Chapter 28: Global 3D Mapping and Modelling Coordination Initiatives

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Introduction

The focus of this Synopsis is on the activities and methodologies of geological survey organisations within their jurisdictions. As described in Part 2 of this volume, the approaches and outputs vary in each GSO for multiple reasons including political and economical drivers, geological survey evolution, their place in government, complexity of the geological environment, and availability and type of baseline data. This chapter presents initiatives that cross boundaries. Despite their justified inward looking focus, GSOs and their staff have been working across boundaries for several decades often in conjunction with staff from academic and professional associations. This chapter aims to give an inventory of these projects and initiatives to demonstrate that science and geology does not stop at political and continental boundaries and that honest knowledge exchange is crucial to advance our understanding of our planet and the processes acting within and upon it.

International projects and initiatives fall into three broad categories:

- Development of regional or international standards and best practice

Advancement of Science and Technology

In the late 1980s, the Deutsche Forschungsgemeinschaft (German Research Foundation) sponsored an extensive research program entitled “Digital Geoscientific Mapping” (Vinken, 1986) which involved many German research teams and supported two International Colloquia – the first at Dinkelsbühl in 1985 (Vinken, 1988), and the second at Würzburg in 1986 (Vinken, 1992). These colloquia included participants from the USA, the UK, and several western European countries, but the knowledge of this project was not widespread. After recognizing that much 3D modelling research was being undertaken in parallel by small groups without the benefit of any forum for exchanging ideas, Raper (1989) published a small collection of 3D modelling topics that had been presented in 1988 at multiple North American and European conferences.

The first international conference devoted to applications of 3D geological modelling was held at Santa Barbara, California on 10-15 December 1989 (Turner, 1991). The NATO Science Committee and the USGS financially supported this conference; it also received significant logistical support from software and hardware suppliers and from the National Center for Geographical Information Analysis located at the University of California at Santa Barbara. About 60 participants representing the majority of the NATO countries attended.

The Santa Barbara conference initiated a long history of successful cooperation amongst geologists and technologists to advance methodologies related to geological mapping and modelling. Several participants modified the focus of their planned October 1990 conference in Freiburg, Germany to emphasize geological modelling topics (Pflug and Harbaugh, 1992). This became the first venue to further explore 3D research and technical advances. The European Science Foundation agreed to sponsor a series of three workshops; these were held in Italy in 1992, the UK in 1996, and The Netherlands in 1997. Each workshop focused on different aspects of a common modelling theme (European Science Foundation, 1992, 1996, 1997). While they served as valuable sources of communication among members of the geological modelling community, there were no published records of their deliberations.
By the mid-1990s, the role of 3D models as a part of groundwater resource modelling became an important research topic. The International Commission on Groundwater of the International Association of Hydrological Sciences (IAHS), with support from the United Nations Educational, Scientific and Cultural Organization (UNESCO) organized two international conferences held in Vienna, Austria. Proceedings for both these conferences were subsequently published (Kovar and Nachtnebel, 1993, 1996).

In 2001, the European Science Foundation agreed to sponsor one additional workshop which addressed the importance of modelling the shallow subsurface for developing subsurface infrastructure and environmental assessment (European Science Foundation, 2001). The proceedings of this workshop were formally published (Rosenbaum and Turner, 2003).

Dedicated workshops and sessions on 3D geological modelling are part of three prominent international geoscience conferences 1) Geological Society of America annual meetings (https://www.geosociety.org/GSA/Events/Future_Annual_Meetings/GSA/Events/Annual_Meeting.aspx), 2) annual European Geoscience Union meetings (https://www.egu.eu/meetings/) and, 3) annual American Geophysical Union meetings (https://meetings.agu.org/).

The latter two have a slightly more academic focus, whereas the GSA meetings offer more opportunities on applied aspects of geology and therefore are the usual home of Three-Dimensional Geological Mapping Workshops (http://isgs.illinois.edu/three-dimensional-geological-mapping). Since 2001, North American and European geologists have attended, on a biennial schedule, this series of special workshops (a total of 10) which provide a unique international forum for exchange of best practices and innovation of 3D geological modelling methodologies and applications. The Illinois State Geological Survey maintains an online resource for all of the presentations at these workshops (https://www.isgs.illinois.edu/three-dimensional-geological-mapping). These workshops allow the 3D community to present and exchange ideas. This has not only assured the continued improvement of processes in the individual GSOs, but also has led to countless bi-lateral research projects and ultimately to the publication of this Synopsis and its previous version (Berg et al., 2011).

In 2011, a group of European participants at the Geological Society of America meeting in Minneapolis (http://www.geosociety.org/) decided to establish an equivalent European 3D geological modelling community to help coordinate and exchange information among the geological surveys of Europe. Its mission is to “exchange progress, problems and solutions in our common quest to understand and communicate the 3D composition and properties of the subsurface to support science-based decision making”. Meetings have been held at Utrecht in 2013, Edinburgh in 2014, Wiesbaden in 2016, Orléans in 2018, and Bern in 2019. A website contains the presentations, abstracts, and some images from those meetings (http://www.3dgeology.org/).

Together the members of these groups make up a highly innovative, collaborative, technically diverse, strategic, and inspiring group of geoscientists from around the world working together and motivating each other to push the boundaries of multi-dimensional geospatial modelling (K. MacCormack, pers. comm., 2019).

Cross-Border Cooperation to Solve a Particular Resource, Regulatory or Geoscience Question

In the 2011 Synopsis there were numerous mentions that cross-border collaborative 3D modelling projects would be beneficial. As of 2019 many of these projects that were at the concept phase in 2011 have been successfully completed, are proving to have a positive impact, and are positively resonating.

One of the first cross-border initiatives, with a particular focus on the need to understand the Quaternary deposits for groundwater management is the Central Great Lakes Geologic Mapping Coalition (Berg et al., 2016). It was formed in the late 1990s by the state geological surveys of Illinois, Indiana, Michigan, and Ohio and the U.S. Geological Survey. In 2008, the Coalition expanded to include four additional states bordering the Great Lakes (Minnesota, New York, Pennsylvania, and Wisconsin), and it changed its name to the Great Lakes Geologic Mapping Coalition. It expanded again in 2012 by adding the Ontario Geological Survey. These eight U.S. states and one Canadian province have similar geologic conditions and common societal issues about land and water resources, the environment, and geologic hazards that required immediate attention with a focus on 3D mapping and modelling. By integrating their expertise and resources, geological surveys are addressing these issues more effectively than could any one agency. The Great Lakes Geological Mapping Co-
alition was a seed corn for the establishment of the Three-Dimensional Geological Mapping Workshops mentioned above.

The Geological Survey of Canada (GSC) has developed a national 3D mapping initiative in collaboration with provincial and territorial surveys through the National Geological Surveys Committee (NGSC). The national committee provides guidance and coordination between the 10 provincial and three territorial geological surveys and the GSC. A recent project initiated by the GSC called Canada3D aims to develop a 3D geological model and associated knowledge-base for the approximately 17,000,000 km² of the Canadian onshore and offshore subsurface. It is anticipated that Canada-3D will become the authoritative state of knowledge for the geology of Canada at a national scale. It is a response to shifting scientific methods and emerging opportunities that favour digital techniques, as well as a response to the demands of a Canadian government open data strategy as well as global open data concerns. Canada-3D is also developing collaborative trans-boundary initiatives with the United States to provide as seamless coverage as possible between the two nations along their common very lengthy border. Such rationalization and synchronization already have been initiated through a variety of project scale initiatives, in part to support groundwater and surface water management of transboundary aquifers (Canada). Initial national scale modelling is focused on a three-layer model of the surficial, bedrock, and mantle layers along with consolidation of surface bedrock and surficial geological mapping.

Several initiatives in Europe are worth highlighting as they show how the beginnings of a promising collaborative work-driven initiative that is directed by user needs and requirements.

Various stakeholders in the Netherlands, Flanders (northern Belgium), and north-west Germany expressed the need to harmonize the (hydro) geological models in the shared border region. Accordingly, the H30 project was initiated in March 2012 with the aim to produce cross-border, up-to-date, three-dimensional geological and hydrogeological models of Cenozoic deposits. Details are published by Heyvaert et al. (2016) and Vernes et al. (2016). Figure 1 shows

Figure 1. Cross-border section showing geological edge matches that were corrected during the H30 project from Vernes, R. et al., 2016.
the geological edge match issue at the border and the resulting harmonised model. Similar transboundary stratigraphic reconciliations between Alberta (Canada) and Montana (USA) have supported numerical groundwater modelling and an improved understanding of transboundary aquifers and it has supported water resource management.

**Project GEORG** was co-financed by the European Union European Regional Development Fund. It developed a cross-border geological and geo-thermal model of the Upper Rhine Graben, which has a high potential for geothermal energy exploitation. The data and model are delivered in a web-based viewer (Figure 2).

The **Geomol project** (http://www.geomol.eu/home/index_html) was established to assess the subsurface potential of the Alpine Foreland Basins for sustainable planning and use of natural resources, in particular geothermal energy. The results of the initiative are not only an openly accessible 3D geological model of the northern and southern Molasse Basins, but the collaboration has led to significant progress on the harmonisation of differing stratigraphic frameworks and an improved capability and development of standards for the interpretation and modelling of geological horizons from historic seismic data (GeoMol Team, 2015).

A generalised tectonic crustal-scale model has been developed for the **British Isles** (Ireland, Northern Ireland, Scotland, England and Wales). This conceptual model comprises cross-sections down to 15 km depth and major fault surfaces (see Figure 3). It was developed through collaboration between the Geological Survey of Northern Ireland (GSNI), the Geological Survey of Ireland (GSI) and the British Geological Survey (BGS).

Early pan-European initiatives resulting in 3D data were the **Millennium Atlas** and the **Southern Permian Basin Atlas** (SPBA). These were developed to present a comprehensive and

**Figure 2.** GEORG web viewer (http://www.geopotenziale.org/geopotenziale/geothermal?lang=2).
systematic overview of the results of over 150 years of petroleum exploration and research in the North Sea and Southern Permian Basin area and to stimulate the petroleum exploration and production industry to continue their activities in this mature basin. The initiatives were funded by the Geological Surveys of the United Kingdom, Norway, Belgium, Denmark, the Netherlands, Germany, and Poland (https://www.tno.nl/en/focus-areas/ecn-part-of-tno/roadmaps/geological-survey-of-the-netherlands/geological-survey-of-the-netherlands/geological-survey-of-the-netherlands/petroleum-geological-atlas-of-the-southern-permian-basin/).

In addition, several cross-border projects are ongoing across national borders to understand groundwater resources, geothermal energy potential and ground conditions for tunnelling between Germany, Poland, and the Czech Republic (Krentz and Zander, 2016). Figure 4 shows their extent.

### International Initiatives to Set Best Practice and Standards

One of the most prolific and influential global projects is the OneGeology initiative (http://www.onegeology.org/) which was initiated in the mid 2000s to deliver the world’s geological data in a seamless, interoperable, and interactive manner via the OneGeology portal. In recent years, the interest in 3D geology has grown and as a result, an Australian led initiative called “Loop - enabling 3D stochastic geological modelling” (Figure 5; https://loop3d.org/) has been established bringing a range of international GSOs and researchers together to develop open source modelling solutions to mitigate 3D geological risk in resources management. It aims to do so by integrating mathematical methods, structural geology concepts, and probabilistic programming to create new approaches to 3D geological modelling. The expected outcomes are an enhanced capability to model the subsurface, characterize model

![Figure 3. Crustal-scale model of Caledonian tectonic terranes bounded by major faults viewed from the south-west (from https://www.bgs.ac.uk/research/ukgeology/nationalGeologicalModel/home.html).](image-url)
Figure 4. Geological map of Saxony showing study areas of five transboundary projects: 1, Transgeotherm; 2, Caldera of Altenberg Teplice; 3, Elbe Zone; 4, GRACE; 5, NBS Dresden-Prag. (from: Krentz and Zander, 2016).

Figure 5. The concept behind the Loop project (from https://loop3d.org/).
uncertainty, and test multiple geological scenarios.

Sub-Urban (http://sub-urban.squarespace.com/) is a recently concluded 5-year pan-European project with a focus on improved modelling and management of the subsurface beneath cities. It was initiated by the British and Norwegian Geological Surveys, and funded by the European Union’s COST action programme. Its final reports contain a large number of case studies from across Europe, as well as a series of recommendations and discussions on how to better integrate subsurface characterization into regional and city building planning, as well as for use by the construction industry.

The development of international standards for 3D geological model data and related in/outputs is still in its infancy. However, a Geoscience Domain Working Group has been established by the Open Geospatial Consortium which lists relevant initiatives and attempts to bring together various strands of standards development on its website (https://www.opengeospatial.org/projects/groups/geosciencedwg).

The European Union and EuroGeoSurveys (http://www.eurogeosurveys.org) are beginning to join forces in to establish a European Geological Data Infrastructure (EGDI) initiative to provide access to pan-European and national geological datasets including 3D geological models (more detail is given in Chapter 3). Early attempts are emerging through the GeoEra

3DGEO-EU project (http://geoera.eu/projects/3dgeo-eu/), where components of the Permian Atlas mentioned above are published on-line.

The Geological Surveys of Europe

Conclusions

Geology and science in general does not recognise borders, and knowledge sharing and technology transfer is essential in order to avoid repeating mistakes, progressing our science, saving time and resources, and ultimately making better predictions about the subsurface so keenly needed for a range of societal challenges. The authors hope that, by the next edition of this Synopsis, the above initiatives have continued to flourish and we will be closer to a unified model and a more thorough understanding of the solid earth.

References


