Building a 3-D Geologic Model of the Paleozoic Bedrock of Southern Ontario


Groundwater Geoscience in Southern Ontario
Open House 2018, Guelph, Ontario
Project Plan

- Model formation contact data from Ontario petroleum well data to create a 3-D lithostratigraphic model of the Paleozoic bedrock strata of south-central and western Ontario.
- Update bedrock topography – MOECC WWIS & PGMN wells.
- Translation of lithostratigraphic layers into hydrostratigraphic layers.
- Leapfrog Hydro software vs Leapfrog Geo to facilitate regional numeric modeling
- 2015-2019 project time frame

Project partners:

- Ontario Ministry of Natural Resources and Forestry
- Oil, Gas & Salt Resources Library
- Ontario 125th Anniversary
- Canada 150th Anniversary
- CarterGeologic
Project Scope

• All Paleozoic bedrock of south-central & -western Ontario; excluding Manitoulin Island

• 56 Paleozoic formations + Precambrian + bedrock topography + Quaternary Geology + soils

• 110,000 km²
Paleozoic 3D Model – Team

Bedrock Subcrop
Lee Fortner – MNRF Geologist
Maia Somers – OGSR Library

Project Lead
Hazen Russell - GSC

Bedrock Topo & Subcrop
Kei Yeung – OGS-MNDM
GIS Applicationist

Project Coordinator, deep groundwater
Terry Carter

OGSR Library Team
Brenna Gray – database clerk
Liz Sutherland – GIS Tech
Maia Somers – Subcrop Geol
Matt Dupont – database clerk
Jordan Clark – Manager
Candace Freckelton – QA Geol
Connor Davis – Sands, QA Geol

OGS Project Lead
Frank Brunton – OGS-MNDM

Leapfrog 3-D Modeler
Charles Logan – GSC – NRCan

Geology QA/QC
Jessica Flynn, Candace Freckelton

Stratigraphy, karst, potable groundwater
Hazen Russell - GSC

Leapfrog 3-D Modeler
Charles Logan – GSC – NRCan
Building the Model

1. Update lithostratigraphic chart: formation layers
2. Extract formation contact data from database (OPDS)
3. Construct model layers of each formation
4. Constrain model layers with 3-D vector objects constructed from digital maps of surface topography (DEM, bathymetry), bedrock topography, bedrock subcrop boundaries, cuestas
5. Expert geological appraisal + QA/QC of anomalous/missing data
6. Repeat steps 2 to 5

• Current model is version 5
Model Input Data

- Petroleum well database: MNRF/OGSR Library
- Lithostratigraphic subdivisions: Brunton & Carter
- New digital subcrop geology and extrapolated Great Lakes geology: compilation of OGS and GSC mapping - by OGSR Library & MNRF
- Digital bedrock topography & subcrop mapping: new compilation by OGS – using MOECC WWIS-PGMN
- Great Lakes bathymetry: NOAA & CHS
- Digital elevation model: SRTM
- Bedrock elevation in lakes
Well Records: Ontario Petroleum Data System

- Formation contacts are primary data input for modeled layers representing the formations
- Oracle relational database linked to ArcGIS
- Geographic coordinates for well locations
- Elevation data for formation contacts
- Active QA/QC
- MNRF owner with data management by OGSR Library
Petroleum Well Data

Ontario Petroleum Data System – 26,700 wells;
Current 3D Model utilizes – 21,237 wells
Petroleum Well Data: Cross-Section View

- Each column is one well
- Well path is colour-coded by geological formation
- All formations are represented by a model layer, no grouping
Phanerozoic Lithostratigraphic Chart

*NEW*

- Integrates rock lithology; relative significance of disconformities (white gaps and line weight) and erosional bedrock cuestas
- Formation thickness not-to-scale
- Stratigraphic coding of model layers
Digital Subcrop Geology - *NEW*

Subcrop belts draped on bedrock topography surface as a cloud of 3-D points to control updip extrapolation of model formation layers

New compilation by MNRF/OGSR Library from GSC 1335A, 1263A, 1194A, OGS P.3811, OGS MRD 219
3-D subcrop geology link to modeled formation layer

3-D vector object of subcrop geology + bedrock topography

Queenston Formation

3-D vector subcrop + model layer of Queenston Formation

Queenston Formation
Bedrock Topography

- Bedrock topography provides 3-D control for subcrop edge of modeled formations
- version: OGS MRD 207 (2009)
- revision in progress by OGS (Kei and Brunton)
Bedrock Topography Revisions

- OGS MRD 207 (2006)
- Draft revision of bedrock topography
- OGS GRS 015 (2016) with geophysical surveying

Legend

<table>
<thead>
<tr>
<th>Bedrock Topography (m) Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>High : 439.717</td>
</tr>
<tr>
<td>Low : 195.147</td>
</tr>
</tbody>
</table>

0 2.5 5 Kilometres
3-D control of subcrop edge of modeled formations beneath Great Lakes

https://www.ngdc.noaa.gov/mgg/greatlakes/greatlakes.html
Modeled bedrock layers with drift cover

- Shuttle Radar Topography Mission (SRTM)
- 3-D control for top of Quaternary layer
Challenges: Software & Data Support Limitations

• Leapfrog Hydro lacks ability to model faults or truncation of layers at cuestas - manual editing required at cuestas

![Image: Extrapolated tongues of Goat Island Formation drooping down face of Niagara Escarpment]

• Areas with low data density create gaps in model layers - insert control points with inferred formation depths

• Thin layers (< 1-3 m.) may be pinched out by highs in underlying formations
Challenges: Data quality and distribution

- Extrapolation beyond data coverage is inaccurate: e.g. Lake Huron
- Missing subdivisions of Lockport Group – QA/QC of 397 wells
- Inconsistent correlation/identification of Bois Blanc and Onondaga formations – still to be resolved
- Inconsistent identification of Devonian sandstones – separate project to characterize and map (Davis, 2017)
- Time-consuming QA/QC editing of anomalous formation contact data for individual wells
- Correction of obsolete stratigraphic terminology
Geology QA/QC

- Formation contacts verified by QA/QC geologists by review of source records, drill cuttings, drill core, geophysical logs
- Revised/new picks recorded in database

<table>
<thead>
<tr>
<th>Date</th>
<th>Project</th>
<th>Number of Wells Fixed</th>
<th>Formations QA’ed</th>
</tr>
</thead>
<tbody>
<tr>
<td>2015</td>
<td>Chatham-Sag Project</td>
<td>2,956</td>
<td></td>
</tr>
<tr>
<td>2016</td>
<td>Devonian Sands Project (Connor)</td>
<td>1,319</td>
<td>Devonian sands, 198 formation picks removed, 818 formation picks edited</td>
</tr>
<tr>
<td>2016-2017</td>
<td>Hydrogeology Updates (Candace)</td>
<td>1,323</td>
<td>All formations, top to bottom of each well</td>
</tr>
<tr>
<td>2016-2017</td>
<td>Bedrock Top Fixes (Maia)</td>
<td>616</td>
<td>Top of bedrock formation pick (1-2 formations per well)</td>
</tr>
</tbody>
</table>
• Modeled Paleozoic bedrock formations + Precambrian; no Quaternary strat
• OGS bedrock topography forms upper boundary
• 56 Paleozoic fms + Precambrian
Modeled Formation Layers by Geological Age

Surficial + older

Ordovician + older

Devonian + older

Cambrian + older

Silurian + older

Precambrian
How Can the Model be Used?

- Bedrock topography
- Mineral and hydrocarbon resources
- Scientific investigation
- Geologic visualization, cross-sections
- Data integrity
Bedrock Topography – valleys, reentrants, cuesta-scarps, deep-troughs subparallel (in front of) to scarp-margins
Salt Resources – Upper Silurian Salina Group
Oil, gas, natural gas storage: Lockport Group/Guelph Pinnacle Reefs
Visualization - Model "slicing"

- Slices can be made anywhere on the model volume
- This example:
  - Vertical slice orthogonal to strike
  - Regional dip to southwest at 1-3 m/km
Cross-sections

Chatham Sag

Algonquin Arch

Michigan Basin

Appalachian Basin
Visualization of faults, reefs

Lockport Group 3D structures

Kimball-Colinville Fault
Visualization: Salt Dissolution and Collapse

- Dissolution of salt beds results in collapse and deformation of overlying strata or thickening into dissolution depression.
Formation contact data from individual wells can be viewed for editing
Phase 2 - Translate Lithostratigraphic Model to Hydrostratigraphic Model
Hydrostratigraphy

*NEW*

- Carter and Brunton, in prep
- Compilation and combination of several years of regional studies of deep and shallow groundwater
- Contact aquifer along subcrop edge of all formations
- Remodel lithostratigraphic layers in Leapfrog as hydrostratigraphic layers
2-D Conceptual Groundwater Model

Shallow Fresh Water
0-250 m

Brackish Sulphur Water
30-500 m

Deep Brines
200 m +

Updated from Carter et al. 2014
OGS Groundwater Mapping - Potable Aquifers

- Ordovician (Late Cambrian) Geology (blue & purples)
- Silurian Geology (beige & yellows)
- Devonian Geology (greens)

- Grenville Geologic Province
- Ordovician (Late Cambrian) Geology (blue & purples)
- Middle Devonian - Carbonate bedrock Aquifers
- Early-Late Silurian - Carbonate bedrock Aquifers
- Late Ordovician - Carbonate bedrock Aquifers

(compiled - OGS Topo/Karst & Bedrock Grdwrtr Studies - 2004-2008)
OGS
Groundwater Mapping – Silurian Cuesta

<table>
<thead>
<tr>
<th>Lithology</th>
<th>Formation</th>
<th>Member</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lockport Group</td>
<td>Guelph</td>
<td>Hanlon</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Wellington</td>
</tr>
<tr>
<td></td>
<td>Eramosa</td>
<td>Stone Road</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Reformatory Quarry</td>
</tr>
<tr>
<td></td>
<td>Goat Island</td>
<td>Ancaster</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Niagara Falls (≡ upper unit of unsubdivided Amabel Fm)</td>
</tr>
<tr>
<td></td>
<td>Gasport</td>
<td>Pekin</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Gothic Hill (≡ middle unit of unsubdivided Amabel Fm)</td>
</tr>
<tr>
<td>Clinton Group</td>
<td>Irondequoi</td>
<td>(= basal unit of unsubdivided Amabel Fm)</td>
</tr>
<tr>
<td></td>
<td>Rockway</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Merritton</td>
<td>(= upper Fossil Hill Fm)</td>
</tr>
<tr>
<td></td>
<td>Cabot Head</td>
<td></td>
</tr>
</tbody>
</table>

(modified from Brunton 2009; Brunton et al. 2012)

Karstic Bdrk Flow zones
- Overburden & Interface Aquifers
- Unconfined Bedrock Aquifers (Guelph & Eramosa HGUs)
- Sub-regional Aquitard Bedrock Aquifers (Goat Island HGUs)
- Lower transmissivity zone
- Main Confined Bedrock Aquifers (Gasport HGU)
- Sub-regional Aquitard
- Lower transmissivity zone
- Minor Confined Bedrock Aquifer
- Regional Aquitard
OGS Groundwater Mapping
Devonian Karstic Aquifers

Aquifers:
* Lower Dundee-Upper Lucas (not shown)
* Lower Lucas
* Amherstburg

Thick overburden commonly >20 m

Breathing Wells
Lucas Fm

Dundee Formation - limestones
Lucas Formation - sabkha/lakes
Amherstburg Formation - reefal limestones
Bois Blanc Fm - cherty, dolo-limestones
Bertie - Bass Islands formations - microbial/sabkha cycles

Salina Group – salts, shales, carbonates

Devonian
Paleo karst

Silurian
Regional Faults enable lateral & vertical fluid migration

NORTH

Lockport Escarpment
Tonawanda Lowland
Onondaga Escarpment

Precambrian limestone
Queenston Shale

Lake Ontario

SOUTH

Devonian Shales
Lake Erie
Further Model Refinements

- Add 3-D representation of oil and gas reservoirs
- Add 3-D representation of fault locations (NOT modeled faults)
- Fix remaining anomalies
- Integrate revised bedrock topography for 3-D Paleozoic and Quaternary models – focusing on specific regions (cuesta margins & bedrock valleys)
Project Publications & Presentations

- Brunton, F R; Carter, T; Logan, C; Clark, J; Yeung, K; Fortner, L; Freckelton, C; Sutherland, L; Russell, H A J 2017 Lithostratigraphic compilation of Phanerozoic bedrock units and 3D geological model of southern Ontario [Abstract] in, Regional-scale groundwater geoscience in southern Ontario: an Ontario Geological Survey and Geological Survey of Canada groundwater geoscience open house; Russell, H A J; Ford, D; Priebe, E H; Geological Survey of Canada, Open File 8212, p. 3, https://doi.org/10.4095/299759


- Carter, T R; Brunton, F R; Clark, J; Fortner, L; Hamblin, A; Logan, C; Russell, H A J; 2016. 3D hydrostratigraphic modelling of the Paleozoic bedrock of southern Ontario [Abstract] in, Regional-scale groundwater geoscience in southern Ontario: an Ontario Geological Survey and Geological Survey of Canada groundwater geoscience open house; Russell, H A J; Priebe, E H; Geological Survey of Canada, Open File 8022, 2016 p. 5,


- Russell, H A J; Brodaric, B; Brunton, F R; Carter, T; Clark, J; Logan, C E; Sutherland, L; 2017. Communicating the value and insights of 3D Geological Models to a broader audience: A case study from Southern Ontario Geological Survey of Canada, Scientific Presentation 68, 2017; 3.6 minutes, https://doi.org/10.4095/305363

- Russell, H A J; Brodaric, B; Brunton, F R; Carter, T; Clark, J; Logan, C; Sutherland, L. 2017. Communicating the value and insights of 3D Geological Models to a broader audience: A case study from Southern Ontario (ESS Cont.# 20160436, GAC 2017 Kingston.

Summary

• Geologically robust 3-D model has been constructed, with further improvements underway
• On target for completion in late 2018, with release in early 2019
• New lithostratigraphic chart
• New hydrostratigraphic chart
• Preliminary numeric modeling of water flow is underway by Aquanty using Hydrogeosphere
• Publication of government reports/presentations and future journal articles