial erosion during multiple Quaternary glaciations and infilled with glaciolacustrine and glaciofluvial outwash deposits during the retreat of the BIIS.

The development of glaciofluvial and glaciolacustrine deposits thus reflects complex glacial and topographic controls on deposition, with local interactions between glaciofluvial outwash and glaciolacustrine systems. In some areas, interbedding of till with sand & gravel and/or laminated clay indicates complex sequences that may reflect glacier advance over proglacial deposits during glacial surges (e.g. Evans et al., 2024).

Following deglaciation of the area, river terrace deposits and alluvium have been deposited along rivers and streams, particularly along the Rivers Tyne, Team, Wear and Derwent. These river deposits may have locally reworked the earlier glaciofluvial and glaciolacustrine deposits in these areas.

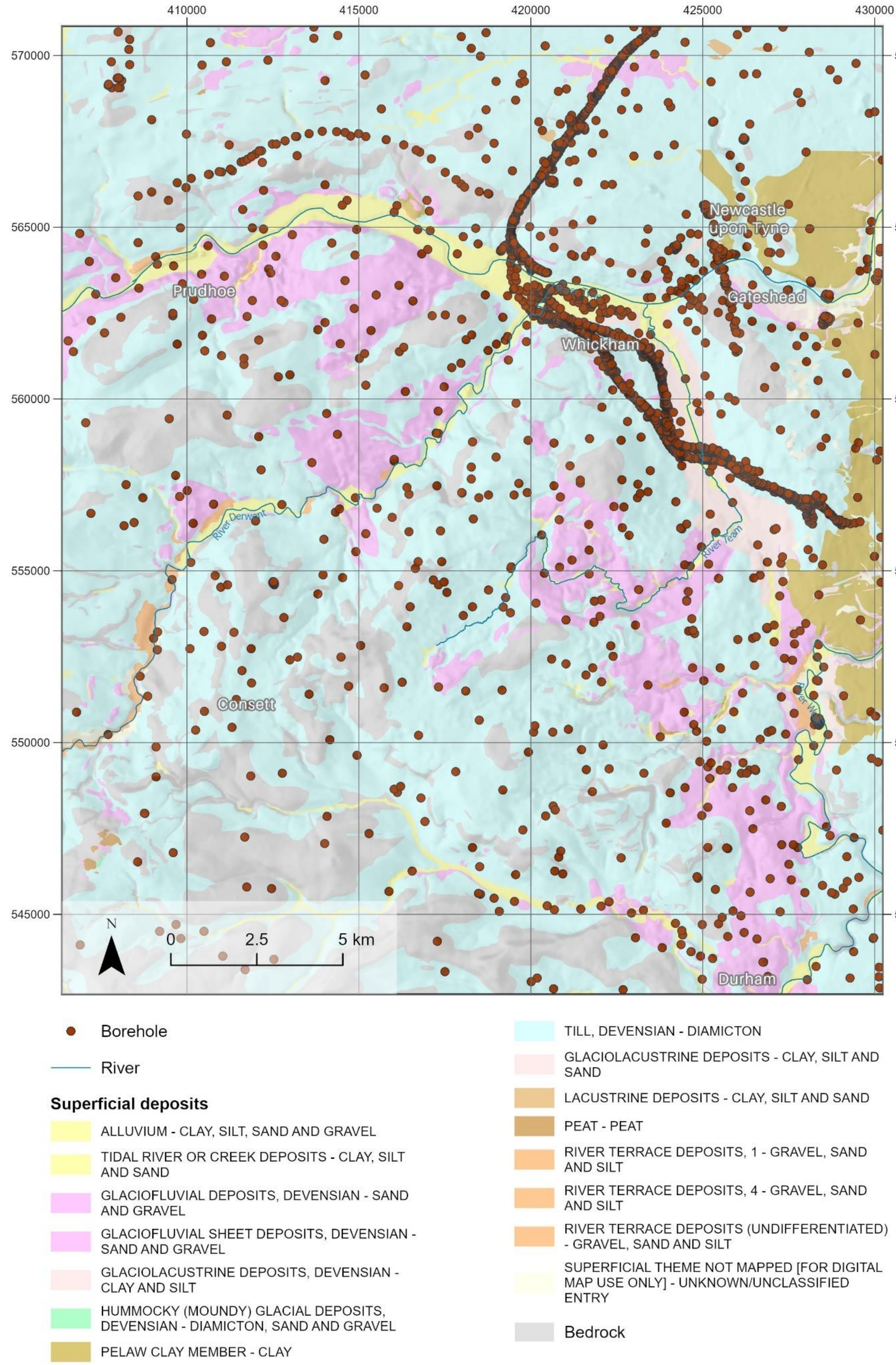

Figure 2 – Superficial geological map of the study area with boreholes coded for the project and selected boreholes from the BGS Borehole Geology database. Contains Ordnance Survey data © Crown copyright and database rights 2024. Contains BGS Geology 50K © UKRI 2024.

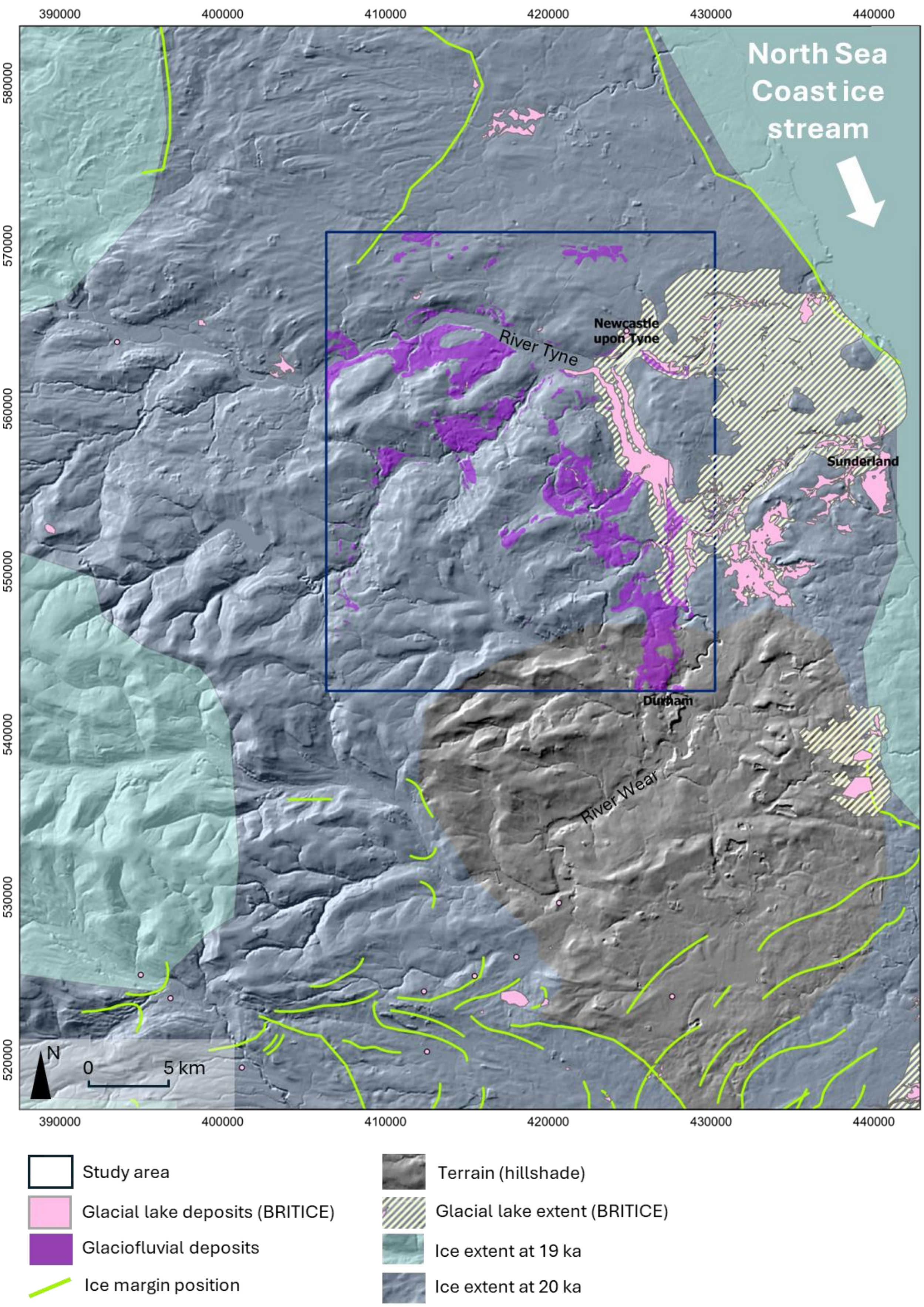

Figure 3 – Regional glacial history of northeast England after Davies et al. (2019), and Clarke et al. (2017). Hillshade is derived from the NextMap DTM at 50m resolution © Getmapping: Licence Number UKP2006/01. Contains BGS Geology 50 © UKRI 2024.

2 Methodology

2.1 BOREHOLE CODING

A database of 409 coded boreholes were collated, including over 220 boreholes coded for the project, along with additional boreholes and rockhead (base of the superficial deposits) picks from the BGS borehole database. The boreholes coded for the project were selected to ensure at least one borehole for every 2 km^2 of the study area to constrain interpolations and ensure regional sampling of the deposits. In addition, more focused coding was undertaken for key areas of complexity, particularly buried valleys where additional boreholes are available.

Boreholes which reach rockhead were selected preferentially, with boreholes that penetrate superficial deposits but not reaching rockhead selected if these were the only ones available in the area. The latter account for ~ 17% of the boreholes coded and generally occur in areas where superficial deposits exceed ~15 m thickness. Borehole logs were also inspected to identify those with the most consistent and detailed records of the superficial strata. Boreholes were coded into the BGS borehole geology database using the BGS coding scheme for superficial deposits (Cooper et al., 2006).

The lithologies in the borehole data are recorded as lettered codes with each letter referring to a specific sediment type and the first letter indicating the primary lithology (see Appendix 2). For example, the code 'CSV' indicates a clay (C) containing sand (S) and gravel (V) in order of decreasing relative proportions. Each individual combination of letters, i.e. each lithology code, was assigned a permeability class as either 'permeable' or 'low permeability' (Appendix 3). This classification is based on the BGS Guide to Permeability Indices (Lewis et al., 2006) and previous work conducted in the Vale of York (Ford et al., 2003). The assignment for this study was based on the first two letters in the lithology code, to ensure that the presence of substantial amounts of clay within the matrix of mixed deposits was accounted for in the permeability attribution. Lewis et al. (2006) was the preferred schema for assigning a permeability class. However, lithologies that were not included in their classification were attributed according to Ford et al. (2003). In general, units containing clay or silt as a primary or secondary component are classified as having a 'low permeability', whereas units that are predominantly sand, gravel or larger are defined as 'permeable'.

The above classification was only applied to superficial sediments, i.e. bedrock and artificial layers are not considered in this analysis. Boreholes recording undifferentiated superficial deposits (e.g. "drift") were used to constrain the depth of rockhead (interpreted top of bedrock; see section 2.2) but were excluded from the analysis of hydrogeological properties.

To reduce the number of coded layers into manageable pieces, the individual layers of the borehole data were summarised into units of the same permeability attribution (**Figure 4**). Such permeability units are referred to as either 'aquifer' or 'aquitard' – depending on their permeability attribution – in the following sections and form the basis for further analysis to inform the hydrogeological domain classification (see section 2.3).

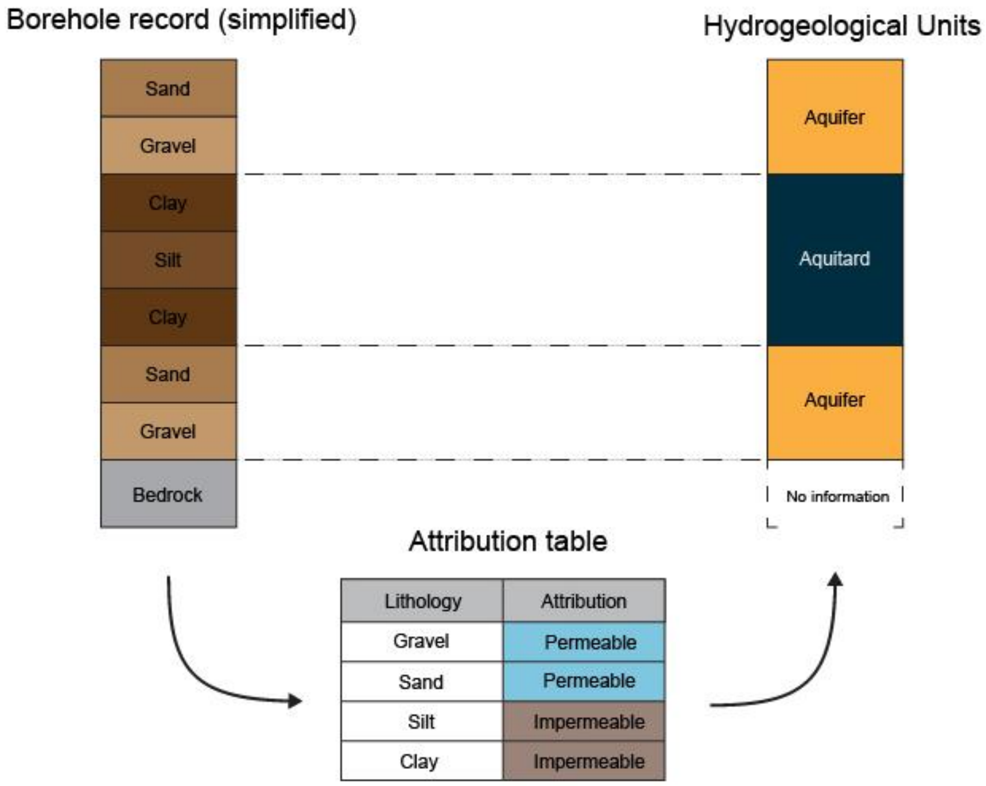

Figure 4 – Illustration of the permeability attribution process for borehole data. BGS © UKRI 2024

2.2 SUPERFICIAL THICKNESS MAPPING

The superficial thickness model for the study area was derived from 7641 available borehole records in the study area itself and an additional 3994 boreholes within a 5 km buffer zone. An additional 1663 input points with a thickness of zero were manually added in areas with no mapped superficial deposits on BGS Geology 1:50,000 maps to constrain areas with rock at the ground surface. These boreholes from the BGS database include both the coded records and those that have summary codes for undifferentiated superficial deposits.

Of the available boreholes, 6746 reach rockhead (~88% of all boreholes used). These, together with the manually added '0' thickness points, were used to derive a preliminary interpolation which was compared to the remaining boreholes that did *not* reach RH. A further 895 boreholes (~12% of all boreholes used) that did *not* reach RH were identified as having thicker superficial deposits than predicted by the preliminary interpolation. The terminal depth of these boreholes, with an additional 1 m added to reflect a conservative estimate of the true thickness, was used to constrain the final interpolation. In these areas, the true thickness of superficial deposits may be greater than predicted by the superficial thickness model. The model therefore reflects a minimum thickness of deposits. The final interpolation was carried out in Esri ArcPro 3.2 using a Natural Neighbour algorithm with a cell size of 50 m.

2.3 HYDROGEOLOGICAL DOMAINS CHARACTERISATION

A classification scheme of six principal hydrogeological domains was developed to characterise the superficial deposits with respect to their potential for groundwater flow connectivity, four of which are further divided into subdomains (**Table 1**, **Figure 5**). This classification was developed in consultation with project partners to reflect the need to assess both recharge to, and discharge from, underlying aquifers. It is based on a combination of unit thickness, predominant composition and the vertical sequence of strata.

Domain 1 is defined where superficial deposits are less than 2 m thick. Effectively 2 m is considered as the thickness below which any superficial deposits may be reasonably assumed to be permeable. Previous domain studies in the region (e.g. Price et al., 2007) have specified a 5 m threshold. However, the 2 m thickness threshold used in this study was defined following consultation and reflects a balance between the need for local understanding of recharge-discharge dynamics and the resolution of geological data.

The 2 m threshold for **Domain 1** is considered conservative given uncertainty in both the borehole depths (often due to uncertainty in the ground surface elevation), and the superficial deposits mapping. The latter is limited to deposits greater than ~1 m thick and may generalise areas where the coverage of thin deposits is patchy. The 2 m threshold is also reflective of typical weathering profiles of glacial till (Russell and Eyles, 1985), which may increase permeability in the upper 1 – 2 m of surface deposits, and relevant for typical depths of subsurface sewerage and water infrastructure.

Domain 2 was included to account for areas where thicker developments of permeable superficial deposits are present overlying bedrock. These areas have no aquitard (defined as greater than 2 m of continuous low permeability deposits) present in the succession. Low permeability deposits (clay-dominated lithologies) less than 2 m thick may be present, but these thinner deposits are considered likely to be laterally discontinuous with a correspondingly higher likelihood of vertical and lateral continuity.

Where an aquitard comprising more than 2 m of continuous low permeability deposits is present in the deposits, the classification scheme differentiates zones based on the maximum thickness of continuous aquitard present (**domains 3 - 5**), and the relationship between the aquitard and an associated aquifer (greater than 2 m continuous thickness of higher-permeability deposits) if present. This approach was used to classify regions with no perched aquifer (sub-domain a), an unconfined perched aquifer (sub-domain b) and one or more confined perched aquifers (sub-domain c).

Sand-dominated beds and lenses may vary in thickness from a few centimetres to tens of metres, with many less than 1 m thick. This high variability combined with limited borehole density means that in many areas it is not possible to correlate sand bodies laterally. The use of a 2 m thickness threshold to define an aquifer reflects a pragmatic balance between the vertical detail of a borehole and the lateral continuity of the respective units. Thinner units are more likely to be discontinuous and therefore a threshold of 2 m was selected as the lower limit for the domain mapping.

Note that all areas that fulfil the criteria for domain 5 occur within the region defined as buried valley so are included within **Domain 6**. Domain 5 is therefore not included in the outputs or discussed further in the report. Domain 6 reflects the presence of deep, elongated buried valleys with complex sediment infills. Further sub-division of this domain is based on analysis of the architecture of geological units and the presence /absence of perched aquifers within the superficial strata.

Table 1 – The superficial hydro-domains classification scheme. Rows are principal domains (1-6) based on total thickness of superficial deposits and thickest aquitard. Columns are subdomains (a-c) based on the sequence of permeability units as observed within individual boreholes (left units in column title are above right units). Note that subdomain classification a-c only applies to principal domains 3-5. Additional aquifers and aquitards in subdomain b and c are only considered if they equal or exceed 2 m in thickness. The thickest aquitard in subdomain c can be either the lower or upper aquitard in the sequence (cf. **Figure 5**).

	Aquitard Glacial till Glaciolacustrine deposits on till	**Aquifer | Aquitard** Glaciofluvial deposits on till Sandy alluvial deposits on till Glaciofluvial on glaciolacustrine deposits	**Aquitard | Aquifer | Aquitard** Glaciofluvial deposits within till or glaciolacustrine deposits Sandy alluvial deposits between till, glaciolacustrine deposits, or clayey alluvium
Superficial deposits < 2 m	1		
Superficial deposits > 2m no **aquitard** > 2 m	2		
Thickest **aquitard** between 2 – 10 m	3a	3b	3c
Thickest **aquitard** between 10 – 30 m	4a	4b	4c*
Thickest **aquitard** > 30 m	5a*	5b*	5c*
Buried valley	6 d-h†		

***These domains are present in this scheme but were not identified in the study area (see section 3).**

†Buried valleys are here defined as longitudinally connected areas with more than 10 metres of superficial deposits. See Section 3.3 for explanation of subdomains.

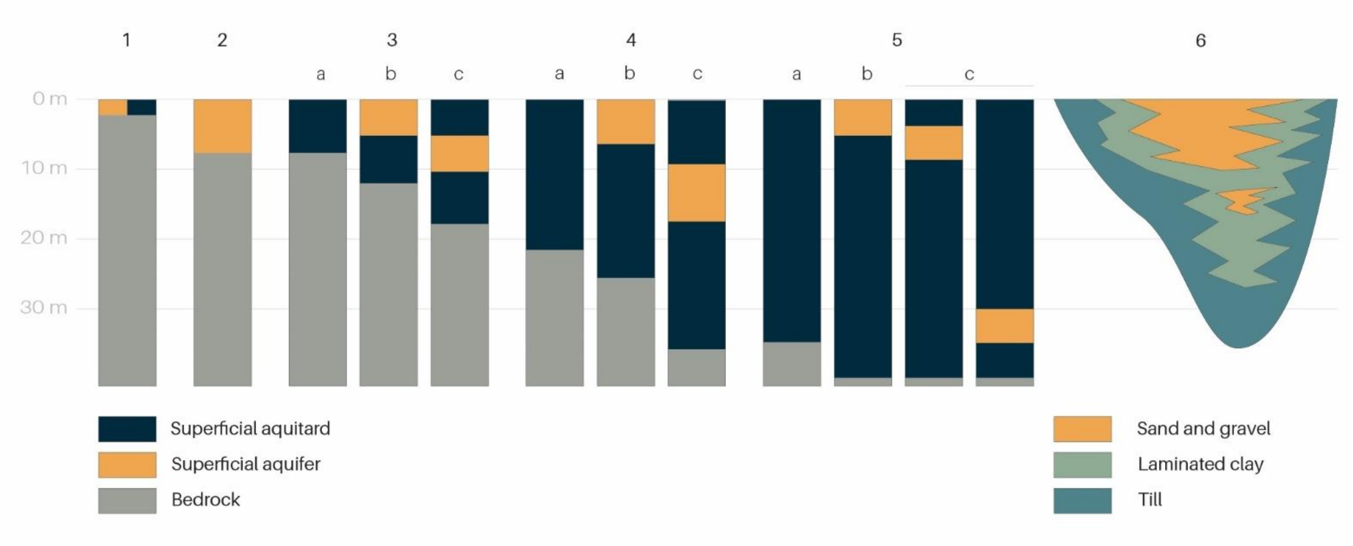

Figure 5 – Illustration of the Superficial hydrogeological domains described in Table 1. BGS © UKRI 2024.

2.4 HYDROGEOLOGICAL DOMAIN MAPPING

Boreholes were classified by domain according to Table 1. The same domains have also been mapped across the study area (shown in **Figure 8**) based on the combined data from the updated superficial thickness model (section 2.2), the predominant borehole class (Table 1), superficial geological maps, and regional geological understanding. The process for mapping the domains is illustrated in **Figure 6**.

Areas in which superficial deposits are absent or thinner than 2 m correspond to domain 1. The area of domain 1 was delineated using a maximum threshold of 2 m applied to the updated superficial thickness model (**Figure 6**, steps 1-3). Note that areas where superficial deposits are absent can be identified from the BGS superficial geological map.

Similarly, principal domain 6 (buried valleys) was mapped by applying a threshold of 10 metres to the updated superficial thickness model followed by manual selection to ensure only elongated “valley” geometries were captured (**Figure 6**, step 4). The subdivision of domain 6 (buried valleys) was informed by borehole analysis and construction of cross-sections (locations of the sections are shown on **Figure A1-1** in the Appendix). The subdomains are based on the predominant valley fills and include:

d) Sand & gravel + till (the sand & gravel may include either/both glaciofluvial deposits and sandy alluvium)
e) Till
f) Glaciolacustrine (clay dominated)
g) Glaciolacustrine (mixed sand and clay)
h) Complex

The residual area, i.e. the area where neither a classification of 1 nor 6 was assigned, was subdivided into principal domains 2 – 5 and their respective subdomains as shown in Table 1. This was done by manually mapping out the dominant trend in respective regions based on the borehole classification, 1:50,000 scale superficial geological map and regional geological understanding (**Figure 6**, step 5). The final map is a collation of the stages described above (**Figure 6**, step 6).

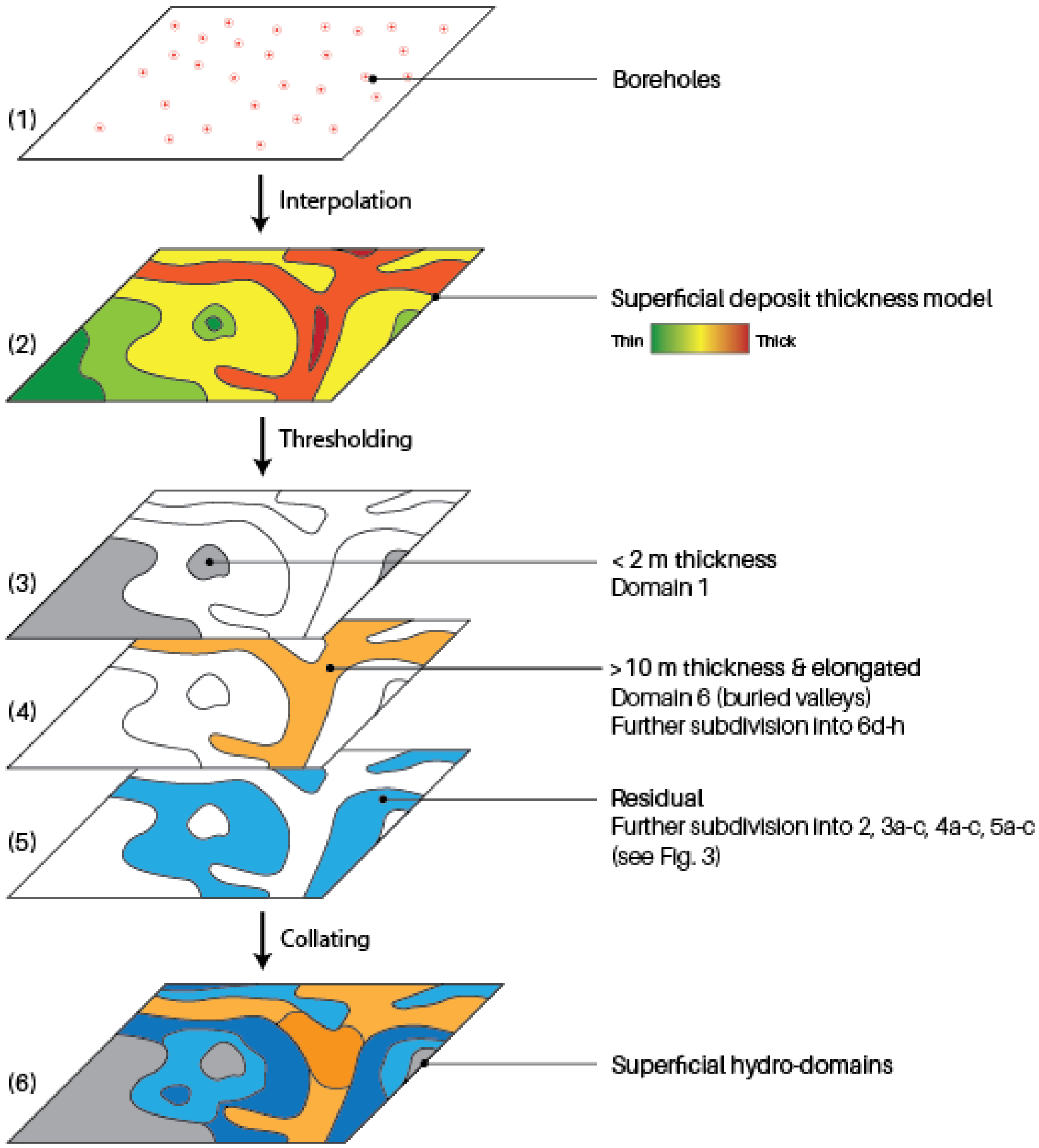

Figure 6 – Methodology for mapping the superficial hydrogeological domains. BGS © UKRI 2024.

3 Hydrogeological domains

3.1 SUPERFICIAL DEPOSIT THICKNESS MODEL

Modelled superficial deposit thicknesses vary from 0 to over 50 m across the study area (**Figure 7).** In the west and southwest of the study area, the thickness of superficial deposits is typically thin - commonly less than 2 m.

The thickest sequences can be found within the buried valley system. This covers large parts of the study area, most prominently in the centre, southeast, east and northeast. The most continuous and elongated structure bisects the study area from the southeast towards the north-northwest with a significant bend between Whickham and Gateshead where it continues to the west.

Numerous smaller buried valleys are observed to branch off the main structure, most of which have a roughly northeast – southwest orientation and are approx. 5-10 km long. To the northeast, wider basin-like structures are observed, these extend beyond the margins of the study area. Deposits surrounding the buried valleys are typically 2 – 10 m thick and form an irregular fringe surrounding the buried valleys themselves. Noticeable exceptions to this can be found northeast of Consett, along the River Derwent in the central to southwest part of the study area, where superficial deposits are locally greater than 30 m thick (**Figure 7**).

3.2 SUPERFICIAL DOMAINS

The superficial domains schema in Table 1 represents a set of initial domain definitions considered in this study. However, subdomains 4c and 5a-c are not found in boreholes within the area and have not been mapped in the area therefore are not further described. Approximately 67% percent of the study area is covered by domains 1, 3 and 6 (**Figure 8**, **Table 2**).

Domain 1, which has less than 2 m superficial deposit thickness, covers ca. 31% of the area and has been defined from the 2 m contour of the superficial thickness model described in section 3.1. It is most extensive on the higher ground in the west and southwest of the study area.

Domain 2, which represents superficial deposits that are over 2 m thick but comprise only sand or sand & gravel (i.e. no aquitard), occurs as a roughly 6 km long and 0.5 – 2 km wide band in the central part of the study area, between the rivers Derwent and Team (and their associated buried valley structures). It covers a fraction of ca. 1% of the study area. The distribution is defined where superficial deposits are over 2 m thick and boreholes indicate the presence of sand and sand & gravel deposits. Although mapped as glacial till in BGS Geology 1:50,000 scale superficial geological maps, this area may reflect unmapped glaciofluvial deposits or the presence of very sandy till.

The distribution of domains 3, 4 and 6 reflects minimum estimates because boreholes in some areas do not reach rockhead and may therefore underestimate the thickness of deposits. Domains 3 and 4 reflect continuous thicknesses of 2 – 10 m and 10 – 30 m of aquitard present within the succession respectively. Domain 3 covers ca. 34% of the study area, with 33% of the study area attributed to subdomain 3a alone. Domain 3a essentially reflects areas of till cover that are 2 – 10 m thick. Subdomains 3b and 3c occur locally on the northern side of the River Derwent where spreads of sand & gravel overlie the till.

Subdomains 4a and 4b are found near subdomain 3c and extend to areas south of the River Derwent. Domain 4 reflects areas of locally thick till deposits (4a) overlain by glaciofluvial cover (4b). The distribution of domains 3 and 4, and their subdomains, is constrained by the borehole data and informed by geological mapping of glaciofluvial deposits in this area.

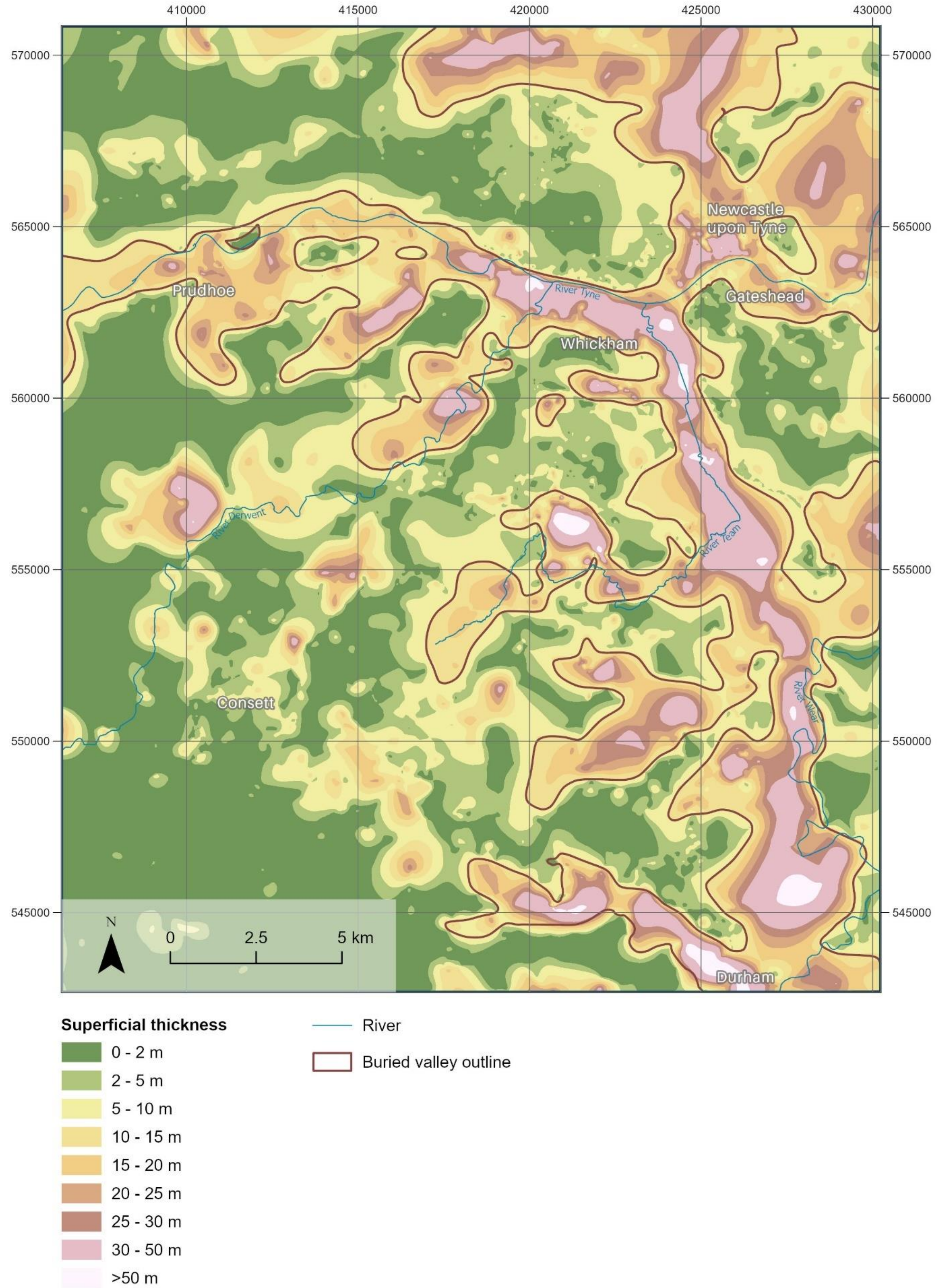

Figure 7 – Superficial thickness model for the area. The area categorised as buried valley domain (domain 6) is shown. Contains Ordnance Survey data © Crown copyright and database rights 2024. BGS © UKRI 2024.

Domain 6 refers to thick sequences of superficial deposits within elongate buried valley structures. These occur widely and cover approximately 31% of the study area. The buried valley domain has been further subdivided into subdomains 6d-h based on analysis of the sediment types and architecture. The deposits of the buried valley subdomains are described in section 3.3.

Subdomain 6d (sand & gravel + till) is the most extensive subdomain within domain 6, covering ca. 19% of the study area. It is mostly associated with peripheral parts of the buried valley network (**Figure 8**). Subdomain 6e (till) occupies the outermost areas of some of the smaller tributary branches. The main buried valleys of the River Tyne and Team-Wear are covered by domains 6f and 6g which reflect glaciolacustrine clay-dominated and glaciolacustrine sand & clay successions. Subdomain 6h is an additional area where complex layered till, and sand & gravel deposits occur along the line of the River Tyne between Newcastle and Gateshead.

Table 2 – Summary description of domains 1-4.

Sub-Domain	Domain Name	Summary description of domain	% coverage
1	Superficial deposits < 2 m	**Limited superficial cover.** Less than 2m of superficial deposits regardless of deposit type. Includes areas where rock is at surface and areas with till / glaciofluvial deposits / other deposits where they are less than 2m.	31%
2	Superficial deposits > 2m no **aquitard** > 2 m	**No superficial aquitard.** Areas where superficial deposits exceed 2 m but no aquitard greater than 2m thick is present. This occurs in an area were glaciofluvial deposits and glacial till are mapped but the till is locally described in boreholes as comprising sand & gravel or sand & boulders.	1%
3a	2 – 10 m **aquitard**	**Moderate thickness of superficial aquitard, no superficial aquifer.** Areas where 2 - 10 m continuous thickness of clay-dominated deposits, but no sand-dominated deposits greater than 2 m thick, are present. This predominantly includes areas of thicker glacial till.	33%
3b	**Aquifer** > 2 m <u>overlying</u> **aquitard** 2 – 10 m	**Superficial aquifer at surface, above a moderate thickness of superficial aquitard.** Areas where 2 - 10 m continuous thickness of clay-dominated deposits are overlain by sand-dominated deposits greater than 2 m thick. This predominantly includes areas of glaciofluvial deposits or sandy alluvium overlying till.	< 1%
3c	**Aquifer** > 2 m <u>between</u> **aquitard** 2 – 10 m	**Superficial aquifer within superficial aquitard of moderate thickness.** Areas where sand-dominated deposits (aquifer) greater than 2 m thick are present within a clay-dominated sequence where a continuous sequence of 2 - 10 m aquitard is present below the aquifer, and >2m aquitard occurs above.	< 1%

		This reflects perched aquifers glaciofluvial deposits within or between layers of glacial till.	
4a	**Aquitard** 10 – 30 m	**Thick superficial aquitard, no superficial aquifer.** Areas where 10 – 30 m continuous thickness of clay-dominated deposits, but no sand-dominated deposits greater than 2 m thick, are present. This predominantly includes areas of thicker glacial till.	1%
4b	**Aquifer** > 2 m overlying **aquitard** 10 – 30 m	**Superficial aquifer at surface, above a thick superficial aquitard.** Areas where 10 - 30 m continuous thickness of clay-dominated deposits are overlain by sand-dominated deposits greater than 2 m thick. This predominantly includes areas of glaciofluvial deposits or sandy alluvium overlying till.	1%
6	Buried Valley domain	Variable relationships. See section 3.3 and Table 3 for description of subdomains	31%

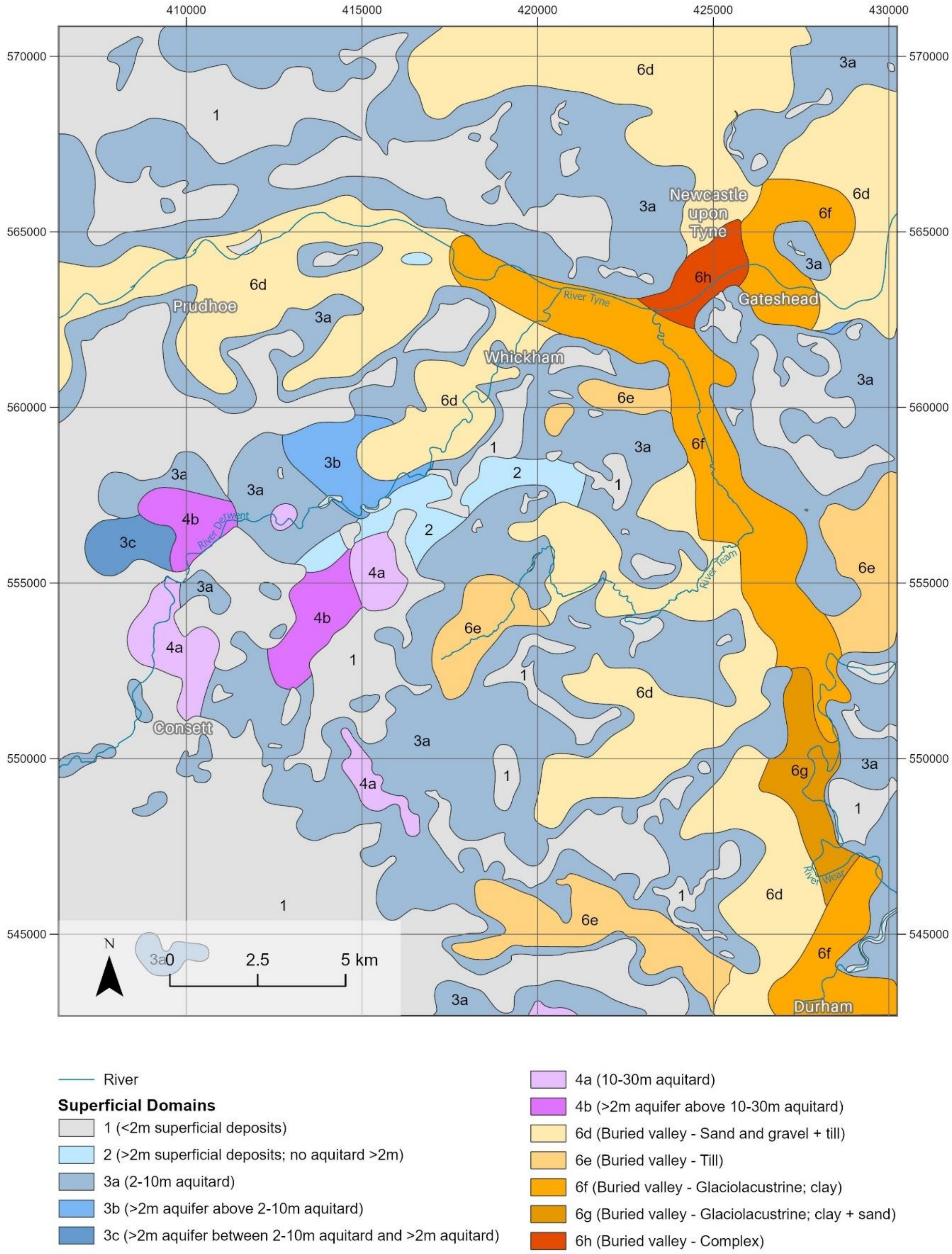

Figure 8 – Superficial hydrogeological domains for the Newcastle-Gateshead area. Contains Ordnance Survey data © Crown copyright and database rights. BGS © UKRI 2024.

3.3 BURIED VALLEY ARCHITECTURE AND DOMAIN DESCRIPTION

The buried valley domain characterises the typically thick and complex sequences of glacial and post-glacial deposits infilling the buried valley network. The main buried valley system along the modern rivers valleys of the Tyne, Team and Wear is known to contain a thick infill of laminated clay and silt deposited in a proglacial lake (**Figure 3**). However, sand and sand & gravel deposits occur locally and within the clay-dominated succession. The sand-bodies reflect coarser sediment input into the former lake by pro-glacial streams, and the development of postglacial river channels following lake drainage. Where present, these sand bodies are likely to act as perched aquifers and may be conduits for lateral groundwater flow, particularly when channelised.

A range of potential sand-body geometries are illustrated in **Figure 9**, including glaciofluvial deposits adjacent to and potentially interfingering with the lacustrine clay along the valley margins (a), alluvial gravels (b), glaciofluvial sand & gravel lenses or channels within the lacustrine clay (c) or at the base of it (d), and sand & gravel lenses occurring below clay or till along the valley side (e).

If present, these sand bodies may give rise to a range of aquifer-aquitard interactions including:

- perched superficial aquifers as lenses or channel bodies at different levels (**Figure 9 b**, **c**)
- potential sub-surface continuity in channelised sand-bodies that may give rise to lateral flow (**Figure 9 b** and **d**)
- connections between glaciofluvial or alluvial deposits at surface with those at depth (**Figure 9 a**)
- basal sand-bodies connected to bedrock aquifers (**Figure 9 d** and **e**).

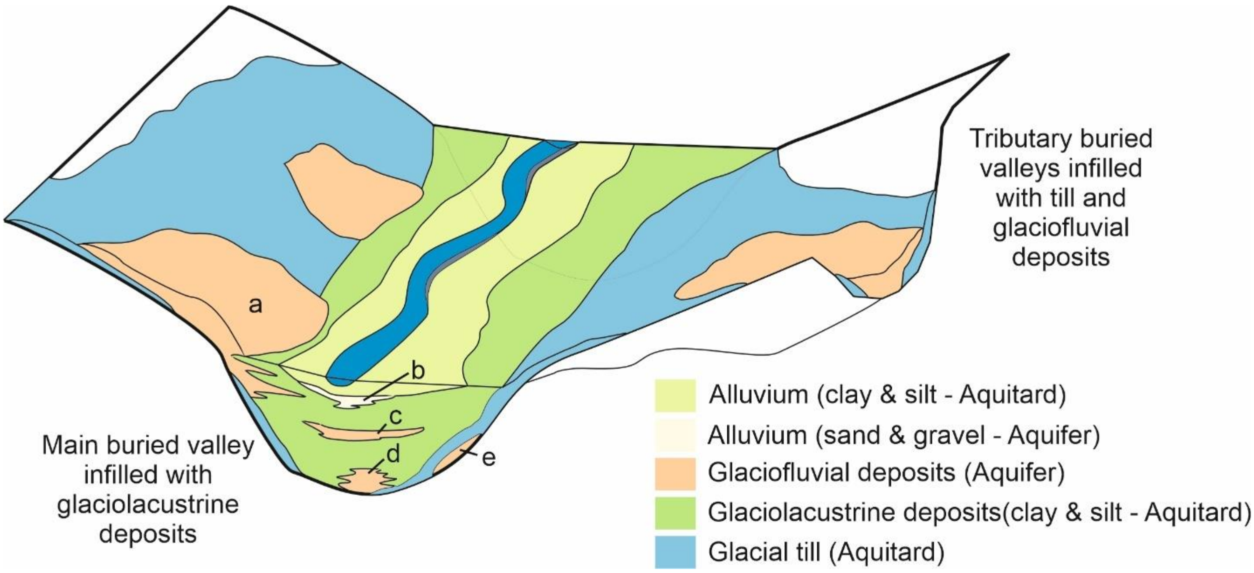

Figure 9 – Sketch diagram illustrating potential scenarios for buried valley architecture. Letters refer to features discussed in the text. BGS © UKRI 2024.

The architecture of the buried valley fill deposits was investigated through analysis of the coded boreholes and the construction of cross-sections from borehole data using BGS Groundhog software, with particular focus on the nature and association of sand-dominated deposits. Five buried valley sub-domains (6d-h) were identified through this process (**Figure 8**, **Table 3**).

The architecture of domains 6 d-g are summarised in **Figure 10** to illustrate the key associations of sand-bodies and clay-dominated deposits (glaciolacustrine deposits and till), domain 6h is described in **Figure 12**. The cross-sections used to inform these summaries are provided in Appendix 1.

Table 3 – Summary descriptions of the Buried Valley sub-domains (6 d-h).

Sub-Domain	Domain Name	Summary description of buried valley fill
6d	Sand & gravel over till	**Superficial aquifer overlying variable thickness of aquitard.** Areas where sand & gravel (glaciofluvial deposits and alluvium) overlies glacial till. Note that the till may be locally thin or absent resulting in localised areas of direct connection between bedrock and the sand & gravel deposits.
6e	Till dominant	**Superficial aquitard with minor confined aquifers.** Areas one or more tills make up the succession. Thin sand & gravel beds may be present within or between till layers but are unlikely to exceed 2 m thickness, and are considered unlikely to be laterally continuous
6f	Glaciolacustrine (clay-dominated) and till	**Superficial aquitard with confined and unconfined aquifers.** Zone where glaciolacustrine deposits comprising laminated clay and silt overly glacial till. These deposits are locally over 100 m thick in the deepest parts of the buried valley. Glacial till is locally absent below the glaciolacustrine deposits. Sand & gravel deposits occur locally below the glaciolacustrine deposits (between them and the till). These appear to be developed as spreads along the valley flanks and may give rise to localised perched aquifers. Note that the glaciolacustrine deposits may be locally sandier or contain more sand beds near confluences with minor streams due to input of coarser sediment reworked from adjacent areas of glaciofluvial deposits. Glaciolacustrine deposits are overlain by alluvial and estuarine deposits along the rivers Tyne, Team and Wear. These typically comprise a lower sand & gravel layer 1-5 m thick, overlain by 2-5 m of soft silty clay with organic matter and peat locally developed.
6g	Glaciolacustrine (sand-dominated) and till	**Superficial aquifer with patchy basal aquitard.** Zone of sandier glacio-lacustrine deposits including sandy clay, and/or thicker sand units interbedded with laminated silt and clay. This region occurs near the ‘gap’ between the Rivers Wear and Team and may reflect higher sand input from glaciofluvial deposits on the western flank of the buried valley.
6h	Complex	**Complex layered superficial aquifers and aquitards.** Area along the River Tyne in Newcastle/Gateshead in which boreholes prove multiple layers of till and sand & gravel, with silt beds and laminated clay also present. Relatively thick sand & gravel deposits commonly occur at the base of the superficial succession, directly overlying bedrock. The complexity of the zone may reflect stacked thrusts of glaciofluvial and glaciolacustrine deposits arising from glaciotectonic processes during successive glacier advances.

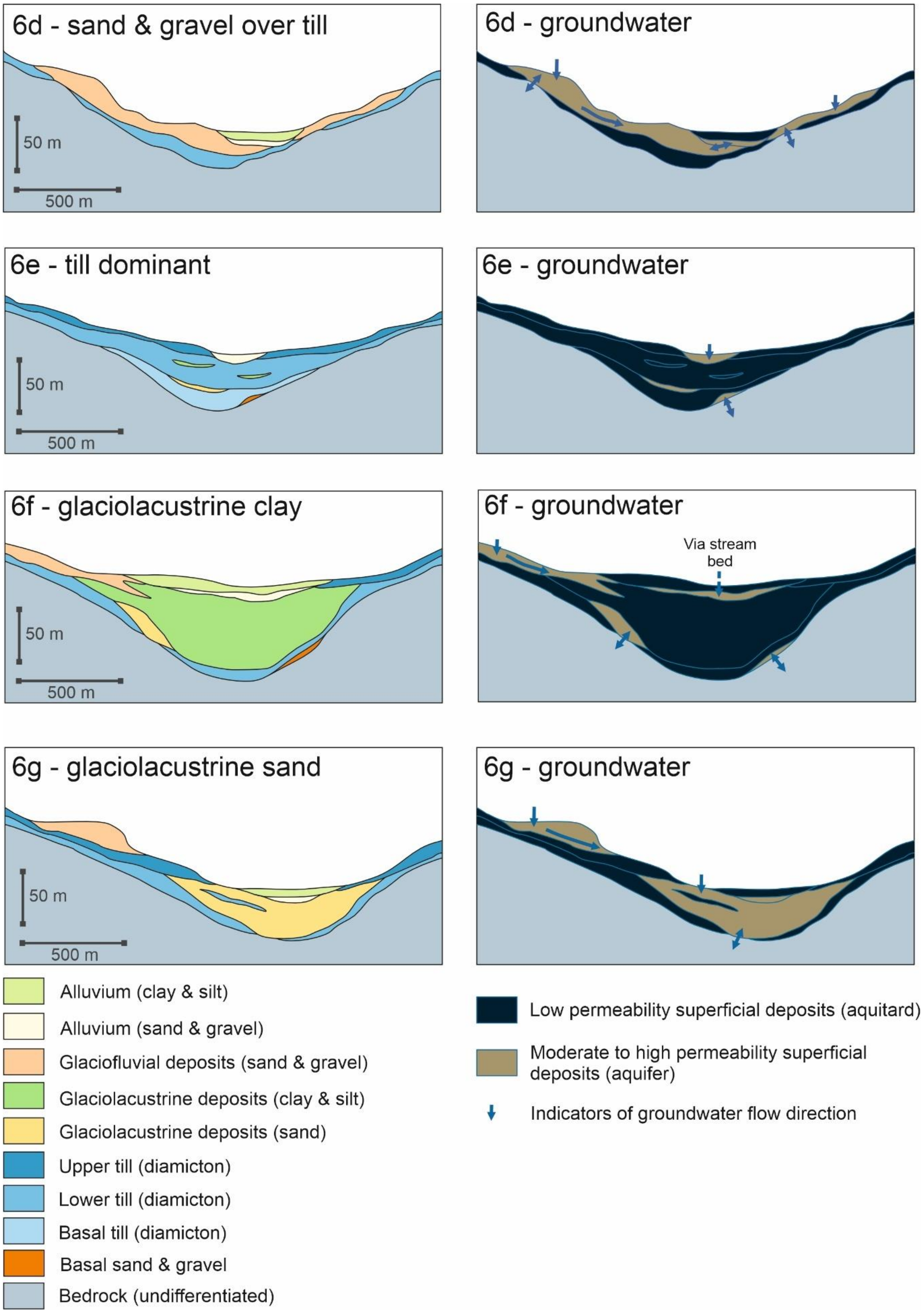

Figure 10 – Summary sketches of the buried valley fill deposits in sub-domains 6d – 6g showing the general geological architecture of the deposits and the implications for groundwater flow. The summary sketches are based on borehole inspection and generalised from cross-sections constructed from the coded boreholes (Appendix 1). Note sub-domain 6h is described further in the text. BGS © UKRI 2024.

3.3.1 Buried valley sub-domains

The five buried valley sub-domains are characterised by the main association of sand-dominated units with respect to clay-dominated valley fill.

Sub-domain 6d – Till overlain by Sand and Gravel

Domain 6d includes areas where the main valley fill comprises glacifluvial sand and gravel deposits. These typically occur at surface and are underlain by glacial till (**Figure 10**). The sub-domain covers the western section of the River Tyne as well as tributary valleys to the west of the Team buried valley that are roughly aligned with the River Derwent, Black Burn, River Team, Cong Burn, South Burn and River Browney (**Figure 8**).

The glaciofluvial deposits include spreads of moundy ice-contact sand and gravel which are present along the River Tyne west of Prudhoe (Yorke et al., 2007, 2012), and in a tract along the western flank of the Team-Wear buried valley. The deposits largely comprise stratified sequences of sand, silty sand, and sand & gravel. In places, as described by Yorke et al. (2007, 2012), the sands are intercalated with thin silt bands and may locally contain lenses of clayey diamicton. Boreholes indicate that thin till deposits overly the sand & gravel in some areas.

Areas of outwash gravels and fans are also deposited along the Tyne Valley and locally along the Team valley near Urpeth. These outwash gravels may locally intercalate with glaciolacustrine clay and silt deposits at the margin of Glacial Lake Wear (Yorke et al, 2012) (Appendix 1-2 - Section PGNY2_15).

Whilst till cover at rockhead is widespread, patches where till is absent occur locally. At these 'windows' through the till, glaciofluvial sands & gravels are in direct contact with bedrock. Prediction of the distribution of these 'windows' is not possible based on the available borehole data.

Sub-domain 6e – Till dominant

In the upper parts of the River Team and River Browney buried valleys, boreholes records indicate a till sequence comprising one or multiple clayey diamictons. These are generally described as firm to stiff, with gravel and/or boulders. In several borehole records variable compositions of till, including units of "clay and boulders" as well as silty or sandy diamictons suggest there may be more than one till present, with stratification arising from potential transitions between dense lodgement tills and less consolidated melt-out tills. Lenses of sand & gravel, typically less than 1m thick are locally intercalated within and between till units. However, the available borehole data does not provide sufficient detail with which to map out the stratigraphy of till sequences within the area. Basal sand and gravel deposits, thought to be localised patches or mounds are proved in boreholes locally beneath the till.

Sub-domain 6f – Glaciolacustrine (clay)

Glaciolacustrine deposits are developed along the Tyne valley and Team-Wear buried valleys (**Figure 10**). This corresponds to the deepest sections of the buried valley system (**Figure 13**).

The glaciolacustrine deposits (Tyne and Wear Glaciolacustrine Formation) comprise a relatively thick continuous sequence of laminated clay and silt, with thin laminations of sand in places and occasional gravel. Thicker units of laminated sand, silty sand and sandy clay are present in some areas beneath the clay/silt or as lenses within it (**Figure 10**). These may reflect the distal parts of alluvial fans associated with streams draining into the lake margin during the early phase of lake deposition.

The glaciolacustrine deposits are underlain by thin glacial till in many areas, although the till is thin or absent in places. It is also overlain by alluvial deposits along the rivers Tyne, Team and Wear. These alluvial deposits comprise a basal sand and gravel layer which is likely to be erosively based, overlain by soft silty clay with sand bands and peat locally developed. The alluvial sand and gravel may form a perched superficial aquifer between the glaciolacustrine deposits and overlying clay-dominated alluvium.

Basal sand or sand & gravel, occurring between the bedrock and overlying till or lacustrine clay/silt is penetrated in several boreholes within this sub-domain (**Figure 10**). These appear to form patches or lenses along the margins of the valley and may not be laterally continuous. Several borehole records note the basal sand or sand & gravel as water bearing.

Sub-domain 6g – Glaciolacustrine (clay & sand)

In the southern section of the Team-Wear buried valley, the glaciolacustrine deposits appear to be sandier. Borehole records indicate a region of predominantly sand & gravel deposits with thin clay bands that transitions laterally into clayey or silty sand interbedded with the lacustrine clay and silt. A summary sketch of the possible relationship of sandy units with lacustrine clay and silt is shown in **Figure 11**. The presence of higher sand content in this area is consistent with the deposition of a delta system into Glacial Lake Wear, with sand and gravel sourced from pro-glacial outwash or reworking of glaciofluvial deposits by minor streams.

Till is locally absent at the base of the buried valley with potential for direct connection between the sand-dominated deposits and bedrock. The overlying alluvium is likely to be discontinuous and is likely to comprise sand & gravel locally. Note that some boreholes record the sand beds intercalated within the laminated clay as water-bearing (e.g. BGSID 875553).

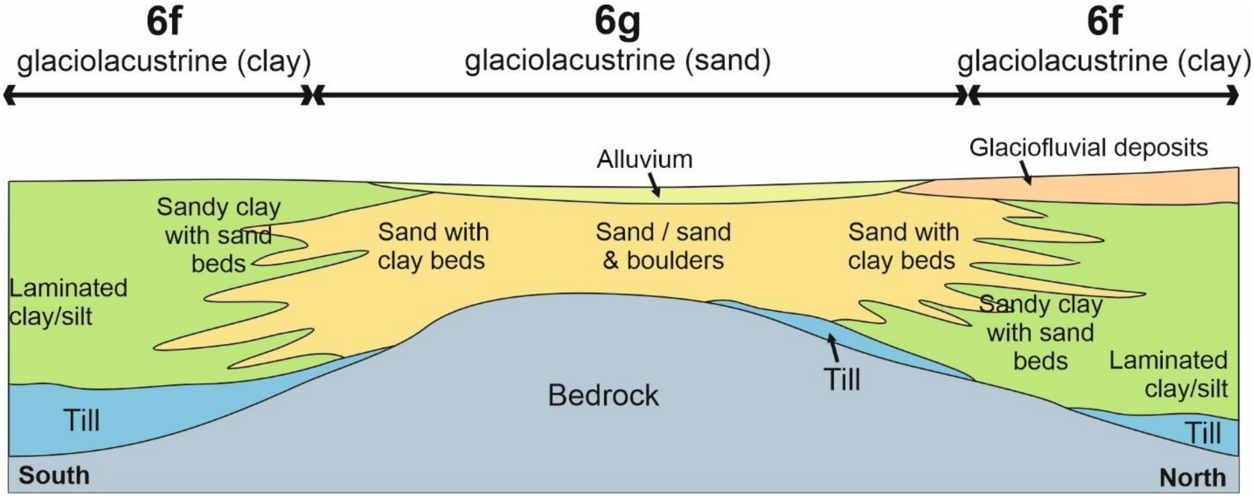

Figure 11 – Summary sketch section along a north-south transect through domain 6g showing the association of the sand-dominated glaciolacustrine deposits with adjacent areas of laminated glaciolacustrine clay and silt (domain 6f). Key as for **Figure 10**.

Sub-domain 6h – Complex

Along the stretch of the Tyne separating Newcastle from Gateshead, is a small domain reflecting highly complex buried valley fill. Boreholes in this area indicate multiple layers of glacial till intercalated with sand & gravel and silt, and a relatively thick sand and gravel deposit at the base of the succession (**Figure 10**). The uppermost sand and gravels are likely to be terraces of the River Tyne, with the underlying sequence of deposits tentatively interpreted as a succession of interdigitated glacial till, glaciofluvial and glaciolacustrine sediments associated with ice advance into Glacial Lake Wear (e.g. Evans et al., 2024). There is a strong likelihood of hydrological connection between bedrock and basal sands, and interconnection within the sand layers in the succession. Made ground deposits are also likely to be extensive and of variable thickness throughout the area, providing additional pathways for groundwater flow between the superficial aquifers.

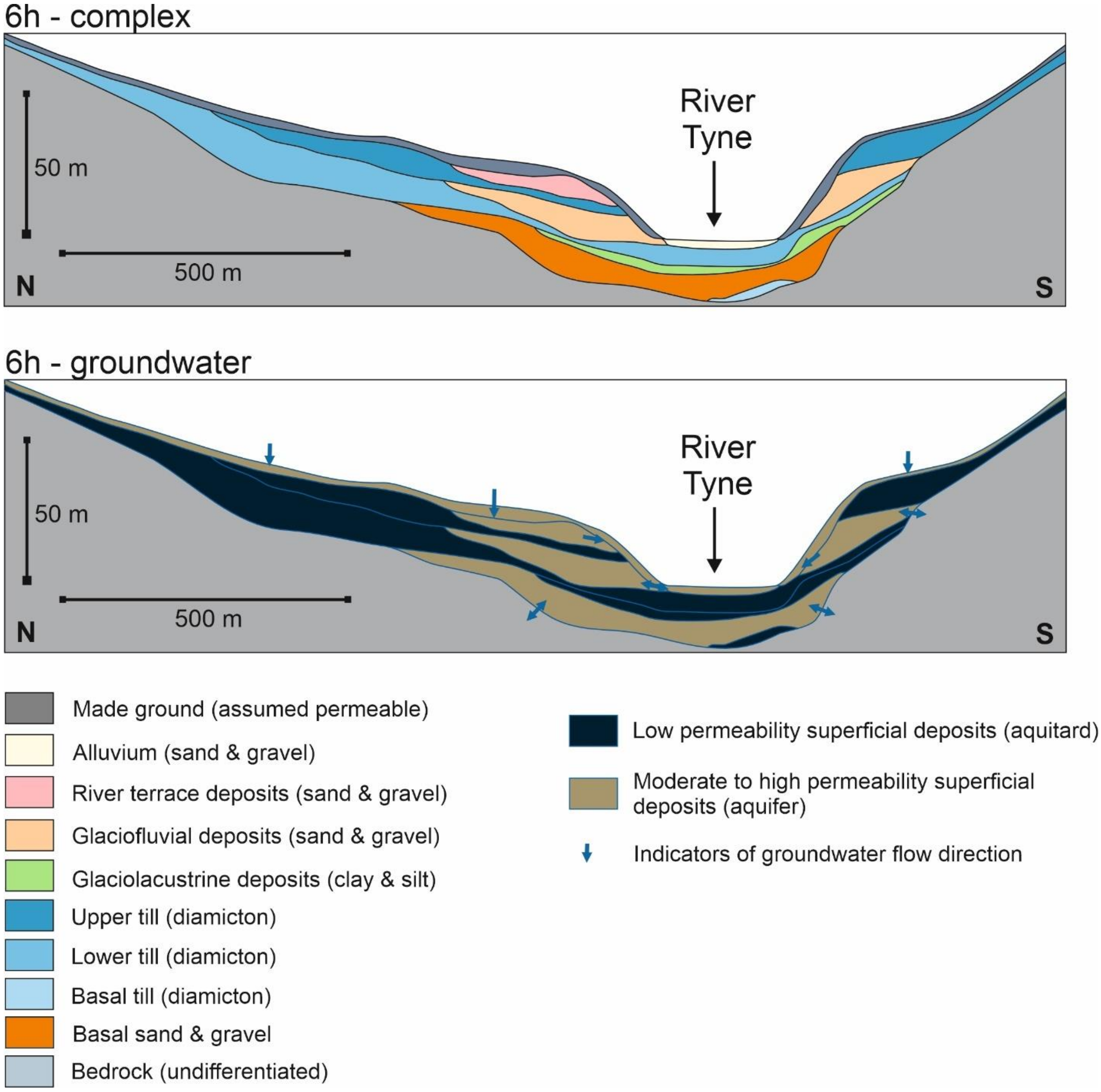

Figure 12 - Cross-section through buried valley of the River Tyne at the Redheugh Bridge (A189) (Redrawn from section PGNY2_11 – Appendix A1-2). Contains Ordnance Survey data © Crown copyright and database rights. BGS © UKRI 2024.

3.3.2 Basal sand and gravel deposits

As noted in the sections above, basal sand & gravel bodies that lie directly on rockhead (referred to here as 'basal sand deposits') are proved in several boreholes throughout the buried valley system (**Figure 13**). In places, the thickness of these deposits locally exceeds 10 – 25 m (**Figure 13**).

Many of the examples of thicker basal sands deposits are associated with areas of glaciofluvial deposits and reflect localised absences of any underlying glacial till. Similarly, thicker 'basal sands' occur within and adjacent to domain 6h, consistent with the presence of glaciofluvial deposits flanking the buried valley and sandy glaciolacustrine deposits as the valley fill in this area.

Elsewhere along the buried valley system, thinner (0 - 6 m thick) basal sand deposits are located mostly along the valley flanks, and isolated boreholes in the centre of the valley show a broad range of thicknesses of basal sands. The limited distribution of borehole records precludes detailed mapping of the lateral extent of these basal sand deposits, and their geometry and lateral connectivity remains poorly known.

The locations of boreholes proving basal sands adjacent to high points in the undulating base of the buried valley indicate that they are unlikely to be continuous channel bodies at the base of the lacustrine succession (cf. **Figure 9 d**). Rather, the presence of basal sand deposits on the valley flanks, and the flanks of 'highs' in the trough floor indicates that they may occur as thin spreads or lobes underlying glacial till and/ or glaciolacustrine clay deposits (**Figure 9 e**).

Where these spreads of valley-flank basal sands underly glacial till, they may reflect buried pre-glacial deposits or glaciofluvial sediment preserved from glacier advance over the area. Where they underly the glaciolacustrine deposits (and till is absent) the basal sands may have been formed during and after ice retreat as ice-marginal outwash fans and/or glaciofluvial deltas formed where pro-glacial streams deposited sand at the margins of Glacial Lake Wear.

The available data is too limited to map the extent of the valley-flanking basal sands, but a general form of the deposits and their associations with other valley fill deposits are shown in the schematic sections in **Figure 10** (see also cross-sections PGNY2_10, PGNY2_12, PGNY2_15 in Appendix A1-2). Two clusters of boreholes proving basal sand deposits are marked a and b in **Figure 13**. The presence of these clusters in part reflects relatively high densities of boreholes in these areas.

A cluster of boreholes proving basal sands below the glacial till and glaciolacustrine deposits are found in the area where the River Derwent joins the Tyne Valley (**Figure 13** cluster a). This is likely to occur as spreads and mounds of 2-10 m thickness. In areas where glacial till is thin or absent, the basal sand & gravel is hard to distinguish in boreholes from overlying glaciofluvial sand and gravel deposits and the thickness values in **Figure 10** reflect the continuous sequence of sand & gravel.

A second cluster occurs along the Tyne valley between the confluences of the River Team and River Ouse (**Figure 13** cluster b), and reflects the presence of a thicker basal sand & gravel deposit within the complex domain 6h (**Figure 12**).

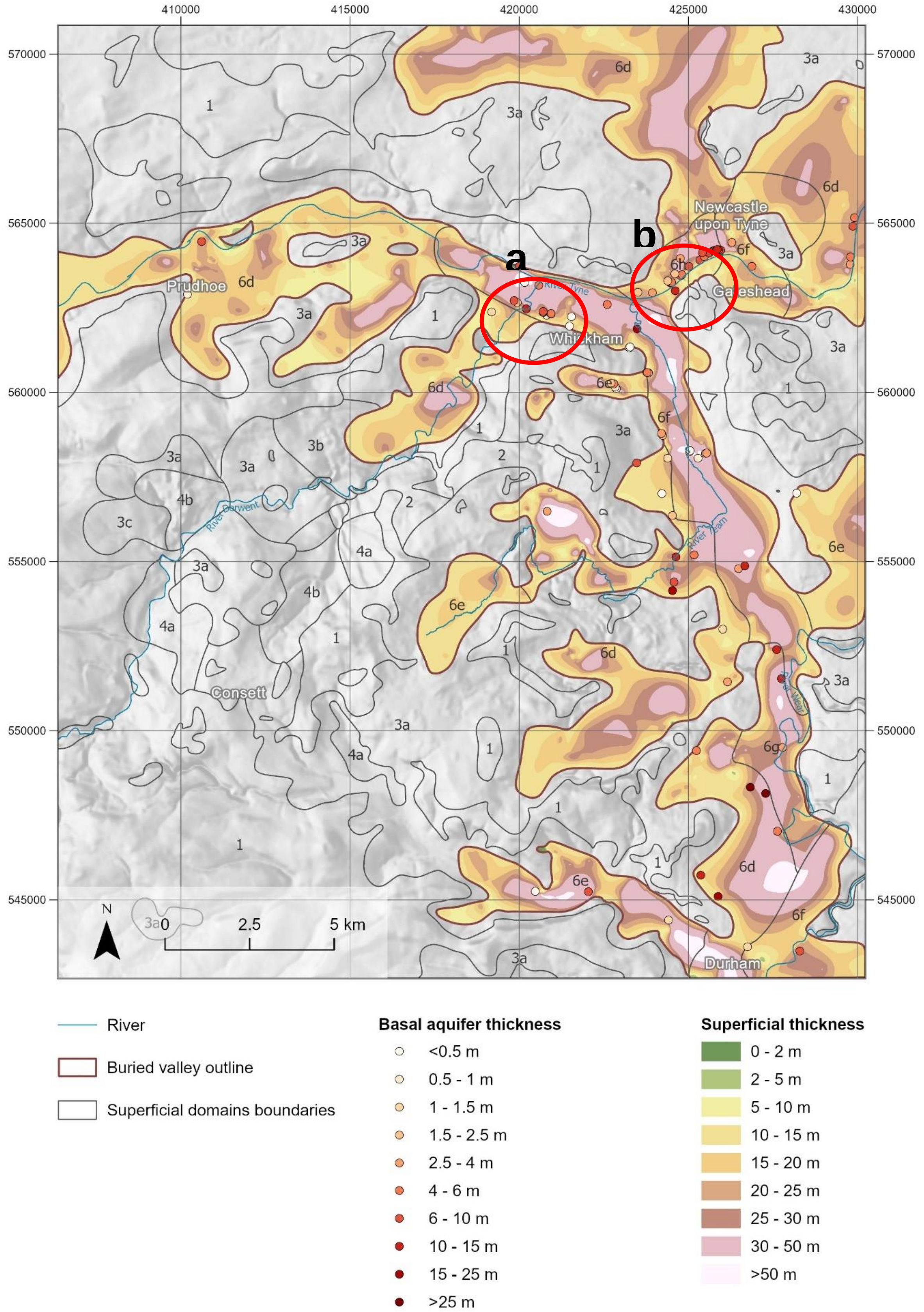

Figure 13 – The distribution and thickness of proved basal sand deposits for boreholes within the buried valley domain area. The domains are shown as transparent outlines and the superficial deposit thickness for the buried valley domain is also shown. Contains Ordnance Survey data © Crown copyright and database rights. BGS © UKRI 2024.

4 Limitations

Hydrogeological parameterisation

The boreholes are attributed for permeability following a binary attribution (Appendix 3). This is a considerable simplification of the very wide permeability range of porous geological media (e.g., Fetter 2018). Any analysis is highly dependent on the initial classification scheme, i.e. the outcomes presented here might change even if only small changes were made to the attribution.

Borehole records and descriptions

Borehole data used in this study is largely third-party data supplied to BGS, with records ranging from over 100 years old to the present day. The quality of the descriptions of lithologies are variable. In addition, the inclusion of AGS boreholes with engineering geological logs means that definitions of sediment types differ from standard geological descriptions. Differences between geological and engineering geological logs affect the attributions of boreholes used to inform the analysis. This has been considered in the interpretation and mapping of the domains, but still represents a limitation of the current study.

➢ **See recommendations 1 and 2**

Borehole coverage and geological complexity

The strategy for borehole coding was designed to provide relatively consistent coverage across the region but is limited by variations in the underlying distribution of borehole records. This means that some areas have few boreholes (and/or few that penetrate to rockhead). The restricted borehole coverage, in conjunction with the high complexity of the deposits in many parts of the area is a key limitation on the analysis.

The complexity of the geological succession combined with the limitations of the borehole coverage mean that there is still substantial uncertainty over the lateral extent, continuity and connections between sand bodies within and between the glaciolacustrine deposits and till of the buried valley system. Outstanding questions include:

- whether channelised sand bodies occur within the glaciolacustrine sequence,
- the extent and morphology of sand deltas and lobes within and underlying the glaciolacustrine clay
- the extent of basal sand bodies below the lowermost till
- the nature of the relationship, and potential connectivity, between glaciofluvial deposits which mantle the slopes adjacent to the buried valley and the glaciolacustrine deposits.

Additionally, in areas where glaciofluvial and glaciolacustrine deposits overly till, there is uncertainty over the locations of patches where till is locally absent potentially giving rise to connections between the bedrock and superficial aquifers.

➢ **See recommendations 3 and 4**

Borehole depths

In addition to coverage, the depth of penetration of boreholes is a limiting factor on the analysis, with many boreholes not reaching rockhead.

The thickness of superficial deposits may be underestimated in areas where boreholes do not reach rockhead. The superficial thickness model therefore provides a minimum estimate of the thickness of deposits in these areas.

Boreholes may under-estimate the thickness of aquitard or the presence of aquitard/aquifer units at depth, and therefore interpretations of the distributions of domains 3-6, which reflect the thicker superficial sequences, should be considered as minimum estimates.

➢ **See recommendation 5**

The nature of the domains approach

The domains approach is particularly suited for characterising variability in vertical flow through superficial deposits. However, lateral flow through (and between) perched aquifer bodies may be a significant factor in the study area due to the presence of complex glaciofluvial deposits associated with former ice-margin areas and glaciolacustrine deposits. An alternative approach such as localised modelling may help to better characterise the architecture of sand-bodies within the strata if suitable borehole data is available.

- **See recommendation 6**

Resolution of the domain map

Borehole records indicate the presence of heterogeneous deposits in parts of the study area with interbedding of sand-dominated and clay-dominated units at scales ranging from centimetres to tens of metres. The domains approach developed here reflects a spatial generalisation of this complex superficial stratigraphy, which is limited by the resolution of geological mapping and the availability and quality of the borehole data. The domains do not capture small-scale lithological variations, such as the presence of thin sand bodies (perched aquifers) that may influence vertical and lateral groundwater flows.

Integration of other data sources

Integration of other hydrogeological factors such as the distribution of bedrock aquifers, mining information, geological structure (e.g. fault zones), and local hydrology such as springs and topographic focussing of flow was beyond the scope of this work.

- **See recommendation 7**

5 Recommendations for future work

The following recommendations reflect opportunities for future data acquisition and further work to better characterise the extent and connectivity of sand bodies, improve the hydrogeological attribution and reduce uncertainty in the mapping of the domain areas.

Relatively low-cost work to reduce uncertainty and enhance the mapping of superficial hydrogeological domains could be undertaken by combining some or all of recommendations 2, 3, 4, 5, 6 and 7.

Recommendation 1: Future cored drilling of the superficial deposits to allow for detailed geological logging of the superficial sequence would be highly beneficial for constraining the hydrogeological parameterisation of the deposits and providing a basis for evaluating the descriptions provided in existing borehole data.

Recommendation 2: Detailed sedimentary logging and hydrogeological characterisation of sections in the field would provide high quality descriptions of key geological units to better constrain the range of lithological variability and hydrogeological properties in key units such as glacial till and glaciofluvial deposits.

Recommendation 3: Targeted coding of existing BGS-held SOBI borehole records in areas with denser coverage could be used to inform more focused analysis of the sedimentary architecture through detailed cross-section construction and/or geological modelling (see recommendation 5).

Recommendation 4: Targeted acquisition of borehole records from third-parties (e.g. the EA, Gateshead Council, local contractors etc.), particularly in the complex areas identified in this study, and where high-quality lithological logs down to rockhead are available.

Recommendation 5: Non-invasive geophysical methods (e.g. passive seismic using a Tromino device) could be used to estimate the depth of the buried valley fill in areas with low density of borehole data.

Recommendation 6: In conjunction with recommendations 3 and 4 (additional borehole acquisition coding), targeted geological modelling of the buried valley fill could be used to evaluate/estimate the architecture of the buried valley fill with application to the geometry and connectivity of sand bodies. Modelling outcomes may be useful in reviewing and updating the domains methodology to account for potential lateral flow.

Recommendation 7: The superficial hydrogeological domains can be combined with analysis of the distribution of mine workings, and sandstone units within the underlying bedrock to generate full groundwater system domains. In addition, information relating to groundwater levels and springs could be integrated to provide further analysis of the groundwater system. This may be particularly useful in focus areas where groundwater flooding or mine water discharge are known to occur.

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

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Glossary

Alluvial – deposits associated with rivers and streams

Diamicton – a general term used to describe poorly-sorted sediment containing a wide range of particle sizes

Glacial till – a deposit formed under glaciers through the deposition of material eroded and entrained within moving ice. It is commonly firm to stiff and poorly-sorted, with gravel, cobbles and boulders embedded in a matrix comprising variable amounts of clay, slit and sand.

Glaciofluvial – this term is used for landforms and deposits created by the action of streams sourced directly from the melting of glacier ice.

Glaciolacustrine – this term refers to landforms and deposits associated with lakes created adjacent to or beneath glaciers.

Laminated - refers to the presence of fine layers developed within a rock or sediment deposit which are typically less than 1mm to several mm in thickness.

Appendix 1 – Cross-sections for the buried valley domain

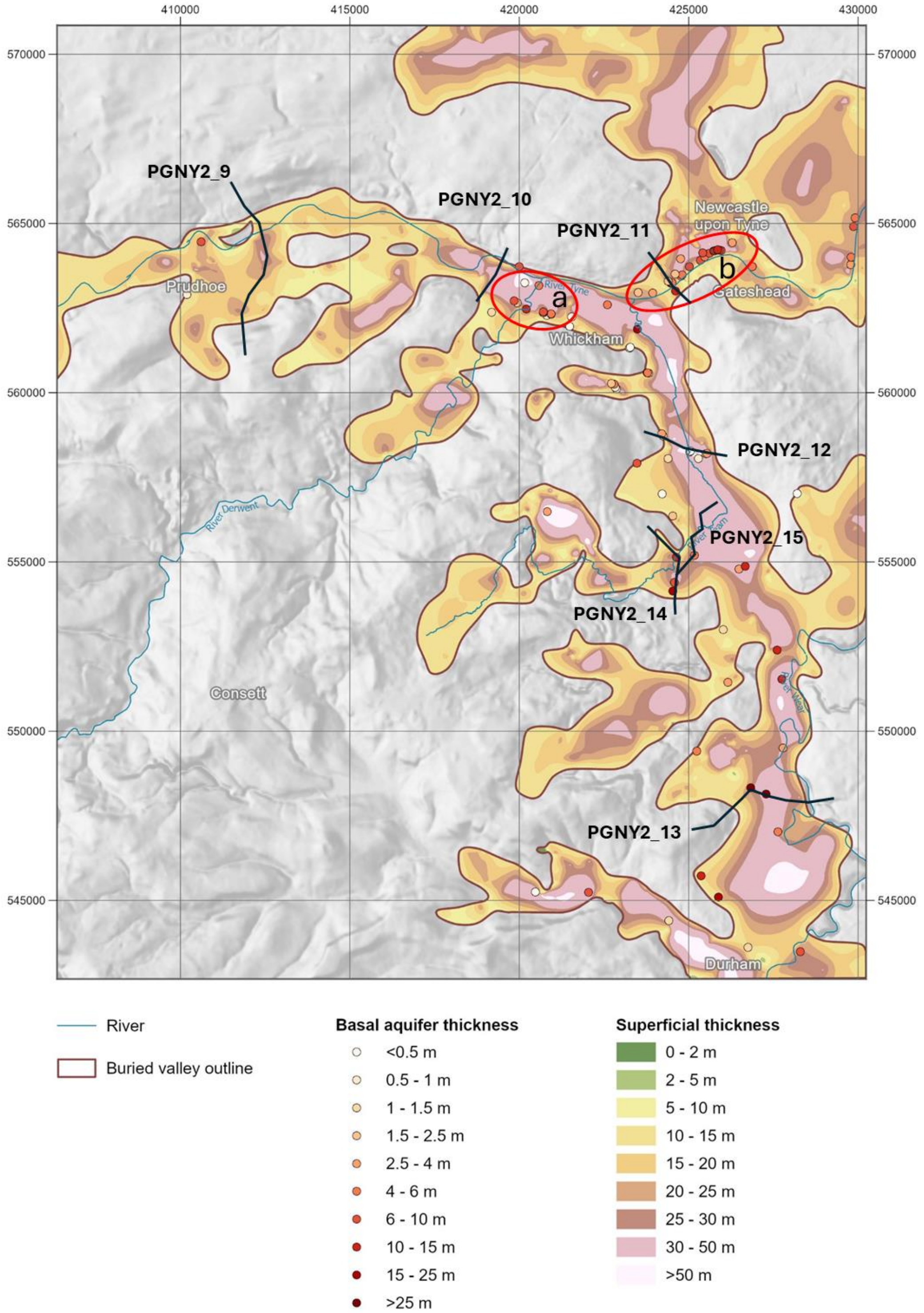
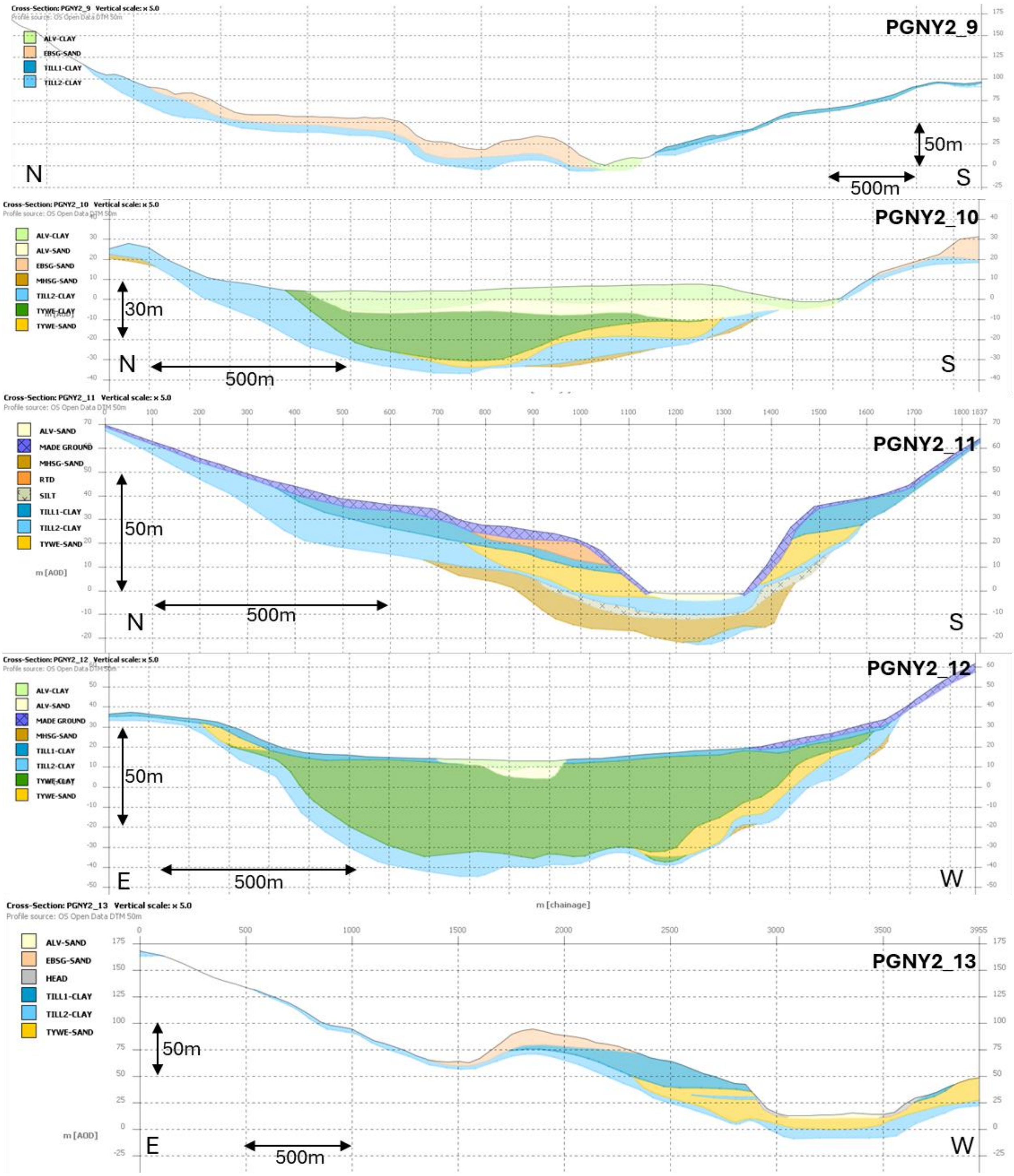


Figure A1-1 – Extent of the buried valley domain (Domain 6) showing the variations in superficial thickness along the valleys. The presence of a basal sand or sand & gravel aquifer at rockhead is indicated where proved in boreholes. Borehole clusters marked by letters a and b are discussed in the text. Contains Ordnance Survey data © Crown copyright and database rights 2024. BGS © UKRI 2024.

Table A1-1 – Stratigraphy used for the construction of cross-sections

Geological stratigraphy (after Price et al. 2007)		Hydro-stratigraphy	
Artificial Ground		Anthropogenic	
Made Ground		MADE GROUND	Unknown
Holocene deposits		**Holocene**	
Alluvium Sand, sand and gravel, silty clay		ALV-CLAY	Aquitard
		ALV-SAND	Aquifer
North Pennine Subgroup	**North Sea Coast Subgroup**	**Late Devensian**	
Ebchester Sand and Gravel Formation Sand, sand and gravel		EBSG-SAND	Aquifer
Butterby Till Member Silty clay, sand, gravel	**Horden Till Formation** Silty clay, gravel	TILL2-CLAY	Aquitard
Tyne and Wear Glaciolacustrine Formation Clay, Silt, Sand, (thin till)	**Peterlee Sand and Gravel Formation** Sand, silt, clay, gravel	PELC-CLAY	Aquitard
		TYWE-CLAY	Aquitard
		TYWE-SAND	Aquifer
Wear Till Formation Silty, sandy clay, gravel, cobbles, boulders	**Blackhall Till Formation** Silty clay, sand, gravel, cobbles	TILL1-CLAY	Aquitard
		TILL1-SAND_BLDR	Aquifer
Un-named Till layer Silty, sandy clay, gravel, cobbles, boulders		TILL-BASAL	Aquitard
Maiden's Hall Sand and Gravel Formation Sand, sand and gravel	**Limekiln Gill Gravel Formation** Sand, sand and gravel	MHSG-SAND	Aquifer



Cross-Section: PGNY2_9 Vertical scale: x 5.0
Profile source: OS Open Data DTM 50m
PGNY2_9
ALV-CLAY
EBSG-SAND
TILL1-CLAY
TILL2-CLAY
N
S
50m
500m
Cross-Section: PGNY2_10 Vertical scale: x 5.0
Profile source: OS Open Data DTM 50m
PGNY2_10
ALV-CLAY
ALV-SAND
EBSG-SAND
MHSG-SAND
TILL2-CLAY
TYWE-CLAY
TYWE-SAND
30m
N
500m
S
Cross-Section: PGNY2_11 Vertical scale: x 5.0
Profile source: OS Open Data DTM 50m
PGNY2_11
ALV-SAND
MADE GROUND
MHSG-SAND
RTD
SILT
TILL1-CLAY
TILL2-CLAY
TYWE-SAND
m [AOD]
50m
N
500m
S
Cross-Section: PGNY2_12 Vertical scale: x 5.0
Profile source: OS Open Data DTM 50m
PGNY2_12
ALV-CLAY
ALV-SAND
MADE GROUND
MHSG-SAND
TILL1-CLAY
TILL2-CLAY
TYWE-CLAY
TYWE-SAND
50m
E
500m
W
m [chainage]
Cross-Section: PGNY2_13 Vertical scale: x 5.0
Profile source: OS Open Data DTM 50m
PGNY2_13
ALV-SAND
EBSG-SAND
HEAD
TILL1-CLAY
TILL2-CLAY
TYWE-SAND
50m
m [AOD]
E
500m
W

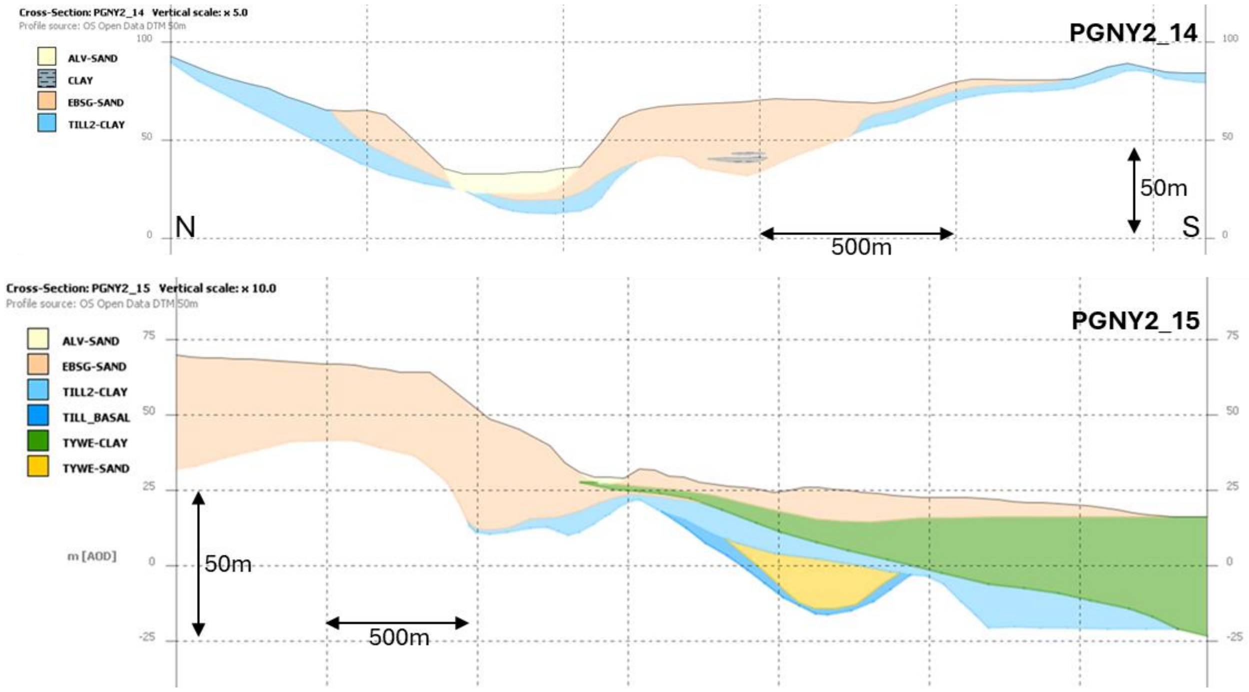


Figure A1-2 – Cross-sections through buried valleys of the River Tyne near Crawcrook (PGNY2_9), River Tyne at Blaydon Bridge (PGNY2_10), the River Tyne at Redheugh Bridge (A189) (PGNY2_11), the River Team at the A1 (PGNY2_12), the Wear valley near Kimblesworth (PGNY2_13), the River Team near Kibblesworth (PGNY2_14, PGNY2_15). The key to the stratigraphic codes used for the deposits is provided in Table A1-1. Note that the legends are not in stratigraphic order. Locations of the cross-sections are shown in **Figure A1-1**. Contains Ordnance Survey data © Crown copyright and database rights. BGS © UKRI 2024.

Appendix 2 – Lithological codes for superficial deposits

The coding scheme for unlithified deposits from Cooper et al. (2006), with examples illustrating the construction of composite codes.

Lithology	Code
Clay	C
Silt	Z
Sand	S
Gravel	V
Cobbles	C
Boulders	B
Peat	P
Examples of composite codes	
Clayey SAND	SC
Silty SAND	SZ
Gravelly, silty SAND	SZV
Silty sandy CLAY	CSZ

Appendix 3 – Lithological attribution used for borehole data

Lithology code	Primary Lithology	Attribution
B	B	permeable
BC	B	permeable
BCS	B	permeable
BL	B	permeable
BLC	B	permeable
BLS	B	permeable
BLV	B	permeable
BLVC	B	permeable
BS	B	permeable
BSC	B	permeable
BV	B	permeable
C	C	low permeability
CB	C	low permeability
CL	C	low permeability
CLAY	C	low permeability
CLB	C	low permeability
CLGV	V	low permeability
CLSA	S	low permeability
CLSGV	V	permeable
CLVS	C	low permeability
CP	C	low permeability
CPS	C	low permeability
CPSV	C	low permeability
CPV	C	low permeability
CS	C	low permeability
CSB	C	low permeability
CSL	C	low permeability
CSLB	C	low permeability
CSP	C	low permeability
CSV	C	low permeability
CSVB	C	low permeability
CSVBL	C	low permeability
CSVL	C	low permeability
CSVLB	C	low permeability
CSZ	C	low permeability
CSZV	C	low permeability
CSZVB	C	low permeability
CSZVLB	C	low permeability
CV	C	low permeability
CVB	C	low permeability
CVBZ	C	low permeability
CVL	C	low permeability

CVLB	C	low permeability
CVLS	C	low permeability
CVP	C	low permeability
CVS	C	low permeability
CVSB	C	low permeability
CVSL	C	low permeability
CVSLB	C	low permeability
CVSZ	C	low permeability
CVZ	C	low permeability
CVZS	C	low permeability
CZ	C	low permeability
CZB	C	low permeability
CZL	C	low permeability
CZP	C	low permeability
CZS	C	low permeability
CZSB	C	low permeability
CZSL	C	low permeability
CZSV	C	low permeability
CZSVB	C	low permeability
CZSVL	C	low permeability
CZSVLB	C	low permeability
CZV	C	low permeability
CZVS	C	low permeability
GRAV	V	permeable
L	L	permeable
LB	L	permeable
LBC	L	permeable
LBCS	L	permeable
LBV	L	permeable
LBVS	L	permeable
LC	L	permeable
LCS	L	permeable
LCSV	L	permeable
LCV	L	permeable
LSC	L	permeable
LSV	L	permeable
LV	L	permeable
LVB	L	permeable
LVC	L	permeable
LVCS	L	permeable
LVS	L	permeable
LVSC	L	permeable
LVSZ	L	permeable
P	P	low permeability
PC	P	low permeability
PCS	P	low permeability
PECL	C	low permeability

PESA	S	permeable
PSC	P	low permeability
PSV	P	low permeability
PV	P	low permeability
PZ	P	low permeability
PZC	P	low permeability
PZS	P	low permeability
S	S	permeable
SACL	C	low permeability
SAGR	S	permeable
SANDU	S	permeable
SB	S	permeable
SC	S	low permeability
SCB	S	low permeability
SCL	S	low permeability
SCLB	S	low permeability
SCPV	S	low permeability
SCV	S	low permeability
SCVB	S	low permeability
SCVL	S	low permeability
SCVLB	S	low permeability
SCZ	S	low permeability
SICL	C	low permeability
SILT	Z	low permeability
SL	S	permeable
SLV	S	permeable
SNDGVI	V	permeable
SP	S	permeable
SPV	S	permeable
SV	S	permeable
SVB	S	permeable
SVC	S	permeable
SVCL	S	permeable
SVCLB	S	permeable
SVCZ	S	permeable
SVL	S	permeable
SVLB	S	permeable
SVLZ	S	permeable
SVZ	S	permeable
SVZC	S	permeable
SVZL	S	permeable
SVZLB	S	permeable
SZ	S	permeable
SZB	S	permeable
SZC	S	permeable
SZCV	S	permeable
SZL	S	permeable

SZP	S	permeable
SZV	S	permeable
SZVL	S	permeable
SZVLB	S	permeable
V	V	permeable
VB	V	permeable
VBC	V	permeable
VC	V	low permeability
VCB	V	low permeability
VCL	V	low permeability
VCLB	V	low permeability
VCS	V	low permeability
VCSL	V	low permeability
VCSLB	V	low permeability
VCZ	V	low permeability
VCZL	V	low permeability
VCZS	V	low permeability
VL	V	permeable
VLB	V	permeable
VLBC	V	permeable
VLBCS	V	permeable
VLBSC	V	permeable
VLC	V	permeable
VLCS	V	permeable
VLS	V	permeable
VLSC	V	permeable
VLSCB	V	permeable
VLSZ	V	permeable
VS	V	permeable
VSB	V	permeable
VSC	V	permeable
VSCB	V	permeable
VSCL	V	permeable
VSCLB	V	permeable
VSL	V	permeable
VSLB	V	permeable
VSZ	V	permeable
VSZC	V	permeable
VSZL	V	permeable
VSZLB	V	permeable
VZ	V	permeable
VZC	V	permeable
VZS	V	permeable
VZSL	V	permeable
XCS	C	low permeability
XCSV	C	low permeability
XCZ	C	low permeability

XCZS	C	low permeability
XSC	S	low permeability
XSV	S	permeable
XSZ	S	low permeability
XZC	Z	low permeability
Z	Z	low permeability
ZC	Z	low permeability
ZCS	Z	low permeability
ZCSV	Z	low permeability
ZCV	Z	low permeability
ZP	Z	permeable
ZS	Z	low permeability
ZSC	Z	low permeability
ZSCV	Z	low permeability
ZSV	Z	low permeability
ZSVL	Z	low permeability
ZSVLB	Z	low permeability
ZV	Z	permeable