GS-17 Three-dimensional geological mapping in Manitoba: overview and products

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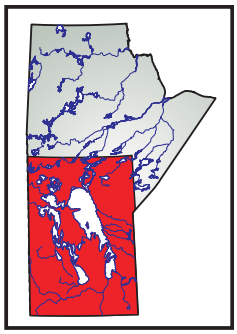

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Summary

The Manitoba Geological Survey (MGS) is nearing completion of a three-dimensional (3-D) geological model of the Phanerozoic succession in southern Manitoba, south of 55°N. As the MGS works toward this goal, several input datasets are refined and improved as new outputs are created. Many of these datasets have become noteworthy products and are able to stand on their own. For example, crossprovince digital vertical maps, originally devised to resolve nomenclature and modelling issues from region to region, are now thought of as primary web-accessible products. This paper briefly discusses the MGS modelling methods and provides a review of the significant products resulting from the 3-D modelling process as well as web links to the products discussed.

As in the past, progress on the 3-D model is being benchmarked with that of other Canadian, U.S. and European geological survey organizations through international workshops. The Manitoba Geological Survey has attended these meetings since the inaugural workshop held in Bloomington, Illinois in 2001, and current work has most recently been presented at the Geological Society of America workshop in Minneapolis, Minnesota in October 2011.

Introduction

This paper is modified from Keller et al. (2011). The Manitoba Geological Survey (MGS) has been generating 3-D geological maps since early 2000 (Keller et al., 2009). These maps are based on data compiled over approximately a decade, and data inputs include Manitoba's water well, oil well and stratigraphic drillhole databases, large-lake bathymetry, the Lake Winnipeg seismic survey and surface datasets such as the provincial surficial geology compilation map series. All of these datasets have been standardized to be used in a GIS environment and much of this work was completed in co-operation with the Geological Survey of Canada (GSC), either as part of the National Geoscience Mapping Program (NATMAP) or the Targeted Geoscience Initiative (TGI). As a result, many of these modified input datasets have become significant standalone products.

For example, the modelling methods that the MGS employs uses a series of large cross-sections, which represent east-west transects spaced 5 km apart across the entire province. These cross-sections include all data available within 2.5 km from the line of the section. Each 3-D modelling project uses a slightly different layout for the cross-section; however, the basic methodology is the same: the sections are created, printed and then hand interpreted. This 'final' interpretation is then captured at a 5 km east-west interval, imported as a series of 'tops' and then modelled using 3-D software. This method is being slightly modified for the southern Manitoba model (south of 55°N) in that the combined cross-section interpretations (TGI, NATMAP, SEMB and Lake Winnipeg) were being reinterpreted collectively, digitized and directly imported into our 3-D modelling software as a set of vertical maps (Figures GS-17-1 and -2).

These 'vertical maps' were initially thought of as a means to an end; that is, they would be measured and the unit tops would be imported and modelled. However, because of the lack of inexpensive, readily available 3-D model viewing and querying software, the vertical maps were realized as a very useful product on their own. Whereas the 3-D model and its outputs are useful to a select group of clients, for example, the Engineering Department at the University of Manitoba for its groundwater-flow model developed from the MGS's earlier modelling work (Kennedy and Woodbury, 2005), most clients, whether professional or lay, are more comfortable using an ArcGIS shape file or a jpeg image generated from one of the vertical maps. To this end, we have started posting these vertical maps on the Internet, accessible by clicking on a particular location on our provincial surficial map via our map server. These vertical maps have already proven useful for educational purposes, to resolve complex aquifer issues and have been used to define the 'base of groundwater protection' (the depth to which oil wells are cased) on behalf of Manitoba's Water Branch.

Model construction

As discussed in Keller et al. (2009), the MGS has spent a great deal of time designing a workable infrastructure for data collection, integration and output as it relates to 3-D modelling. Our cross-section methods have allowed us to create the NATMAP southeastern Manitoba model, as well as the Lake Winnipeg model. The TGI Williston

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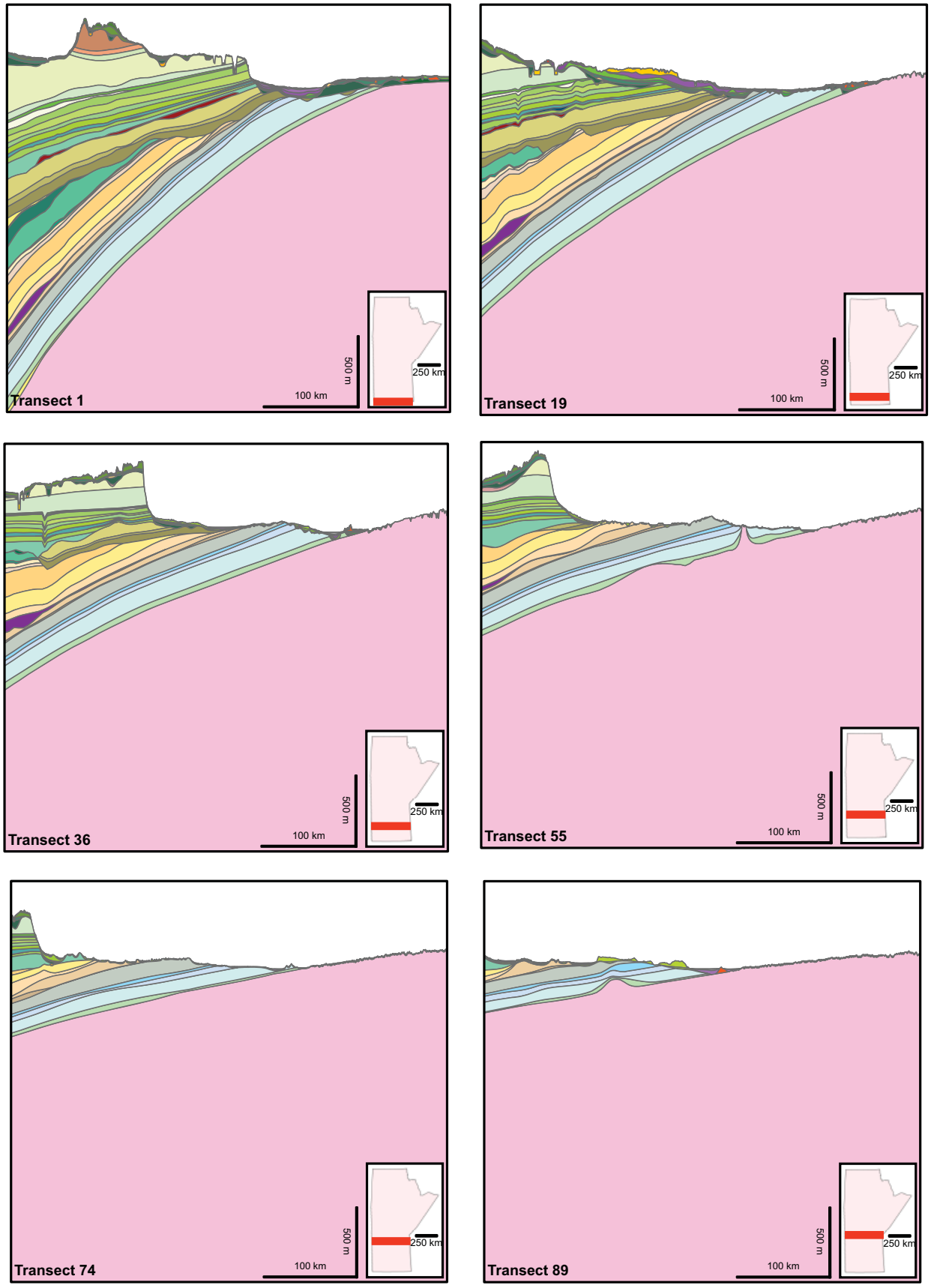

Figure GS-17-1: *Transects 1, 19, 36, 55, 74 and 89 are represented as vertical maps with the transect location in the lower right. Each transect extends from the Ontario border to the Saskatchewan border.*

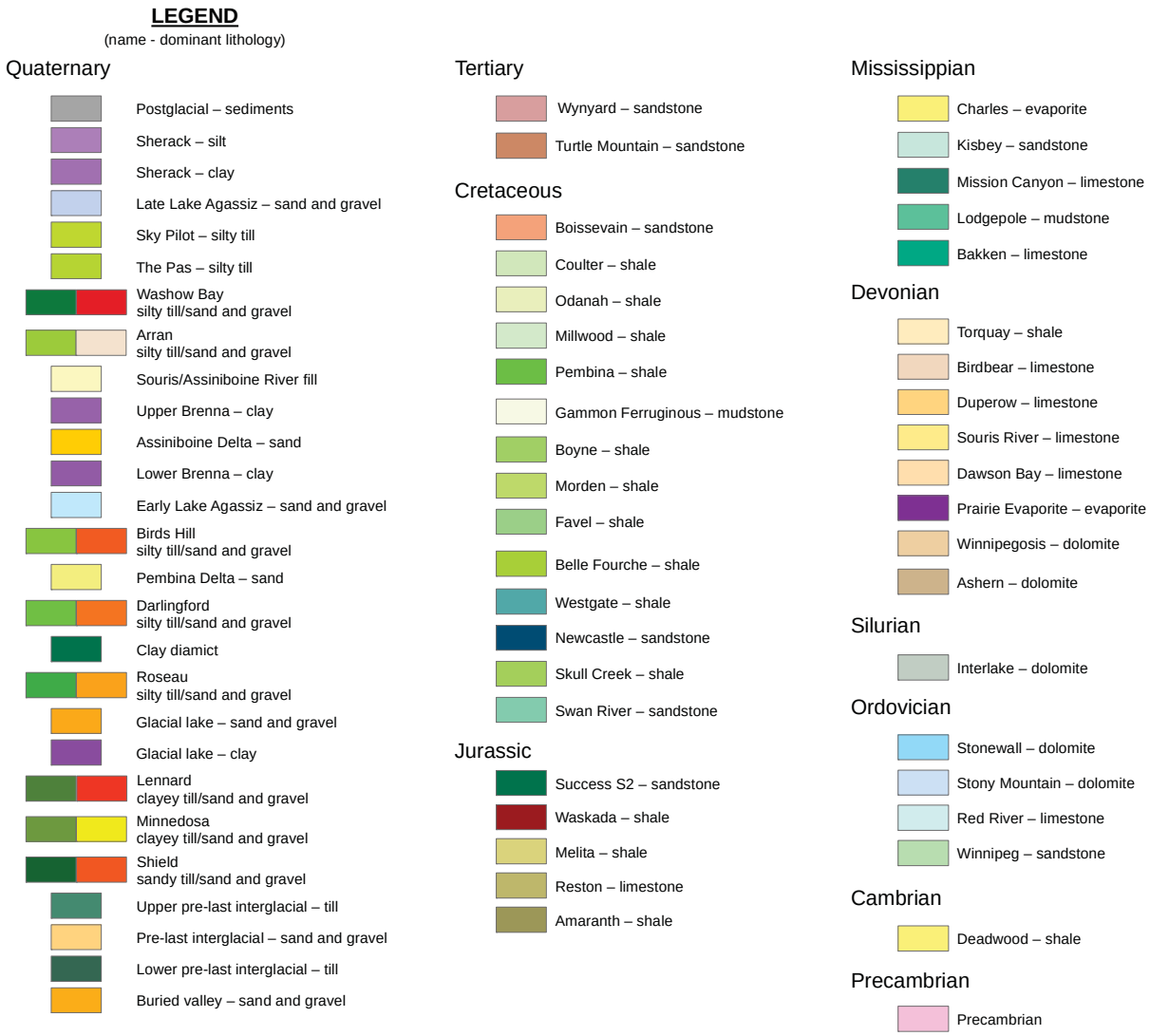

Figure GS-17-2: *Three-dimensional model vertical map legend.*

Basin model, on the other hand, was modelled directly from high-quality drillhole data. A modified version of the cross-section methodology is now being used to model all of Manitoba's Phanerozoic terrane south of 55°N.

During the initial stages of the modelling process, we use several datasets that are directly and indirectly related to the geological interpretation. Geological maps and reports including published and unpublished subsurface and surficial information by various geologists are considered. Data representing various aspects of paleogeography for the area are also included. This allows a greater understanding of both glacial retreat and glacial Lake Agassiz, both of which factor strongly into the geological interpretation. Overall, we endeavour to ensure that every piece of available information from every available source is integrated into the cross-sections.

The geological interpretation for Manitoba south of 55°N is nearing completion. It was decided that the southwestern Manitoba area should not be modelled separately as was done in previous projects, but instead be modelled by combining all of the previous models into one large southern Manitoba model south of 55°N. This method was selected to resolve two issues: 1) subtle nomenclature differences from area to area and 2) TGI modelling issues resulting from rock formation edges along escarpments plotting in 3-D at elevations other than the projected trend of that particular formation. To resolve these issues and consolidate the regional geological interpretations into one model, geological east-west transects representing a 5 km wide swath containing all available geological data for that area, along with hand-drawn rock and Quaternary (sediment) units from previously modelled regions, are being combined into 134 province-wide georeferenced vertical maps. Hand-drawn transects from Phase 1 (southeast Manitoba), Phase 2 (Lake Winnipeg) and Phase 3 (southwest Manitoba) were scanned, georeferenced and combined in ArcGIS with computer-generated transects containing predicted stratigraphy points (PSPs) or virtual drillholes

from the TGI Williston Basin Project (Table GS-17-1, Figure GS-17-3). All 134 province-wide transects are currently being digitized to depict up to 41 rock formations and 35 Quaternary units (Figures GS-17-1 and -2). These complete vertical maps will then be imported into our 3-D modelling software.

Model inputs and products

It may seem unusual to mention model inputs after model construction; however, virtually every input used in the modelling process had to be modified in some manner in order to be useable. As a result, many model inputs became significant standalone products.

Database standardization (GWDrill)

Although drillhole data used in the model is derived from various sources, the vast majority of drillhole information used in modelling is gleaned from the GWDrill waterwell database, which is housed at the Manitoba Conservation Water Branch (Manitoba Water Stewardship, 2007). This database of close to 100,000 holes required three significant upgrades prior to its use

Table GS-17-1: Model extents (Figure GS-17-3).

Model	Latitude Range	Longitude Range	Area	Units
Southeast Manitoba	49° to 51°	–98° to –95°	45 000 sq km (17 500 sq mi)	14 bedrock units, 17 Quaternary units
Lake Winnipeg	51° to 54°	–100.3° to –95.3°	78 000 sq km (30 000 sq mi)	8 bedrock units, 24 Quaternary units
TGI Williston Basin	49° to 55.5°	–106° to –96°	494 000 sq km (190 700 sq mi)	42 bedrock units
Southwest Manitoba	49° to 55°	–101.5° to –98°	176 225 sq km (68 041 sq mi)	41 bedrock units, 35 Quaternary units (includes units from all model areas)

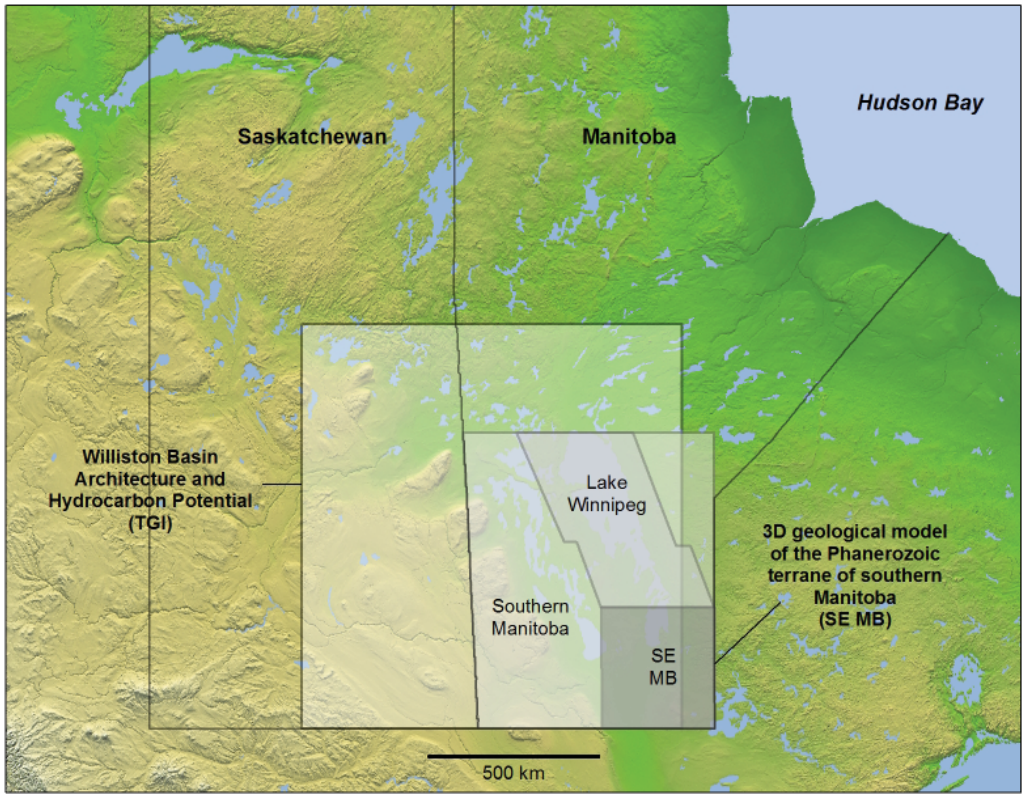

Figure GS-17-3: *Index map of model areas (Abbreviations: SE MB, southeastern Manitoba; TGI, Targeted Geoscience Initiative Project).*

as an input in the 3-D modelling: 1) the addition of x-y co-ordinates instead of only township-range-section, 2) the addition of an elevation or z value and 3) the classification of 75,000 unit descriptions into 18 sediment types. These upgrades have made the database infinitely more valuable to clients of the Water Branch, so much so that these upgrades have been built into the Water Branch's version and are being maintained as such.

Digital elevation models and maps

Digital elevation models (DEMs) help form the backbone of the 3-D model. Without elevation, the drillhole data could not be vertically positioned and would be inadequate for modelling. Realizing the need for an accurate DEM of the province, in the late 1990s, the MGS began creating a DEM from orthophoto rectification files. This DEM (DEMSM v.1), released as an online and CD product, became the MGS standard DEM until the release of the SRTM (Shuttle Radar Topography Mission) data in 2002 (United States Geological Survey, 2002). Understanding the educational benefit inherent in visualized DEM data, the MGS released the *Shaded Relief Topography of Manitoba Map* in 2004 (Matile and Keller, 2004), which was based on the SRTM data. An updated anaglyph version of this map was released in 2005 in association with the University of Minnesota (Morin et al., 2005).

Bathymetry and Knudson

Large lakes such as Lake Winnipeg, Lake Manitoba, Lake Winnipegosis, Playgreen Lake and Lake of the Woods occur within the modelling area. The lake-bottom relief of these large water bodies cannot be ignored because they provide insight into the geology. To capture these features, more than 31,000 soundings on 22 Canadian Hydrographic Survey (CHS) charts were digitized and corrected relative to shorelines, as depicted on NTS 1:250 000 topographic maps. Several corrections were made, including adjusting the soundings from the varying CHS low-water datum to a consistent value. The bathymetric data have subsequently been added to the SRTM DEM, providing a seamless elevation model, which includes large lake bottom topography.

Bathymetry provided a valuable glimpse into the sublake geology; however, it was seismic stratigraphy that helped complete the picture. In the mid-1990s, two cruises of the Canadian Coast Guard Ship Namao recorded low- and high-frequency seismic data for more than 1000 km of survey lines (Todd et al., 1998). The data was interpreted for Quaternary sediments and Paleozoic bedrock, and was subsequently added to our knowledge base for the 3-D model. In 1999, the MGS added several kilometres of Knudson echo-sounding data to the sublake geology in areas inaccessible to the previous cruise surveys. This data, along with the original Namao data, helped refine the location of the escarpment representing the Phanerozoic edge within Lake Winnipeg.

Surficial geology

Accurate surficial geological mapping is an invaluable input to the 3-D model because it allows a top-down interpretation where there is a shortage of data. To this end, the MGS began the onerous task of creating a new digital version of the surficial geology of Manitoba, which replaces the original 1:1 000 000 mapping released in 1981 (Nielsen et al., 1981). A large part of the task had been the conversion of data from paper maps to digital vector coverage. Map legends were standardized, map polygon boundary discrepancies were corrected with the aid of the SRTM shaded relief topography and data gaps were filled using a combination of detailed soils mapping and the SRTM DEM. The final product was released in 2007 as a two-sided 1:1 000 000 scale printed map and a DVD, which includes 1:250 000, 1:500 000 and 1:1 000 000 scale maps for all of Manitoba as well as associated educational information, which make the maps more usable by lay clients (Matile and Keller, 2007).

TGI maps

A significant portion of the upcoming southern Manitoba 3-D model uses modelled data from the TGI II Williston Basin Project. This project's primary objective was to develop a geological model of the Paleozoic and Mesozoic rocks from basement to outcrop in a 494 000 km^2 area in southeastern Saskatchewan and southwestern Manitoba (TGI II Working Group, 2009). Outputs from this project include 45 structure and 53 isopach maps as well as a 3-D geological model. This information is available online at http://www.willistonTGI.com.

Phanerozoic geology

In addition to surficial geology, accurate Phanerozoic mapping is critical to the 3-D mapping process. Similarly, Phanerozoic mapping indicates where stratigraphic units visible in drillholes should terminate in the subsurface. The TGI Williston Basin Project and subsequent mapping and modelling indicated that several changes were necessary to the existing unit edges. These changes necessitated a new map set representing the most current interpretation of the Phanerozoic strata of southern Manitoba. This two-map set (Paleozoic and Phanerozoic), depicting a complete sequence of 46 Phanerozoic formations for the Williston Basin area of southern Manitoba, is a valuable geoscientific and exploration tool useful to the petroleum, mineral resource and industrial minerals industries, as well as universities, government and environmental organizations (Nicolas et al., 2010).

Web content

The MGS releases most publications, data and maps on the Internet for free download. The following is a list of products associated with the MGS 3-D model and their associated URLs:

- Manitoba Mineral Resources Division Home (http://www.manitoba.ca/iem/mrd/index.html) contains links to all projects, maps and business areas under the Mineral Resources Division.
- Manitoba GIS Map Gallery: Geoscientific Maps (http://www.manitoba.ca/iem/mrd/geo/gis/geoscimaps.html) contains the Surficial Geology Compilation Map Series map server link, which includes links to display the vertical maps.
- Surficial Geology Compilation Map Series (SGCMS; http://www.manitoba.ca/iem/mrd/geo/gis/surfgeomap.html) contains a description of the mapping project, links to all maps in the series in PDF and ESRI shapefile formats (1:250 000, 1:500 000 and 1:1 000 000) as well as legend descriptions and educational material.
- Manitoba Stratigraphic Map Series (http://www.manitoba.ca/iem/mrd/geo/stratmaps/index.html) contains links to the Phanerozoic geology of southern Manitoba (MAP 2010-1), the two-map set at a scale of 1:600 000, as well as the Williston Basin TGI II Project (98 maps).
- Digital Elevation Model of Manitoba (http://www.manitoba.ca/iem/mrd/geo/demsm/introduction.html) contains four digital elevation models (orthophoto based as well as SRTM based) and several images derived from the model.
- Three-Dimensional (3-D) Geological Model of Manitoba (http://www.manitoba.ca/iem/mrd/geo/3dmodel/index.html) contains video clips and data related to the southeastern Manitoba 3-D model.

Economic considerations

Manitoba continues to play an active and leading role as a contributor to local, national and international 3-D modelling projects. The 3-D models, which unite disparate datasets and modify them to use a single standardized nomenclature, significantly contribute to a variety of geoscience knowledge bases relevant to Phanerozoic stratigraphy, hydrocarbon, groundwater and industrial-mineral resource development, and geological education.

The 3-D model itself is not a standalone product. There are a large number of 'spin-off' products associated with the modelling process. These products further increase our geoscience knowledge base and provide both professional and lay clientele an expanded array of scientific and educational materials.

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