3-D Geological Modelling at the OGS – Products and Applications

Abigail Burt (abigail.burt@ontario.ca), Andy Bajc, Desmond Rainsford, John Dodge and Riley Mulligan

Ontario Geological Survey, 933 Ramsey Lake Road, Sudbury, ON P3E 6B5

Introduction

It was Prince Otto von Bismarck who coined the phrase ‘politics is the art of the possible’ and noted that ‘politics is not an exact science’. Substitute ‘geology’ for ‘politics’ and we have succinct descriptions of the challenges facing researchers developing and delivering 3-D geological models which genuinely provide public benefit. The challenges are rooted in the geology; often complex and consisting of Quaternary sequences from multiple glaciations. They continue with the fact that we must use legacy data of diverse origin and quality. Designing a field and analytical program (mapping, geophysics, drilling, sampling, and monitoring well installation) that delivers optimum results for multiple clients within a restricted budget and timeframe is difficult at best. Neither is asking a geoscientist to be a consummate 3-D modeller. But the hardest challenge is conveying what the esoteric 3-D geological outcomes of this work mean for the public – our internal and external clients. Internal clients are geoscientists within the OGS and other Ontario ministries who are using various products to aid in their own work while external clients range from groundwater flow modellers, researchers and educators to engineers and policy makers. All use our products and each has different levels of geological knowledge (and interest) and different needs.

This presentation will explore the life-cycle of Ontario Geological Survey (OGS) 3-D mapping projects, focusing on the different products that are being released along the way. We will look at who uses the products, how they are being used and what our clients have suggested we could do to improve them.

What is the OGS 3-D mapping team doing?

3-D mapping project areas are identified based on client needs (gap analysis and client requests) and prioritized during the OGS project planning process. Seven 3-D sediment mapping projects (1500 to 5000 km^2 in area) have either been completed or are underway in southern Ontario. They focus primarily on areas reliant on groundwater obtained from thick glacial deposits overlying bedrock. The goal of each project is to build an interactive 3-D model of Quaternary deposits that form both regional and local aquifers and aquitards. Key objectives are 1) reconstruction of the regional Quaternary history, 2) development of a 3-D model of Quaternary sediments and 3) characterization of the properties of the modelled sediment packages. The models are based on the interpretation of natural and man-made exposures, legacy datasets (e.g., water wells, geotechnical records) and new drilling and geophysical data. Each 3-D mapping project typically takes 4-5 years from conception to release of the final products. Given the length of time it takes to complete each project, it is important to release interim products to assist those clients with immediate needs for subsurface information as well as to appease government auditors that require well defined, timely outputs as justification for tax dollars spent (Table 1).

Reconnaissance and surficial map assessment

3-D mapping projects are initiated with an abbreviated reconnaissance field season to improve understanding of late-glacial history, verify existing surficial mapping (which may involve the identification of areas that require updating) and to log natural and man-made exposures. This information is invaluable for the development of a conceptual geologic framework, especially for the shallow subsurface. A Summary of Fieldwork article, which is part of a published annual report outlining all OGS activities, is completed following this first field season and may include field descriptions and basic interpretations of the various landform-sediment assemblages, a compilation of existing mapping, photos and summary logs. The traditional view taken of Summary of Fieldwork reports is that they have limited distribution and are often viewed by just a select few. In spite of this, feedback from numerous consultants indicated that these articles are indeed accessed and read. There are numerous large and small hydrogeological consulting companies working in southern Ontario, and their geologists routinely download the summary reports to see where OGS geologists are working (and where they can expect to find high quality, detailed reports and data in the future), what progress has been made on multi-year projects and to gain early access to continuously-cored borehole information. Our observations and preliminary interpretations are used to refine conceptualizations of regional stratigraphy, particularly in areas where there has been limited detailed work to date.

Geophysics

In recent years, ground-based gravity surveys have been conducted during the first year of each project to identify the locations buried bedrock valleys. These are of considerable interest as they not only have the potential to host large and productive aquifers but may also move groundwater across watershed boundaries. The gravity surveys are designed around the needs of our 3D mapping projects. We use them to select drilling targets in areas known, or suspected, to have buried bedrock valley systems. There aren't sufficient resources to drill every potential target on every survey line, but we are able to drill enough to confirm the results of the survey. Results of the geophysical surveys are released in map form and as a geophysical dataset that includes both raw and processed gravity and elevation data, grids of the gravity and elevation products, residual Bouguer gravity contours, profiles of elevation, Bouguer gravity, regional gradient, and residual Bouguer gravity in portable document format, and survey report and documentation (see Table 1 for file formats). The geophysical datasets and maps have also been used by external clients, for example municipal engineers, to answer questions about the bedrock surface.

Other geophysical methods, have been (and are being) used to assist with 3-D modelling. These include an airborne electromagnetic (EM) test survey, high resolution seismic reflection surveys and borehole geophysical logging. The latter two activities have been carried out in collaboration with the Geological Survey of Canada (GSC). Airborne EM methods offer the possibility of covering large areas quickly, but suffer from cultural "noise" (e.g. powerlines) and require strong electrical conductivity contrasts to distinguish subsurface units. Seismic reflection surveys, carried out using the GSC's Minivibe landstreamer system, have yielded high resolution images of Quaternary sediments and underlying bedrock surface. Access to this technology is, however, limited and only a few strategically placed profiles can be obtained in any project area. The borehole physical property data, which have been acquired both by commercial contractors and the GSC, are instrumental in understanding the results of the ground and airborne geophysics as well as in the processing of the seismic data. The results of this work are published as standalone geophysical data sets, Summaries of Fieldwork articles and GSC open file reports.

Drilling

Subsequent field seasons (two or three depending on the project area and sediment thicknesses) are devoted to drilling, typically mud rotary, continuously-cored holes. Drilling targets are selected within distinct physiographic regions to define/refine sediment stratigraphy, establish landform-sediment associations and determine the nature of buried bedrock valley fills. In the field, the core is logged, photographed and sampled for grain size, carbonate and heavy mineral content. In some project areas, additional samples are taken for other analytical determinations (eg. thin section analysis, magnetic susceptibility and moisture content) as part of collaborative efforts with universities and other government agencies. In an effort to meet client needs, pocket penetrometer readings have also been

Table 1. 3-D project products and release formats.

Product	Description	Format
Summary of Fieldwork reports 1-4	• Observations, conceptual geological framework, summary logs of boreholes, and preliminary interpretations	• Text and graphics (.pdf)
Geophysical maps	• Contour of residual bouguer gravity (ground) • Contoured residual magnetic field, EM decay constant and apparent conductance (airborne)	• Text and graphics (.pdf)
Geophysical datasets	• Database of ground gravity and elevation data • Grids of residual bouguer gravity and DEM • Colour image and contours of residual bouguer gravity • Gravity station locations • Gravity survey logistics and processing report • Database of airborne EM and magnetic data • Grids of residual magnetic field, EM decay constant and apparent conductance • Colour images and contours of residual magnetic field, EM decay constant and apparent conductance • Flight line locations • Sections of inverted electrical conductance • Airborne survey logistics and processing report	• ASCII (.xyz) and Geosoft® (.gdb) • ASCII (.gxf) and Geosoft® (.grd) • Raster (geoTIFF), Vector (.dxf) • Vector (.dxf) • Text and graphics (.pdf) • ASCII (.xyz) and Geosoft® (.gdb) • ASCII (.gxf) and Geosoft® (.grd) • Raster (geoTIFF) and Vector (.dxf) • Vector (.dxf) • Text and graphics (.pdf) • Text and graphics (.pdf)
Borehole data	• Interactive graphic borehole logs, detailed descriptions, analytical data, core photos and geophysical logs.	• Text and graphics (.pdf), database (.mdb), spreadsheet (.xls), photos (.jpg)
New interactive map	• Interactive maps of borehole logs and interpreted hydrostratigraphic units, GIS project, printable maps.	• Text and graphics (.pdf), database (.mdb), spreadsheet (.xls), GIS project (.mxd)
Groundwater Resources Study	• Report: Data sources and translations, modelling process, Quaternary reconstruction, discussion of modelled surfaces and aquifer vulnerability	• Text and graphics (.pdf)
	• Analytical Data: Coded according to hydrostratigraphic unit and depositional environment.	• Database (.mdb), spreadsheet (.xls)
	• GIS Grids: Structural contour and isopach grids of modelled units. Hillshade (25 m cell size) of the bedrock surface.	• GIS raster datasets

Product	Description	Format
	• Google Earth: Isopach and structural contour maps of hydrostratigraphic units, subsurface database and excerpts from seamless geology maps viewable using Google EarthTM mapping service.	• Google EarthTM (.kml, .kmz) and portable network graphic (.png)
	• Graphic borehole logs.	• Graphics (.jpg)
	• Modelled Surfaces: Isopach and structural contour data on a 100 m grid for each hydrostratigraphic unit.	• Comma-delimited data files (.csv)
	• Movies showing the use of the cross-section viewer and the Google Earth™ mapping service.	• Movies (.avi)
	• High-resolution plates: Cross-sections (hydrostratigraphic units and aquifer / aquitard class legends) and isopach, structural contour and aquifer vulnerability maps.	• Graphics (.pdf)
	• Section Viewer: Displays cross-sections of the block model along user-defined lines. Cross-sections can be saved then viewed in Google EarthTM.	• Microsoft® Virtual Earth™ executable SectionViewer.exe
	• Subsurface Data: Abbreviated version of the dataset used to construct the 3-D block model including location, formation and picks tables.	• Database (.mdb),
Scientific contributions	• Fieldtrip guidebooks, journal papers, workshop proceedings and conference proceedings	• Various formats

added to the routine core logging in clay-rich areas. Monitoring wells are installed in some boreholes for municipalities and conservation authorities to allow for long-term groundwater monitoring of both shallow and deep groundwater.

Summary of Fieldwork reports are released containing preliminary graphic logs, example photos and preliminary interpretations of key sediment packages. The OGS works on the principal that ‘no one gets it until everyone gets it’. What this means is that, as a publicly funded organization, we have a mandate to publish as much information as possible. The only stipulation is that all clients must have the opportunity to obtain the information at the same time. Publishing preliminary summary logs, often while drilling is still in progress, means that we can engage in meaningful discussions with clients before the final products are released. The price for speed is that there aren’t any analytical results and stratigraphic interpretations may change as key datasets come in and new boreholes are acquired.

Once all drilling activities have been completed, and the results of grain size, carbonate and heavy mineral analyses obtained, more formal products are released. The first product is a borehole release consisting of detailed written logs, graphic logs, interpreted depositional environments, analytical data (pebble counts, grain size, carbonate, heavy mineral and borehole geophysical data) and core photos as well as a visual representation of the information in a hyperlinked portable document format (.pdf) file. This release is designed for consultants working within specific project areas as a supplement to their own drilling and publicly available legacy datasets. In return, consultants often share information with us and even provide samples so that we can compare analytical results. The release is also useful for academics and other geoscientists by providing insights on glacial history and climate change, an improved understanding of groundwater flow and information on the characteristics of key stratigraphic units that can be used to support ongoing studies. Over the years, it has become apparent that an excessive level of detail can overwhelm some clients. Follow-up meetings have prompted the addition of simplified geological interpretations including a basic aquifer – aquitard classification. Most recently, there has been a request to add a graphic log and database table to reflect oxidized vs reduced conditions in the sediment logs.

Recently, a new digital interactive product was designed to make hydrostratigraphic information available to clients prior to completion of the 3-D block model and detailed report. The product consists of new graphic logs (including aquifer class, hydrostratigraphic units, summary geology and interpreted environments) presented on interactive and printable maps. There are links to a slideshow of drilling operations, the conceptual geologic model, descriptions of the hydrostratigraphic units, and a fully functioning GIS project containing files used to build the hydrostratigraphic map. The product grew out of a simple map depicting surficial geology and detailed borehole geology that was being used internally to aid with the 3-D modelling process. It is now being used by conservation authority clients to determine which aquifer their monitoring wells are screened in. The final 3-D model would be better, but this is useful in the interim.

3-D model and final products

Following completion of fieldwork and construction of interim products, the geologist is tasked with building a 3-D model of the project area using the hydrostratigraphic units defined in the conceptual geologic framework. The model is created from borehole location, standardized geologic formation and screen / static water level data using Datamine Studio ® software. 3-D points (referred to as picks), identifying the upper surface of a given hydrostratigraphic unit, are manually digitized onto the borehole traces with additional picks digitized off trace in order to refine the geometry of the modelled surfaces. Wireframe surfaces representing the elevations of each hydrostratigraphic unit are interpolated on a 100 m grid using all picks within user-defined search radii. The final 3-D block model is generated by filling in the spaces between the wireframe surfaces using 100 X 100 m blocks of variable thickness. The blocks are used to calculate the volume of each hydrostratigraphic unit and produce a series of output files.

The final model outputs are released digitally as a Groundwater Resources Study (GRS) comprising both data and interpretative material (see Table 1). Comma-delimited (.csv) files, depicting the elevation of each hydrostratigraphic unit as x, y, and z coordinates on a 100 m grid generated from the block model, are the primary outputs. Printable structural contour maps depicting the surface topography, isopach maps indicating the thickness of each hydrostratigraphic unit, maps of the digitized picks, colour-coded by quality, that were used to generate the surfaces and a series of west-east and north-south cross-sections are designed as reference guides. A cross-section viewer was developed that allows flexibility to cut sections of any length and orientation using the legend of choice. The cross-sections can be saved then imported into Google Earth™ resulting in customized output. The structural contour maps, isopach maps and standardized subsurface database are also viewable using Google Earth™. Many of the data files have been designed so that they may be used as inputs to other software packages; for example for hydrogeological modelling, or visualisation.

What do our users think of the final products? A client recently told me that the GRS's are like having a present within a present within a present. An OGS colleague said it best – people are only just starting to discover the many uses for our products as we start working in their geographical areas of interest. The cross-section viewer is one of the most popular products with a wide range of clients. For example, one conservation authority is using it to determine the hydrostratigraphy around their monitoring wells and categorize their datasets by specific aquifer unit. Geoscientists within the OGS are using the viewer for similar purposes when we aren't available to input specific well data into our modelling software. The 'picks' table used to create wireframe surfaces generates most interest within the database. Other feedback is that the models we generate are great for the regional picture but when you zoom in to site specific projects, there is room for improvement. Much of this is a reflection of us not having access to confidential information adjacent to areas of hydrogeological concern such as waste disposal sites, brownfields or municipal well fields.

Getting the message out!

One of the greatest challenges we face is getting our products into the hands of those that need it to do their job. Cost is not the issue, as everything can be downloaded free of charge from our website. The problem is that people still don't know what we are doing. How do we get the message out? Are we talking to the right people? Is it our job to 'market' ourselves or should this be part of a broader organizational activity? Is there value in tracking downloads to see where and to whom we need to focus our attention? How can we improve our products and are there new directions that we should be exploring?

In an attempt to assist clients with searching OGS products, the organization has developed a platform called OGSEarth www.ontario.ca/ogsearth that enables the user to view a large number of Ontario's geological, mining and index datasets in Google Earth. OGSEarth provides metadata for all OGS publications and allows one to quickly download maps, reports and digital datasets held within the online warehouse known as GeologyOntario www.ontario.ca/geology This tool has had a lot of positive feedback from clients. Geology Ontario http://www.geologyontario.mndm.gov.on.ca/, a text based search engine on the ministry website, also allows publications to be downloaded using more traditional search criteria (author, date, key word, etc.).