

PROGRESS IN 3D GEOLOGICAL MAPPING IN THE EASTERN PRAIRIES OF CANADA AND THE USA

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INTRODUCTION

Increasing demand for groundwater and hydrocarbons have been the two main drivers for 3D mapping in Manitoba. In order to satisfy these demands, and to broaden our knowledge of the subsurface, the Manitoba Geological Survey has been working toward a provincial 3D model by developing regional and detailed models, as well as protocols and methodologies for model construction. Early in 2000, after years of data compilation, the first of Manitoba's 3D models was built. This hydrostratigraphic model, built with funding from the National Geoscience Mapping Program (NATMAP), covered the 200 km by 230 km Winnipeg area of southeastern Manitoba. Subsequently, Paula Kennedy of the University of Manitoba completed a groundwater-flow model based upon this data, proving its feasibility for groundwater modeling (Kennedy and Woodbury, 2005). The model has since been extended northward to include the Lake Winnipeg basin and is currently being extended westward to complete all of the southern Manitoba Phanerozoic terrane south of 55° North Latitude. The southwest Manitoba model will include bedrock units derived from the recently completed Williston Basin architecture and hydrocarbon potential project 3D model which was funded by the federal (Canada) Targeted Geoscience Initiative (TGI). This cooperative model was created using high quality drill data from both Manitoba and Saskatchewan. A regional scale model was recently created using data from the Atlas of the Western Canadian Sedimentary Basin (WCSB) (Mossop and Shetsen, 1994). It was built using digitized structure contours, and covers Manitoba, Saskatchewan, and Alberta. Future modeling will include further cooperation with both Minnesota and North Dakota in order to produce the Red River Valley 3D geological model. This model will connect the existing Manitoba models with the 3D geological model of groundwater-bearing strata in the Fargo-Moorhead region. Early in 2009, the first step was taken toward this end by creating a cross-border seamless Quaternary map covering the study area. Finally, a new project on the hydrocarbon potential of the Hudson Bay and Foxe basins has been initiated. This project is part of the new Geological Survey of Canada northern Geoscience of Energy and Minerals program (GEM). One of the planned products is a 3D model of the Hudson Bay Lowland (HBL) area of northern Manitoba.

Table 1. Model extents (Figure 1).

<u>Model</u>	<u>Latitude Range</u>	<u>Longitude Range</u>	<u>Area</u>	<u>Units</u>
Southeast Manitoba	49° to 51°	-98° to -95°	45 000 km ² (17 500 mi ²)	14 bedrock units, 17 Quaternary units
Lake Winnipeg	51° to 54°	-100.3° to -95.3°	78 000 km ² (30 000 mi ²)	8 bedrock units, 24 Quaternary units
TGI Williston Basin	49° to 55.5°	-106° to -96°	494 000 km ² (190 700 mi ²)	42 bedrock units
WCSB	Manitoba, Saskatchewan and Alberta		2 920 940 km ² (1 127 780 mi ²)	10 bedrock units (chronostratigraphic)
Southwest Manitoba	49° to 55°	-101.5° to -98°	176 225 km ² (68 041 mi ²)	Yet to be determined
Red River Valley	45.5° to 51°	-98° to -95°	136 100 km ² (52 550 mi ²)	Yet to be determined
Hudson Bay Low	~ 54° to ~ 59°	~-97.5° to ~ -89°	190 060 km ² (73 400 mi ²)	Yet to be determined

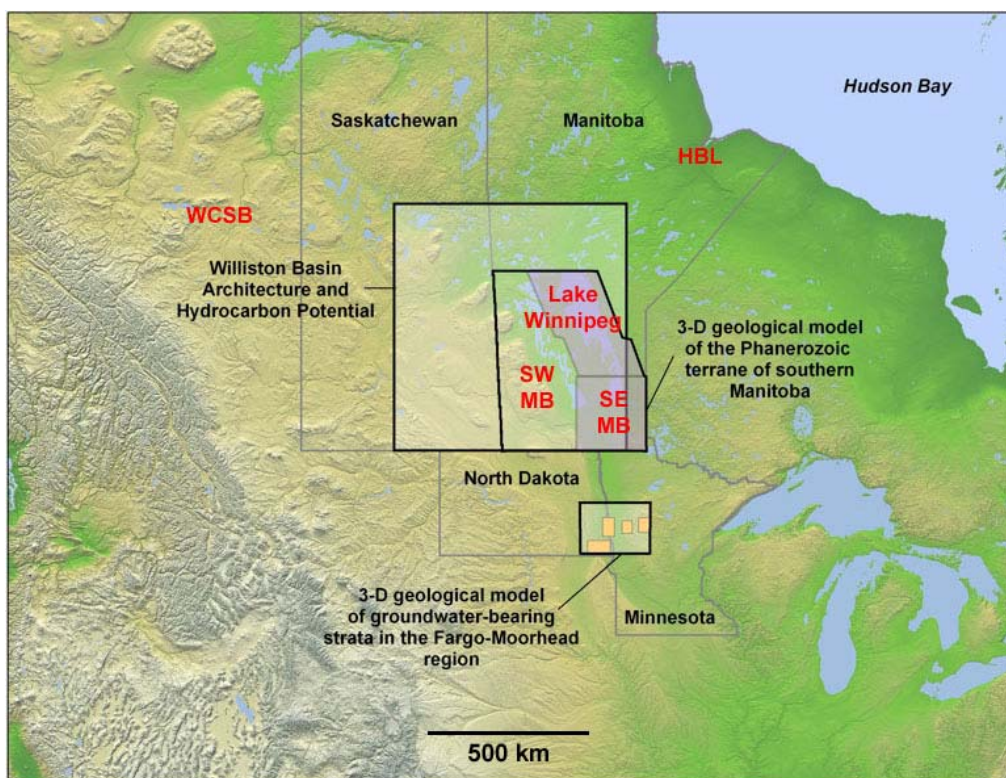


Figure 1. Index map of model areas. Orange blocks indicate areas of higher detail within the Fargo-Moorhead model.

MODEL INPUTS

Many years, in the early stage of this 3D mapping work, were spent building the data infrastructure, and integrating numerous disparate datasets, required for the cross-section method of building the NATMAP southeastern Manitoba model. This is the same methodology we used to create the Lake Winnipeg model and a modified version of which we are using to build the southwestern Manitoba model.

Cross-sections

Cross-sections (Figure 2) are plotted on 42 by 54-inch paper. They represent an east-west transect drawn every 5 km and include all available data within 2.5 km from the line of cross-section. For reference, the cross-sections include two map windows across the top containing bedrock mapped extents and surficial geology polygons with Shuttle Radar Topography Mission (SRTM) digital elevation model (DEM) shaded relief and drillhole locations for the area of the cross-section. The cross-section itself comprises an SRTM DEM surface profile and drillhole plots from the Manitoba GWdrill water well database (107 000 drillholes) (Manitoba Water Stewardship, 2007), Manitoba oil and gas well information system database (MOGWIS) (4 400 drillholes), Manitoba Stratigraphic database (4 800 drillholes), TGI Williston Basin formation tops database (9 012 drillholes) (TGI II working group, 2009), Western Canada Sedimentary Basin database (750 drillholes), and 27 rotosonic drillholes which were drilled under the auspices of the Canadian NATMAP program of the early 1990's. The drillholes are colour coded based on lithology for sediments and formation for rock. The cross-sections are drawn (correlated) by hand and the stratigraphy is captured every 5 km. The resultant 5 km grid of predicted stratigraphic points are then input to the Gocad software and built into a 3D model. The glacial stratigraphy is then correlated to the prominent published stratigraphic model in the region (Teller and Fenton (1980) for southeast Manitoba and Klassen (1979) in southwest Manitoba).

ArcMap project file

For reference during the interpretation stage of the cross-sections, an ArcMap project was compiled containing additional map data representing various aspects of a paleogeographic reconstruction for the area based on previous work. For example, the understanding of both glacial retreat and glacial Lake Agassiz factor strongly into the interpretation of the cross-sections and these and other concepts need to be readily available for reference. The map base for the ArcMap project is the surficial geology from Matile and Keller (2007) with shaded-relief from the USGS

(2003). Layers that can be draped on the surficial geology include: glacial ice margins modified from Thorleifson (1996), Elson (1956) and Christiansen (1979), Lake Agassiz shorelines, levels and isobases modified from Thorleifson (1996), pre-glacial drainage from Elson (1956), and the locations of various obscure subsurface data, such as river sections from Klassen (1979) and bedrock outcrops.

Correlation to adjacent regions

Previously interpreted cross-sections from eastern Manitoba are used to correlate to previous 3D mapping and to verify that the interpretation is still valid when taking into account the additional western data. We are also fortunate to have available interpreted cross-sections, depth to bedrock and bedrock geology maps from the Saskatchewan Research Council, Sask Water, Geology and Groundwater Resources of southern Saskatchewan (<http://www.swa.ca/WaterManagement/Groundwater.asp?type=Mapping>), which we use to correlate our 3D mapping to the Saskatchewan sub-surface geology.

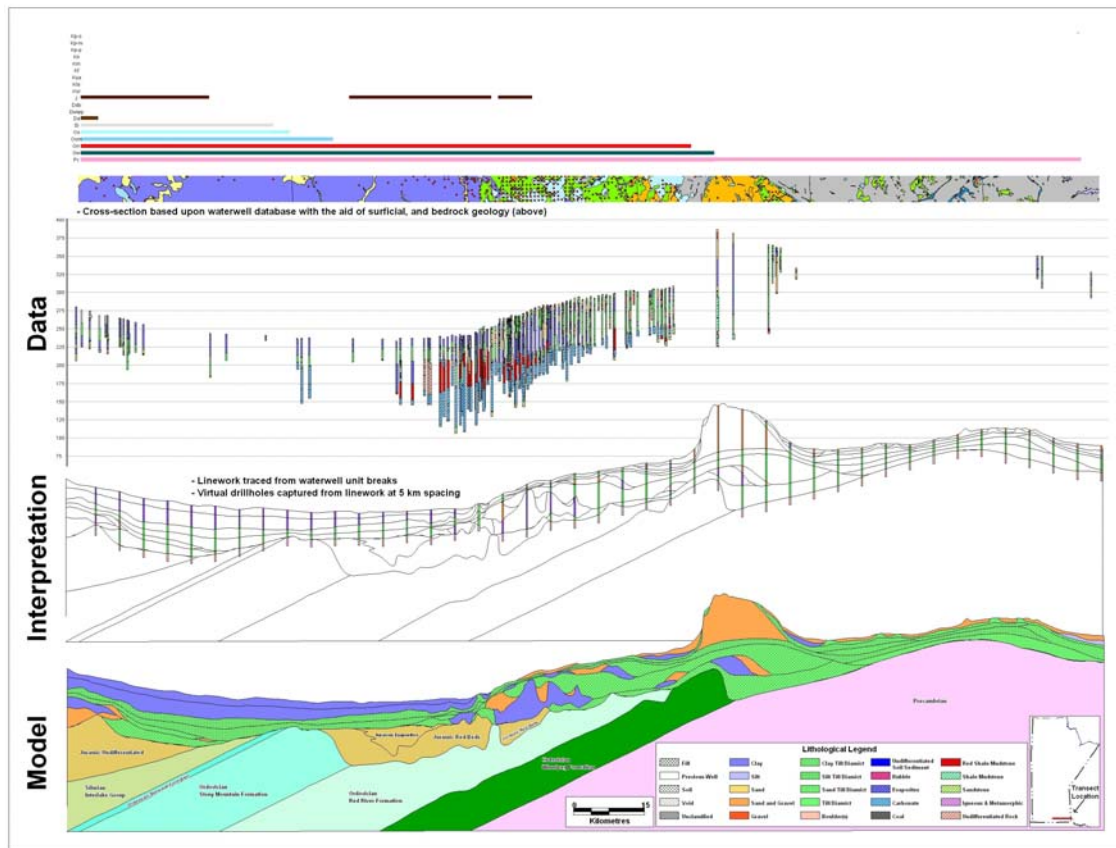


Figure 2. Cross-section methodology of 3D modeling depicting a typical 5 km east-west transect from southeast Manitoba. Depicted at the top are bedrock extent and surficial geology. Below are various iterations of the cross-section and the hand-drawn geological interpretation.

MODEL CONSTRUCTION

To date, three different approaches to 3D mapping have been used based on the nature of the project and the availability of data. The southeast Manitoba model was our first foray into 3D mapping. We used manually interpreted cross-sections to filter datasets with variable data quality. The Lake Winnipeg area used the same approach; however, we had the added luxury of having available to us high quality seismic data from the bottom of Lake Winnipeg. A second approach was used for the TGI Williston Basin project. Again, with the TGI project, we had high quality data and therefore were able to use the data directly for 3D modeling. The issue with the TGI project was limited drillhole data in the fringe areas leading to potential edge issues and occasional flattened escarpments. A third approach was used in the creation of the WCSB model, which was converting a published 2D version of a 3D geological model into a fully 3D digital model. This was achieved by scanning and georectifying unit structure contours and edges and transforming them into 3D point sets. The three approaches are described below.

Southeast Manitoba model

The SE Manitoba 3D Geological model (Figure 3) is based on a 5 km grid of predicted stratigraphy points which were brought into Gocad for modeling. The individual units were modeled from the bottom up, starting with the Precambrian surface. In this methodology, each predicted stratigraphic point contains a measurement for every possible unit in the model. Where a unit does not exist, it is given a zero thickness value. Therefore, there is a 5 km grid of tops for each mapped unit which was used to create a surface for that unit. Unit edges were controlled by pressing the surface being modeled (upper) below the underlying unit where the upper unit does not exist (has a zero thickness value) and then clipping that upper surface with the underlying surface. This methodology gives the geologist considerable control over the unit morphology and the nature of the edge. A surface and a Sgrid (Gocad stratigraphic grid) were created for each of the units in the model.

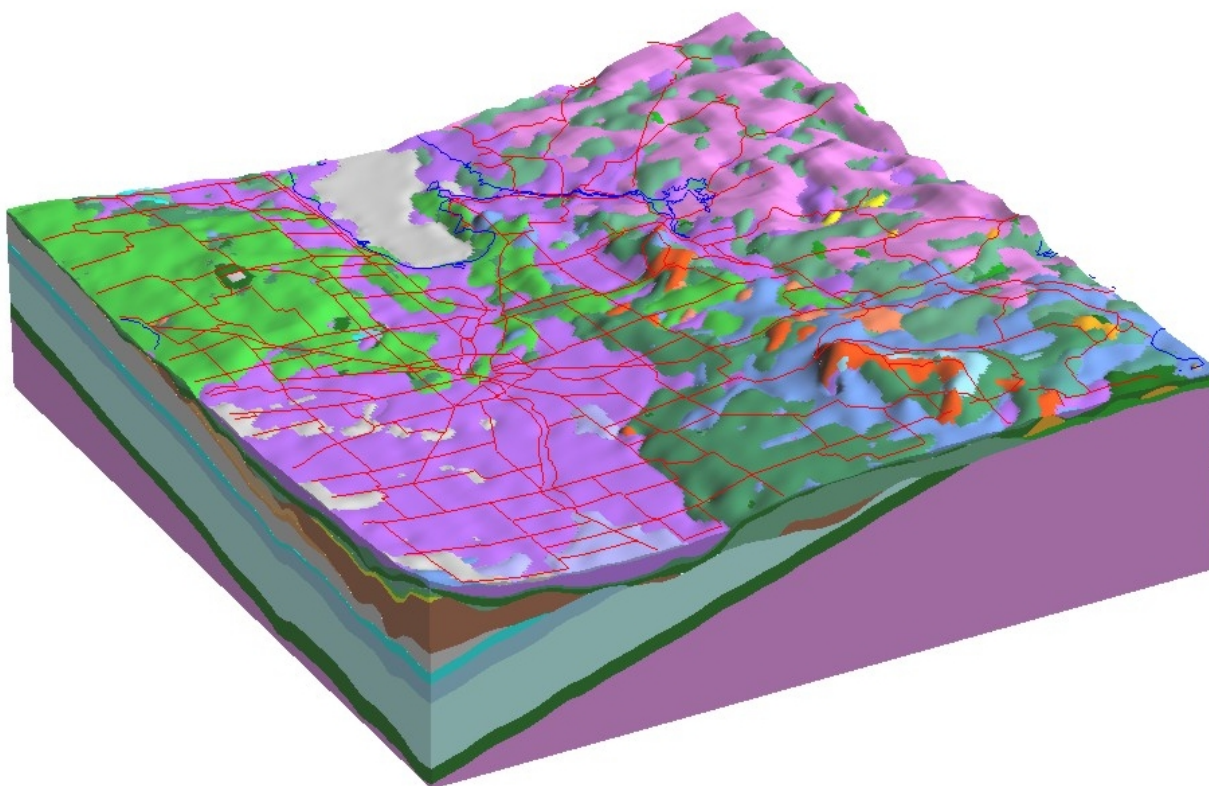


Figure 3. 3D geological model of the Winnipeg region.

TGI model

Whereas the drillhole data of highly variable quality in southeastern Manitoba was screened through the geological interpretation of 5 km transects, drillhole data in the TGI Williston Basin project has been screened at a very high level of consistency by re-picking five to eight deep, stratigraphically significant drillholes per township (10 km by 10 km). This dataset of re-picked formation tops and a new set of formation edges form the basis of the TGI Williston Basin model (Figure 4). The 3D surfaces were constructed using these picked tops from a total of 9012 wells, which includes 5046 wells from Saskatchewan, 2606 wells from Manitoba, 771 wells from North Dakota, and 589 wells from Montana. The North Dakota and Montana wells were included to reduce edge effects and to more easily correlate to the American portion of the Red River Valley 3D model in the future. Although tops for 60 formations were picked in the TGI Williston Basin project, only 42 were selected for modeling. Again, this model is based entirely on the unit tops dataset, and formation edges were defined by forcing the surfaces to conform to the predefined TGI unit edges. Many fringe areas have a low data density, especially those areas close to unit edges. Because of this shortcoming,

the expression of the unit edge, especially along escarpments, is not always accurately predicted. No solid model was created.

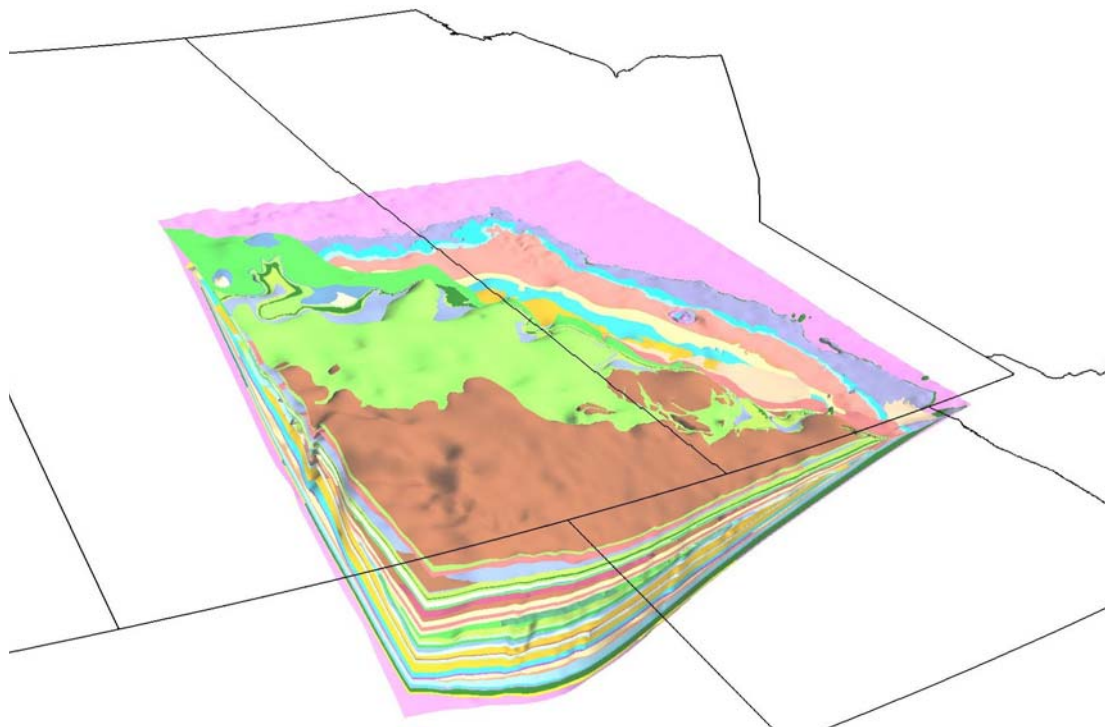


Figure 4. 3D geological model of the TGI Williston Basin region.

WCSB model

The WCSB 3D model (Figure 5) is based entirely on the published structure contours contained in the WCSB Atlas (Mossop and Shetsen, 1994). Structure contours for each geological time period were scanned, digitized, and georectified. The structure contours were then broken into points and given xyz coordinates. The same was done with the published edges for each time period. However, the edges were pressed onto the next older unit to obtain an elevation. This point set, derived from the contours and the unit edges, was then brought into Gocad and a unit surface was created. The surface was then trimmed at the published edge. No solid model was created.

ISSUES

While having a 5 km width of drillholes merged onto a single cross-section does, in data-rich areas, make cross-section interpretation difficult, in data-poor areas, it increases the probability of having some data to aid interpretation. In data-poor areas there is also a tendency to have cross-section parallel ridges due to slight variations in the interpreted unit tops; an issue which is eliminated when using strictly picked drillhole tops. However, we believe that having all available data visible on the cross-section ties together all of the different aspects of the geology, even in data-poor areas and especially in areas of high local relief at ground or rock surface. Drawing unit edges in plan view and then transposing them into 3D (as was done in the TGI model) vertically distorts the edges leading to flattened bedrock escarpments. In the southwest Manitoba model we have the benefit of the high quality TGI dataset, and using the cross-section method allows us to supplement the TGI dataset with predicted stratigraphic points based on extrapolated rock trends onto the interpreted bedrock surface which may or may not correspond to the ground (SRTM) surface. This allows us to tweak the TGI rock surfaces and integrate them with the glacial sediments.

A network of pre-glacial/Tertiary buried valley aquifers has been cut into the bedrock surface in southern Manitoba, but has yet to be systematically mapped in detail. These channels are an important water source in some areas. We

have recognized these channels on some of the cross-sections, but not consistently enough to map them with confidence. We assume that they are recognizable only when the channel is orthogonal to the cross-section.

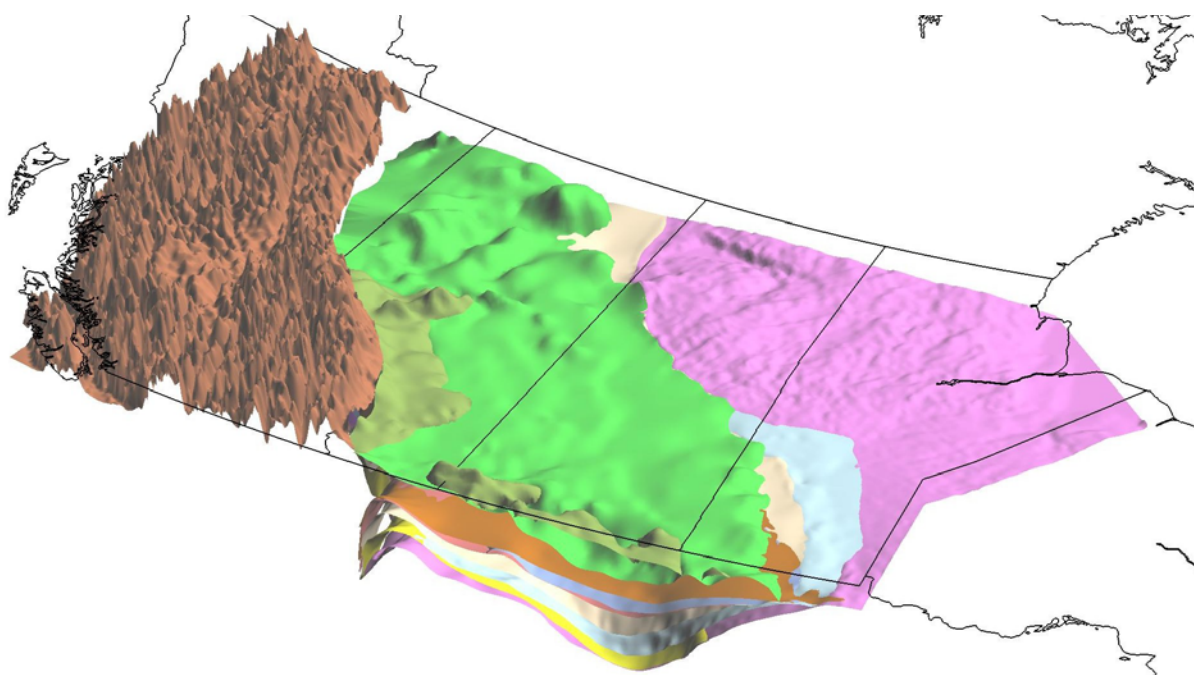


Figure 5. 3D geological model of the WCSB spanning across Manitoba, Saskatchewan, and Alberta.

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