Why 3D? The Need For Solution Based Modeling In A National Geoscience Organization.

Ricky Terrington[a], Bruce Napier[a] Andy Howard[a], Jon Ford[a] and William Hatton[b]

[a]British Geological Survey, Kingsley Dunham Centre, Nicker Hill, Keyworth, Nottinghamshire, BG12 5GG
[b]SRK Consulting (UK) Limited, Floor 5, Churchill Way, Cardiff, CF10 2HH

Abstract. In recent years national geoscience organizations have increasingly utilized 3D model data as an output to the stakeholder community. Advances in both software and hardware have led to an increasing use of 3D depictions of geoscience data alongside the standard 2D data formats such as maps and GIS data. By characterizing geoscience data in 3D, knowledge transfer between geoscientists and stakeholders is improved as the mindset and thought processes are communicated more effectively in a 3D model than in a 2D flat file format. 3D models allow the user to understand the conceptual basis of the 2D data and aids the decision making process at local, regional and national scales. Some of these issues include foundation and engineering conditions, ground water vulnerability, aquifer recharge and flow, and resource extraction and storage. The British Geological Survey has established a mechanism and infrastructure through the Digital Geoscience Spatial Model Programme (DGSM) to produce these types of 3D geoscience outputs. This cyber-infrastructure not only allows good data and information management, it enables geoscientists to capture their know-how and implicit and tacit knowledge for their 3D interpretations. A user of this data will then have access to value-added information for the 3D dataset including the knowledge, approach, inferences, uncertainty, wider context and best practice acquired during the 3D interpretation. To complement this cyber-infrastructure, an immersive 3D Visualization Facility was constructed at the British Geological Survey offices in Keyworth, Nottingham and Edinburgh. These custom built facilities allow stereo projection of geoscience data, immersing the users and stakeholders in a wealth of 3D geological data. Successful uses of these facilities include collaborative 3D modeling, demonstrations to public stakeholders and Virtual Field Mapping Reconnaissance.

Keywords: 3D, Model, Geoscience, DGSM.
PACS: 01.10.Fv

WHY 3D? BACKGROUND

Geological survey organizations (GSOs) are established by most nations to provide a geoscience evidence base for effective decision-making on mitigating the impacts of natural hazards and global change, and on sustainable management of natural resources. The value of the evidence base as a national asset is continually enhanced by two-way transfer of knowledge between GSOs as data and information providers and the stakeholder community as knowledge ‘users and exploiters’.

Geological maps and associated narrative texts typically form the core of national geoscience evidence bases, but have some inherent limitations as methods of capturing and articulating knowledge. Much knowledge about the 3D spatial interpretation and its derivation and uncertainty, and the wider contextual value of the knowledge, remains intangible in the minds of the mapping geologist in implicit and tacit form.

To realize the value of these knowledge assets, the British Geological Survey (BGS) has established a workflow-based cyber-infrastructure to enhance its knowledge management capability. Future geoscience surveys in the BGS will contribute to a national, 3D digital evidence base on UK geology, with the associated implicit and tacit information captured as metadata, qualitative assessments of uncertainty, and documentation of best practice. This paper builds upon the work that was achieved under the Digital Geoscience Spatial Model and described in several papers since (Hatton and Napier, 2005; Smith *et al*. 2005.) In this paper the authors describe directly some of the results from this work that have solved direct problems in geoscience resource and engineering applications.

Evidence-based decision-making at all levels of society requires both the accessibility and reliability of knowledge to be enhanced in the grid-based world. Establishment of a cyber-infrastructures geoscience knowledge management and transfer will ensure that GSOs, as knowledge-based organizations, can make their contribution to this wider goal.

WHY 3D? IN A MODERN GEOSCIENCE KNOWLEDGE MANAGEMENT INFRASTRUCTURE

Geology is inherently a 3D science and geologists always have a 3 or even a 4 dimensional model in their mind, inevitably linked to temporal attributes as well as physical multi-dimensional attribution. BGS placed a large investment into creating the DGSM and is now realizing added value from a fully operational digital 3D modeling environment, where data models can be located, created, attributed and archived easily for future use in a consistent and systematic manner. The development of such a cyber-infrastructure for 3D modeling has now released more time for the geoscientist to think and solve problems for the end-user of these models. They can now focus on the model and science, rather than struggle with the mechanics of building information system requirements. This has resulted in many excellent examples of solution based models, rather than models just for the sake of creating 3D models themselves.

The components of the infrastructure were originally developed with separate, specific objectives in mind, but are gradually converging, through continual development, into an integrated knowledge management system with the following main objectives (cf. McCaffery *et al*. 2006):

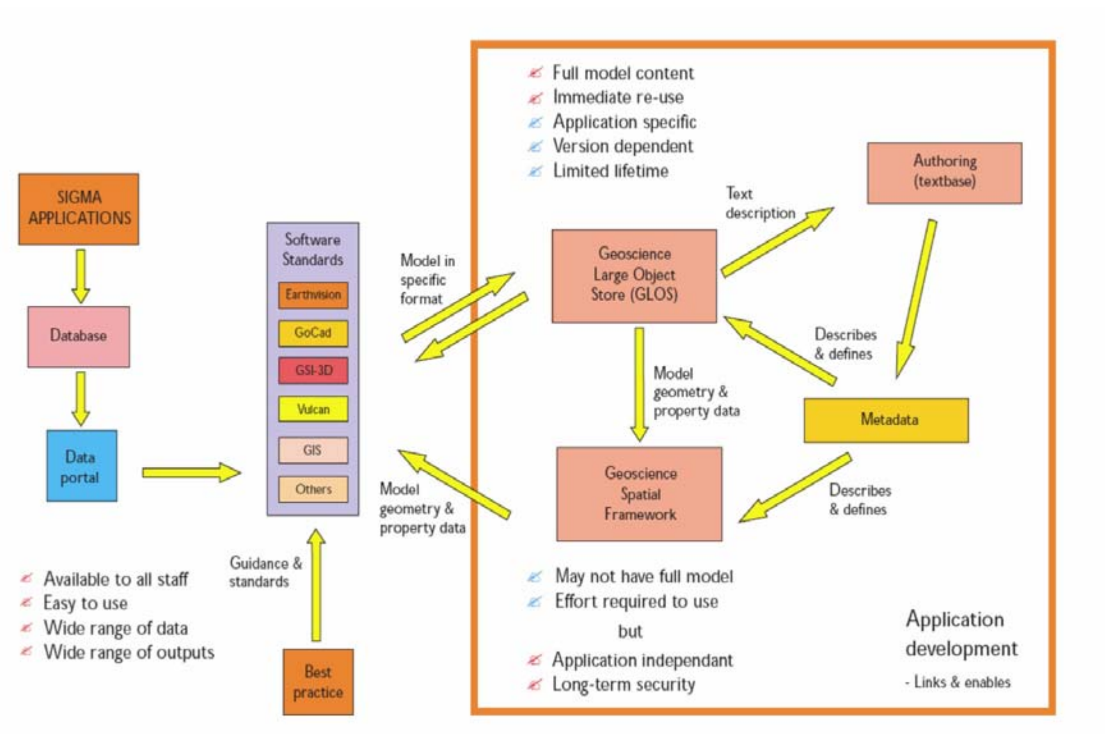
- Capture and communicate geologists' 3 and 4D perception of subsurface geology acquired by geological survey projects
- Ensure all data and knowledge is recorded using common, documented standards to promote wider interoperability and data and knowledge exchange
- Speed up the process of data and knowledge capture and delivery

- Ensure knowledge capture is carried out in the context of prior information, i.e. it builds on and augments prior information, without re-inventing it
- Ensure that the data and knowledge capture process is verifiable, repeatable and auditable
- Record a greater proportion of implicit knowledge
- Differentiate observation from interpretation, as far as practically possible
- Record and communicate the sources of information and uncertainty involved in the interpretation process.

The knowledge framework of the DGSM has 7 main components (Smith *et al*. 2005)

- Data portal
- Information and software standards
- Geoscience large object store
- Geoscience spatial framework
- Metadata
- Uncertainty
- Best practice

To draw the DGSM knowledge capture components together into a coherent system, a workflow based application has been developed that leads the user through the spatial modeling process, via a series of key steps (Fig. 1).



The flow of data through the DGSM framework.

FIGURE 1. Data Flows through the DGSM

These ensure contextual and timely capture of metadata, information about uncertainty and best practices. Checklists built into the workflow system enable repeatability and audit of the modeling and knowledge capture process. As population of the BGS 3D knowledge base proceeds, the technologies developed by DGSM will, with continual development, enable the BGS to offer a more comprehensive spatial interpretation, and users to obtain more relevant and accurate spatial knowledge.

WHY 3D? THE USE OF IMMERSIVE TECHNOLOGIES TO PROMOTE THE UNDERSTANDING OF 3D DATA

To augment and promote the work in the Digital Geoscience Spatial Model programme and 3D modeling at BGS, it was decided to install immersive 3D Visualization Facilities (i3DVF) at its Keyworth and Edinburgh offices in 2005 (Hatton *et al*. 2005). The installation provides a fully immersive modeling and viewing environment, using a single-channel active rear projection system splitting geoscientific images into left and right eye stereo channels. Large national datasets were acquired for the facility such as aerial photography and digital terrain models (NextMap) to complement existing datasets such as the Digital Geological Map of the UK (DigMap UK) and the extensive national borehole databases. This facility has three main functions:

1. Education and outreach through demonstrations to visitors
2. Collaborative 3D geological modeling
3. Landscape visualization

Using stereo projections of 3D data, the i3DVF further entices a geoscientist to impart their knowledge either to other geoscientists through collaborative research or to the stakeholder community through demonstrations. One area in which the 3D visualization facility has been successfully employed is through the integration of the Mobile Integrated Data Acquisition System (MIDAS) and the i3DVF. MIDAS is a tablet PC based system for the digital recording of geological data in the field, an eventual replacement for the field notebook and paper field-slip. MIDAS and the i3DVF have been combined into a single Virtual Field Reconnaissance (VFR) tool that allows geological surveyors to review mapping at local, regional and national scales (Napier *et al.* 2007). The system allows teams of geoscientists to survey an area of interest before commencing fieldwork, thus building an understanding of the terrain, combined with any existing interpretations. This initial assessment allows surveyors to effectively target fieldwork in areas where surveying is most required (Fig. 2). VFR is a highly extensible system, having also found practical uses overseas, in sea bed environments, and on planetary remote sensing data such as that available for Mars.

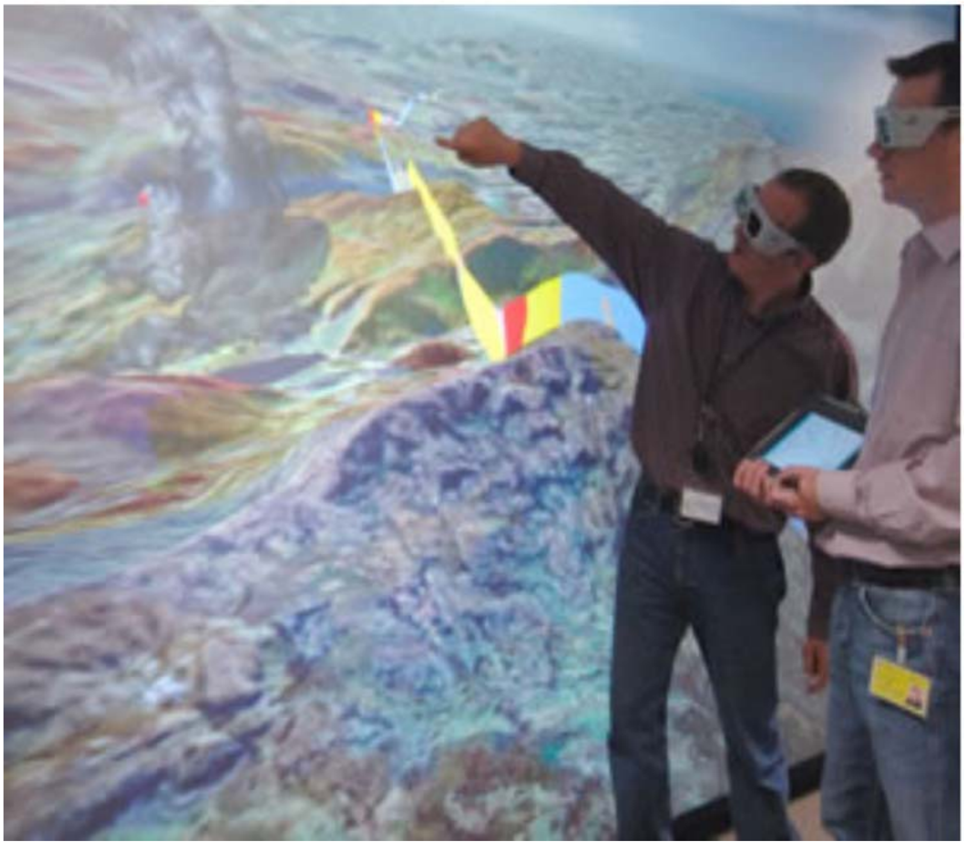


FIGURE 2. VFR in use in BGS' i3DVF
- Aerial Photography © UKP/Getmapping Licence No. UKP2006/01
- Based on NEXTMap Britain elevation data from Intermap Technologies

The following section gives examples of where the BGS have successfully created added value with solutions based around 3D models for both UK Government and commercial contracts using the DGSM protocols and outputs. These examples also show the vast range of scales that 3D models can be deployed and utilized in industry. These include regional scale studies of aquifers to site specific investigations of soil processes.

RECENT EXAMPLES TAKEN FROM THE DGSM – 3D GEOSCIENCE SOLUTIONS TO STAKEHOLDER PROBLEMS

In 2005, the Environment Agency of England and Wales (EA) initiated a project for the BGS to build a 3D geological model of the East Midlands Permo-Triassic aquifer system, for use in groundwater flow modeling. The BGS responded to this commercial request by producing a 3D geological model of the Sherwood Sandstone aquifer at 1:50 000 scale (Ford *et al*. 2007), highlighting the structure of the Triassic Sherwood Sandstone Group and its relationship to the underlying Permian succession (Fig. 3).

This work used DGSM modeling workflows to synthesize regional geological expertise and knowledge derived from a variety of baseline datasets including 2D seismic supplied by the UK Onshore Geophysical Library (UKOGL), boreholes, geological maps and mine information. The model covers an area extending from Nottingham to Doncaster (4000 km^2) to a depth of 1500m. The Sherwood Sandstone Aquifer project was one of the first to utilize the full DGSM workflow standards and best practice. The appropriate nomenclature was used, data was extracted from corporate sources and databases, and the derived 3D data was stored into corporate stores. The resulting model highlights a range of issues pertinent to effective groundwater management, such as the situation where the faulted juxtaposition of the Sherwood Sandstone Group against carbonate units in the Permian succession creates the potential for recharge or cross-contamination between aquifers.

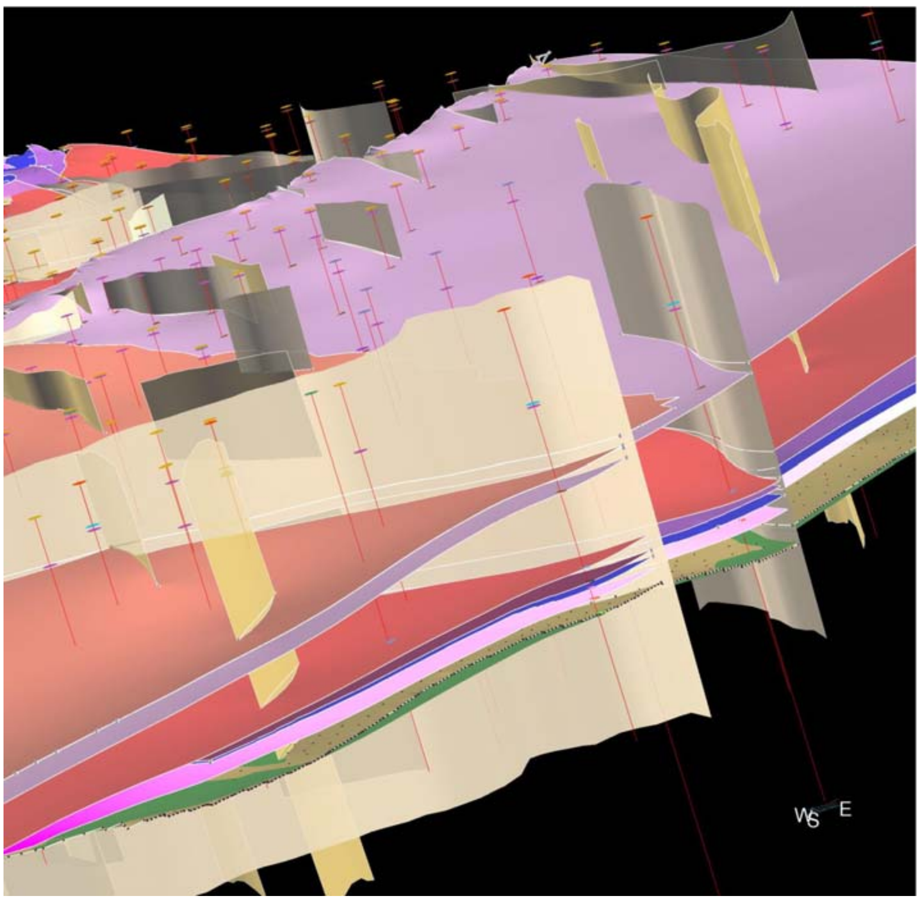


FIGURE 3. The Triassic Sherwood Sandstone Group of Yorkshire and the East Midlands (UK Environment Agency groundwater modeling project)

At a strategic scale, the BGS Thames Gateway project has modeled central and eastern parts of London covering an estimated area of 800 km2 using GSI3DTM software. These geological models have subsequently been attributed with hydrogeological and engineering properties. Figure 4 shows the Lower Lea Valley model from the Thames Gateway project, and comprises the site for the Olympic Park 2012 London games. The context provided by the attribution of the model provides information on water flow pathways, ground hazard ratings and potential foundation conditions.

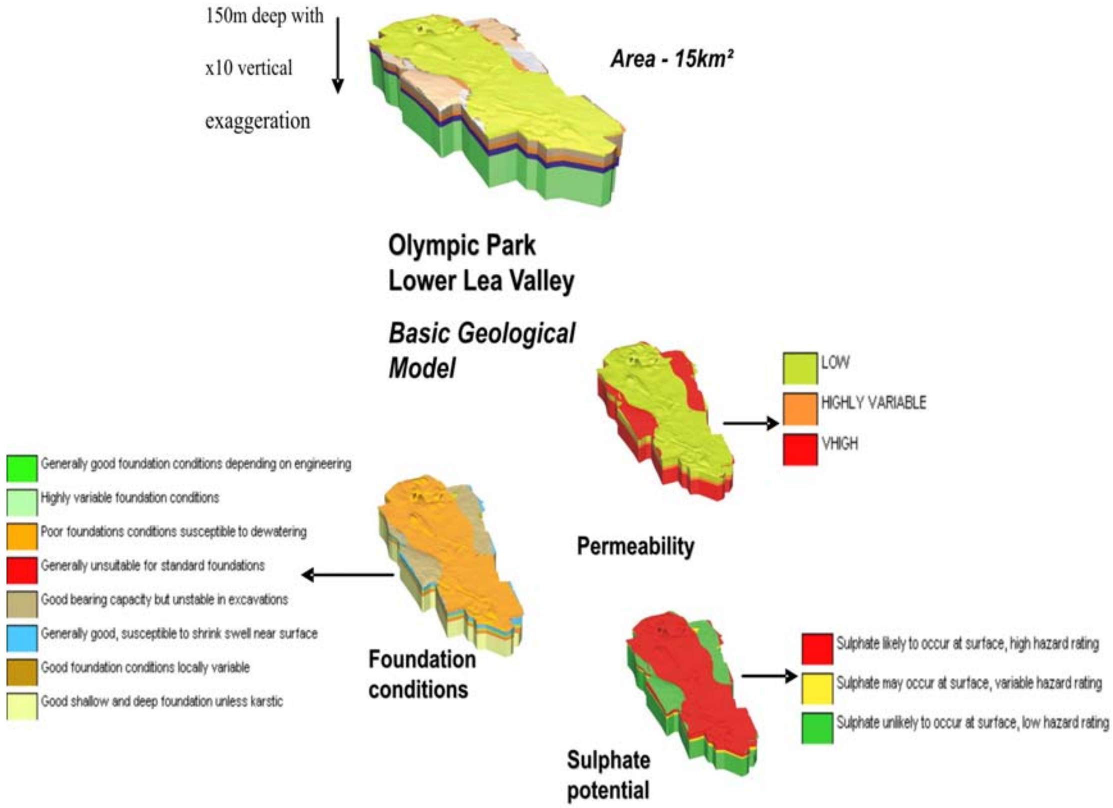


FIGURE 4. Geological Model of the Lower Lea Valley (Olympic Park London 2012) with permeability, foundation conditions and sulphate potential attribution

A comprehensive study of soil dynamics using various technologies has been conducted by the BGS in the Trent Valley at Shelford in Nottinghamshire (Smith et al 2007). These technologies include satellite and airborne remote sensing and geophysical surveys coupled with spatial/numerical analysis and observational data such as field information and associated measurements. These have been integrated in GSI3DTM software to provide 3D model outputs that have given new insights into soil processes such as erosion, contamination and surface run-off (Fig. 5).

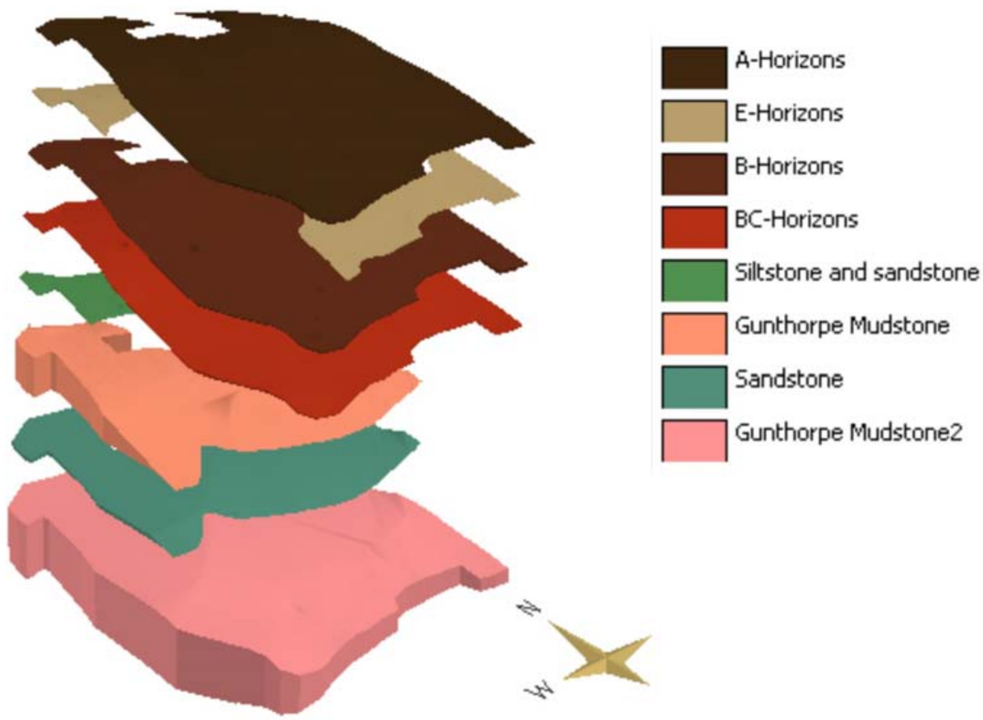


FIGURE 5. Exploded view of Shelford Model (2 km^2) showing different types of soil horizons above bedrock formations

CONCLUSIONS

- Assembling the national geoscientific evidence base, and transfer of its knowledge content to underpin decision-making, are key roles of national geoscience surveys. Effective knowledge management and transfer require not only good data and information management, but also an analysis of those 'missing' implicit and tacit knowledge assets that need new methods to capture and exploit. These include knowledge of the 3D geology, approach, inferences, uncertainty, wider context and best practice acquired during the process of geological mapping.

- A coherent and well-designed cyber-infrastructure, linked to a familiar workflow of core functions in the geological mapping and modeling process, together with software that enables the geologists to easily transfer their experience and know-how into 3D interpretations, enables capture of the key elements of this implicit and tacit knowledge.

- Immersive 3D technologies encourage knowledge exchange between specialists and non-specialists. Facilities with immersive technologies have successfully been employed for collaborative 3D geological modeling (Fig. 6) and for Virtual Field Mapping Reconnaissance.

FIGURE 6. Collaborative 3D modeling using Immersive 3D Visualization Facility

ACKNOWLEDGMENTS

We thank our many colleagues at the BGS who have been involved in the development, testing and deployment of the DGSM, especially Vic Loudon and Ian Smith. This paper is published with the permission of the Chief Executive Director of the British Geological Survey.

REFERENCES

1. W. Hatton, S. Henley and B Napier. Multi-dimensional modeling for the BGS – The DGSM @ 2005 and beyond. In : Proceedings of IAMG [International Association for Mathematical Geology] 2005: GIS and Spatial Analysis, Toronto, Canada, 2005, Vol.1, pp 255-260.
2. A. Howard, W. Hatton and F Reitsma. Developing a geoscience knowledge framework for a national geological survey organization. 2007. (Computers and Geoscience: under review)
3. K. J. W. McCaffery, R. R. Jones, R. E Holdsworth, R. W. Wilson, P. Clegg, J. Imber, N. Holliman, I. Trinks. Unlocking the spatial dimension: digital technologies and the future of geoscience fieldwork. Journal of the Geological Society, London, 2005. 162, 927-938.
4. B. Napier, W. Hatton, A.P. Connell, K. O'Connor. Visualisation and Interpretation of Large Datasets Using a Virtual Field Reconnaissance System. In: Proceedings of IAMG [International Association for Mathematical Geology] 2007 Geographical Information Systems and Geoinformatics, 2007, pp. 275-277.
5. I. F. Smith. (Ed). Digital Geoscience Spatial Model Project Final Report, British Geological Survey Occasional Publication No.9, British Geological Survey, Keyworth, UK. 2005. 56pp.
6. J. R. Ford, T. C. Pharaoh, B. Napier, C. Vincent, A. H. Cooper and M. Shepley. 3D geology as a decision support tool for groundwater management: a LithoFrame50 model of the Permo-Triassic of the British Midlands. British Geological Survey, Keyworth, UK. 2007.
7. B. Smith, H. Kessler, A. Scheib, A. J. Brown, S. E. Brown, R. C. Palmer, O. Kuras, C. Scheib. C. J. Jordan. "Chapter 16: 3D Modelling of Geology and Soils – A case Study from the UK" in Digital Soil mapping with Limited Data, edited by A. E. Hartemink, A. B. McBratney and M. L. Mendonca-Santos. Amsterdam, Elsevier. 2007.