Chapter 29: Future of 3D Geological Mapping and Modelling at Geological Survey Organizations

Richard C. Berg[1], Holger Kessler[2], Kelsey E. MacCormack[3], Hazen A.J. Russell[4], and L. Harvey Thorleifson[5]

[1] Illinois State Geological Survey, Prairie Research Institute, University of Illinois at Urbana-Champaign, 615 East Peabody Drive, Champaign, IL 61820, USA; rberg@illinois.edu

[2] British Geological Survey, Environmental Science Centre, Nicker Hill, Keyworth, Nottingham, NG12 5GG, UK; hke@bgs.ac.uk

[3] Alberta Energy Regulator / Alberta Geological Survey, 4999 98th Avenue, Edmonton, Alberta, Canada; kelsey.maccormack@aer.ca

[4] Geological Survey of Canada, 601 Booth St., Ottawa, ON K1A 7E8, Canada; hazen.russell@canada.ca

[5] Minnesota Geological Survey, 2609 West Territorial Road, St Paul, MN 55114-1009 USA; thorleif@umn.edu

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Introduction

The “Next Steps” section contained within each of the 22 geological survey organization (GSO) submissions provided useful insights on directions and significant impacts of 3D geological modelling both in the short and long term. Highlighted is the positive global impact of these modelling projects and initiatives at multiple scales, the result of which will continue to prove essential for addressing a myriad of societal and research issues related to water and mineral resources, natural hazards and risk mitigation, the environment, and infrastructure development. Major emphasis of future work include (1) expanding the use and diversity of 3D geomodelling activities within GSOs, (2) improving data management strategies, (3) better understanding and improving work force and work flow issues, and (4) enhancing the dissemination of 3D models and associated data to users and stakeholders.

Expansion of 3D Geomodelling Scales and Applications

An overarching theme of future plans by the GSOs emphasizes expansion of 3D geomodelling activities within their jurisdictions, and this includes:

1) Infilling coverage gaps (enhancing regional coverage).
2) Shifting 3D geomodelling emphases from small scale to large scale and vice versa.
3) Flexibility and adaptability to incorporate models and geological interpretations (point data, maps, grids) created by external organizations.
4) Leveraging a variety of geomodelling methods to include specific geologic units and structural features of interest.
5) Geomodelling to support multidisciplinary themes and scientific investigations.
6) Ensuring that models are adaptable and can include very complex and detailed geomodels that are required for assessing the subsurface of urban areas.
7) Interoperability for data description and exchange, as well as the ability to access models online within a sharable structure.

All of the above are dependent on the various geomodelling capabilities of the GSOs, levels of known subsurface information, and needs of constituents and stakeholders. Constituent and stakeholder needs will drive the prioritization for enhancing geological characterization in areas of strategic importance (e.g., urban regions, groundwater and mineral resource areas, transportation corridors, recreation areas, environmentally sensitive regions, as well as for attracting external investment opportunities).

The 3D modelling priorities for the 22 jurisdictions, and whether they are transitioning to larger scaled or smaller scaled 3D models, vary depending on where and how they began their modelling activities. Some jurisdictions started building models at a small (nation, state, or provincial) scale and are now in the process of infilling and transitioning to more detailed models of specific counties or regions, while others started by modelling counties and regions and are now working to integrate these localized models into large jurisdiction-wide models. The advantage to initiating geomodelling activities with large jurisdiction-wide models is that it provides a framework and context for construction of the more detailed large-scale models. The advantage of developing numerous local-scale geomodels is that it allows modelling teams to focus their efforts on developing 3D models in high-priority regions more quickly. Many organizations that have taken this approach to building models are now in the process of integrating these models into a single jurisdictional-scale model, thus creating a much desired single-source of geological information at various scales that can be updated with relative ease as new data becomes available.

Geomodelling of specific geologic units and structural features are GSO goals that address several thematic and scientific issues, including resource-scaled models that can be embedded into jurisdictional-scale models. They include modelling of:

- Bedrock structures beneath sedimentary basins to assess potential for thermal groundwater and geothermal energy.
- Deep tectonic structures to provide scientific insight on the general geologic framework.
- Onshore-offshore bedrock for energy potential.
- Nearshore bottom sediments to assess littoral transport and shore protection effectiveness.
- Structural basins and terranes for energy potential and development of predictive flow models for reservoir engineering and hydrocarbon maturation.
- Deep bedrock to assess the subsurface for deep thermal storage, geothermal systems performance, critical minerals, and carbon storage.
- Shallow bedrock and Quaternary/Holocene deposits to evaluate groundwater availability and its contamination potential, develop numerical models of hydrologic processes, monitor potential environmental changes associated with climate change, and for infrastructure development and hazard assessments. This also includes incorporating high resolution seismic profiling, ground penetrating radar, electrical earth resistivity, airborne electromagnetics, and other geophysical methods into the 3D modelling exercise.
- Shallow and deep bedrock to assess the energy-water nexus, including potential interactions between aquifers and producing regions of oil and gas fields, and potential interactions between aquifers and injection of fracking liquids and other produced waters.
- Mineral resource deposits assessment.
- Physical parameters of the subsurface in urban and infrastructure corridors.

Some survey organizations provided very specific future plans that elaborated on the need for increased 3D geological modelling of urban settings where infrastructure, near-surface geohazards, contaminant migration, and evaluation/conjunctive delineation of groundwater and surface water interactions at a detailed scale is essential for optimal land-use planning and decision making. In this dynamic setting of large and shifting populations and constantly changing land uses, high resolution, up-to-date, and easily updatable and accessible 3D geological modelling (including physical property modelling) of the upper ~100m is a priority, followed by integrating the subsurface data with man-made deposits, detailed topographic data (preferably LiDAR), and above-ground information. It is a goal of GSOs to ensure that resources and features (human and natural) at land surface and in the subsurface are integrated.

Many survey organizations indicated that they are striving to provide easily understandable and accessible 3D geological models so that land-use decision makers and economic developers can mitigate future risks (and therefore future liabilities), identify opportunities for cost-savings to government, increase public awareness, and take advantage of land areas posing less risk, as well as avoid conflicting land-use activities. This information directly feeds into the need for quantitative subsurface information for infrastructure development and supplementing Building Information Models (BIM) in subsurface urban planning. There must also be better integration of geological information with the engineering community as shallow geological material character, thickness, and variability directly affects infrastructure design, maintenance and longevity of constructed facilities, and industry bidding on excavation projects.

Data Management

An issue that still faces the global GSO 3D modelling community is dealing with large and diverse data sets, and their standardization, utilization, and dissemination. While some GSOs have this issue “well under control”, for most it looms as a major obstacle that must be overcome for fully implemented 3D geomodelling to proceed effectively and efficiently. It should also be noted that there are still many GSOs not included in this publication that lack the necessary subsurface data to even initiate a 3D geomodelling program.

Even for well-established programs, future plans call for the need to improve data management and the associated metadata that provides for its discovery and roots, and also for databases to incorporate information on, for example, mineral resources, rock properties, formation temperatures, and hydrogeological and other fluid flow data. Planning, administering, and implementing a central data storage and management system for 3D data and models is emphasized by several GSOs, followed by standardizing the creation of 3D geomodels, maintaining quality assurance processes, and sharing of modelling results. In particular, quite sophisticated 3D model databases and database management programs have been accomplished by, for example, the British, Netherlands, and Danish geological surveys.

It is essential that model validation, as well as the need to establish a time table for quality control, be conducted at various steps throughout the modelling workflow, and also that various parameters for quality assessments be defined. Finally, newly emerging machine learning and deep learning methods are aimed to assist with the above mentioned issues as they can optimize data, as well as enhance 3D geomodelling products and data interpretation efficiencies.

Availability of Technical Experts and Work Flow Issues

Two issues of immediate concern for future 3D modelling endeavors are (1) the availability of technical staff with modelling expertise to build models due to the increased rate of demand, and (2) the ability to build high quality models consistently and efficiently. Unfortunately, a general lack of 3D geomodelling training at many universities has resulted in a paucity of qualified practitioners. Currently, the majority of staff receive training on how to build 3D geological models on-the-job at the GSOs. It is critical that both current and future geomodellers have an understanding of computer programing, geostatistics, and most importantly a strong background in geological principles achieved through field based training, to ensure the models they develop are as accurate as possible. In addition, succession planning to insure that trainers/educators can train new staff in 3D geomodelling will be a challenge for academic institutions in the near future.

Some GSOs are indeed increasing the number of geologists involved in 3D geological models (Alberta, Netherlands). After all, geology is a multidimensional science and it makes sense that GSOs would train their geologists to properly characterize and categorize their data, and then be able to construct their 3D models with a working knowledge of their geology and its complexities.

For jurisdictions that have noticed an increased demand to build multiple geomodels as quickly as possible, there is an increased reliance on the use of workflows to allow them to build and update their models more efficiently. Many jurisdictions have indicated their intent to allocate time and resources to developing, improving, and/or standardizing workflows within their geomodelling teams. Workflows can range from being generic to very specific and highly detailed. Generic workflows serve the purpose of informing model users and stakeholders with a general overview of the modelling process that is used within a GSO. Very detailed and specific workflows (modelling scripts) can be constructed within a modelling software package to allow modellers to efficiently rerun and generate a new 3D model using an identical workflow after alterations or updates to the model dataset have been made. These modelling workflows are particularly important in areas where geological models need to be updated frequently, often to incorporate new data (Netherlands), and have been shown to significantly decrease the amount of time needed to rebuild the model (Alberta).

Data and Model Dissemination

The final major goal for the future identified by most GSOs, is improving mechanisms for disseminating 3D geomodels, and their associated databases, and doing so in formats that are understandable and can be leveraged by researchers, educators, decision makers, developers, and others with an interest in a region's surface and/or subsurface geology. Since the early 1990s there has been a transition from data discovery, organization and production, to dissemination of integrated data. The steps in between include production of maps, the construction of individual surfaces and volumes of subsurface units, and 3D geomodels, followed by the full servicing of all information, including keeping 3D geological models dynamic and up-to-date, as well as delivering earth and environmental process data and modelling associated with various scenarios including climate change. These transitional steps are needed to ensure that the complexity of the subsurface is understandable to the public, and that the data and models are properly utilized. When building 3D models that will likely be used for many purposes, it is important to make sure that the model metadata, including measures of model uncertainty, are properly documented and made available to all users.

A basic problem has been that GSOs who construct 3D geomodels generally have access to high-end computer hardware and software, and this far exceeds the capabilities of most users, and particularly those at more local and regional levels of government as well as the general public. It is a challenge to ensure that users have easy and low-cost access to compatible software programs, and/or can manipulate online applications using a web viewer to (1) retrieve relevant input data from a central database, (2) integrate, visualize, and evaluate the data within 3D geological models, and (3) create new custom-made models and a variety of derivative products. Open-source 3D viewers will be an important tool of the future for GSOs to leverage, and this will ensure that their models can be accessed and used by as many stakeholders as possible.

Emerging technology for augmented reality, virtual reality, serious-gaming, various visualization technologies, and 3D printing are allowing stakeholders to view and interact with 3D geomodel information in previously unimaginable ways. Many GSOs are leveraging these technologies to enhance communication of their geoscience information and products to all stakeholders, and also promoting knowledge sharing through various national and international exchange sites. An example of knowledge sharing is the OneGeology initiative called Loop (https://loop3d.org). It consists of a consortium comprised of geological surveys and research institutions in Australia, Canada, France, Germany and the UK, with a specific intent to provide Open Source information to help construct future 3D geological modelling tools. It will allow users to better define their subsurface geology, assess data needs at various scales, and address geological problems and resource evaluations (Ailleres et al. 2018).

The role of 3D mapping and modelling in advancing understanding of the complexity of the geology that underpins many of society's needs appears to be well positioned. GSO contributions are highlighting this from the perspective of individual organizations and collaborative groups. Thorleifson et al. (2010) highlighted the role and responsibility of GSOs to tackle 3D geological mapping as a continuum of their nearly 200 year evolution. This message is being reinforced and championed by both national (e.g. Boyd and Thorleifson, 2018) and international groups (EuroGeoSureys 2014). It is also being recognized more broadly by geoscience NGO's with an educational, regulatory, and policy orientation (e.g., Geoscientists Canada 2018).

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