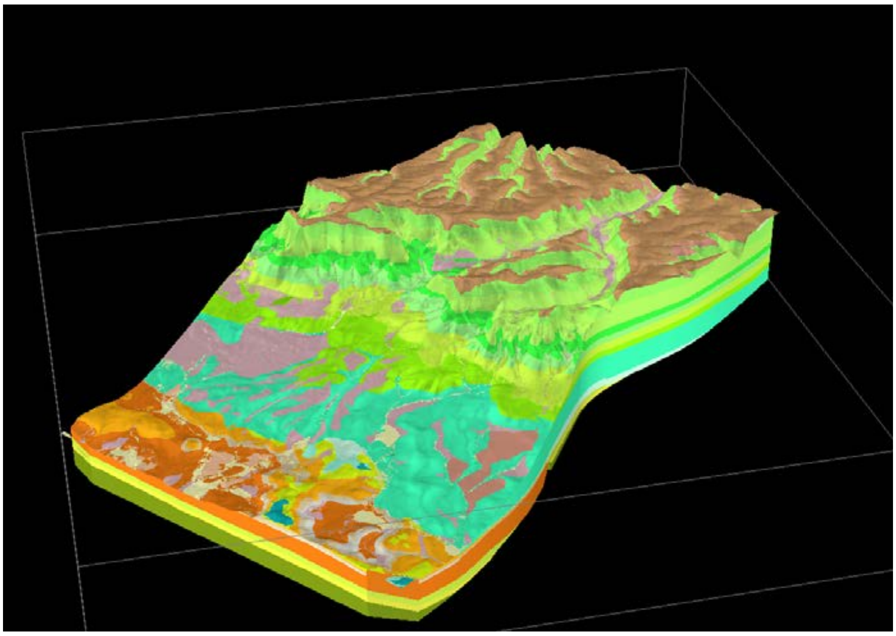
Model metadata report for HS2 Area 1 (Great Missenden to Aylesbury)

Geology and Regional Geophysics Programme

Open Report OR/14/075



BRITISH GEOLOGICAL SURVEY

GEOLOGY AND REGIONAL GEOPHYSICS PROGRAMME

OPEN REPORT OR/14/075

Model metadata report for HS2 Area 1 (Great Missenden to Aylesbury)

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Summary

This report describes the 3D geological model of HS2 (High Speed 2 rail link) Area 1 (Great Missenden to Aylesbury), created by Dr Andrew Farrant with support from Steve Thorpe and Ricky Terrington. The model was created as part of a set of nine geological models that cover the proposed HS2 rail route from the end of the HS2 London model to Birmingham and the West Coast Main Line near Lichfield. The models were funded from the NERC/BGS Science Budget to promote BGS modelling and geological interpretation services to this important infrastructure project and to test methodologies and procedures for creating geological models by multiple compilers.

The report describes the model construction and purpose, with spatial limits and scale, sources of information, data processing, workflow, decisions, assumptions, rules and limitations, together with images of the model.

1 Modelled Volume, Purpose and Scale

This model is of the geology of an area along the proposed route of the High Speed Rail link between London and Birmingham (HS2). It covers the section of the HS2 route between Great Missenden and Aylesbury (Figure 1). The geology of this section of the route is dominated by Cretaceous and Upper Jurassic strata, together with superficial deposits (artificial ground has not been modelled in this area). This is one of an initial group of nine models along the proposed route, and on its southern margin, borders the London Lithoframe model. This model is suitable for use at scales between 1:100,000-1:10,000, down to a depth of 30 m below OD.

Prior to the geological modelling work, an assessment of the quality and availability of the digital geological linework and existing 3D models of the whole HS2 route between London and Birmingham was undertaken (Barron et al., 2012). This informed where improvements in the existing data sets were necessary prior to modelling. As a consequence of this review, re-mapping of the Upper Cretaceous sequence in the Aylesbury area was undertaken in 2011-12. The primary reason for this remapping was to update the Chalk lithostratigraphy and improve the superficial linework for the Chalk and Upper Greensand outcrop. Thus, this 3D model is based on geological linework from both existing 1:10K (Figure 2 and Figure 3) and 1:50K scale DiGMap data and from data derived from the remapping of the Cretaceous outcrop (Figure 4 and Figure 5).

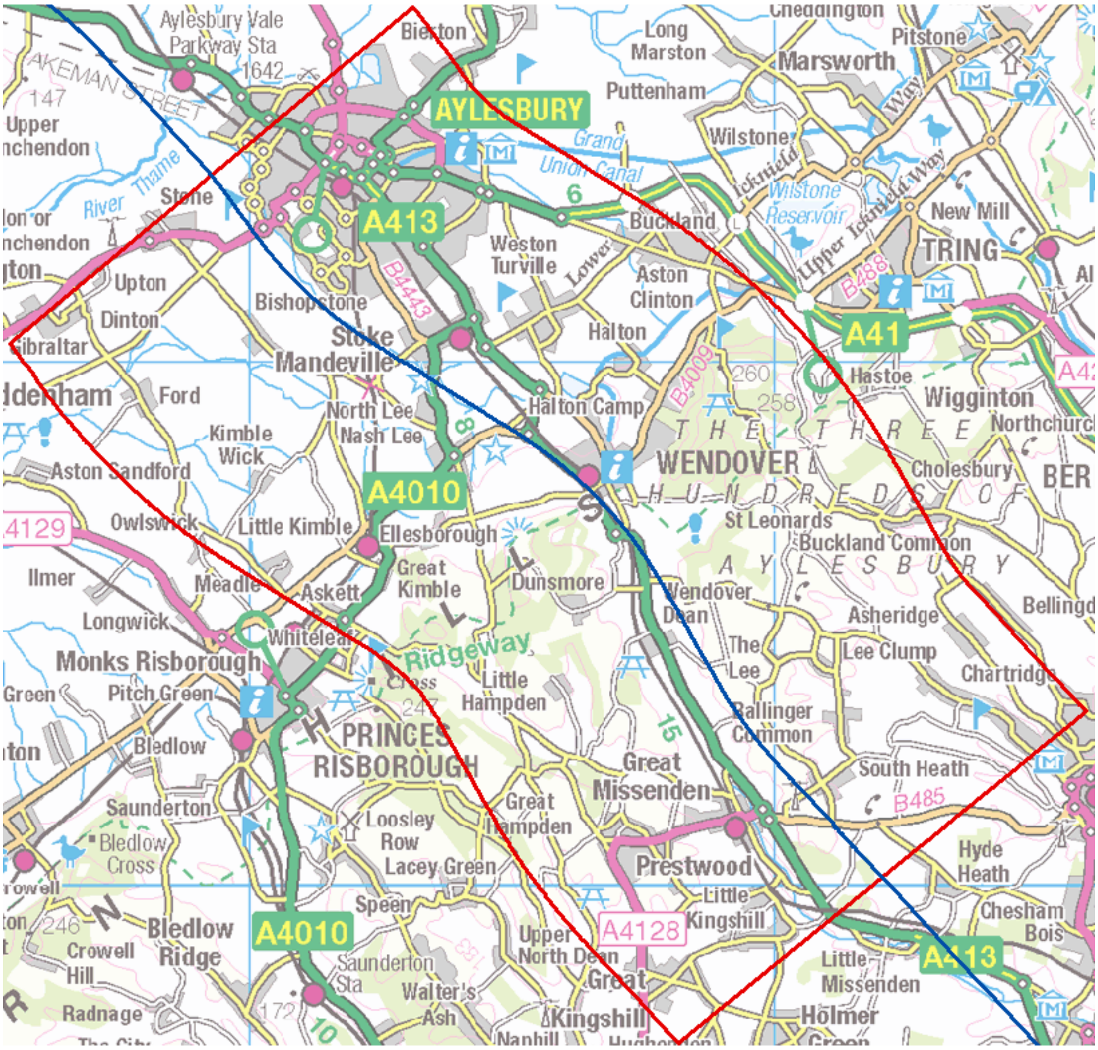

Figure 1 Location of the model outlined in red. The blue line marks the proposed route of High Speed 2. Contains Ordnance Survey data © Crown copyright and database rights 2014.

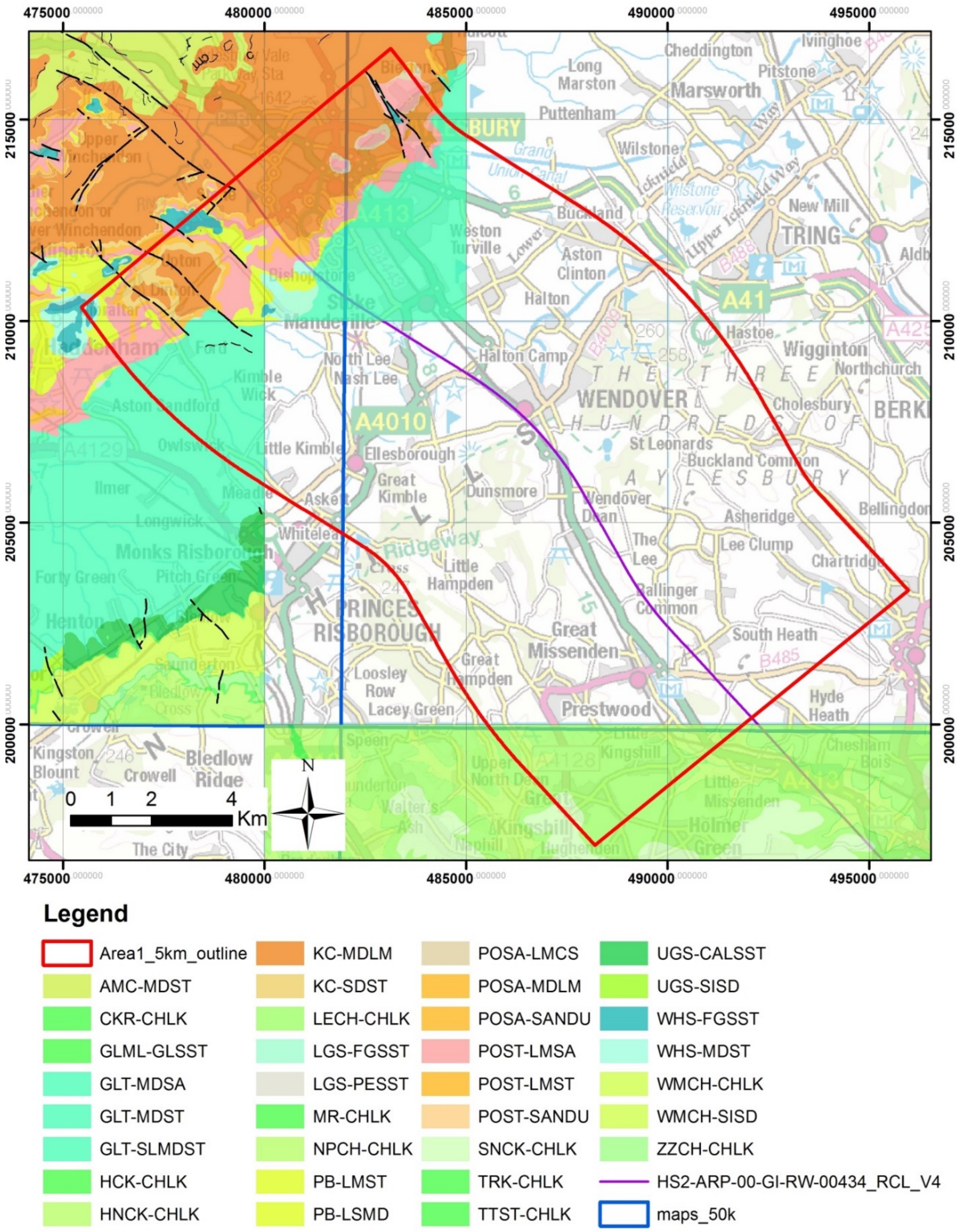

Figure 2. Existing 1:10 000 DiGMap bedrock data used in the model. Contains Ordnance Survey data © Crown Copyright and database rights 2014.

The colour shaded polygons are the 1:10 000 scale DiGMap superficial dataset. The bedrock units are listed in alphabetical order with their BGS LEX-RCS codes in Figure 2. These codes give access to further information about the geological unit and its rock type through the Lexicon of Named Rock Units and Rock Classification Scheme query pages on the BGS website, www.bgs.ac.uk.

NB: for the purpose of the model construction, many of the DiGMap units in Figure 2 are combined with other units in the model, or are given alternative RCS codes. See Table 1.

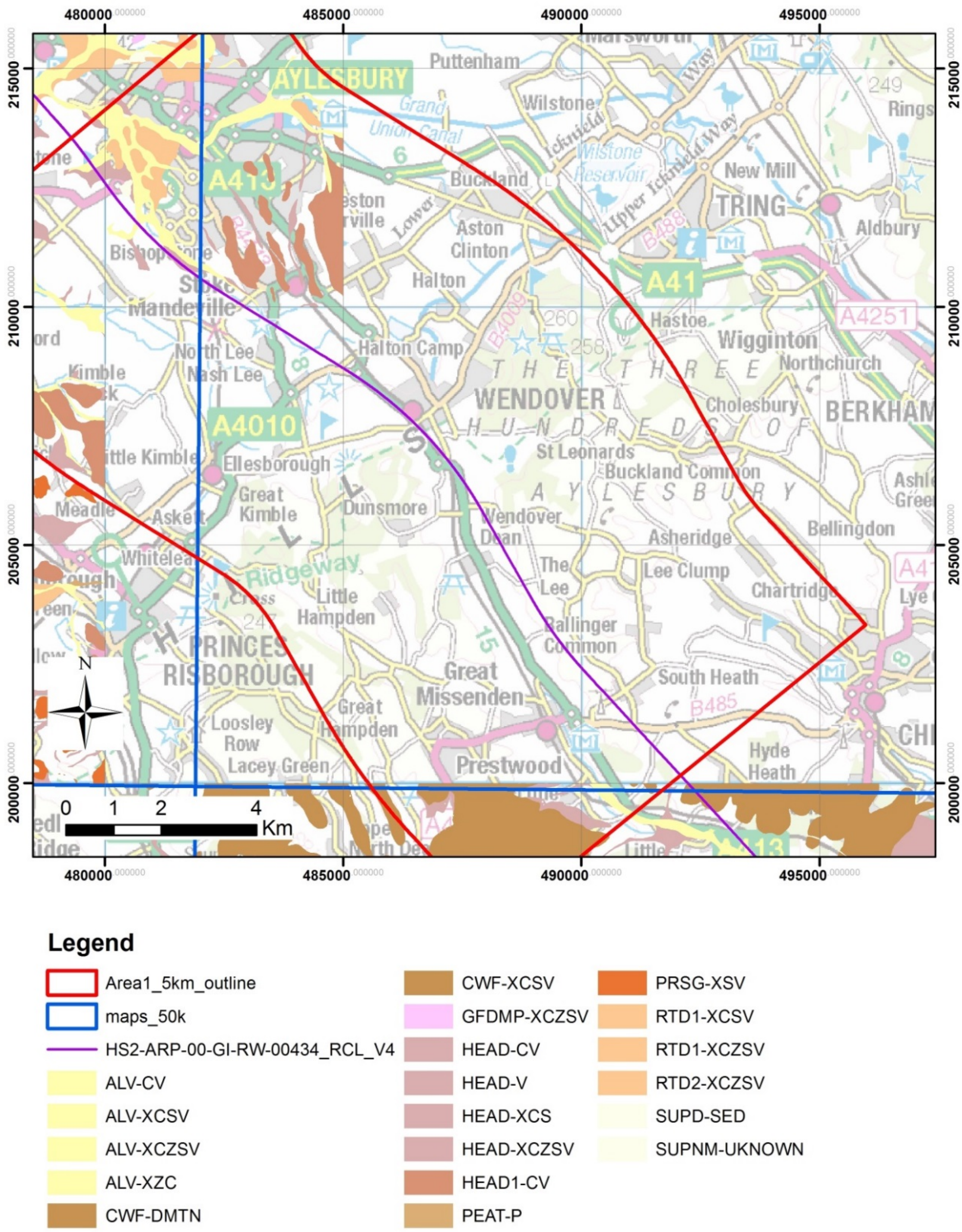

Figure 3. Existing 1:10 000 DiGMap superficial deposits data used in the model. Contains Ordnance Survey data © Crown Copyright and database rights 2014.

The colour shaded polygons are the 1:10 000 DiGMap superficial dataset. As with the bedrock data, the superficial units are listed in alphabetical order with their BGS LEX-RCS codes in Table 1. These codes give access to further information about the geological unit and its rock type through the Lexicon of Named Rock Units and Rock Classification Scheme query pages on the BGS website, www.bgs.ac.uk.

NB: for the purpose of the model construction, many of the DiGMap units in Figure 3 are combined with other units in the model, or are given alternative RCS codes or lie outside its area. See Table 1.

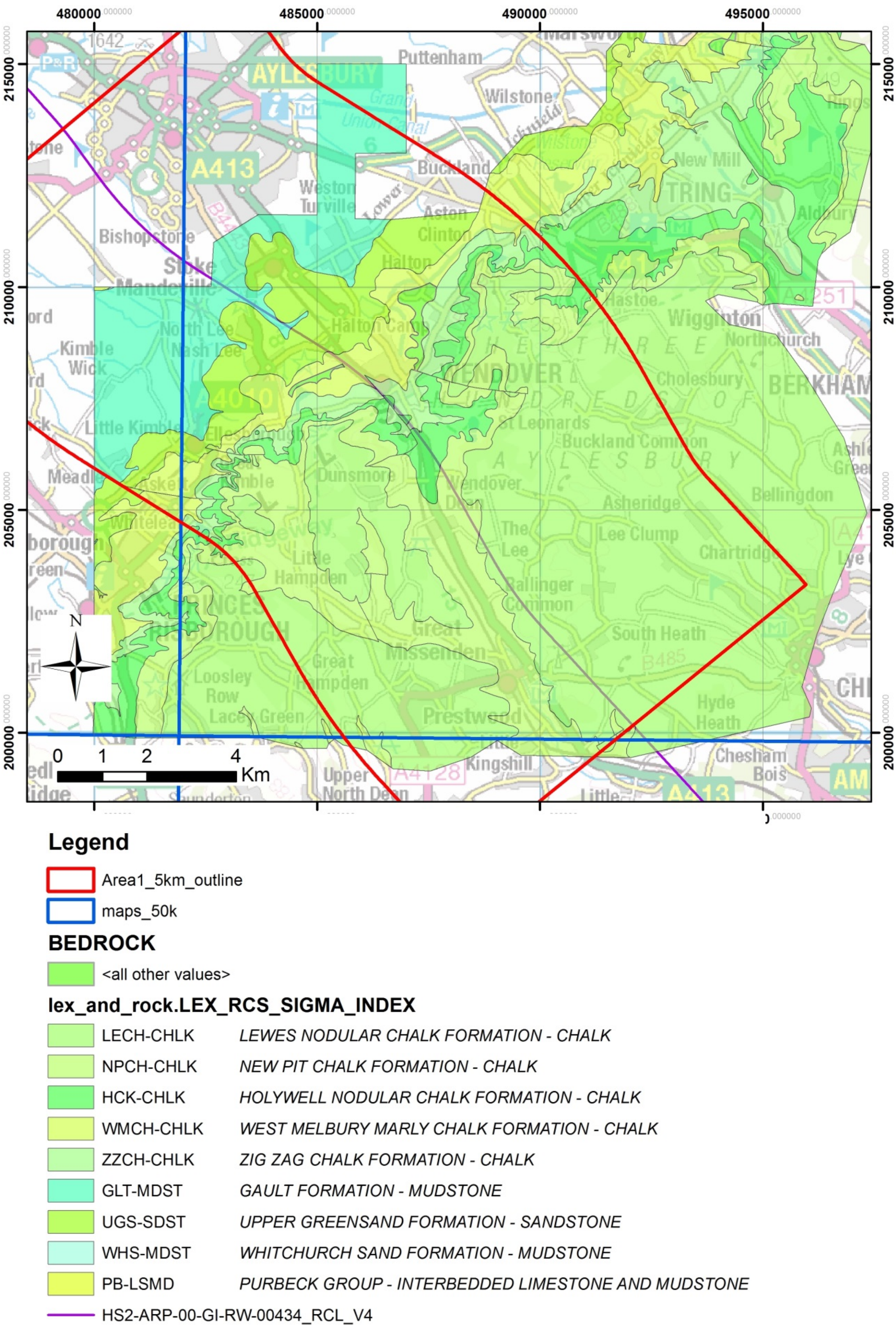

Figure 4. Updated 1:10 000 bedrock geological linework used in the model, based on remapping of the area in 2010-11 by A R Farrant and P M Hopson. Contains Ordnance Survey data © Crown Copyright and database rights 2014.

NB: some of the units in Figure 4 are given other RCS codes in the model. See Table 1.

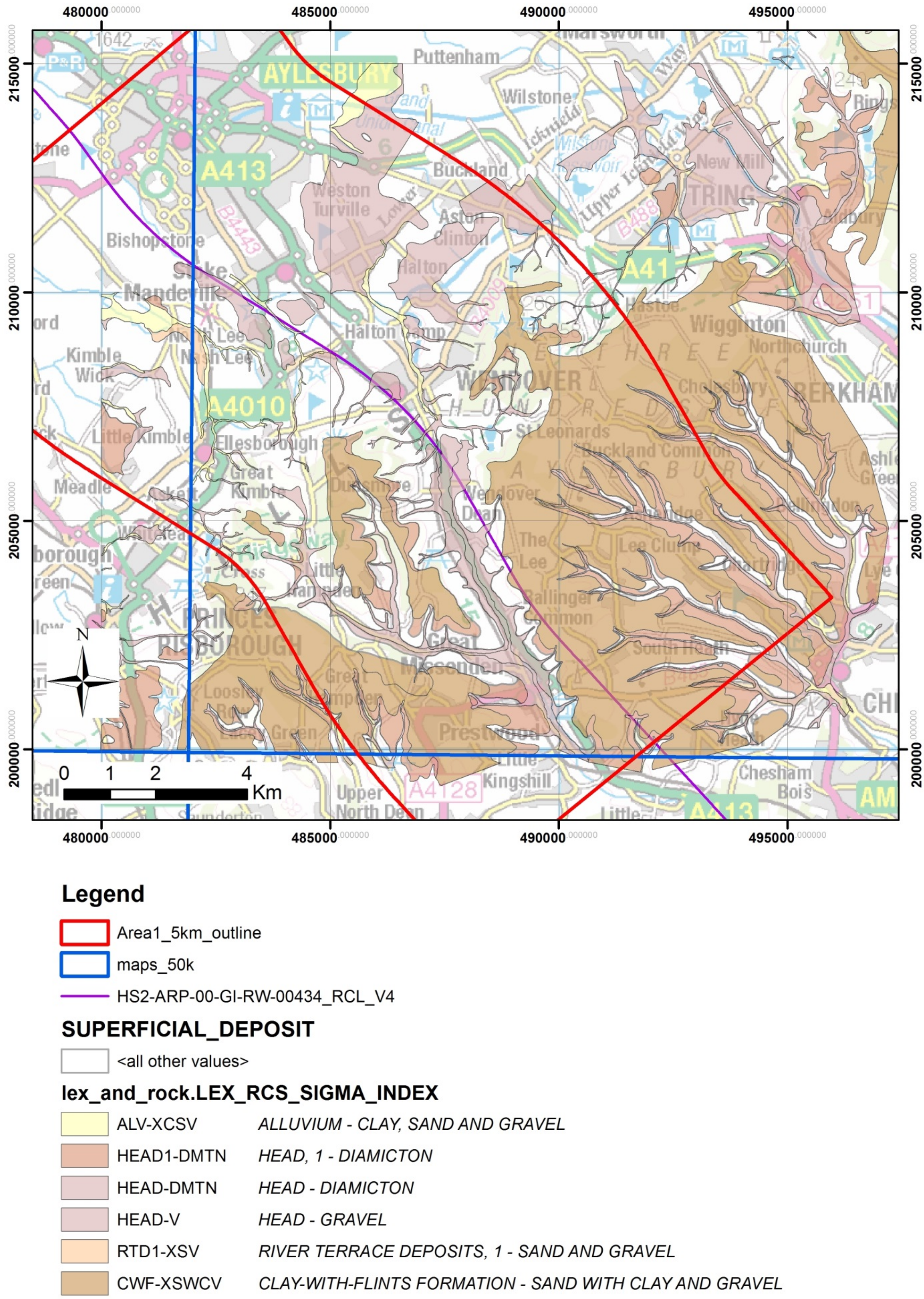

Figure 5. Updated 1:10 000 superficial geological linework used in the model, based on remapping of the area in 2010-11 by A R Farrant and P M Hopson. Contains Ordnance Survey data © Crown Copyright and database rights 2014.

NB: some of the units in Figure 5 are given alternative RCS codes in the model. See Table 1.

2 Modelled Surfaces/Volumes

The modelled bedrock and superficial deposits are listed in Table 1 in the relative stratigraphic order used in the model. Brief descriptions of the geological units are given here, but more detail can be found in the BGS Lexicon of Named Rock Units. The level of detail and extent of the natural geology in the model may differ from that shown in other BGS datasets. Table 1 should be used as the legend for viewing images of the model in this report.

Table 1 List of geological units modelled

LEX-RCS code	LEX translation or description	Composition	Included units (some in places only)
NONE-NONE	Areas of woodland or buildings that mask the true DTM	N/A	
ALV-XCZSV	ALLUVIUM	CLAY, SILT, SAND AND GRAVEL	ALV-CV, ALV-XCSV, ALV-XZC
HEAD-XCZSV	HEAD	CLAY, SILT, SAND AND GRAVEL	HEAD-CV, HEAD-DMTN, HEAD-XCS, HEAD1-XCZSV, HEAD1-CV, RTD1-XSV
HEAD-V	HEAD	GRAVEL	HEAD-XCZSV, HEAD1-XCZSV, ALV-XCZSV
HEAD1-XCZSV	HEAD 1	CLAY, SILT, SAND AND GRAVEL	HEAD1-DMTN, HEAD-V, HEAD1-CV, CWF-XCZSV
RTD1-XSV	RIVER TERRACE DEPOSITS 1	SAND AND GRAVEL	RTD1-XCSV, RTD1-XCZSV
CWF-XCZSV	CLAY-WITH-FLINTS FORMATION	CLAY, SILT, SAND AND GRAVEL	CWF-DMTN, CWF-XSWCV, CWF-XCSV
SNCK-CHLK	SEAFORD CHALK FORMATION AND NEWHAVEN CHALK FORMATION - UNDIFF.	CHALK	
LECH-CHLK	LEWES NODULAR CHALK FORMATION	CHALK	CKR-CHLK, TRK-CHLK
NPCH-CHLK	NEW PIT CHALK FORMATION	CHALK	HNCK-CHLK (part)
HCK-CHLK	HOLYWELL NODULAR CHALK FORMATION	CHALK	HNCK-CHLK (part), MR-CHLK
ZZCH-CHLK	ZIG ZAG CHALK FORMATION	CHALK	TTST-CHLK
WMCH-CHLK	WEST MELBURY MARLY CHALK FORMATION	CHALK	GLML-GLSST, WMCH-SISD
UGS-SISD	UPPER GREENSAND FORMATION	SILTSTONE AND SANDSTONE	UGS-CALSST
GLT-MDST	GAULT FORMATION	MUDSTONE	GLT-MDSA, GLT-SLMDST
LGS-SDST	LOWER GREENSAND GROUP	SANDSTONE	LGS-PESST, LGS-FGSST
WHS-SDST	WHITCHURCH SAND FORMATION	SANDSTONE	WHS-FGSST
WHS-MDST	WHITCHURCH SAND FORMATION	MUDSTONE	
PB-LMAR	PURBECK GROUP	LIMESTONE AND [SUBEQUAL/ SUBORDINATE] ARGILLACEOUS ROCKS, INTERBEDDED	PB-LMST, PB-LSMD
POST-LMST	PORTLAND STONE FORMATION	LIMESTONE	POST-LMSA, POST-SANDU
POSA-LMCS	PORTLAND SAND FORMATION	LIMESTONE AND CALCAREOUS SANDSTONE	POSA-MDLM, POSA-SANDU
KC-SISD	KIMMERIDGE CLAY FORMATION	SILTSTONE AND SANDSTONE	KC-SDST
KC-MDST	KIMMERIDGE CLAY FORMATION	MUDSTONE	KC-MDLM
AMC-MDST	AMPTHILL CLAY FORMATION	MUDSTONE	
WWB-MDST	WEST WALTON FORMATION	MUDSTONE	
KLOX-MDSS	KELLAWAYS FORMATION AND OXFORD CLAY FORMATION, UNDIFFERENTIATED	MUDSTONE, SILTSTONE AND SANDSTONE	

Most of the surface bedrock units are modelled separately, but in the subsurface, it is impossible to differentiate the Kellaways Formation and the Oxford Clay Formation, so these are grouped together. The Seaford Chalk and Newhaven Chalk groups are grouped together, mainly because that is how they were mapped on the Beaconsfield area to the south. However, it is unlikely that any Newhaven Chalk is present in the area modelled.

Sections are named according to a wider HS2 project convention with five longitudinal sections running southeast to northwest named HS2_Area1_ARF_SE_NW_xx as appropriate (the middle section follows the proposed route of HS2), and 11 northeast to southwest ‘rung’ sections named HS2_Area1_ARF_SW_NE_xx (Figure 6 and Figure 7). A few filler sections were used to help constrain faulted areas of where borehole data was sufficient to warrant an extra section. These were named HS2_Area1_ARF_Filler xx.

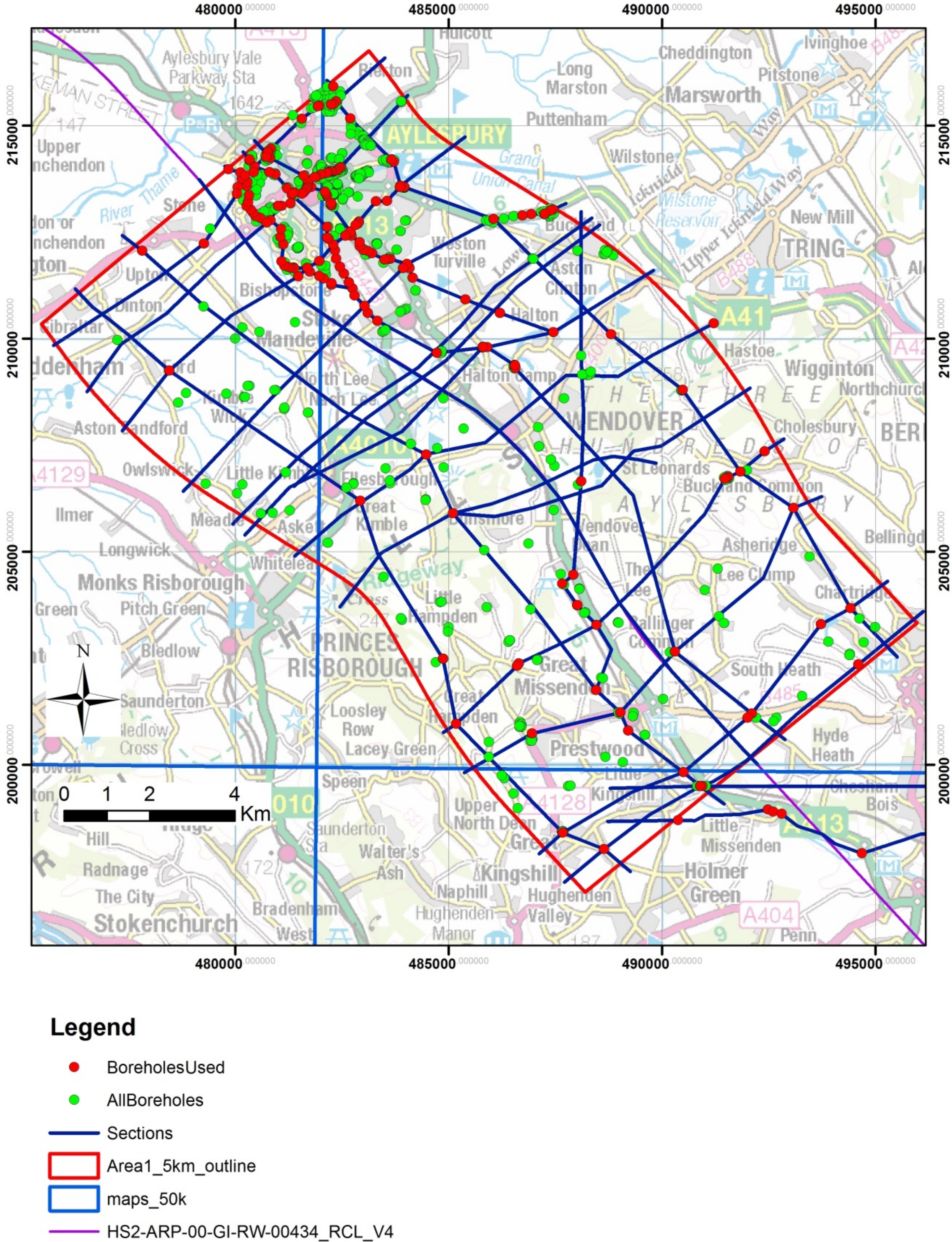

Figure 6. Boreholes used and sections drawn for the 3D Model. Boreholes used in the model are shaded red, whilst those not coded are shown in green. Contains Ordnance Survey data © Crown Copyright and database rights 2014.

The axial NW-SE cross section mirrors the proposed route of HS2.

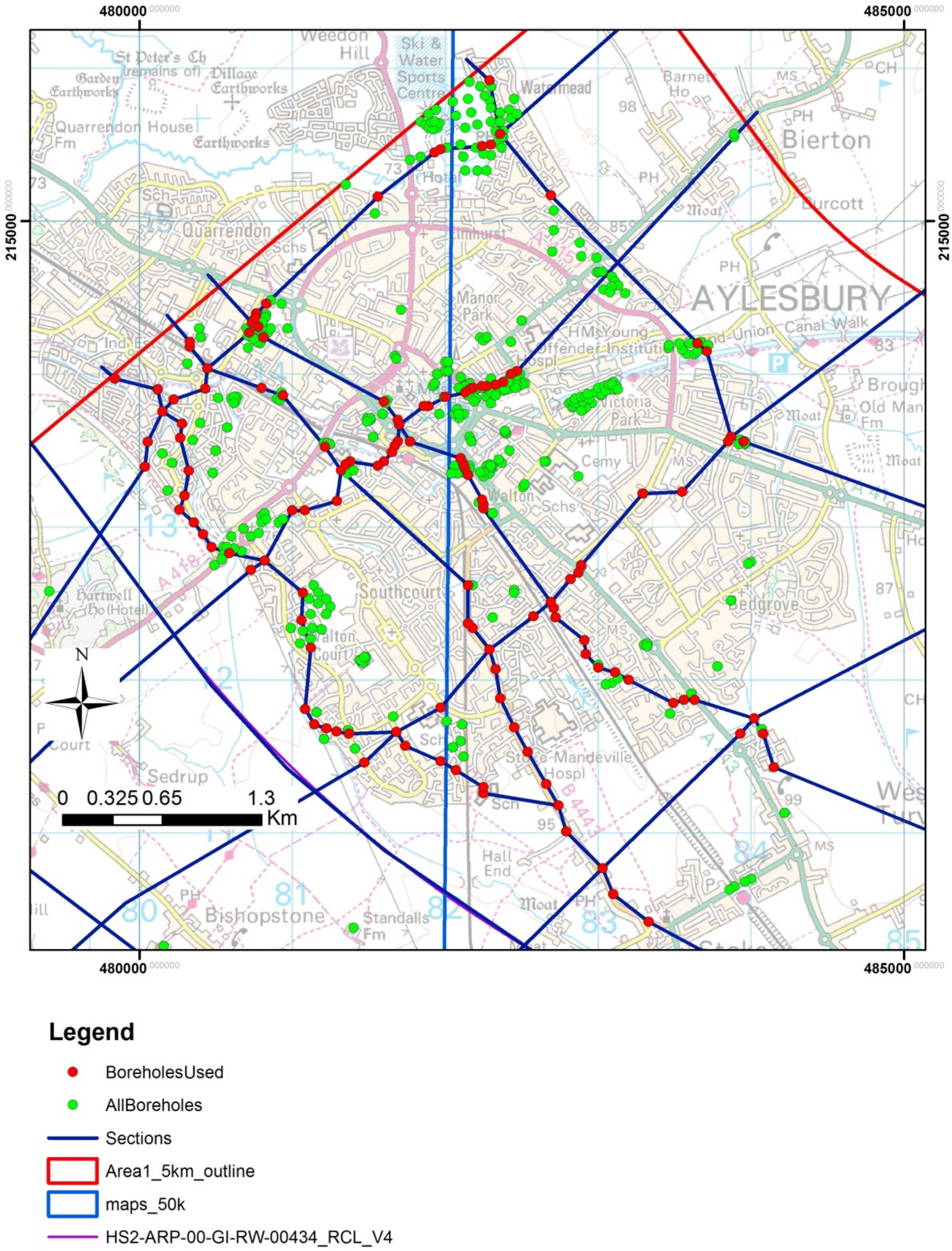

Figure 7. Close up of the boreholes used and sections drawn for the 3D Model in the Aylesbury area. Boreholes used in the model are shaded red, whilst those not coded are shown in green. Contains Ordnance Survey data © Crown Copyright and database rights 2014.

3 Modelled Faults

Several small faults, most with throws of less than 10 m were modelled, largely based on surface faults observed from the most recent remapping. These were modelled using the GSI3D superficial engine as steps in the geological surfaces rather than as a faulted bedrock model. No major surface faults occur in the modelled area. However, limited borehole evidence suggests that the subcrop of the Kimmeridge Clay is limited southwards by a fault which is truncated by the sub-Cretaceous unconformity at the base of the Lower Greensand. This has been modelled trending parallel to the Chalk escarpment, but there is little borehole evidence at depth within the model to support this.

4 Model Workflow

The standard GSI3D modelling workflow was followed for this project. GSI3D software utilises a range of data such as boreholes, digital terrain models (DTM) and geological linework to enable the geologist to construct a series of interlocking cross-sections. Borehole data is represented in GSI3D by two proprietary files: a borehole identification file (.bid), that contains 'index'-level information including location and start-heights; a borehole log file (.blg), that contains the borehole interpretation. Constructing cross-sections is intuitive and flexible, combining borehole and outcrop data with the geologist's experience to refine the interpretation.

In HS2 area 1, the previous geological linework was deemed to be inadequate across the southern part of the model, new data was collected by field mapping. The 1:10,000 geological lines were captured digitally using BGS SIGMA*mobile* (System for Integrated Geological Mapping) which were then cleaned in BGS SIGMA*desktop* and turned into polygons. The resulting ArcGIS shapefiles were then provided for use in the model construction.

Using the information from the cross-sections and the distribution of each unit a calculation algorithm creates the triangulated surfaces for the top and base of each unit. In order to control the relative vertical ordering of the calculation, a generalised vertical section file (.gvs) is established. A proprietary legend file (.gleg) is created to control symbolisation of the cross-section and model. The modeller can view all the units in 3D and iteratively return to the cross-section to make amendments or add further cross-sections to refine the model. This process is a standard methodology within BGS for modelling Quaternary and simple bedrock horizons and is fully documented in Kessler *et al* (2009).

5 Model Datasets

5.1 GVS AND GLEG FILES

The generalised vertical section (.gvs) and geological legend (.gleg) files were assembled using Notepad or Excel and iterated as the model expanded and new units were encountered. The GVS was based on DiGMapGB-50 data by identifying all those geological units that are within a 5km area of the HS2 route. However some units occur only in subcrop, so additional units in the GVS had to be appended as modelling progressed. The GLEG files were created using the standard BGS colours from DigMap-50. Overall GVS and GLEG files were created for the whole HS2 route, rather than for each individual model area. Thus the units used in this model are only a subset of those available in the overall HS2 GVS file.

5.2 GEOLOGICAL LINEWORK

Modern 1:10 000 scale digital geological linework was used where available. The previous 1:10 000 bedrock and superficial data was restricted to the northern end of the model around Aylesbury and a small area in the southwest corner on the Beaconsfield 1:50 000 map sheet (Figure 2 and Figure 3. The Aylesbury area data include sheets SP81SW (mapped by M G Sumbler and A J M Barron in 1988 and 1990), SP81NW (mapped by A J M Barron in 1988), SP 70 NE (mapped by M G Sumbler, 1989) and SP 71SE (mapped by M G Sumbler, 1988), together with the western part of sheet SP80NW (mapped by M G Sumbler, 1990). The Beaconsfield data is based on a rapid partial survey in 2002 and revised county series 1:10560 field slips. The 1:10,000 scale geological mapping in the south of the model area was revised and the resulting new geological linework was used in the model with minor amendments made during model construction.

The 1:10K bedrock units are listed in alphabetical order with their BGS LEX-RCS codes in Figure 2. These codes give access to further information about the geological unit and its rock type through the Lexicon of Named Rock Units and Rock Classification Scheme query pages on the BGS website, www.bgs.ac.uk.

For the rest of the model area, the only existing linework available was from 1:10 560-scale county series surveys dating from 1910-12. The geological data on these sheets were deemed inadequate for modelling purposes, given that they did not show the new Chalk lithostratigraphic subdivisions, or many of the superficial deposits known to exist in the model area.

In light of this inadequate data, the northwest part of the Aylesbury 1:50K geological map sheet was remapped by A R Farrant and P M Hopson in 2010-11 with palaeontological support from M A Woods and I P Wilkinson. The linework was compiled at 1:10K scale using SIGMA mobile. Where the existing 10K data and the new linework overlap, the new linework supersedes the previous data. In several instances, the modelling work demonstrated that the mapped linework was inaccurate, especially in the faulted area south of Wendover. In these cases, the geological linework was amended in an iterative manner in SIGMA mobile as the modelling progressed, so as to match the geological line-work with the geological model. The new data is shown in Figure 4 and Figure 5. The Chalk units have been mapped using the most up to date Chalk lithostratigraphy as defined in the BGS Lexicon. Head deposits have been subdivided into three units in the recent mapping: Head; Head1 and Head Gravel.

Head (HEAD-XCZSV) is formed mostly by hillwash and soil creep and usually occupies the floor of dry valleys. Greater thicknesses are generally associated with the centre of valleys or accumulations on the lower-parts of hillsides. The composition of head deposits is very variable, typically represented in the study area by clay, flinty gravel, sand and silt. Head is modelled as a deposit that occupies valley-bottoms and hillsides across large parts of the study area. An assumption has been made for the model that Head may be concealed beneath alluvium.

Head Gravel (HEAD-V) occurs in the bottom of dry valleys, particularly in the lower reaches, and is thought to represent Head deposits where the finer grained material has been winnowed out by fluvial or periglacial action. For the purposes of the model, HEAD-V is modelled as being older than HEAD-XCZSV.

Head 1 (formerly 'Older Head') is formed by the solifluction of the Clay with Flints Formation or river terrace deposits downslope. It occurs on valley sides, particularly in the upper part of the dry valley networks. Like the Head deposits, its composition is very variable, typically represented in the study area by clay, flint gravel, sand and silt but it has been modelled as a single geological unit.

5.3 DIGITAL TERRAIN MODEL

The terrain model used in this model was the BGS Bald Earth 20 m DTM obtained from the BaldEarth model and trimmed to the project area (5 km buffer of the route shapefile). A NextMap DTM was also included, but not used for modelling.

5.4 BOREHOLE DATA

Borehole records examined included both Keyworth and Wallingford held logs. Closely clustered sets of boreholes were not all coded but the deepest and most representative were included. Any significant local variation in sequence was also recorded by coding. Entries were all made directly into the corporate BGS *Borehole Geology* database. However, many of the boreholes were either very shallow and thus did not provide any data on the bedrock geology, or did not contain sufficient information to be coded in any meaningful way. This includes many of the old Chalk borehole records which do not provide sufficient data to subdivide the Chalk into its constituent formations.

After borehole coding was completed, the boreholes were extracted from the BGS *Single Onshore Borehole Index* database using a set of queries. The borehole log file (.BLG) needed to be deduplicated and a borehole filter tool was used to address this. A set of priorities were applied to borehole records that were coded by more than one project. This left a total of 312 boreholes coded out of a total borehole count of 811. The location of the boreholes is shown in Figure 6 and Figure 7.

5.5 LONDON LITHOFRAME 50 MODEL.

The southern end of the model adjoins the northern end of the London LithoFrame 50 Model, and the more detailed update for HS2 (Model Number 181_HS2_London). The model comprises a revision of a 'corridor' of radius 1100 m (for bedrock) and 500 m (for superficials and Artificially Modified Ground) for the part of the planned HS2 route that is within the London LithoFrame 50 model. This was completed in 2012. However, the London model did not update the existing geological mapping on the Aylesbury 1: 50 000 DiGMap dataset, whereas the model described in this document uses more up to date geological mapping. The new model is fitted to the revised geological linework, so could not be fully correlated with the London LithoFrame 50 Model and the HS2 update. The same geological units were used, but there is a slight mismatch in modelled surfaces.

6 Model Assumptions, Geological Rules Used etc.

Several assumptions were used in the making of this model. Buried river terrace deposits were assumed to extend beneath the overlying alluvium unless borehole data suggests otherwise. Head and Head1 deposits are assumed to overlie the Clay-with-Flints. The geological line-work honours the Ordnance Survey topography as shown on their 1:10 000 and 1:25 000 scale topographic contours. Where the model DTM differs from the OS contour data (for example, where valley bottom head deposits appear to occur on valley sides) it is assumed that the DTM is inaccurate due to trees. In these cases a new unit, Non-geological mass was added only in cross sections for areas of woodland or buildings that mask the true ground surface.

In this model we assume that Chalk formation thicknesses remain relatively constant through the model. The data from boreholes and outcrops is not sufficient to delimit facies and thickness variations that are known to exist in the West Melbury Marly Chalk and Zig Zag Chalk formations from biostratigraphical data in the Tring area.

In Area 2 Weymouth, Stewartby and Peterborough Members have been modelled, but in Area 1 these have been modelled at group level as KLOX-MDSS

7 Model Limitations

7.1 MODEL SPECIFIC LIMITATIONS

- This model predates any site investigation work on HS2, and thus does not include any site investigation or borehole data drilled as part of the HS2 investigations. The subsurface data is based on very limited borehole data, and not supported by seismic or other geophysical data. Thus the confidence in the model for units below the Upper Greensand across the southern part of the model is low and the interpretation should be viewed with caution. The data points constraining for example, the over-step of the Kimmeridge Clay by the Lower Greensand, and the down-dip subcrop extent of the Purbeck and Portlandian strata are few and far between. The fault delimiting the southern extent of the Kimmeridge Clay is based on the absence of the

Kimmeridge Clay in the Tring deep hydrocarbon well [SP91SW_28]. Thus the model should be viewed as a first pass interpretation of the limited data available.

- Many of the Chalk boreholes are old water wells and do not record the new Chalk lithostratigraphy. Consequently, most of the Chalk surfaces are derived by interpolation from the new geological mapping and are not constrained by borehole data. Thus in the south of the region, where only the New Pit, Lewes and Seaford Chalk units are exposed at surface, the lower Chalk units are interpolated by estimated thickness only, as are the underlying units.

- The rockhead surface on the Chalk outcrop is likely to be highly irregular beneath the Clay-with-Flints and any remnant Palaeogene deposits due to the presence of dissolution pipes. These may extend up to 20 m into the underlying Chalk. Thus borehole records of the superficial thickness are unreliable, and are only relevant to spot locations and cannot be used to extrapolate the rock-head surface with any certainty. Thus the modelled base Clay-with-Flints surface is a smoothed approximation of the rock-head surface.

- In many of the narrow dry valleys in the southern part of the model, the DTM does not accurately reflect the Ordnance Survey contour profiles upon which the geological linework is based. Thus in many instances, the valley bottom Head deposits or Alluvium appear in the GSI3D model to occur on the valley sides rather than sit in the valley bottom. This is an artefact of the DTM used which includes trees, and therefore does not match OS contour data.

- Artificial deposits are not modelled in three dimensions but are drawn in some cross-sections.

- The Kellaways Formation and Oxford Clay Formation are represented as a single unit in this model. In Area 2 to the north, however, the Oxford Clay Formation is subdivided into the Weymouth Member and Stewartby Member, with the Kellaways Formation modelled as a separate unit.

7.2 GENERAL MODELLING LIMITATIONS

- Geological interpretations are made according to the prevailing understanding of the geology at the time. The quality of such interpretations may be affected by the availability of new data, by subsequent advances in geological knowledge, improved methods of interpretation, improved databases and modelling software, and better access to sampling locations. Therefore, geological modelling is an empirical approach.

- It is important to note that this 3D geological model represents an individual interpretation of a subset of the available data; other interpretations may be valid. The full complexity of the geology may not be represented by the model due to the spatial distribution of the data at the time of model construction and other limitations including those set out elsewhere in this report.

- Best endeavours (detailed quality checking procedures) are employed to minimise data entry errors but given the diversity and volume of data used, it is anticipated that occasional erroneous entries will still be present (e.g. boreholes locations, elevations etc.) Any raw data considered when building geological models may have been transcribed from analogue to digital format. Such processes are subjected to quality control to ensure reliability; however undetected errors may exist. Borehole locations are obtained from borehole records or site plans.

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

- Borehole coding (including observations and interpretations) was captured in a corporate database before the commencement of modelling and any lithostratigraphic interpretations may have been re-interpreted in the context of other evidence during cross-section drawing and modelling, resulting in occasional mismatches between BGS databases and modelled interpretations.

- Digital elevation models (DEMs) are sourced externally by BGS and are used to cap geological models. DEMs may have been processed to remove surface features including vegetation and buildings. However, some surface features or artefacts may remain, particularly those associated with hillside forests. The digital terrain model may be sub-sampled to reduce its resolution and file size; therefore, some topographical detail may be lost.

- Geological units of any formal rank may be modelled. Lithostratigraphical (sedimentary/metasedimentary) units are typically modelled at Group, Formation or Member level, but Supergroup, Subgroup or Bed may be used. Where appropriate, generic (e.g. alluvium – ALV), composite (e.g. West Walton Formation and Ampthill Clay Formation, undifferentiated – WWAC) or exceptionally informal units may also be used in the model, for example where no equivalent is shown on the surface geological map. Formal lithodemic igneous units may be named Intrusions or Dykes or may take the name of their parent (Pluton or Swarm/Centre or Cluster/Subsuite/Suite), or if mixed units Complex may be used. Highly deformed terranes may use a combined scheme with additional rank terms.

- The geological map linework in the model files may be modified during the modelling process to remove detail or modify the interpretation where new data is available. Hence, in some cases, faults or geological units that are shown in the BGS approved digital geological map data (DiGMapGB) may not appear in the geological model or vice versa. Modelled units may be coloured differently to the equivalent units in the published geological maps.

8 Model QA

In order for a geological model to be approved for publication or delivery to a client a series of QA checks is carried out. This includes visual examination of the modelled cross-sections to ensure that they match each other at cross-section intersections and fit the borehole and geological map data used. The model calculation is checked to ensure that all units calculate to their full extent within the area of interest and the modelled geological surfaces are checked for artefacts such as spikes and thickness anomalies. The naming convention of the modelled geological units is checked to ensure that recognised entries in the BGS Lexicon of Named Rock Units (http://www.bgs.ac.uk/lexicon/home.html) and the BGS Rock Classification Scheme (http://www.bgs.ac.uk/bgsrcs/) are used as far as possible. Any issues found in the QA checking process are recorded and addressed before delivery/publication of the model.

9 Model Images

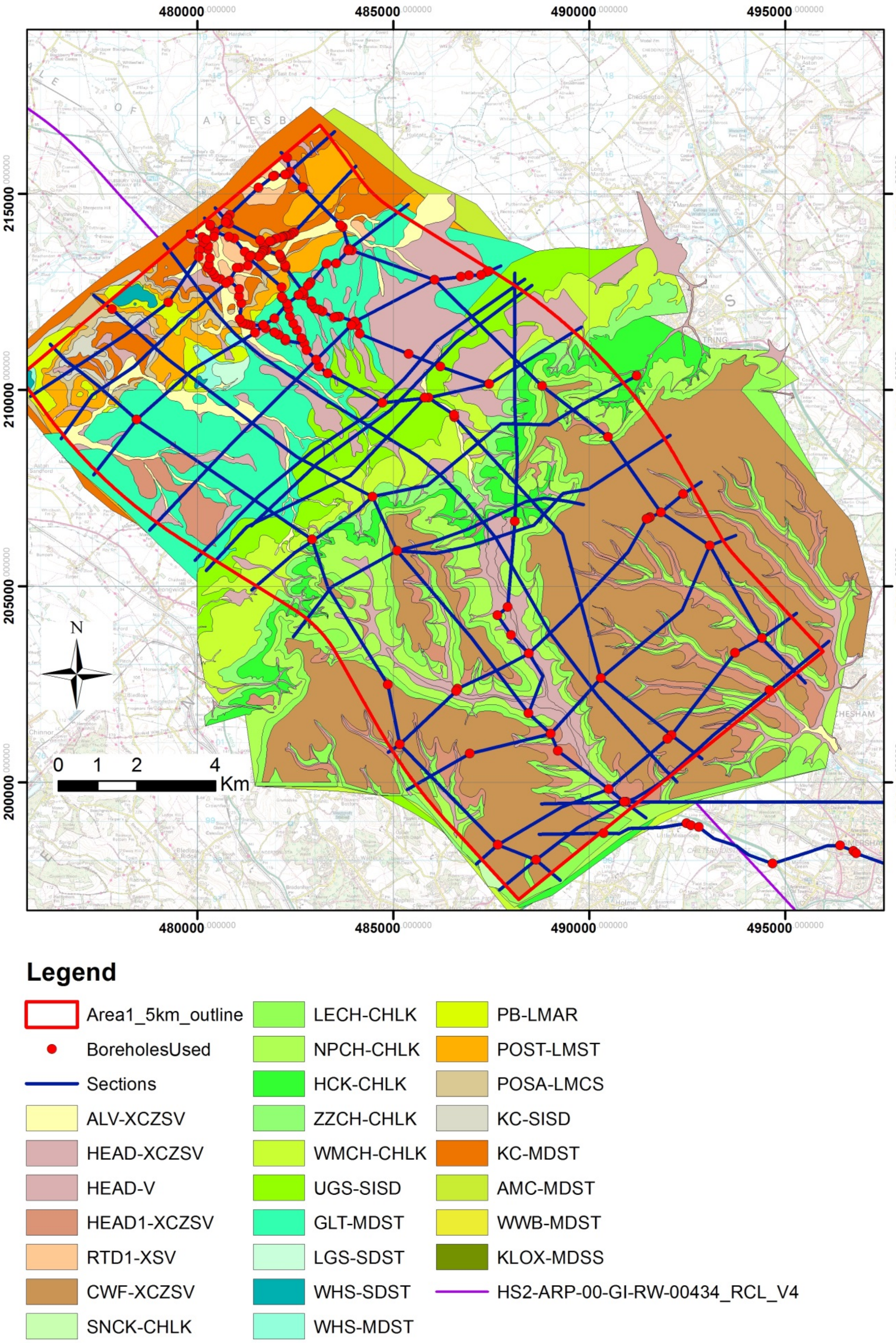

Figure 8. Envelopes, sections and boreholes used to create the model.

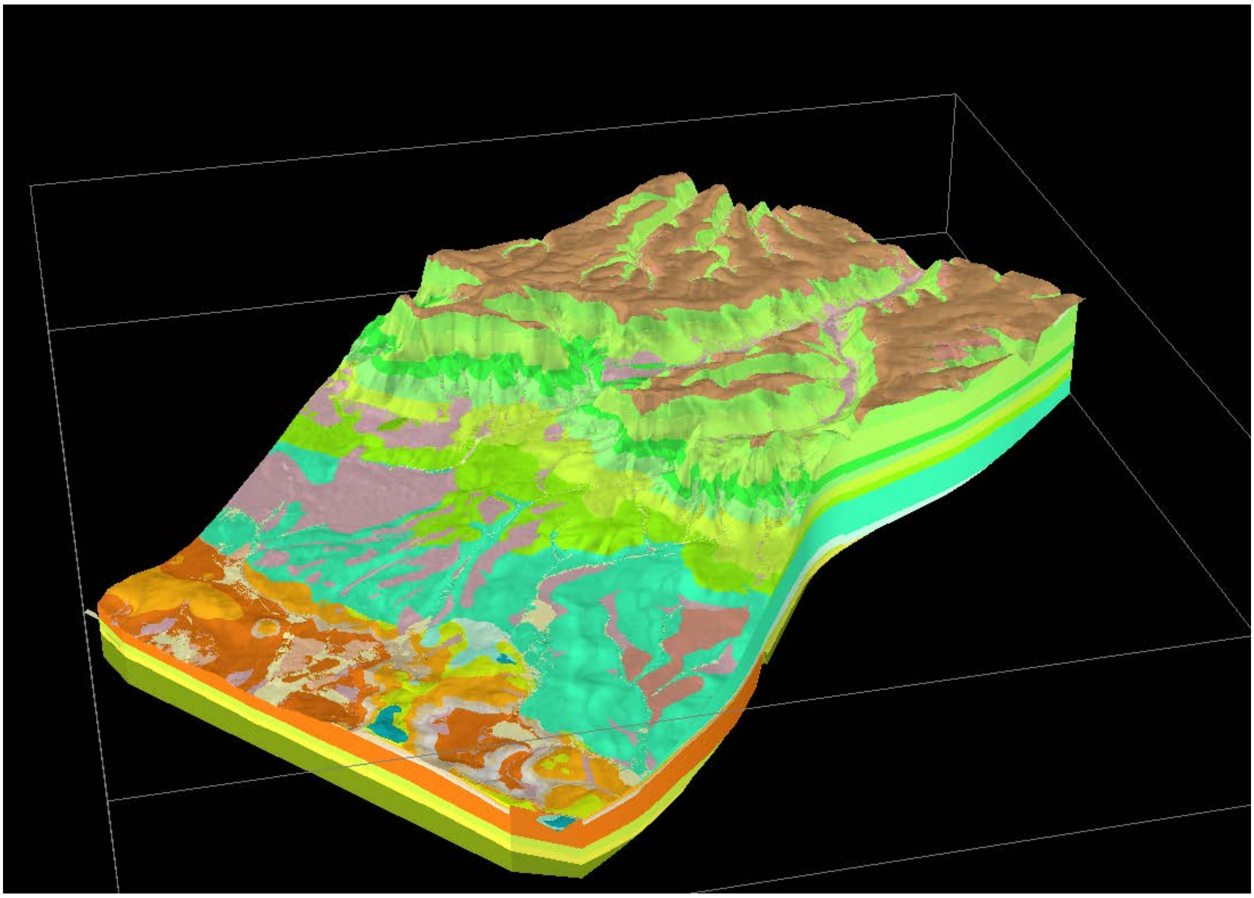

Figure 9. View of the model looking to the southeast. Vertical exaggeration x10. Key as per Table 1.

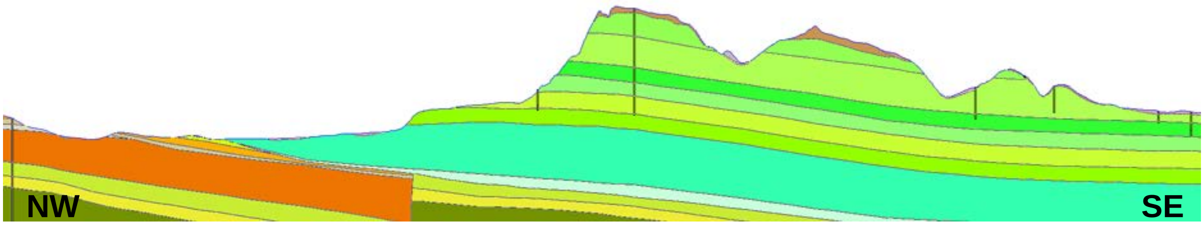

Figure 10. Cross-section *HS2_Area1_ARF_NW_SE_3*, which corresponds with the proposed route of HS2. This section predates site investigation work on HS2 and therefore does not include any HS2 site investigation data. Vertical exaggeration x12. Key as per Table 1.

10 References

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

Barron, A J M, Thompson, J, and Powell, J H. 2016. Assessment of BGS maps and 3D models along the proposed HS2 route British Geological Survey Internal Report, IR/12/043. 30pp.

Kessler, H., Mathers, S. J., Sobisch, H-G., 2009. The capture and dissemination of integrated 3D geospatial knowledge at the British Geological Survey using GSI3D software and methodology. *Computers and Geoscience* 36 (6), pp 1311-1321