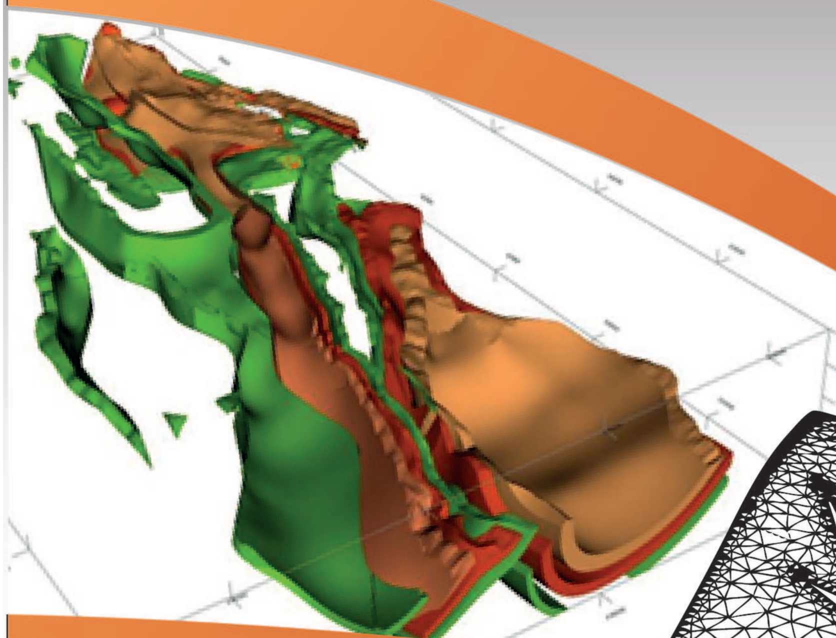
Delivering Subsurface Models for Societal Challenges

4th meeting of the European 3D Geomodelling community

21st to 23rd February 2018
Orléans, France
Hotel Dupanloup

Program & Abstracts



Plateau de Sault geological model
Martel *et al.*, 2015, BRGM

Geoscience for a sustainable Earth
brgm

ORLÉANS MÉTROPOLE
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Staatliche Geologische Dienste Deutschlands
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Lunch Break at Dupanloup Hotel

ABSTRACTS PRESENTATION

France country update

Presented by Pierre Toulhoat, BRGM's deputy managing director and scientific director

BRGM has been investing in the development of innovative geological modeling techniques and tools for more than 50 years, with geostatistics as their main backbone. This continuous investment resulted in several codes and numerical tools among which two production grade software: GDM and GeoModeller. GDM (Geological Data Management; http://www.brgm.eu/scientific-output/scientific-software/gdm-suite-software-suite-allowing-to-model-represent) is a 2.5D modelling suite (stacking of interpolated elevation or thickness maps) which provides a powerful way of managing geological data integrating cross validation and modeling constraints. GeoModeller (*Intrepid Geophysics; https://www.intrepid-geophysics.com/ig/index.php?page=geomodeller*) is a full 3D modelling tool that was initially developed for geological mapping purposes and can handle orientation data (stratigraphy, foliations…) and complex fault networks. It comes with a geophysical inversion toolbox.

Both tools are used on a daily basis to produce multi-purpose geological models. As there is an ever-increasing demand for a quantitative characterization of the subsurface, we are clearly entering an era of wider diffusion of geological models with a wide variety of producers and an even wider range of consumers. This requires to give an intuitive and efficient access to geological modeling techniques but also to manage the lifecycle of these models (versioning), archive them and deliver them, possibly through processing steps to the user (Loiselet *et al.*, this meeting). Standards are a cornerstone of this workflow and BRGM has been recently pushing for the creation of an OGC Geosciences Domain Working Group. Another important step here is the possibility to produce flexible spatial discretizations of the geological model (meshes) that can be used for physical simulations (hydrogeology, geophysics, risk assessment…) (Courrioux *et al.*, this meeting). Integration of geological models and other models such as BIM is also a main concern along with the efficient modeling of the “critical zone” in urban and non-urban contexts (Beaufils *et al.*, this meeting).

These innovative 3D techniques and tools are needed and used within the frame of the French Geological Referential Program (http://rgf.brgm.fr), the nationwide program that aims to build the new geoscientific infrastructure of France. The Program federates projects devoted to research and public service, with the objective of providing information on and access to data concerning the nature and properties of rocks at any point in the country’s 3D space. The adopted strategy is to focus our efforts on large regional objects in close partnership with university and industry. Currently the program is focused on the Pyrenees (2014-2019) and work is starting on the Alps and the Paris basin.

There is still much research needed to be able to model the full variety of geological structures that are observed on the French territories. Currently, the focus is on fault networks with various fault mechanisms and the integration of variable anisotropies (folded structures) (Courrioux *et al.*, this meeting). Modeling work must also cope with novel acquisition techniques than can produce locally millions of data and call for multi-scale and/or hierarchical approaches (Allanic *et al.*, this meeting). Integration of uncertainties is also a long-term goal with the improvement of inversion techniques and multi model approaches.

Finally, an effort is also put in refactoring our modeling tools to adopt a modular approach that is compliant with the advent of the cloud era and the need for microservices architecture that can integrate a production platform and be combined in different ways (Lopez *et al.*, this meeting).

Country Update - Germany

Gerold W. Diepolder – Bavarian Environment Agency (LfU) – Geological Survey,
chief executive of the Task Force 3D Structural Models of the German State GSOs

At present, 14 of the 16 German State GSOs and 2 Federal Institutes are actively involved in 3D geological modelling. These are organized in the informal "Task Force 3D Structural Models" (formerly "Study Group 3D", Kf3D). The principal remit of the task force is to safeguard the interoperability of 3D geological models across the state borders. Since all State GSOs have a regional rather than overarching mandate there is no common strategy or focus with respect to 3D modelling activities. Transregional collaboration is fairly exceptional unless stimulated by federal or European funding or legislation. Two major cross-border 3D modelling projects are in progress or are envisaged for implementation in case of funding:
Within the 2014-2021 project „Subsurface potentials for storage and economic use in the North German Basin" (German acronym TUNB), the federal institute BGR and 8 geological surveys of the northern German federal states are developing a 3D model of the central part of the Southern Permian Basin harmonized across the state borders. TUNB is geared towards providing the fundamentals for analysis and assessment of deep subsurface potentials as well as potential conflicts of use. The 3D model is based on scientific assessment and interpretation of available structural geological data, and information from structural contour and isopach maps, deep well drillings, and reflection seismic investigations. The model will consist of 13 horizons related to lithostratigraphic units, including salt structures and faults. Cross-border harmonization with neighboring countries (DK, NL, PL) is the core of the proposed 2018-2021 GeoERA project 3DGeo-NEU.

Also proposed in GeoERA, thus subject to approval, is the merger, extension and refinement of the 3D geo-models of the German Alpine Foreland Basin (Molasse Basin) as one of the case studies of the 2018-2021 HotLime project. Principal aim is the 3-dimensional capture and parameterization of the entire Upper Jurassic karstified limestone aquifer (including its shallow and exposed parts), as the host of a geothermal bonanza featuring more than 35 deep geothermal installations in operation, and to enable numerical groundwater modelling of the entire catchment area for the improved understanding of the hydrothermal system. Like all other HotLime case studies, the Molasse Basin's hydrothermal aquifer(s) will be characterized in line with TBD common methods for estimation, comparison and prospect ranking of hydrothermal resources in deep carbonate bedrock. The structural inventory will feed into the European Fault Database.

Since such time-consuming knitting projects for seamless dovetailing of 3D geological layer models, i.e. the cross-border harmonization of the modelled formations and structural features, will remain an exceptional approach also in the foreseeable future, the Task Force by a majority promotes the setup of a workaround based on semantic comparison instead of tangible (physical) harmonization:
Commonly, 3D geological layer models are developed on interpretations of lithologic features and their array in lithostratigraphic units. This subdivision into distinct (mappable) formations reflects the natural variability of the subject matter in space and time and evolved from distinct regional approaches. As a consequence, the distinction and designation of the formations and hence – inherent to the stratigraphic terminology which implies a certain depth or time interval – their thickness may vary considerably. However, these stratigraphic schemes are evidence-based, well-established and published widely, thus they are regional standards precarious to be aligned.

Especially where realignment/re-mapping of formations for harmonization, tantamount to the equalization of the terminology (semantics), is deemed too effortful or virtually impossible, a novel approach based on advanced semantic net technologies may provide a powerful tool to elucidate similarities and differences of the formations concepts and hence explain possible distortions across state borders. The Open Linked Data Semantic Web concept and technology allows the juxtaposition of formation (names), the semantic relation among them (synonyms, close match, broad match, super- and subordinate terms) and the addition of underpinning information to all entries, thus making it a true knowledge base. Prerequisite is that all components are RDF enabled (all entries must have a unique identifier (URI)) and a controlled vocabulary thesaurus of formation names. The latter also may serve as a drop-down menu for tagging the model units in the metadata (KeywordTypeCode: stratum, ISO 19115 allows for multiple entries) thus providing a direct link to the knowledge base.

At present, Task Force members are preparing interoperability tests with respect to the ISO 19115 compliant extension of their proprietary metadata information systems (MIS) for "3D metadata" and elucidate the sematic relation between the general legends of some States as the first step towards a Sematic Web. The implementation of a comprehensive Linked Data Semantic Web is envisaged within the scope of pan-European cooperation of GeoERA projects in the next three years. The Task Force 3D Structural Models intends to substantially support this promising development and to spearhead its application by providing real case processed data sets for prototyping and validation.

New advances in 3D geological modelling at the Czech geological survey

Jan Franěk[1], Lucie Kondrová[1], Jan Jelének[1], Ondřej Švagera[1]

[1] Czech Geological Survey

Czech Geological Survey (CGS) is a research institute of the Ministry of Environment of the Czech Republic. The mission of the CGS, the history of which has started in 1919, is the provision of the state geological service in the Czech Republic and research in geosciences. CGS leads and participates in basic and interdisciplinary research projects.

The system of CGS district geologists and associated specialists assists in acquisition and assessment of data on the geological composition of the state territory and the CGS provides expert information to the authorities for the political, economic and environmental decision-making. The relevant survey's core skills include data management, geo-ICT and 3D modelling. The organisation hosts the national repository for subsurface data and information and is the designated state advisor of all geological matters related to the Mining Act.

As the owner of the large geoscientific datasets from the whole Czech Republic area, the CGS recently has been developing a unified methodology of the data compilation and their subsequent use in geological 3D modelling. This activity is managed in cooperation with individual projects and contracts that involve production of the 3D geological models. The most important recently developed outputs include models for high-speed railway tunnels, recalculation of mineral resources, assessment of geothermal energy potential, or location of a deep radioactive waste repository.

For the 3D geological modelling, the CGS is using mainly MOVE sw. developed by the Midland valley Ltd. The models created are composed of mesh surfaces, no 3D volumes are involved due to complex shape of some modelled bodies and subsequent large size of the volume models. Scarcity and complexity of geological data do not allow any semi-automatic model calculation.

The 3D geological models created at the CGS cover a broad spectrum of scales and lithotectonic environments. Concerning scale they range from meters in case of outcrop fracturing quantification for DFN models (Fig. 1), to regional scale covering X00 km^2. They depict structurally simple sedimentary formations as well as complex high–grade units that exhibit several episodes of pervasive ductile deformation, partial melting and emplacement of magmatic bodies. Integral part of the model production at the CGS is also an initial assessment of model credibility e.g. for purposes of safety analysis of radioactive waste deep repository potential localities.

Regarding e.g. the hot topic of radioactive waste underground storage, based on our geological 3D models, hydraulic and transport 3D numerical simulations are performed, to estimate flow of groundwater and paths of radionuclides from a hypothetical broken HLW storage to Earth surface.

Future issues to be solved at the CGS comprise unified identification and classification of sources of uncertainty in geomodels and development of visualization methods to make the user aware of it. Another target is to create a unified inventory of 3D geo models and related applications for further use in frame of CGS or for presentation to broader public.

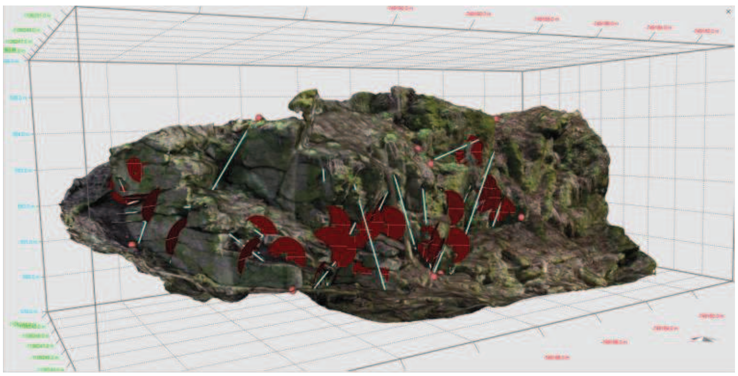


Fig. 1 3D model of a fractured granite outcrop evaluated for DFN modelling.

Steps towards a National Geological 3D-framework of Finland

Jarmo Kohonen, Jouni Luukas and Jouni Vuollo - GTK

GTK (Geological Survey of Finland) has during the last ten years developed a vision and a national approach for production, storage and services for interpreted geological data (e.g. maps and models). The 2D realization is a seamless bedrock map database with nationwide thematic layers. The themes 'bedrock units' and 'metamorphic domains' are completed and the themes 'structural geology', 'tectonostratigraphic units' and 'metallogeny' are in compilation. The bedrock theme is linked to non-spatial stratigraphic database (Finstrati) with references to primary scientific publications and reports.

In 2017 GTK started preparation for a National Geological 3D-framework of Finland ('3DSuomi'). The first realization (2019) will be a crustal scale 3D-model displaying the depth of Moho, the tectonic provinces and major crustal scale structures. The model will be based of seismic profiles, other geophysical data and tectonic evolution models of Fennoscandia.

The most important aim of the '3DSuomi' is, however, the creation of conceptual and technical framework for national geological research and new interpretations. In our approach the first steps towards the goal are not only technology related issues ('how') but primarily challenges related to our overall objective ('why').

Definition of precise, use-case based requirements for the National Geological 3D-framework is found as a very demanding task, but on general level the framework shall be scientifically solid, fully harmonized with the 2D map database concepts and capable to accommodate more detailed (larger scale) models.

We will discuss the challenges and general requirements by using the following points of view: (1) the conceptual data model must be nationally relevant and compatible with international standards, (2) the framework must be capable to accommodate various geological themes (e.g. tectonic modelling, mineral systems modelling), (3) the fundamental, nationwide realizations (models) must act as an integrated basis for various types of geological interpretation and (4) 3DSuomi must act as a framework and guide for future research.

Poland – country update

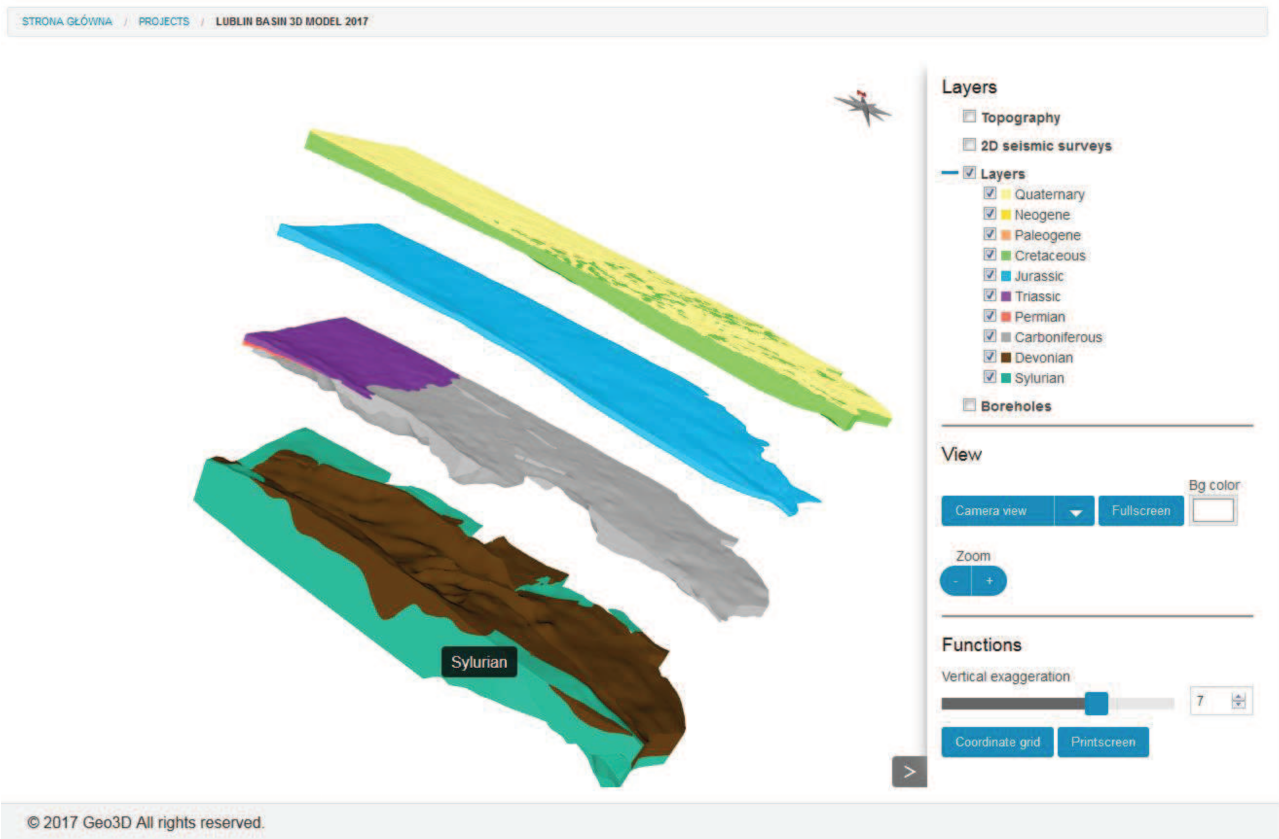
Ewa Szynkaruk[1], Urszula Stępień[1]

[1] Polish Geological Institute - National Research Institute

Last few years at the PGI-NRI brought increasing focus on systematic geomodelling aimed at eventually having all our sedimentary basins mapped in 3D. Our current approach is to model entire sedimentary cover of Poland, basin by basin. This sedimentary cover supports the vast majority of human activity related to geo-resources, what justifies such focus. Our aim is to capture basic geological knowledge in accessible and re-usable format, allowing further research and subsurface use planning. To produce these models we engage geologists specializing in resolving concrete, regional problems, thus preserving and promoting their knowledge. The models, apart from producing fault networks and stratigraphic horizons, also include grids storing lithology, litostratigraphy, porosities, permeabilities, total mineralization and other parameters, depending on data availability. Base horizontal resolution is 250 m, with vertical resolution depending most of all on parameter variability.

This 3D mapping campaign has produced its first, pilot model of sedimentary cover of Lublin basin. Next in the line – Gorzów block model – is in process of being developed and further models will follow building on our expanding (both in terms of content and functionalities) digital database and parallel baseline projects compiling georesources-related data.

PGI-NRI is also constantly developing an in-house desktop and web model viewers: Geo3Ddesktop and Geo3Dweb http://webcad.pgi.gov.pl/geo3d/pl/projekty. Current functional versions allow to view solid models, cross-sections, horizontal section maps and virtual boreholes. Layers can be switched on and off or "exploded" – that is uplifted with mouse to see next layer's top (Fig. 1). Viewers are being upgraded and we hope to have parametric grid web viewer in relatively near future. We are also exploring ways of visualizing uncertainty in our models.



PGI-NRI team is also engaged in implementation of the INSPIRE rules, both to modeling project results and to organization's products in general. We are experienced in creation of metadata application to solve metadata redundancy problem. Team members joined GeoScience Domain Working Group (OGC) this year.

Systematic 3D modelling at the Geological Survey of the Netherlands – country update

M.J. van der Meulen, D. Maljers, J. Stafleu, R.W. Vernes, J.C. Doornenbal, J.L. Gunnink
TNO, Geological Survey of the Netherlands

The Geological Survey of the Netherlands maintains a portfolio of four national subsurface models. Layer-based models include the geological framework models DGM (Digital Geological Model) and DGM-deep, and the hydrogeological model REGIS-II. The distinction between deep and shallow modelling relates to both the application of the model and modelling methods. Shallow modelling, having evolved from traditional geologic mapping, is primarily based on the correlation of boreholes and covers depths that are relevant to geotechnical and groundwater studies (generally down to about 500 m below the surface). Deep modelling, originally targeted at hydrocarbon resources, primarily uses seismic data down to about 5 km below the surface. Voxel (i.e. 3D raster) models of the upper tens of meters of the subsurface include GeoTOP, a high-resolution model that is in the process of being built and covers about half of the country, and NL3D, a lower-resolution model that already has national coverage. Developments in Dutch geomodelling after the previous status update (Wiesbaden, 2016) include the following highlights:

- GeoTOP now includes all coastal provinces and the Rhine-Meuse delta, serving the areas that are most vulnerable to adverse ground conditions and flooding. Research preparing for geochemical and hydraulic parametrisation of GeoTOP is well underway, to be eventually followed by geotechnical parametrisation.
- A new version of REGIS-II has been released, which is geometrically compatible with the last release of DGM (2014).
- The layer modelling step of GeoTOP has been integrated with that of DGM, in order to enhance geometrical consistency.
- Following on a first project that started in 2014, two more transboundary hydrogeological models are being constructed together with counterpart organisations in Belgium and Germany. The results will present water managers in the border areas with better (seamless) information, and the exchange of knowledge between project partners boosted our collective understanding of the regional (hydro)stratigraphy. The results of the individual projects will be fed back in the DGM, REGIS-II and DGM-deep programmes.

Beyond technical-scientific progress, pending developments in Dutch geomodelling primary relate to a new law on subsurface information. Since 2010, our Survey has been preparing for a transformation of our databases to a ‘key register for the subsurface’ (further referred by its Dutch acronym BRO). A key register is legally defined register containing high-quality data that the government is obliged to use for its public tasks, existing ones containing personally identifiable information; identification and ownership of real estate, companies and vehicles; real-estate value; income, employment relations and social-security benefits; addresses and buildings; and base topography. The BRO recognises the government’s reliance on subsurface data and information for a number important planning and permitting procedures, e.g., for land use planning; exploration and production of hydrocarbons, minerals and geothermal heat; storage of CO_2 and natural gas; and groundwater management. Beyond that, it is expected to help reduce the considerable societal risks and costs associated with adverse ground conditions in public works, especially infrastructure projects.

The BRO law is now in a process of stepwise implementation, i.e., datatype by datatype, which will take several years. For systematic geomodelling, the BRO law is crucial: it is the only way in which we can substantially increase the inflow of data to our survey. In this way, we expect the law to be instrumental in achieving higher model resolutions at lower uncertainties.

GeoQuat project:
Semi-automated 3D voxel modelling of Quaternary deposits and post-products generation

Philip Wehrens[1], Stefan Volken[1], Giona Preisig[2], Michael Gaehwiler[3], Andreas Möri[1]

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[2] Center for Hydrogeology and Geothermics, Rue Emile-Argand 11, CH-2000 Neuchâtel
[3] Service de géologie, sols et déchets (GESDEC), Quai du Rhône 12, CH-1205 Genève

Knowledge about composition and spatial distribution of Quaternary deposits is essential for managing the subsurface (e.g. drinking water resources, raw materials such as gravels and sands).

The GeoQuat project has been launched by the Federal Office of Topography swisstopo in cooperation with the Federal Office for the Environment FOEN and the Federal Office of Energy SFOE in order to: i) Develop a system for structured storage of unconsolidated rock data (QLG data model and database). ii) Build workflows and tools for the realization of 3D geological and parametric models (voxel models) of Quaternary deposits. iii) Make the developed tools, models and derived products accessible to users working in the different fields of applied geology.

Here, emphasis is laid on the added-value of data harmonization and workflow automation for analyzing, modelling and processing data from Quaternary deposits. A homogeneous and structured Quaternary deposit data model (QLG) has been implemented in the central Swiss Geological Survey (SGS) database. This is vital as it permits data comparison and exchangeability. Moreover, data standardization in the QLG harmonized database, in itself allows for the creation of automated tools and workflows, where users can directly apply such tools favoring the exchangeability of standardized data. Boreholes, geological cross-sections and geophysical data are harmonized, as they are the main components of the QLG database and the basis for the 3D models. Automated tools and workflows were built with the Feature Manipulation Engine, i.e. FME (Safe Software, 2017), to i) pre-process data for the 3D voxel models and to ii) generate derived products from the 3D models. i)

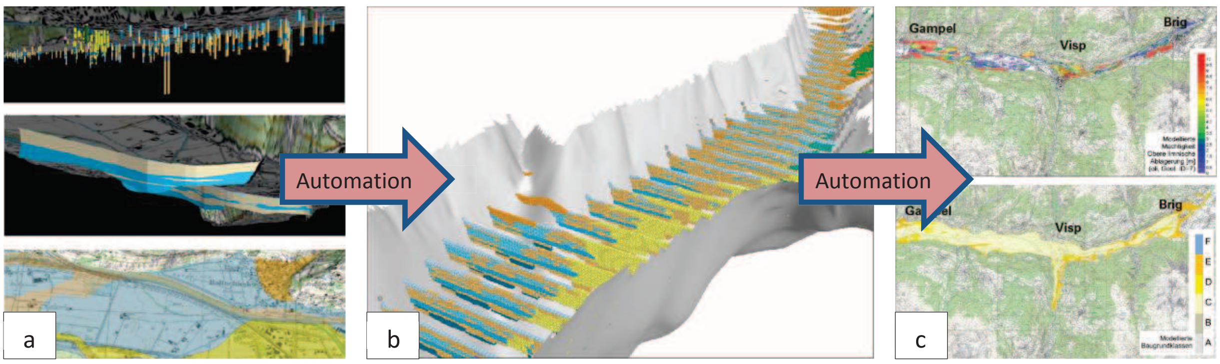


Fig. 1a): Harmonized and standardized data allows for automation into b) 3D voxel models and derived from that c) formation thickness and ground class maps.

The raw harmonized data consists of various elements (e.g., geological formations, unified soil classification, etc.) and can exist in many formats (e.g., points or lines along boreholes, polygons on maps or cross-sections). In pre-processing, automated workflows gather all data and convert them to points with specific dimensions as needed for 3D voxel modeling. ii) Various automated analyses are carried out on the 3D voxel model and visualized in the form of post-products (e.g., map of foundation soil classes, volume and quality map of resources, etc.). Automation allows for fast testing of different scenarios or updating the model with the implementation of new input data. Furthermore, FME visually represent transformations on the data, in essence documenting the workflow. Overall, this semi-automated framework greatly enhances the use of (harmonized) observational data (e.g. borehole data) for producing flexible and reproducible 3D voxel models, as well as the realization of comprehensible post-products. Additionally, standardized data in combination with a multitude of tools for derived products are accessible and exchangeable for users in the fields of geology, hydrogeology, geotechnical engineering, contaminated sites, natural hazards, non-energetic mineral resources and geothermics.

A new coherent 3D fault and (hydro)geological layer model for the eastern part of Flanders (Belgium) from the lower Carboniferous strata up to the surface

Jef Deckers[1], Bernd Rombaut[1], Stijn Bos[1], Tom van Haren[1], Katrijn Dirix[1]

[1] VITO, Flemish Institute for Technological Research, Boeretang 200, BE-2400 Mol, Belgium.

With finances from the Flemish Government, VITO is building a new 3D (hydro)geological model for the different Late Paleozoic to recent (hydro)geological units in the eastern part of Flanders (north-eastern Belgium). This area consists of (generally more than 2000 meters) of Upper Paleozoïc, Mesozoic and Cenozoic strata that became strongly faulted and deformed during multiple tectonic phases of both compression and extension. Currently, the area is part of the Roer Valley Rift System, with the differentially subsiding Roer Valley Graben in the east and the Campine Block in the west. During the Carboniferous, the Campine Block was part of a shallow subsiding area where coal seams were deposited which were exploited in the 20th century. To model this geologically complex area, large amounts of existing 2D seismic and borehole data, locally supported by information from the coal mines, were for the first time integrated from the lower Carboniferous strata up to the surface.

First, the available data were gathered, vectorized if necessary, loaded and correctly positioned into the modelling software. Next, we created a selection set of boreholes (preferably with wireline log data) that were interpreted for the major lithostratigraphic units that we wanted to pick on the seismic data. For this purpose, the lithostratigraphic interpretations were converted into the time-domain (by synthetic seismograms or time-depth couples) to be correlated with nearby seismic lines, using acoustic velocity data (sonic logs, VSP's). Once the horizons were picked along the boreholes, they were interpreted on the surrounding/crossing seismic lines.
Simultaneously with the interpretation of the horizons, fault lines were interpreted on the seismic lines. After their interpretation, the fault lines that were considered to be part of the same fault plane were grouped into different fault line sets. The decision on which fault lines are grouped into sets holds a large uncertainty. This uncertainty was reduced by adding additional information such as geomorphology, coal mining information, gravity data, etc.. After interpretation and grouping of the fault lines, they were modeled into 3D fault planes using a specific workflow of the GOCAD-software.
Next, in the same workflow, the 3D fault planes were used to model the seismic horizons into 3D surfaces. Contacts between the fault planes and initial horizon surfaces were introduced and modified if necessary, after which the fault throws were created in the surfaces. The surfaces were further optimized by adding the time-depths of the lithostratigraphic interpretations of the same horizons in the borehole selection sets (based on an initial velocity model).

Once the 3D fault planes and horizon surfaces were created in time, a velocity model was created to transform these towards the depth domain. The methodology for conversion from the time-domain towards the depth-domain varied for the different layers:
- For the Cenozoic to uppermost Paleozoic (Permian) layers, there are a lot of borehole data compared to the relatively few velocity data. Therefore, we used the time-surfaces and depths of the different layers in the boreholes to extract interval velocities at the locations of the boreholes and to model them into acoustic velocity maps.
- For the Upper Paleozoic (Carboniferous) interval, there are less boreholes and relatively high numbers of acoustic data. Therefore, we used sonic interval velocities to create velocity maps, taking into account the current overcompaction of this interval (due to post-depositional uplift).

After conversion into the depth domain, the different horizon surfaces can be used as building stones (reference surfaces) to create upper and intermediate litho- and hydrostratigraphic layers, which are primarily interpreted in boreholes. Creating intermediate layers will be performed by using proportion maps or absolute thickness maps. The choice between the two will depend upon the characteristics of the layer, such as for example the thickness variations.

Using this methodology, a new comprehensive 3D layer cake model is built for the eastern part of Flanders. In this model, we will also integrate the Cenozoic 3D (hydro)geological cross-border models with the Netherlands of the Roer Valley Graben and the north-eastern Campine Block. The model will be finished by the end of 2018.

ACKNOWLEDGEMENTS

We gratefully acknowledge financial support from Bureau for Environment and Spatial Development – Flanders and the Flemish Environment Agency. This work was also done with the support of the EU, ERDF, Flanders Innovation & Entrepreneurship and the Province of Limburg (Grant 1510487 – SALK GeoWatt).

Country Overview - UK

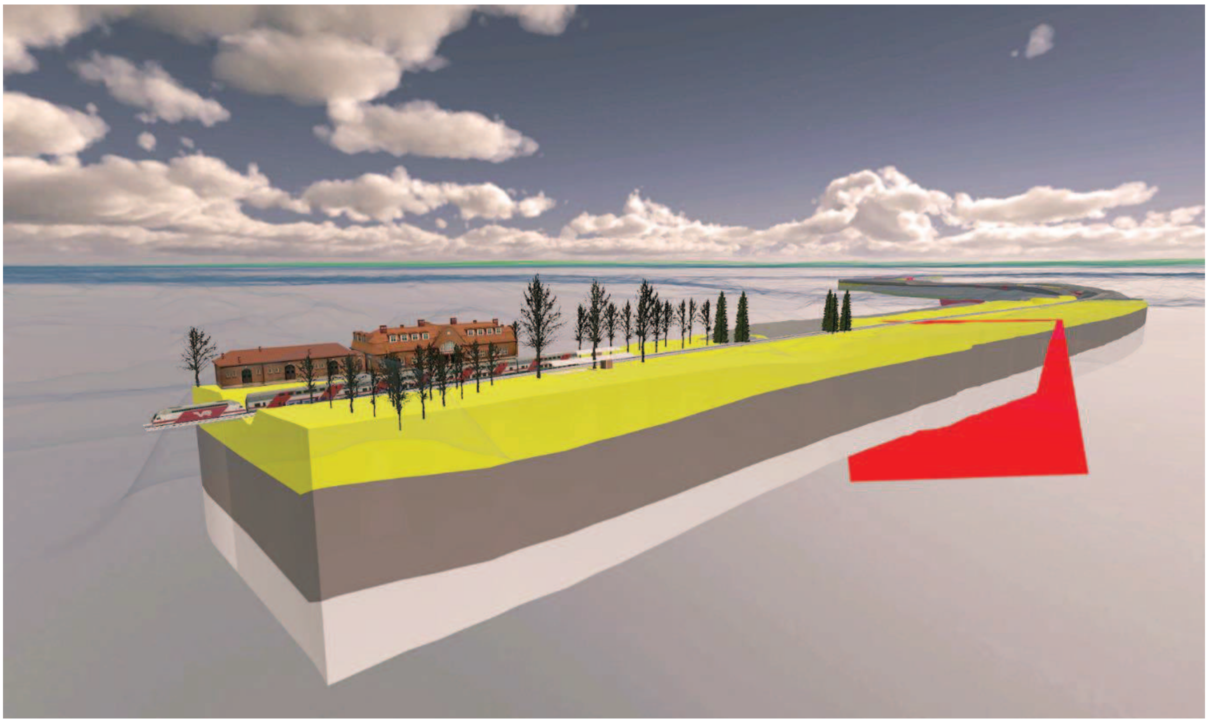
Holger Kessler - British Geological Survey

The BGS Strategy is currently focussing on “Sensing the Earth” and we are preparing the installation of two UK Geoenergy Observatories. One site in Glasgow, which will have a focus on passive geothermal heat in a regenerating urban environment, a second site is planned for the Ince Marshes area of Cheshire. It will provide scientific information vital for the optimising and environmental monitoring of several subsurface, low-carbon energy solutions (shale gas, carbon capture and storage, deep geothermal, energy storage and waste management).

The national bedrock geological model, ‘UK3D’, and derivatives are being used by the Environmental Regulators to understand and communicate risk from subsurface activities to UK’s aquifers. UK3D is a principal information source in the UK’s programme of National Geological Screening for the geological disposal of radioactive waste. Ongoing work is continuing to develop UK3D with the introduction of a national fault network.

Major investments in the national infrastructure (flood defences, road, rail, defences, airports and housing) are increasing the demand for up-to-date geological data and increasingly 3D geological models are becoming the standard - the implementation of BIM (Building Information Modelling) on major projects is adding to this demand. Furthermore stresses on the UK’s groundwater supplies are pushing the need for ever more sophisticated groundwater models and therefore the demand for detailed 3D characterisation of the aquifers and overlying units.

To support and deliver these objectives the BGS continues to invest and extend its corporate database and software architecture. Major developments are the capture and streaming of sensor data from monitoring sites, the first webservice for geotechnical data, the deployment of Groundhog in the environmental and engineering sector and the increasing use of 3D PDF and web based visualisation.



Visual3D – A European network of infrastructure with focus on 3D/4D geomodelling

Tobias C. Kampmann1, Tobias E. Bauer1

[1] Luleå University of Technology, Sweden

While the territory of the EU in many parts shows a very high exploration potential and many EU countries remain attractive to investors (e.g. Fraser Institute, 2015), a mere 4% of global exploration expenditure is currently invested within European countries. One tool to trigger a higher degree of investment in exploration and to secure the domestic supply of both main commodities and critical raw materials (CRM) is to enhance our three-dimensional geometric understanding of the Earth's crust.

For these reasons, EIT Raw Materials decided to fund a network of infrastructure (NoI) –Visual3D – for three years (2017–2019). Visual3D involves to-date 14 partner organisations from nine EU countries. The NoI aims to integrate expertise within exploration and 3D modelling from industry, academia and research institutes, with the ambition to increase the understanding of geological bodies in 3D and 4D through improved visualisation techniques.

During its first year, Visual3D has worked to identify common issues in the field of geomodelling, the solutions to which may be facilitated by a Pan-European network approach:

1. *Data compatibility.* The vast majority of European mining companies are currently working with 3D solutions for mine planning, resource estimation and production, utilizing a vast variety of expert programs (e.g. Leapfrog, Vulcan, Surpac, gOcad, MOVE). This leads to a wide range in character of 3D-models, as well as various types of data and file formats. Especially the combination of models on different scales, such as the incorporation of deposit scale models into regional-scale models, often necessitates simplifications and may lead to a loss of data. Therefore, a NoI that improves the interchangeability of models and furthermore enables full data integration will increase the usability of geomodels in exploration and research.
2. *Communication of geomodels.* Commonly, specific expert software in order to make different data formats readable and communicate geomodels between collaborators, clients, stakeholders and decision makers. This limits the group of possible co-workers in a modelling project and the group of people that can utilize such models to the amount of available and often expensive licenses. A network of 3D-modelling users can substantially widen the possibilities to make geomodels accessible to a wider audience.
3. *Complexity and variety of CAM software.* Software packages for computer-aided modelling (CAM) for geology and for industry standard mineral resource and reserve models are rather complex. Furthermore, there is a wide variety of available CAM software, each yielding individual functions, advantages and disadvantages. Changing a software or personnel within an organisation necessitates investment in additional training and causes downtimes. Implementing work flows for data interoperability may minimize expenditures on software and training for mining and exploration companies. Hence the NoI aims to work on solutions in order to optimize the generation, interpretation and application of geomodels, and improve the time and cost efficiency of these processes.

Integration and improved outward communication of the available visualisation tools at the NoI partners will support better targeting of new mineral resources at depth, and eventually reduce environmental impacts and costs by enhancing the efficiency of exploration workflows. The distribution and possible commercialization of the NoI´s outcomes among stakeholders of the extractive industry will improve the competitiveness of European exploration and mining.

Fig. 1: Partner organisations of the Visual3D network of infrastructure (EIT Raw Materials).

Towards a European Fault Database - storage of 2D and 3D faults and properties

Johan ten Veen[1], Serge van Gessel[1], Harry Middelburg[1], Maryke den Dulk[1]

[1] TNO – Geological Survey of the Netherlands

Within the context of GeoERA* an initiative is launched to set up the first harmonized European spatial fault database (FDB) that compiles 2D and 3D fault information. The rationale is that faults have specific and unique characteristics that are very often not well-captured by standard 2D maps and 3D layer models. The FDB will be capable of storing and providing all related static and dynamic geological and physical characteristics of faults. Moreover, it will include both the spatial fault object itself, either in 2 or 3 dimensions, as well as property data that informs on parameters such as length, depth, type, fluid behavior and reactivation potential (natural or induced). The motivation for development is given by the fact that these structures play a key role in seismic hazards, ground movements, fluid migration, contaminations, and containment of fluids and gases. While information on faults is currently not standardized nor centrally available, this project aims to harmonize and integrate the essential characteristics of such structures from various areas and settings in Europe. Next to data collection and storage, the FDB will support the use of fault data in a wide variety of applications and at multiple scales by developing appropriate end-user functionality.

For European policy support the FDB will be crucial for 1) reliably prediction of presence and continuity of subsurface resources, 2) identification of possible connections between energy and groundwater resources, 3) marking abrupt changes in the quality and characteristics of resources and 4) anticipating potential hazards related to the extraction and injection of resources and fluids. Faults may also define resource potential by themselves, e.g. as conduits for high temperature water. For one thing, the movements of faults through geological times may have a huge impact on the occurrence and thickness of resource-bearing layers as well as the present day prospectivity of resources (i.e. burial/temperature history, development of seals and traps, migration of fluids).

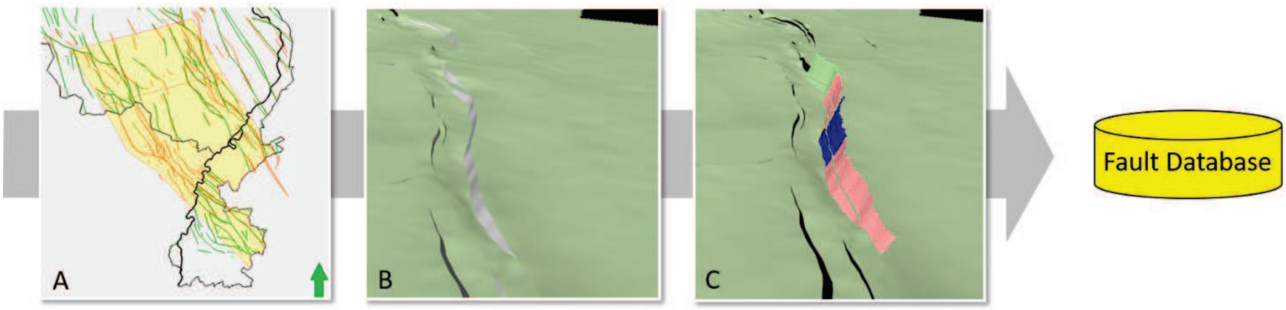


Fig. 1: The European Fault Database will facilitate multiscale and -format fault data uptake, for instance A) 2D fault lines, B) 3D fault-included surfaces, and C) 3D fault-gaps and/or fault surfaces with representation of associated properties (here dip azimuth).

The fault database will be built upon the experiences of all participating GSO's and should facilitate multiscale and multiformat upload and download functionality. A pilot database for Dutch subsurface faults has been developed and is now operational for several years. This proof-of-concept database, which started off as a PostgreSQL/PostGIS database, has now been fully developed in Oracle. Realizing that this concept needs to be extended in order to generate the anticipated functionality, we will here present and discuss our thoughts on uptake and retrieval of fault data in its many different forms.

** GeoERA joins 48 national and regional GSO''s from 33 European countries and will fund transnational research projects that will aim to support 1) a more integrated and efficient management and 2) more responsible and publicly accepted, exploitation and use of the subsurface.*

Alberta's 3D Geological Framework: Enhancing Science-Based Decision Making and Communication of Complex Geoscience Information to Stakeholders

Kelsey MacCormack, Paulina Branscombe, Mahshid Babakhani
Alberta Geological Survey, Alberta Energy Regulator

Alberta has immense resource potential from both energy and non-energy related sources, and has experienced unprecedented growth in population, industrial activity and land-use challenges over the past few decades. This has resulted in significant activity and modification both above and below the ground surface. To faciliate resource development in a safe and sustainable manner , the Alberta Geological Survey (AGS) developed an integrated platform to facilitate data integration and interdisciplinary communication enabling efficient, effective, risk-based decision-making. The 3D Geological Framework is a sophisticated platform, capable of integrating a variety of data types from multiple sources enabling the development of multi-scale, interdisciplinary models with built-in feedback mechanisms and workflows, allowing the individual components of the model to adapt and evolve over time as our knowledge and understanding of the subsurface increases and additional data and information becomes available. The 3D Geological Framework covers 602,825 km^2 and includes both provincial-scale and local-scale 3D models. These models have been constructed at a grid cell resolution of 500m or less, with some models containing as many as 54 geologic units, interpolated with upwards of 620,812 data points (Fig. 1 A).

The Geological Framework has significantly improved our ability to effectively integrate and evaluate any type of geospatial data to provide science-based decisions in support of land-use planning, environmental sustainability, economic diversification and public safety (Fig 1 B and C).

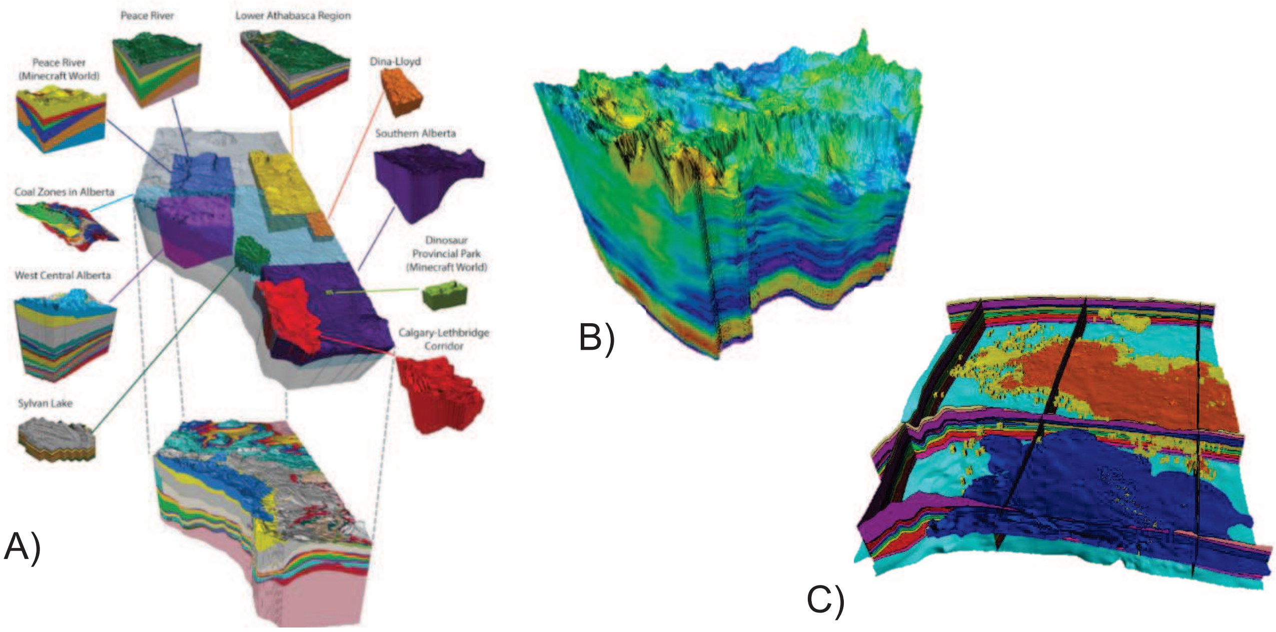


Fig. 1 A) The 3D Geological Framework includes the provincial-scale model and all sub-models completed to support a variety of local- to regional-scale geological investigations, B) 3D property models, C) integration of 3D geobodies highlighting the spatial association of an aquifer and gas play within the subsurface.

The success of our 3D Geological Framework is contingent on properly documented and transparent processes to generate reproducible and scientifically credible predictions, as well as ensure that users are properly informed as to the model limitations and uncertainties. We have developed workflows to facilitate documentation of our modelling processes, and reduce the time needed to update some of our models from 2 days to 2 hours, which represents an efficiency savings of 87.5%. This presentation will focus on how our 3D Geological Framework is being used to build trust and confidence with stakeholders, government, and the general public by facilitating transparent communication of complex geological and environmental issues using tangible graphics and visualizations, which are easy to understand and are based on scientific evidence.

Geological mapping in the USA

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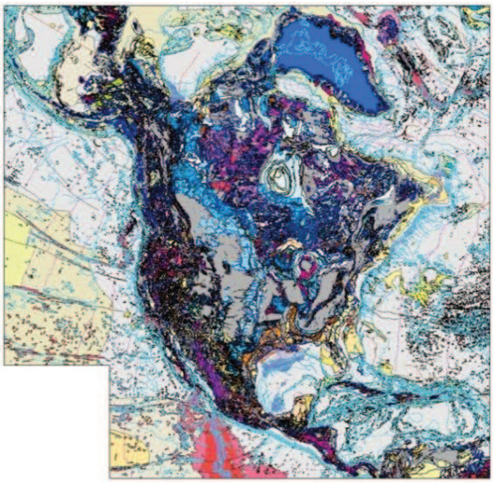

In Lexington, Kentucky, on June 11, 2014, members of the Association of American State Geologists (AASG) unanimously passed a resolution that endorsed planning by U.S. Geological Survey (USGS), and that cited pressing issues related to energy, minerals, water, hazards, climate change, environment, waste, and engineering, as well as research priorities, to call for accelerated progress on a national, regularly-updated, well-coordinated, multi-resolution, seamless, 3D, material-properties-based geological mapping database. Researchers and land use managers increasingly rely on and therefore need to invest in geologic mapping that will return benefits, including lives saved, resources discovered, costs avoided, increased efficiency, and improved understanding of earth composition, structure, and history. Provision of standardized and accessible geologic mapping is facilitated by the National Geologic Map Database (NGMDB), which is managed by USGS in cooperation with AASG, with proven arrangements for administration, data, stratigraphy, and standards. Mapping at state and national scales in the US is complete, although in need of updating. At scales needed for planning, coverage is only about 50%, and these maps typically are unreconciled relative to each other. Subsurface mapping needed for groundwater management and sedimentary basin assessments is even less complete. The superb nature of completed mapping, and compelling user needs, thus call for acceleration and enhancement of this activity. Users now expect maps to be zoomable, and to be queryable over broad areas. In addition, the demands of modelling increasingly call for a focus on material properties such as lithology and hydraulic conductivity. The public sector role commences with county and quadrangle-scale 2D mapping, the most important scale for land use planning. Each state geological survey can determine the most appropriate scale for their focused investigations, and also the intermediate scale that will be achievable state-wide. State-wide seamless compilations of quadrangle- or county-scale mapping are being built on an incremental basis, in part to make GIS resources manageable. Links to source information, at least as scanned versions of both maps and reports, provide documentation for advanced users, as well as credit and responsibility for the source map authors. Accompanying 3D geological mapping that depicts extent, thickness, properties, heterogeneity, and uncertainty of strata is based on data compilation and acquisition, facies modelling, and basin analysis. Model construction, including use of geostatistics, varies depending on resolution, complexity, as well as data format and adequacy. A basement map also is needed, with geometry of selected structures, along with discretized physical properties. The urgency of user needs calls for mapping of this nature to be completed nationally at appropriate levels of resolution within a decade or two, and updated periodically, in some areas every two decades or so, owing to increasing access, new topographic mapping, accumulation of data, as well as progress in science and technology. There thus is an urgent need for geological mapping to be progressively more: focused on user needs while accommodating unanticipated applications; conducted as part of a well-planned program based on ongoing assessment of required databases; focused on the most detailed mapping where needed; committed to jurisdiction-wide completion at an appropriate level of resolution; reconciled from onshore to offshore with topographic and bathymetric data; coordinated with soil mapping; based on compilation of drillhole and other data, along with strategic drilling and newly acquired geochronology, geochemistry, and geophysics; based on sound stratigraphic naming; categorized using accepted terminology; committed to regular updating; assembled as state-wide seamless compilations; 3D, in which the extent, thickness, and properties of layers, and geometry of selected basement structures are distinguished; material properties-based; coordinated with 3D versions of state, continental, and global-scale maps; accessible through open-source software; and linked to databases as well as searchable publications. Surveys need to aggressively transition to this approach, to better fulfil their essential role in society. (*Figure: Geologic map of North America; Reed, J.C., Jr., Wheeler, J.O., and Tucholke, J.E., 2005, Geologic map of North America, Geological Society of America, 1:5,000,000*)

How Geological Architecture Helps 3D Modelling

Philippe Calcagno, Gabriel Courrioux, Simon Lopez, Bernard Bourgine - BRGM

3D Geological modelling aims at representing the geology of the subsurface in 3 dimensions. Building a 3D geological model is not only pushing data through a code to obtain a representation of the geology. Two kinds of knowledge are mainly used to complete a geological model. The first one is explicit and consists in the data that constrain the model. The other one is generally implicit and consists in the geological knowledge that is used – sometimes unconsciously– by the person(s) in charge of completing the model. This knowledge is essential to drive the interpretation supporting the model.

The geological knowledge can be seen as an architecture underlying the 3D model. This geological architecture is derived from data, observations, interpretations, and experience. It needs to be compatible with the data but the same geological architecture may apply to various sets of data. Then, a 3D model is a geometrical realization of the topology represented by the geological architecture.

Formalizing such relations between geological structures and bodies is a way to conceptualize, to store, and to retrieve the geological knowledge. It is also a tool for the automation of the 3D model computation (Calcagno et al., 2008; Perrin and Rainaud, 2013). In that case, the geometry of the modelled structures can be generated using the data and the rules of the geological architecture. The presentation will demonstrate how the geological architecture can be set up to represent various geological contexts. Finally, the pertinence of storing 3D model, data, and geological architecture will be debated.

Calcagno, P., Courrioux, G., Guillen, A., Chilès, J.P. (2008). Geological modelling from field data and geological knowledge, Part I – Modelling method coupling 3D potential-field interpolation and geological rules, Physics of the Earth and Planetary Interiors, 171, 147–157.

Perrin, M., and Rainaud, J.-F. (2013). Shared Earth Modeling: Knowledge Driven Solutions for Building and Managing Subsurface 3D Geological Models. Publisher: Technip, Paris, ISBN 978-2-7108-1002-5.

Storing and delivering numerical geological models on demand

Christelle Loiselet[1], Christian Bellier[1], Simon Lopez[1], Gabriel Courrioux[1], Jonathan Durand[1], Étienne Taffoureau[1], Nicolas Mauroy[1], Adrien Quentin[1], Jean Gonçalves[1], et François Robida[1]

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BRGM (the French geological survey) is France's reference public institution for Earth Science applications, which works on management and delivering geosciences data to be used for helps to decision-making for spatial planning, mineral prospecting, groundwater prospecting and protection, pollution control, natural risk prevention and the characterization of local areas. Some of this data are produced from 3D geological modelling which is now a classical tool to better constrain geometries of complex geological systems and provide a continuous description of the subsurface out of sparse and indirect data. Then, BRGM has to work on geomodel management and their representation for delivering and disseminating 3D geological information.

We propose a new approach that consists in distinguishing the storage of the model from the representation of the model: models are stored using native format of the tool used to generate with (software project files). This choice guarantees that there is neither loss of data nor loss of precision. This strategy requires that each tool has to implement a common interface using only two predicates related to (1) the geological domain that any point lie in and (2) the geological contact (horizon or fault) that an arbitrary ray might intersect. Hence, answering only these two questions allow retrieving all the topological information automatically from the model and to generate model representation on demand (log, profils, 3D gridding, …). Most of the interface has been designed independently from geomodelling softwares. It requires that geomodelling tools implement only the two aforementioned predicates.

Our approach implements an associated informatics architecture using interoperable concept allowing to reference, to store geo models and to access and deliver information related to. We define a metadata to describe 3D geological models and their representation. A standard profile is implemented (i) to allow web application to edit and to manage data; (ii) to ensure interoperability in the delivery. 3D geomodel metadata which are indexed by a search engine and displayed in a geoscientific portal such as Infoterre (http://infoterre.brgm.fr/viewer). This work is linked to international initiatives (such as (i) OGC[2] – Geoscience DWG; IUGS / CGI[3] for standard and (ii) One Geology[4] and EPOS[5] projects to test implementation) to define an interoperable model and to ensure common metadata for geological models. We also implement OGC standard web services to get different model representation delivered with GeoSciML format and allowing, at the same time, to call the querying model interface and common model representation components based on.

[1] http://inspire.ec.europa.eu/;

[2] http://www.opengeospatial.org/;

[3] http://www.cgi-iugs.org/;

[4] http://www.onegeology.org/;

[5] https://www.epos-ip.org/

Efficient management of 3d subsurface models and its metadata

Paul Gabriel[1], Daniel Buse[1], Helmut Schaeben[2], Georg Semmler[1,2]

[1] GiGa infosystems GmbH,

[2] TU Bergakademie Freiberg

Managing and accessing subsurface information has become a tremendous task. More and more data is being produce or made available with new techniques. Some implicit modelling approaches allow to produce 3d subsurface models easily. Yet further approaches like comparing the results of the modelling process deliver more models. These structural 3d models are the base for modelling transport flow, heat flow, resources, risk assessment and more. In order to be able to manage different models in the same or distinct areas in various level of details we developed the software GST. The software allows to store 3d subsurface models and connect it with properties in order to make it available for further use. Such use cases might involve simple as well as complex simulations of dynamics but also data mining in order to prepare the technology for a new modelling approaches such as machine learning.

Within the past year 3d modelling has made a lot advanced with regards to available technique and available data. For example it is possible to use handheld devices such as phones in order to collect field measurements and integrate those instantly within the 3d model. Furthermore recent advances in machine learning and its wide availability allow to reprocess data like images, seismics and more within just a few moments. This amount of data becomes hard to handle and creates unclear data pool easily. GST has proven in several geological surveys that its capabilities allow to manage such model pools. Moreover by managing and connecting their metadata with data models which are already being used at those surveys or already available like GeoSciML.

The recent development of GST to a new version now also allows to store grid geometries not just vector based geometries. In order to open the core of GST for more geometry types it has been completely renewed. The renewal of the geometric core allows now not just to store regular grids but also speeds up the use of GST by far. We tested geometries of 3.2 giga bytes. Such a geometry would need around 18 minutes within GST2 to load a tile of 10,000 km² and just 5 seconds in GST3. This enhancement by more than 100% allows GST to be used in the daily work but moreover broaden the use cases from a 3d subsurface model storage to a big data enabled storage which can even feed modern machine learning or statistical algorithms in order to predict resources, risks and others. Additionally the geometric core of GST3 stayed generic which allows theoretically to support unstructured grids, such as stratigraphical grids, and other grid structures, e.g. made up of prisms.

Increasing the usability of 3D geological models through applying user-centered design principles

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End users should be in focus to succeed when developing a 3D model to meet societal challenges. In the recent years a lot of effort has been made by the geological surveys to increase the deliverance of 3D geological information. How do we ensure the usability of the products delivered, so that will be used by the intended users? In this presentation, based on a literature review on use, user and usability research in geographical information science, some suggestions are made on how the end-user can be involved in the development processes.

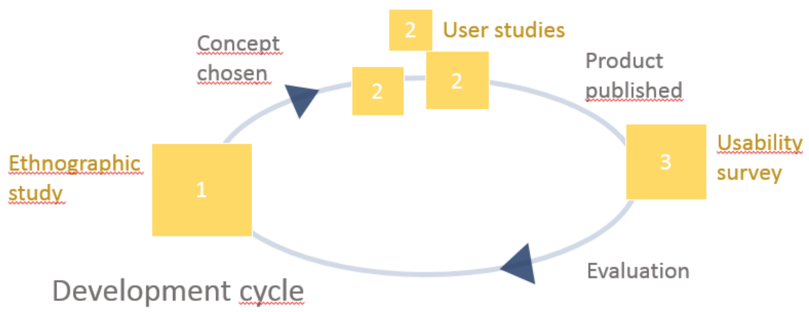

Fig. 1: Three ways of applying use, user and usability research in the development process: Ethnographic study (1), user studies (2) and usability survey (3).

1) Ethnographic mixed with textual methods can be successfully used to really understand the processes, institutions, social groups and practices where the geological information is aimed to be used (Perkins 2008, Suchan and Brewer 2000). A visit to one or a few users for an in-depth study will help to ensure the product in development will fit the use cases. This method fits early in the development process.

2) When a product is being developed, user studies could be performed, where a representative group of users is given a 3D model, data or services for testing. This could give important feedback before finalizing the value chain and data management system. This could be done typically by asking the user to perform a set of pre-defined and relevant tasks, and at the same time think aloud while solving the task. The transcripts are structured, analyzed and used as input to further development.

3) After a product is official and in use, the evaluation should not end (Schobesboerger, 2012). Usability studies formed as for example a web survey may be one option to measure usability metrics and possible barriers for use. A web survey is neither time-consuming or expensive and opens for a large group of participants. It can be repeated to measure changes over time when products are better known or further developed.

There should be good reasons for putting the user in the center of the development processes. There are a range of well-tried methods to apply to systematically include usability and user research when developing 3D geological models and value chains.

Perkins, C. (2008). Cultures of map use. *The Cartographic Journal.* **45**(2), 150-158.

Schobesberger, D. (2012). Towards a Framework for Improving the Usability of Web-mapping Products, RMIT University, Wien. Lloyd, D., Dykes, J. & Radburn, R. (2007). Understanding geovisualization users and their requirements – a user-centered approach. In: Dykes, J., MacEachren, A.M. and Kraak. M.J. 2005 *Exploring Geovisualization.* Elsevier Ltd.

Suchan, T. A. & Brewer, C. A. (2000). Qualitative methods for research on mapmaking and map use, *The Professional Geographer*, **52**, 1, 145-54.

Examples of how 3D models are used for protecting and managing groundwater resources

Eva Jirner[1], Johan Daniels[1], Lars Rodhe[1] & Lars-Kristian Stölen[1]

[1] Geological survey of Sweden - SGU

At SGU, we have produced a number of 3D models of eskers and Quaternary deposits.

The Uppsala esker model was produced in co-operation with Uppsala Vatten (the company for drinking water supply) in order to investigate the esker's continued viability as the main water supply for the City of Uppsala.

The model can be visualized at SGU´s web page at http://apps.sgu.se/sgu3d/

SGU has used Agency9 Cityplanner, a web-based 3D visualisation-tool, to visualise geological information in three dimensions. You can follow the different geological data horizontally and vertically, you can see boreholes and cross-sections. You can also download 3D PFDs and grids. This information have been used by universities in groundwater management training.

In cooperation with the British geological survey (BGS) SGU have made a map viewer of both The Uppsala esker model and the Enköping esker model. (http://mapapps.bgs.ac.uk/sweden_esker_pilot/). In the viewer you can draw sections and/or syntetic drillholes and get an overview of the stratigraphy. We know that the map viewer has been useful when oil pollution due to a traffic accident happened close to the groundwater reservoir.

We have also 3D-printed a simplified model which has been very useful for explaining the geology.

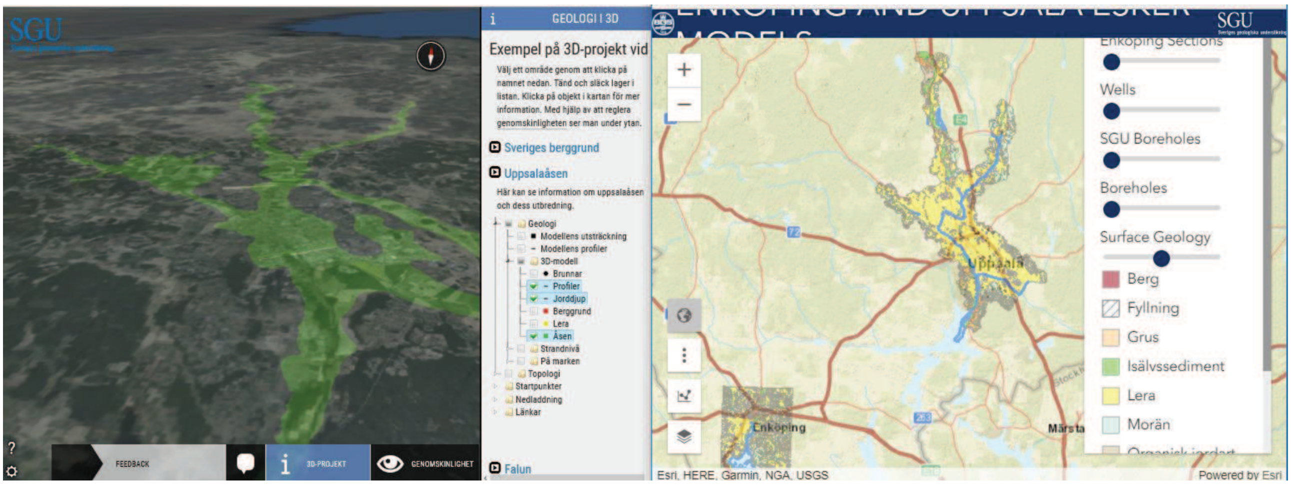

Fig. 1: Different ways to view the models.

Jirner, E., Johansson, PO., McConnachie, D., Djurberg, H., McCleaf, P., Hummel, A., Ahlgren, S., Rodhe, L., & Mikko, H., (2016) Jordlagermodellering i 3D – exempel från Uppsalaåsen med hydrogeologisk tillämpning . *SGU-rapport 2016:19.* 31 s

Advancements in cloud based visualisation of geological models

Holger Kessler[1], Holger Lipke[2]

[1]British Geological Survey, [2] ESRI Deutschland

The delivery of complex geological maps and models to clients and stakeholders has long been a big obstacle for model producers (Kessler et al 2005). Many options are available ranging from printed models, 3DPDF, stand-alone model viewers, export of models into GIS systems and recently the use of web-based model viewers (Kessler & Dearden 2014). Recent developments in browser technology (WebGL), the increasing availability of open datasets, webservices and APIs plus the emergence of cloud-based GIS systems open up great opportunities for model producers to maximise the impact and usefulness of 3D geological models. This presentation will summarise the history of model delivery and present recent efforts by the British Geological Survey, the TNO, the German geological surveys and ESRI Deutschland including a discussion of the remaining technical and legal issues.

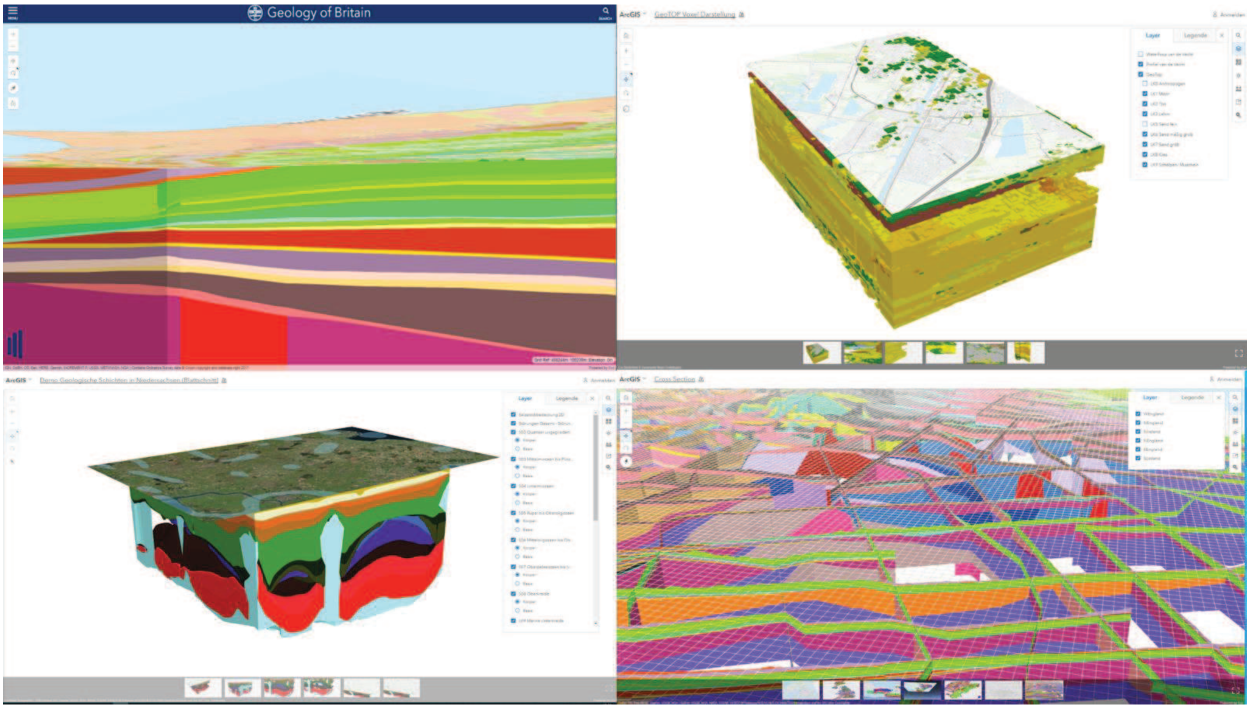

Figure 1: BGS Geology of Britain Viewer, TNO GeoTop Model, LBEG geological model,BGS UK3D model with transparent DTM.

Kessler, H, et al. 2005. 3D geoscience models and their delivery to customers. In: *Annual meeting Geological Society of America, Utah, USA, 15 Oct 2005*. Ontario, Canada, Geological Survey of Canada, 39-42.
http://nora.nerc.ac.uk/id/eprint/5325/1/kessler2005.pdf

Kessler, Holger; **Dearden, Rachel**. 2014. *Scoping study for a Pan-European geological data infrastructure : D 3.4 : technical requirements for serving 3D geological models.* EGDI Scope, 22pp.
http://nora.nerc.ac.uk/id/eprint/509262/1/OR14072.pdf

Vel-IO 3D: a recipe for 3D management of velocity data and time-depth conversion

Francesco Emanuele Maesano[1], Chiara D'Ambrogi[2]

[1] INGV,

[2] Servizio Geologico d'Italia - ISPRA

3D geological model production, especially in wide flat regions (e.g. foreland basins, large intermountain basins), where subsurface structures have no surface expression, is mainly based on large seismic dataset and hopefully well logs. In such geological contexts, even though seismic interpretation remains a basic early step in the 3D modeling workflow, the most critical phase is represented by the construction of an effective 3D velocity model able to describe the variation of the velocity parameters related to strong facies and thickness variability and to high geological complexity.

We present a comprehensive workflow that includes: the management of large seismic and velocity data, the construction of a 3D instantaneous multilayer-cake velocity model, the time-depth conversion of highly heterogeneous geological framework, including both depositional and structural complexities.

The core of the workflow is represented by Vel-IO 3D tool (Maesano and D'Ambrogi, 2017) that is composed by three scripts (Fig. 1), written in Python 2.7.11 under ArcGIS ArcPy environment. The 3D instantaneous velocity model builder (script 1) creates a preliminary 3D instantaneous velocity model using key horizons in time domain and velocity data obtained from the analysis of well and pseudo-well logs. The script applies spatial interpolation to the velocity parameters and calculates the value of depth of each point on each horizon bounding the layer-cake velocity model. The velocity model optimizer (script 2) improves the consistency of the velocity model by adding new velocity data indirectly derived from measured depths, thus reducing the geometrical uncertainties in the areas located far from the original velocity data. The time-depth converter (script 3) runs the time-depth conversion of any object located inside the 3D velocity model.

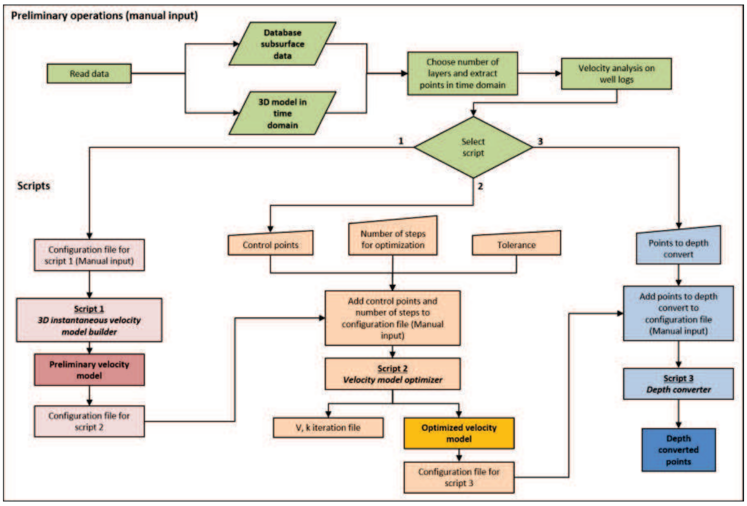

Fig. 1 Simplified flowchart for Vel-IO 3D tool.

The Vel-IO 3D has been tested for the construction of the 3D geological model of a 5,700 km^2 wide flat region, in the central part of the Po Plain (Northern Italy), in the frame of the European funded Project GeoMol (www.geomol.eu) and furtherly has been used for 3D reconstruction of the Calabrian subduction slab interface (Southern Italy) (Maesano et al, 2017), and for a basin scale analysis of the entire Po Plain in the Plio-Pleistocene time interval.

Maesano, F.E. and D'Ambrogi, C. (2017) Vel-IO 3D: A tool for 3D velocity model construction, optimization and time-depth conversion in 3D geological modeling workflow. *Computers and Geosciences,* **99**, 171-182. doi: 10.1016/j.cageo.2016.11.013. Vel-IO 3D is available at: https://github.com/framae80/Vel-IO3D

Maesano, F.E., Tiberti, M.M. and Basili, R. (2017) The Calabrian Arc: three-dimensional modelling of the subduction interface. *Scientific Reports*, **7**, 8887. DOI:10.1038/s41598-017-09074-8

RESQML V2.2 How the Geomodeling community can take benefit of this standard to exchange between Geomodeling Software

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Background:

RESQML is the Petroleum industry-defined data-exchange standard used in Exploration and Production (E&P) to transfer earth models between software applications in a vendor-neutral, open, and explicit format. In Version 2.0.1 (published in September 2015), RESQML defines a richer, more complete set of data objects (than previous Version 1 and RESCUE) across the Geomodeling subsurface work flow. RESQML now also defines precise classifications of data objects and the relationships between them to create a knowledge hierarchy of subsurface features, human interpretations of those features, the data representations and geometry of those interpretations, and the properties indexed onto those representations. These and other new features now make it possible to exchange and store meta information on the geological knowledge acquired on Earth Model, iterate, and update models along the entire subsurface work flow used in the.

Today a lot of company proprietary and vendor software tools in the Petroleum E&P Domain are starting to implement RESQML import and export facilities in their commercial product. By example Total, Shell and Exxon Mobil have proprietary implementations and Paradigm, Emerson/Roxar, DGI, CGM, IFP En and even Schlumberger have commercial Implementations.

Objective / scope of the presentation.

Now, As this is the time of adoption of this actually Open standard, It may be the time for the Geomodeling community to have a look on it and evaluate if this community could take benefit of all the work achieved by these companies.

The first objective of this talk is to present the particularities of the work achieved. Not only the Data Model published, but the philosophy behind, the methods and tools used and the relationships between this work and the work started previously with the GeosciML and One Geology initiative.

The second Objective will be to propose some initiatives and present the benefit the Geomodeling community can take from these initiatives.

Examples of these initiatives could be :

- Use The RESQML data model to exchange between existing tools (presentation of the Petroleum E&P community gifts : Documentation , Schemas, Tools, Open source API, Exploration/Validation)
- Use the RESQML data model to create research tools having RESQML Data model embedded into (this will facilitate Import/export with main commercial E&P domain products).
- Use The RESQML data model to set up Open source meta data base mechanisms which can facilitate Geomodeling information sharing on Data Lakes between applications.
- Use Resqml Activity Model/Activity Template to set up and monitor new Geomodeling Workflows.

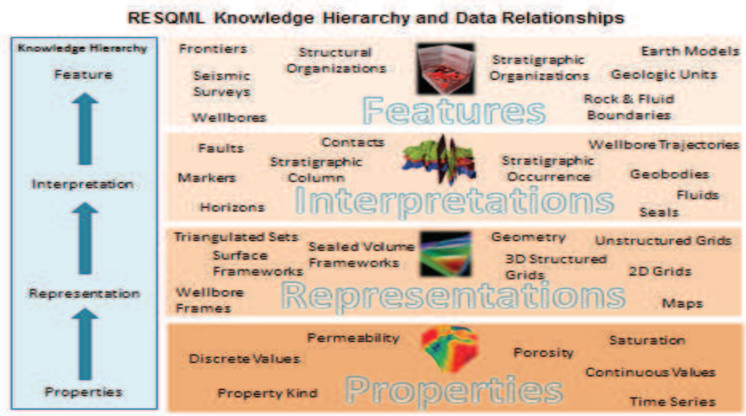


Fig. 1: The Feature / Interpretation / representation / property Knowledge Hierarchy of the RESQML Data Model.

Development of BGS Groundhog software with GTK for use in hydrogeological investigations and environmental monitoring in Finland

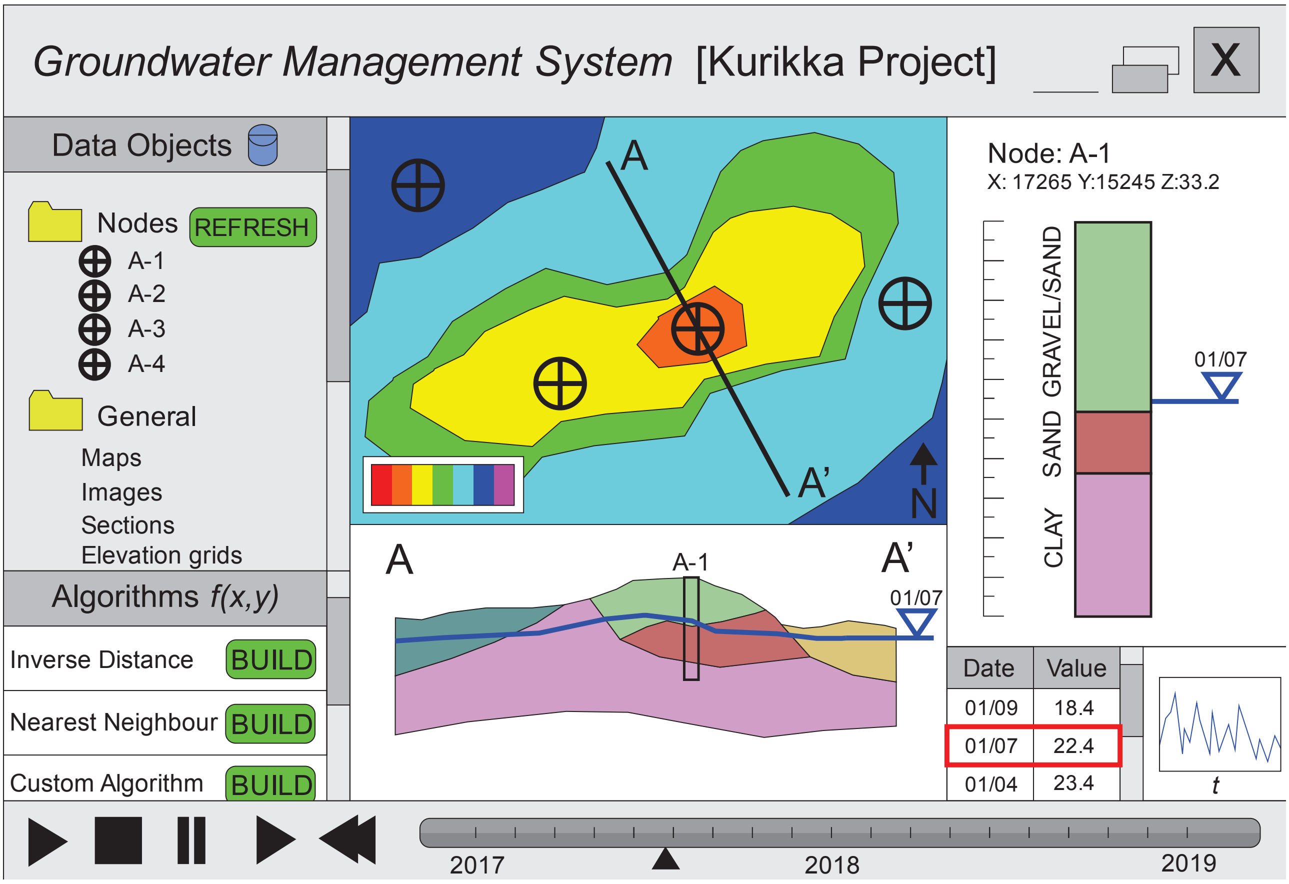
Ben Wood[1], Niko Putkinen[2]

[1] BGS, [2] GTK

Groundwater is of societal importance and, in Finland, efficient management of the groundwater resources requires high-level scientific knowledge about the hosting sediment aquifers linked with underlying bedrock and also groundwater-dependent ecosystems. In Finland, municipal drinking water supply relies on groundwater. Growth centres, food production and surrounding industrial plants increasing need of clean water leads to the exploring new groundwater resources.

In this project BGS and GTK are working together for Finnish water companies on developing free–to-use geological software (BGS Groundhog Desktop) for use in hydrogeological investigations and environmental monitoring. Data e.g. groundwater levels will be collected in the field in real-time using an innovative sensor technique. Working with software and data specialists from GTK, BGS are extending the capability of the free-to-use Groundhog Desktop software so that it can display the monitoring data from the GTK databases. The project will develop visualization capability for this data, including the ability to step through the time dimension, and interpolation routines will be added, allowing the analysis of trends across monitoring sites. Within GTK, connections to corporate databases will be established, making data exploration simple and intuitive for GTK geoscientists and the supervising authority.

Sharing real time groundwater data in Groundhog Desktop 3D, and visualizing interactively in maps, logs and cross-sections, will significantly help environmental agencies to monitor and control the sustainable use of water.



RINGMesh: An open source data model for integrative numerical geology

Francois Bonneau[1], Arnaud Botella[2], Pierre Anquez[1], Benjamin Chauvin[3], Antoine Mazuyer[1], Guillaume Caumon[1]

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[2] Total S.A./ASGA

[3] Earth and Planetary Sciences, Faculty of Arts and Sciences, Harvard University

A geological model is an interpretation of the subsurface organization combining data measured on the field and geological concepts. RINGMesh is an open-source initiative that proposes a data model to hold the geometry and the topology of such a geological model (Pellerin *et al*., 2017). It is neither a geomodeler nor a mesher but, it implements a "GeoModel" object that aims at defining and sharing tools and algorithms to perform validity checks and classical fixes related to both geometrical and topological issues. RINGMesh gathers a set of features to load, export and visualize “GeoModels”. The primary use of the library is to convert geological models through various file formats and to link software (e.g. geomodeler, mesher, and simulator). It is a smart converter because of validity tests and repairing options.

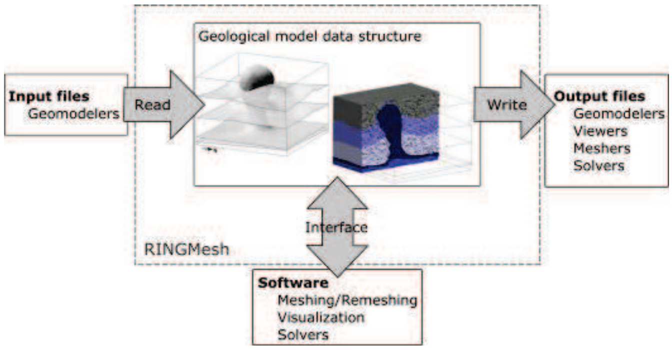

Fig. 1: RINGMesh provides an open source data model to handle geological models. The current implementation shares a set of classical tests and algorithms based on the “GeoModel” geometry and topology.

Since its first implementation, described by Pellerin *et al*. (2017), the GeoModel has been evolving and has gained flexibility. RINGMesh now supports both 2D and 3D models. The GeoModel data structure is composed by a set of entities and a bi-directional scheme gives access to entity adjacencies. Mesh entities define the topology and the geometry of each Corner, Line, Surface and Region. Geological entities are composed of a set of Mesh entities that have the same geological feature (e.g. horizon, fault and layer). An abstraction degree has been added in order to be able to manipulate a purely topological GeoModel. The implementation is now based on an abstract mesh that can be specified according to any data structure (e.g. discretized mesh made of vertex, segment, polygons and cells; mathematical parametric (spline, NURBS)). This enlarges its representation ability and may provide a direct wrapper to physical simulators, mesher and geomodeler. The default mesh data structure of the mesh entities is implemented in the geometric algorithm library "Geogram" (Levy, 2017).

RINGMesh proposes an extensive and mutable design. We encourage the community to develop their own applications and workflows (e.g. Chauvin *et al*., 2016, Botella, 2016) and to feed the project with generic tools and features. It is developed in C++11 and regularly tested by continuous integration tools. Non regression and unit tests are run before and after any merge to the main repository. The library can be downloaded from its github repository (https://github.com/ringmesh/RINGMesh). An up-to-date list of features and tutorials are available on the website of the project (http://ringmesh.org).

References

Botella, A. (2016) Génération de maillages non structurés volumiques de modèles géologiques pour la simulation de phénomènes physiques, PhD thesis, *Université de Lorraine*.

Chauvin, B., Lovely, P.J., Stockmeyer, B., Plesch, A., Caumon, G., Shaw, J.H., (2017) Validating novel boundary conditions for 3D mechanics-based restoration: an extensional sandbox model example *AAPG Bulletin,* doi: 10.1306/0504171620817154.

Levy, B. (2017) Geogram. Last date of access 2017-12-04. URL http://alice.loria.fr/software/geogram

Pellerin, J., Botella, A., Mazuyer, A., Chauvin, B., Bonneau, F., Caumon, G., Levy, B. (2017) RINGMesh: A programming library for developing mesh based geomodeling applications. *Computers & Geosciences*, 104, 93-100, doi: 10.1016/j.cageo.2017.03.005.

3D implicit GeoStructural Simulator: On the inversion of geological data to build 3D models

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[2] RING-Georessources, Universite de Lorraine,

[3] Centre for Exploration Targeting, University of Western Australia.

One of the great challenges in resource exploration and geological research is to predict and represent geology in 3D. Building 3D models, even with the advent of implicit techniques, is still a highly specialised and costly task (both in time and computing resources) and often only adapted to "simpler" basin geometries. There is currently a critical technology gap in our 3D geological modelling workflow. Current platforms only use a subset of the geological information available which makes building 3D geological models of hard-rock terranes very difficult. The integration with geophysical imaging is limited to the use of interpretative cross- sections as input data or a posteriori inversions that ignore geological data and information. Finally, uncertainty is extremely high and usually not quantified nor utilised. These three shortcomings in the modelling process conspire together to promote the production of geologically unrealistic models.

Although part of a bigger research project, we are presenting here the first attempt at a "Time-Aware Geological Modelling Engine" that allows modelling of poly-deformed terranes and in particular, modelling of multiple generation of folding events overprinting each other. The method is based on modelling each foliation and fold axis as scalar fields (lineations are modelled perpendicular to a scalar field) one after the other, starting with the youngest foliation and progressing backward until the primary foliation is modelled. The fold profile and geometry are derived from structural data analysis including Fourier frequency analysis to model parasitic folds and multi-wavelength folds (Jessell *et al*., 2010; Laurent *et al*., 2016) using analytical method presented in Grose *et al*., (2017).

Recent developments, using Bayesian inferences, on the fold frame of Laurent et al., (2016) and the data analytics of Grose *et al*., (2017) allow to jointly invert structural data to estimate the fold axis orientation and the fold profile at every point of the modelled volume at the same time.

This is the first time that such a structural geology likelihood function is developed.

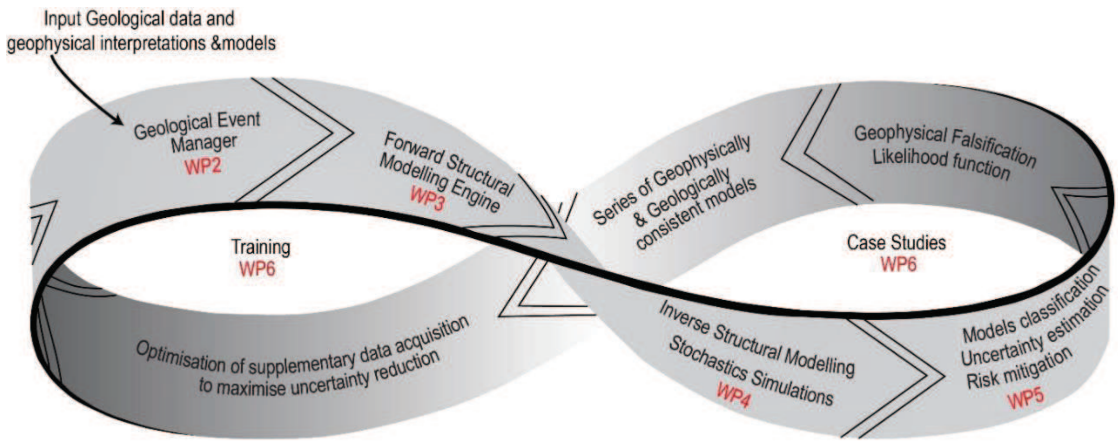

Fig.1: Newly proposed open source platform (called Loop) to solve 3D structural geological modelling problems from the mine scale to the plate scale and including geological problems, related resources exploration and management in urban geology settings, basins geology environment and poly-deformed terranes.

Jessell, M., Ailleres, L., deKemp, E., 2010, *Tectonophysics*, **490** (3-4), 294-306.

Laurent, G., Ailleres, L., Grose, L., Caumon, G., Jessell, M., Armit, R., 2016, *EPSL*, **456**, 26-38.

Grose, L., Laurent, G., Ailleres, L., Armit, R., Jessell, M., Caumon, G., 2017. Structural data constraints for implicit modelling of folds. *Journal of Structural Geology*, **104**, 80-92.

Probabilistic Geomodelling and Geological Inference

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[1] Computational Geoscience and Reservoir Engineering (CGRE), RWTH Aachen, Germany

Geological models often provide an important basis for subsequent subsurface investigations. As these models are generally built with a limited amount of information, they can contain significant uncertainties – and it is reasonable to assume that these uncertainties can potentially influence decisions or a subsequent model use, for example in process simulations. However, the investigation of uncertainties in geological models is not straightforward – and, even though recent advances have been made in the field, there is yet no out-of-the-box implementation to analyze uncertainties.

We present here results of recent developments to address this problem with an efficient implementation of a geological modeling method for complex structural models (Lajaunie et al., 1997), integrated in an efficient probabilistic programming framework (Salvatier et al., 2016). The implemented geological modeling approach is based on a full 3-D implicit interpolation that directly respects interface positions and orientation measurements, as well as the influence of faults (see also Calcagno et al., 2008). In combination, the approach allows us to generate ensembles of geological model realizations, constrained by additional information in the form of likelihood functions to ensure consistency with additional geological aspects (e.g. sequence continuity, topology, fault network consistency), and we demonstrate the potential of the method in an application to the investigation of a greenstone belt in Western Australia (Wellmann et al., 2017). Current extensions include the definition of additional geologically-motivated likelihood functions, and the link to decision theory. With this approach, we aim to contribute to a better understanding of the influence of geological uncertainties on subsequent process simulations, for example in the context of geothermal exploration.

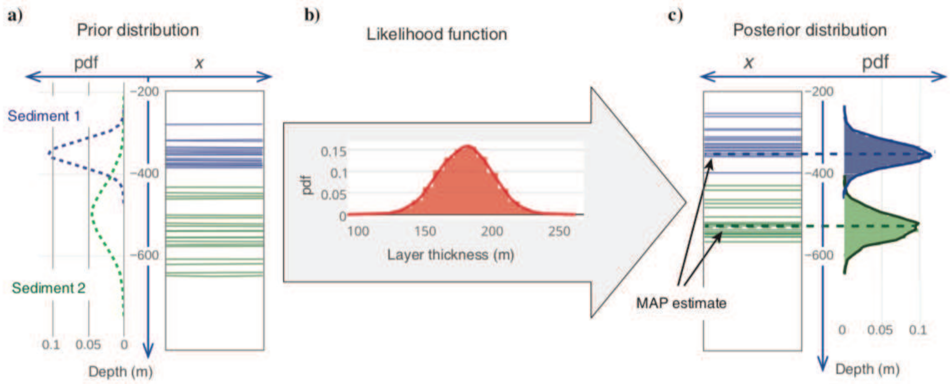

Fig. 1: Conceptual example of adding geological information in the form of a likelihood function to stochastic geomodel (de la Varga and Wellmann, 2016).

Calcagno, P., Chiles, J.-P., Courrioux, G. and Guillen, A. (2008) 'Geological modelling from field data and geological knowledge: Part I. Modelling method coupling 3D potential-field interpolation and geological rules: Recent Advances in Computational Geodynamics: Theory, Numerics and Applications', *Physics of the Earth and Planetary Interiors*, 171(1-4), pp. 147–157.

la Varga, de, M. and Wellmann, J.F. (2016) 'Structural geologic modeling as an inference problem: A Bayesian perspective', *Interpretation*, 4(3) Society of Exploration Geophysicists and American Association of Petroleum Geologists, pp. 1–16.

Lajaunie, C., Courrioux, G. and Manuel, L. (1997) Foliation fields and 3D cartography in geology; principles of a method based on potential interpolation. *Mathematical Geology,* **29**, 571-584.

Salvatier, J., Wiecki, T.V. and Fonnesbeck, C. (2016) 'Probabilistic programming in Python using PyMC3', *PeerJ Computer Science*, 2(2) PeerJ Inc., p. e55.

Wellmann, J.F., la Varga, de, M., Murdie, R.E., Gessner, K. and Jessell, M.W. (2017) 'Uncertainty estimation for a geological model of the Sandstone greenstone belt, Western Australia – insights from integrated geological and geophysical inversion in a Bayesian inference framework', *Geological Society, London, Special Publications*, 453 Geological Society of London.

Overview of R&D on 3D Geological Modelling at BRGM

Gabriel Courrioux[1], Simon Lopez[1], Bernard Bourgine[1], Laure Pizzella[2], Christelle Loiselet[1], Christian Bellier[1] Philippe Calcagno[1], Cécile Allanic[1], Sunseare Gabalda[1], Severine Caritg[1]

[1] BRGM, [2] École des Mines Paris

BRGM has invested for long in the development of methods for geological modelling. These methods have progressively moved to industrialization through « homemade » software (GDM-Multilayer, 3DGeomodeller). Considering the wide range of applications and geological settings, the choice for own developments allows better flexibility and adaptive capabilities on tools and methods.

Modelling geology in complex tectonic environment:

In the frame of Potential and Gradients Cokriging method (Lajaunie *et al*., 1997), one of critical parameters when interpolating natural objects concerns the anisotropy which in current methods is at best considered as uniform within the domain. The introduction of spatially variable anisotropies will allow to model structures such as folds whose characteristics are variable in space, intrusive systems in orogenic domains, or even meandering alluvial systems (Fig.1). This will contribute to increase the realism of geological models.

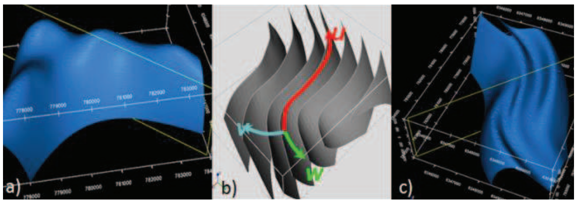

Fig.1: a) Rather bubble shapes if not accounting for anisotropy b) Anisotropy tensor field varying in orientation and intensity c) Interpolation accounting for anisotropy field

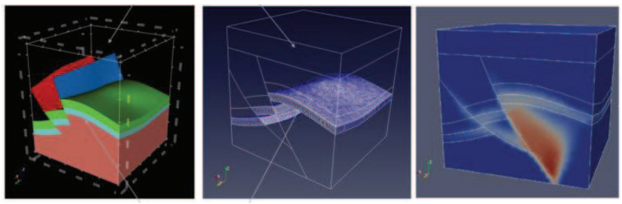

Fig. 2: 3D Geological model of a faulted aquifer and subsequent mesh for flow simulation

Meshing problematic

Diversity of applications and physical domains lead to as many requirements for meshing type: (1) Obtain a conformable mesh to faults and layers boundaries described by implicit functions, (2) Respect of singularities and sharp angles, (3) size and shape criteria, (4) Respect of internal anisotropies. We recently used the Computational Geometry Algorithms Library (CGAL) to build conformal simplicial (tetrahedral) meshes that match any geological 3D object and its boundaries or internal 2D features such as fault surfaces (Fig.2).

Geological architecture

This concerns the description of geological, topological, chronologic rules to combine sets of modelled surfaces so that they provide a partition of space corresponding to expected geology (Calcagno et al., this volume).

Storing and delivering geological models for every day Earth Sciences applications

Considering that no standard is currently yet accepted for 3D geological models, we started following an alternative approach based on a very simple concept. The idea is to try to escape from definition of standard formats, but rather try to define standard queries on models and standard services around models exploitation. In this scheme, models are stored in their native formats. For each type of format an API that provides an index-geology dictionary and implements simple geometric queries, called “oracles” has to be developed : (1) returns the geological formation for a given point p (2) returns an interface location in a segment [p1, p2]. With these two “oracles” and an index/geological unit we make the guess that it is possible to rebuild visualizations and extracts of any model.

The drawback is the necessity to implement readers and these two “oracles” for each native format. The advantage is to provide homogeneous services around models independent of native formats: predictive drill-holes, sections, Standard presentations, 3D views, meshing, maps, and delivery in interoperable exchange formats.

Lajaunie, C., Courrioux, G. and Manuel, L. (1997) Foliation fields and 3D cartography in geology; principles of a method based on potential interpolation. *Mathematical Geology,* **29**, 571-584.

Collaborative 3D modelling: Hidden pitfalls – A case study from Switzerland

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[1] Swiss Geological Survey, CH 3084-Wabern

Between 2013 and 2016, a geological model of the Swiss Molasse Basin (SMB) was developed (Landesgeologie 2017) in order to allow interested parties to visualize the most densely populated and intensely used area in Switzerland in 3D. The amount of data, which had to be processed and then modelled to produce an approximately 33'000km^3 model consisting of 12 geological horizons and several 100 fault planes exceeded the scope of what the SGS could process independently. In order to expedite the project, a consortium of six institutions assembled under the auspice of the SGS worked independently to achieve a common goal.

3D collaborative modelling was successfully tested in other projects (e.g. GeoMol). Methodologies and workflows do not necessarily change from a lower to a higher-resolution model, as was the case in our example (from 200x200m to 100x100m grid size). As best practice, jointly defined boundary lines divide adjacent modelling areas. Furthermore, horizons and fault zones modelled by different partners overlap in so-called buffer zones, where geological surfaces and fault planes were adjusted parallel to the boundary lines. Besides best practice, and in some cases even using the same input data, the six 3D models show discrepancies due to differences in the applied geological concept, the workflows applied and the experience of the modellers. The most striking examples shown in Fig. 1 illustrate the difference in elevation for the Top Dogger horizon along the boundary lines between adjacent models.

We will demonstrate some of these hidden pitfalls faced during the model evolution and their effects on modelling results. The focus will be on data quality, data density, and mutual correlation of input data, differences in interpretation, applied geological concepts as well as modelling software packages used.

The final model features the major geological boundary surfaces and fault zones consistently adjusted across the model boundaries and throughout the entire Swiss Molasse Basin.

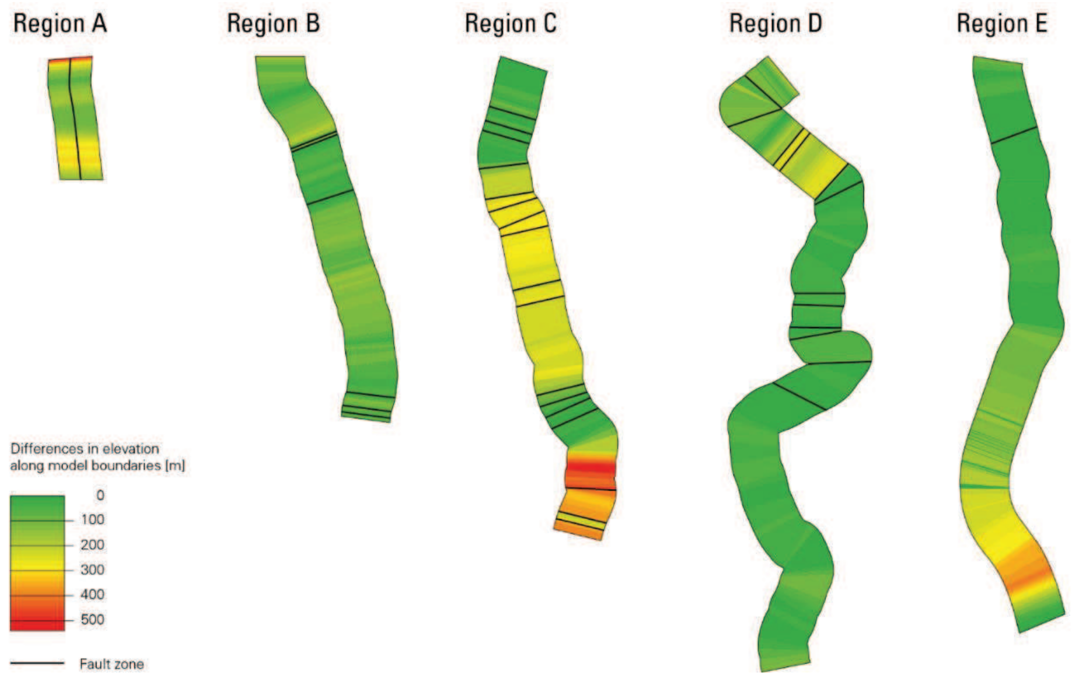

Fig. 1: Boundary adjustment between adjacent 3D geological models. Illustrations of differences in elevation within boundary regions for Top Dogger horizon.

Landesgeologie (2017): GeoMol: Geologisches 3D-Modell des Schweizer Molassebeckens - Schlussbericht. - *Ber. Landesgeol.* ***10***.

Framework for modelling national scale 3D geological models

Michael Hillier[1], Boyan Brodaric[1]

[1] Geological Survey of Canada, Ottawa

National geological models are increasingly being developed to help address a variety of continental and global issues such as those related to climate, water, or hazards. However, their nascent development is highlighting many scientific and technological challenges, primarily related to the construction and maintenance of very large 3D models. These are manifest technologically as gaps in modeling methods, related to sparse data and regional interpretation, as well as infrastructure gaps related to the handling of massive data volumes that overwhelm present commercial modeling systems. To overcome this infrastructure gap, new approaches are taken here for the storage, management, viewing and dissemination of a national geological 3D model for Canada, ranging from the surface to the deep subsurface (~46km). The infrastructure is comprised of several components: geometry data model, hierarchical data structure, geospatial database, visualization software, and an upcoming web portal. To represent the wide variety of possible geometries for 3D geological models (points, curves, surface meshes, structured and unstructured 3D grids) the open source VTK (Visualization Tool Kit) data model is adopted. Interactive visualization of a massive 3D model is accomplished by 3D tiling, in which 3D model components are inserted into an octree-based hierarchical data structure that partitions the data into blocks with different resolutions and sizes, limiting viewing to relevant data. The evolving national 3D geology model is stored in an open source database, PostgreSQL, which contrasts with prevalent file-based modeling systems. It is visualized directly from this database using customizations of the Paraview and ParaviewWeb software, for both desktop and forthcoming web-based environments. Ongoing tests on desktop system have shown this environment to scale effectively for the expected data volumes, indicating this approach is promising as a national 3D geological modeling infrastructure.

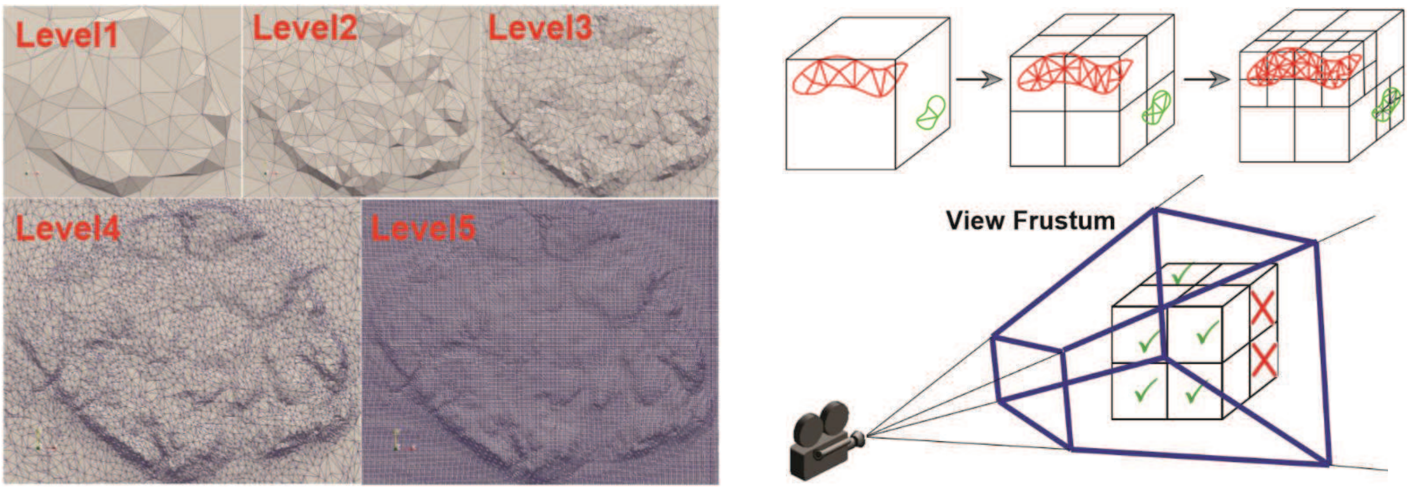

Fig. 1: Hierarchical data structure for 3D visualization of big data.

Visual KARSYS, a web-platform for the documentation of karst aquifers including online geological modelling

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[3] i4ds Institute of 4D Technologies, Fachhochschule Nordwestschweiz, Bahnhofstrasse 6, CH5210 Windisch

Visual KARSYS is a web tool under development which is dedicated to the exploration, the documentation and the management of groundwater resources in karst aquifers. The web tool makes it possible for users to apply KARSYS (Jeannin *et al.* 2013) by themselves to address specific issues (construction, water supply, geothermic, natural hazards, etc.). At the same time, it makes it possible for end users to consult and to analyze the resulting documentation on a site of interest.

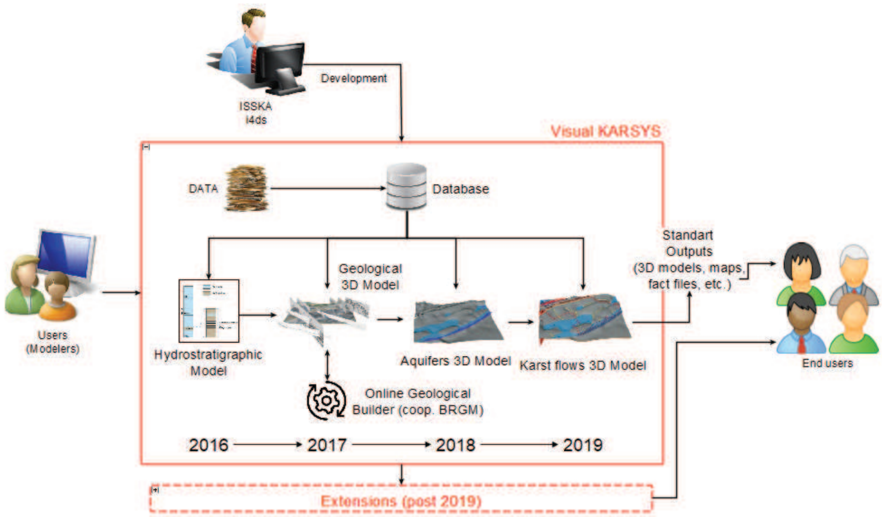

Fig. 1: Workflow of Visual KARSYS; users (Modelers) can process the successive KARSYS models step by step.

As the application of KARSYS requires the establishment of an implicit 3D geological model before modelling aquifers, cooperation with the BRGM has been undertaken in order to develop an online geological builder which could be operated via Visual KARSYS. With this solution, users can perform all the steps of the KARSYS approach within Visual KARSYS itself. Geological and hydrological data are stored in the same place and linked to the resulting models in order to ensure traceability and integrity of the data.

The Visual KARSYS project is supported by the Swiss Federal Office for Environment for three years and is now being implemented by SISKA and i4ds. Users can reach the web tool at visualkarsys.isska.ch after having registered. A number of features are already operational and users are kindly invited to test them. In the current stage of implementation, users can initiate and export a GeoModeller project as .zip file (including project's parameters, DEM, maps, cross-sections and formations.) which can be imported with a desktop installation of GeoModeller. DEM and cross-sections which exceed the project's bounding-box are automatically cropped to the limits. Other functionalities will be progressively implemented (including a dedicated interface for entering geological data). Modules related the production of the aquifers 3D models and of the groundwater flows will be developed in 2018 and users will be able to process the complete KARSYS workflow through Visual KARSYS in mid-2019. Post 2019, specific extensions including recharge simulation and hydraulic flows will be added.

Actual functionalities of Visual KARSYS and upcoming developments will be presented during the conference.

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Bringing an outcrop back to the office: which methods and what to do with it?

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[2] Uni Research, Bergen, Norway;
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Digital Outcrop Models have become increasingly popular in the last decade. They arise from the advent of new sensing platforms such as Unmanned Aerial Vehicles, and ever more versatile sensor for range and color, including terrestrial lidar, handheld mobile lidar, hyperspectral sensors and cheap to acquire multiview photos for structure-from-motion. While obtaining geometric and colour data sets at centimeter-scale is increasingly efficient, extracting meaningful, end-user-driven metrics remains a challenge.

A short review of acquisition techniques will highlight their shortcomings and solutions in the framework of structural geological analysis. Then, two *free-for-public-research* software will be presented for visualizing digital outcrop models as textured mesh and point clouds to increase their interpretative value: LIME (virtualoutcrop.com) and CloudCompare (cloudcompare.org).

LIME (Buckley et al., submitted) features visualization and interpretation tools for textured meshed models. Interpretation tools include manual polyline tracing tools and flat 2D panel objects in 3D space. Interpretative polylines are can be used for describing interfaces and structural features. They can be exported in ASCII to populate 3D geo-modelling tools. 2D panels can dynamically receive the projection of 3D outcrop texture along any section, or dynamically project their own texture onto the digital outcrop model. Panel texture may be an interpreted 2D section or a log, or a third party geophysical data section.

CloudCompare is dedicated to visualizing dense point clouds, from which to extract relevant geological quantities: dip/strike, spacing, thicknesses, volumes, etc. Two specific plug-ins, FACETS and COMPASS, are relevant to 3D geomodelling. FACETS, provided with a point cloud with normals, will automatically extract planar point sets (Dewez et al., 2016). Points with normal and planar facets can be dynamically queried and segmented on a stereogram display to be exported as ASCII or polygon vector Shapefiles for further plane set analyses (virtual scanlines, etc). COMPASS (Thiele et al., 2017) is designed for manual fracture mapping, both as planar faces or trace lines. Extracted planar objects are compatible for display into FACETS's stereogram window.

LIME and CloudCompare will be demonstrated in an application dedicated to mapping naturally occurring asbestos (Fig. 2**Erreur ! Source du renvoi introuvable.**). The roadside digital outcrop model is used (i) for interpreting the geological architecture; (ii) inferring an asbestos presence hazard model and (iii) supporting an asbestos rock sampling strategy.

These tools bridge the gap between multi-million 3D points outcrop and geomodelling software.

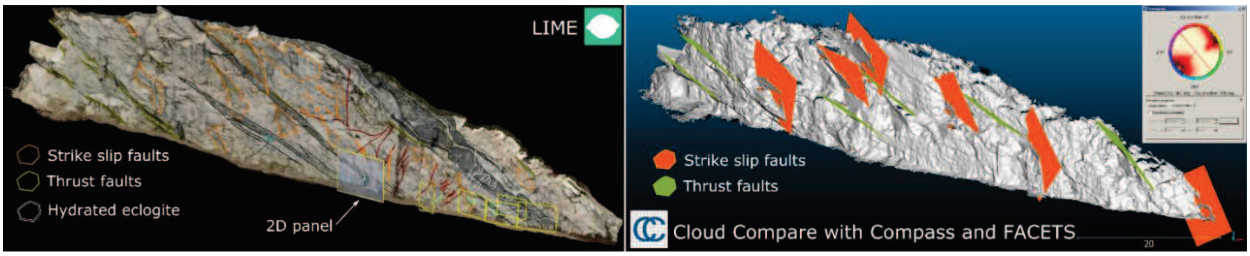

Fig. 2: Digital Outcrop Model interpretation. Textured mesh with geological architecture and field photos annotations in LIME (left). Quantitative interpretation of point clouds in Cloud Compare (right) with major fault planes mapped manually with Compass and stereogram display from FACETS.

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Dewez, T.J.B., Girardeau-Montaut, D., Allanic, C., and Rohmer, J., 2016, FACETS : a Cloud Compare plugin to extract geological planes from unstructured 3D point clouds, Int. Arch. Photogramm. Rem. Sens. Spat. Inf. Sci., doi: 10.5194/isprs-archives-XLI-B5-799-2016.

Thiele, S. T., Grose, L., Samsu, A., Micklethwaite, S., Vollgger, S. A., and Cruden, A. R., , in review 2017, Rapid, semi-automatic fracture and contact mapping for point clouds, images and geophysical data, Solid Earth Discuss., doi: 10.5194/se-2017-83.

Digging into 3D Geological Models with cavity laser point clouds: a preliminary approach

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The practice of geological field data capture is currently evolving with the advent of semi-automated laser scanning and digital photogrammetric acquisition that can usefully complement collected (deca-)metric GPS locations and compass readings. Today, the introduction of mobile underground laser scanning tools, such as Zeb-Revo handheld laser scanners provide a wealth of detailed information. The output from this acquisition is a, possibly noisy, unstructured multi-million 3D points cloud that need processing to obtain discrete models – typically topologically consistent triangulated surfaces - of the sampled surfaces. Handling this geometric complexity with a multi-scale approach of geomodelling is then a new frontier.

In this presentation, we explored a preliminary approach on a case study based on underground laser scanned galleries. The gallery network (ca. 1 ha) is located in the eastern suburbs of Orléans, central France, and was visited during the workshop demo session. It was scanned at *ca.* 1pt/1cm with a Zeb-Revo. The original point cloud was segmented into ceiling and floor with Cloud Compare's raster minimum and maximum elevation grid tool. Indeed, (local) 2.5D surface segmentation, is a possible and convenient option to denoise and compute gallery normals coherently when the software cannot compute normal from sensor location, or when sensor locations are not provided to end users. Merged ceiling and floor sub-clouds were then meshed into a watertight surface. This automated pre-processing approach limited manual interaction with the point cloud data, at the expense of severely diminishing the relative abundance sub-vertical structural features, compared to horizontal ones (here bedding).

From this extensive body of data, two ways interactions are possible:

- the capture of relevant geomodelling information: both raw point clouds and meshed models may provide structural data - typically fracture or bedding planes, geological contacts… - either by visual interpretation and interactive picking or (semi-)automated processing (figure 1),
- the integration of models of the sampled surfaces (here the quarry) into multi-purpose comprehensive models of the subsurface, ranging from the mere static visualization (*e.g.* direct evaluation of the geomodel on raw points or mesh elements - figure 2) to full interaction with joint modifications.

A geomodel of the case study subsurface area (*Calcaire de Beauce*, Tertiary) was made with the *GeoModeller* software, considering a tabular sub-horizontal multilayer environment. Both the geological and cavity models can then be queried simultaneously through an independent API, relying on the use of two single spatial queries: the spatial domain at a given point, and interfaces intersected by a given segment. Then, it provides a unified representation of the underlying models. Typical applications include consistent 3D mesh generation to perform simulation of coupled physical processes between rocks and cavities.

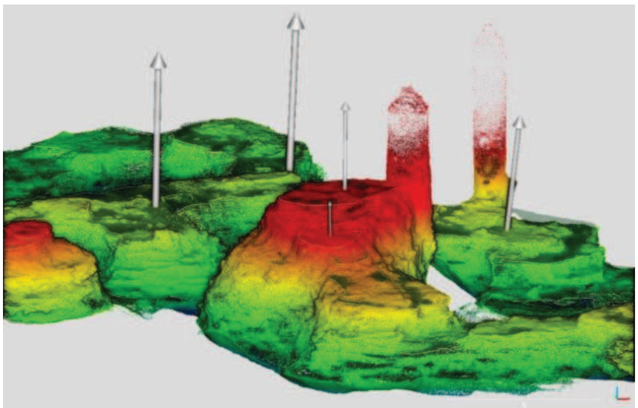

Figure 1: capturing bedding orientations with the Compass plugin in Cloud Compare.

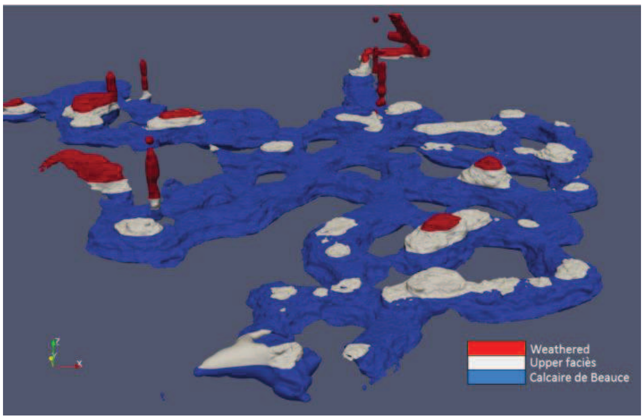

Figure 2: intersecting the geological model (GeoModeller) with the cavity envelop.

The first step to a 3D model of the North German Basin - The TUNB "Pilotregion"

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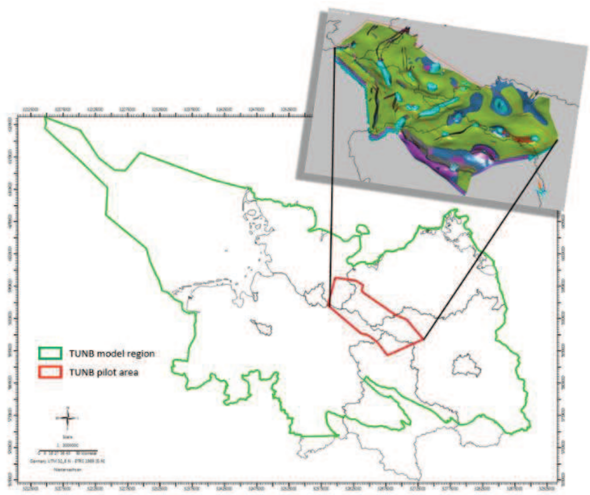
Utilisation of the deep subsurface in Germany is continuously increasing. Next to the established production of mineral water, thermal water, and hydrocarbons, the deeper subsurface will also be used for the production of hydrothermal energy and the storage of renewable energy such as compressed air and synthetic natural gas, or potentially carbon dioxide. The different demands raise the need for more detailed geological information, e.g. in the form of 3D models of the deep subsurface. The project "Subsurface Potentials for Storage and Economic Use in the North German Basin (TUNB)", starting back in 2014, aims to create such a model.

The model of the North German Basin will be created by the Federal Institute for Geosciences and Natural Resources (BGR) and the state geological survey organisations (GSO) of the north German federal states Schleswig-Holstein, Niedersachsen, Mecklenburg-Vorpommern, Brandenburg, Sachsen-Anhalt. While every GSO is responsible for its territory, the BGR is responsible for modelling the area of the German North Sea. Due to quite heterogeneous data bases, two different Atlases are in use, one containing structural contour and isopach maps of seismic reflection horizons [1], the second builds on lithostratigraphic units [2], a lot of effort has been taken to harmonise the data and the modelling approaches.



As a first step a pilot modelling area was chosen to develop and check harmonisation, working and documentation routines. The "Pilotregion" area covers a small region, where the five federal states lie in close proximity to each other. It stretches over 150 km in NW-SE and 50 km in E-W direction and is located at the former inner-German border SE of Hamburg (see figure).

The model comprises 16 horizons, 24 salt structures and more than 200 faults. It covers about 7,800 km² (~5% of the final model). The model of the "Pilotregion" will also serve as testing area for future work (volume modelling, parametrization, distribution).

[1] REINHARDT, H.G. [Hrsg.] (1960-1991): Regionales geophysikalisches Kartenwerk der DDR. – Unveröffentlichtes Kartenwerk/Bericht, VEB Geophysik; Leipzig.

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3D distribution of groundwater salinity as derived from airborne EM and a stochastic geological model

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The availability of fresh groundwater in the province of Zeeland, the Netherlands, is limited. Recurrent transgressions have deposited marine and tidal sediments and salinized the groundwater. Recently infiltrated rainwater has formed shallow freshwater lenses that are important for agricultural, industrial and ecological purposes. Assessment of the current distribution of fresh groundwater and modelling of the effects of future changes asks for detailed information on the current salinity distribution.

A consortium of Deltares, GSN-TNO and BGR conducted a province-wide survey, collecting airborne electromagnetic measurements that were inverted to resistivity. To calculate groundwater salinity, the resistivity values first have to be separated into two parts: a part attributed to sediment resistivity (depending on lithology) and a part attributed to groundwater resistivity. GSN-TNO develops and maintains a detailed 3D stochastic voxel model of lithology classes at a resolution of 100x100x0.5 m voxels (GeoTOP). After parameterization of GeoTOP with sediment resistivity values based on lithological properties, groundwater resistivity was calculated along the flight lines by taking into account the resistivity of sediments. The calculations from bulk resistivity, via sediment resistivity to groundwater salinity are embedded in a Monte Carlo approach, enabling the incorporation of several sources of uncertainty. This includes, among others, uncertainty of the inversion method and the uncertainty of sediment resistivity, the latter resulting from the imperfect knowledge of lithology that is captured in the stochastic properties of the GeoTOP model. The calculated groundwater salinity along the flight lines was interpolated to a voxel model. This 3D groundwater salinity model, incorporating the above mentioned uncertainties as well as uncertainty arising from spatial interpolation, provides end-users with a realistic upper- and lower bounds of the fresh-to-saline interface.

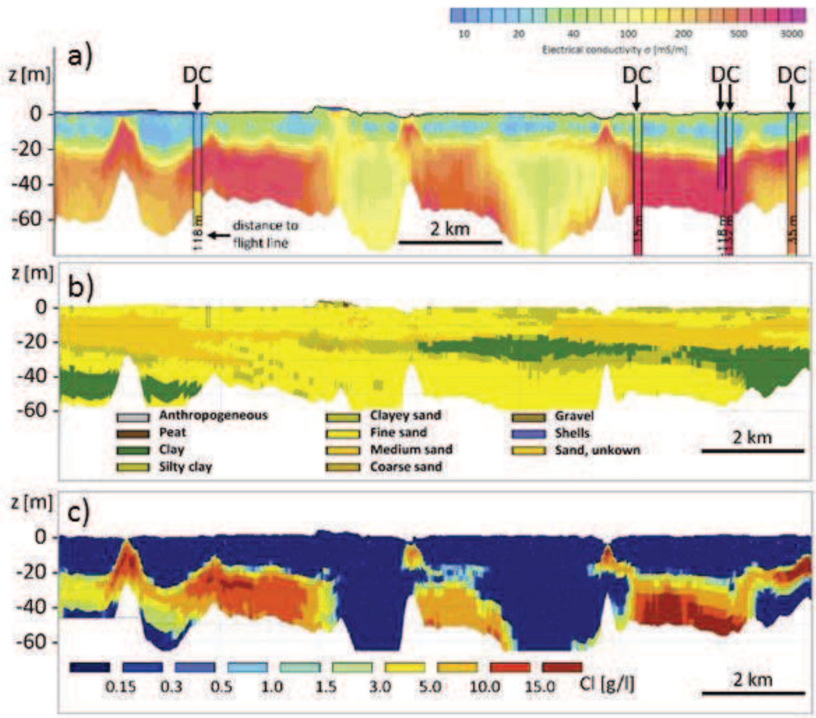

Fig. 1: Profile along a flight line showing a) bulk resistivity, b) most probable lithology derived from the 3D geological model GeoTOP and c) Chloride concentration as calculated from bulk resistivity and sediment resistivity.

3D Geological modelling and gravity inversion of a structurally complex carbonate area: Application for karstified massif localization

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In Languedoc (S. France), significant water resources are found in karstified limestones of mostly Late Jurassic age, deposited as platform carbonate on the Tethyan margin (Maréchal *et al.,* 2013). The area is structurally complex, as a result of polyphase cover tectonics, including uplift, folding and reverse faulting, as well as extensional bloc-faulting and subsidence. From mid-Cretaceous, up to 4 phases of karstification have affected the carbonates, when and where they were exposed (Husson, 2013). The need for increased water resources leads to target deep karsts buried beneath younger sedimentary cover. We propose a new methodology to improve the location of potential karstified areas by gravity inversion of a 3D geological model.

The model covers 70 x 30 km area which encompasses the structural complexity; it is 5.5km thick, in order to include the entire post-Palaeozoic sedimentary cover. The available data comprise: 1/250.000 and 1/50.000 geological maps, about 250 km of reprocessed 2D seismic reflection profiles, 14 petroleum exploration boreholes, 693 shallower boreholes, and gravimetric survey. In area devoid of seismic reflection data, depth sections were drawn from surface geological maps and borehole data, where available. Regional geology provided a general template and constraints while building the 3D model. The stratigraphy for the model distinguishes 11 intervals with either reservoir or seal characteristics. The structural framework is compartmented by 37 major faults.

The model is built by integrating field-based or seismic reflection-based geological sections. Modeling with 3D GeoModeller allowed us to check for inconsistencies within the input data. For example, although some sections may be consistent as a 2D construction, they fail to be integrated in a coherent 3D model. Further, there are several difficulties that 3D GeoModeller helps overcome, especially in the poorly documented areas: not imaged by seismic, or distant from borehole data, or cover by recent alluvium. In that case, the model computes the simplest geometrical solution by interpolation of the nearest data. Such solution can be confirmed or modified by the user, according to geological interpretation and gravimetric data interpretation, imported in the software.

Its theoretical gravimetric response is compared to gravity field during the forward problem in order to evaluate the validity/robustness of the geological model. The coherency between the gravity field and the gravimetric response is tested. The litho-inversion modelling quantifies the distribution of rock density in a probabilistic way, taking into account the geology and physical properties of rocks, while respecting the geological structures represented in the 3D model. The result of the inversion process provides a density distribution within carbonate formations that can be discussed in term of karstification distribution. Thus, lower densities correlate with areas that are strongly karstified. Conversely, higher than mean densities are found in carbonate formations mostly located under marly and impervious formations, preserving carbonate from karstification and paleokarstification.

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Marechal, J. C., Vestier, A., Jourde, H. and Dörfliger, N. (2013) L'hydrosystème du Lez: une gestion active pour un karst à enjeux. *Karstologia*, **62**, 1-6.

Coupling of GeoModeller and FEFLOW: A Case Study with demonstration - Tunisian Groundwater challenges addressed

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In north African nations such as Tunisia, geological exploration under cover remains the most difficult challenge to success in finding continuing water resources, geothermal energy, oil and gas, and minerals. Achieving such goals requires understanding the 3D geometries of subsurface geology and structures.

Creation of a realistic 3D geological and structural model of the Kasserine Aquifer System (KAS) in central Tunisia and north-east Algeria, was the main workflow of stage one of this project. This was achieved using an implicit 3D method, which honours prior geological data for both formation boundaries and faults. The model built in GeoModeller software provides defendable predictions for the spatial distribution of geology and water resources in aquifers throughout the regional-scale model-domain.

Aquifer connectivity and the hydraulic significance of the major faults was assessed using the 3D model. This was carried out by evaluating the influence of faults on known groundwater flow directions, and the locations of springs, within and between four compartments of the multilayered, KAS hydrogeological system. Results indicate: (1) Possible dual nature of faults in the KAS with some faults acting both as barriers to horizontal groundwater flow, and simultaneously as conduits for vertical flow; (2) the possibility of two flow directions occurring in the region of a small syncline near Feriana; (3) predicted existence, mainly in the west, of the Aquitanian red clay aquitard (up to 100 m thick) separating Cretaceous limestone from Mid-Miocene sandstone, supported also by the absence of springs coinciding with the modelled extents of this aquitard in the west.

The conceptual model at regional scale, was next used to estimate volumetric groundwater resources, and perform numerical flow modelling on a finite element mesh coupled with geological information derived from the model, using FEFLOW software. This integrated 3D approach, linked to a model of realistic geology and faults has world-wide applicability for critical understanding of groundwater systems as resources.

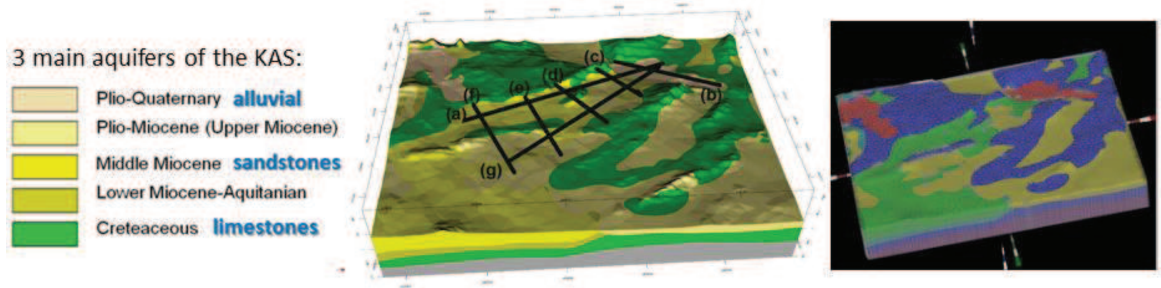

Fig. 1 left: hydro-stratigraphic units of the KAS; middle: regional conceptual 3D geological model of the KAS (GeoModeller); right: exported finite element mesh for flow simulation viewed in FEFLOW software.

Dufour, R., Gibson, H. Mariethoz, G. and Carpentier, A. (2013). Groundwater flow solutions based on different degrees of geological complexity: A case study from the north Perth Basin, Western Australia. *Proceedings of the IAH Conference,* Perth 2013.

Hassen, I., Gibson, H., Hamzaoui-Azaza, F., Negro, F., Rachid, K. and Bouhlila R. (2016). 3D geological modeling of the Kasserine Aquifer System, Central Tunisia: New insights into aquifer-geometry and interconnections for a better assessment of groundwater resources. *Journal of Hydrology* **539**, 223–236.

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Reservoir Heterogeneity and modeling of the Oolithe Blanche (Dogger of the Paris Basin)

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[1] BRGM,

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The Oolithe Blanche Formation (Bathonian) of the Paris Basin, is with the Trias, a key deep saline aquifer for both geothermal and CO_2 geological storage applications. It corresponds to an open-marine to shoal barrier and restricted lagoon carbonate ramp, and its reservoir performance has been addressed in many reservoir hydrogeological studies.

Yet strong uncertainties remain regarding: (a) the sedimentary geometries and associated facies in subsurface and (b) the nature, location and connectivity of the permeable producing levels in the geothermal area (Paris area).

The present study proposes through basin- and field-scale wells-correlations, a refined characterization of the Oolithe Blanche Formation (sedimentary geometries and facies), together along a reservoir modelling (facies and petrophysical). This model will provide first answers on the nature and connectivity of the porous and/or permeable levels.

The 3rd order well-correlations show a subdivision of the large-cycles defined by Gaumet (1997) into 7 minor cycles. They illustrate relative flattened and continuous geometries, traducing a low-inclined depositional profile registering quick facies variations induced by relative-sea level variations. The lowermost cycles show large-scale smooth progradation of the ramp, with scattered shoal developments (uppermost Bajocian - lower Bathonian). They grade to more aggrading/retrograding cycles (middle-upper Bathonian) in which shoals tend to stack and form a more continuous barrier. The flooding of the ramp yields to a relocation of the carbonate production in the proximal area, while the starving distal ramp undercomes an early diagenesis responsible for a strong cementation of the facies (Hardground). Finally, the late Bathonian spans the widespread development and progradation of restricted marine deposits and barrier facies above open-marine marly facies traducing a drop of the relative-sea level recorded in the Eastern basin by a weathering surface and a time gap (Brigaud, 2009).

Using this sequence stratigraphy and facies analysis on well-logs, a reservoir model was built. Facies were simulated sequence by sequence using truncated Gaussian simulations. Several Porosity and permeability distributions were established on core-data: a strong linear phi/k law (optimistic) and a low phi/k law (pessimistic). Using dynamic data, each well was assigned one of these 2 laws accounting for local dynamic; and following this approach, an optimistic or pessimistic law was simulated within each sequence.

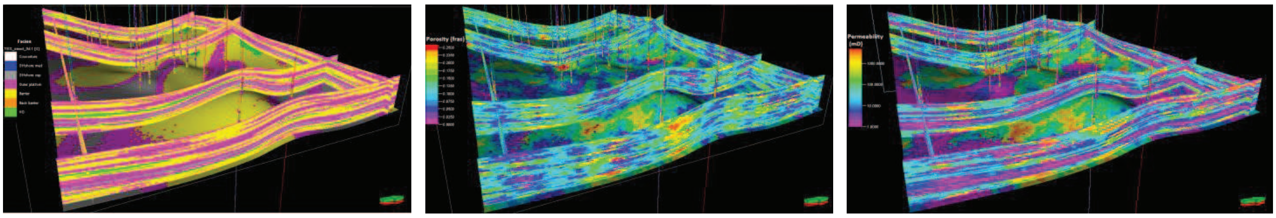

Figure 1: Facies (Left), Porosity (Center) and Permeabilty (Right) model. In Yellow are represented the shoal facies which comprises the highest porosity and permeability values. On the contrary, pink (outer-ramp), grey (marly outer-ramp) and green (hardground) facies show relative poor reservoir properties.

The model allows the identification of several reservoirs: (a) above the flooding surface within shoal facies (poorly cemented grainstone), (b) at the Hardground-shoal contact (following the MFS,) and (c) within open-marine tight and marly facies. The reservoir quality is thus controlled by initial porosity preservation in relative continuous reservoir bodies, drains-dynamic within at the Hardground-shoal interface (facies and petrophyscial contrast), and probable fracturation or fissuration (both hardground and outer-ramp facies) with a very poor connectivity at the doublet scale.

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Brigaud, B., 2009 - Influence du contexte sédimentaire et de la diagenèse sur les propriétés pétrophysiques du dogger calcaire de l'est du bassin de Paris. PhD. Thesis, University Dijon.

Geological modelling of the El Golfo multi-event landslide (El Hierro Island, Canary Archipelago)

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This work presents a 3D geological model of the El Golfo debris avalanche, island of El Hierro (Canary Archipelago, Spain). The 3D model has been developed combining onshore and offshore geological and morphological data (Leon et al., 2017). This methodology is a valuable tool in assessing the tsunamigenic potential of flank collapses in oceanic volcanic islands.

Offshore data from multibeam echosounders, chirp subbottom profiles and multichannel seismic reflection data and onshore data coming from water-wells and galleries have been analyzed. The geomorphology and the internal architecture of this giant flank collapse are defined in order to determine its multi-event nature.

The subaerial headscarp shows a non-continuous arcuate profile formed by two nested semi-circular amphitheaters that extend offshore along a smooth chute, suggesting the occurrence of at least two large retrogressive events. In the lower slope, two subunits of submarine mass transport deposits (MTDs), debris avalanche, are identified on multichannel seismic reflection profiles. Data from wells and galleries show abrasion platforms with beach deposits at sea-level (0 masl) formed after the landslide scar and buried by the post-collapse El Golfo lavas infill, suggesting an age at least older than 23.5–82.5 Ka for the landslide.

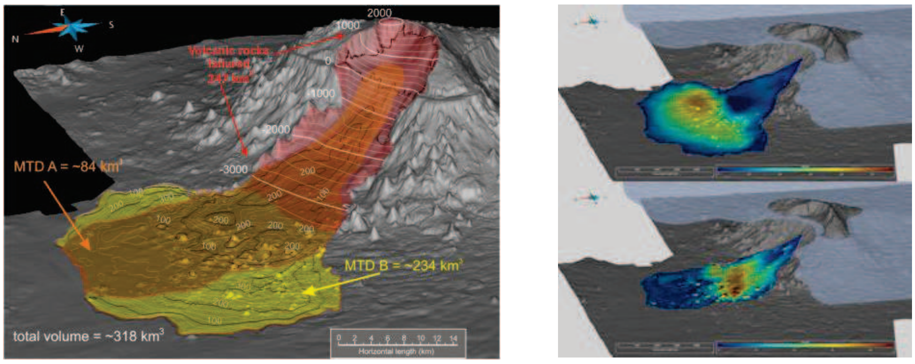

Fig. 1: 3D Geological model of the two mass transport deposits episodes.

Three main surfaces have been created, using the software Paradigm® SKUA-GOCAD 15.5™: the previous relief and the two MTDs delimited by the geomorphological data and the seismic profiles.

The landslide planes have been constructed from the lines interpreted from the seismic profiles which have been extrapolated on land from the well data. The MTDs horizons were transformed from time to depth domains and fitted with the bathymetric map and the geomorphological cartography, which allows to delimit the extension of the deposits.

The original relief of the island has been interpolated from the flanks that can be observed on the sides of the landslide both on land and partly submerged. Curves have been delineated at several heights following the trend of the actual relief, up to 2000m high from the sea level.

The post-collapse lavas are eliminated from the estimated slipped volume by extending the base of the landslides under the lava deposits up to the base of the escarpment that marks the sliding scar and adjusting it to the depths measured from the well data. The perimeter of such lavas has been delimited from the cartography. Then, a surface has been built with which the current relief has been intersected, forming the base of the detachment. This hypothetic volume of the island involved in the failure has allowed to estimate the uncertainty, following two methodologies.

The volumes of the landslide and the deposits have been calculated, with a total estimated volume of 318 km^3: ~84 km^3 and ~234 km^3, for the younger and older MTDs respectively (León et al., 2017).

Reference:

León, R., *et al.*, 2017. Multi-event oceanic island landslides: New onshore-offshore insights from El Hierro Island, Canary Archipelago, *Marine Geology 393: 156-175.*

A role to play for geological surveys in urban information platforms ?

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Geo-Hazards (ground stability, subsidence, earthquake, flooding), resources and services (water, geothermal energy, energy storage, building materials), remediation of polluted soils, urban wastelands… are key challenges for smart / sustainable / resilient cities and infrastructures. However, urban stakeholders (local authorities, planners, engineers, citizen) are not used to handle and process "geological information". Geological surveys have a lot of expertise in those domains but usually provide very specific information about one specific question (in a “silo”) and not a global representation of the knowledge. This results in a limited use of geological information even when the development of cities is focusing on the use of subsurface space. Moreover, the interaction of geological (sl) information with the build environment, and the natural components above the surface (air, water) is often not defined.

Scientific and technical developments have to be conducted to facilitate those connections. This includes the development and implementation of standards for interoperability between the domains. Integration of multi-domain data into simulation tools or big data processes will benefit from this approach.

From a city perspective, one view would be to develop large information platforms involving the local authorities, public agencies (as geological survey, environment agency,…) and industry (very often building and/or operating urban infrastructures) to collect, manage, share the information about the built and natural environment of cities. For the geological surveys who consider that they have a mission to provide a reference information for the development and management of urban areas, it is therefore critical to define what role they may play in this ecosystem…

The presentation will address some opportunities and challenges around those platforms: what could be the role of the different parties, what business model put in place, what legal incentives should be necessary…

Putting our models to work: Applications of 3D voxel models in real life situations

Jan Stafleu[1], Denise Maljers[1], Jan Gunnink[1], Freek Busschers[1], Kay Koster[1], Vasilis Hademenos[2]

[1] TNO - Geological Survey of the Netherlands, [2] RCMG - Ghent University, Belgium

Geological voxel models subdivide the subsurface in a regular grid of rectangular blocks ('voxels', 'tiles' or '3D cells') in a Cartesian coordinate system. Each voxel contains multiple properties that describe the geometry of stratigraphical units and the spatial variation of lithology within these units. Using voxel models, the architecture and internal heterogeneity of stratigraphical units in the subsurface can be modelled in great detail. By assigning physical properties to the voxels we are able to turn the models into powerful instruments for a wide range of applications such as: groundwater management, risk assessments, the planning of infrastructural works and aggregate resource assessments. The underlying assumption is that the spatial variation of many subsurface properties, such as hydraulic conductivity and shear-wave velocity, strongly depends on the two main geological properties in the model: stratigraphy and lithology (Figure 1).

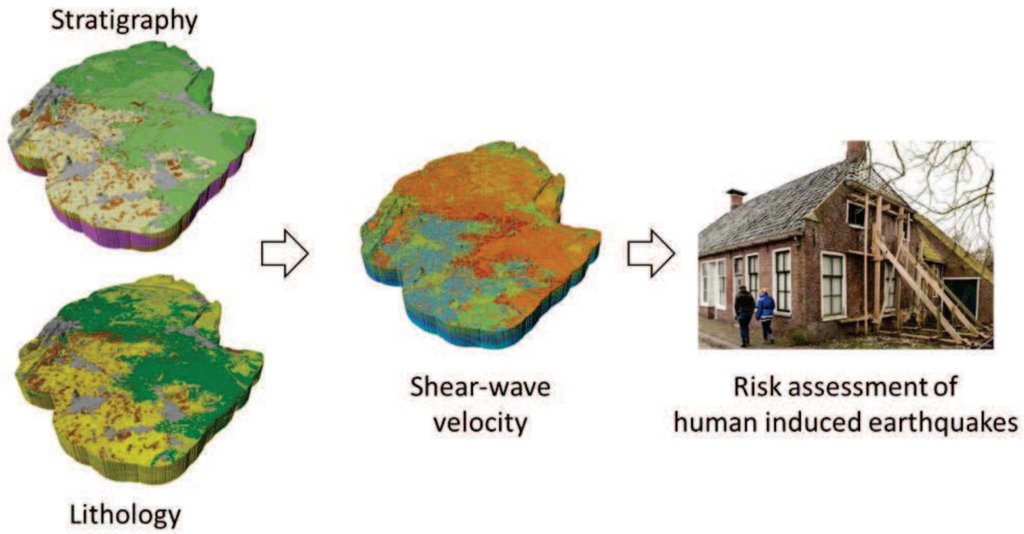

Fig. 1: Putting geological voxel models to work by adding properties related to the application at hand.

In this presentation, we will show the following real life applications of geological voxel models attributed with physical properties: 1) the Netherland's nation-wide mapping programme GeoTOP, 2) a detailed model of the subsurface of Tokyo Lowland, Japan, and 3) a voxel model of the Belgian Continental Shelf. These models cover the upper 50 m of the subsurface.

The GeoTOP model covers 23,325 km^2 (57%) of the surface area of the Netherlands. It is a multi-purpose model that has already been used in a number of different applications. A recent application is the risk-assessment of damage caused by human induced earthquakes in the Groningen gas field (Figure 1). Another GeoTOP-application is the long-term prediction of land subsidence due to the oxidation and compression of peat layers.

The model of the Tokyo Lowland was used to study the relation between the accumulated thickness of soft Holocene mud and the amount of damage caused by natural earthquakes.

The Quaternary sands of the Belgian Continental Shelf are a resource for the construction industry and for the reinforcement of the Belgian coast. A voxel model based on shallow seismic profiles and a limited amount of boreholes was developed and subsequently complemented with an online query-tool. This tool enables the users to perform volume calculations, which are crucial for the management of raw materials in the marine environment.

These case studies exemplify the value of geological voxel models in real life applications. Furthermore, they show that voxel models attributed with physical properties are deployable in a wide range of geological settings.

Modeling gypsum thickness in order to evaluate collapse hazard in Paris area

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[1] BRGM,

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Realization or exploitation of geothermal drilling intersecting gypsiferous layers can provoke terrain collapse in case of gypsum dissolution. French regulations require mapping geographical areas where such risks may exist. This is why the BRGM and the CEREMA where commissioned by the DRIEE to evaluate geological hazard related to the presence of gypsum layers in Paris area ("Île-de-France" Region).

In Paris area, gypsum is present in two main geological "units": on one hand in a set of three geological stages of Paleogene (Sannoisian, Ludian and Marinesian) and, on the other hand, in upper Lutetian/Bartonian formations.

This paper presents the methodology developed in order to compute maps of gypsum thickness as a function of depth to the surface.

The methodology is based on the use of 5059 drill holes from the national drill holes database (BSS), which holds lithological and litho-stratigraphical interpretations for each run. Recent work of Briais* (2015, PhD thesis supported by BRGM), based on sequence stratigraphy concepts and using a subset of 488 high quality drill holes owning a gamma ray log (here after named "reference holes"), enabled to build reference geological surfaces, including top and base of Paleogene and Lutetian/Bartonian formations. As a result, a first 3D geological model of gypsiferous formations was obtained.

Then, remaining drill holes (approx. 4,600) were automatically compared to the reference surfaces and to the 3D model in order to (1) identify the drill holes that were matching the reference surfaces, and (2) detect drill holes that needed re-interpretation. This step included a geostatistical analysis, and a cross validation of low quality holes against high quality "reference holes". A total of 388 drill holes integrated the "reference holes" list, thus reaching nearly 900 holes.

At last, cumulated gypsum thickness encountered within various depth ranges (example 0-25m; 50m-100m – Fig. 1) was interpolated within each of the two gypsiferous "units", using the full data set. A particular attention was paid to properly take into account holes not intersecting the whole depth interval. Thickness maps were then combined with hydrogeological data to quantify geological hazard.

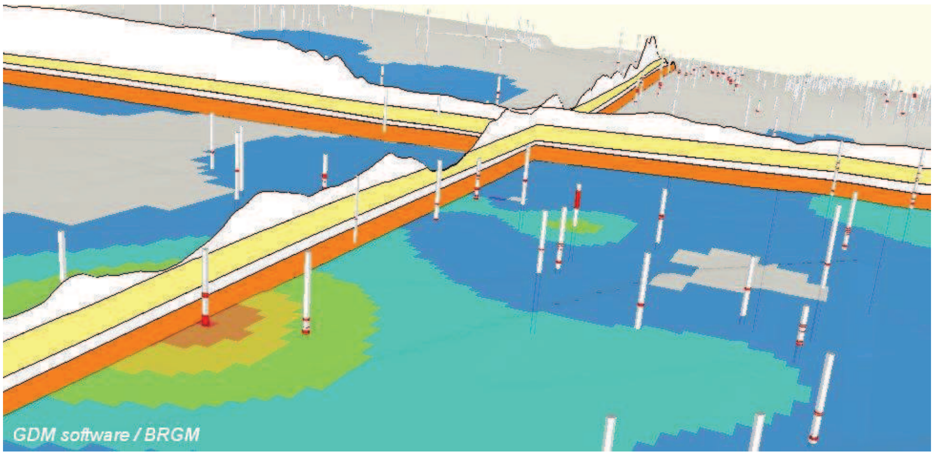

Fig. 1: Example of two sections in the geological model (yellow layer: Sannoisian to Marinesian unit; orange layer: Lutetian/Bartonian unit) and projection of the cumulated gypsum thickness map for the Lutetian/Bartonian (50-100m depth). Gypsum layers are represented by red levels in drill holes.

* Briais J. (2015) Le Cénozoïque du bassin de Paris : un enregistrement sédimentaire haute résolution des déformations lithosphériques en régime de faible subsidence. Phd Thesis, Université de Rennes 1, 450p.

3D geological reconstructions for the development of geothematic layers useful for urban planning: El Papiol case study (Barcelona Metropolitan Area)

Roser Pi[1], Miquel Vilà[1]

[1] ICGC (Institut Cartogràfic i Geològic de Catalunya)

A 3D geological reconstruction has been carried out within the framework of an urban geology project in the municipality of el Papiol, in the Metropolitan Area of Barcelona. For this project, that is based on a detailed geological survey, a series of cartographic layers related to basic geology, hazards, resources and geothechnical constraints have been developed. As a whole, 22 geothematic layer groups relevant to the planning, development and sustainability of the municipality have been done. One of these layer groups refers to the reconstruction of the main geological surfaces that compartmentalize the subsurface of the study area.

Based on the geological frame and objectives of the project, it has been established that the subsurface of the study area is compartmentalized by five main lithostratigraphical horizons: 1) base of the anthropic deposits; 2) base of the Quaternary deposits; 3) base of the Pliocene deposits; 4) base of the Miocene deposits; 5) base the Triassic deposits. The 3D geological modeling is focused on the reconstruction of these surfaces, which correspond to major unconformities. The reconstructions have been carried out after an exhaustive compilation and analysis of borehole information and, at the same time to the detailed mapping (1:5000 scale) of the anthropic deposits, Quaternary deposits and the pre-Quaternary basement.

These surfaces have been obtained from contour lines at 5-metre intervals defined on the basis of expert criteria, assuming different conceptual models and integrating the surface geology with the available subsurface data. The main criteria in the reconstruction of the contour lines vary depending on the geomorphometry of the area, the nature of the surface and, the availability of borehole and outcropping data, including structural measurements. The isopach maps of the Antropocene, Quaternary, Pliocene, Miocene and Triassic deposits have been generated from these surfaces. These maps, combined with other lithological and geotechnical information of the materials that compose the cartographic units of the study area, have permitted the execution of a series of ground engineering conditions layers concerning excavatability, slope design, foundations as well as suitability of deposits as engineered fill. The 3D reconstruction has also served to create other geothematic layers related to landslide hazards, ground-water vulnerability to contamination and seismic ground response of this part of the Barcelona Metropolitan Area.

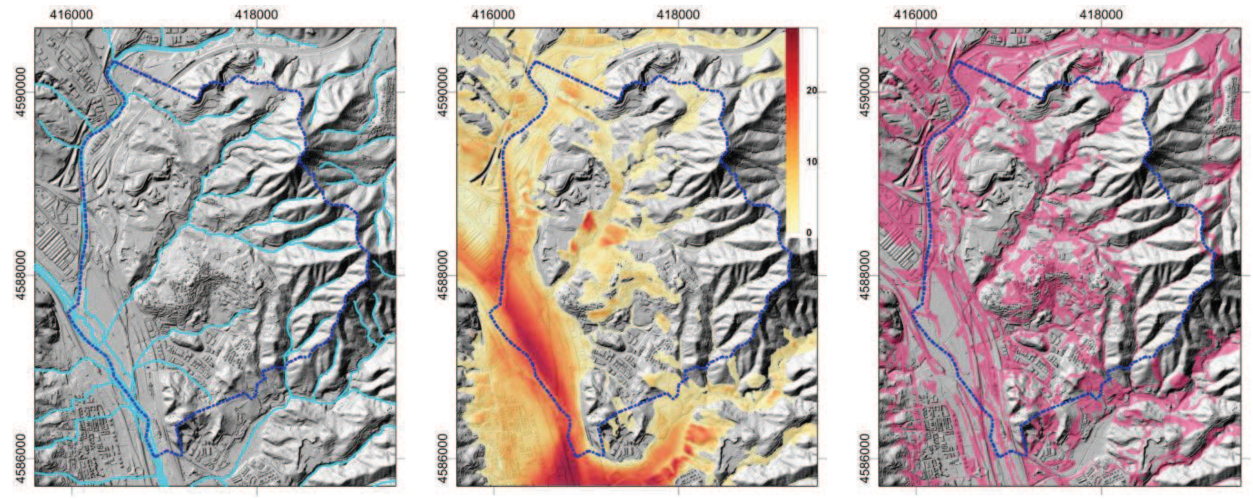

Fig. 1: Representative figures of the presentation: study area (left); thickness of Quaternary deposits (centre) and; areas with near-surface variable geology (thickness of the outcropping geological units less than 5 meters) useful to address several engineering ground conditions (right).

BIM and GIS: Excavated Material Management

Maxime Beaudouin, Haddad Latif

SYSTRA

Nowadays, social concern for sustainable design and environmental conservation is making the management of excavated material more complex. But new developments in processes and technologies, notably due to the BIM approach, are providing tools and methods facilitating forward planning and control of this management. Data classified as soon as it is collected, made available to the various trades practically in real time, and interoperable with specific dedicated tools, will make it possible to rapidity model the subsoil and its infrastructure, and simulate flows of excavated material for the design engineering part of the project. Field tools connected to this data, used during the works phase, will finalise this management.

The data of ground are stored in AGS format via the applications SIG stemming from the platform SIG SYSTRA: Geosystra. These Web-applications give to the various actors an interface to share their data and the system is in charge to organize in the database the information. With the GDM solution, edited by the BRGM, it's possible to create a 3D model of the ground by using a connexion on this base. This process give more simplicity to collect the primary data and to enhance reliability of the data so the model.

With BIM IN ONE CLICK, solution created by the SYSTRA, the design mockup by Civil engineering generates its structures associated with their attributes automatically and easily alongside the 3D ground mockup. This simple way to create linear and regular structure in BIM model with Excel files given by the engineer is a very important gain of time without a decrease of the quality. For Example, structure element of the tunnel can be created from a template and the system had information of the Excel file.

In the federated model, in visualisation, structure of the tunnel and the underground are mixed. But you can extract the information of the underground of the ground cross in each object. All of the element are distributed in rings and each have a localisation, structure information and volume of different ground intersected. This result can be used for anticipate some problem of interface between structure and ground, to found solution and adapt or adjust the construction method. But, now, a planning of the ground excavated may be extracted of the federated model.

A localisation of outlet, a planning of the excavated ground, a localisation of the different usable area and implantation of the road, rails and river…. push all of that in a GIS system and the result is a flux modelling of the ground for the project. Because the studies use BIM process, you can change one element or mockup and create in very quick time a new simulation.

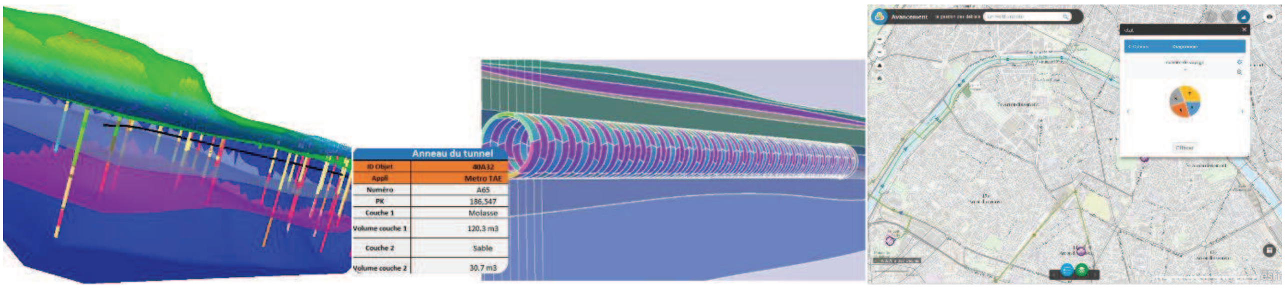

Fig.: GDM 3D Model, BIM IN ONE CLICK with ground information, GIS application.

In the construction phase, a team provided with mobility tools collect the information in real time and push the data in the database. A web-application share the collected data and compare with the simulation. For the customer, this tool give a possibility of increase the management of ground and decrease the risk. With data in real time, the answer of a problem can be very quick.

Strangely close friend by their philosophy to want to place the datum in the center of their tools, and with difficulty interoperable due to their clean structuring, the BIM and the SIG can solve together problems which would be difficult for them to resolve independently one of the other one. 3D model of the underground is telling example of this.

Setting interoperability between BIM and Geological Modeling: Feedback from the French MIN^{n}D UC8 project

Mickaël Beaufils[1], François Robida[1] on behalf of the MIN^{n}D UC8-GT team.

[1] BRGM

Advent of Building Information Modeling (BIM) lead to the design of more and more building 3D models. Following the CAD approach, those models are most of the time built by assembling (at least visually) individual components, and therefore are very detailed, representative of the real building, thus useful in conception, construction and maintenance.

Some projects like MIN^{n}D [1] in France focus on enhancing BIM capabilities to deal with infrastructures, such as roads, bridges or railways. One major activity consist in extending the IFC standards, endorsed by building Smart International (bSI), to properly describe infrastructure and their equipment's. However, due to its size, infrastructure modelling is more complex than building modeling as it must also be compatible with environmental models to be useful during each step of the life of the infrastructure.

Several projects like RaxEnv [2] or DeepCity3D [3] demonstrated feasibility of having building and geology represented together. However, this was restricted to visualization, thus not machine readable and hard to maintain and update. Then integrated models with building and geology are not really widespread.

The main reason of this is a lack of interoperability between building and environmental models. Thus, defining standardized semantic and tools to describe building, infrastructure and their environment is clearly a hot topic to work on: the MIN^{n}D Use Case #8 project explore this.

Started in June 2017, MIN^{n}D UC8 is dedicated to Underground Infrastructure, including tunnels where comprehension of geology is critical and must be considered at each step of the project: conception, construction and maintenance processes.

The UC8-GT team come together to study current practices in geomodelling in construction context, to identify geological and geotechnical elements, properties that shall be properly describe and semantic to use to facilitate collaborative work between partners. Existing standards, especially the one endorsed by the GeoScience Domain Working Group from the Open Geospatial Consortium (OGC) are studied and propositions of extensions made in order to enhance knowledge of the subsurface, thus facilitate sustainable construction and maintenance of buildings and infrastructures.

The proposed presentation will highlight first results of the MIN^{n}D UC8-GT team.

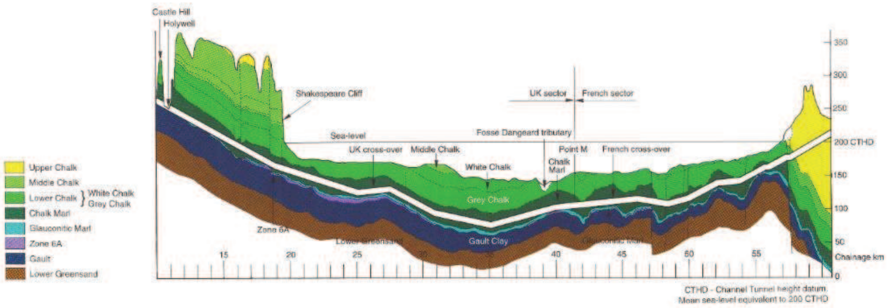

Figure 1 : Cross-section of the Channel Tunnel [4]
An example of coordination between geology and construction domain.

[1] MIN^{n}D project website: http://www.mindd.fr/en/

[2] Zendjebil & al., 2008. Outdoor Augmented Realtity: State of the art and Issues. https://www.researchgate.net/figure/Figure-16-Raxenv-in-urban-scenario-Conceptuel-view_29607565_fig9

[3] DeepCity3D project website: http://www.deepcity3d.fr/default.aspx

[4] With the courtesy of the Geological Society (https://www.geolsoc.org.uk/GeositesChannelTunnel)

Supporting BIM by integrated geological 3D-modeling of urban underground– case study Darmstadt, Hesse, Germany

Rouwen Lehné[1], Christina Habenberger[2], Jacob Wächter[2], Heiner Heggemann[1]

[1] Hessian Agency for the Environment, Nature Conservation and Geology (HLNUG), Wiesbaden, Germany

[2] Darmstadt University of Technology

The city of Darmstadt, with a population of approximately 150,000 (HSL, 2016), occupies about 122 km² within the Frankfurt/Rhine-Main metropolitan region, economically one of the most dynamic regions in Europe. Better knowledge of subsurface conditions would allow more efficient planning, development, and management of water, soil, and raw material resources. Reliable subsurface information for specific locations will permit more efficient construction. While geological 3-D subsurface modeling has recently become an economically and technically viable technology (Arndt et al., 2011; Lehné et al., 2013), its application for urban planning in Darmstadt has been limited by a lack of experience and understanding of the technology by the urban authorities. Adoption of 3-D geological modeling has been hampered by the absence of standardized geological data definitions, no integration of geological and underground infrastructure information, and incompatible multiple platforms for processing geological data.

The Hessian Agency for the Environment, Natural Protection and Geology (HLNUG) therefore developed "Project Darmstadt_3D" in 2015 to address five goals:

- Creation of a high-resolution 3D-model for the urban underground,
- Integration of infrastructure information with a geological/hydrological 3-D subsurface model,
- Development of understandable parameterized geological information that would support urban decision-making,
- Storage of outcomes in a 3-D database, and
- Dissemination of information without charges or restrictions to all relevant user groups and institutions.

A special focus is set on integrating underground infrastructure with the geological/hydrological subsurface model. Foundations and sewage system have been provided by the city of Darmstadt, gas and water supply by a regional supplier. At this stage of the project foundations complement the modeled volume as 3D-objects (Fig. 1a), while the sewage system and supply lines exist as individual objects, which mainly are used for being blended with multi temporal groundwater surfaces in order to track down interaction areas (Fig. 1b).

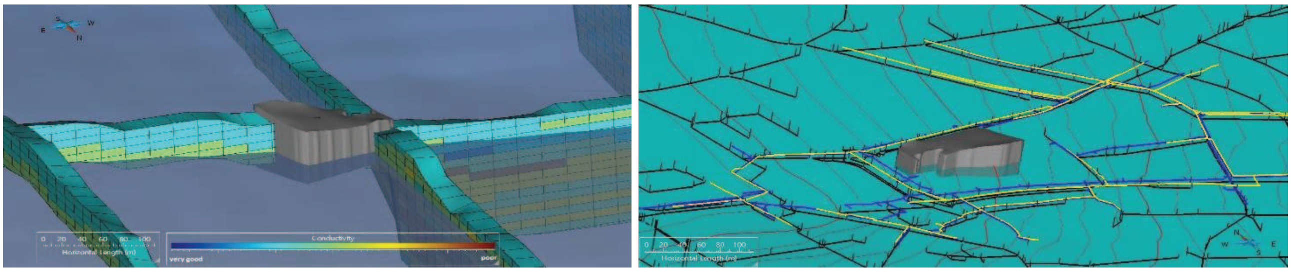

Fig. 1: a) in the geological 3D-model building foundations (grey) replace geological volumes, b) supply infrastructure is part of the 3D-model as well (black = sewage system, blue = water supply, yellow = gas supply, grey = building foundation).

All data and results of the ongoing project are migrated to the generic 3D-database GST and available through desktop and web-based interfaces.

Arndt, D., Bär, K., Fritsche, J.-G., Kracht, M., Sass, I. & A. Hoppe (2011) 3D Structural Model of the Federal State of Hesse (Germany) for Geo-Potential Evaluation. *Zeitschrift der Deutschen Gesellschaft für Geowissenschaften (ZDGG)*. **162(4).** p. 353-370.

HSL (2016): Hessische Gemeindestatistik 2016 - *Ausgewählte Strukturdaten aus Bevölkerung und Wirtschaft 2015.* Hessisches Statistisches Landesamt, Wiesbaden.

Lehné, R.J., Hoselmann, C., Heggemann, H., Budde, H. & A. Hoppe (2013) Geological 3D Modelling in the Densely Populated Metropolitan Area Frankfurt/Rhine-Main. *Zeitschrift der Deutschen Gesellschaft für Geowissenschaften (ZDGG)*. **164(4).** p. 591-603.

POSTER PRESENTATIONS

Contribution of 3D geological modeling in decrypting complex geological settings of water springs, Eastern Algerian area.

Benagoune Farouk[1], Menani Mohammad Redha[2].

[1]University of Mustapha Ben Boulaïd – Batna, [2]MGRE/Laboratory – University of Mustapha Ben Boulaïd – Batna.

Ras el Ain major water spring flows with an average of 70L/s, due to the artesian action of water resulting from an E-W kilometric barrier hidden fault, this fault takes place at the immediate limit of the conglomeratic Miocene immersion under the marly Miocene with gypsum and sandstone, this last is covered by a calcareous and dolomitic coarse conglomerates date since the Quaternary (Saletian).

The water springs through two open diaclases, situate at the Quaternary described, the emergence of water results from an E-W fault, stumbling by the subsidence of the Quaternary and Miocene of the north fault compartment, against the limy Turonian, and partially the calcareous and dolomitic Cenomanian of the South fault compartment, that is responsible of draining water.

Two distinctive probable origins are responsible of supplying this water spring, the first one is the western side of the North flank of the central bulging, that is responsible of the main part of the infiltrated water. The Miocene undifferentiated sediments mostly constitute this side (conglomerates, breccia, lithothamnium limestone), with the very fractured and permeable marly Miocene within sandstone and gypsum, these sediments covers in considerable part the limy and marly Turonian, and sometimes the lower carbonate Turonian.Water agglomerate through the NW-SE fault plan that cut the E-W barrier fault plan, this fault constitute a canal with free flow as the audible noise of streaming through a diaclase in the spring uphill (about 1km) proves (Bellion, 1972).

At the other hand, waters infiltrate and been resembled at the oriental side of the North flank of the central bulging, due to the missive dolomitic outcrop of the upper Cenomanian and the lower Turonian, very fractured and well rained. This happen due to the privileged position of this side among the axial zone of the central bulging. After that, waters will be transported through the dense network of fractures oriented mainly NW-SE by the effect of slope to the immersion limit of Miocene under the Quaternary (immersion of the relief under the plain), and transited finally by a N70°E major fault revealed by geophysics investigation, which been cut at different repeat by NW-SE fractures (Bellion, 1972).

This N95°E hidden fault covered by the Quaternary plain, which is in fact the oriental part of the South flank of Oued Chair-Barika syncline, appears at the western ending of the pointed and refolded anticline of Refaa-Reched. Moreover, it reappears at several repeats from side to side of N'Gaous village sub-parallel to the submersion limit of the upper Cretaceous relief under the Neogene and Quaternary plain.

Bellion, J.C. (1973) Etude géologique et hydrogéologique de la partie occidentale des monts de Bellezma (Algérie)," Ph.D Thesis. 3rd cycle ; Paris VI, 222 p,.

3D geological modeling of the superficial formations, practical applications

Anne Bialkowski[1], Bruno Tourlière[1], Caroline Prognon-Ricordel [1], Frédéric Lacquement [1], Robert Wyns [1]

[1] BRGM

The interest in surface formations or "regoliths" is generating a growing demand, not only in terms of geological knowledge (cartography, lithology, origin, properties, geological connections) but also in terms of issues for the territories (planning, risks, resources management) and therefore economic interests.

In 2009, the BRGM carried out a first survey of the knowledge of the Regolith in France, at a scale of 1: 1 000 000, both for allochthonous deposits (continental deposits linked to the transport process) and for land. autochthonous deposits (weathering patterns). This work, continued since 2013, highlighted a strong heterogeneity in the quality of available geological information and targets the work to be done, especially in the field.

Geometric modeling of the geological units constituting the Regolith is an essential tool to advance the knowledge of the spatial distribution of formations. The application of this tool, closely associated with known geological knowledge, constitutes a first approach and a guide for the development of a potential acquisition strategy on the field.

The methodology implemented in the framework of the modeling of allochthonous and autochthonous regolith formations, carried out under GDM-Multilayer, at the level of each department area, then assembled at the scale of a region (from available geological maps data and drilling data from the Underground Data Bank, BRGM).

This work was done initially at the scale of the Brittany region and it aims to expand to the entire Armorican basement (Fig. 1). Interpolated data maps (roof and thickness) also highlight over- or under-valued results in certain geographic areas, which raises questions about both the relevance of the model input data and the need for local control in the field.

The results make it possible to propose new products in terms of tracks for predictive geosciences, such as lithological map and to offer support for over fields of geosciences (hydrogeological units for example).

http://www.brgm.fr/content/regolithe-geologie-tres-proche-sous-sol-amenagement

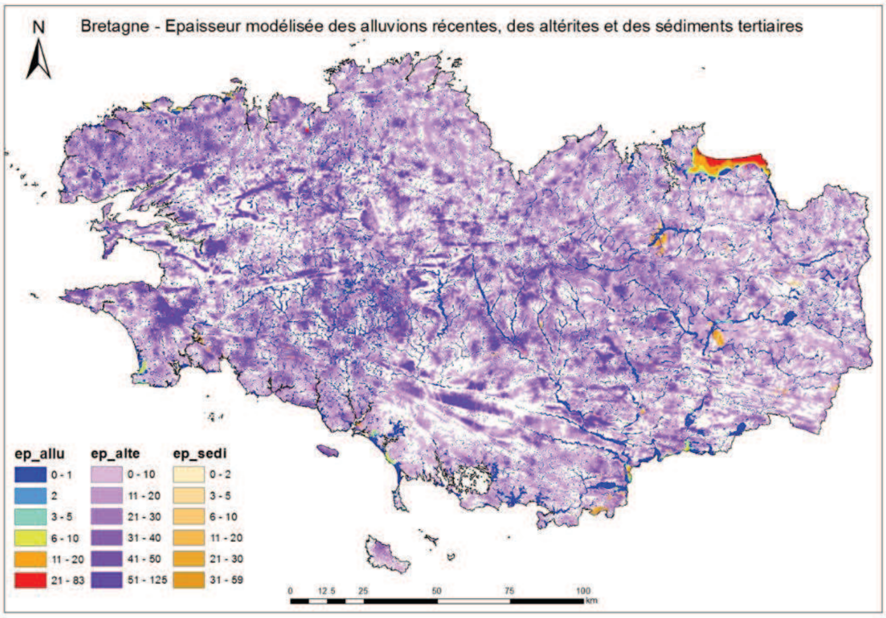

Fig. 1 Modelled thickness of recent alluvium, autochthonous surface formations and tertiary sedimentary deposits, Brittany, France.

RING: Toward stochastic and multiscale geomodeling

François Bonneau[1], Guillaume Caumon[1], Pauline Collon[1], Paul Cupillard[1]

[1] RING, ENSG-GeoRessources, Université de Lorraine/CNRS/CREGU/ASGA

The main goal of RING is to find new ways to integrate multidisciplinary observations about the earth by formalizing geological knowledge. This is what we call Integrative Numerical Geology, which we translate into theories, methodologies and algorithms implemented in software.

Essentially RING means to develop new structural and stratigraphic modeling methods and to find novel ways of representing sedimentary and diagenetic bodies to quickly explore interpretation scenarios and sample uncertainty. However, to be truly integrative, these representations must honor indirect data (production, time-lapse, monitoring, etc.). This calls for discretizing objects at the appropriate scale into meshes and for making physical computations, for instance in geomechanics, wave propagation, and subsurface flow. Historically, we have tended to give priority to bottom-up modeling approaches (starting from spatial data and prior geological information). However, RING principles and technologies can also be used in top-down modeling methods (starting from indirect data and downscaling consistently with prior information and spatial data). Our objective for the coming years is to strengthen and integrate these four research lines into consistent workflows that appropriately handle scale by combining bottom-up and top-down approaches.

3D fabric domains estimation in the eclogitised continental crust of the Sesia Lanzo Zone, Mt. Mucrone area, Western Alps

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[1] Dipartimento di Scienze della Terra "Ardito Desio" – Università degli Studi di Milano
* Corresponding author mail: luca.corti@unimi.it)

A multidisciplinary approach based on multiscale relationships between superposed structural stages and metamorphic imprints is a robust tool to reconstruction the tectonometamorphic history of lithospheric slices affected by contrasting memory and evolution along subduction-collision systems (Spalla *et al*., 2005; Gosso *et al*., 2015). A quantitative 3D estimation of rock volumes characterized by homogeneous fabric evolution and metamorphic reaction progress is applied to evaluate the volume of textural heterogeneities (Salvi *et al*., 2010) developed during HP-LT Alpine deformation partitioning in Mt. Mucrone area (Sesia-Lanzo Zone). This area consists of metaintrusive characterized by relicts of magmatic texture and igneous minerals, and related country rocks that show granulitic-to-amphibolitic Variscan imprints. Multiscale structural analysis reveals seven groups of superposed structures, showing metamorphic imprints developed under eclogite facies (D1 to D3) and successively under lower-P blueschist facies (D4) during oceanic lithosphere subduction, to greenschist facies (D5 to D7) throughout the continental collision (Zucali *et al*., 2002). D1 and D2 eclogitic stages are the dominant imprints and are characterized by isoclinal folding associated with pervasive foliations (Delleani *et al.* 2012).

In this contribution, we integrated the petrostructural mapping and multiscale structural analysis performed by Zucali *et al*. (2002) and Delleani *et al.* (2013) to perform 2D-fabric and metamorphic transformation domain maps. The contouring of domains that show homogeneous fabric evolution (FE) is based on the estimation of volumes occupied by successive planar fabric (0-20%; 21-60%; 61-100%). Whereas, the domains with homogeneous metamorphic transformation (MT) is determined based on the modal amount of successive mineral assemblages (0-20%; 21-60%; and 61-100%).

The fabric and metamorphic transformation domain maps linked to twenty interpretative cross-sections are used to constrain 3D volumes using Move 2016.2 software, that allow to define the size and shape of rock volumes showing the same degree of fabric evolution and metamorphic transformation during the dominant tectonometamorphic stage imprint. The results demonstrated that this approach can be a powerful tool to unravel the variation in size of rock volumes that sharing homogeneous evolution during subduction-collision-exhumation cycles.

Delleani, F., Spalla, M. I., Castelli, D., & Gosso, G. (2012). Multiscale structural analysis in the subducted continental crust of the internal Sesia-Lanzo Zone (Monte Mucrone, Western Alps). Journal of the Virtual Explorer, 41(7), 1-35, doi: 10.3809/jvirtex.2011.00287.

Delleani, F., Spalla, M. I., Castelli, D., & Gosso, G. (2013). A new petro-structural map of the Monte Mucrone metagranitoids (Sesia-Lanzo Zone, Western Alps). Journal of Maps, 9(3), 410-424, doi: 10.1080/17445647.2013.800004.

Gosso, G., Rebay, G., Roda, M., Spalla, M. I., Tarallo, M., Zanoni, D., & Zucali, M. (2015). Taking advantage of petrostructural heterogeneities in subduction-collisional orogens, and effect on the scale of analysis. Periodico di Mineralogia, 84(3B), 779–825, doi: 10.2451/2015PM0452.

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GemPy: Model based machine learning in geological modelling

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The representation of subsurface structures is an essential aspect of a wide variety of geoscientific investigations and applications: ranging from geofluid reservoir studies, over raw material investigations, to geo-sequestration, as well as many branches of geoscientific research studies and applications in geological surveys. A wide range of methods exists to generate geological models. However, especially the powerful methods are locked away in expensive commercial packages. We present *GemPy* a full open-source geomodeling method, based on an implicit potential-field interpolation approach.

The interpolation algorithm (based on Lajaunie et al., 1997 potential field method) is comparable to implementations in commercial packages and capable of constructing complex full 3-D geological models, including fault networks, fault-surface interactions, unconformities, and dome structures. *GemPy* is implemented in the programming language Python, making use of a highly efficient underlying library – theano (Theano Development team, 2016) – for efficient code generation that enables a direct execution on GPU's as well as performs automatic differentiation. This property allows the computation of gradients cheaply what enables many of the latest algorithms in optimization and inferences.

GemPy's functionality can be separated into the core aspects required to generate 3-D geological models and additional assets for advanced scientific investigations. These assets provide the full power behind our approach, as they enable the link to Machine Learning and Bayesian inference frameworks and thus a path to stochastic geological modeling and inference.

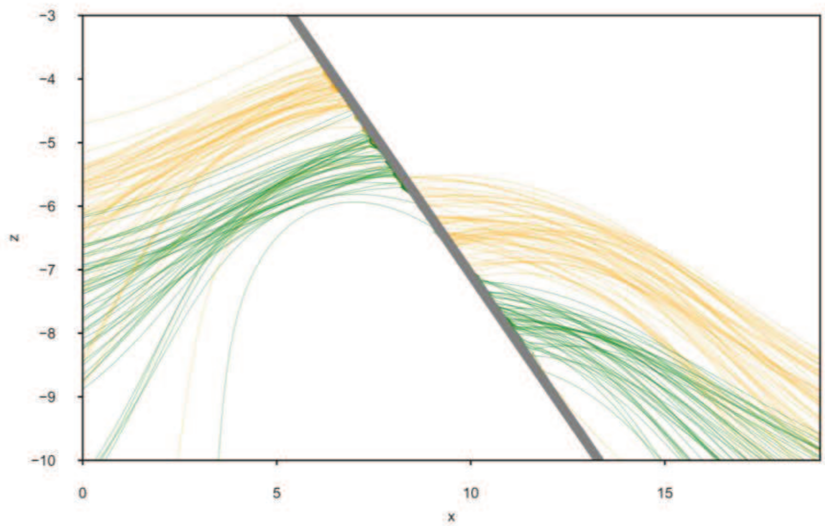

Fig. 1: Example of stochastic geological models performed with GemPy and PyMC 3: Cross-section of a faulted geological model of two layers (dimensionless) with a standard deviation of the input data of 0.3.

In addition, we provide methods to analyse model topology and to compute gravity fields on the basis of the geological models and assigned density values. Regarding visualization, we make use of many of the different options available in the Python eco-system such as Matplotlib, Visual Tool Kit (vtk) or even Blender.

In summary, we provide a basis for open scientific research using geological models, with the aim to foster reproducible research in the field of geomodeling.

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3D Geological Uncertainty - using Google Protocol Buffers for automation

Desmond FitzGerald[1], Helen Gibson[1], Evren Pakyuz-Charrier[2]

[1] Intrepid Geophysics, [2] University Western Australia

A high-level interface to the many function points in 3DGeomodeller is now available for all users. This is based upon using standard Google Protocol Buffer messaging format. These API methods have progressively been updated so that a very small specification of quite complex geological scenarios can be made – the essential facts plus their uncertainties.

Modelling geology uncertainty: Monte Carlo Simulation Uncertainty Estimation (MCUE) is a heuristic stochastic method which samples from predefined disturbance probability distributions that represent the uncertainty of the original input data set. MCUE is used to produce hundreds to thousands of altered unique data sets. The altered data sets are used as inputs to produce a range of plausible 3D models. The plausible models are then combined into a single probabilistic model as a means to propagate uncertainty from the input data to the final model. Pakyuz-Charrier et al. 2017 (https://doi.org/10.5194/se-2017-115)

Status with Geomodeller V4:

- Foliations' orientations are perturbed using a Spherical Cap, von Mises-Fisher or Kent disturbance distribution.
- Interface points and foliations' locations are perturbed using either a Uniform, Normal or Laplace disturbance distribution.
- Drillholes' path (survey) and log (geology) are perturbed using two continuous Markov Chains (limiting distributions are analogous to the generalized Irwinn-Hall distribution) see figure 1.
- MCUE produces plausible models with varying likelihoods. Although, variance of likelihoods is low because of the dimensionality of the input datasets (figure 2).

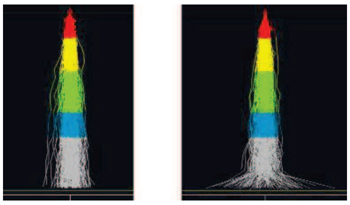

Fig.1: a) Markov Chain – Monte Carlo treatment of borehole uncertainty.

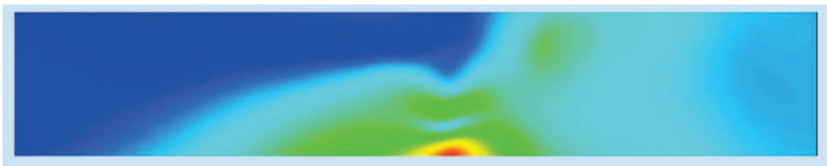

Fig. 2: 3D Geological model of Mansfield, Victoria, showing uncertainty once the borehole is subject to the MCUE treatment.

Conversion from the traditional approach

It is now easy to save any Geomodeller project to its original observations ie foliations, contacts, fold geometry, DTM, geological pile, material properties, fault network. In the process, it is recommended to concentrate on those parts of the model that are truly poorly understood. The aim should be to create more than 100 3D geology variations, to explore model space more fully, and have these constructed and merged into a common analysis space, in less than 1 hour on a common desktop.

- Sections are removed, topography is removed, 3D rendering is avoided entirely and saving to xml may be avoided too.
- In its current form, best performance is attained by running the application on a SSD (preferably M2 or PCI-Express) with high end CPU (i7, xeon) and appropriate #threads/memory ratio (4-8GB per physical thread).

Storing and delivering geological models for every day Earth Sciences applications

Considering that this Google protocol buffer format now represents a terse and simple way to store 3D geological models, we have published a set of examples by application on the Intrepid Geophysics GITHUB repository, that are feely downloadable, and that work from this format. (https://github.com/intrepid-geophysics)

Geological Modelling of the Lopín structure, Ebro Basin (Spain).

Jose F. Mediato[1], Jesus Garcia-Crespo[1]

[1] Geological survey of Spain (IGME). Ríos Rosas 23, 28003-Madrid, Spain

IGME has been developing a program of Subsurface Geology and CO_2 Geological Storage site screening and characterization, whose aim was to increase the knowledge of the subsurface structure of the country and to select and characterize a number of suitable areas for CO_2 storage. In the first phase of the program (ALGECO2) 70 areas were chosen and studied. Contour maps of potential storage formations were built from geological cross-sections and seismic lines (García Lobón et al., 2011). In this phase the Lopín structure was selected and studied obtaining contour maps for the Buntsandstein facies (IGME, 2010). In the second phase of the program the Lopín structure has been selected to be revisited because of its proximity to a significant CO_2 emission centre.

Seismic interpretation was done in GEOGRAPHIX (© LMKR) and the 3D structural modelling was obtained with SKUA-GOCAD (© Paradigm). The modelling process consists in creating horizons and faults, contours maps, upscaling well data, and layering, in order to generate a grid. Finally, a 3D model is created from the surfaces for the reservoir volume estimation.

Seismic surveys from the 70s were reinterpreted, taking into account the Lopín, La Zaida and Gelsa well data together with the surface information (geological map). In the seismic interpretation we distinguished eight horizons, although only six of them have been considered to build surfaces for the 3D model of the Lopín structure: Buntsandstein Top, Muschelkalk II Top, Muschelkalk III Top, Keuper Top, Lias Top and Cenozoic Bottom (Figure 1a). The reservoir and seal formations were selected following available information: porosity, salinity and depth data, from well logs. These formations are Triassic in age and in the Lopín area are affected by a NW-SE-trending anticline several tenths of kilometres long (Figure 1b). Two target reservoirs were considered (Figure 1b): Buntsandstein and Muschelkalk (MIII) facies.

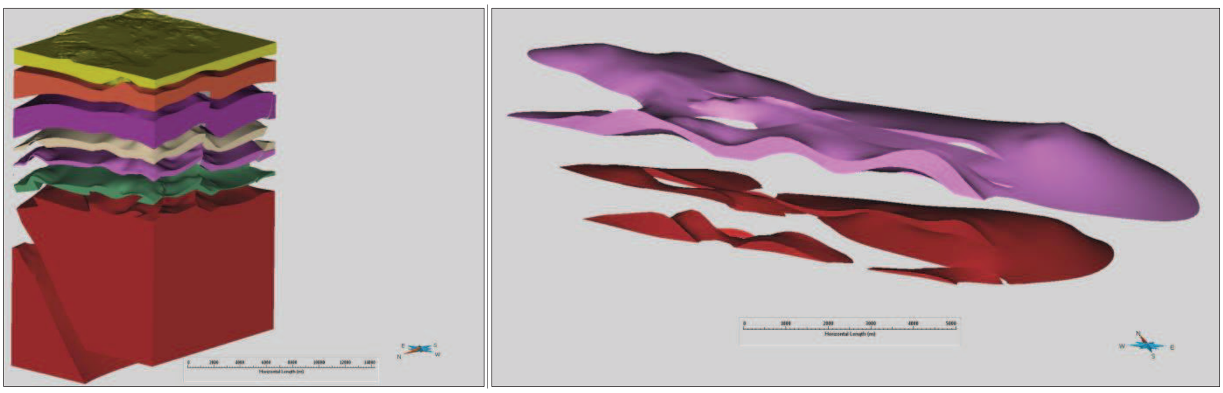

Fig. 1: 3D Geological model.

GARCÍA LOBÓN, J.L., REGUERA GARCÍA, M.I., MARTÍN LEÓN, J., REY MORAL, C. & BERREZUETA ALVARADO, E.R. (2011) - *Plan de selección y caracterización de áreas y estructuras favorables para el almacenamiento geológico de CO2 en España, Resumen ejecutivo*, Fondo documental del IGME. Documento nº 64.055 (72 pp).

IGME (2010) - Plan de Almacenamiento geológico de CO_2 del IGME – Plan ALGECO2, Volumen II Pirineo–Ebro. *Geología*. Fondo Documental del IGME

The harmonized 3D modelling workflow for shallow geothermal use in Central Europe: An important deliverable of the GeoPLASMA-CE project

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The European Union INTERREG project GeoPLASMA-CE - Shallow Geothermal Energy Planning, Assessment and Mapping Strategies in Central Europe - intends to foster the market share of shallow geothermal use for heating and cooling. GeoPLASMA-CE will produce a transnational, web-based platform for knowledge transfer, which includes decision support tools and geothermal risk and potential maps. 3D modelling of geological subsurface layers is a very important part of this project, since several models describing the potential for energy production and land-use conflicts will be elaborated based on the 3D model. In order to achieve comparable modelling results, all project partners will use a harmonized modelling workflow. It comprises steps of data preparation, structural modelling, quality checks and post-processing. The partners agreed on uniform model specifications: The European Terrestrial Reference System ETRS1989 33/34-TM and the European Vertical Reference Frame will be used as spatial reference systems. The 3D models will have a depth of 200m. The top is specified by a digital elevation model (DEM). The base of the model will be defined by the translated minimum envelope of the DEM, which provides a smooth base with small variations of the model depth. Dense and decomposed or fractured rocks have to be modelled as separate rock units, such that varying thermal parameters can be assigned to the units. All GeoPLASMA-CE partners use software working with boundary surfaces, which represent the tops of the geological units. The scheme of lithological units specifies the sequence of geological units which will be modelled and their contact relations; the harmonized fault network specifies the objects and the level of detail of the modelled faults. The 3D models will be used for the calculation of the geothermal potential for closed loop systems which is specified by the specific heat conductivity in W/(m*K) and the specific heat extraction capacity for a standard single family house in W/m. The ArcGIS extension IEGeothermie is used for these calculations; and the top boundary surfaces have to be provided as 2D grids. Furthermore, the data from the 3D model describes some aspects of the conflict potential related to the shallow geothermal use, such as the location of confined or artesic aquifers, hydraulically separated aquifers which must not be connected or the location of rock formations with swellable rocks. Limitations of the drilling depth can be determined by calculating the minimum of all critical rock units. Finally, the 3D models will be visualized in cross-sections or virtual boreholes on the web-platform by the software GST-web.

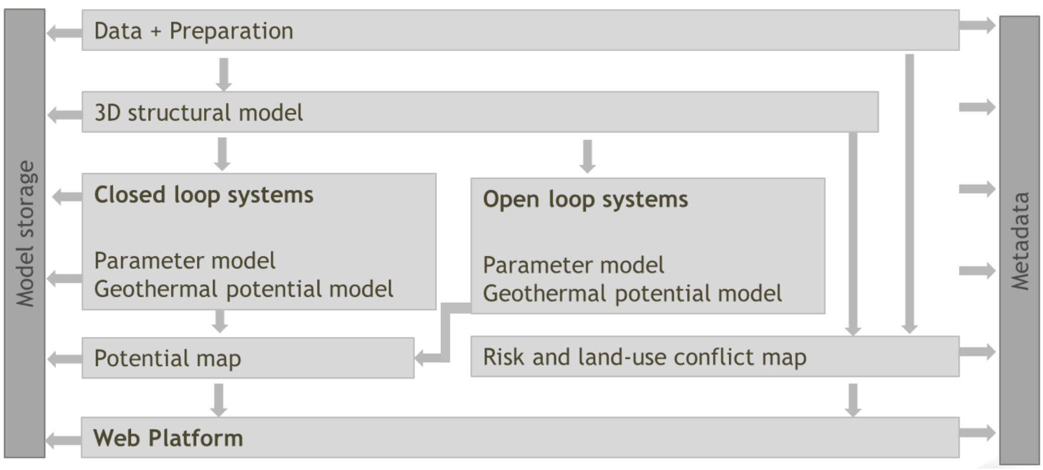

Fig. 1: 3D Geological model of a faulted aquifer and subsequent mesh for flow simulation.

3D seismics in crystalline rocks: challenges of interpretation and 3D modelling (case study: deep geothermal research borehole)

Sascha Görne[1], Ewald Lüschen[2], Felix Hlousek[3]

[1] Geological Survey of Saxony, [2] LIAG Hannover, [3] TU Bergakademie Freiberg

A 3D seismic survey was recorded in 2012 to explore a petrothermal reservoir in a crystalline environment (granite intrusion, metamorphic cover) within the Erzgebirge in Saxony. The intention and challenge was to image and characterize a steeply dipping fault zone and therewith potentially permeable fracture zones at target depths of 5-6 km and temperatures well above 150 °C. The vibroseis technique was used in the core experiment, accompanied by a special explosive seismic experiment. Field acquisition was characterized by severe noise conditions and a highly irregular layout. These conditions required extensive preprocessing and data conditioning. Images and indications of fracture and crack porosity of a prominent fault zone provide the background to define an optimum drill path for a deep geothermal research borehole. This is considered as the next stage for a possible geothermal power plant.

Prior to the seismic survey a 3D geological model was created using SKUA-GOCAD (see fig. 1a). The model incorporated all data available; geological maps, borehole data, information from former mining activities an interpreted data from airborne geophysical measurements. The granite intrusion and other geological structures like the “Roter Kamm” fault have been extrapolated down to 5 km depth.

The seismic results were used to verify and to improve the preliminary model afterwards. A rich repertoire of structures within the granite pluton has been imaged. The contours of the granite body are well documented in part by the past mining operations, in other parts by the truncation of the overburden, as seen in the seismic images, and by the velocity model. Steeply dipping normal faults and conjugate faults appeared with sharp reflection strengths, partly in accordance with the pre-survey model, however, at different positions and with different characteristics. The prominent “Roter Kamm” fault is imaged partly directly, but commonly by the truncation and offset of conjugate faults, and shows indications of fracture porosity at depth.

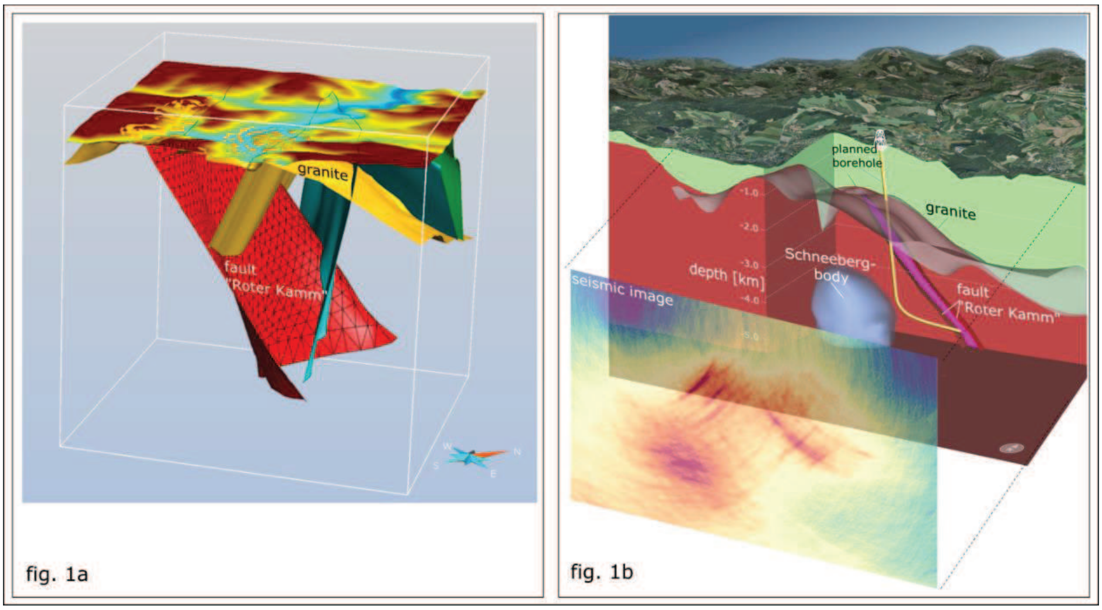

Fig. 1: 3D Geological model of the Schneeberg region; (a) preliminary model, (b) model with seismic interpretations.

The 3D seismic reflection technique and its interpretation and visualization in 3D modeling software was shown to be an indispensable tool for geothermal exploration, even in crystalline basement rocks.

Lüschen, E. et al. (2014) 3D Seismic Survey for a Petrothermal Research Project in Crystalline Rocks of Saxony. *76th EAGE Conference & Exhibition 2014, Amsterdam RAI*.

Görne, S., Berger, H.-J., Felix, M. (2010): Tiefengeothermie Sachsen : 1. Arbeitsetappe 09/2009-07/2010, Schriftenreihe des Landesamtes für Umwelt, Landwirtschaft und Geologie ; 2011/9

Uncertainties in geo- and hydrogeological 3D layer models as integral part of modelling procedures

Jan Hummelman[1], Denise Maljers[1], Willem Dabekaussen[1]

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The Geological Survey of the Netherlands (GSN) develops and maintains subsurface layer models with regional to national coverage. These geo- and hydrogeological models are used by different local and national authorities and cover domains that span depth ranges from shallow (<50 m) to deep (> several km's). The subsequent variety in available data calls for differences in modelling scale, software and modelling technique. The GSN aims to provide all information from 3D geo- and hydrogeological layer models with uncertainty.

Quantifying the uncertainty of geological and hydrogeological layer models that are constructed using multiple data types as well as geo- and hydrogeological expert-knowledge is not straightforward. Examples of expert-knowledge are trend surfaces displaying the regional thickness trends of basin fills or steering points that are used to guide the pinching out of geological formations. This added a-priori knowledge, combined with the assumptions underlying the spatial interpolation by kriging (normality and second-order stationarity), makes the kriging standard error an incorrect measure of uncertainty for these models. Therefore the Geological Survey of the Netherlands has developed methods for each type of 3D layer model as an integral part of the modelling process, resulting in reproducible uncertainty values. Based on either cross-validation (DGM Shallow), simulation techniques (GeoTOP) or a combination precision and accuracy of data (DGM Deep), each layer model is assigned values for uncertainty that is most appropriate for the specific data that is used.

The uncertainty values can be considered a good starting point for incorporating other errors that contribute to uncertainties of geo- and hydrogeological 3D layer models.

At the moment most of the models have uncertainty information and are disseminated through our web portal (www.dinoloket.nl) in on-line map viewers and as downloadable GIS products.

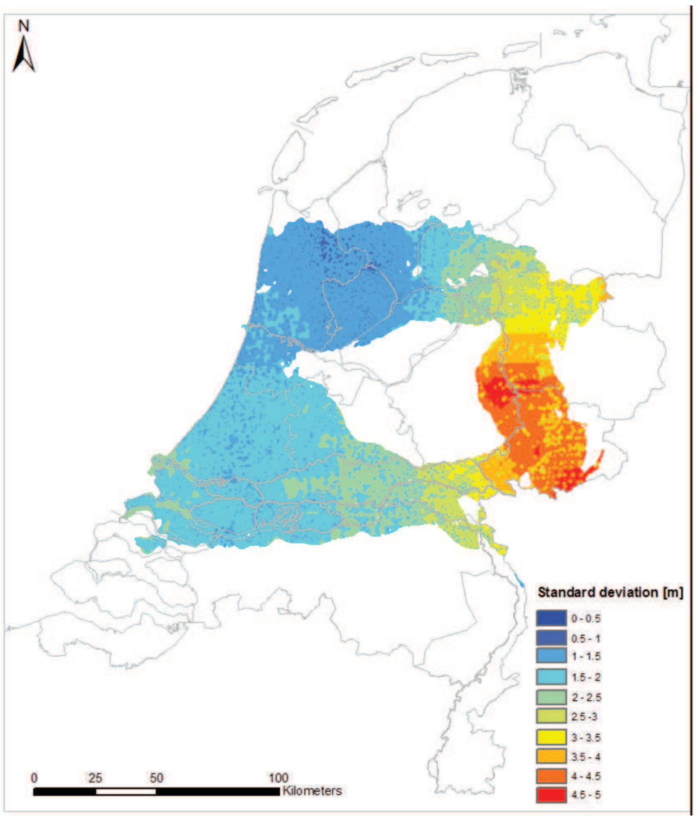


Fig. 1: Example Standard Deviation base Kreftenheye Formation (Blue = low SD; red = high SD).

Paleogeography - Facies simulation of the Albian of the Paris Basin

Benoit Issautier[1], Magali Sevenier[1,2], Eric Lasseur[1], Sunseare Gabalda[1], Anne-Gaelle Bader[1,] Bernard Bourgine[1]

[1] BRGM, [2] CV&Associés

The Albian of the Paris Basin represents a strategic aquifer for water supply, since the "Sables verts", "Drillon" and "Frecambault" Formation form together a thick sandy reservoir containing a non-negligible volume of potable water. The reservoir consists in a complex layout of fluvial-deltaic and estuarine facies passing frequently both laterally and vertically to shales. The aquifer is considered as a layer-cake of sand interlayered with shales passing to the south-east of the Basin to homogeneous clayey facies which are a target for nuclear-waste storage.

Regarding the co-existence of a strategic aquifer and a potential nuclear-waste site, the Albian deposits require a very detailed study of their architecture. Moreover, its classical layer-cake's interpretation is obsolete and must be revised to better understand the reservoir architecture and the lithostratigraphic pile.

The present study focuses on the modelling task of a project which purpose was (a) to understand at basin scale, the sedimentary geometries and paleogeography of the Albian interval; and (b) to realize at the Paris Basins scale, a facies model of the Albian deposits.

Three 3rd order cycles were identified, corresponding to the Sables Verts, Drillons and Frécambault Formations. The Sables verts cycle comprises an estuary, grading vertically to a more wave-dominated delta; both developing in a transgressive trend. The Drillon cycle is more complex, since it spans a eustatic fall, and a basin deformation responsible for a paleogeography re-orientation. It consists in a Lowstand System Tracts located in the southern Basin (N-S oriented fluvial-dominated delta). As the available space increases, sedimentation spreads in the nearly entire domain and a wave-dominated delta develops. Finally, The Frécambault cycle corresponds to the installation of a continuous W-E oriented (*i.e.* Failles de Bray orientation) wave-dominated delta with the widespread development of clean sand.

The facies model (rather Paleogeographic model) was realized at basin scale and at the 4th order sequences resolution. The choice of this very fine scale is related to the need to reproduce the lowstand wedge, the quick lateral and vertical facies evolution, as well as the shales intercalations between each sequence, which might play a strong role in the flow dynamic. Several algorithms were used: Truncated Gaussian Simulations and indicator kriging for the relative well organized depositional profiles (Frécambault, Drillons), and Multiple-point statistics for the very complex heterogeneous depositional profile. To better constrain the geometries, secondary data such as proportion curve and maps were introduced, as well as imbricated simulations when the lateral facies evolution was too complex to represent using c classical algorithms.

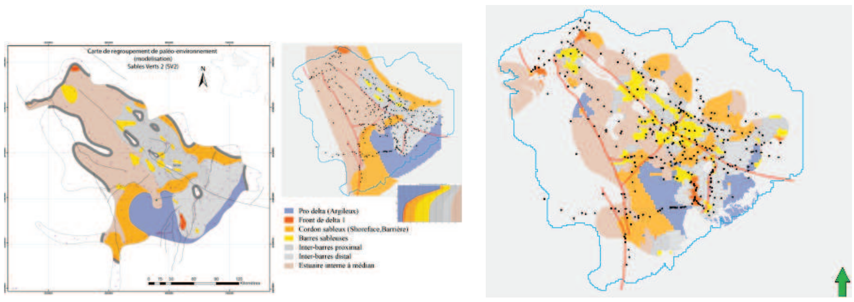
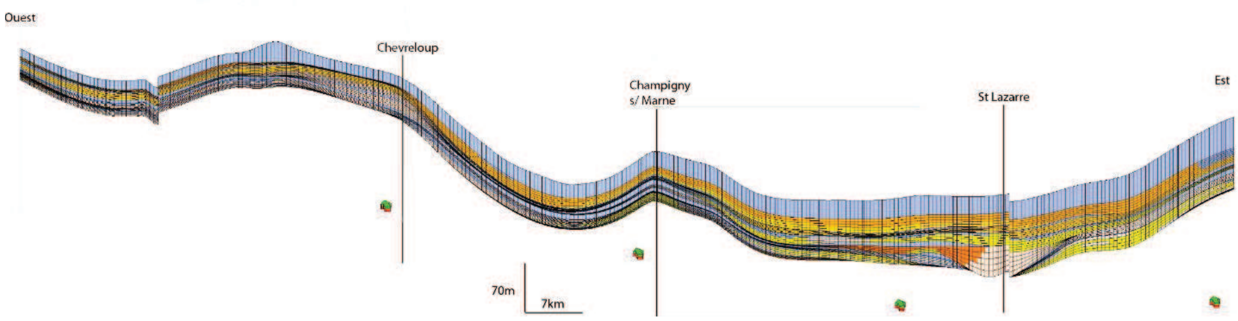


Figure 1a: Comparison between the paleogeography map and training image (left) and the Multiple Point statistics simulated map (right).

Figure 1b : W-E cross section within the model, illustrating the complex facies layout and the fault impact on the geometries(below).



Metadata for 3D Geological Models and Their Coherence with the Semantic Web

Lucie Kondrová[1], Gerold W. Diepolder[2]

[1] Czech Geological Survey (CGS),
[2] Bavarian Environment Agency (LfU) – Geological Survey

The creation of geological models of the subsurface and their visualization is becoming increasingly demanded by public authorities for planning and decision support as well as by experts from other disciplines (urban and land use planning, environmental and geo-energy issues, BIM, etc.) and by the general public. To make these models findable and accessible through standardized metadata is the first step to bring this scientific activity into focus.

Compared to the metadata of 2D spatial datasets, metadata of 3D geological models are very complex. Therefore, three different components should be distinguished: metadata for discovery, technical metadata, and modelling metadata. Metadata for discovery should contain the basic bibliographic information such as title, abstract, keywords, geographic location, contact information etc. Technical metadata should include information about the software used for modelling, conditions and constraints for use etc. Both these two components of metadata must be ISO 19115 compliant. To achieve at least the minimum level of transnational interoperability, these should also be INSPIRE compliant.

The third component of the metadata is the most complex one, and as such should be considered as an extension to these standards including information on modelling parameters, uncertainty, input data etc. They are part of a full data model for 3D geological information, e.g. based on GeoSciML and OCE Observations & Measurements encoding. Their definition requires the joint expertise of 3D modelers and data modelers and are thus beyond the scope of this contribution.

First step towards standardized metadata for 3D geological models is the joint definition of discovery metadata based on ISO 19115. Especially for discovery metadata tagging by use of controlled vocabularies is highly recommended as it opens up promising possibilities with respect to the efficient search by keywords and the parallelization of cross-border model units where harmonization is not yet implemented or virtually impossible. ISO 19115 allows the indication of multiple keywords (e.g. – KeywordTypeCode: stratum – for the modelled geological formations) and associated thesauri. Provided that these thesauri and their entries are integral part of an Open Linked Data Semantic Web, the metadata keywords can be linked to underpinning information including related concepts (synonyms, close match, broad match, super- and subordinate terms). Through this juxtaposition of geological concepts the interrelation of geological formations, i.e. the lithostratigraphic units as the gist of 3D geological models, can be elucidated and linked to further information.

In geosciences, due to the natural variability of the subject matter in space and time, many nomenclatures of factual scope have been set up. These standards with a limited areal validity evolved from regional approaches and only rarely have undergone cross-border harmonization. Descriptive texts are often used to caption those terminologies whose meanings are not standardized or are not conclusively clarified in the international context. This leads to distortion and ambiguousness when cross-border datasets are compiled, not only caused by national languages but also due to regional peculiarities and the semantic changes in historical evolution of terms. Standardization of geological interpretation terminologies, however, is virtually impossible to gain as pluralism of terms is fact-based, well-established and has been used in geoscientific publications over decades. Especially in geology, semantics also defines the delimitation of units (e.g. depth of strata), thus, equalization of terms such as lithostratigraphic subdivisions (geological formations) would require an extensive realignment/re-mapping of geological units.

Controlled vocabularies as part of a comprehensive Semantic Web are planned to be further developed and established through the pan-European cooperation in the frame of the GeoERA projects in the next years. Furthermore, this approach has been recognized by the OCG and is proposed for interoperability tests within the OGC/CGI-IUGS GeoScience DWG.

As all Metadata Information Systems compliant with ISO 19115, even though not prepared for full metadata of 3D geological models, are enabled to incorporate the multiple keyword approach, the 3D modelling community should spearhead this advancement through tagging the 3D geo-model units accordingly. This would also facilitate the retrieval of freely chosen formations (e.g. the XX-formation incl. all its synonymous and congeneric formations) through search by keywords.

Urban 3D modelling: a typology of anthropogenic deposits to anticipate pollution issues

Cécile Le Guern[1], Vivien Baudouin[1], Baptiste Sauvaget[1,2], Maxime Delayre, Pierre Conil[1], Bernard Bourgine[1], Christelle Loiselet[1]

[1] BRGM

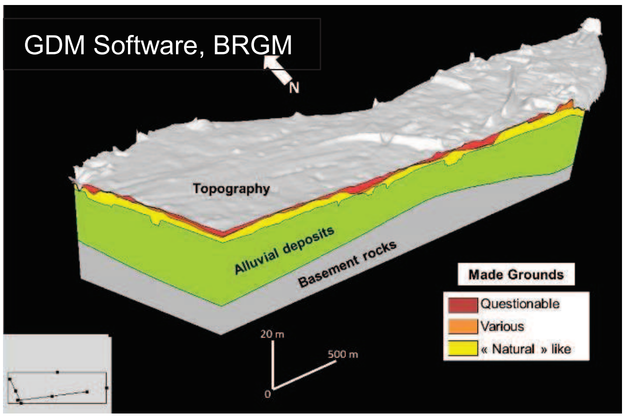
[2] MinesParisTech

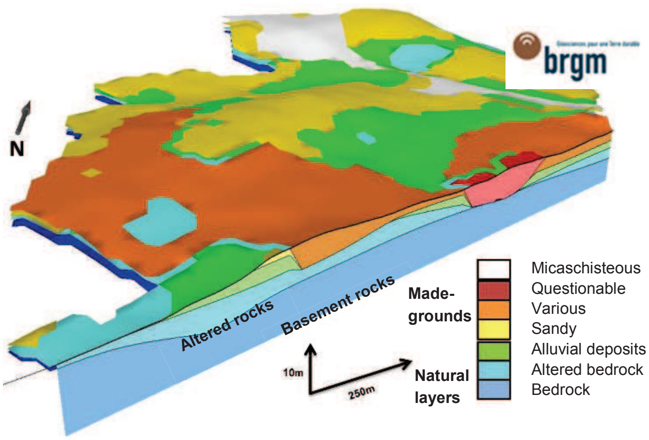
Urban soils and subsoils may be contaminated by industrial activities but also by the materials contained in the anthropogenic deposits. In order to anticipate the management of excavated soils that are produced in huge amounts in urban redevelopment projects, their qualities and quantities need to be assessed. In such a context, 3D representation of urban soils and subsoils is very useful. It is however challenging, especially if we want to take into account the anthropogenic deposits that present important geochemical heterogeneities. A typology of anthropogenic deposits has been developed according to their intrinsic potential of pollution. We aim at presenting the feedback on 3D geological modelling and its application perspectives for excavated soils management based on case studies.

To build a 3D urban subsurface model applicable to anticipate the management of excavated materials at quarter scale, using geological tools, the challenge is to define a stratigraphic pile both geologically and geochemically relevant. In this frame, we defined a typology of made grounds based on an iterative approach (literature review, borehole descriptions, geochemical data) for the Ile de Nantes quarter (France). The relevance of the made ground typology proposed was verified by a statistical approach on the representative samples and analyses selected in the database. This typology was then applied in other quarters of Nantes (France), after adaptation to the local context.

Three types of made grounds have been retained in the first quarter. They show contrasted geochemistry. The *made grounds* that are *comparable to natural subsoils* correspond in the case study to alluvial type materials. They show similarity with a typology and geochemistry of alluvial materials. The *questionable man-made grounds,* containing potentially contaminated anthropogenic materials such as bottom ash or slag, are characterized statistically by higher contaminant levels than other types of made grounds (eg. PAH, Zn, Pb, Cu,...). The *various man-made grounds*, corresponding to the remaining materials and containing for instance demolition materials, are characterized statistically by higher levels of PCBs. The typology has been used in a 3D representation of the Ile de Nantes subsoils, which served as a decision aid tool for the developer. The adaptation to other quarters rise questions on the possible degree of precision in relation to the quality and amount of data, but also on the historical contamination pressure.

The knowledge on urban subsoil geochemistry may help defining redevelopment projects, by adapting soil use to subsoil quality. In this frame, the development of a geochemically relevant made ground typology taking into account their intrinsic potential of contamination appears useful. A proper description of the intrinsic components of the made grounds is essential. It is indispensable to use some rigorously defined and internationally agreed terms.





Le Guern C., Baudouin V., Sauvaget B., Delayre M., Conil P. (2016). *A typology of anthropogenic deposits as a tool for modelling urban subsoil geochemistry: example of the Ile de Nantes (France).* Journal of Soil and Sediments. DOI 10.1007_s11368-016-1594-z

Geothermal modeling in complex geological systems with the ComPASS code

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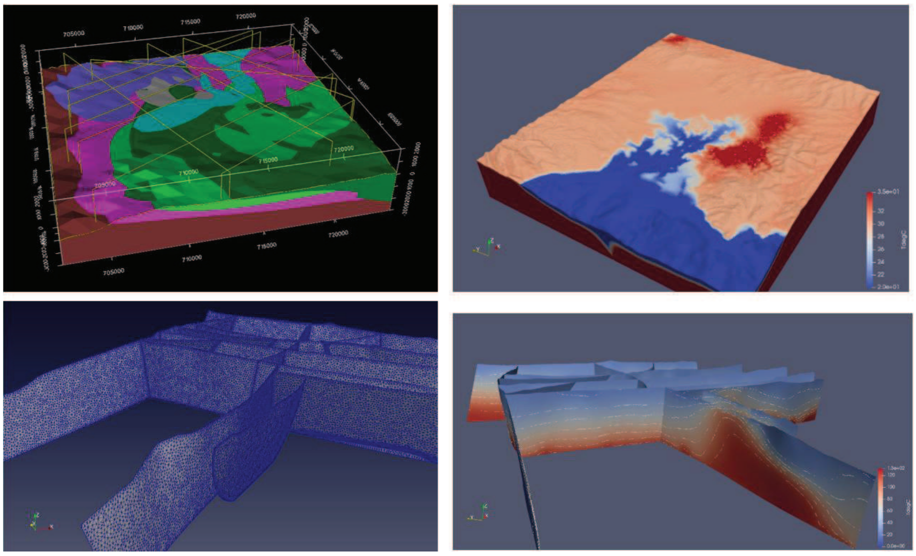
Deep geothermal systems often lie in complex geological settings, with multi-scale geological structures that exert a dominant control on convective processes and the transfer of geothermal heat. Geological modelling methods based on the implicit description of geometrical objects offer an efficient framework to quickly build structural models of such contexts with the occurrence of discontinuities like faults and fractures (e.g. Calcagno *et al.*, 2008; Lajaunie *et al.*, 1997). Yet, when it comes to discretizing such models the implicit nature of surfaces make volume meshing a non-trivial task and the results are unstructured polyhedral meshes.

Over the last few years, much progress has been made towards the consistent and robust discretization of diffusion processes in porous media. These research efforts resulted in several numerical schemes designed with a sound mathematical basis and able to deal with subsurface spatial heterogeneities (permeability variations, anisotropies…) and general polyhedral meshes. The poster introduces the ComPASS platform, which is an open source initiative that aims at building a geothermal simulation platform relying on one such scheme and recent numerical techniques.

The current code is able to handle compositional multiphase Darcy flows, relying on a Coats type formulation, coupled to the conductive and convective transfers of energy. Simulations can be run on unstructured meshes including complex networks of – possibly intersecting - fractures. Flow inside the fractures is modelled with a so called hybrid-dimensional model, using a 2D model in the fractures that can have variable apertures and permeability and is coupled with 3D transfers in the matrix. The physics is discretized using a fully implicit time integration combined with the Vertex Approximate Gradient (VAG) finite volume scheme. The fully coupled system is assembled and solved in parallel using the PETSc library and can be run on large computing clusters. An efficient preconditioner is implemented to solve the linear systems at each time step and each Newton type iteration of the simulation. A high level interface to describe the simulations is provided by the Python language, whereas the core routine are written in Fortran and C++.



Preliminary results from the modeling of the geothermal potential of the Baie Lamentin area (Martinique). A geological model (upper left) was meshed (lower left). Right figures show the yet uncalibrated results of temperature in the matrix (upper right) and the fracture network (lower right).

Yet another geological modeling library…

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Geological mapping is one of BRGM's historical missions, as part of both its Geological Survey role covering national territory, and of its international activities. Field works that are necessary for any geological map result in a collection of both lithological observations, sometimes with the area of contact between two types of rock, and structural measurements of planes (e.g. stratifications, metamorphic or magmatic foliations) and lines (e.g. stretching lineations). Back in the 90s, starting from the observation that abandoning of these orientation data (often collected in abundance) during the modelling process would represent a regrettable loss of information on system geometry, joint research between the BRGM and École des Mines de Paris led to a geological modeling method coined as the *potential field* method (Lajaunie *et al.*, 1997). The new idea was to model geological interfaces as implicit level sets of a 3D scalar field of which the gradients - or tangents - are constrained by the orientation data. The scalar field was obtained by universal co-kriging of all those data (multivariate interpolation). This method was later generalized to include infinite or finite faults and the concept of geological pile including geological series – which is broader than a mere chronostratigraphical pile concept - to manage topological relations between geological formations (Calcagno *et al.*, 2008). This method was eventually implemented in the *Editeur Géologique* software, ancestor of the *GeoModeller* software, which is now a complete geological modeling suite, developed and distributed in collaboration with *Intrepid Geophysics*.

In its early days, the *potential field* method, suffered from poor (hardware) computing performance and could not handle a large amount of data. Yet, with the advent of multicore architectures and GPU, the implicit description of geometrical objects now offers an efficient framework to quickly build structural models of complex geological contexts with the occurrence of folds and discontinuities like faults and fractures. Several other implicit geological modeling methods have been proposed and they are implemented in various academic and/or commercial software.

More than twenty years later, the *potential field* method now comes in various flavors including open source contributions (RGeostats, geomod3D, GemPy to name a few). The gmlib project from BRGM is a contribution to these efforts towards openness and provides a completely refactored version of the historical routines that aims to become a repository for both legacy and new modeling methods in the form of an efficient low level library written in modern C++. This library can serve as:

- a research tool to prototype new methods, considerably reducing development cycles with the use of python bindings (available through pybind11),
- a geological modeling kernel that can be plugged into/linked to any other software such as geological modeling suite, meshing algorithms, or end-users applications (e.g. VisualKarsys, Malard et al., 2018).

The project is in an early phase of development and the poster will introduce its main roadmap.

Calcagno, P., Chilès, J.-P., Courrioux, G. & Guillen, A. (2008). Geological modelling from field data and geological knowledge - Part I. *Physics of the Earth and Planetary Interiors* **171**, 147–157.

Lajaunie, C., Courrioux, G. & Manuel, L. (1997). Foliation Fields and 3D Cartography in Geology : Principles of a Method Based on Potential Interpolation. *Mathematical Geology* **29**, 571–584.

Malard A., S. Randles, P. Hausmann, M. Bucev, S. Lopez, G. Courrioux, P.-Y. Jeannin, M. Vogel (2018), Visual KARSYS, a web-platform for the documentation of karst aquifers including online geological modelling, 4th European Meeting on 3D Geological Modelling, Orléans.

CGAL – The Computational Geometry Algorithms Library

Sébastien Loriot

GeometryFactory

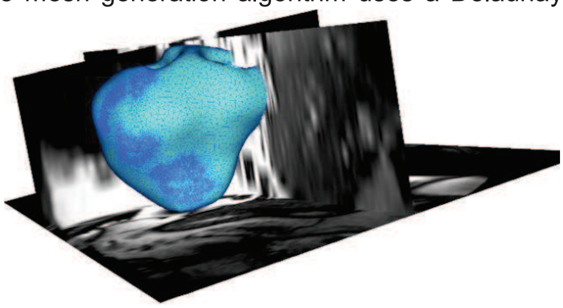
The CGAL Library (http://www.cgal.org) is a collection of robust and efficient geometric data structures and algorithms for users in academia and industry. It is a C++ class library that compiles on all major platforms (OS + compiler), following the *exact computing* paradigm to achieve robustness and efficiency, and the *generic programming* paradigm to achieve flexibility. The library is distributed under a dual licensing scheme (GPL + commercial), with support from the Open Source community as well as from the company GeometryFactory.

As geometry is ubiquitous, the CGAL library is used by application developers in rather diverse domains: geographical information systems, computer aided design, medical image processing, robotics, oil/gas/mining.

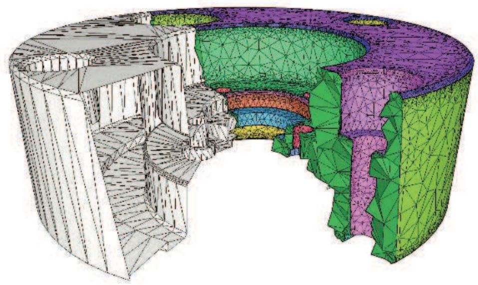
Mesh Generation

CGAL provides a mesh generation framework that can process as input grey level and segmented 3D images, implicit functions, as well as polyhedral surfaces, or even combinations of them. The CGAL algorithms can extract iso-surfaces, remesh boundary surfaces, or fill at the same time volumes with tetrahedra, respecting a given sizing field.

As the mesh generation algorithm uses a Delaunay refinement approach, the triangles do not have small angles, and the notion of an approximation error adapts the triangle size to local features of the input. Additionally, and a sizing field to control the size of simplices can be provided. Extra optimization steps improve the distribution of dihedral angles and remove slivers.



The surface is the iso-surface associated to an iso-value inside the input grey-level 3D image



Tetrahedral mesh for a given polyhedral surface

Using the mesh generator together with the Poisson implicit function results in a surface mesh reconstruction algorithm that takes a point set with normals as input. While Poisson surface reconstruction is appropriate for watertight smooth meshes, CGAL also provides surface reconstruction algorithms for surfaces with holes and sharp features.

Polygon Mesh Processing

CGAL provides polygon mesh processing algorithms, including hole filling, isotropic remeshing, mesh parameterization, mesh segmentation, mesh deformation, computation of shortest geodesic paths on a mesh, as well as the co-refinement of two meshes. The latter is used for Boolean operations.

Point Set Processing

Raw point clouds, often obtained from scanners, need pre-processing such as outlier removal, simplification, smoothing, normal estimation and orientation, principal curvature estimation. Most of these CGAL algorithms are based on a kD-tree for fast neighbor search. Shape detection algorithms enable to fit input points to planes, cylinders or spheres. Classification algorithms based on machine learning algorithms enable to separate, for example, vegetation from ground.

CGAL users in geological modelling reconstruct surfaces from Lidar data of open mines, perform Boolean operations on galleries, parameterize horizons, construct salt bodies from surface points extracted from seismic images and deform these surfaces, fill geological layers given as horizons and faults with tetrahedra for flow simulations.

Yes, we need to integrate our subsurface models!

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[1] TNO – Geological Survey of the Netherlands

TNO – Geological Survey of the Netherlands (GSN) develops and maintains a suite of four subsurface models. These models each have their own historical background, use different data, different modelling techniques and serve different user groups. However, today more and more the call for integration of these subsurface models is heard.

Therefore at GSN we are currently working on the integration of two of these models covering the shallow subsurface. The result is a single, integrated and multiresolution model that displays a great amount of detail in the upper tens of meters, but at the same time reaches, albeit with less detail, depths of several hundreds of meters. In doing so we eliminate differences between realizations of the same geological units. The integration of the shallow framework models appear to be a relatively straightforward step, mainly because they are constructed using comparable datasets (mainly boreholes) and the same modelling software, but is nevertheless time-consuming. The new integrated model will serve as the future carrier of our voxel models with detailed lithological information as well as our hydrogeological information on aquifers and aquitards.

In recent years, progress has been made in the integration of our shallow and deep subsurface models in the context of H3O projects. These projects, carried out in close collaboration with our Belgian and German partners, deliver cross-border hydrogeological models. The main challenges in these projects are the harmonisation of the stratigraphic nomenclatures used on either side of the border, the integrated interpretation of data from boreholes as well as from seismic lines, the handling of faults, and the use of different software.

In the Netherlands, due to the energy transition, geothermal energy receives more and more attention. At greater depths, this energy source often come from reservoir rocks that are already modelled in detail for hydrocarbon exploration. However, the recent shift of focus to more shallow reservoirs in the Netherlands has, to date, received little attention from the geomodelling community. The main reason is that these shallow reservoirs fall outside the depth ranges of the shallow models and lack detail in the deep models, because they were irrelevant for hydrocarbon exploitation (Figure 1).

Although here only one example underpinning the needs for integration is mentioned, the increased use of the subsurface in providing essential resources and storage capacities (and the associated synergies) asks for better integration of subsurface models. Although we do not have all the answers to the way ahead yet, we look forward to discuss the possible approaches for model integration with the audience.

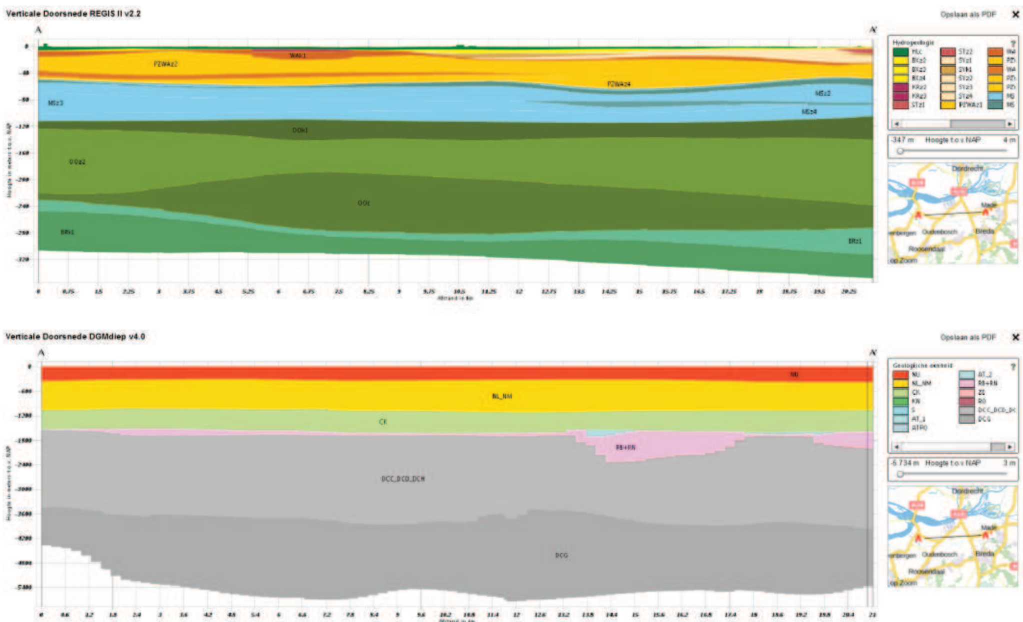

Fig. 1: Example of a cross-section of a shallow subsurface model (upper panel) and a deep subsurface model (lower panel). Interest is currently focussed on the depth range of 600-1200 m below reference level, which is not modelled in the shallow model and has received little attention in the deep model.

A new interpretation of the structure of Massif de Fontfroide based on a 3D integrated structural study

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Recent studies revealed the existence of an Albian extensive phase affecting the Corbières area, northeastern Pyrenean foreland (Ford *et al*., 2016). Then, during the inversion at the Pyrenean compressive phase, inherited halokinesis and resulting salt structures controlled the final 3D structural architecture of the whole area (Ford *et al*., 2016, 2017).

The particularly complex Fontfroide Massif is linking autochthonous Pyrenean foreland to the west with the allochtonous “Nappe des Corbières” to the east. In the light of our newly acquired data in the region, we propose an alternative structural interpretation to those of the study of Dagnac (1963).

The compilation, integration & 3D modelling from ancient and new structural data in a unique 3D framework through the 3D GeoModeller software (©BRGM - Intrepid-Geophysics), let us to reconstruct a 3D coherent structure over the whole area in the light of recent salt-tectonics concepts, and to reinterpret the particularly complex structure of the massif. The stratigraphic contact between the Triassic salt and Albian strata, the presence of salt nodules and “Triassic ophites relics” into the first Albian layers suggest that Albian sediments were deposited between two old NE-SW salt walls corresponding to the actually salt ridges. This is consistent with the high variabilities of 1- Albian sedimentary facies and 2- azimuth and dip of its layers near the boundary with the salt. All the structural data and their polarities of Albian layers represent juxtaposed NE-SW synformals.

Thus, syn-extensive Albian terranes are separated from the western Pyrenean foreland by a NE-SW salt ridge, later reactivated as a preferential decollement surface as a westward thrust. In several places the salt is currently absent but stratigraphic markers reveal its scare. To the west, Albian terranes are separated from the “Nappe des Corbières” by a salt ridge corresponding to the main thrust. Both salt ridges are merging northward and southward, thus surrounding Albian terranes of the Fontfroide Massif.

This preliminary coherent 3D architecture allows to support a salt tectonic origin for the structuration of the Fontfroide massif and allows to target future acquisitions to test several 3D internal architectures of the Albian strata.

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Ford *et al*., October 2017. **Meeting of International Association of Sedimentologists**. Toulouse (France): *Loading and foreland basin evolution during inversion of intersecting salt-rich rift systems, Cretaceous to Oligocene, eastern Pyrenees*

Ford *et al*., (October 2016). **Earth Sciences Meeting.** Pau (France): *The Corbières orocline –inversion of an inherited crustal transfer zone*

Ford *et al*., (April 2016) **EGU General Assembly 2016**. Wien (Austria): *The role of salt tectonics in the evolution of the northeastern Pyrenees*

Ogunfolabo poster

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Introduction

Well logging might be translated as "a record of characteristics of rock formations traversed by a measuring device in the well bore. There will always be a possibility of finding more oil and gas deposits if more accurate exploration techniques are employed in its search from the history of petroleum exploration and also proper knowledge of the underlying geology helps to accurately predict the hydrocarbon potential and reserve estimation of a petroleum field. It is very important to determine and understand the petrophysical properties and mechanical properties of eservoir rocks, accurate estimates of porosity and permeability values in certain stratigraphic intervals can be derived from well log types, i.e. sonic, neutron or bulk density logs.

Sequence stratigraphic approach has turned out to be one of such unique techniques for generating exploration prospects and predicting reservoir and seal qualities in both stratigraphic and structural traps. Sequence stratigraphy evolves as an aspect of stratigraphy that subdivides rock record using a succession of depositional sequences composed of genetically related strata as regional and inter-regional correlative units (Haq *et al.*,1988). Thus, genetically related facies are studied within a frame work of chronostratigraphically significant surfaces (Van Wagoner *et al.*, 1990), and rock units that are genetically related are constrained by time lines (Reijers, 1998).

The objectives of this research are to utilize petrophysical and sequence stratigraphic analysis approach using 3D seismic, check shot, geophysical well log data to delineate the reservoir units in the field, determine the geometric properties of the reservoir rocks and a potential unifying framework for interpreting the stratigraphy of the deltaic sequence within a particular field in the Niger Delta. Nigeria.

Theory and/or Method

The materials used for this research include digital 3-D seismic lines, borehole logs, velocity check shot survey data and a base map of the field. The available software for this project include petrel™ 2009, interactive petrophysics and surfer 2010.

Figure 1.1 is a flow chart depicting the steps involved in the interpretation of well logs and seismic data. These steps of data analysis and interpretation include the following: Data loading, quality control, seismic data interpretation, log data interpretation, seismic to well tie, extraction of seismic attributes, reservoir properties modelling and environments of sediment deposition.

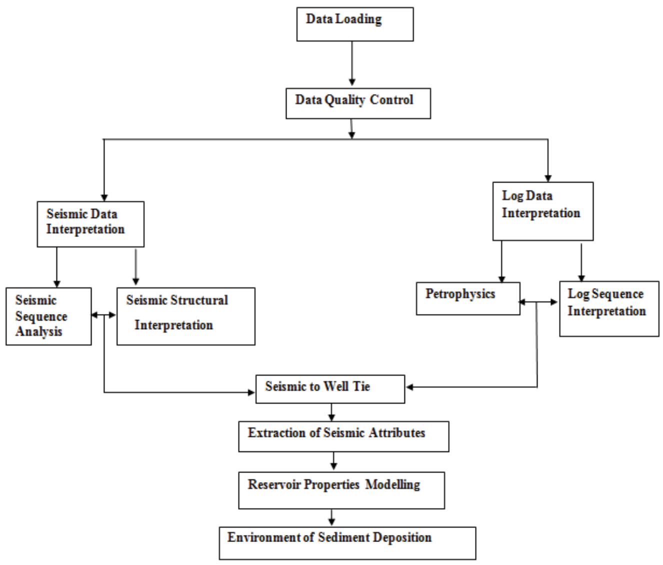

Figure 1.1: Flowchart Showing the Procedure of Methodology.

The suite of wireline logs available for this project include: gamma ray, neutron, density, sonic and deep resistivity. Prospective intervals and hydrocarbon bearing reservoirs were delineated and identified on the basis of logs signatures. Both qualitative and quantitative interpretations were carried out in this research. Qualitative log Interpretation entails the visual inspection and description of anomalous regions on logs in relation to petrophysical parameters. Some important parameters considered during qualitative log interpretation include log: shapes, lithology, hydrocarbon and water bearing zones, fluid contacts, fluid type, stratigraphic surfaces, parasequence stacking patterns and environments of sediments deposition. In quantitative log interpretation, reservoir properties determined are porosity, volume of shale, gross sand, net sand, net to gross, water saturation, hydrocarbon saturation, permeability, irreducible water etc, using mathematical expressions.

The seismic volume was imported into a user defined folder in SEG-Y format and then realized. 3 D seismic data interpretation was performed on the realized volume. The network of faults was identified and mapped using criteria such as reflection discontinuity at fault plane, and vertical displacement of reflectors. Prominent seismic marker surfaces which corresponded with sequence boundaries were also mapped on the basis of reflector quality (continuity and events strength) and prospectivity. To ensure accuracy of the interpretation, well to seismic tie was essential. The two methods that were used to tie well with seismic data are check shot data and synthetic seismogram. Synthetic seismogram was produced from sonic and density logs, this was necessary to establish a relation between well information and seismic data.

The horizons mapped on both crosslines and inlines were used to generate a 3 D grid that was auto tracked and used to generate time and depth structural maps of the sequence boundaries. These structural maps gave insight into the probable structure harbouring oil and gas in the area of study. Sediment deposition takes place on land, desert and marine environments. This project tries to study the mechanism of sediment transport and deposition in a field offshore Niger Delta. Log shapes and seismic reflection patterns were utilized for the evaluation of environment of sediment deposition.

Conclusions

The area of study is covered by 3D seismic lines and a suite of borehole logs from five wells. Borehole logs were used in the description of sequences, systems tracts and characterization of hydrocarbon bearing reservoirs. The gamma ray aided lithologic identification, resistivity log indicated nature of fluids (hydrocarbon and water) and neutron and density logs indicated the porosity as well as fluid types. Borehole data played a complementary role to surface seismic. They ensure accurate determination of key stratigraphic surfaces and resultant time structural maps that are productive.

Acknowledgments

With joy in my heart, I want to express my gratitude to the All Sovereign God for His protection and guidance over my life and for his promise to see me through this research in Federal University of Technology, Akure.

Firstly, I am indebted to my caring, co-operating and understanding research supervisor, Dr. M. A. Ayuk for his guidance and technical advice in the research. My gratitude goes to the Head of Department, Prof. G. O Omosuyi, and other lecturers in the Department for their contributions towards my success during this work. I will never forget the efforts of Mr. Oyeleke K. Zaid, Mr. Akingbade Oluwaseun and my colleagues for their advice, effort and contributions in the successful completion of this research, God will reward you all accordingly.

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Reijers, T. J. A., (1998): Selected Chapters on Geology: with notes on Sedimentary Geology, Sequence Stratigraphy and three case studies and a field guide. S.P.D.C. Corporate Reprographic Services, Warri, Nigeria. 197p.

3D geological modelling as a standard application in mining

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In the Zielitz mine in North Germany the room and pillar method is used with drilling and blasting due to flat lying potash seams (K3RoSy). Before blasting, the blast holes and three collapse holes with a diameter of 280 mm and with a length of about 7 m are drilled in the working face (round length). The direction and angle of the collapse holes control the excavation of the workings.

Long range exploration boreholes (2000 m, core drilling) and short range exploration boreholes (60 m, no core drilling) are drilled in order to determine the spatial position and quality of the potash seam. In some long range and in all short range exploration boreholes radar measurements (ground penetrating radar) are conducted, because the deposition planes of the seam are visually hard to determine. Radar measurements providing continuous 2D-profiles of the top and bottom surfaces of the potash seam as well as of an overlaying anhydrite layer (am1) allow to generate reliable 3D-geological models.

The main goal of the modelling is to improve the ore to waste ratios (potash/salt) in the potash salt mined underground. The targets of the optimization are the angle and direction of the collapse holes. The contribution of 3D-geomodelling is to provide the top and bottom surfaces of the potash seam and the surface of the overlaying anhydrite layer. Standard functionalities of the modelling software are used (i.e. structural workflow) for generating the surfaces. The constraints of the optimization are the geological surfaces of the seam and the anhydrite layer and further parameters like height, horizontal/lateral angle and shape of the round or distance to the am1. This optimization is not calculated inside the modelling software and is done using a Big Data approach. A further step of the process will be to include the distribution of potash and salt minerals within the potash seam.

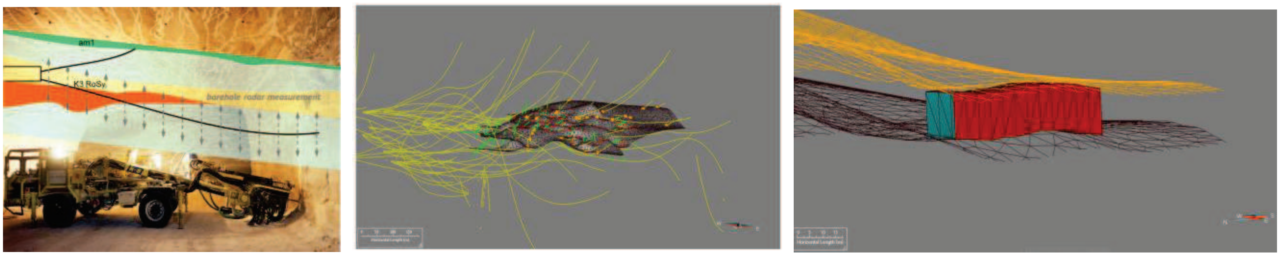


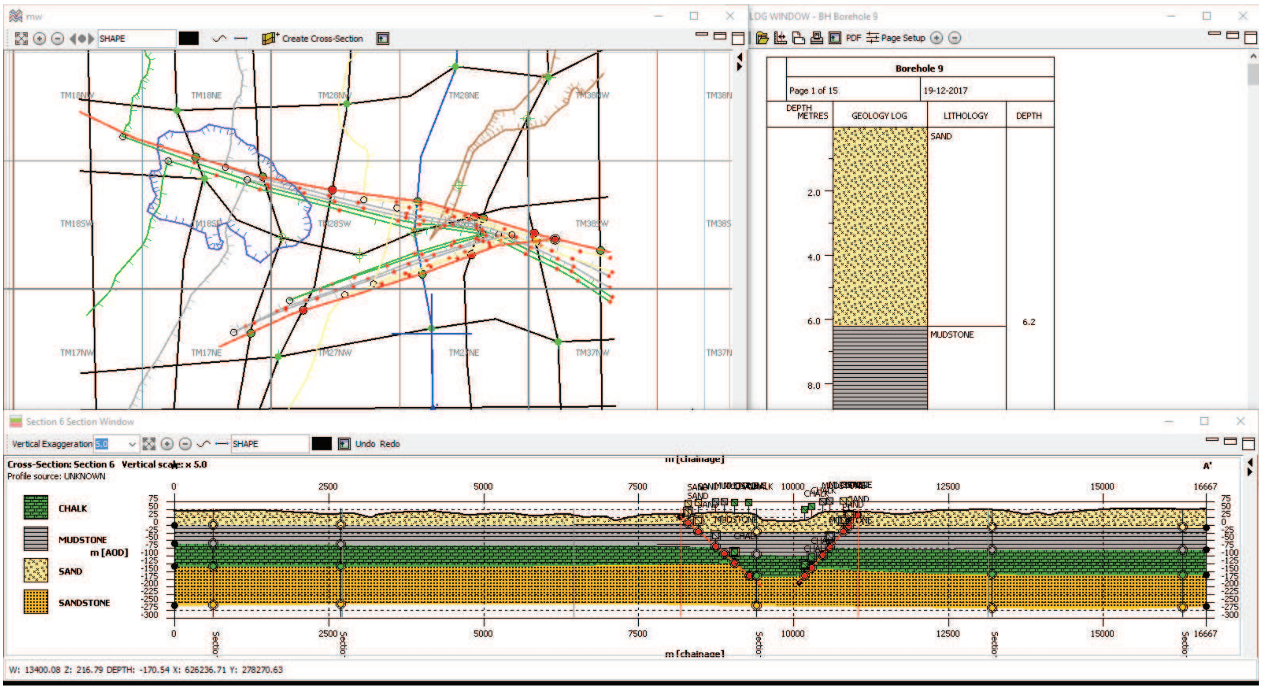
Fig. 1 Borehole radar, example of a 3D geological model and optimized shape and position of proposed mine openings.

For efficient data and model management standardization and documentation are two essential requirements. The data management includes the handling of the raw data, the import interface to the geomodelling software and the data handling inside the geomodelling software. During the modelling, processed data is generated by changing the raw data or by creating new data items. Both need an administration of objects that includes naming, documentation and a data model for structuring and typing. The modelling process and the model results have to be treated the same way. Finally the complete model has to be stored in a database in order not only to save the work but also to allow 1. multi user access, 2. automatic versioning of models and 3. tiling of large models (loading/saving of parts of a model from/to the database). Well organized data and model management are the key for routine use of 3D-geological models.

BGS Groundhog Desktop

Richmond Tanya

BGS Groundhog Desktop (Groundhog) is geological software developed by the British Geological Survey (BGS) for the display and editing of subsurface geological information. Groundhog Desktop is intended as a basic GeoScientific Information System (GSIS*) – a software tool which facilitates the collation, display, filtering and editing of a range of data relevant to subsurface interpretation and modelling.



BGS will present a poster and live demonstration on the latest developments in Groundhog and our plans including current and future collaborative work with other geological and commercial institutions.

3D outcrop models and their benefits

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[1] Czech Geological Survey

One of the tasks currently being solved at Czech Geological Survey is the problematics of discreet fracture network modelling (DFN). Understanding the distribution of brittle deformation throughout the rock massif is one of the very important factors for safety assessment of underground facilities like for example deep underground repositories for spent nuclear waste. In initial stages of geological survey on localities like these there is not much space for extensive drilling campaigns although need for geological data is high. Therefore we decided to create in cooperation with Faculty of Civil Engineering in Czech technical University in Prague in-house software that will be able to calculate optimized parameters for DFN using only limited surface outcrop data.

For this software we developed an enhanced methodology, how to process standard structural measurements taken in the field. As was necessary to obtain large amount of 3D referenced data like fracture traces, measurement positions, bounding boxes etc. we decided to work in 3D environment as soon as possible. Rather than do post-referencing of 2D outcrop pictures we used the technique of photogrammetry, which has been developed already for years (Linder, 2009) and is very "field-use friendly" because all what is necessary is a DSLR camera with high resolution. By taking pictures in various camera positions all around the outcrop it is possible to recreate, using adequate software (commercial or opensource), the whole outcrop as point cloud and subsequently triangulated mesh. Adding the 3D photorealistic texture on the mesh model it is possible to work with an outcrop like if it was in the field (apart from taking a sample of course). 3D Outcrops are referenced in space using GPS coordinates and accurately in-field measured orthogonal surfaces which are than matched with those on the 3D outcrop.

Beside imprinting field measurements, extracting fracture traces, bounding boxes etc. it's possible in adequate software (we are using MOVE™) to perform new virtual measurements, which are especially useful in a places where it is hard or impossible to get (e.g. quarries and mines). Using technology like UAVs (unmanned aerial vehicle) it is now possible to reach further destinations and encompass larger areas. Temporary outcrops, appearing during construction of railways or motorways can be stored in 3D library for further use and examination. All what is necessary is an DSLR camera, geological compass and software.

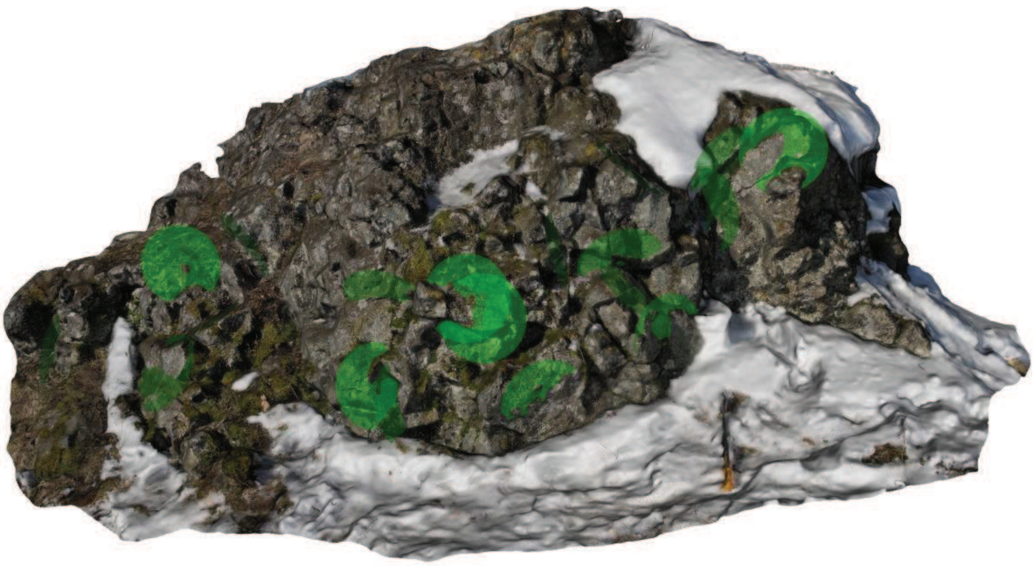

Fig. 1: 3D outcrop of volcanic origin with visualized field measurements.

Linder, W. (2009): Digital photogrammetry. A practical Course, Springer-Vertag, Heidelberg, Germany, 226 p. ISBN: 978-3-540-92724-2

A 3D voxel model of Pleistocene gravel and sand deposits in Flanders (Belgium)

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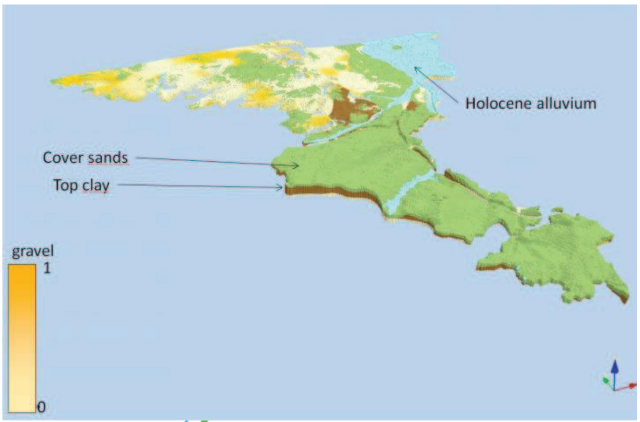
Keywords: voxel modelling, raw materials, Quaternary, river deposits.

The Pleistocene sand and gravel deposits are of primary importance for the Flemish (northern part of Belgium) building industry. Therefore, a thorough resource assessment is essential for maintaining its long-term exploitability. In this respect, the Flemish Government financed VITO to build a 3D voxel model of these resources, returning the lithological distribution and thickness variation of the deposits on a regional scale. This model will be part of a larger 3D (hydro)geological model of Flanders (G3Dv3). It succeeds Flanders' first voxel model, which focused on the Quarternary loess deposits (Van Haren et al., 2016).

The deposits that are modelled were deposited by the river Rhine and the river Meuse during the Pleistocene. They are hence river deposits, which are typically heterogeneous in thickness, spatial distribution and lithology. The framework of the voxel model was created based on the regional geological layer model of Flanders, which holds 3D lithostratigraphical information on Formation level. In the area of interest (ca 1230 km²), ca 8500 boreholes are present. After an extensive intensive quality check, ca. 5000 boreholes were used for the actual construction of the model. Next, an in-house developed application automatically encodes and classifies the lithological borehole descriptions into specific geological parameters. These parameters were 3Dinterpolated using Voxler® software, and the resulting 52 million voxels (with dimensions of 25 x 25 x 0.5 m) were managed, processed and linked with the existing 3D geological layer model using Microsoft Sequel Server®. The database structure allows to analyse the results and set certain conditions (minimal thickness or maximum depth of aggregates, maximum thickness of intercalating clays) on the model in order to calculate and view distributions of deposits which meet these conditions. These results are interesting for pre-prospective purposes, illustrating the distribution of lithological information and making the end user more aware of the potential economic value of the subsurface.



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Lorraine Basin Case Study: how to represent complex geology of coal seams with GeoModeller

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The coal basin of Lorraine (NE-France) is a Late-Paleozoic Basin resulted from the subsidence in the external Hercynien chain and is composed of more than 1500m of sediments. These sediments were folded and faulted during the Lower Permien. The sandstones of Middle Permien overlies these deformed sediments by a discordant contact. The geological geometry and distribution of coal seams are complex with many faults and folds moving and displacing beds. 3D geological modelling is useful tool to represent and visualize complex geological geometry. The phenome-logical analysis on PSO-STOCK project (internal BRGM project) aims at understanding the evolution of methane gas into a mining well through the space/time analysis. The phenome-logical analysis identifies phenomena, as hydrogeological, thermal, chemical and radiological from the begging of mining works to the end of exploitation (site closure). The 3D geological model of Lorraine coal basin is the first step of the phenomena analysis, as it represents the initial state of the system before mining works that will change through time with the exploitation of coals.

The challenge of 3D geological modelling of Lorraine coal basin is the complexity of geology and the difficult to represent the coal seams spatially. The modelled area has 30 x 20 km of size and 1000 m depth, and is located at the Germany border in Lorraine (France). The coal seams are discontinuous spatially and have variable thickness according to the location on either fold limb. This study discusses the workflow to build the 3D geological model. The input data is essentially 2D. Geological maps and sections supplied sedimentary contacts for building 3D surfaces. The structural framework is built from faults with an important offset and regional faults.

An approach and implementation for the management of diverse geoscientific data

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Geological surveys, such as the BGR, deal with a very wide variety of data types, ranging e.g. from seismic data and 3D models to Excel files and scanned maps. Some data refer to geographic objects, while others do not. Many data are gathered during projects carried out, often by temporary staff, and it is therefore important to keep track of the information about which data exist and where these are stored, and to make this information searchable. In our contribution, we describe a simple way that this could be done using Microsoft's SQL Server and ESRI's ArcGIS. As a proof of concept, and as a basis for further discussion within our organization, we provide two implementations for the user interface, one desktop-based, using ESRI's C#.NET API for ArcMap and one web-based, using con terra's map.apps that is based on ESRI's ArcGIS API for JavaScript and the Dojo Toolkit. While our implementation is based on maps (2D), the concept easily extends to 3D by adapting our code to ArcScene instead of ArcMap, to ESRI's new ArcGIS Pro, or to map.apps 4.

At the BGR, most of the data are stored on hard disks in raid systems. These disks are usually specific for certain projects or user groups and limit the data access accordingly. One problem with this approach is that people who might be interested in certain data do not even have access to the knowledge that these data exist. In order to make this knowledge more readily available, our approach is to set up a database with meta-information for each data set in the corresponding directory on the hard disks. The description might contain textual information, predefined key words, the position in the stratigraphic column, the type and the "owner". If the data set has a relation to geo-objects and can be georeferenced, such as the location of boreholes or the trace of a seismic section, the corresponding geo-objects are created in an additional geo-database and the link between metadata and geo-data is established as an [m:n] relationship.

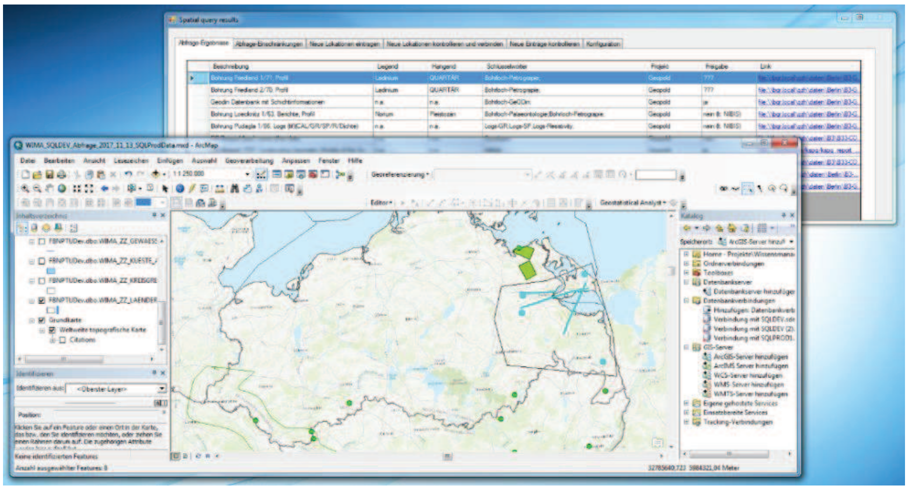

Fig. 1: Screenshot of our ArcGIS based application.

While the use of key words to search for information is common, e.g. in library catalogues, the option of supporting this search with spatial information is non-standard. Our first implementation used ESRI's C#.NET API and its add-in mechanism by extending ArcMap's spatial selection tools by inheritance and by providing a dialog for making adjustments and displaying the results. Once geo-objects have been selected in the map, an SQL query is generated which searches the database for all corresponding data available. This search can be limited to key words and stratigraphic intervals. The result of the query – a list with the metadata for each data set and a link to the original data – is shown in the dialog. This link could be a directory on our raid system or a web location. One disadvantage of this first implementation was the requirement to have an ArcGIS installation on each desktop and the need for users to have the corresponding software knowledge. For this reason we implemented a second browser-based application, based on the conterra map.apps software. This has been achieved by defining database views, publishing an ArcGIS map service and configuring the built-in tools for spatial and attribute-based search.

Geological constraints to model complex hydrostratigraphy: case studies from the Quaternary Po Hydrogeological Basin (Northern Italy)

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Hydrogeological modeling of porous aquifers at different scales is best performed if the hydrostratigraphic architecture is well constrained to the geological history of aquifer origin and groundwater saturation. Reliable hydrostratigraphic models should account also for the tectono-sedimentary history of aquifer building and disruption. Critical controlling factors on good models are the hierarchy of sedimentary bodies, which depends on the intensity and duration of depositional/erosional processes, the resulting nested multiple scales of subsurface heterogeneities and the syn- to post depositional deformation history.

Focusing on the best modelling procedure of the Quaternary hydrostratigraphy of the Po Hydrogeological Basin South of Milan, we chose two key-sectors to apply the method: i) the glacio-fluvial and alluvial terraced landscape at the northern alpine margin of the Basin, directly influenced by the Pleistocene glacial pulses; ii) the Apennine tectonic reliefs which emerge in the southern Po Plain and involve the Quaternary, alpine-sourced alluvial succession in Apennine folding and faulting. The specific aim of the work is to define a consistent 3-D stratigraphic framework of the two sectors at different scales, with the help of static geomodeling techniques, constrained by all the available data.

Field-based geological reconstruction provided the entry data for multi-scale GIS management. Original geological mapping, stratigraphic, sedimentological, pedological, paleontological, geomorphological and structural observations were firstly carried out. Hundreds of subsurface borehole and geophysical data were also used, after normalized digitalization based on a specifically built litho-textural Code. Field-based ‘hard data’ were combined to 1-D facies analysis of subsurface logs, then correlated into a fence of 2-D geological sections. In this stages of pre-processing for the 3-D analysis, GIS software was interfaced with GeoModeller® software to rapidly simulate and visualize the stratigraphic/tectonic relations, honoring the geological constraints. Several forward models were computed to compare different and even contrasting architectures and evolutions.

The 3-D results permit a first comparison between the contrasting hydro-stratigraphic architectures of the two sectors, in relation to the different geological evolutions. At the Alpine border, uplift related to glacio-isostatic and tectonic rebound determined nesting of entrenched pre-glacial valleys and glacio-fluvial terraces. At the Apennine border, thrusting and wrenching determined the palimpsest of tectonic culminations and depocentres, lately cut by the post-glacial river valleys. The 3-D model of this highest rank framework could be filled with the nested, low-rank hydrostratigraphic units, confining the potential field modelling within each highest rank geological volume, that means constraining the geological geometries to the shape of the top boundary of each unit, which is determined by the predating incremental geo-history. This attempt yielded a satisfactory image of the spatial arrangement of the different rank bodies; hence, it deserves to be taken in consideration to orient further simulations of the internal facies heterogeneities. The tectonically active sector at the Apennine border, permits also to deal with modeling of aquifer bodies whose geometries and thicknesses change dramatically within short distances owing to syn- and post depositional folding and faulting. The attempt to constrain the 3-D realizations with the incremental geological evolution required to model the geological hierarchy. Since ‘Hierarchic stratigraphic piles’ are not encompassed in the GeoModeller suite, we propose some hints to overcome this limit, starting from *ad hoc* scripts that we are carrying out at the present state of this ongoing research.

Analogue study of the Permian fanglomerates based on pseudo-3D GPR data from the Zygmuntówka quarry, Chęciny, South Poland

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Multi-scale 3D geological modelling of the sedimentary cover of the Gorzów Block (north-west Poland) involves reconstructing spatial distribution of lithofacies of Permian and younger deposits overlying the Variscan basement. However their great depth and sparse borehole data motivate us to use analogues of dominant lithostratigraphic units in the South Permian Basin (SPB) to properly delineate these distributions. A significant proportion of the sedimentary cover in the Gorzów Block is formed by alluvial-fan conglomerates which accumulated around volcanic elevations of the north-western part of the Wolsztyn High. The nearest Permian outcrops can be found in the Sudetes and in the Holy Cross Mountains. Although the depositional architecture of the SPB is mainly controlled by local tectonics, quantitative relationships measured in analogue geological situations can aid reconstructions of lithofacies distribution between deep boreholes.

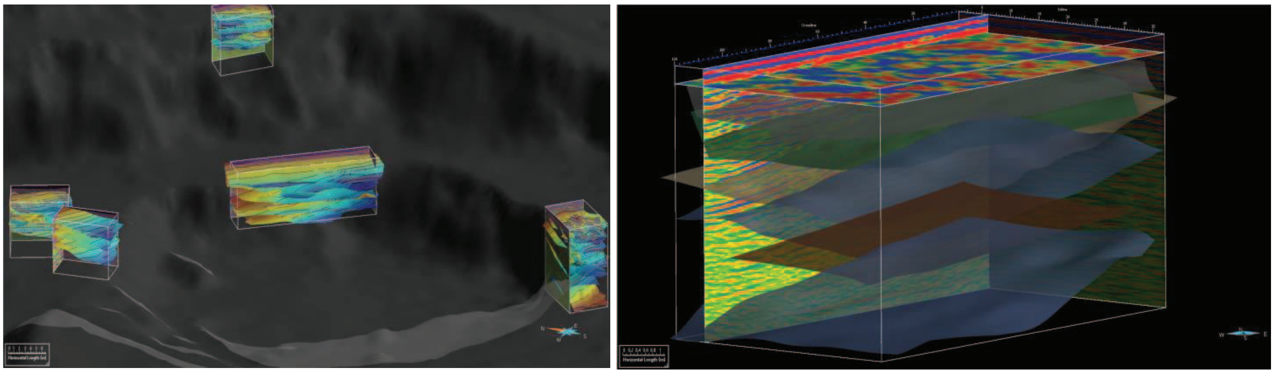

Fig.: Digital elevation model of the Zygmuntówka quarry (left image) with the pseudo-3D GPR datasets (surfaces displaying elevation values). The image on the right shows one of the GPR datasets (amplitude) with interpretation.

We analysed five pseudo-3D GPR datasets from the Zygmuntówka quarry near the town of Chęciny (Holy Cross Mountains), South Poland where coarse-grained, matrix-supported and clast-supported conglomerates of Late Permian age are exposed. The strata is mostly composed of Devonian limestone clasts deposited by cohesive flows in arid and semi-arid environment (Zbroja *et al*., 1998). GPR grid dimensions ranged from 5 to 25 m. Closely-spaced parallel GPR profiles were processed and compiled for display and interpretation with SKUA-GOCAD. Planar as well as trough-shaped bedding was traced across the datasets, and their dips and azimuths were statistically analysed within each data grid, and transferred into one larger grid with dimensions of 210 x 230 m in order to interpolate their distribution at a wider scale. The arrangement of channel deposits was also reconstructed using multiple point statistics. The results were referred to the local geological settings, particularly to the configuration of the boundary between the Permian and Devonian.

The alluvial fan architecture is one of the most heterogeneous due to the complexity of depositional processes; many surfaces are only apparent in some sections of the datasets, thus correlating them between GPR dataset is problematic. Two more GPR grids, partly overlapping each other, will be collected from the quarry, interpreted and compared with the model to assess its reliability. The model will also be validated with new field observations, particularly distribution of channels and planar stratification in the quarry outcrops. The final geostatistical model will be applied to the palaeogeographical settings in the Gorzów Block in order to test the possibility of reconstructing alluvial fan lithofacies for the 3D multi-scale geological model of the Gorzów Block.

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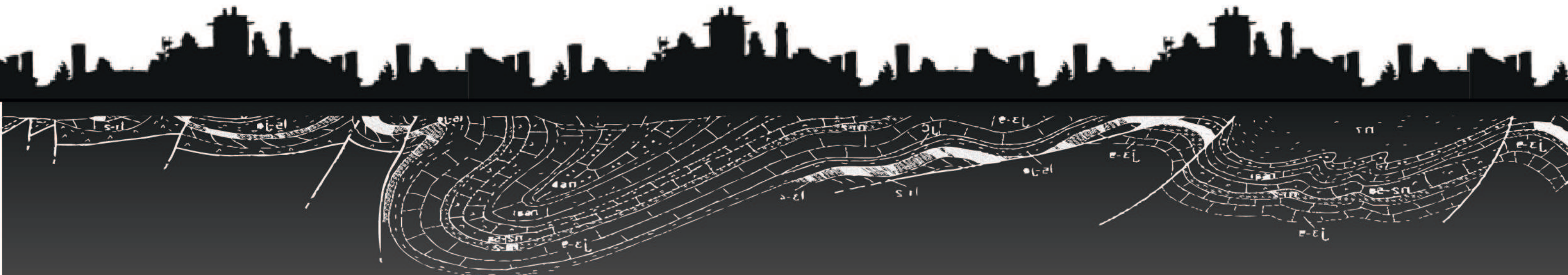

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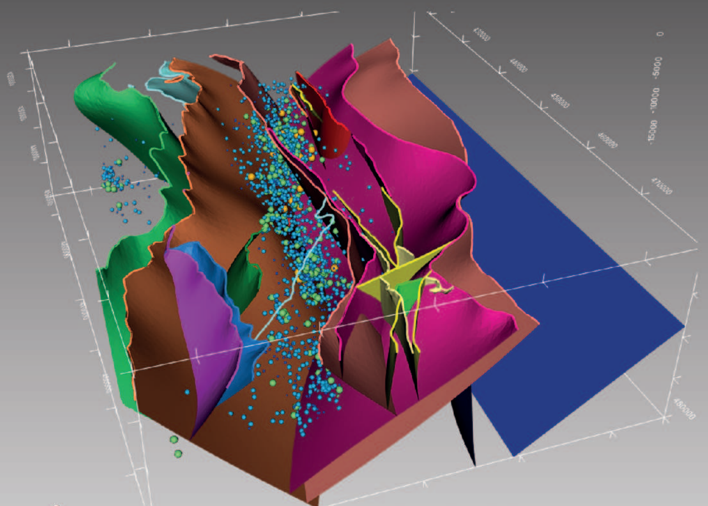

Pyrenean geological model & seismicity
Argentin *et al.*, 2015, BRGM

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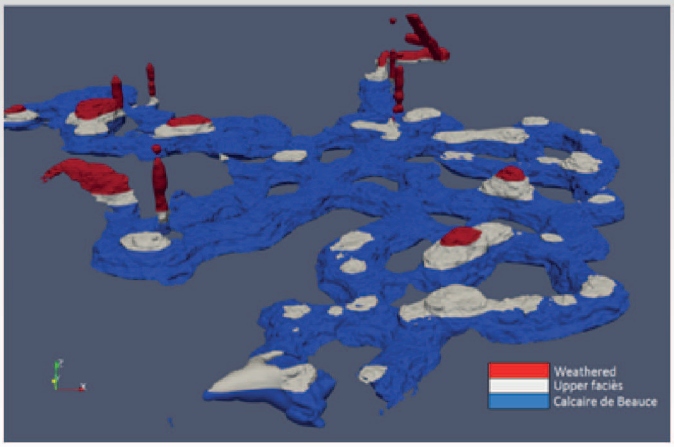

Underground quarry & French geological model (Courioux *et al.*, 2018, BRGM)

Geoscience for a sustainable Earth

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