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Pan-European Geological Data Infrastructure

D 3.4

Technical requirements for serving 3D geological models - OR/14/072

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Contents

1 Introduction to Work Package Task 3.4

This task considers the technical requirements for delivering and serving 3D geological models within Europe. It explores the types of data that can be exported from geological models, typical delivery solutions, technical requirements for delivery methods to external clients, and it reviews recent developments in European geological survey organisations (GSOs).

2 Introduction to 3D geological modelling

A 3D geological model is a stratigraphic framework that delineates geological boundaries in three-dimensions. Expertise in building and delivering geological models is world-leading within Europe. This expertise is mostly concentrated within geological surveys such as the surveys of the Netherlands, Denmark and Greenland, Britain and France, but there is also significant expertise in some universities such as Freiberg and Bonn in Germany and Nancy in France. The leaders in geological modelling within Europe are well-connected and meet biannually to compare methodologies and best practice. Whilst well-connected and aware of each other's activities, the approaches to geological modelling and delivery of geological models are highly diverse. This is a result of numerous factors for example, the geology of each country, the type and availability of geological data that underpins models, historical use of modelling systems, modelling expertise, governance and in one case, even legislation. The diversity means that geological modelling is performed using numerous systems and approaches that are very different. These approaches are described by Berg et al (2011) and can be briefly described as:

- Cross-section approach (GSI3D). This approach uses interpreted boreholes and maps, images, point data and digital terrain models to iteratively construct cross-sections and areal unit extents, akin to traditional methods of geological mapping. Surfaces are generated between manually digitised points.
- Surface interpolation approach (Gocad, Isatis and Move). Borehole, geophysical and surface observational data are interpreted stratigraphically to create picks that define geological boundaries. Surfaces are generated via interpolation between picks of identical stratigraphic coding using proprietary software algorithms.
- Statistical modelling approach. Geological models are generated by stochastically analysing geological data to predict the properties between data, e.g. borehole data. Typically, the output is a 3D grid. Petrel, SKUA, Isatis and Gocad all have capabilities to generate statistical geological models.
- Hybrid approaches. Many geological surveys use a combination of approaches and software tool in conjunction. GEUS (who are using GeoScene3D) are investigating "manual voxel modelling" where a statistically generated models can be iterated by Geologists (Jørgensen et al. 2013).

In most Geological Survey Organisations some combination of these methods will be used during a project and many use middleware such as FME (http://www.safe.com/fme/fme-technology/) is deployed to transfer datasets between software systems.

This Work Package explores the technical requirements necessary for delivering geological models in Europe. It considers the developments ongoing across Europe and considers how these could be developed and/or standardised to provide European-wide solutions.

The drivers for developing methodologies and standards to share 3D geological model data across Europe are the same as those for sharing geological map data (D3.2, D3.3). These drivers include facilitating the ability to make environmental decisions that have implications across national boundaries. Examples include:

- Disaster planning
- Minerals planning
- Flood risk
- Geological hazard assessment
- Aquifer management

As part of this Task, a survey was distributed to all European geological surveys. The survey was distributed at EGDI meetings and via the EuroGeoSurveys magazine and direct mailing lists. A total of 22 organisations responded, which included the majority of organisations with significant active 3D modelling projects. A further 23 surveys did not respond. Throughout this document the results of this survey are reported.

Table 1 Organisations who contributed to the statistics in this Work Package*

Organisations
Federal Institute for Geosciences and Natural Resources (BGR)
Geological Survey of Austria
Geological Survey of Slovenia
Geological Survey of Denmark and Greenland
Geological Survey of Ireland
Geological Survey of Finland
Geological Survey of the Netherlands
State Geological Institute of Dionýz Štúr (Slovakia)
Geological Survey of Norway
Geological Survey Baden-Württemberg
State Authority for Mining, Energy and Geology, Geological Survey of Lower Saxony (LBEG)
Polish Geological Institute - National Research Institute
Thuringian State Institute for Environment and Geology
Federal Office of Topography – Swiss Geological Survey
Hessisches Landesamt für Umwelt und Geologie (HLUG) (Hessian Agency for Environment and Geology)
Saxon State Office for Environment, Agriculture and Geology
Geologisches Landesamt Hamburg
Geological Survey of Bremen
Bavarian Environment Agency – Geological Survey
Geologischer Dienst NRW
Czech Geological Survey
British Geological Survey

* several German states responded independently

The options for the delivery of geological models varies greatly from static printed maps and sections to interactive stand-alone viewers and web-based systems, Chapter 5 examines all options for model delivery in detail and gives real examples from Geological Survey Organisations across Europe.

3 3D geological modelling in Europe

Systematic three-dimensional geological modelling in Europe began in the mid-90s. Since then expertise and methodologies have become sufficiently mature that a more systematic approach to modelling has become possible in some countries.

Notable projects and national modelling programmes include:

- The Geological Survey of the Netherlands (part of TNO http://www.en.geologicalsurvey.nl/) was the first European geological survey to create a national geological framework model, completed in the late 90s. Since then the TNO has moved systematically across the country producing a 3D property model of the shallow subsurface. The history and future of geological modelling at the Geological Survey of the Netherlands is documented by van der Meulen et al (2013).
- The GeoMol project (http://geomol.eu/home/index_html) is a transnational project to model the Alpine Foreland Basins for sustainable planning and use of natural resources. A major challenge for this project is the harmonisation of seismic interpretation methodologies, the agreement on common nomenclature, the sharing of models and data across borders as well as the delivery of models to make them useable. The project is managed by LfU (Bavarian Geological Survey) and has the following member countries:
  - Amt der Oberösterreichischen Landesregierung (LandOö)
  - Bayerisches Landesamt für Umwelt (LfU)
  - Bureau de Recherches Géologiques et Minières (BRGM)
  - Geologische Bundesanstalt Österreich (GBA)
  - Geološki zavod Slovenije (GeoZS)
  - Istituto Superiore per la Protezione e la Ricerca Ambientale (ISPRA)
  - Landesamt für Geologie, Rohstoffe und Bergbau Baden-Württemberg (LGRB)
  - Regionalverband Bodensee-Oberschwaben (RVBO)
  - Regione Emilia-Romagna, Servizio Geologico, Sismico e dei Suoli (RER-SGSS)
  - Regione Lombardia - Direzione Generale Territorio e Urbanistica (RLB)
  - Republique et Canton de Genève, Office de l'environnement (DSPE)
  - Schweizerisches Bundesamt für Energie (BfE)
  - Schweizerisches Bundesamt für Landestopografie (swisstopo)
  - Technische Universität Bergakademie Freiberg (TU BAF)

  A summary of the GeoMol project has been published by Gerold Diepolder (http://geomol.eu/home/technique/pdf_pool/Diepolder_GeoMol_Abstract_pag.pdf?lang=2).
- The British Geological Survey has recently completed GB3D a national bedrock fence diagram. The BGS is currently working towards a multi-scaled national geological block model. This will entail the combination and harmonisation of many regional and high resolution models. The GB3D methodology is written up by Mathers et al (2013) and the BGS modelling strategy and systems are described here:
  http://www.bgs.ac.uk/research/ukgeology/nationalGeologicalModel/home.html
  http://www.bgs.ac.uk/research/technologies_dmm.html
- The Geological Survey of Denmark (GEUS) is about to complete a 15 year project to map the countries aquifers using SkyTem technology. About 40% of the country has been mapped and 3D hydrostratigraphic models have been developed for these areas. The Survey is now planning to create a nationwide geological model using this data as well as geological maps and boreholes (Joergenson, 2013) (http://isgs.illinois.edu/sites/isgs/files/files/abstracts/Jrgensen.pdf)

- BRGM have a series of geological models across France and are beginning to develop a consistent model for France called the French Geological Reference Platform (http://www.brgm.eu/content/french-geological-reference-platform)
- On behalf of the Flemish government, Vision on Technology (VITO) has built a 3D geological model of Flanders. It is available from http://dov.vlaanderen.be.
- The Lower Saxony Geological Survey (LBEG) has created a 3D geological model called the Geotectonic Atlas of NW Germany and the German North Sea Sector (GTA3D) (http://www.lbeg.niedersachsen.de/portal/live.php?navigation_id=669&article_id=839&_psmand=4). It can be accessed via the webpages of the http://nibis.lbeg.de/cardomap3/?L-CUST-Schnitte=DOCKED
- Six nations (Belgium, Denmark, Germany, Poland, the Netherlands and the UK) collaborated to produce a geological model that informed the Southern Permian Basin Atlas. The project was sponsored by the petroleum industry and academia and aimed to systematically describe the onshore and offshore hydrocarbon-related geology, on a system by system basis. The output was a printed map but the images and maps were based on a single geological model, the digital outputs are available through a license (http://www.bgs.ac.uk/research/highlights/2011/spba.html)
- Twelve institutions and authorities collaborated on the Interreg IV Project (GeORG http://www.geopotenziale.org/home/index_html) to explore the geological potential of the deep Upper Rhine Graben. This has resulted in a structural and geothermal model of the Rheingraben, extensive documentation on the workflows has been published here http://www.geopotenziale.org/products/fta/pdf_pool/georg_fta_3_results_de.pdf?lang=1 and the model can be interrogated here http://maps.geopotenziale.eu/?app=georg&lang=en
- The H3O project focuses on the Roer Valley Graben that runs from Germany in a north-westerly direction over the central part of Limburg and the aim of the project is to make a cross-border, up-to-date, three-dimensional geological and hydrogeological model of the Quaternary and Tertiary deposits in the Limburg, Southeast Brabant and Flemish part of this region. http://www.bgr.bund.de/EN/Themen/Wasser/Veranstaltungen/workshop_ihme_2013/poster_13_vernes1.pdf?__blob=publicationFile&v=2
- Neftex is a UK based company that uses publically available data to create tectonic and stratigraphic framework for the entire world to support exploration industries. The models are based on sequence stratigraphy and are commercially available: http://www.neftex.com/solutions/earth-model/earth-model/europe

As shown above, the extent to which surveys have modelled the landmass is highly variable. Figure 1 indicates the scale of modelling being undertaken by organisations who responded to the survey in Europe. Almost all surveys questioned are undertaking regional-scale modelling, whilst some also focus on the local scale. Modelling at the national or multi-national scale is less common. Indeed, the multinational scale modelling in Figure 1 is the result of one project (GeoMol).

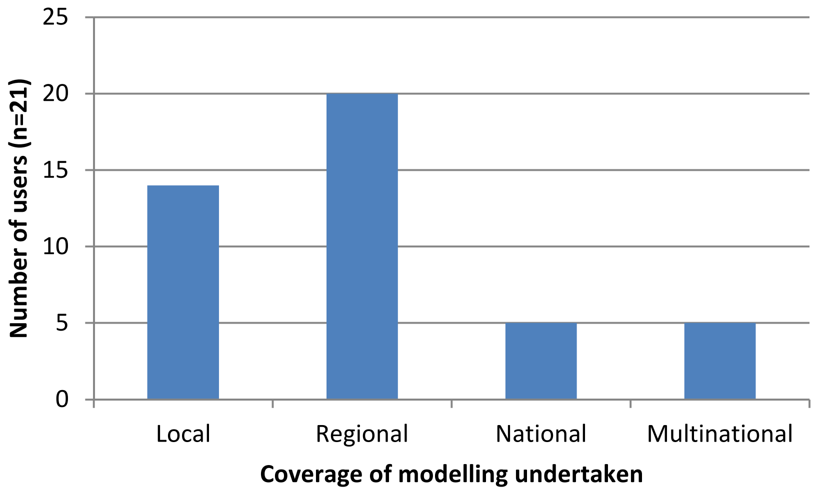

Figure 1. Coverage of modelling in 21 surveys questioned.

4 Types of 3D geological model data

Two types of geological model are considered here:

- Geological framework models, in which stratigraphic boundaries are denoted in space by surfaces.
- Voxel models, in which the 3D space is gridded (voxellated), with each cell or voxel having an attribute to describe the geology within that volume. Voxel models can be generated from geological framework models, or generated stochastically from lithological or geophysical data for example.

Both model types can also be property models; those in which the 3D space is attributed with geological properties. Such property attribution could be made to a bulk geometry in a geological framework model, or to individual cells in a voxel model. The latter is done either manually or via statistical methods.

In order to share the outputs from these models, the type and format of the data must be considered so that it can be viewed and loaded in a standardised way across Europe. This may appear to be a significant challenge because many different software packages are used to create models (Figure 2). However, homogenisation is still a long way off, as most proprietary software systems allow export of geological model data in a variety of standard formats. Such standard formats are listed in

Table 2; note that there is some differences in the standard exported outputs from framework and voxel models. The relative use of methodologies is indicated in Figure 3.

Table 2 Types of data exported from geological models and formats that are commonly in use.

		Type of models	
Type of data export	**Common formats**	**Framework models**	**Voxel/property models**
Maps	Shapefiles	Yes	Yes

2D cross-section linework	GOCAD P-line format, 2D/3D shapefiles	Yes	Uncommon
Surfaces	Triangular irregular networks Grids (ESRI, accii) Contours (.dxf/.shp)	Yes Yes Yes	Sometimes Yes Yes
Thickness grids	ASCII/ ESRI grids	Yes	Possible
3D shells	GOCAD s-grid	Yes	Yes
3D property grids	3D Ascii grid	No	Yes
CAD	dxf, dgn	Yes	Uncommon
Alternative proprietary software formats	Various	Sometimes	Sometimes

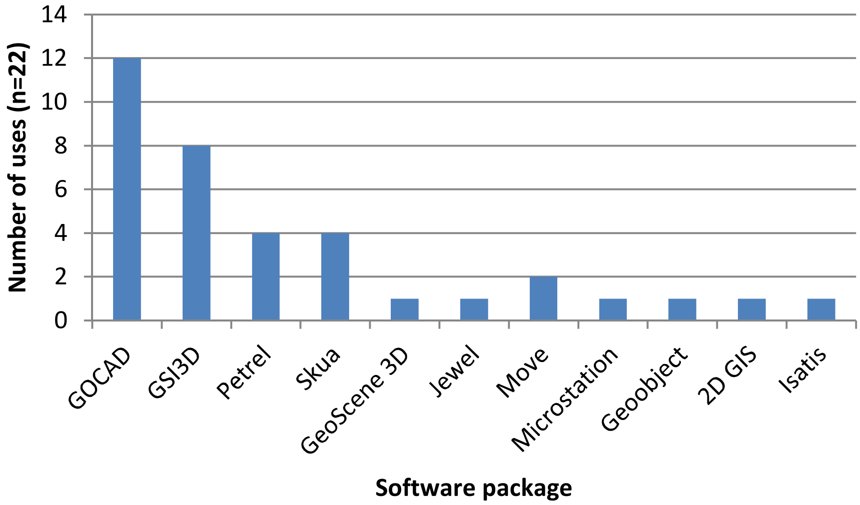

Figure 2 Geological modelling software packages used in Europe

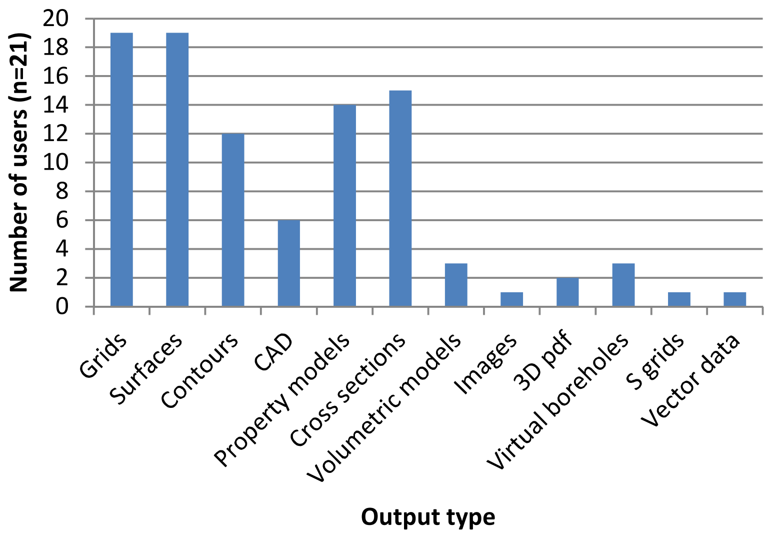

Figure 3 Formats of geological model outputs used in Europe

Whilst the formats and type of data exported from geological models is fairly standard, it is important that users understand the methodologies by which the original models were created. Each methodology has particular limitations that may affect the form of the final model. The respective modelling methodologies are described in extensive detail in the literature (Mallet, 2002; Kessler et al, 2009, Norden & Frykman 2013) only a few prominent differences in the approaches are listed here:

- GOCAD
  - Mathematical interpolation between known data points. Additional interpretative input varies depending on modellers expertise and resources
- GSI3D
  - Explicit modelling methodology requiring modeller to interpret geology in cross sections and areal unit extents, strongly guided by the modelling geologist.
- Petrel
  - Predominantly based on statistical methodologies, principle format is a geo-cellular 3D grid (voxels)

In addition to geological model data, each model should therefore have a metadata report that explains the data used to create the model, the area covered, stratigraphic complexity, intended use, lineage, revisions, digital terrain model resolution and name, limitations and information about the geological context of the model.

Around one-third of models in Europe are also accompanied by uncertainty information. Because geological models are often derived numerically through the use of algorithms to generate geological surfaces, or to populate voxel cells with parameters, it is important that the relative certainty on the resulting model is known. The type of certainty information provided depends on the modelling methodology employed.

5 Current methods for delivering geological model data

5.1 Overview

The data exported from geological models can be shared in the standard formats discussed in Section 4. Commonly however, geological models are shared in other ways to facilitate viewing or analysis of the data. Table 3 highlights some of the methodologies currently being used by surveys to deliver 3D geological models.

Table 3. Methods of delivery being used by European surveys

Synthetic sections, boreholes, slices (images and contour plots)
Standalone interactive viewers
PDFs (2D and 3D)
Web portals (2D)
Web portals (3D)
Mobile apps

Whilst geological models are inherently three-dimensional, it is commonly 2D outputs that are most useful for decision making. This is largely because understanding the detail in a 3D model is challenging and geologists have traditionally used, and are comfortable with, 2D cross sections and maps. Many of the delivery approaches therefore use a combination of both 2D and 3D methods for delivery. The main approaches being used in Europe are described below.

5.2 Synthetic Sections and boreholes

Almost all geological modelling software packages allow the export of synthetic cross sections and boreholes from models. For delivery purposes, these outputs can be simply saved as images in standard formats (e.g. Figure 4). It may be helpful if such images are georeferenced, but they are typically just inserted into reports.

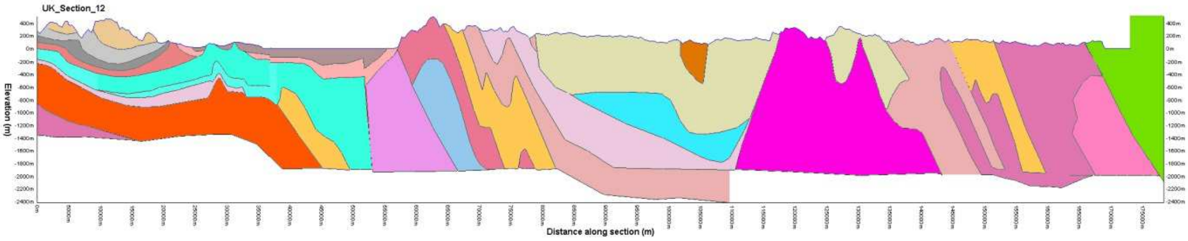

Figure 4 Output from the BGS GB3D cross section diagram as a jpeg.

5.3 Desktop interactive viewers

Users of geological models often do not have the proprietary software within which the geological models were originally created, but they may still wish to benefit from the visualisation and analysis capabilities of the software. For this reason, a number of desk-top interactive viewers have been developed, which allow model analysis, but not model building or editing. These viewers are sometimes provided by software companies and a charge is made for their use. Sometimes this charge is paid by the survey that created the model, with the data being encrypted within the viewer to prevent unauthorised use of the viewer with other model data. Such viewers allow the user to view maps and 3D visualisations of the model, and generate cross sections, horizontal slices and boreholes. Examples of these viewers include the INSIGHT GmbH Subsurface Viewer, which is used by Flanders GSO and TNO (Figure 6). The British Geological Survey use a similar viewer, also supplied by INSIGHT GmbH and a specialist software, GeoVisionary (http://www.virtalis.com/geovisionary/). The latter allows the integration of very large volumes of data from multiple sources, allowing a greater understanding of diverse spatial datasets (Figure 5).

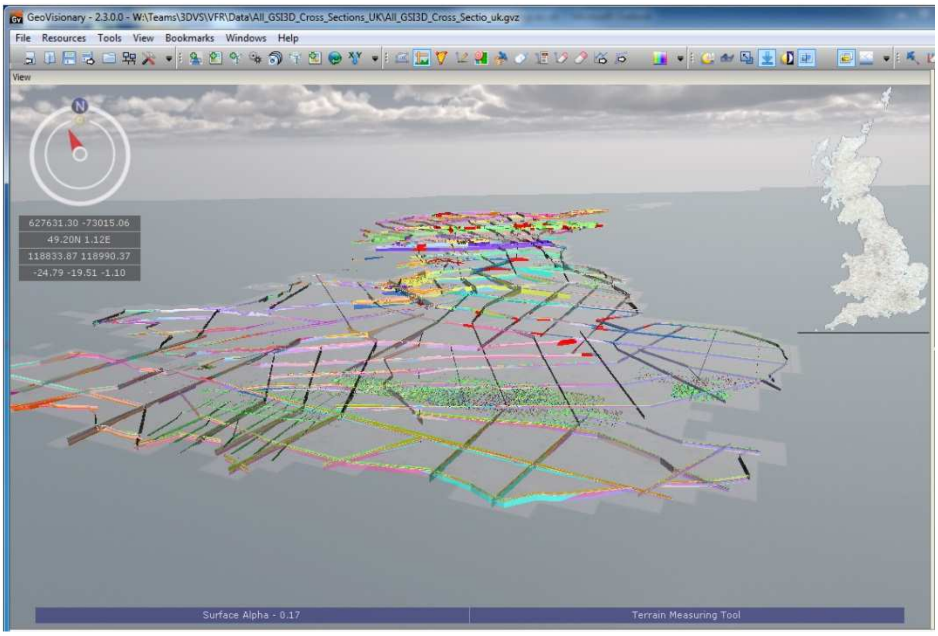

Figure 5 The BGS National Bedrock Fence Diagram in Geovisionary

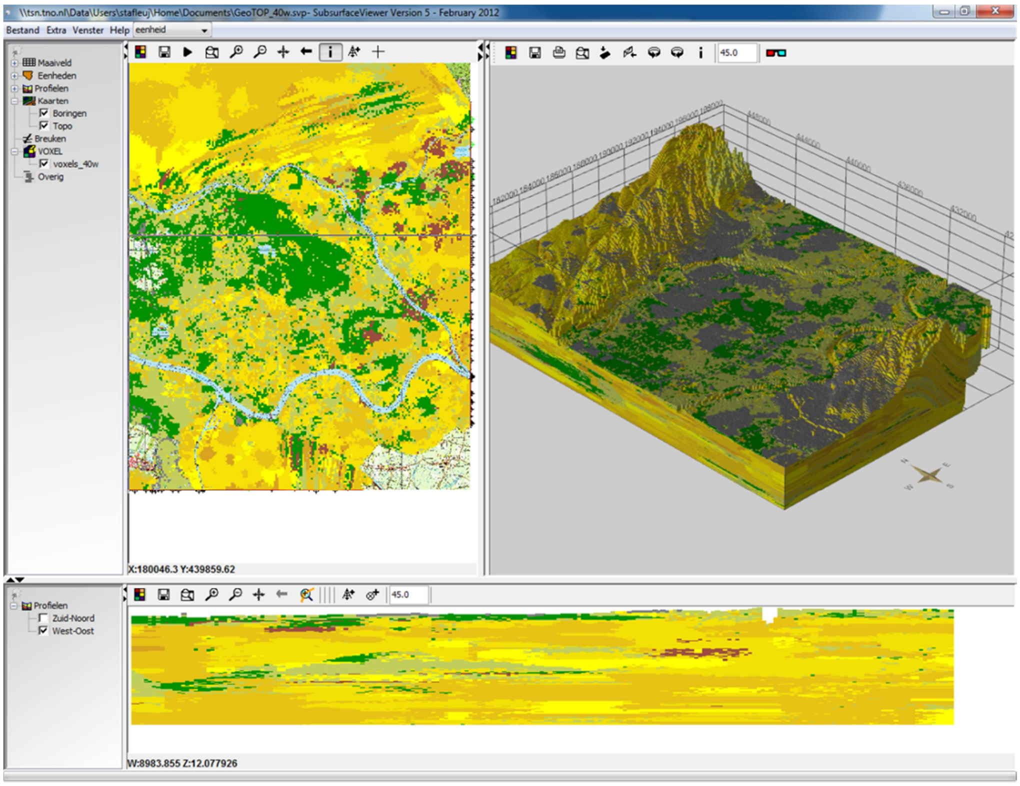

Figure 6 Subsurface viewer used by TNO, showing map (upper left), vertical cross section (bottom) and 3D view (upper right).

A number of free desktop interactive viewers are also available, for example [ParaView]() (Figure **8**) and [Geocando](). In addition, Google Earth can display 3D data(Figure 7), however it doesn't represent the subsurface with true Z-coordinates.

Figure 7 GB3D – The BGS fence diagram in Google Earth

Whilst free interactive viewers are good; they often have too much functionality, which novices find confusing. Paraview is an open source software and can be customised for geological purposes. An example is GVS, Groundwater Visualisation Software (http://www.qut.edu.au/research/research-projects/groundwater-systems-research) shown in Figure 9 (Queensland University of Technology in Brisbane, Australia).

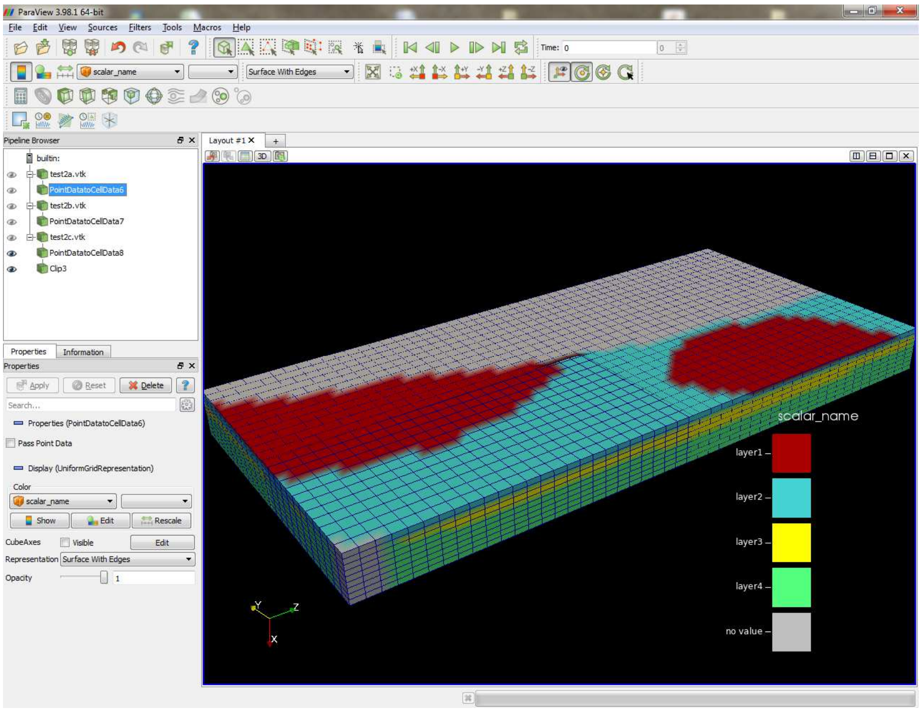

Figure 8. A voxel model in ParaView

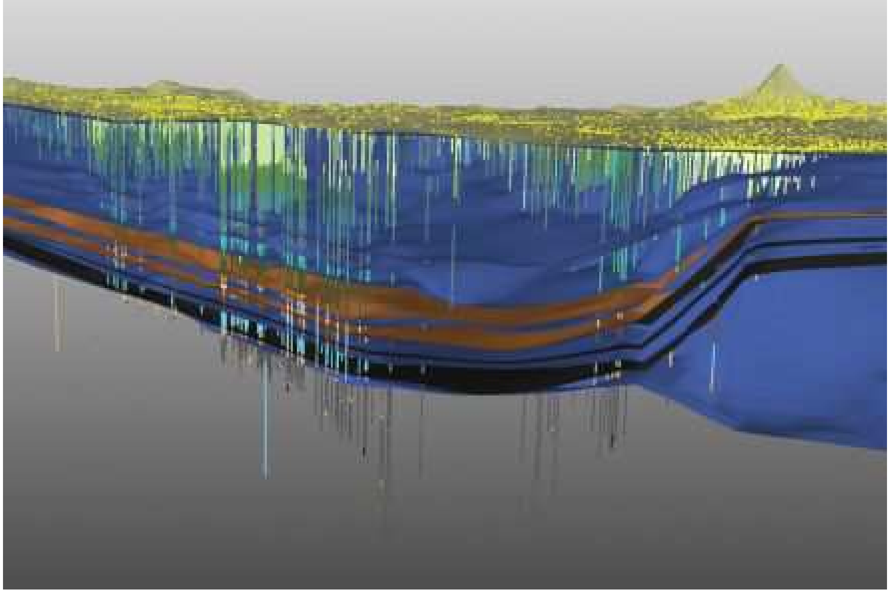

Figure 9 A 3D model vied in GVS (Groundwater Visualisation System), a customised version of Paraview

5.4 PDFs

PDFs allow the user to interact with models in 3D. They do not enable the user to generate sections and other realisations from the model, but pre-set outputs can be incorporated within the document for users to view. This method of delivery is particularly suitable for educational and marketing purposes, as they are easily deployable and can be customised to include text.

Examples are available from LBEG http://nibis.lbeg.de/cardomap3/?TH=3DPDF and BGS http://www.bgs.ac.uk/research/ukgeology/assyntCulmination.html.

5.5 Web portals

Web portals provide access to, and analysis of, 3D geological models online without the need to download software. Almost half of the surveys questioned in the survey have access to such a portal. Portals vary in sophistication from allowing purely 2D visualisations (e.g. cross sections) to be generated from a map interface, to allowing both 3D visualisation and query functions. The 2D and 3D viewers currently in use are described below.

Web portals (2D)

- Groundhog viewer

The Groundhog viewer provides a 2D map interface from where cross sections (Figure 10), horizontal slices and synthetic boreholes can be generated. The viewer queries binary grid files derived from the 3D geological model.

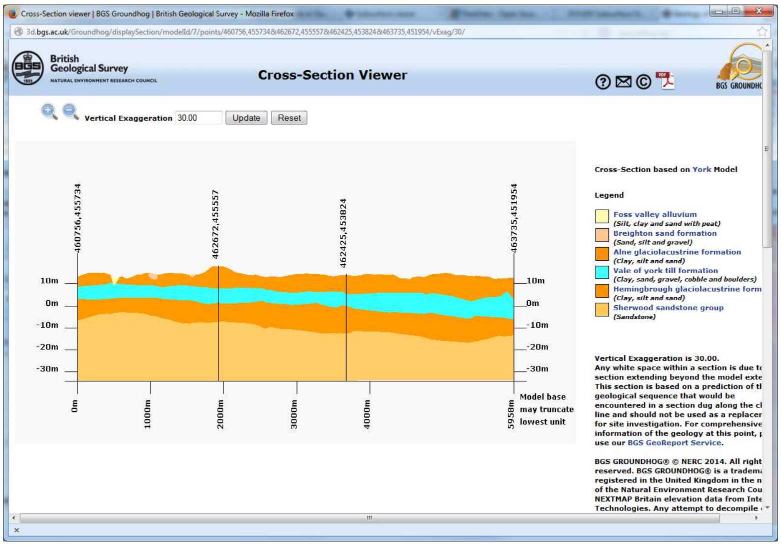

Figure 10 Export from the Groundhog viewer

- [TNO](TNO)

TNO models are disseminated through the DINO-portal (www.dinoloket.nl) in a number of ways, including in an online map viewer with the option to create virtual boreholes and vertical cross-sections through the models, and as a series of downloadable GIS products. The 3D geological models are downloaded as pre-processed geo-referenced items directly from a document management system as a series of grids in case of a layer-based model. Depth and thickness maps can be viewed directly online calling a map server. The virtual boreholes and vertical cross-sections are visualized through a Java-based sampler and renderer, developed by TNO. For fast sampling these 3D models are internally stored in netCDF format. (http://en.wikipedia.org/wiki/NetCDF)

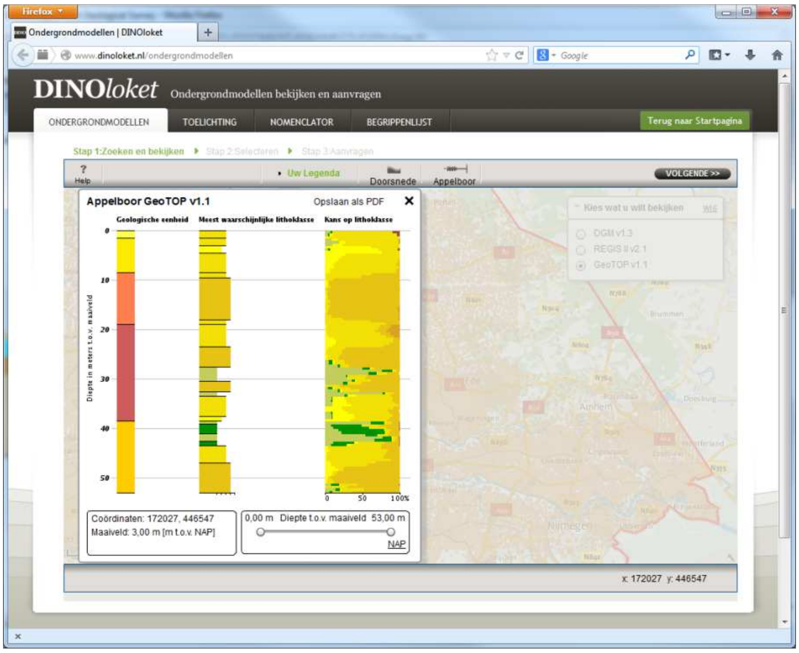

Figure 11 The DINOloket web portal showing a virtual borehole through a voxel property-model.

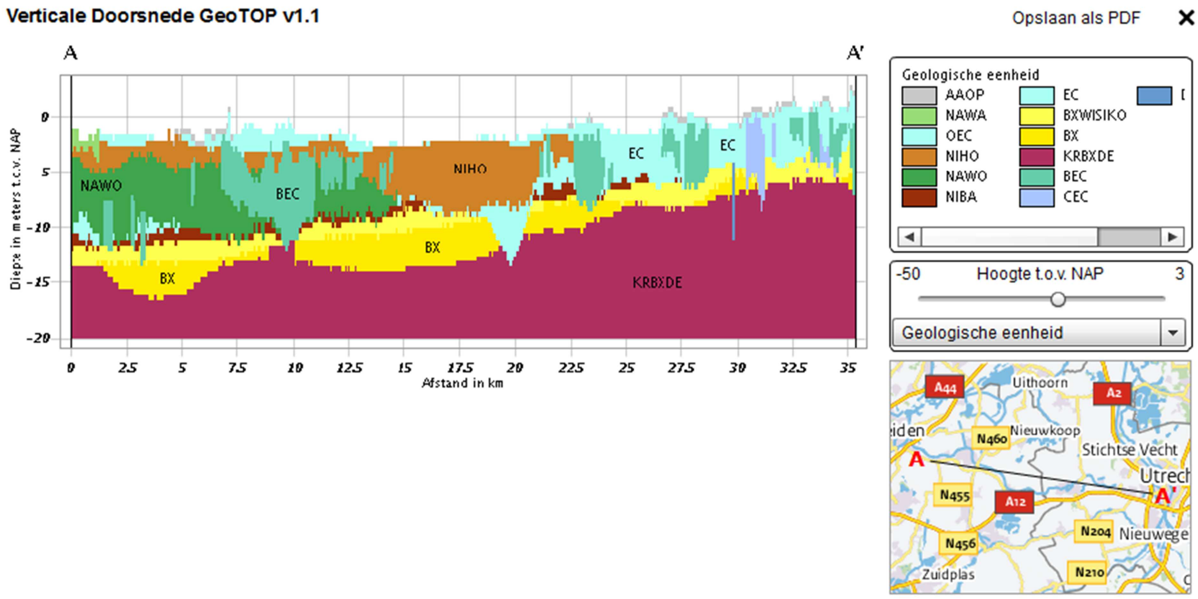

Figure 12 Vertical cross-section through GeoTOP using the DINOloket web viewer

- North West German Tectonic Atlas

The State Geological Survey of Lower Saxony in Germany (LBEG) has served the North West German Tectonic Atlas via their internet portal. The application enables synthetic sections and borehole prognoses to be generated. Figure 13 shows a cross-section within the portal. Note that the section displays lines and not coloured panels, which is because the underlying model comprises individual surfaces and is not a spatially complete model stack. Such information is important to convey by linework attributes or in the metadata.

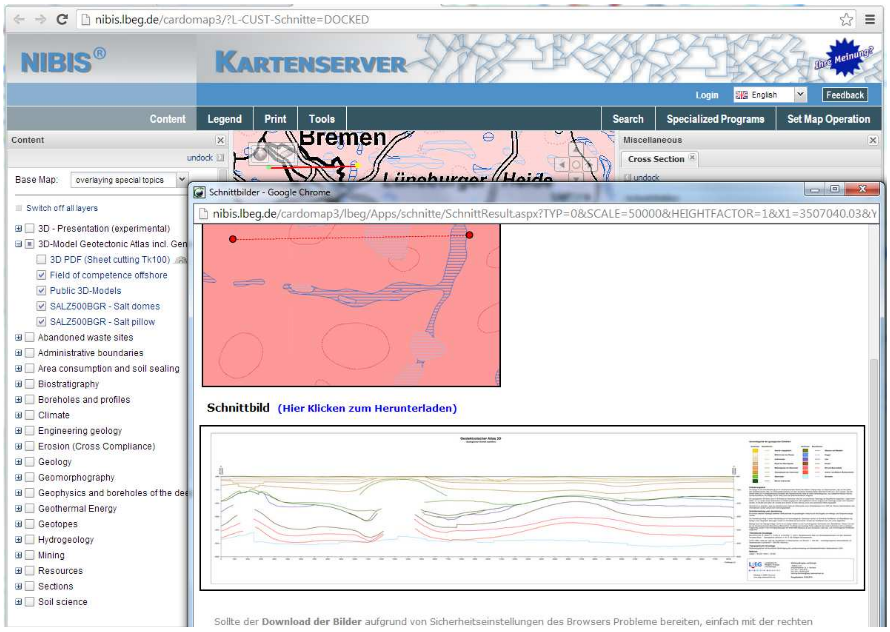

Figure 13 North West German Tectonic Atlas served through Kartenserver

- GeORG Project

The geological models created as part of the GeORG project are served as grids and are accessible via a web portal. The data portal (Figure 15 and 15) allows the user to specify vertical and horizontal sections. The GeORG section view also displays the isotherms of a 3D temperature model and is currently the only viewer known in Europe that accesses and displays results from a property model in conjunction with the geology. The horizontal slice (Figure 14) displays how well the model is constructed, as the fault network displays sensible structures in a randomly chosen slice – something that is not trivial to achieve.

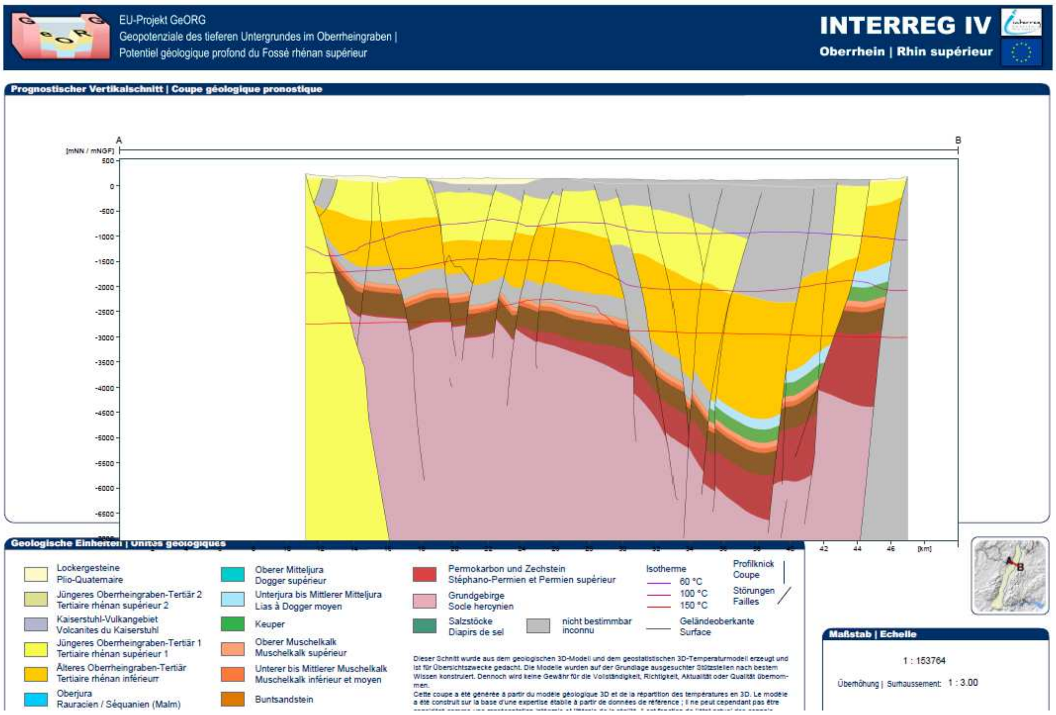

Figure 14 The GeORG project portal – vertical section including isotherms derived from a 3D Temperature model

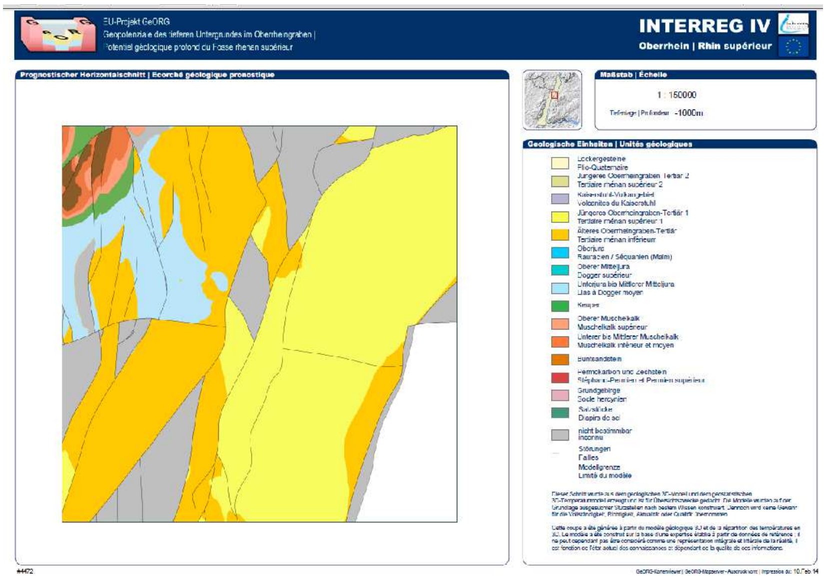

Figure 15 The GeORG project portal – horizontal section

Web portals (3D)

There are three projects in Europe investigating and developing 3D web portals.

Examples of 3D web portals include:

- GeoMol

The [GeoMol viewer](#) is developed by [Giga](#) using WebGL technology. It allows points, lines, triangulated surfaces and tetrahedron networks to be displayed directly in a web browser. http://tu-freiberg.de/fakult3/IS4GEO/gOcad2011.pdf The GeoMol project is described in section 3 of this report.

- [Brandenburg 3D modelling project](#)

The Brandenburg 3D viewer (Figure 16) also uses WebGL technology and displays TINS, lines and points within a web browser. It uses x3dom technology.

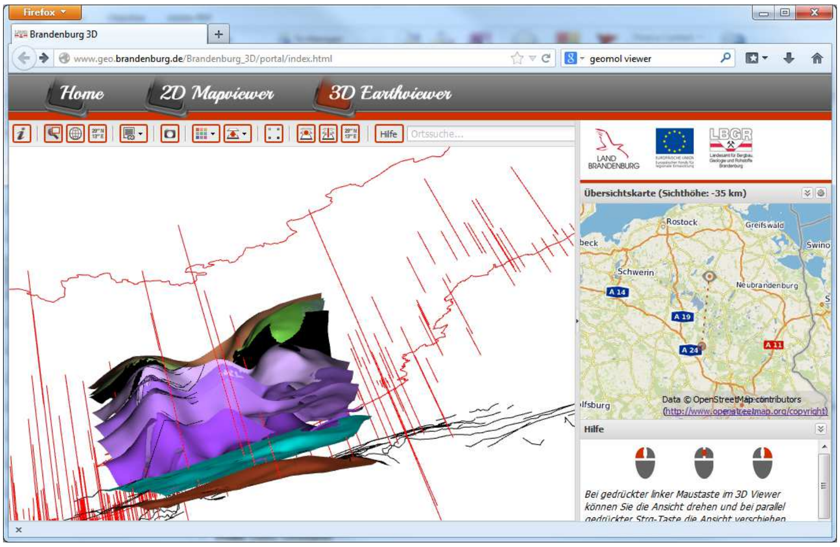

Figure 16 Brandenburg viewer

- [The EarthServer Initiative](#)

EarthServer is an EU funded initiative that attempts to establish open access and ad-hoc analytics on extreme-size Earth Science data. The BGS has developed one of the EarthServer's lighthouse applications serving a geological model from Glasgow (UK) using WebGL technology (Figure 17).

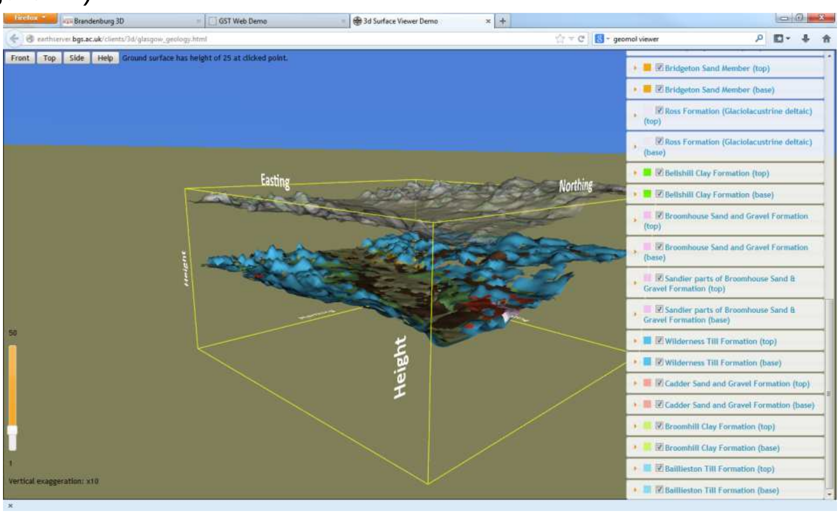

Figure 17 EarthServer viewer

5.6 Mobile applications

The future of delivery of geoscience data will inevitably move to mobile technologies. Once the 3D model data is web-based, it is relatively easy to develop access to models through mobile applications, Figure 18 shows the BGS Groundhog viewer deployed on a smartphone from where the user can generate a PDF for onward use.

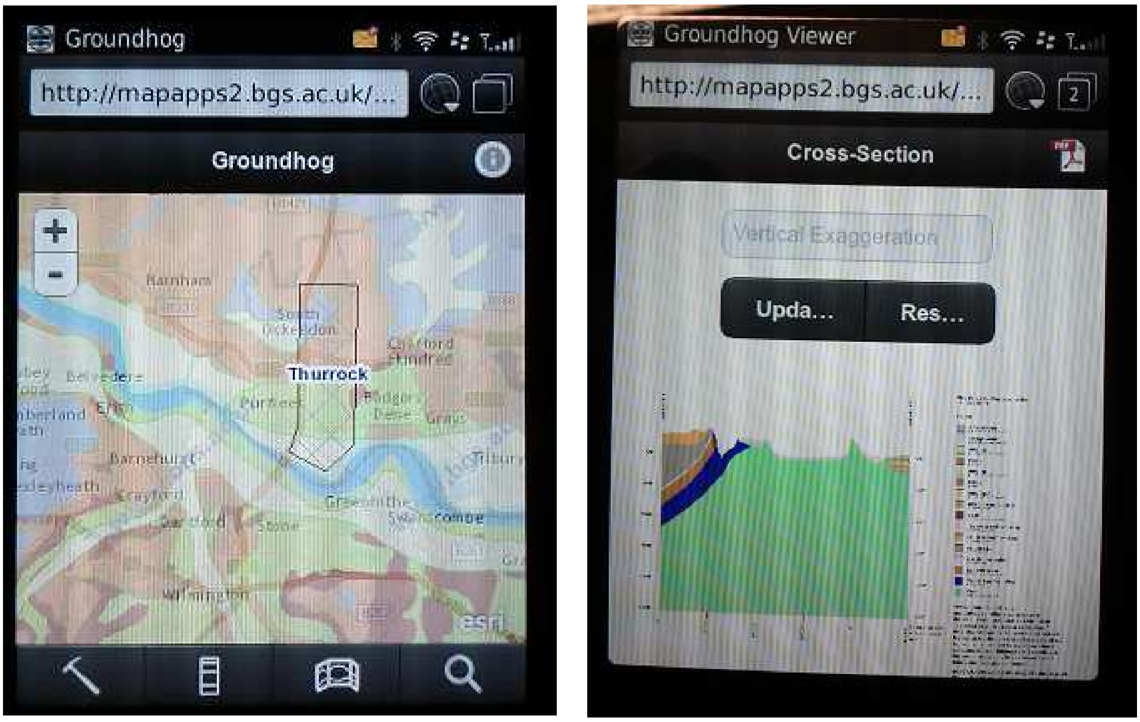

Figure 18 Screen on the left shows the Groundhog interface and screen on the right a synthetic section delivered to the smartphone.

The arrival of Google glass and similar devices will literally open up the possibility of ‘seeing’ into the ground revealing the models and their properties, research is in the early stages in this area.

A very good example of a intuitive mobile 3D app has been developed and deployed by the Estonian Geological Survey. The app allows the visualisation and analysis of their national model the app is free and downloadable here:
https://play.google.com/store/apps/details?id=com.Nortal.GeoMudel2

Figure 199 3D Geological Viewer app (Android only) from the Geological Survey of Estonia

6 Summary and future developments

This task has shown the scope of the activity ongoing in Europe to deliver 3D geological models and highlighted some of the ways in which geological models are being delivered within Europe. In terms of future delivery of 3D geological models, surveys are most interested in pursuing delivery via a web portal, with functionality for viewing and analysing 3D geological models (both framework and voxel models) and downloading model data (Table 4). There are a number of 3D viewers being developed across Europe, both free and available via license. At present it is not obvious whether one of these viewers will become a standard across Europe.

Table 4 Methods for future delivery of 3D models

Delivery method	Number of responses
Web portal	15
Creates synthetic cross sections, boreholes and maps	7
Viewing of voxel grids and integration of models with other data	5
Model download	7
No idea	2
3D pdf	2
Hologram 3D models	1
3D plastic models	1
3D databases	1
KML delivery	1

To ensure that data can be downloaded and delivered through standard viewers, considerations should include the standardisation of exports from geological models, in particular:

- Agree whether bases or tops of geological units are modelled
- The basic attribution of the models (Lithostratigaphy, Age, Lithology)
- Agree on a spatial projection system
- Standardise grid file formats (x,y,z start point)
- Standardise legend formats

Recommendations:

We need to seriously assess real end-user feedback from all organisations who currently have web-based 3D model viewers. This could be proposed under a future COST action where each organisation attends including some user representatives from all different sectors.

We might aim to have some key components made available as open source code (as is the case with some of the mentioned viewers) in order to support GSOs without any IT capabilities or those who are just starting out. Options include looking at looking at the Cesium (http://cesiumjs.org/) WebGL Virtual Globe and Map Engine and the components and architecture of OpenStreetMap (http://wiki.openstreetmap.org/wiki/Component_overview)

How much standardisation is needed and sensible for a shared architecture to be possible? A working group (comprising of geological and technical teams in GSOs) could be established to assess the feasibility (some surveys charge for models, some cannot display boreholes, some have model coverage, some only have surfaces, some have complex geology). Links to INSPIRE teams need to be established from the 3D modelling community.

Shall we start to investigate truly transactional (2 way) delivery mechanisms of models, where clients can suggest edits and insert new observations (akin to OpenStreetMap)?

Assess which methodologies that currently exist could cope with amount of data available in the GSOs at present. Models from different surveys could be tested in some of the Viewers available. A stock take of all presently approved, available and accessible geological models could be carried out.

A cross-GSO team should keep a watching brief on emerging technologies and share the information regularly (e.g. ESRI 3D API, Google developments, Free and Open Source Solutions).

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