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Clyde Basin GSI3D superficial geology model of NS66SW (Rutherglen)

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Clyde Basin GSI3D superficial geology model of NS66SW (Rutherglen)

S.Loughlin & J. Cavill

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Front cover

View of GSI3D model looking to
the SE along the Clyde Valley.

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Foreword

This report describes a pilot study into the use of the GSI3D software package to model the superficial geology of the Clyde Basin area and the production of a 3D model of 10k sheet NS66SW (Rutherglen). The pilot study was conceived by Mike Browne and Alison Monaghan as part of the Midland Valley DGSM and Clyde Basin projects. Feedback on the use of the GSI3D software to the designer Prof. H. Sobisch was continuous throughout the project and new ideas generated in this study have already been included into the software.

Acknowledgements

Assistance and guidance has been received from Alison Monaghan and Mike Browne at all stages of the study. Mike Browne also gave specific advice about the lithostratigraphy of the study area and Alison Monaghan assisted with the retrieval of data from the records. Tony Irving compiled all the digital data and gave advice on data management of the borehole records. Jonathan Ford provided a very useful and informative one day training course on the use of GSI3D at the onset of the pilot study and freely gave advice in the following months. Holger Kessler and Steve Mathers gave a course in GSI3D which was very helpful and informative. Simon Price also provided much assistance on the use of GSI3D. Many thanks are due to Prof. Hans-Georg Sobisch who listened to our ideas and incorporated them swiftly into the software.

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Summary

10k Sheet NS66SW (Rutherglen) in eastern Glasgow is the first 3D model of the superficial geology of Scotland to be created in GSI3D. Following a successful pilot study and the concurrent rapid development of the GSI3D software, a final model was produced in August 2004.

This report is a summary of the development of the NS66SW superficial model in terms of the software evolution, methodology and the geological interpretation. The geological interpretation has been based on the lithostratigraphy and ideas presented by Browne and MacMillan (1989). The limitations of the methodology and the uncertainties in the model are discussed, as are interesting geological problems uncovered by the modelling.

The data files used in the modelling are described in the appendices. Ten Best Practice documents have been compiled and are available in the project folder and will shortly be on the DGSM Best Practice web page.

1 Introduction

This work began with a GSI3D pilot study initiated as part of the Midland Valley DGSM and IGSN Clyde Basin projects to investigate the use of GSI3D software for 3D modelling of superficial deposits in the Glasgow area.

The pilot study was devised to a) assess the effectiveness of the new GSI3D software and give feedback during software development, b) investigate methodologies for assigning lithostratigraphy to partially interpreted superficial deposits in the borehole geology database, and c) produce a first draft 3D model of the superficial deposits of sheet NS66SW.

The authors attended informal and formal training sessions in GSI3D with Holger Kessler, Jonathan Ford and Steve Mathers which were highly informative and enabled rapid progress to be made. The software was found to be easy to use and effective.

At the end of the pilot study, in December 2003, a first draft 3D model was generated of the Quaternary geology on sheet NS66SW. The model was a reasonable first attempt and highlighted where methodologies and the software could be improved. Three 'Best Practice' documents were written during the pilot study.

In March 2004 the initial GSI3D model was revised using upgraded computers then, following revision of the software in April, a further revision was made in May-June 2004. Several 'Best Practice' documents were produced during the development of this 3D model (Appendix 1) and these should be referred to in conjunction with the GSI3D manual (Kessler et al., 2004). Best practice documents are also available on the BGS Intranet DGSM home page. Some minor changes were made to the final model in August 2004.

The appendices comprise notes on using the GSI3D software, data files used for NS66SW, best practice and the presentation of the model.

2 Aims

At the beginning of the pilot study, less than half of the superficial deposits in borehole records for the Glasgow area had been entered into the corporate Oracle database BGS.Borehole_Geology (by user DJLO in an old lithological classification scheme). Coding of the remaining superficial deposits was ongoing during the pilot study (by user AAMI) using the new Rock Classification Scheme (RCS). The intention was to ensure that all NS66SW boreholes in the database were coded to the level of key stratigraphic divisions and also assigned lithostratigraphical names based on Browne and McMillan (1989). Fully attributed digital borehole databases are a fundamental and essential resource for the Clyde Basin Environmental Project.

The method was:

1. Ensure all boreholes on sheet NS66SW are loaded to a defined standard of key lithostratigraphic divisions.
2. Create a 3D model of sheet NS66SW in GSI3D using all available maps and borehole data - this required an interpretation of the lithostratigraphy of the previously lithologically coded boreholes.
3. Investigate methods of feeding the interpreted lithostratigraphy from the model back to the borehole geology database.
4. Establish 'Best Practice' for the production, iteration and presentation of GSI3D models.
5. Add further geological information to corporate databases such as geotechnical, geochemical and hydrogeological data that could be incorporated into the existing 3D model.

3 Methodology

The methodology for creating a GSI3D model is outlined in the manual by Kessler et al. (2004) and also in several DGSM Best Practice documents (Appendix 1). The following is a specific account of the development of the NS66SW superficial geology model.

3.1 DATA PREPARATION

A generalised vertical section (gvs) is critical to GSI3D modelling as it gives the order of superposition of units (in this case formations - Fig. 1). The stratigraphy devised by Browne and McMillan (1989) was used to create a *.gvs file in Excel (see Appendix 4) with the main lithology of each formation recorded. Additional properties and characteristics of the units should be added to the .gvs file as they become available since a fully attributed .gvs file is an important end product for the potential user (see section 2.1.6 in Kessler et al., 2004). The name of the DTM file used is given at the top of the .gvs file (without the file ending).

The borehole index file (*.bid) containing borehole identifiers, location and start heights was retrieved from BGS.SOBI (Appendix 4). Boreholes with no start heights were deleted (although, if necessary, they can be used in GSI3D by hanging them from the Digital Terrain Model (DTM)).

Using an SQL code (BP/PREP/0022 and BP/PREP/0023), data were retrieved from the BGS.Borehole_Geology database. For the pilot study, two borehole log files were created in Excel (*.blg), one containing DJLO-interpreter data and one containing AAMI-interpreter data. This was because it was unclear at the outset if it was feasible to use very large quantities of data in GSI3D. Initially, only the DJLO data were used for modelling because the boreholes were all coded, albeit in the old lithological classification scheme, whereas the superficial deposits in most AAMI boreholes were uncoded. During the pilot study, we imported only the first (of

potentially four) lithology codes which had an impact on our interpretation (see section 4). By altering the SQL code (BP/PREP/0023), second and third lithologies or other data from the BGS.Borehole_Geology_Property database can be imported as required. For the final model we imported first, second and third lithologies and used the AAMI-interpreter data that had by then been entered into the database. This improved our ability to distinguish lithological details in areas where interpreting the geology was difficult. Importing properties from corporate databases will be important when modelling specific requirements for a customer (e.g. hydrogeological, geotechnical and geochemical properties).

Spaces between the borehole number and suffix were deleted in Excel to ensure that the identifier was the same in the .bid and .blg files.

A legend file (NS66SW_Legend.gleg) was generated in Excel in order to colour up the sections (and model) and was based on the generalised vertical section (Appendix 2). Suitable RGB (Red-Green-Blue) values were supplied by Jonathan Ford but can also be obtained from the Drawing Office.

A 100m Digital Terrain Model (DTM) (CEH) was used during the pilot study and a 50 m DTM (CEH) with a 50 m buffer was used for the final model. Modelling was started using a NEXTMAP 5 m DTM but it made processing extremely slow and a high specification machine was not always available, so the 50 m DTM was used. There were also some very obvious spikes in the 5m DTM which should be removed but there is no doubt that this resolution is preferable for 5 x 5km squares such as NS66SW. A method for creating a DTM using Ordnance Survey contours was investigated (see IR/04/114) but it wasn't an improvement because of localised spikes, although given sufficient time this DTM could have been improved and spikes removed.

There were often discrepancies of several metres between the 50 m DTM and the top of the boreholes, this was also seen when the 5 m DTM was used. This mainly affected the modelling of made and worked ground which commonly appeared to be above the DTM. Some boreholes were up to 10 m above the DTM, these large differences were checked and the start heights generally found to be as listed in the records. We assume that the borehole start heights are more accurate than, in this case, the 50 m DTM. Those boreholes that didn't have a listed start height were assigned one (by Tony Irving) from the 1:10,000 scale topo map with 5 m contours. As a result there is a *maximum* error of ± 5 m in those start heights. Given sufficient time, a DTM could be altered in GoCAD to fit the borehole start heights, this may be important for some areas of made ground and the effort would be worthwhile if a model is to be provided to a customer. However, in other areas the ground surface may have changes since the borehole was drilled so care must be taken. Some ground-truthing may be necessary.

A contoured and gridded rockhead model based on data interpreted during the Environmental Geology project of Browne & McMillan (1989) was also displayed. This was intended to aid drawing the base of the superficial deposits and it was a useful guide. However, it was not followed that closely due to its local inaccuracy in the light of the additional borehole data.

3.2 MODELLING

A number of the Glasgow boreholes were logged by Browne and McMillan (1989) in great detail. A lithostratigraphy was assigned to ones such as the Bridgeton Borehole (BGS Reg.No. NS66SW BH826, NGR [NS6121 6367]). GSI3D modelling started by selecting these known boreholes and working away from them, progressively correlating the lithologies between boreholes and assigning formation names. For some distinctive lithologies such as diamicton (Wilderness Till) or thick clay and silt (Paisley Formation) this was quite straightforward. In areas where there are two tills, or where the Paisley and Linwood Formation both exist,

distinguishing them on the basis of lithology alone is not always possible. In addition, thin clays and silts could belong to other formations. The alluvial Law and Gourock formations comprise basically the same lithologies. In order to distinguish between them we referred to the distribution of these formations in Browne and McMillan (1989). There are also several lithostratigraphical units containing sand, and sand and gravel, so distinguishing these units is particularly difficult. Using second and third lithologies helped in these instances because, for example, a 'silty sand' is unlikely to belong to the Bridgeton Formation. However, commonly the description available is simply 'sand' or 'sand and gravel' and in these cases interpretation and modelling was based on the palaeoenvironmental interpretations and geological maps of Browne and McMillan (1989) (Figures 2 and 3).

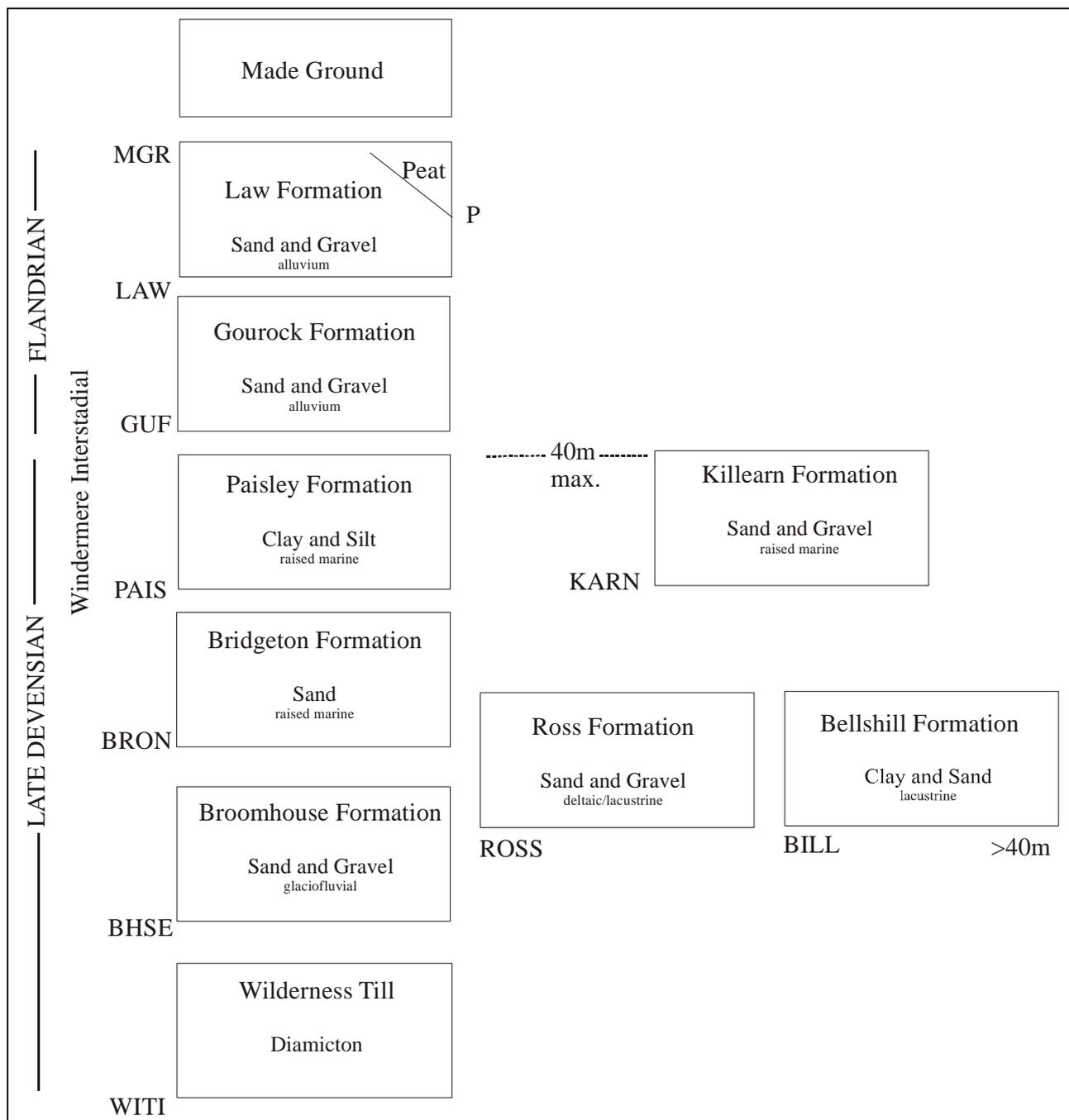


Figure 1 GVS used for GSI3D modelling of superficial geology on NS66SW based on mapping by Browne and McMillan (1989).

Cross sections interpreted between the boreholes should ideally form an equally-spaced grid although this depends ultimately on the borehole coverage (Fig. 4). Compiling a good number of sections in GSI3D obviously improves correlations and viewing the resulting fence diagram in the 3D viewer highlights unlikely geological relationships. These discrepancies can then be resolved by altering the sections accordingly. For the final model, short 'helper' sections were drawn in awkward areas to help with correlations (see draft Best Practice documents - Appendix 1). 'Helper' sections were also drawn along the 5 by 5 km sheet margins in anticipation of joining with adjacent sheets. These margin sections should in fact have been drawn 10m inside the sheet boundary (see Kessler et al., 2004, section 4.9).

The next stage of modelling involved drawing envelopes for each unit. If care has been taken during the section building, and nodes are regularly and carefully placed, construction of envelopes is straightforward (see draft Best Practice documents - Appendix 1). Sections can be corrected/alterd whilst compiling envelopes as unlikely relationships are highlighted and this was necessary during the creation of each model. The envelopes that reach the sheet margins must extend over the DTM (i.e. at least 50m beyond the sheet margin) or the final model calculation will not work.

When all the envelopes were created, a model was generated ('calculate all objects'). GSI3D uses the bases of each unit to calculate the model. For more details refer to Kessler et al., 2004. The geological units generated by the final calculation can be exported as TIN files, GOCAD .ts files, ASCII grids and ASCII xyz. Surfaces can be viewed in Arc Scene (see draft Best Practice documents in project folder). Video clips were produced showing these surfaces and the rotating fence diagram (see draft Best Practice documents - Appendix 1). An addition to the software in April 2004 allowed the generation of a 3D block diagram that can be 'exploded' and individual units can be viewed as volumes. The base, top and thickness of the units can be calculated and exported for analysis in other software packages. Synthetic sections and blocks can be cut from the model and synthetic boreholes can be shown.

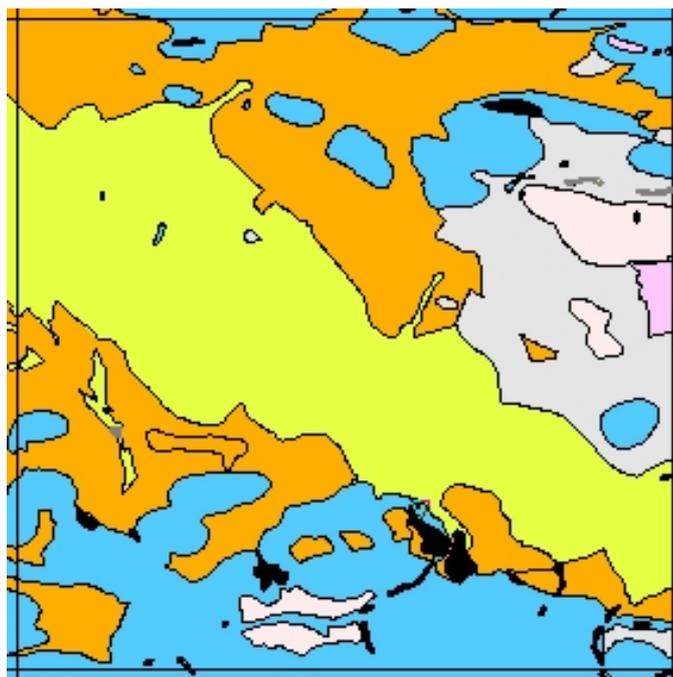


Figure 2 The existing drift map for NS66SW (Browne and McMillan, 1989).

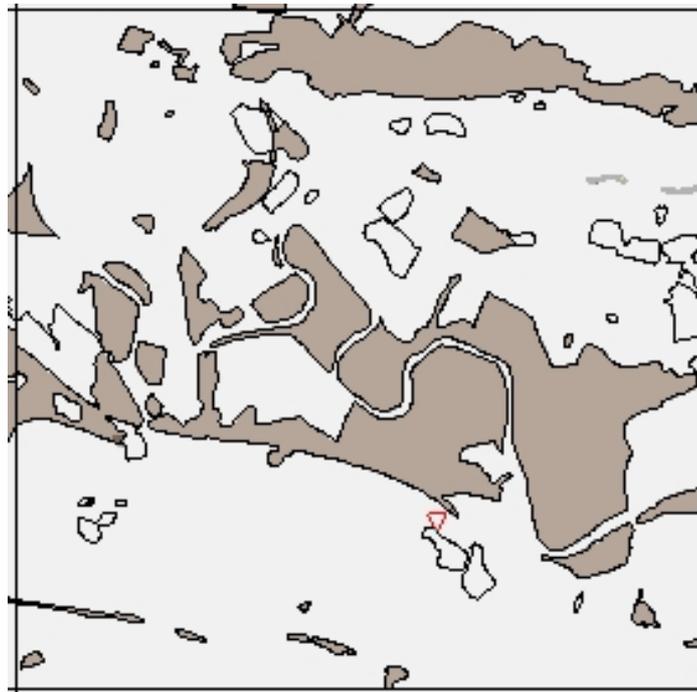


Figure 3 The existing artificial map for NS66SW (Browne and McMillan, 1989).

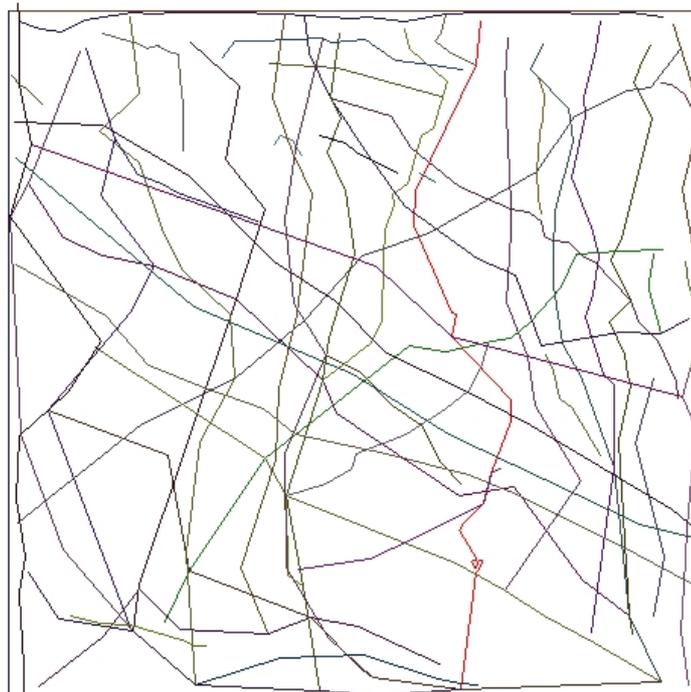


Figure 4 Section coverage of 5 x 5 km on sheet NS66SW. Ideally sections should be regularly spaced in N-S and E-W directions with shorter helper sections along valleys, or other areas lacking borehole control (e.g. small areas of made/worked ground).

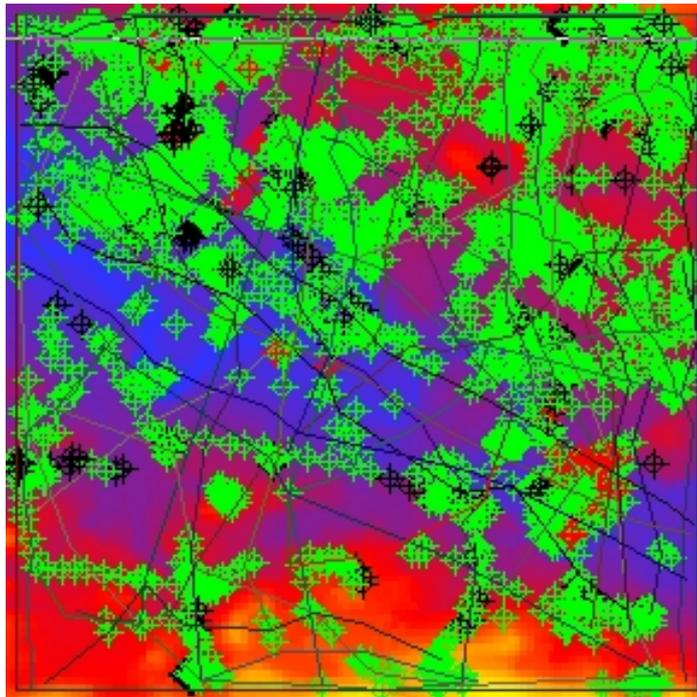


Figure 5 Locations of boreholes with DTM 50m grid shown below (Clyde valley is blue). Green boreholes are those deeper than 5m.

4 Superficial Geology

The lithostratigraphy of the superficial deposits in the Glasgow area was formally described by Browne and McMillan (1989) and is summarised below, with notes about borehole coding. The subsurface distribution of the different units revealed by modelling is discussed along with areas of controversy.

4.1 WILDERNESS TILL FORMATION

This formation is named after temporary sections seen in the Wilderness Plantation area north of Bishopbriggs. It is characterised by a diamicton comprising isolated boulders, gravel and pebbles in a sandy, silty to clayey matrix (Browne & McMillan, 1989).

The Wilderness Till is the only till present across most of the sheet area (Figure 6) and usually occurs at the base of the Quaternary deposits (locally, un-named sand and gravel and clays occur below and within the till). It is usually described in the borehole records of user DJLO as diamicton (DMTN). During borehole coding by AAMI, several different RCS codes that refer to diamicton were assumed to be the Wilderness Till.

The till is thickest and best exposed on high ground (up to 75 m OD) to the north and south of the Clyde valley. On the north side of the valley, a partially buried east-west oriented ridge of diamicton (drumlin?) is over 20m thick. Two discrete diamicton units are shown in some borehole records separated by sand and gravel (especially in the north-east part of the map). This may simply represent a lens of sand and gravel in the Wilderness Till, or there may be an older till present, or alternatively, there may be repetition of the Wilderness Till by glacitectonic thrusting. It was not possible to resolve this issue during the time available. The Wilderness Till covers most of the sheet area, but is locally absent or thin in parts of the sheet. There are small areas throughout the sheet area where rockhead reaches the surface and no superficial deposit are present.

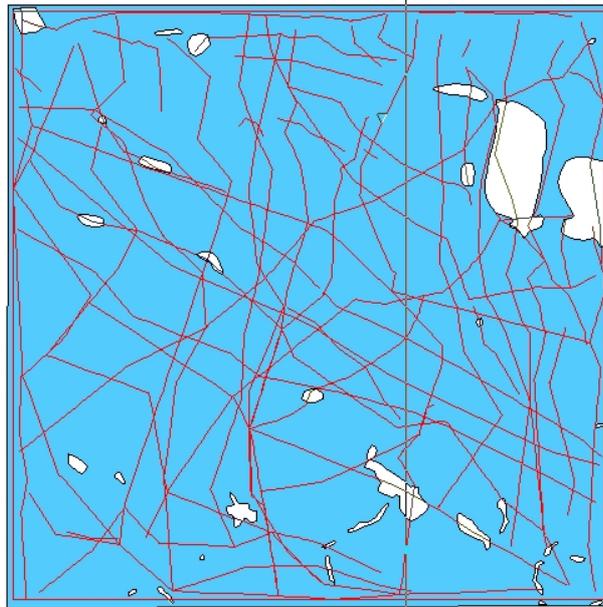


Figure 6 The extent of the Wilderness Till.

In the north-east quadrant of the map, where the Wilderness Till is thin to absent, thin clays are locally present under the sand and gravel of the Broomhouse Formation (Fig. 7). These clays have been separated out - they may have been formed by ablating ice, in which case they would belong to the Wilderness Till Formation, or they may be glaciolacustrine clays in which case they would require a new lithostratigraphical name. They are currently coded bhse_clay.

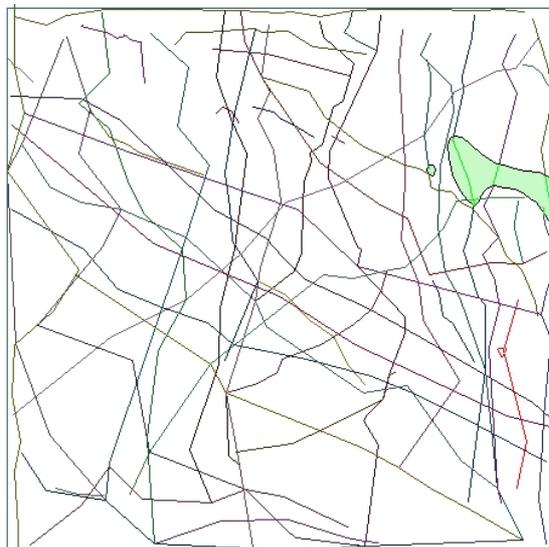


Figure 7 The extent of clays below the Broomhouse Formation

4.2 BROOMHOUSE FORMATION

The Broomhouse Formation is named after the Broomhouse area of eastern Glasgow where it usually overlies the Wilderness Till Formation. It is characterised by sand and gravel deposits emplaced in an ice-contact environment e.g. esker ridges, mounds, isolated flat-topped kames and kettleholes. Overall, the most abundant deposit is sand, except where esker ridges are present where gravel dominates. Sands are planar and trough cross bedded, ripple laminated and

horizontally laminated, gravels are typically massive or crudely bedded. Deposits are up to 25m thick and flow directions were to the east (Browne and MacMillan, 1989).

The subsurface Broomhouse Formation deposits in the NS66SW area are located to the north of the present Clyde valley implying that the valley axis has moved to the south since the Late Devensian.

In general, sands and gravels lying on the Wilderness Till or on rockhead (or on the clays described in section 4.1) were all assigned to the Broomhouse Formation (Fig. 8a) Locally, closely adjacent boreholes contain successions 10s of metres thick that are described as sand in one borehole and sand and gravel in the adjacent borehole, there is clearly some difference of interpretation here which makes the modeller's task very difficult. Areas that on the whole appear to comprise sand and gravel, have been assigned to the Broomhouse Formation. The Broomhouse Formation typically forms WNW-ESE aligned subsurface deposits. The deposits tend to thicken and dip towards the east, implying eastward drainage as suggested by Browne and McMillan (1989). The deposits commonly form positive features typical of ice-contact deposition (Fig. 8b).

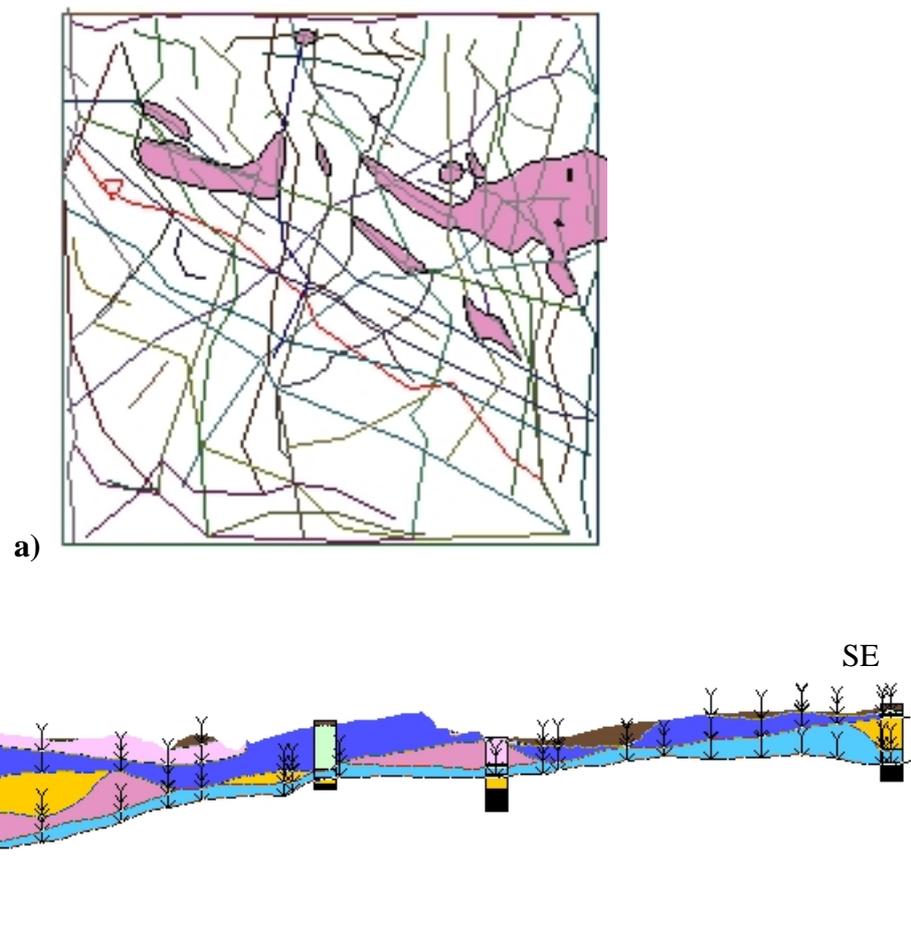


Figure 8 a) The extent of the largely subsurface Broomhouse Formation (sand and gravel).

b) A NW-SE cross section (NWSESL3) showing the typical form of Broomhouse Formation deposits (dark pink). Light blue - Wilderness Till Formation; Yellow - Bridgeton Formation in NW and Ross Formation in the SE; Dark Blue - Paisley Formation; Pale pink - Gourock Formation; Brown - Made Ground.

4.3 ROSS FORMATION

The area assigned to the Ross Formation in the north-east part of NS66SW is shown in Figure 9. It is exposed at surface as an E-W aligned sandy ridge. The main lithology is sand or sand and silt. At the base there are clays and locally there are thin gravel layers. These deposits have been mapped as glacio-lacustrine by Browne and MacMillan (1989). The glaciolacustrine Ross Formation is not generally considered by Browne and McMillan to occur west of the Blantyreferme moraine, although their Fig. 3d shows the Ross Formation to the north-west of the Blantyreferme moraine, apparently ponded between it and the Broomhouse Formation.

For the purposes of modelling, we have separated the different lithologies into different units. Sands with silt as a second lithology (ie interbedded) locally overlie the sand and gravel of the Broomhouse Formation and have been separated from them (Ross_sz, Figure 9). Units of sand (often described as 'massive') at the top of the succession form another unit (Ross-sand, Figure 10) that has been separated from the interbedded sands and silts. These units occur only in the eastern part of sheet NS66SW. On the eastern margin of the sheet, a deep palaeovalley filled with massive sands has been assigned to the Ross Formation rather than the Bridgeton Formation because it appears to slope and thicken to the east. These sands are overlain by clays of the Paisley Formation, so must belong to either the Broomhouse, Ross or Bridgeton formations.

If it is decided in the future that these units belong in different formations, this can be simply done by changing the name of the unit in the .gvs and .gleg files and changing the unit names in the .gxml files (The sections can be changed using 'change line name' in the section window of GSI3D, the envelope names can be changed by opening the .gxml file in Excel).



Figure 9 The extent of largely subsurface sands with interbedded silts (Ross_sz) assigned to the Ross Formation.

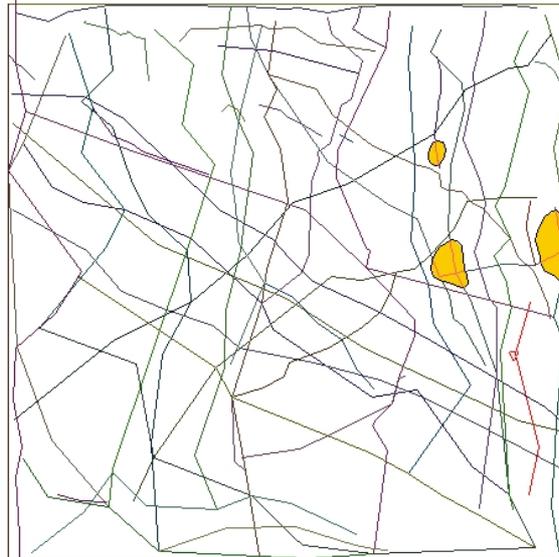


Figure 10 The extent of subsurface sands (Ross_sand) assigned to the Ross Formation.

4.4 BRIDGETON FORMATION

The type section of the Bridgeton Formation is in the Bridgeton Borehole. It is characterised by fine to medium grained, massive sand; locally fine to coarse gravel and boulders occur in a sandy matrix. There is some flat bedding but generally the deposits are massive. Crucially, deposition was by westward flowing floodwater. Browne and MacMillan (1989) suggested that deposition was on submarine outwash fans following catastrophic draining of Lake Clydesdale.

The formation appears to form a broad, roughly flat-topped deposit in a buried valley under the western and northwestern part of NS66SW (Figures 8b and 1a,b). It is deepest in borehole 36 (-28 m OD) shown on section line NSJC3. The 'palaeovalley' runs roughly to the WNW and slopes slightly in that direction reinforcing the interpretation of Browne and MacMillan (1989). Its morphology tends to support its origin as a subaqueous outwash deposit emplaced by westward flowing floodwater. The Bridgeton Formation is absent in the centre of the sheet (section NSJC1; 262150, 663300) where the Wilderness Till forms a small topographic high. To the east of this site, a lensoid mass of sand occurring at low elevations has been assigned to the Bridgeton Formation but with less confidence than the sheet-like deposits farther west. There is some uncertainty in this interpretation due to some contradictory borehole descriptions as described above. It is clear that the Bridgeton Formation occurs only in the western part of sheet NS66SW and along the same 'palaeovalley' axis as the Broomhouse Formation. Browne and McMillan (1989) suggested that the Bridgeton Formation may derive from the Broomhouse Formation (and Ross Formation) and this seems quite likely given the distributions of the two formations (figures 8-11).

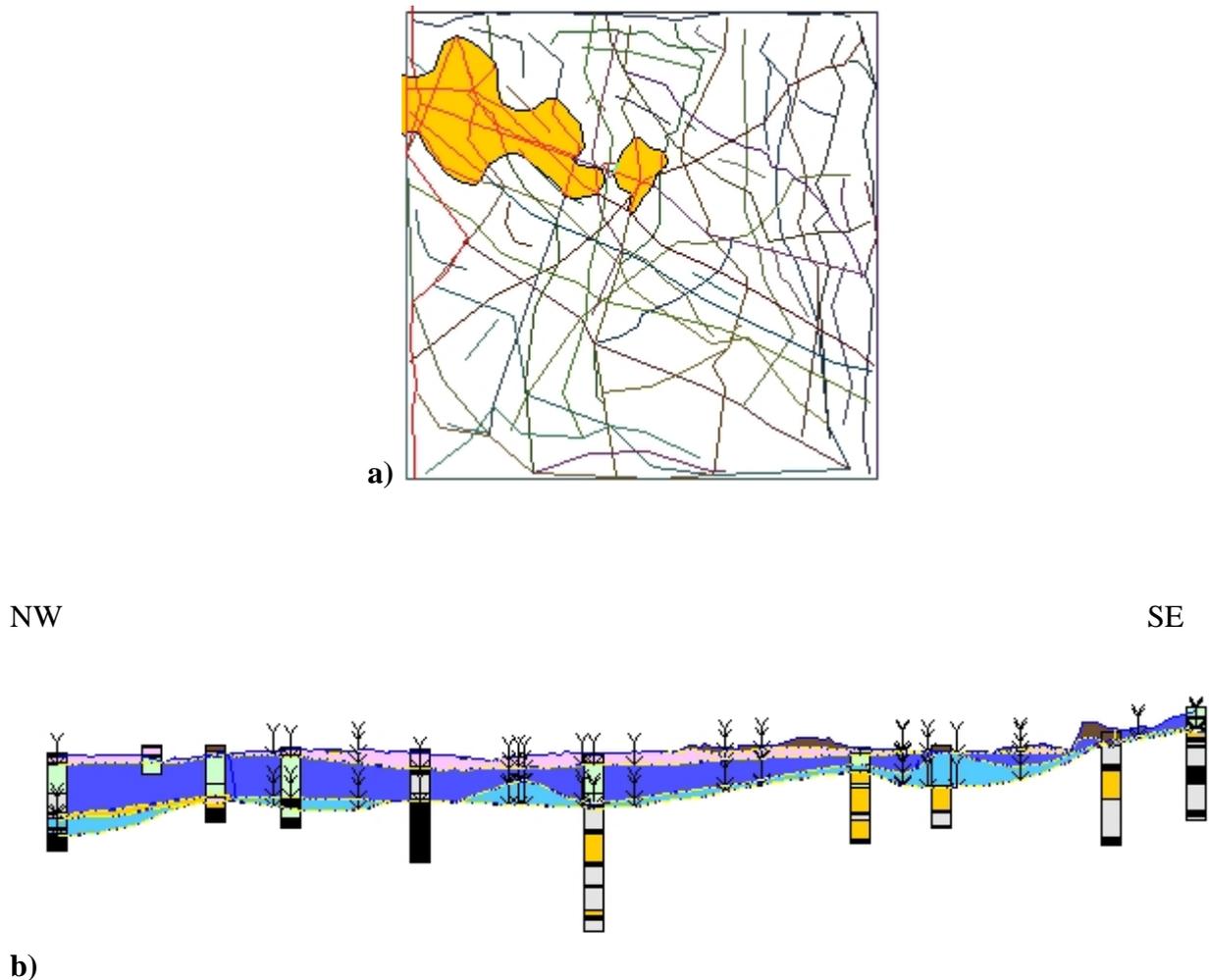


Figure 11 a) The extent of the Bridgeton Formation (entirely covered by younger deposits)
b) A NW-SE cross section (NWSESL3) showing the southern edge of the westward-dipping Bridgeton Formation (yellow) and the N-S ridge of Wilderness Till (pale blue) in the centre of sheet NS66SW. Dark blue - Paisley Formation; Pale pink - Gourock Formation; Brown - Made Ground.

4.5 PAISLEY FORMATION

The type section of the Paisley Formation is in the Linwood Borehole (BGS Reg. No. NS46NW BH62, NGR [NS4459 6588]). It comprises finely layered clays and silts deposited in a glacial marine setting. The retreating glaciers were believed to be to the northwest, in the sea lochs of the Southern Highlands. Relative sea level was high when during deposition of the Paisley Formation commenced so some clays were deposited at elevations up to 40 m above OD (Browne & McMillan, 1989).

The Paisley Formation is a widespread unit which is easily recognised in the boreholes based on lithology (Fig. 12). Most clay and silt units in the boreholes that are greater than 2-3m thick have been assigned to this formation with a high degree of confidence. The only area of difficulty is again in the north-east quarter of the sheet where only thin clays exist and locally there are two thin layers of clay interbedded with sands. In general, we assigned thin clays in areas of varied lithology to the Killearn Formation.

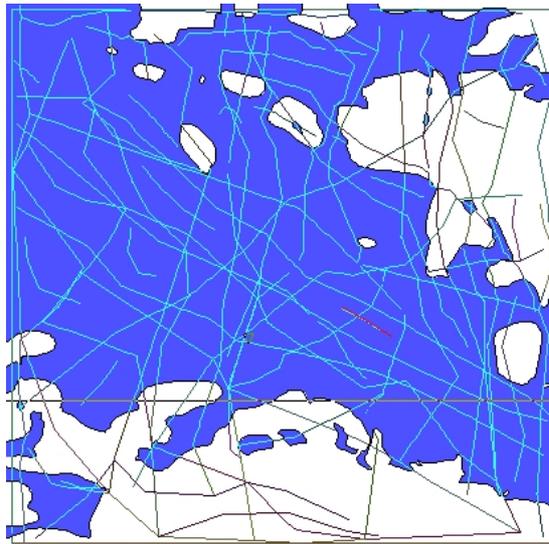


Figure 12 The extent of the Paisley Formation.

4.6 KILLEARN FORMATION

The Killearn Formation is named after the Killearn Borehole (BGS Reg. No. NS68SW BH3, NGR [NS5100 8467]) and comprises mainly sand with some clay layers and some gravel. It does not occur above 40m (Browne & McMillan, 1989). It may include beach, river terrace and delta deposits.

We assigned all sand or sand and gravel units that crop out above the Clyde valley floor and stratigraphically above clays and silts of the Paisley Formation to this formation (Figure 13). The full extent is uncertain but it appears to be well-developed in the north-east quarter of sheet NS66SW where Paisley Formation is poorly developed or not developed. Boreholes show varied assemblages of sand and gravel, sand and thin silt/clay layers and as a result, it is very difficult to distinguish between the Broomhouse, Bridgeton and Killearn Formations. On the basis of distribution maps in Browne and McMillan (1989) and the existing geological map, it is assumed that at surface, much of this area comprises the Killearn Formation dipping mostly to the south and south-west.

On the south side of the Clyde valley, the Killearn Formation forms four separate terraces each at an altitude of 35-40m. These may be beach deposits or river terraces, whereas the large deposit in the north east of the sheet was deltaic with a northerly or northeasterly source.

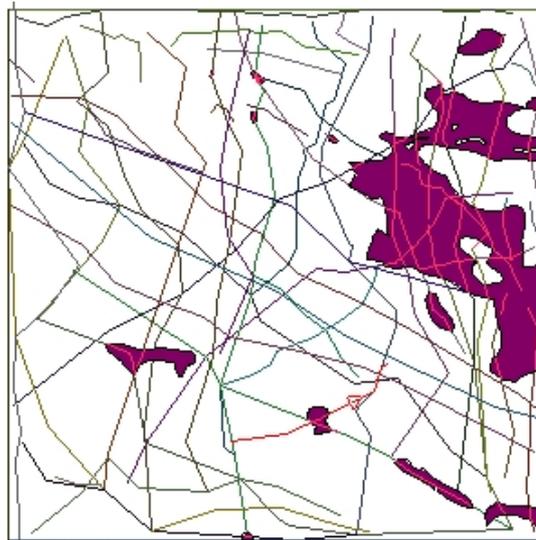


Figure 13 The extent of the Killearn Formation.

4.7 GOUROCK FORMATION

The Gourock Formation is named after the Gourock No.2 Borehole (BGS Reg. No. SE7706 BH3, NGR [244 777]) and is characterised by fine to coarse grained sand with some silt, clay and locally gravel. Deposition was in an estuarine environment with fluvial processes dominating in the east of the Clyde valley and a fully marine environment in the west (Browne & McMillan, 1989).

It is difficult to distinguish the Gourock Formation from the Law Formation using a single lithology identifier. Sheet NS66SW is at the eastern limit of the extent of the Gourock Formation. According to the distribution maps in Browne and McMillan (1989), the Gourock Formation is likely to occur on this map sheet whereas the Law Formation is more likely to occur farther east up the Clyde valley and in the Clyde tributaries. Therefore, much of the alluvium on sheet NS66SW (mostly sand or sand and gravel with some silt layers) has been assigned to the Gourock Formation.

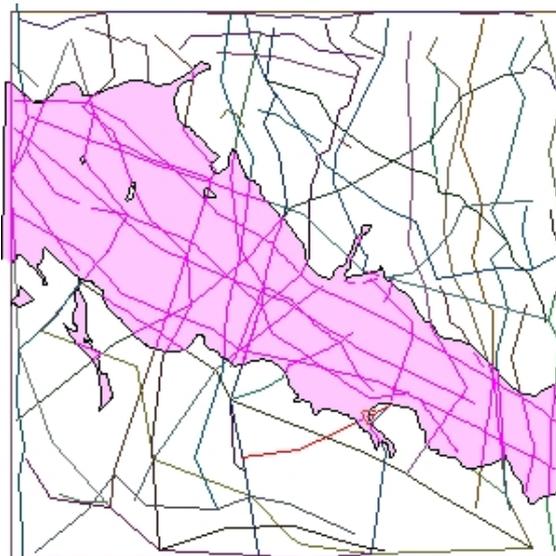


Figure 14 The extent of the Gourock Formation.

4.8 LAW FORMATION

The Law Formation is named from the Law Borehole (BGS Reg. No. NS85SW BH436, NGR [8357 5247]) and comprises fine to coarse grained sand with some silt and fine gravel. The Law Formation also includes recent (currently accumulating) river deposits in the Clyde valley.

In the current model, only the recent alluvium in the tributaries to the Clyde valley, with an altitude above the Clyde valley deposits, have been assigned to this formation.

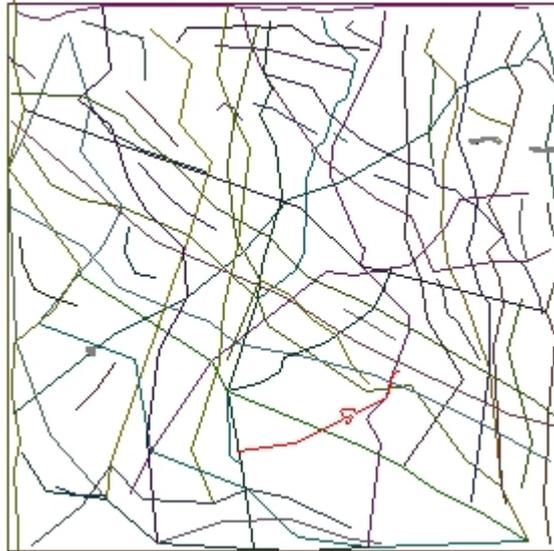


Figure 15 The extent of the Law Formation.

4.9 MADE GROUND

Made ground includes filled and partially back-filled pits and quarries (FILLU - DJLO). There are several examples of made ground being identified in boreholes but occurring outside areas shown on the current map. The model is slightly different to the existing artificial map and changes were made as a result of checking all the available borehole data during envelope construction. In order to properly remap the made ground, all the borehole data should be used (we used a fraction of the available data in the model) with up to date air photographs, as well as field slip evidence. Some boreholes occur well above the DTM, this makes representation of the made ground in the top few metres problematic. An accurate 5 m DTM is essential to the proper modelling of the made ground in the Clyde valley area. In future, the made ground can be subdivided following the recent made-ground classification system if sufficient data is made available in the Borehole Geology database.

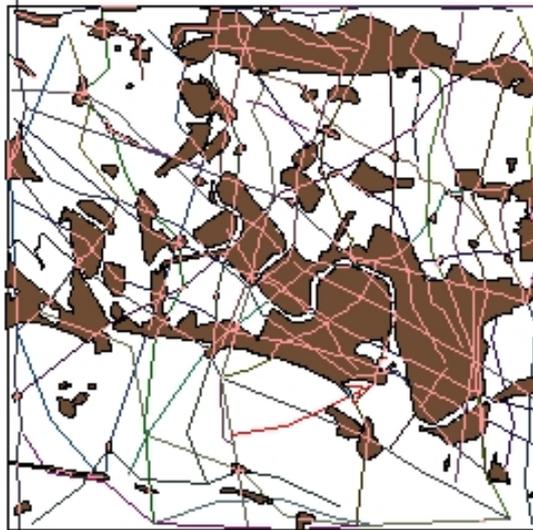


Figure 16 The extent of Made Ground.

5 Model Improvement and Iteration

Checking and editing should be continuous throughout the modelling process in order to ensure a high degree of confidence in the final model. The following are a series of steps that were taken in the production of the model (see draft Best Practice documents - Appendix 1).

5.1 AFTER SECTION DRAWING

When drawing and correlating sections, it is important that all the tie lines match-up where sections intersect one another (down pointing arrows). Correlation lines should fit the existing geological map linework (unless changes are to be made -in which case they should be noted). Sufficient nodes must be drawn on the correlation lines to make envelope drawing easier and also to improve the quality of the eventual TIN files.

If these checks are made before drawing envelopes, time will be saved later on.

5.2 AFTER DRAWING ENVELOPES

The envelope should be carefully and accurately drawn (tick the 'lines' box in 'properties' in the map window to see extent of the unit according to the sections). The envelope can be compared to existing geological linework - make a note of any changes that might affect the existing geological map.

5.3 AFTER MODEL CALCULATION

- a) To check the integrity of the 3D model, a regularly spaced grid of 'synthetic' sections can be drawn and the resulting fence diagram viewed in the 3D window. Any problems of correlation will hopefully be clear.
- b) Similarly, cubes can be cut out of the model and checked.
- c) Each section should be viewed with the .TINs displayed in the section window. The model correlation lines show as blue lines. If these do not fit the drawn sections then the interpretation should be checked and if necessary the section should be changed or more nodes added.

5.4 IMPROVING THE MODEL

Viewing the .TINs for each unit in the map window shows where there are gaps and the triangles are large - add 'helper' sections to improve the model. Helper sections can also be added in small polygons that have no sections crossing them (especially made ground) and along valley floors that are commonly lacking in borehole data.

5.5 SIGN-OFF

The methods used to check this model, i.e. drawing synthetic sections and cutting cubes out of the model, could be used by senior management to check and sign off the models. Managers can use the 'Analysis' version of GSI3D also destined for use by the customer, which allows interrogation of the model but does not allow changes to be made. Where problems are found the grid reference can be noted and passed to the modeller who can make changes as necessary.

6 Results

6.1 FIRST DRAFT MODEL:

During the pilot study, a first draft stratigraphy was assigned to the boreholes and a viable GSI3D model constructed in 15 working days. The file names were: Final041203.gxml and Final051203_Tins.gxml.

As a result of time constraints, some of the sections compiled in the first model did not exactly match with intersecting sections. When viewing some surfaces, jagged outlines of underlying surfaces could be seen poking through. This effect was caused by mis-alignment of nodes on the cross sections. It is essential that the nodes on 'base of unit' lines do not overlap the base line of the overlying unit. Other lessons learned included: envelope margins must extend beyond the DTM at the edges of the model or the surface calculations do not work, and an awareness of topography is essential when drawing envelopes in order to follow the base of units rather than the top.

The model was, therefore, slightly revised in March 2004 when the nodes were adjusted and increased in number, and the cross sections were corrected to ensure that they all correlated exactly with each other.

6.2 VERSION 2

090704.GXML

090704TINS.GXML

Additional cross sections were added and also some helper sections through areas of made ground and areas with little borehole coverage. The resulting model was generally acceptable but locally required a small number of additional helper sections and some minor corrections.

6.3 FINAL MODEL

300804final2.gxml

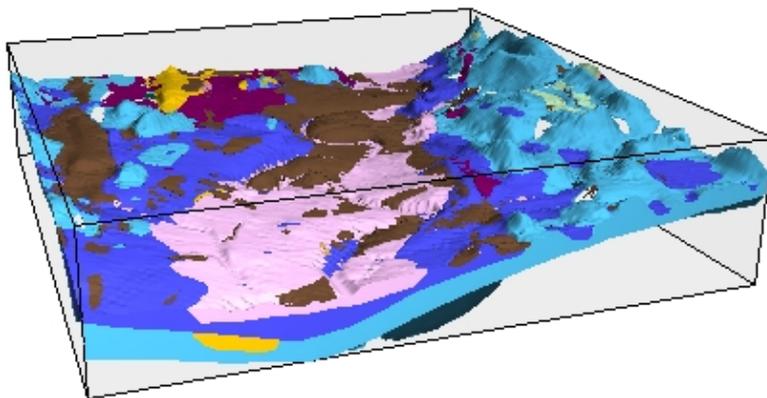
300804finalTINS.gxml

There are still localised problematic areas in the final model but this is by and large a coherent product (Figure 17).

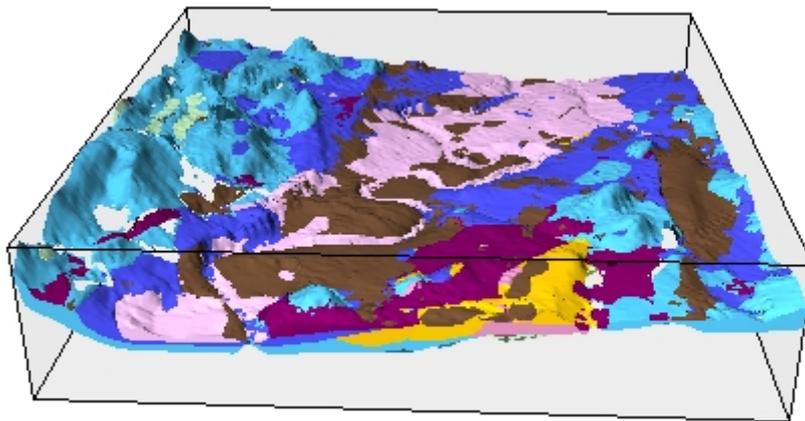
The final model shows a revised surface expression of the superficial geology and shows that the existing geological map needs minor alteration.

In general, there is much more made ground than is shown on the existing map. Most boreholes encountered some form of made ground, though it is often less than 1 m in thickness. This is not a mappable thickness. In the 1980's made ground was mapped generally where more than 3 m thickness occurred.

Two small polygons of 'gravel and clay' in the main Clyde valley are marked as till on the current superficial geology map but boreholes in the area show that the clays overlies the Paisley Formation. The gravel and clay lithologies are more likely to belong to the Gourock Formation. Locally, the Paisley Formation extends farther than is shown on the map (see section 8).



a)



b)

Figure 17 a) The final model of NS66SW viewed from the NW, b) the final model viewed from the east.

All essential data is at:

V:/(MHNTS9)/Lr/IGSN/CLYDE_BASIN/DATA/GSI3D_NS66SW_Final/Data

The cross sections can be viewed as a fence diagram in GSI3D, alternatively

the grids produced by the modelling can be exported for use in GoCAD and other packages. A variety of exports including GOCAD.ts files, a rockhead model and others are available in V:/(MHNTS9)/Lr/IGSN/CLYDE_BASIN/DATA/NS66SW_Final/Exports.

Layers are available in ArcScene:

V:/(MHNTS9)/Lr/IGSN/CLYDE_BASIN/DATA/NS66SW_Final/ArcScene

A Powerpoint demonstration is available:

V:/(MHNTS9)/Lr/IGSN/CLYDE_BASIN/DATA/NS66SW_Final/Documentation/GSI3D_NS66SW.ppt

Figures used in his report and the powerpoint demonstration are available in:

V:/(MHNTS9)/Lr/IGSN/CLYDE_BASIN/DATA/NS66SW_Final/Figures

7 Changing existing geological maps

For NS66SW, the required changes to drift mapping are very minor showing the very high quality of the existing mapping (for examples see Figures 18 and 19).

Any such changes should be double checked using sections, further modelling, 3D visualisation and any other available borehole data before linework on the maps is altered.

Made ground is constantly changing so geological maps and DTMs are likely to be out-of-date.

Any changes to the existing map should be backed up by rigorous data collection and, where necessary, site visits.

The made ground in the current model has been added where shown in boreholes but the outlines of new polygons are rather arbitrary and have been drawn using the topographic base map as a reference. They should be checked using recent air photos and NEXTMAP may also help with this.

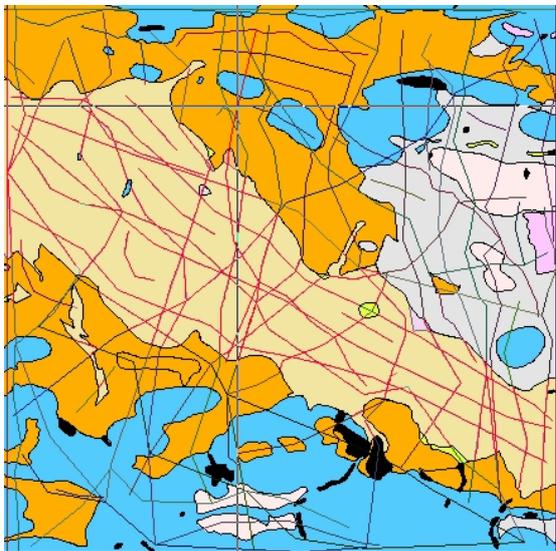


Figure 18. The Gourock Formation envelope (transparent pink) overlying the existing drift map (where alluvium is yellow). Minor changes can be seen where the original yellow alluvium shows through. The circular hole in the alluvium just right of centre should show the underlying Paisley Formation - boreholes prove that there is no alluvium in this area. In the bottom right, the alluvium is marginally less extensive than shown on the existing map.

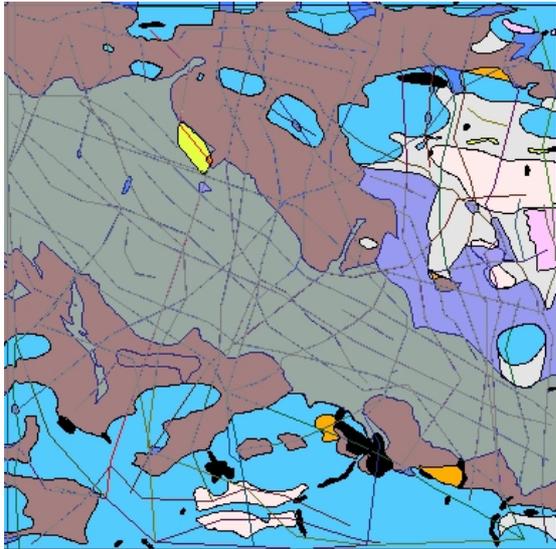


Figure 19. The Paisley Formation envelope (transparent blue) overlies the existing drift map (where Paisley outcrop is orange). Minor changes can be seen where the original orange polygons show through. In the top right corner boreholes prove that the Wilderness Till extends a little farther north than shown on the existing map and the Paisley Formation does not extend as far south. The two areas in the south of the map show mapped polygons that have been assigned to the Killearn Formation rather than the Paisley Formation.

The envelopes (TINs) of each unit in the model can be exported as shape files and used as the basis of a revised Arc GIS map.

8 Limitations of the model

8.1 BOREHOLE DATA

During the pilot study, only the DJLO-interpreted borehole data were used. These are a small subset of all the data available. All the recently updated and coded boreholes interpreted by Tony Irving (username AAMI) were not used because this data set was so large and was in the process of being completed. Interpreter DJLO used the old lithological coding system and initially only single lithologies were retrieved from the borehole database which severely limited out ability to interpret the available data. When the 'second lithology' was added there was still uncertainty about lithology, for example - is 'SAND' with 'SILT' as a second lithology silty sand or is sand interbedded with silt? The current coding practice (unconsolidated superficial deposits coding scheme in the RCS, used by Tony Irving for AAMI boreholes) has resolved both issues as several lithologies can be included in a lithology code (eg CS - sandy clay) and genuine second and third lithologies can also be included. This gives the modeller in GSI3D easy access to all the relevant lithological data. It greatly assists in decision making and enabled distinctions to be made between the sand and gravel units on sheet NS66SW.

For the final model, all the DJLO and AAMI borehole data were available giving excellent coverage of the sheet area. However, the limitations of the old coding system used for the DJLO boreholes were still a problem. Some of the borehole coding is contradictory, as discussed above, where adjacent boreholes clearly containing the same unit have different lithology codes (e.g. sand in one, gravel in the other). This problem goes back to the original borehole logging descriptions and cannot be avoided.

8.2 MODELLING

The initial pilot study model was a good first draft but in places it was difficult to distinguish between formations with only a single lithology. In particular, it was very difficult to distinguish between the Law and Gourrock formations and the Bridgeton, Broomhouse and Killearn formations. The best recourse in most cases was to refer to formation distribution maps in Browne and McMillan (1989). The original borehole logs were frequently referred to for more

information but 'sand' was often the only description available. The model will only be as good as the available data.

A high resolution DTM would resolve some of the minor problems in the final model and would also make modelling of made ground easier. A 5m Nextmap DTM is available but fitting the model to the new DTM must be done on a high specification machine.

The distribution of the borehole data is rather patchy. In places, sections could be drawn between boreholes just a few to tens of metres apart, whereas elsewhere, particularly in the Clyde valley, boreholes were sometimes more than 1 km apart. These 'sparse' areas can be modelled using 'helper sections'. Helper sections are also critical for the modelling of made ground.

The final model has used just a fraction of the total number of boreholes. If a client like Glasgow City Council asks for a model of a specific area, all the boreholes would need to be investigated and the data incorporated.

8.3 FEEDBACK TO BOREHOLE DATABASE

A lithostratigraphy was allocated to the boreholes in GSI3D in constructing the model for NS66SW. A means of entering this directly into the borehole database is necessary. In previous studies the modeller has also been the interpreter but not so in this study. To avoid numerous interpretations a method will be devised to add to the lithological interpretations.

8.4 HARDWARE/SOFTWARE

The GSI3D manual (Kessler et al., 2004) outlines the installation process for the software. A minimum 256 Ram, 700MHz and a good graphics card is necessary. Some difficulties were encountered early on with GSI3D in that the computers often crashed. Feedback from Prof. Sobisch and Jon Ford helped to resolve some of these problems.

During revision of the model, the machines generally worked smoothly. The GSI3D software was more user-friendly as a result of changes, the computers didn't crash and the models were quickly revised. A problem with the 3D window not working properly was resolved by loading a different java execute file (see section 6.1 in Kessler et al., 2004). Using dual monitors helped to speed the whole process up. It was best to close all other applications and when calculating models it may be best to use a high specification machine.

9 Uncertainty

The level of uncertainty of the model was not quantified during the study, a descriptive account is outlined below.

9.1 ALLOCATION OF FORMATION NAMES

The Wilderness Till and Paisley formations were allocated with a high degree of certainty as described above. As a result of good borehole control, the Bridgeton Formation was also modelled with quite a high degree of certainty, although it may extend farther east.

Sand and gravel units were harder to allocate based on lithology. The Law and Gourrock formations are reasonably well-constrained based on distribution maps in Browne and MacMillan (1989). The north-east sector of NS66SW is the area of most uncertainty. Here, the distinction between sands of the Bridgeton, Broomhouse, Ross and Killearn formations is unclear and subjective.

9.2 MODELLING

Basically, the greater the distance from a borehole, the greater the uncertainty. As a result, one area of uncertainty is the Clyde River valley floodplain itself where borehole coverage is low. However, the geology in the valley appears to be quite simple and consistent over distances of several kilometres thus compensating for the poor borehole coverage.

The deltaic deposits in the north-east part of NS66SW are the most poorly constrained. This area lacks the distinctive Paisley Formation which elsewhere acts as a useful marker horizon. Both the formation names and the contacts between formations are largely model-driven, by the assumptions about palaeoenvironments in Browne and McMillan (1989).

10 Conclusions and recommendations

- Staff can learn to use the GSI3D software, manipulate data and create a reasonable 3D model in just a few weeks showing how effective it is for quick user-friendly modelling. The GSI3D software was upgraded throughout the study as a result of feedback and the new features greatly improved efficiency for the revision of the model. Use of dual monitors is to be encouraged.
- Ten Best Practice documents have been produced to cover specific procedures not described in detail in the GSI3D manual (Kessler et al., 2004).
- Borehole coding by user AAMI using the Rock Classification Scheme was ongoing throughout the pilot study and was completed (for sheet NS66SW) before generation of the final model. The RCS system made correlation much easier in complex areas and was truly representative of the existing borehole data.
- As a result of field mapping and the study of selected key boreholes, Browne & McMillan (1989) erected a lithostratigraphy for the Glasgow area which was used as a 'generalised vertical section' for the 3D model. During modelling, lithologies in the boreholes were assigned formation names based on the lithostratigraphy, and criteria defined by Browne and MacMillan (1989). Glaciolacustrine deposits in the north-east quadrant of the map are contemporaneous with, and have been assigned to, the Ross Formation.
- Outcrops on NS66SW appear to represent the westernmost glaciolacustrine deposits that were associated with Lake Clydesdale. In addition, the sheet area may be the easternmost limit of the Bridgeton Formation.
- GSI3D is an excellent way to visualise subsurface geology and study tops and bases and relationships between units. The model has been particularly useful for visualising the Late Devensian sand and gravel deposits. The eastern limit of the Bridgeton Formation may occur on sheet NS66SW. Localised glaciolacustrine deposits, here assigned to the Ross Formation, appear to have been closely associated with the Broomhouse Formation.
- Since deposition of the Bridgeton Formation, the axis of the Clyde valley has migrated slightly southwards.
- GSI3D modelling makes clear where the interpretation is high or low confidence - enabling the geologist to deal more clearly and effectively with customers than would be possible with a conventional 2D map.

- A 5m DTM is preferable for modelling 5 x 5km or 10 x 10km squares but a high specification computer is then essential. The DTM may need spikes removing before modelling starts. Any boreholes that stand well above (or below) the DTM should be investigated and if necessary the DTM altered to fit.
- Cross sections through an area can be provided quickly showing any properties in the borehole database that the customer may require (e.g. lithology, hydrogeological properties etc).
- A formal stratigraphy can be added to some units in the borehole database for sheet NS66SW. In particular, the Wilderness Till and the Paisley formations are easily recognised on a lithological basis. Ideally the GSI3D modeller should be able to update the borehole database as they create a model, perhaps adding a measure of the uncertainty at the same time.
- More data could be added to the Borehole Geology database to enable the made ground to be sub-divided. Additional hydrogeological (eg water-strike) or geotechnical data may assist with the subdivision of the sands and gravels. In addition, the colour of units (if available) may be useful for correlation purposes.
- In terms of 'signing off' by senior management, the 'Analysis' version of GSI3D could be used, enabling the manager to cut synthetic sections and cubes from the model. By noting the grid reference of any problematic areas, the manager can return the model to the geologist for reconsideration as corrections.
- The model described in this report can be improved by a) fitting it to a corrected 5m NextMap DTM, b) checking the outlines of the new made ground polygons, c) improving some of the envelopes in the north east quadrant of the map where small spikes still exist.
- An essential task is to work out a detailed methodology for making changes to existing geological maps based on GSI3D modelling.

Appendix 1 Best Practice

The DGSM home page on the intranet holds the following relevant Best Practice documents:

BP/PREP/0022 Creating a .blg file in GSI3D in areas with vast quantities of data.

BP/PREP/0023 Queries for complex borehole data retrieval for GSI3D- Clyde Basin pilot study, Midland Valley DGSM.

BP/PREP/0017 Recording lithostratigraphical information from borehole data from the DGSM

BP/MODL/0026 Best Practice identified during the geological model building in the Sudbury TL83-84 (DGSM) and Ipswich TM14,24 (Land Survey) projects in Southern East Anglia.

Draft BP documents in: V:/(MHNTS9)/Lr/IGSN/CLYDE_BASIN/DATA/GSI3D_Best_Practice

BP 3 - Exporting to Arc Scene

BP 4 - Making video clips

BP 5 - DTMs

BP 6 - Drawing envelopes

BP 7 - Model iteration

BP 8 - Printing/figures from GSI3D

BP 9 - Rockhead models

BP10 - Drawing sections

Appendix 2 General information

INSTALLATION

Y:/Applications/NCApps/GSI3D

Install GSI3D by following the instructions in the manual (Kessler et al., 2004). GSI3D is mapped from the MH Y drive where it is updated daily with improvements and additions by H. Sobisch via Keyworth.

All data has been stored in the following folders

Version 1: V:/(MHNTS9)/Lr/IGSN/CLYDE_BASIN/DATA/GSI3D_NS66SW/Data.

Version 2: V:/(MHNTS9)/Lr/IGSN/CLYDE_BASIN/DATAGSI3D_NS66SW_V2/Data

Final model: V:/(MHNTS9)/Lr/IGSN/CLYDE_BASIN/DATA/NS66SW_Final/Data

The Clyde basin folder can be mapped to your PC hard drive to save time when loading data into the software.

Appendix 3 Team working

'When working on one model in a team it is important to note that GSI3D does NOT allow multiple concurrent edits to one file.

*Best Practice from recent projects has shown that it is advisable to assign different parts/sections of the model to different project staff. Everyone starts off with the same file (eg. MAN_SEC_V.1.0.gxml) and saves out personalised versions (eg. MAN_SEC_JFORD_V.1.0.gxml) throughout the day **only** editing sections assigned to them.*

After everyone has finished their sessions it is easy to sit down together, maybe with a projector, and compare the work carried out throughout the day.

Using the load sections function everyone's edited sections are loaded from their individual files back into GSI3D. After all sections are back in one project (check that the total number matches the total number of sections in the morning) a common file can be saved out (MAN_SEC_V.2.0.gxml), and is used as the start off file for the next morning.' - from Kessler et al. (2004)..

We followed the above practice naming each days master file MasterDATE.gxml and stored it in the NS66SWGSI3D folder.. We then copied the master file into separate personal folders ready to start work on the next day. As there is no undo button in GSI3D it was essential to keep a copy of the master file in GSI3D in case work had to be restarted during the day for any reason. The master files were deleted 2 working days after they were created in order to avoid a build up of unwanted files. This practice worked well and as long as we met once every day to combine sections working different hours wasn't a problem.

When it comes to creating envelopes, it is best to work one at a time, then changes to sections can be made as necessary. Much time can be saved by ensuring correlation lines on the sections do not stop outside pre-existing solid polygons (unless polygons need to be revised). Also by ensuring a regular distance between nodes on the correlation lines to denote continuous presence of a unit when constructing envelopes.

Appendix 4 Data files

BOREHOLE DATA

The Index file can be derived from SOBI.

nosh - no start heights

(The original files were NS66SWeditednosh.bid and NS66SWedited_hke.blg)

Boreholes with no start height can be hung from the DTM.

editednosh.bid

| | | | |
|--------------|--------|--------|------|
| NS66SW3359S2 | 261165 | 663745 | 0.02 |
| NS66SW353424 | 261910 | 664195 | 0.02 |
| NS66SW117325 | 263620 | 661860 | 2.3 |
| NS66SW117336 | 263630 | 661830 | 2.3 |
| NS66SW117321 | 263600 | 661860 | 2.7 |
| NS66SW117322 | 263600 | 661830 | 2.7 |
| NS66SW466747 | 263658 | 661821 | 3.32 |
| NS66SW5051 | 261210 | 664270 | 3.5 |
| NS66SW5052 | 261220 | 664210 | 3.5 |
| NS66SW5053 | 261210 | 664240 | 3.5 |

Must check that the first column of the .bid and .blg files are similar. For example check that there are no spaces between the borehole number and its suffix, if there are, these can be deleted in excel:

The original .blg file was divided to make two files, NS66SWDJLO.blg and NS66SWAAM.blg
NS66SWDJLO2.blg was edited to remove spaces in the borehole numbers column.

NS66SWDJLO2.blg

| | | | | |
|---------------|-------|--|---------|------|
| NS66SW155314 | 5 | | +<NSD | DJLO |
| NS66SW156. | 0.38 | | SOIL | DJLO |
| NS66SW156. | 2.67 | | SICLY | DJLO |
| NS66SW156. | 7.85 | | DMTN | DJLO |
| NS66SW156. | 2.06 | | SIST | DJLO |
| NS66SW156. | 10.19 | | UNKNOWN | DJLO |
| NS66SW15601M1 | 26 | | UNKNOWN | DJLO |
| NS66SW15601M1 | 6 | | +<NSD | DJLO |
| NS66SW15601M2 | 19 | | UNKNOWN | DJLO |
| NS66SW15601M2 | 5 | | +<NSD | DJLO |
| NS66SW15601M3 | 8 | | UNKNOWN | DJLO |
| NS66SW15601M3 | 4 | | +<NSD | DJLO |
| NS66SW157. | 0.38 | | SOIL | DJLO |

The original .blg file was divided to make two files, NS66SWDJLO.blg and NS66SWAAM.blg. NS66SWDJLO2.blg was edited to remove spaces in the borehole numbers column.

The .blg files are derived from the borehole geology database and borehole geology properties database. If using only the first lithology code (as shown above), only the borehole geology database needs to be queried using an SQL retrieval code as described in Best Practice document 1. In order to use lithology codes 2 and 3 or other properties from the borehole geology properties database (eg NS66SWDJLOprop which includes lithologies 2 and 3) a query builder can extract the data (see Best Practice document 2).

In the .blg table above, the blank column is referred to as column 0, the lithology code is in column 1, DJLO is column 2 etc.

GVS FILE

The gvs file is important because it gives the order of superposition of units, this is the basis of all the surface calculations in GSI3D. To draw a lens you must change the .gvs and .gleg files. In the .gvs file below, a sand and gravel lens has been included in the Wilderness Till (WITI). The baseline of the sand and gravel is called sagr and has a number (95) between the base of witi and the base of bill. The top is called sagrt and this intersects with the base of WITI.

If the project is exported to Arc8, the GVS should be fully attributed (see Kessler et al., 2004).

NS66SW_13_11_03.gvs

| | | |
|-----------|-----|-------|
| dtm_ns66s | 0 | DTM |
| mgr | 10 | MGR |
| p | 20 | P |
| law | 30 | LAW |
| karn | 40 | KARN |
| guf | 50 | GUF |
| pais | 60 | PAIS |
| bron | 70 | BRON |
| bhse | 80 | BHSE |
| bill | 90 | BILL |
| sagrt | 100 | SAGRT |
| sagr | 95 | SAGR |
| witi | 100 | WITI |

LEGEND FILE

The Legend file is essential for colouring/textures above the correlation lines and must show units in the same order as the gvs. Column 6 must show 255 for each unit, not 0 as shown below.

NS66SW_Legend.gleg

| | | | | | | |
|-------|---|-----|-----|-----|---|--------------------|
| MGR | made and worked ground and topsoil | 110 | 76 | 51 | 0 | TEXTURES/fillu.jpg |
| P | Peat | 218 | 174 | 116 | 0 | TEXTURES/P.jpg |
| LAW | Law Formation. Alluvium | 255 | 255 | 204 | 0 | TEXTURES/black.jpg |
| KARN | Killearn Formation. Raised marine sand and gravel. | 254 | 200 | 254 | 0 | TEXTURES/black.jpg |
| GUF | Gourock Formation | 254 | 200 | 254 | 0 | TEXTURES/black.jpg |
| PAIS | Paisley Formation. Raised marine clay and silt. | 204 | 255 | 204 | 0 | TEXTURES/black.jpg |
| BRON | Bridgeton Formation. Sand | 255 | 204 | 0 | 0 | TEXTURES/black.jpg |
| BHSE | Broomhouse Formation. Glacio-fluvial and lacustrine s | 254 | 200 | 254 | 0 | TEXTURES/black.jpg |
| BILL | Bellshill Formation. Plastic laminated clay. | 204 | 255 | 204 | 0 | TEXTURES/black.jpg |
| SAGRT | top of sand and gravel lens | 218 | 254 | 254 | 0 | TEXTURES/black.jpg |
| SAGR | Sand and gravel lens | 254 | 200 | 254 | 0 | TEXTURES/black.jpg |
| WITI | Wilderness Till. | 218 | 254 | 254 | 0 | TEXTURES/black.jpg |
| | | | | | | |

REVISED VERSION 1

Final180304.GXML

TINS180304.GXML

DATA FILES FOR VERSION 2

090704.gxml

090704TINS

NS66SW50New.asc

NS66SW_legend_V2.gleg

NS66SWApril2004.gvs

NS66Sweditednosh.bid

DJLOAAMI2.blg

DATA FILES FOR FINAL VERSION

300804final2.gxml

300804finalTINS.gxml

NS66SW50New.asc

NS66SW_legend_Aug.gleg

NS66SWAug2004.gvs

NS66Sweditednosh.bid

DJLOAAMI2.blg

A number of files have been compiled in order to add a 5m DTM to the existing model - these files are in

V:/(MHNTS9)/Lr/IGSN/CLYDE_BASIN/DATA/GSI3D_NS66SW_final/5mDTM_model

Appendix 5 Loading data**LOAD DEM**

V:\CLYDE_BASIN\DATA\GSI3D_NS66SW_final\data\NS66SW50New.asc

(High resolution files give the best results but can slow GSI3D down - best to turn them off if possible).

Tick the DTM box and change other parameters as required.

There is also a file of rockhead Clydebasin/NS66SWrh/ns66swrhfromev.asc based on map drawn by Browne and McMillan.

LOAD POLYGONS

V:\CLYDE_BASIN\DATA\10kmaps\Superficial deposits\glasgow_Drift_Geology.shp
10kmaps\Superficial deposits\glasgow_Artificial_Geology.shp
LEX better than LEX ROCK

Highlight the grid that the shape file should be attached to (eg artificial with DTM; solid with rockhead), then arrows will be displayed in section window showing where geological units meet that surface.

Making artificial geology transparent (0.5) aids viewing

LOAD BOREHOLES

Index (SOBI) (.bid) and log (.blg) files:

V:\CLYDE_BASIN\DATA\GSI3D_NS66SW_final\Data\NS66SWeditednosh.bid
NS66SWDJLO2.blg

ctrl A highlights all boreholes, then append.

LOAD GVS

V:\CLYDE_BASIN\DATA\GSI3D_NS66SW_final\Data\NS66SWAug2004.gvs

LOAD LEGEND

V:\CLYDE_BASIN\DATA\GSI3D_NS66SW_final\Data\NS66SW_legend_Aug.gleg

LOAD SECTIONS

V:\CLYDE_BASIN\DATA\GSI3D_NS66SW_final\Data\300804final2.gxml.gxml

LOAD BOUNDARIES (ENVELOPES)

V:\CLYDE_BASIN\DATA\GSI3D_NS66SW_final\Data\300804final2.gxml

Sometimes this box shrinks when you click on the units to be loaded - simply expand the box to stop this effect.

LOAD BOUNDARIES (TINS)

V:\CLYDE_BASIN\DATA\GSI3D_NS66SW_final\Data\300804finalTINS.gxml

Appendix 6 Windows in GSI3D

MAP WINDOW

Double click on GSI3D icon in index of each window.

Click on maps and bring Artificial geology to front by right clicking on the filename, make it transparent using 'Properties'.

Boreholes shown as black, or green if over a certain depth (red boreholes are unuseable)- can change colours in properties (right click on .bid file in index of map window).

To show section lines clearly, make shape files transparent using properties.

SECTION WINDOW

To see colours above correlation lines: right click in window and click on properties. Change correlation fields to 1.

To show the DTM and the model correlation lines: right click in window, properties, and click on 'lines' in 'model field'.

To see arrows where section crosses geology polygons: need 2 sections, click the 2nd section on and off, arrows should now show in both sections. If not check that the LEX and DTM are linked in the shape file property box (in toc of map window).

BOREHOLE VIEWER

Click on tools, then borehole viewer.

To see boreholes in colour: Right click in the window and give correct number to properties file (usually 1) this will vary depending on the borehole data file. Column 1 is usually lithostrat, other columns can be added as required (up to 4 properties).

Appendix 7 Metadata and Quality control

Metadata and QC documents for the initial model, the revised model and the final model can be found in

V:\ism\DGSM\PopulationProjects\MidlandValley\DraftArea\draftqcspreadsheets\NS66SWfinalqc2_1.xls and will shortly be transferred to the intranet based DGSM database.

References

Most of the references listed below are held in the Library of the British Geological Survey at Keyworth, Nottingham. Copies of the references may be purchased from the Library subject to the current copyright legislation.

BROWNE, M.A.E, FORSYTH, I. H. AND McMILLAN, A. A. 1986. Glasgow, a case study in urban geology. Journal of the Geological Society, London, 143, 509-520.

BROWNE, M.A.E, AND MCMILLAN, A. A. 1989. Quaternary Geology of the Clyde Valley, British Geological Survey Research Report SA/89/1 Offshore Geology Series

BROWNE, M.A.E, AND MCMILLAN, A. A. 1989. Geology for land use planning: Drift deposits of the Clyde valley. Volume 1: Planning report. British Geological Survey Technical Report WA/89/78.

BROWNE, M.A.E, AND MCMILLAN, A. A. 1989 Geology for land use planning: Drift deposits of the Clyde valley. Volume 2: Details of procedure and technical data. Technical Report WA/89/78.

BROWNE, M.A.E, AND MCMILLAN, A. A. 1989 Geology for land use planning: Drift deposits of the Clyde valley. Volume 3: Thematic Maps. Technical Report WA/89/78.

KESSLER, H., MATHERS, S. & SOBISCHE, H. GSI3D, 2004, The software and methodology to build systematic near-surface 3D geological models, British Geological Survey Internal Report, IR/04/029. 97pp.

MCMILLAN, A. A. AND BROWNE, M. A. E. 1989. Fold basins in Late Devensian glacial marine sediments at Shieldhall, Glasgow. Scottish Journal of Geology, 25 (3), 295-305.
Glasgow Memoir

Best practice document 1 - project folder
Best practice document 2 - project folder
Best practice document 3 - project folder
Best practice document 4 - project folder
Best practice document 5 - project folder
Best practice document 6 - project folder
Best practice document 7 - project folder
Best practice document 8 - project folder
Best practice document 9 - project folder
Best practice document 10 - project folder