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INITIATING TRANSFORMATIVE GEOSCIENCE PRACTICE AT THE GEOLOGICAL SURVEY OF CANADA: CANADA IN 3D

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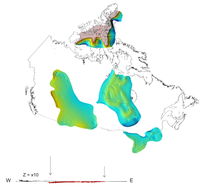


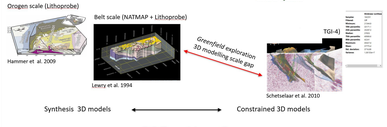
Abstract

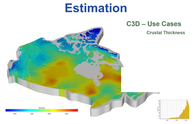
Application of 3D technologies to the wide range of Geosciences knowledge domains is well underway. These have been operationalized in workflows of the hydrocarbon sector for a half-century, and now in mining for over two decades. In Geosciences, algorithms, structured workflows and data integration strategies can support compelling Earth models, however challenges remain to meet the standards of geological plausibility required for most geoscientific studies. There is also missing links in the institutional information infrastructure supporting operational multi-scale 3D data and model development.

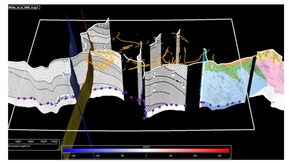
Canada in 3D (C3D) is a vision and road map for transforming the Geological Survey of Canada's (GSC) work practice by leveraging emerging 3D technologies. Primarily the transformation from 2D geological mapping, to a well-structured 3D modelling practice that is both data-driven and knowledge-driven. It is tempting to imagine that advanced 3D computational methods, coupled with Artificial Intelligence and Big Data tools will automate the bulk of this process. To effectively apply these methods there is a need, however, for data to be in a well-organized, classified, georeferenced (3D) format embedded with key information, such as spatial-temporal relations, and earth process knowledge. Another key challenge for C3D is the relative infancy of 3D geoscience technologies for geological inference and 3D modelling using sparse and heterogeneous regional geoscience information, while preserving the insights and expertise of geoscientists maintaining scientific integrity of digital products. In most geological surveys, there remains considerable educational and operational challenges to achieve this balance of digital automation and expert knowledge.

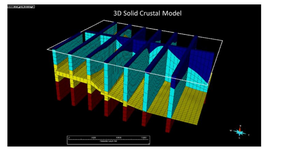
Emerging from the last two decades of research are more efficient workflows, transitioning from cumbersome, explicit (manual) to reproducible implicit semi-automated methods. They are characterized by integrated and iterative, forward and reverse geophysical modelling, coupled with stratigraphic and structural approaches. The full impact of research and development with these 3D tools, geophysical-geological integration and simulation approaches is perhaps unpredictable, but the expectation is that they will produce predictive, instructive models of Canada's geology that will be used to educate, prioritize and influence sustainable policy for stewarding our natural resources.

On the horizon are 3D geological modelling methods spanning the gulf between local and frontier or green-fields, as well as deep crustal characterization. These are key components of mineral systems understanding, integrated and coupled hydrological modelling and energy transition applications, e.g. carbon sequestration, in-situ hydrogen mining, and geothermal exploration. Presented are some case study examples at a range of scales from our efforts in C3D.









White, 2020

Webinars:

Carter, T.R., Brunton, F.R., Clark, J.K., DeKemp, E., Logan, C.E., and Russell, H.A.J. 2020. 3-D geological and hydrogeological modelling of the bedrock geology of southern Ontario. NWMO 2020 geoscience webinar, June 16th 2020. (Related video: https://youtu.be/RgMdHvJaZ04).

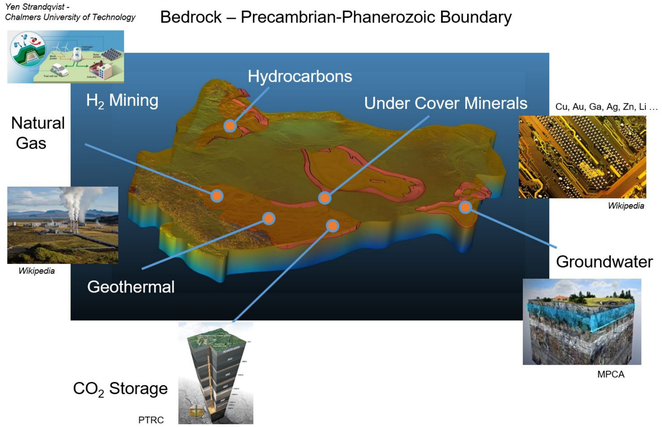
Hillier, M. (2021) Using Graph Neural Networks for 3D Structural Geologic Modelling. LOOP 3D European Modelling Forum, 03 March 2015.

Parquer, M. (2021) Automated 3D Geological Consistency Checking. LOOP 3D European Modelling Forum, 03 March 2015.

Russell, H. et al. "Responding to Societal Needs with 3D Geology, an International Perspective (C3D). International 3D geological Modelling Collaboration. https://www.youtube.com/watch?v=euvoETwjAFA&list=PLTBBnjgZCNWWcGdpdcHwkzHuhbSAQdBb&index=1&t=55s

Sun, S., Brunton, F.R., Carter, T.R., Jin, J., Clark, J.K., Yeun, K., and Russell, H.A.J. 2020. Geographic analysis of the porosity and permeability variations in the Lockport Group, SW Ontario. NWMO 2020 geoscience webinar, June 16th 2020. https://youtu.be/rT8nDf9o_PQ

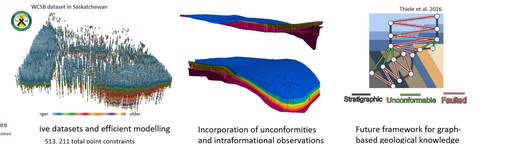
C3D Vision: 3D (4D) Geoscience for a Sustainable Circular Green Economy



Big Data and Knowledge Integration for Regional Stratigraphic Modelling

Method Development for 3D Structural Geological Modelling

- Developing new approach using emerging deep learning methods
  - Considerable flexibility on types of geological constraints included into modelling process
  - Scalable for massive datasets leveraging cloud computing infrastructure
  - Suitable foundation for incorporating relational-based knowledge constraints using graph data structures.

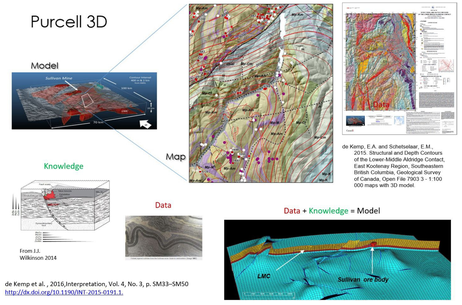


ive datasets and efficient modelling
513, 211 total point constraints

Incorporation of unconformities and intraformational observations

Future framework for graph-based geological knowledge

Predictive Region Model



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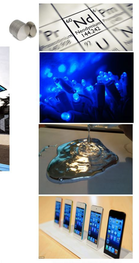
C3D - A National Geological Surveys Committee Project ***C3D https://canada3d.geosciences.ca/***

Metals for the Low Carbon Economy

- Increased demand;
- Copper
- Aluminum
- Nickel
- Au – H_2 Fuel Cells Electronics

Electric Vehicles:	Energy Storage: (1000%)	Solar Photovoltaics: (300%)	Wind: (250%)
Cobalt **x30**	Aluminum	Aluminum	Aluminum
Lithium	Cobalt	Copper	Chromium
Copper	Iron	Indium	Copper
Aluminum	Lead	Iron	Iron
Nickel **x2**	Lithium	Lead	Lead
	Manganese	Molybdenum	Manganese
	Nickel	Nickel	Molybdenum
		Silver	Neodymium
		Zinc	Nickel
			Zinc



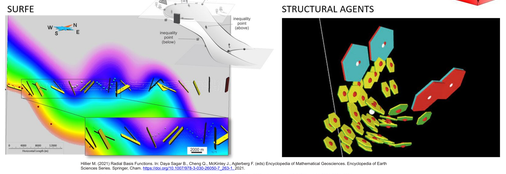
Information from summary article by Carrie Carlson – *FEECO International* on; ***The Growing Role of Minerals and Metals for a Low Carbon Future***. Report, Washington, DC: The World Bank Group, 2017.

3D Workflow of the future…

- Multi-scaler (outcrop to global, mine – regional integration)
- Multi-Parameter (geophysics – geology – geochemistry)
- Circular workflow (many updateable models)
- Challenging terrains (Sparse-Regional)
- Uncertainty Modelling
- Geological Reasonableness (All the **Data + Knowledge**; GeoEvent History)
- Simulation – Process Coupled – Implicit+
- Collaboration Practice **M** = f(Geophysics:Geology)

Method Development for 3D Structural Geological Modelling

- Developed new mathematical constraints to include rock unit observations and structural anisotropy derived from field observations (SURFE)
- Developing agent-based approach (AI) with geological rules to
- build 3D models



Hillier M. (2021) Radial Basis Functions. In: Daya Sagar B., Cheng Q., McKinley J., Agterberg F. (eds) Encyclopedia of Mathematical Geosciences. Encyclopedia of Earth Sciences Series. Springer, Cham. https://doi.org/10.1007/978-3-030-26050-7_263-1, 2021.

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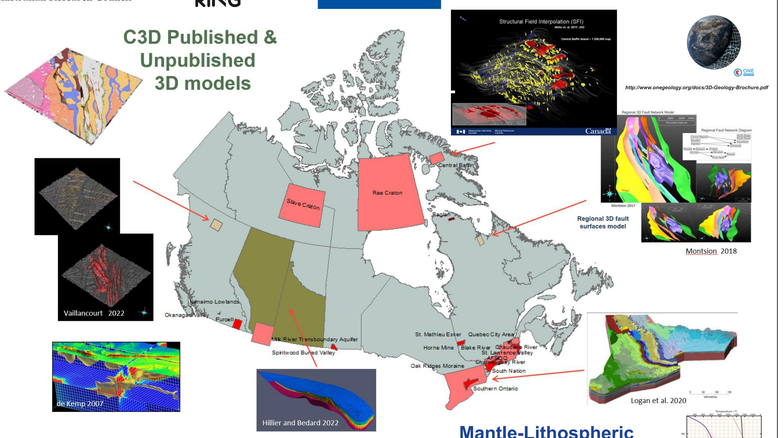
C3D Published & Unpublished 3D models

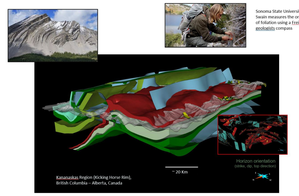


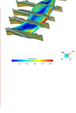
http://www.onegeology.org/docs/3D-Geology-Brochure.pdf

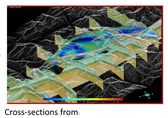
Methods for 3D Structural Geological Modelling

- Two types of approaches
  - Explicit: Requires significant expertise, extensive amount of time to construct model, not updatable or reproducible
  - Implicit: Solves issues with explicit approaches
    - Improvements required to produce better geometric representations that are geologically reasonable for complex structural settings
      - Incorporate more geological knowledge constraints
      - Integrating other geological datasets (geochemical, geophysical, etc)

Volumetric vector 3D model…







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Some 3D Geological Model Examples:

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Version-2 3D model S-ON: https://doi.org/10.4095/328297

Virtual Reality Playlist: https://www.youtube.com/playlist?list=PLLGBWiHEIY2FIu5Mg7ccvdaeoOKuPEF

Augmented Reality Playground: https://ar.ogsrlibrary.com/

Publications

A sampling of recent (2020-2022) mine to national scale 3D modelling (e.g., methods, models, integration and science), follow:

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Carter, T R; Logan, C E; Jin, J; Brunton, F R; Berthelot, K R; Chiang, A M; Pinsonneault, O; Russell, H A J; Ryan, R J; Ryder, A; Thompson, P H; Thurston, P C; Wu, P; Yu, Z; Young, R A, 2021, A three-dimensional geological model of the Paleozoic bedrock of southern Ontario, Geological Survey of Canada, Open File 8795, 2021, 171 pages, https://doi.org/10.4095/328295, (Open Access).

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Schetselaar, E., White, D., Boulanger, O., Craven, J., Bellefleur, G. and Ansari, S., 2022. Regional scale 3D modelling of the Flin Flon Glennie Complex: preparatory data analysis and preliminary results, Geological Survey of Canada, Open File (accepted).

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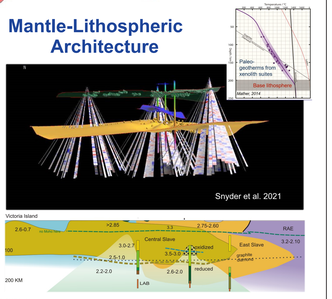
Mantle-Lithospheric Architecture



Vital Pearson and Eric de Kemp discuss Blake River and Central Camp 3D model, Quebec City, 2008.

Knowledge Transfer and Public Engagement

Acknowledgements

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2023

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