Use of 3D visualisation techniques to identify minimal impact sand and gravel extraction sites

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In the UK a high proportion of land-won sand and gravel is extracted from sub-alluvial gravels and river terrace gravels located within river valleys. However, extraction from deposits of this type is increasingly proving to be less acceptable. Quarries within river valleys often have a high visual impact and the cumulative impact of these operations in close proximity to each other can be high (figure 1). River valley operations are almost always restored to open water. Whilst these may be attractive for nature conservation and provide leisure activities, they can also have a serious impact on the natural hydrology of the flood plain. Wet restoration of quarries located close to airports or airfields can also lead to concerns regarding increased risk of bird strike on aircraft. The Civil Aviation Authority recently suggested that an exclusion zone of 13 km be applied around all airports and airfields to reduce the potential for bird strikes on aircraft. This action is likely to have a serious impact on the availability of potential sand and gravel extraction sites in river valleys.

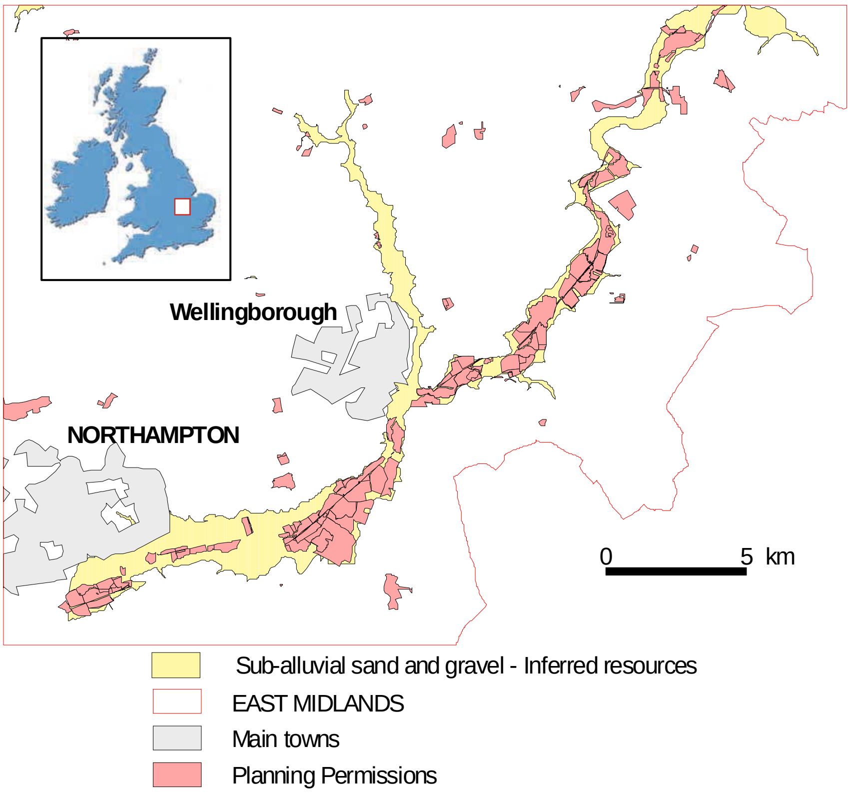

Figure 1. Location of sand and gravel planning permissions in the River Nene, east Midlands region, UK.

The increasing need for more affordable housing across Britain, especially in the south-east England region, will undoubtedly place more strain on existing sand and gravel operations. There is likely to be an increase in pressure to locate new resources when existing quarries become depleted. It is therefore important for planning authorities to be aware of all sand and gravel resources within their region, and to follow the principal of sustainable development by prevention of resource sterilisation by other forms of development, and by encouraging selection of sites with minimal environmental impact.

These factors are leading to an increasing need to locate alternative sources of sand and gravel. In the English Midlands and Eastern England one alternative is glacially derived sand and gravel deposits. These were laid down in thick sheets during and immediately after glacial episodes. Remnant glacial sand and gravel deposits now occur within thick till sequences that cover the interfluve, or plateau areas between river valleys, in the Midlands of Eastern England. Their sporadic occurrence within glacial till makes them difficult to locate and assess. Existing geological mapping of superficial deposits does not give an accurate representation of subsurface resources of sand and gravel, and this is one reason why these deposits have been neglected in the past.

Knowledge of the location, thickness, and quality of glacial sand and gravel deposits is crucial in determining future sites for extraction in the Midlands of Eastern England. Three-dimensional (3D) imaging is a way of visualising these resources in a way that two-dimensional maps have never been able to capture. In recent years the emergence of new technology, national digital datasets and more powerful computers has enabled sub-surface geology to be visualised in 3D so that exploration and extraction of unexposed sand and gravel bodies can be planned more efficiently and in the least environmentally sensitive areas.

Background

The ability to visualise in three-dimensions is an essential skill for the interpretation of geological data. The understanding of geological problems has always required a degree of 3D geological understanding. For a long time the only tools available for the analysis and representation of data have been 2-dimensional. Better comprehension of geological processes, advances in modelling, and availability of more powerful computing tools, have now allowed geologists to confidently tackle problems in 3D.

Recently there has been increasing demand for more detailed information of the shallow sub-surface, dominated in many parts of the UK by Quaternary deposits and artificial ground. The relative paucity of data and the relative disorder of deposits at shallow depth have however frequently led to this requirement being largely ignored. In response to this, the BGS has begun to demonstrate the feasibility of producing systematic 3D geological models of the near-surface using a software tool and methodology called GSI3D (Geological Surveying and Investigation in 3 Dimensions), developed over the last decade by Hans-Georg Sobisch of INSIGHT Geologische Softwaresysteme GmbH, initially in collaboration with the Lower

Saxony Geological Survey, (NLfB) and for the last 3 years with the BGS (Hinze et al 1999, Sobisch, 2000).

The BGS are using existing data (corporately held borehole information, digital geological linework and Digital Terrain Models (DTMs) within a modern geological modelling and visualisation package to produce 3D models that enable a clearer understanding of the subsurface environment. Unexposed sub-surface sand and gravel bodies can be located so that local authorities gain a greater understanding of where resources occur together with the location of environmentally sensitive areas. These models will help to ensure that resources are not sterilised by development and that carefully planned and sustainable quarry planning occurs to minimise the environmental impact of their activities.

Introduction to GSI3D

GSI3D is one of a suite of software tools and methodologies that enable the construction of 3D geological models. Like other geological modelling packages such as Vulcan, Datamine, Surpac and Gemcom, GSI3D uses the same basic elements to produce a 3D geological map. These are:

1. A surface DTM
2. Geological linework
3. Coded borehole data

GSI3D utilises these elements to construct a 3D model that is produced following GSI3D's standard modelling procedure as summarised below (Kessler *et al.,* 2004).

Methodology

Initially, sections are manually constructed through the area based on borehole information. The boreholes in these sections and the outcrops-subcrops of units are correlated with each other by digitising points between the sections to produce a geological fence diagram of the area (Figure 2a-c). Each digitised point along the sections in the fence diagram is known as a node. Once the sections have been constructed and they have been correlated together into a fence diagram the actual 3D model itself is created. The software mathematically interpolates between these nodes along the sections and the limits of the units (the outcrop plus the subcrop). This produces a solid model comprised of a series of stacked triangulated objects (TINs) corresponding to each of the geological units present (Figure 2d-f). Each triangulated point contains the X, Y, and Z co-ordinate for each of the nodes.

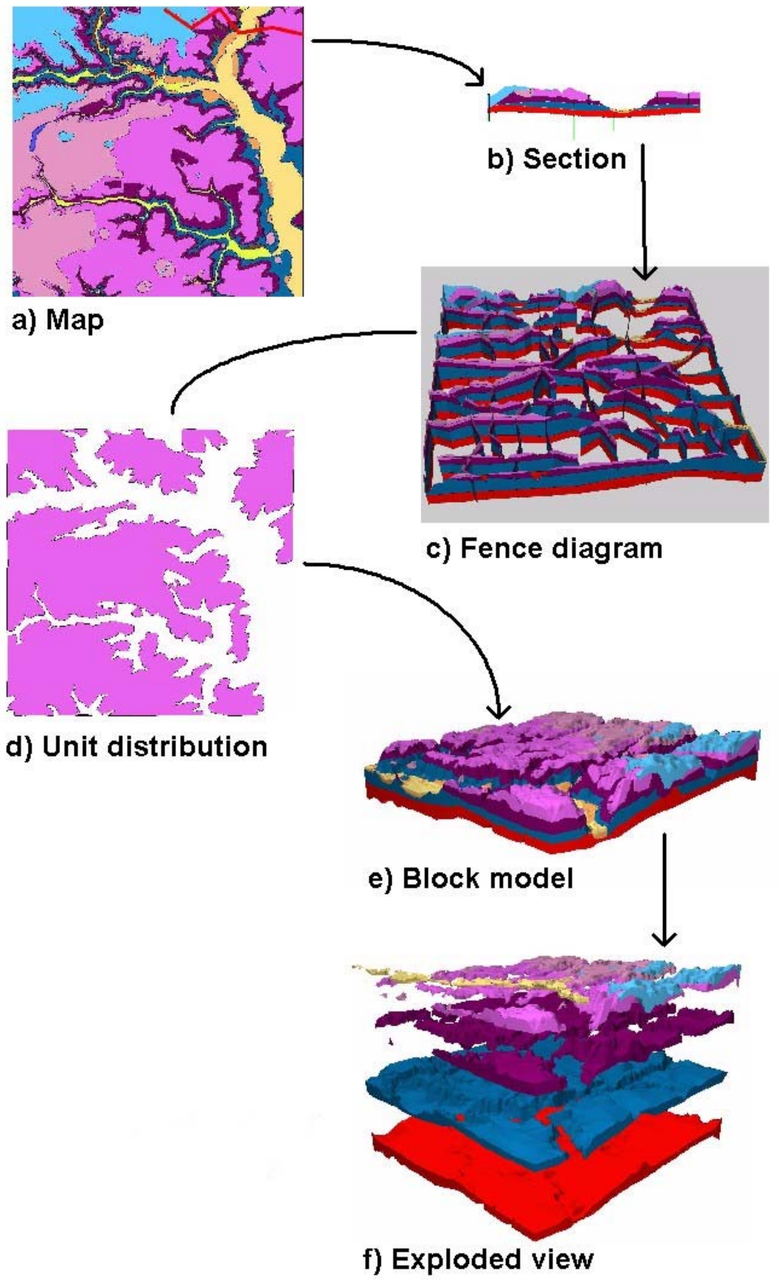

Figure 2. GSI3D workflow for producing 3-D models
Fig 2a Geological map of 1:25.000 sheet TM24, Woodbridge, Suffolk;
Fig 2b Geological section from TM24;
Fig 2c Geological fence diagram of TM24;
Fig 2d Distribution (outcrop plus subcrop) of Kesgrave Sand and Gravel deposit;
Fig. 2e Computed block model of TM24 viewed from the northeast
Fig. 2f Exploded detail of the block model revealing 3-D geometry of key units

GSI3D uses simple files compatible with a number of other software packages in creating the 3D models. Surfaces and elevation models are loaded as standard ASCII grid files (*.asc), and boreholes are loaded as tab separated format files from borehole databases. The file containing the lithostratigraphical relationships, known as the Generalized Vertical Section file (*.gvs), is also an ASCII format file. This file is crucial for the modelling process as it gives the order of superposition of units, and also has the ability to add lenses, intrusions and other features within the general lithostratigraphy. When the geologist has created the sections and envelopes of the units the calculated surfaces can be exported in a file essentially storing indexed TINs.

The 3D map is not automatically generated once boreholes have been loaded and requires lithologies to be correlated between user defined sections. The quality of the 3D model produced is therefore determined from several factors; the knowledge of the geologist using the software; the boreholes being accurately coded so that lithologies are recorded accurately; the lithological succession to the area being accurately known. The advantage of having user input into the creation of the 3D map is that should further information about an area be available (for example the drilling of more boreholes), the model can be easily updated with this new information without the need to redraw 2D paper sections as would have occurred in the past.

Models can be produced at a local (<1 km) or regional scale (>10 km) depending on the level of detail required and the information available (borehole coverage) to construct the sections. Once the models are constructed, automated sections can be placed over an area to visualize the lateral extent of units. The model can also be interrogated at any given point with an automated borehole prognosis for the site, in effect giving "virtual boreholes".

Once constructed, these models have many potential uses as well as being powerful visualization tools and they may be interrogated using GIS-based analytical tools to produce thematic and bespoke outputs. For example, the model can produce new thematic maps and domain maps, thickness plots, predicted boreholes and virtual sections according to specific requirements (Figure 3). The models also have the advantage of being instantly revisable as soon as new data becomes available, and because the models are generic rather than themed, they have many potential uses and users.

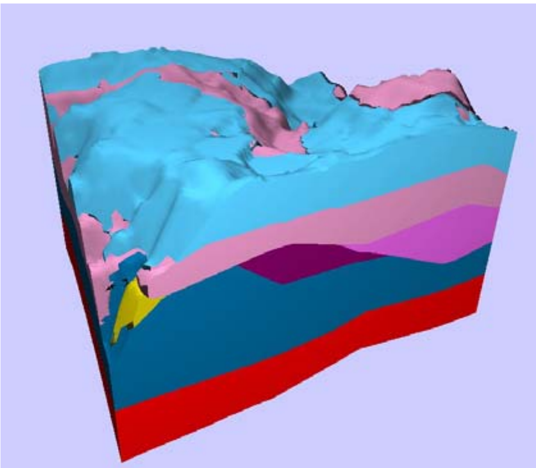

Figure 3. Solid visualisation of non-outcropping glacial units (in purple) intersected by boreholes.

Application of GSI3D for sand and gravel resource visualisation

During the 1970s and 1980s a large number of boreholes were drilled by the BGS Industrial Mineral Assessment Unit (IMAU) to assess the sand and gravel potential across the country (Figure 4). Boreholes were typically drilled at 1 km spacing where possible and were logged on site by geologists. The methodology of classifying the sand and gravel resources in these boreholes was based upon a ternary diagram created by the IMAU in consultation with the aggregate industry. A simplified version of this classification scheme was made in order to visualise sand and gravel in 3D (Figure 5). These maps are still used today and are important in identification of potential sand and gravel extraction sites. However, the main disadvantage of these maps is that they are fixed 2D representations of 3D sand and gravel bodies. They are also difficult to update when new sources of information become available.

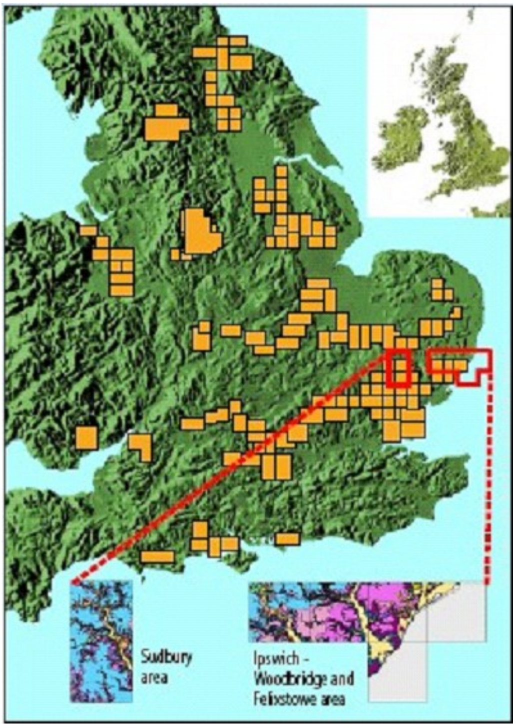

Figure 4. IMAU coverage (orange boxes) in England and Wales and some of the areas that have been modelled.

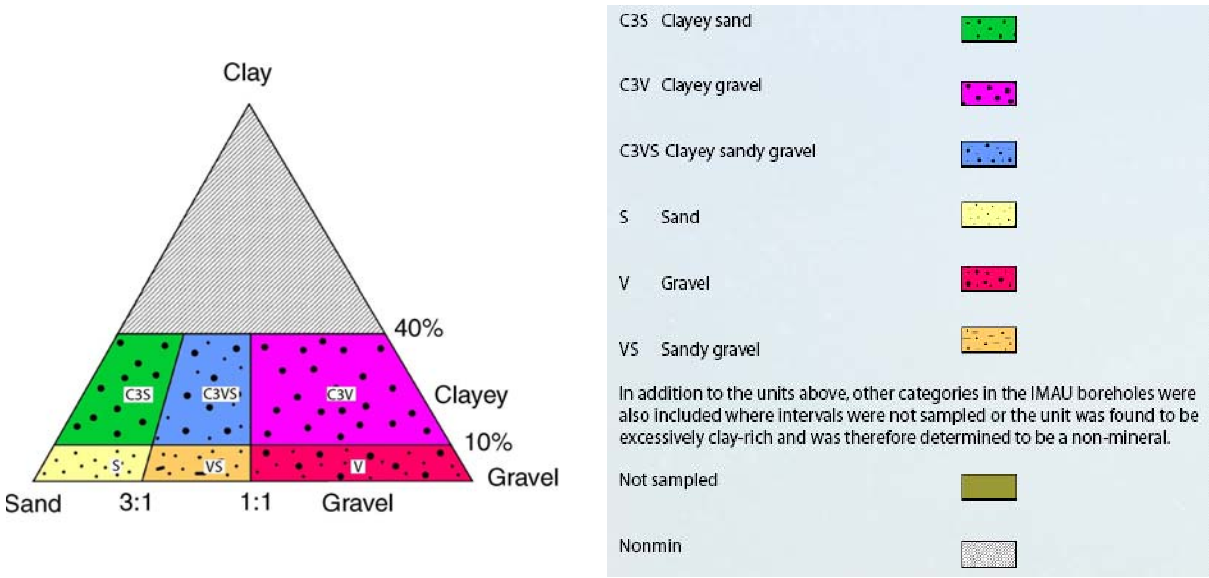

Figure 5. Ternary diagram of sand and gravel classification based on that used in IMAU reports.

The BGS has used these legacy boreholes, together with GSI3D, to produce a modern 3D representation of the near-surface geology in Southern East Anglia. This area was selected for modelling because extensive IMAU surveys were undertaken here. The region also contains important aggregate resources including fluvio-glacial Kesgrave Sands and Gravels (KSG), (also known as the Essex White Ballast). Sections were created and correlated to each other using the revised classification scheme in figure 5. The resource potential of the various stratigraphic units identified in this area was also modelled (Figure 6).

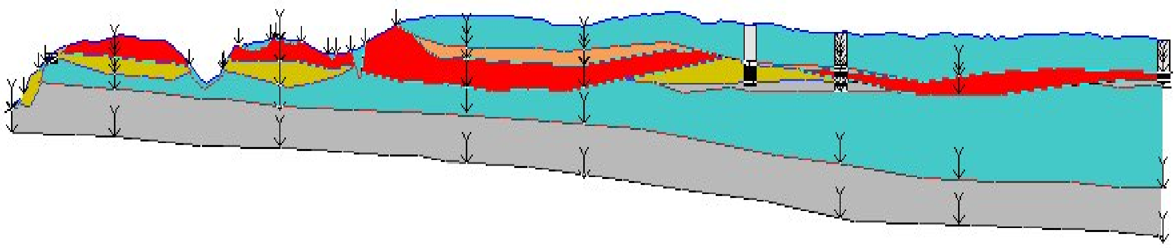

Figure 6. Section classified according to aggregate suitability. Red = Kesgrave sand and gravel (Very high aggregate suitability), Orange = Good aggregate suitability, Yellow/Brown = Moderate aggregate suitability, Blue = Low aggregate suitability, Grey = Not suitable for aggregate use.

The thickness of the KSG and overburden were contoured. These data were overlain on an Ordnance Survey topographic map (Figures 7 and 8). These GSI3D-derived maps are useful because they can be used to help plan sites of future sand and gravel extraction. Interfluves of areas containing the thickest concealed glacial sand and gravel deposits with the thinnest overburden can be identified that would normally be difficult or impossible to locate using conventional 2D maps. Environmental designations such as SSSIs or National Nature Reserves can also be loaded as polygons onto the map so that areas that may require special protection can be easily identified. In this way, preferred sites for sand and gravel extraction that are likely to have minimal environmental impact can be identified.

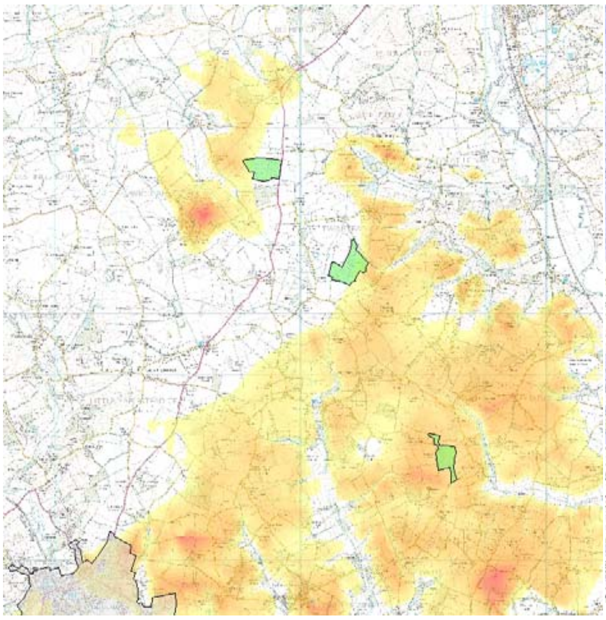

Figure 7. Contoured Kesgrave sand and gravel thickness plot overlain on topographic map sheet in the Sudbury area. The thickest sand and gravel deposits are coloured red, the thinnest pale yellow. Environmental designations are coloured green, sterilised urban areas are coloured grey.

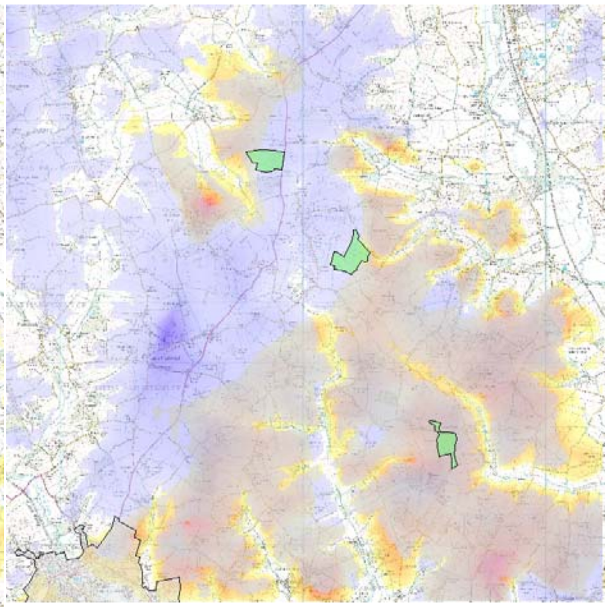

Figure 8. The same area in figure 6 with contoured overburden thickness plot overlain onto Kesgrave thickness plot. Thickest overburden is the darkest blue.

Following these successful trials in Southern East Anglia, the BGS is hoping to extend the coverage of its 3D modelling into other regions. It is hoped such models will prove a useful tool for the exploration of interfluvial glacial sand and gravel deposits. Increased knowledge of the location of these interfluves will help planning and licensing authorities make decisions on where the best locations for future sand and gravel operations occur. Areas containing the thickest glacial sand and gravel and the thinnest overburden are important for future sand and gravel extraction due to increasing pressure on river valley operations. Site selection using techniques such as GSI3D help identify these interfluves and promote the sustainable use of sand and gravel resources in the future.

Conclusions

- An increased demand for housing and other urban developments in south-east England means that there will be pressure on existing river valley aggregate operations.

- Aggregate operations concentrated in river valleys often have cumulative impacts on the environment and on floodplain hydrology.

- Glacial sand and gravel deposits are extensive over some areas of the eastern Midlands and south-east England, but until recently, these have been under-exploited due to the difficulty in locating the deposits.

- Existing 2D maps do not accurately represent the geometry and distribution of subsurface sand and gravel deposits.

- 3D modelling is useful for both planners and the aggregate industry to more confidently predict the location of these deposits.

- The quality of the models depends on accurate and consistent borehole coding. A model is not therefore a substitute for a lack of borehole coverage over an area.

- 3D models are easily revised when further borehole information becomes available. The ability to produce virtual sections and virtual boreholes makes them powerful visualisation packages.

- Overburden thicknesses and sand and gravel thicknesses may be contoured to produce maps showing the distribution of the thickest areas of aggregate together with the areas of minimal overburden.

- Knowledge of the location and distribution of sand and gravel deposits is essential to prevent sterilisation of these deposits by increasing urbanisation.

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