Public geoscience to support critical minerals discovery

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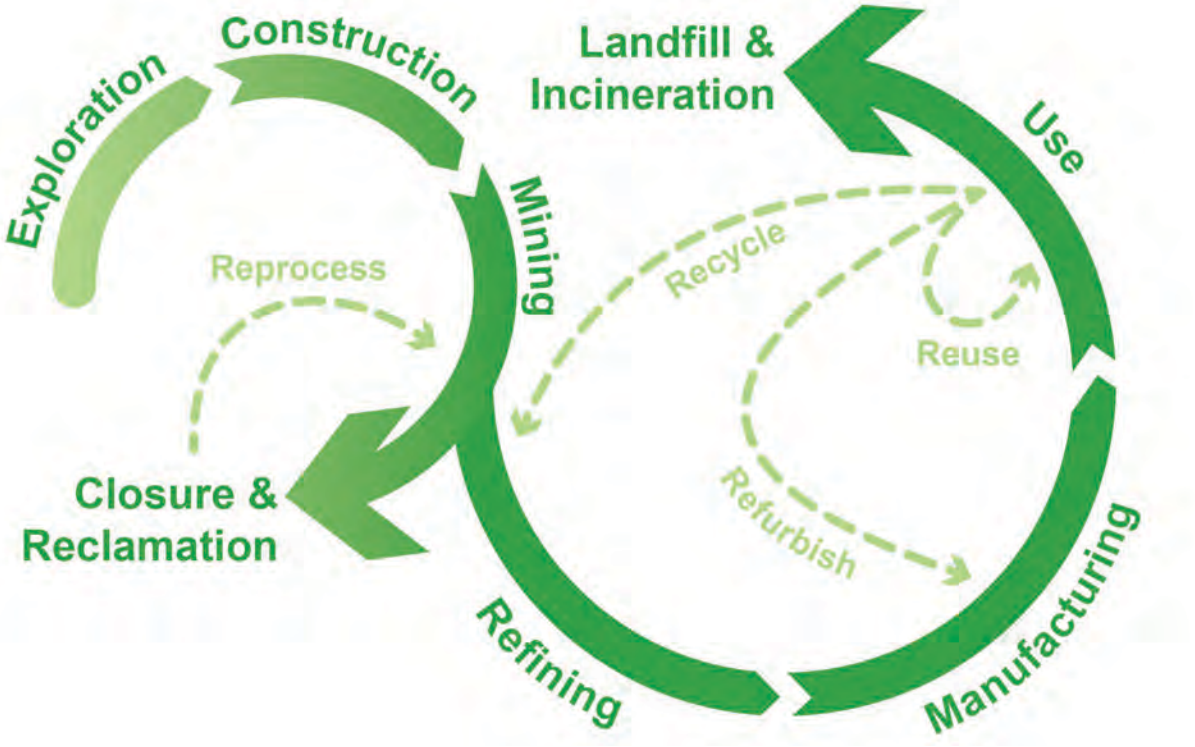
Ressources naturelles Canada

Canada

Mineral development cycle

- Mineral development flows from exploration to discovery to mining
- Public geoscience supports exploration at the start of the development cycle
- Sustainability requires progress towards circular development

Research and technology key to shortcut development times

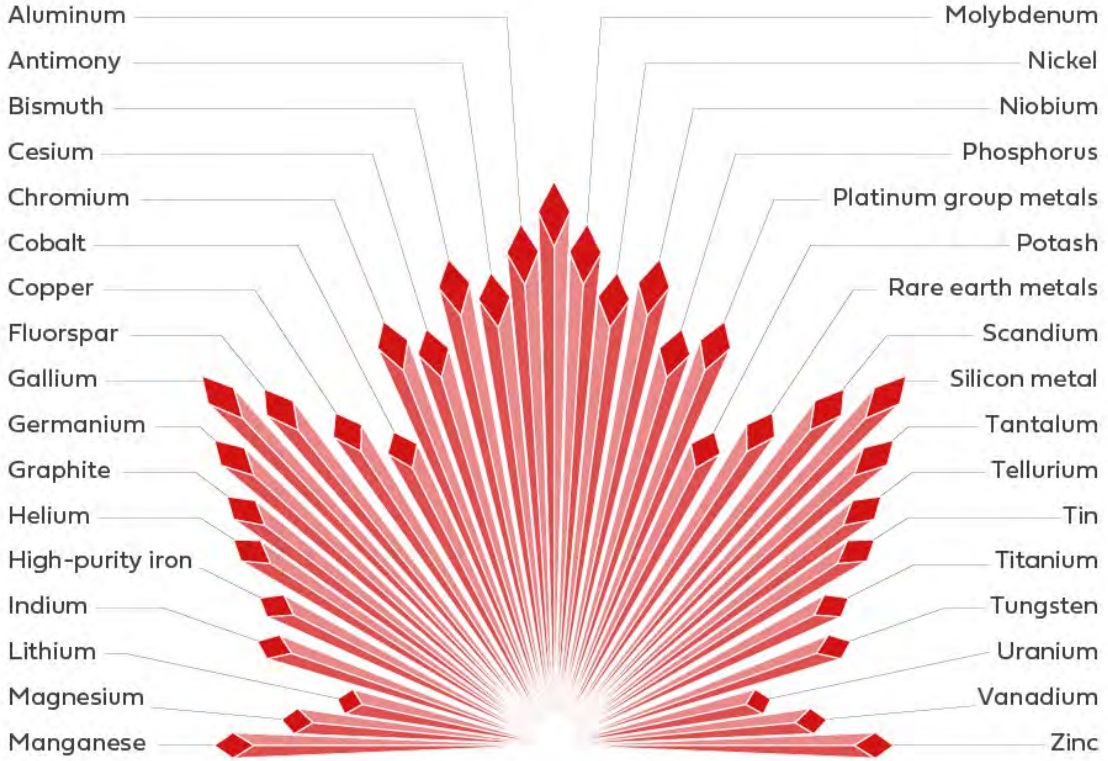


NRCan, 2019

Critical minerals lists

- New list of 34 minerals released in 2024
- Policy tool to focus R&D and investment
- How does Canada define “criticality”?

(1) Supply chain risks
(2) Economic and security
(3) Climate action
(4) Critical for partners



NRCan, 2024

Minerals versus materials

- Critical “minerals” are better described as materials
- Critical mineral lists evolving to include more synthetic materials (e.g., Silicon metal)
- Downstream applications determine the most prospective geological sources of materials

High-purity quartz sand is feedstock for glass but not semiconductors

Diversifying critical mineral supply

- At least three strategies:

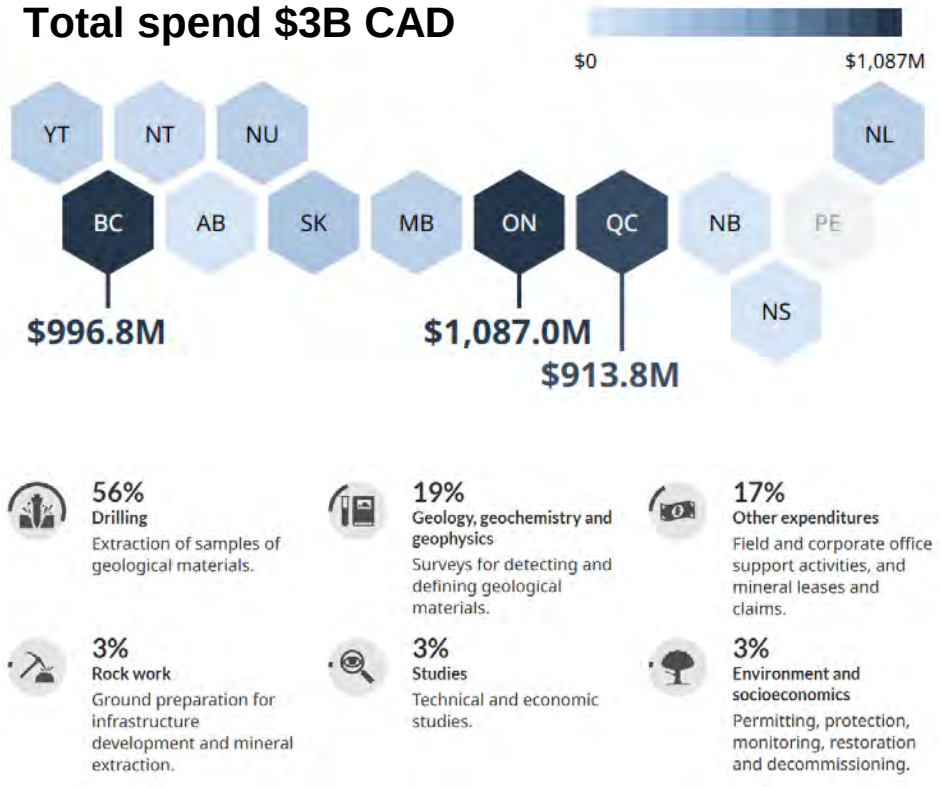
(1) Invent substitute materials (e.g., AI at UC Berkeley)

(2) Identify new ways of mining secondary or unconventional sources (e.g., waste)

(3) Invest in mineral exploration to discover new primary sources of critical minerals

What does exploration do?

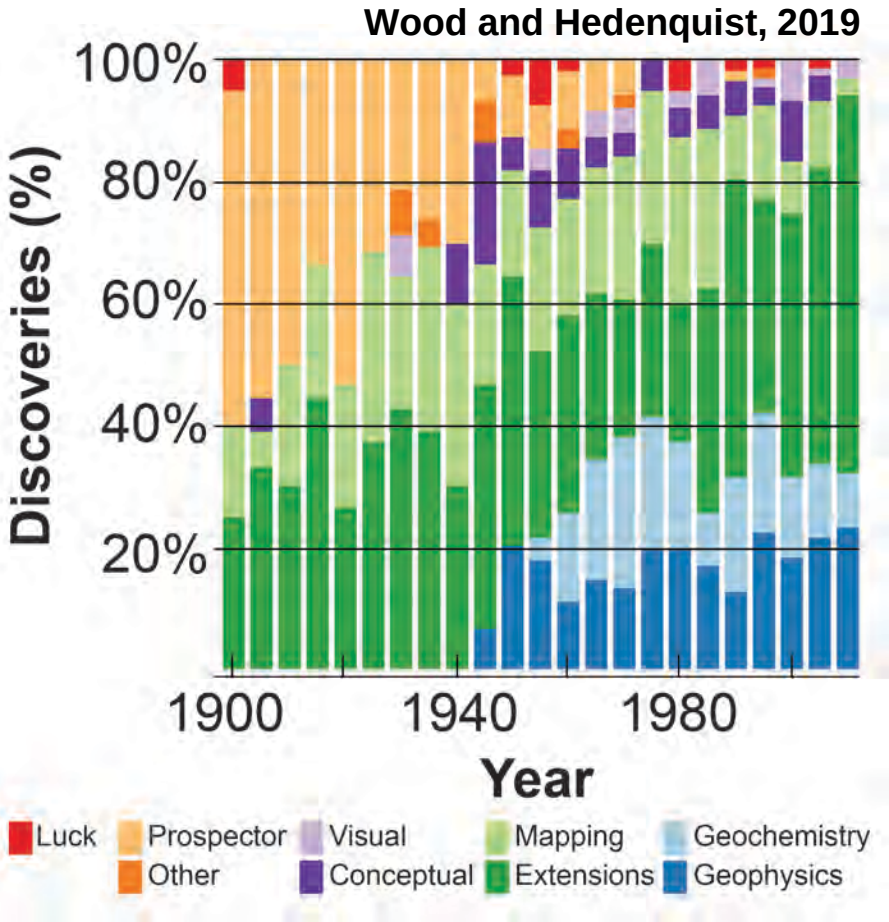
- Mineral exploration in Canada is dominated by gold, uranium, copper, nickel, zinc, lead, iron
- More recent focus on critical minerals, but gold is still dominant
- Most expenditures occur in Ontario, Quebec, and British Columbia



NRCan, 2024

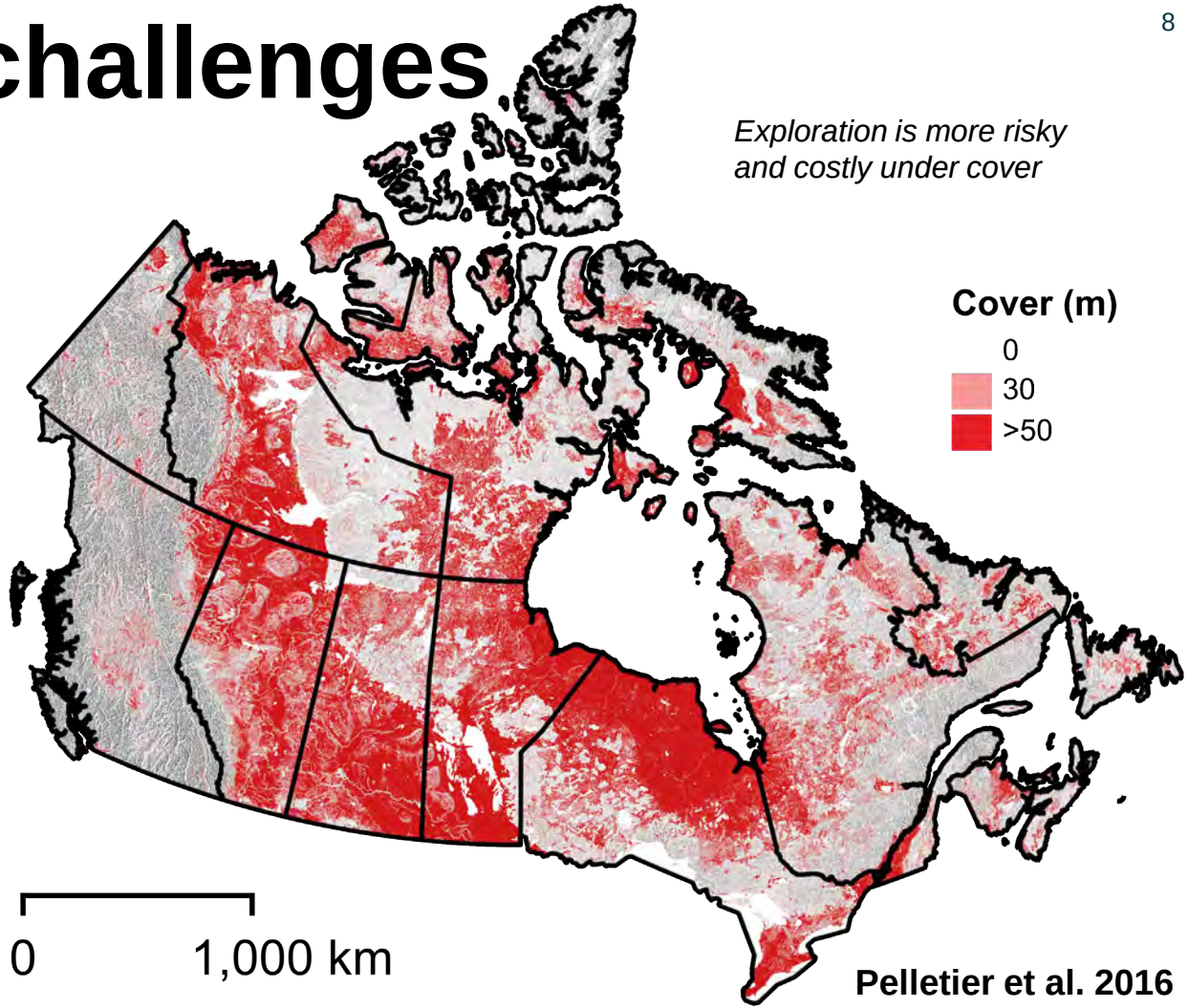
How are discoveries made?

- Discovering a mineral deposit typically involves multiple methods
- Prior to 1940, prospectors discovered over 50% of mineral deposits
- Since 1940, geochemistry, geophysics, and new conceptual models have become important for discovering buried deposits



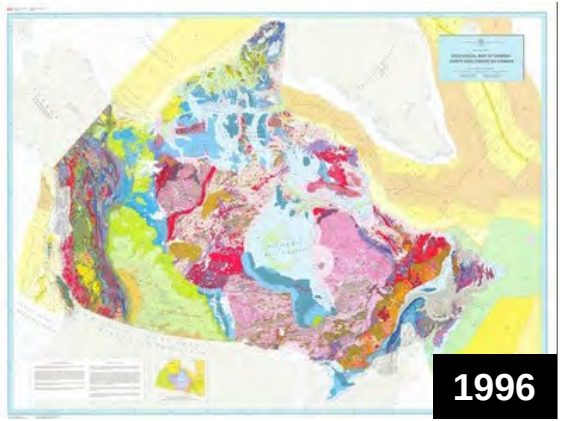
Exploration challenges

- 1 in 1000 discoveries become a mine
- Expensive and slow
- Working in remote and challenging environments
- Discovery rates and grade are declining



What is public geoscience?

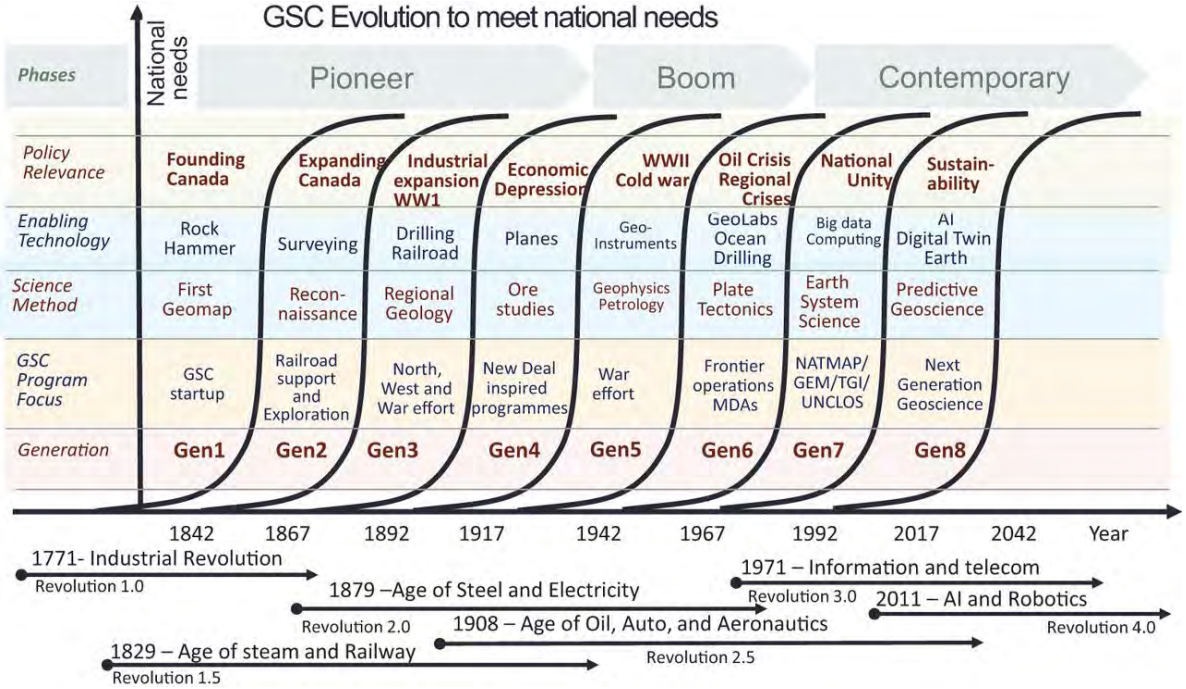
- Geological Survey of Canada founded in 1842, before confederation!
- Minerals, hazards, groundwater, environmental geoscience
- Geoscience as a public good, accessible to all

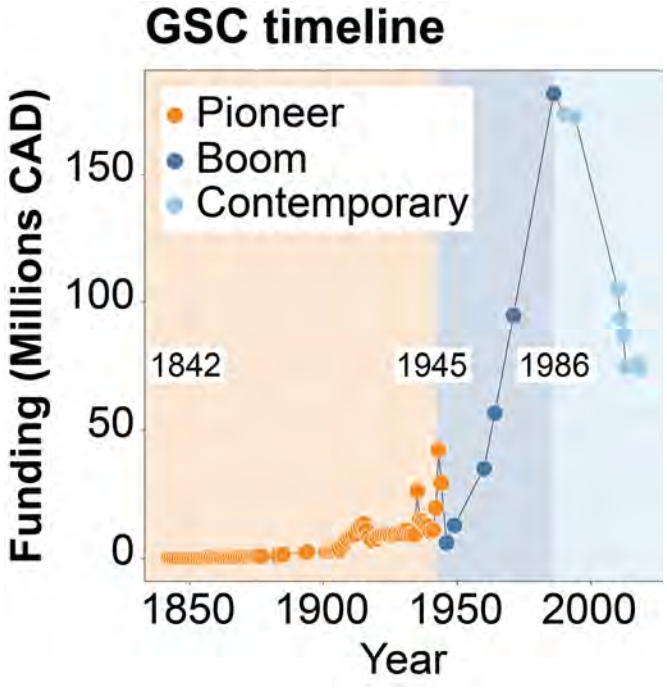


NRCan, 2017

Evolving role of GSOs

- The roles, responsibilities, and methods of geological survey organizations (GSOs) have evolved since 1842



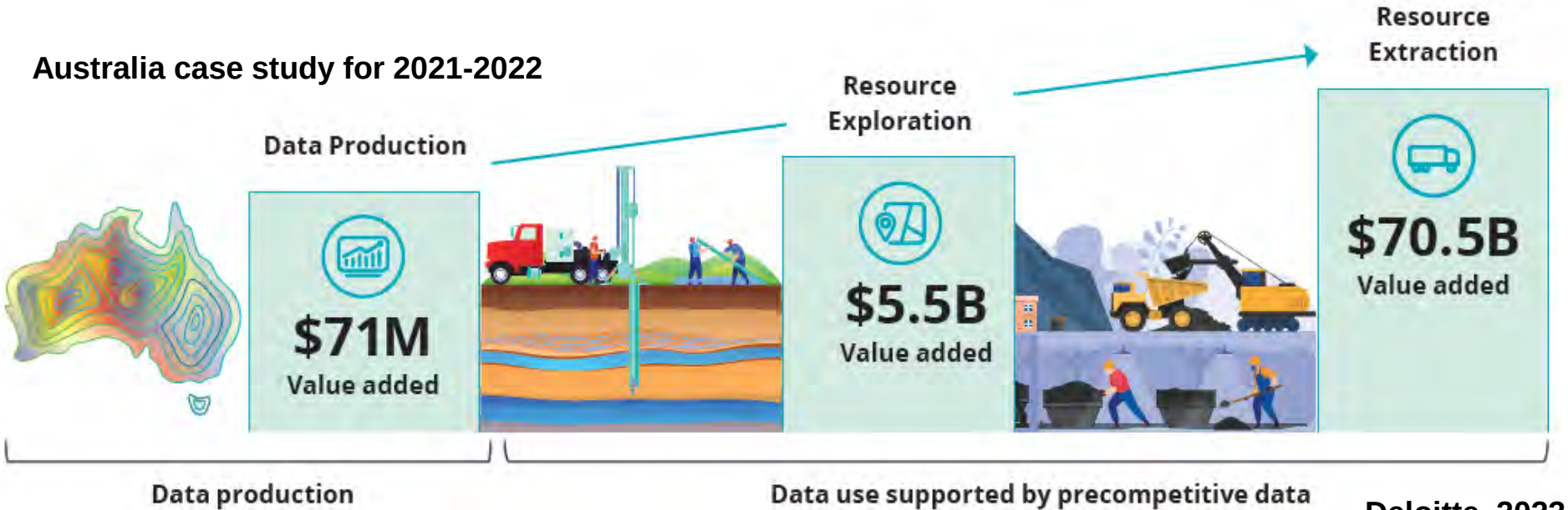


Lebel, 2020

Value proposition

- Each $1 spent attracts $5-7 of private sector expenditure (Duke, 2010)
- Reduces risk, attracts investment, and makes exploration more effective
- Support policy development and public health

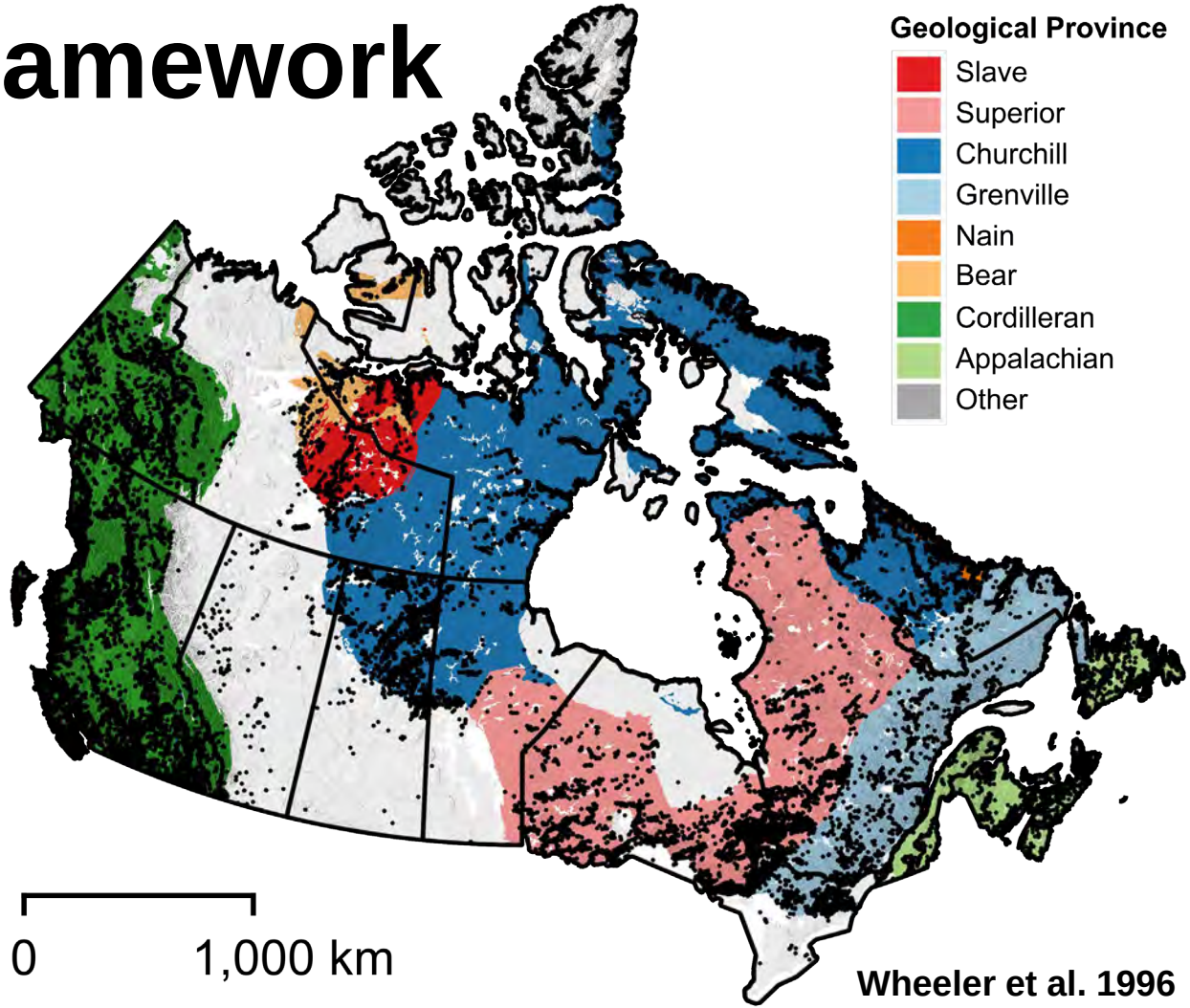
Australia case study for 2021-2022



Deloitte, 2023

Geological framework

- Geologists work at multiple spatial scales and in deep time
- Must work with other jurisdictions to get complete picture (10,000s occurrences)
- Multiple geological sources for each commodity

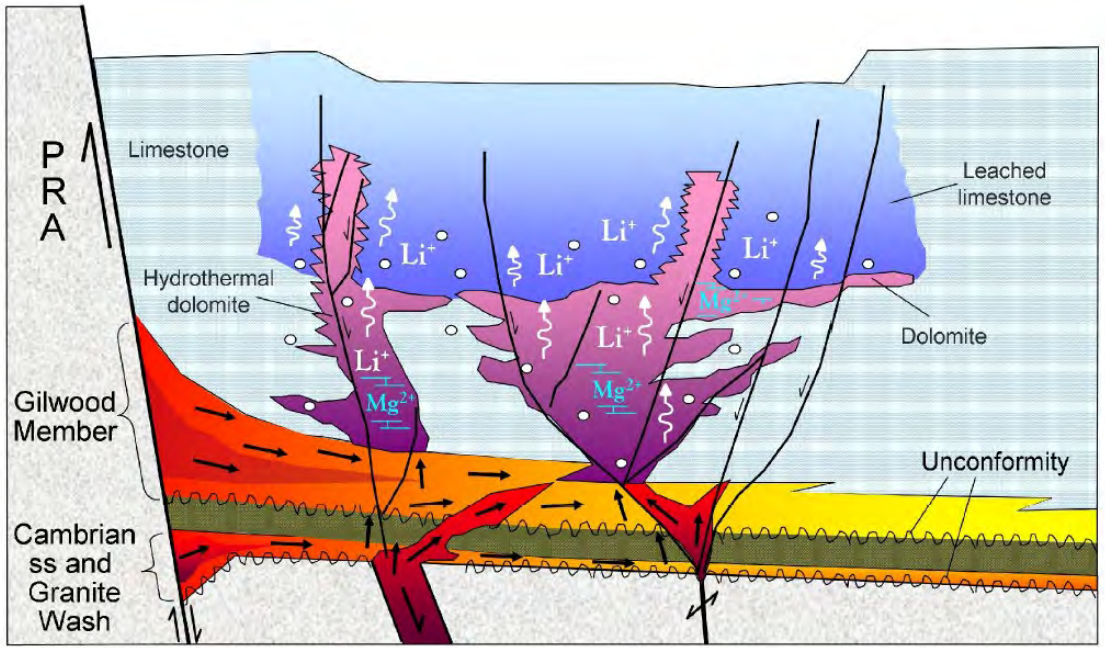


Mineral systems

- Mineral deposits require multiple things to happen at the same time and place
- Together, the required pieces are part of a mineral system
- Like all systems, they don’t work if one piece is missing

Conceptual mineral systems models

- The biggest part of our mineral programs is developing conceptual models
- This requires fieldwork at mineral deposits and a wide range of other tools
- New models support targeting and open new search spaces

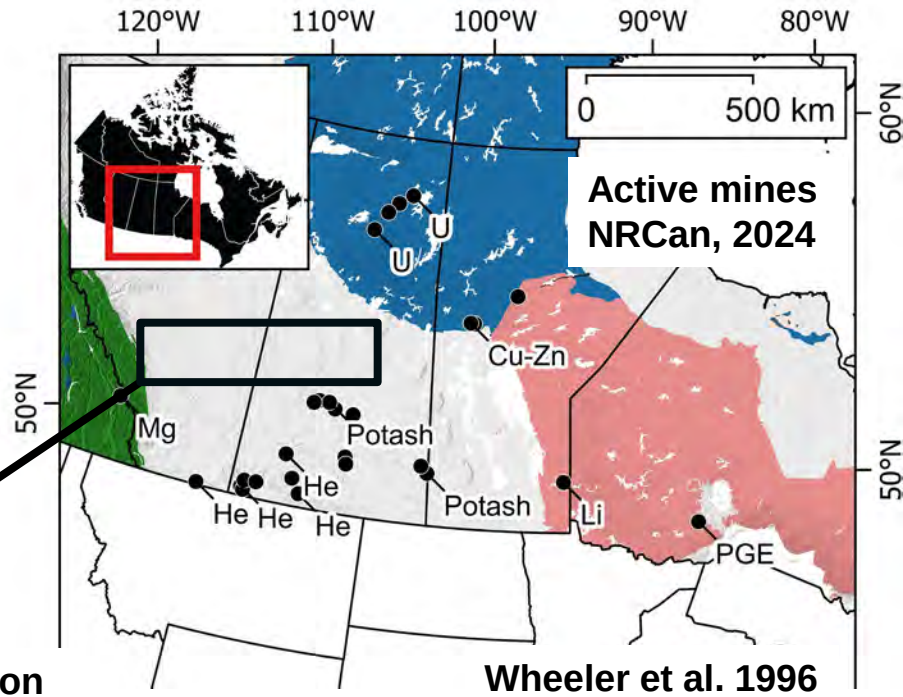


Conceptual model for Li formation water in Saskatchewan. Knowing the source is critical for targeting.

Eccles and Berhane, 2011

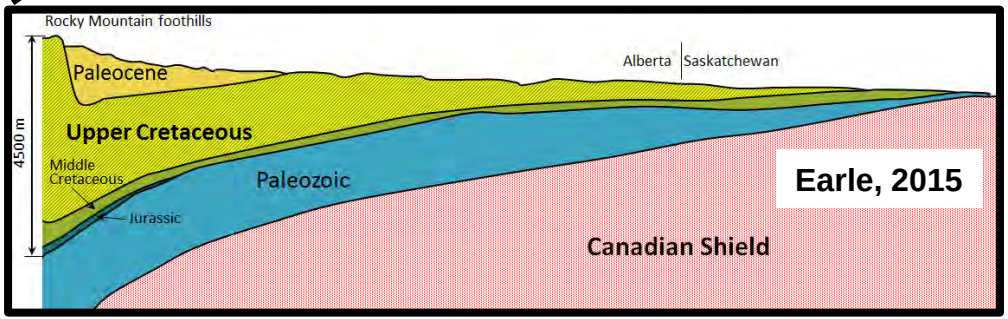
“Young” basins

- Western Interior Seaway deposited rocks famous for oil, gas, and coal
- Older Paleozoic basins famous for potash
- High potential for critical minerals such as helium and lithium



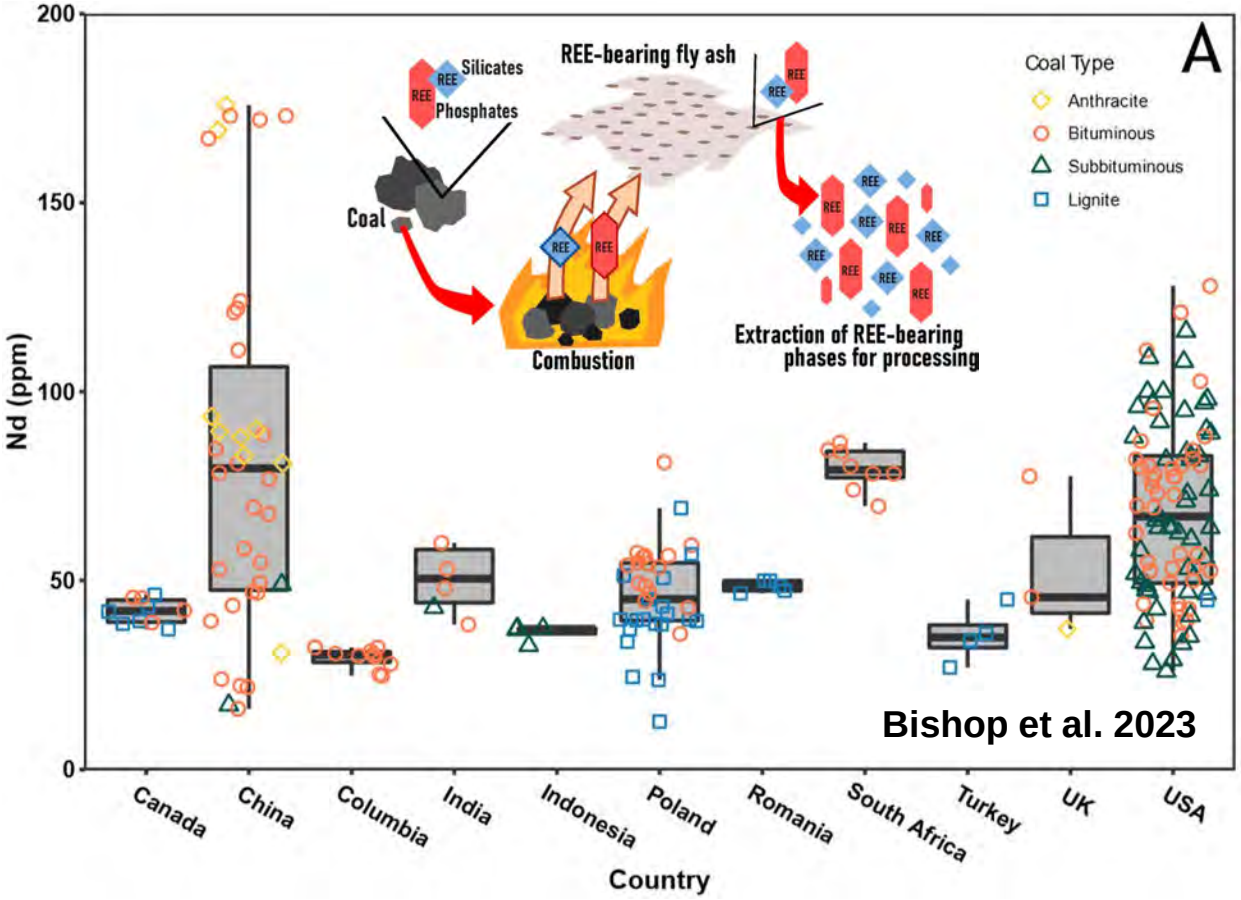
Wheeler et al. 1996

Cross section



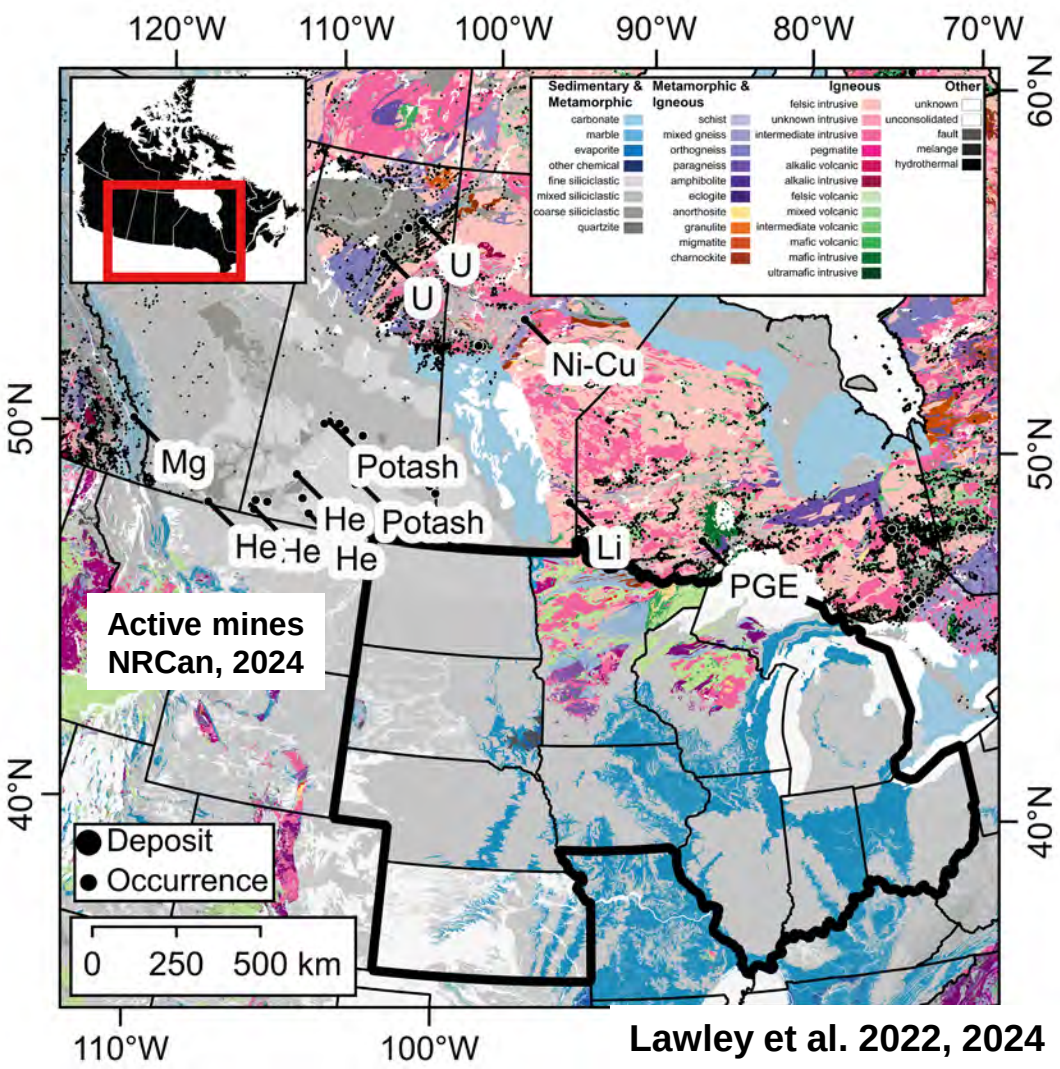
“Young” basins as unconventional sources

- REE as by-products from coal processing
- Li within formation waters (e.g., DLE)
- Research needed to assess potential and to invent processing methods



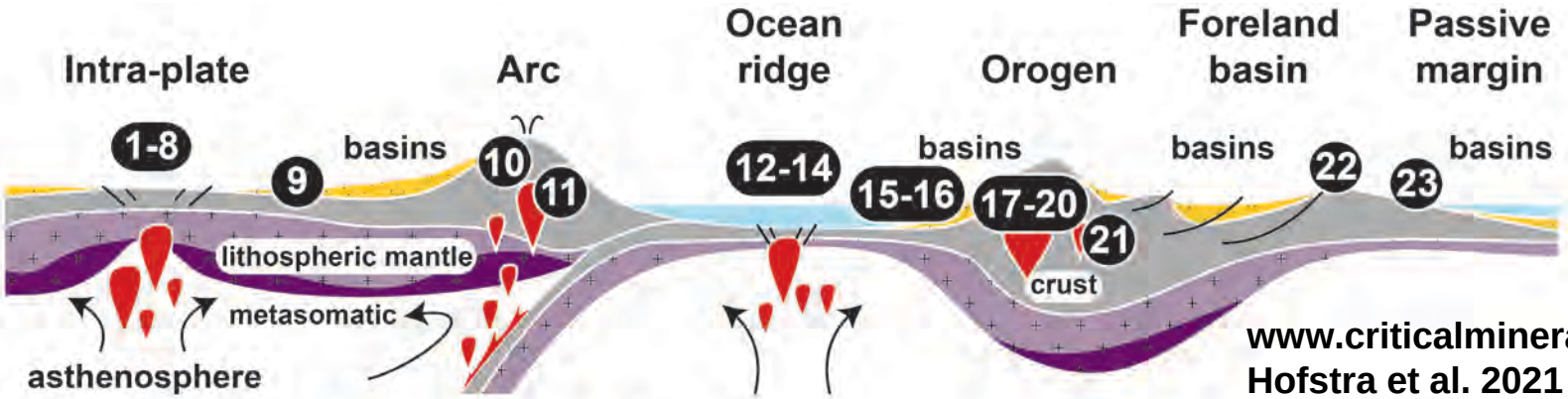
“Old” shield

- Precambrian rocks represent diverse geological settings
- Deformed and metamorphosed
- Magmatic Ni-Cu-PGE; Li pegmatite; Graphite; High-purity quartz
- Sedimentary basins for Zn, Pb, fluorspar



Lawley et al. 2022, 2024

Dozens of mineral systems



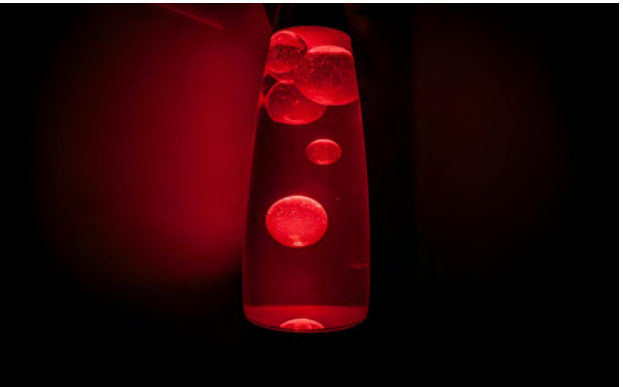
www.criticalminerals.org
Hofstra et al. 2021
Lawley et al. 2022

Mineral systems and their critical minerals

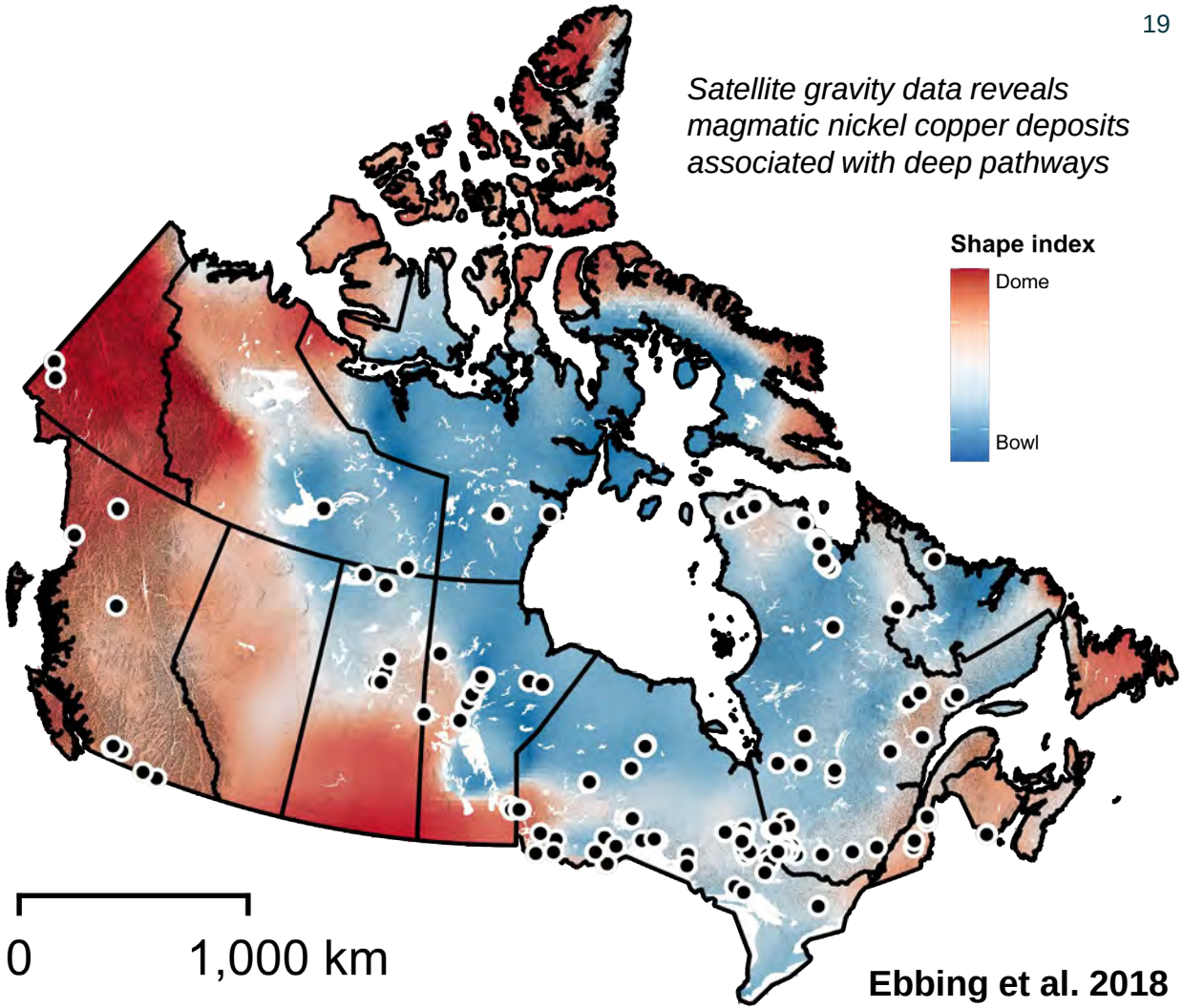
01. Magmatic sulphide (Ni, Cu, PGE, Co)
02. Mafic intrusion-hosted (V, Ti)
03. Kimberlite-hosted (diamond)
04. Carbonatite (REE, Nb)
05. Apatite intrusion (P, REE)
06. Pegmatite (NYF; Li, Nb, Ta, Cs, Be)
07. Iron oxide-apatite (IOA; Fe, REE)
08. Iron oxide-copper-gold (IOCG; Cu, Au, Co, U, Mo, Re)
09. Sediment-hosted, unconformity-related (U)
10. Epithermal (Ag, Au, Hg, Bi, Te, Re)
11. Porphyry (Cu, Mo, Au, Bi, Te, Se, Re)
12. Nodules and crusts (Mn)
13. Volanic massive sluphide (Cu, Pb, Zn, Au, Ag, Ga, Ge, In, Sb)
14. Mafic- to ultramafic cumulate (Cr, PGE)
15. Erosional deposits (Zr, REE, Sn, Au, PGE, diamond)
16. Laterite (Fe, Ni, Co)
17. Intrusion-related skarn (Cu, Fe, Sn, W, Mo),
18. Intrusion-related greisen (Zn, Pb, Sn, W, Mo)
19. Pegmatite (LCT; Li, Nb, Ta, Cs)
20. Metamorphic graphite (C)
21. Orogenic gold (Au, Ag, Sb, Hg)
22. Mississippi Valley-type (MVT; Zn, Pb, Ga, Ge, In, Sb)
23. Clastic-dominated (CD; Zn, Pb, Ga, Ge, In, Sb)

Conceptual to mappable

- Conceptual models identify the key ingredients that then need to be mapped



Satellite gravity data reveals magmatic nickel copper deposits associated with deep pathways

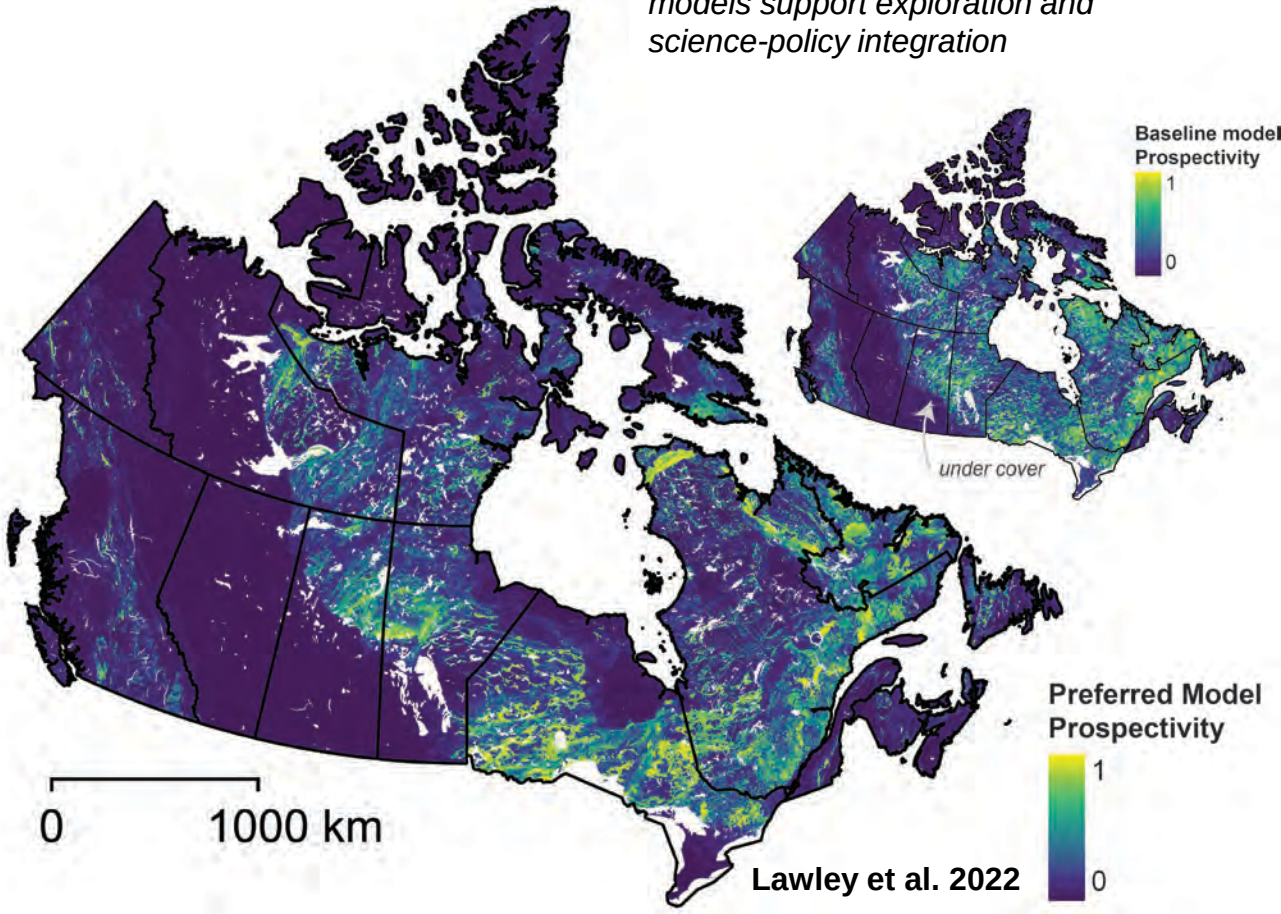


Ebbing et al. 2018

Mineral intelligence

- Combine data for each mineral systems component
- Use areas of known mineralization to train machine learning models
- Model reduces the search space by 90%, but that is not enough on its own!

Magmatic nickel-copper potential models support exploration and science-policy integration



Mineral intelligence

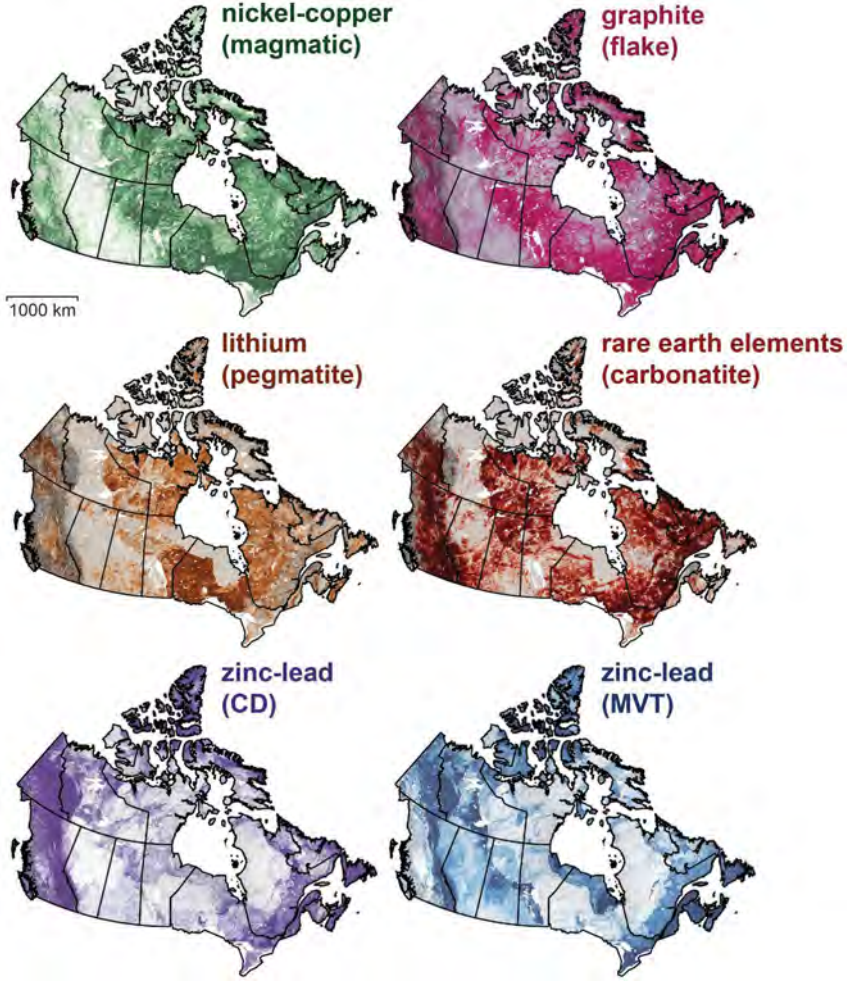
Three components to mineral intelligence at the GSC:

(1) New public geoscience

(2) Apply AI to do more with existing public geoscience data

(3) Advance AI to improve the reliability of predictions

Models available at: **www.geo.ca**

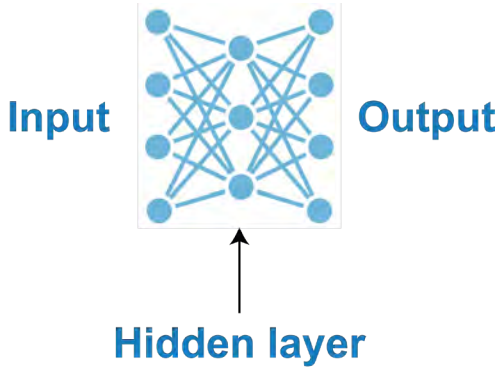


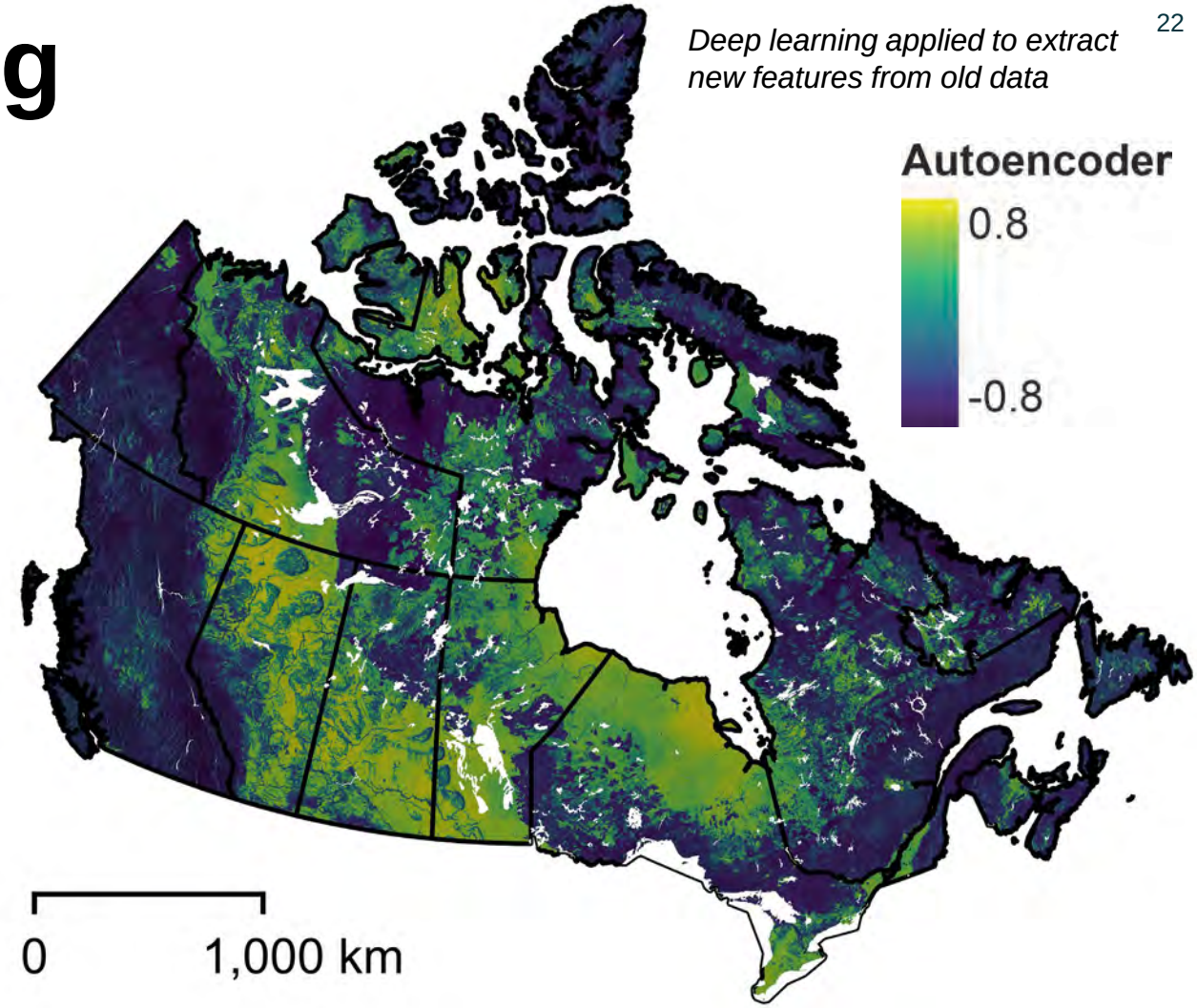
Family of national prospectivity models trained on public geoscience (Lawley, Parsa, and Zhang)

Deep learning

Deep learning applied to extract new features from old data

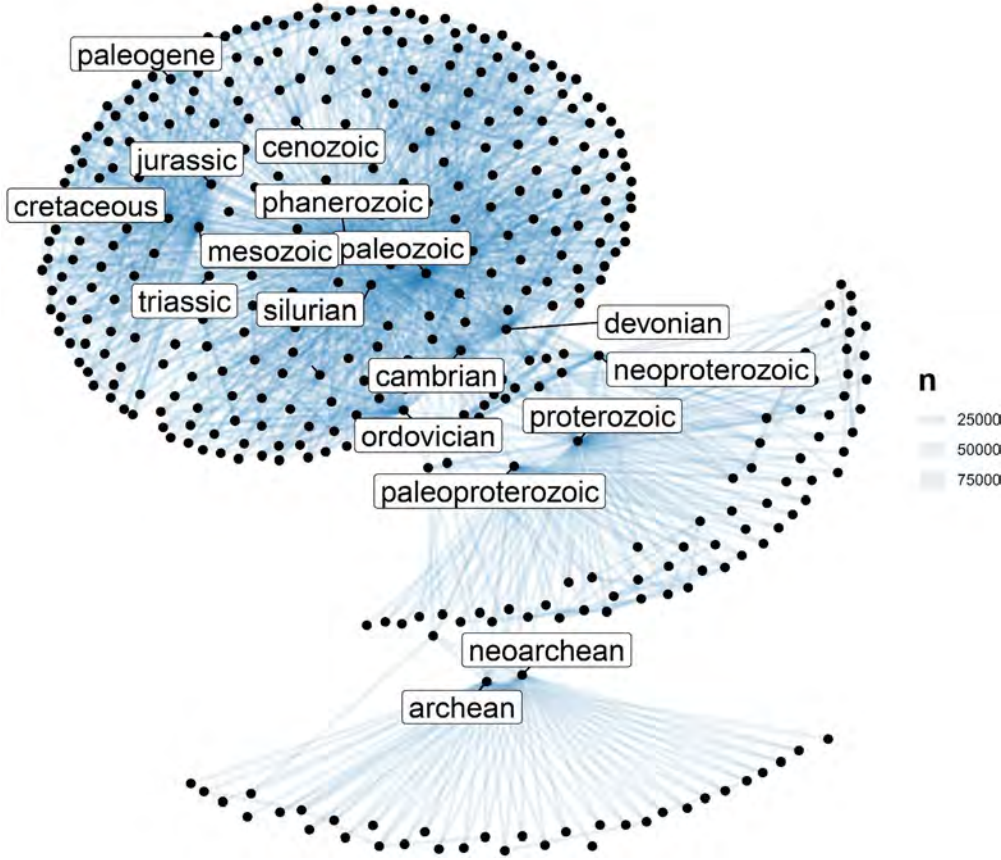
- Moving towards deep learning, self-supervised learning, and foundation models





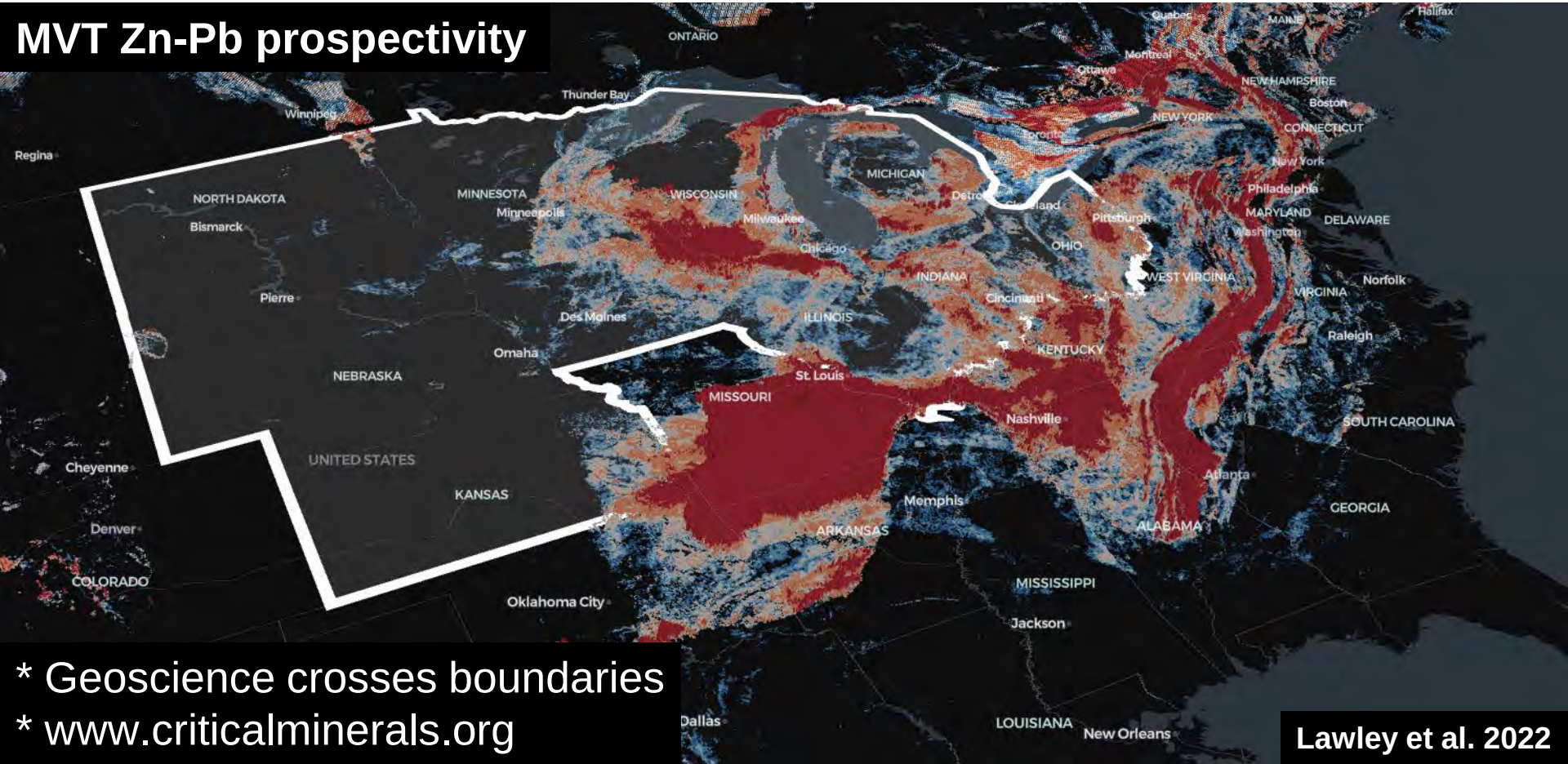
Doing more with what we have

- Apply AI to improve data processing and 3D modelling (Hillier et al. 2024)
- Apply NLP and LLMs to extract more information from geological map databases (Lawley et al. 2023)
- Graphs to embed stratigraphic knowledge into models



Nodes represent lithostratigraphic names across Canada. Edges represent connection strength (Lawley et al. in prep)

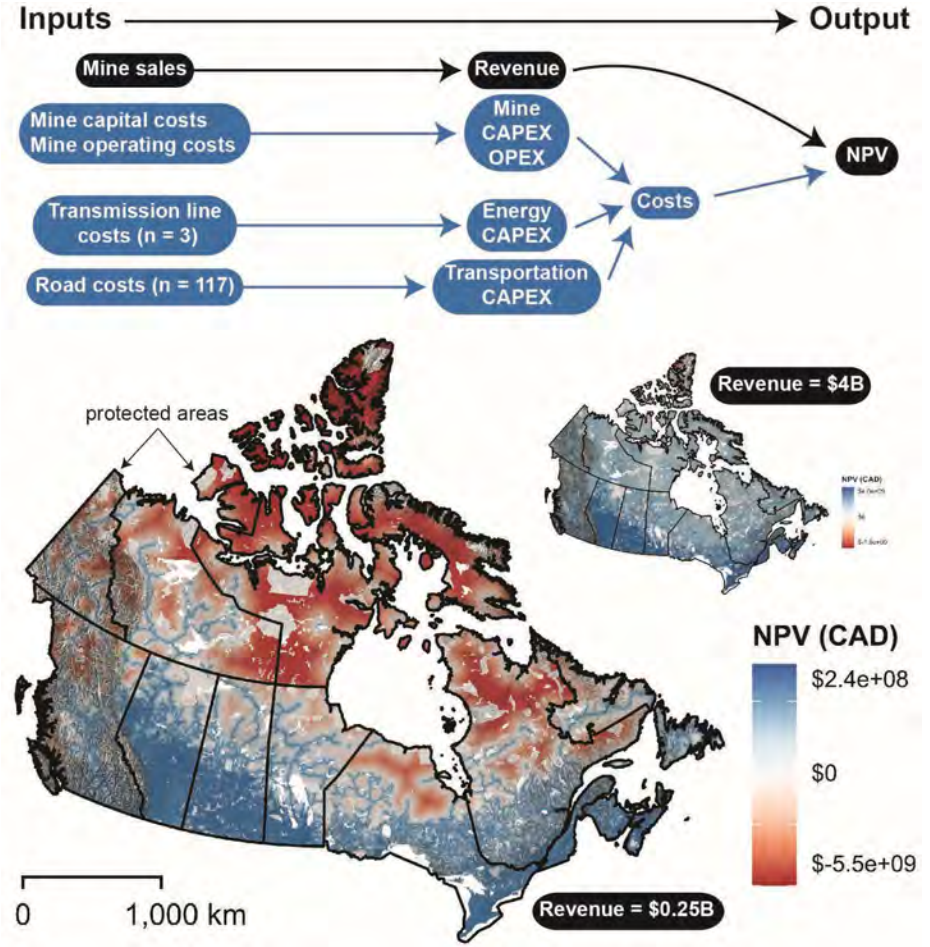
International collaboration



Unlocking critical mineral potential

- Building a pre-pre-feasibility tool that combines economic and infrastructure data to predict net present value (NPV) of critical mineral deposits

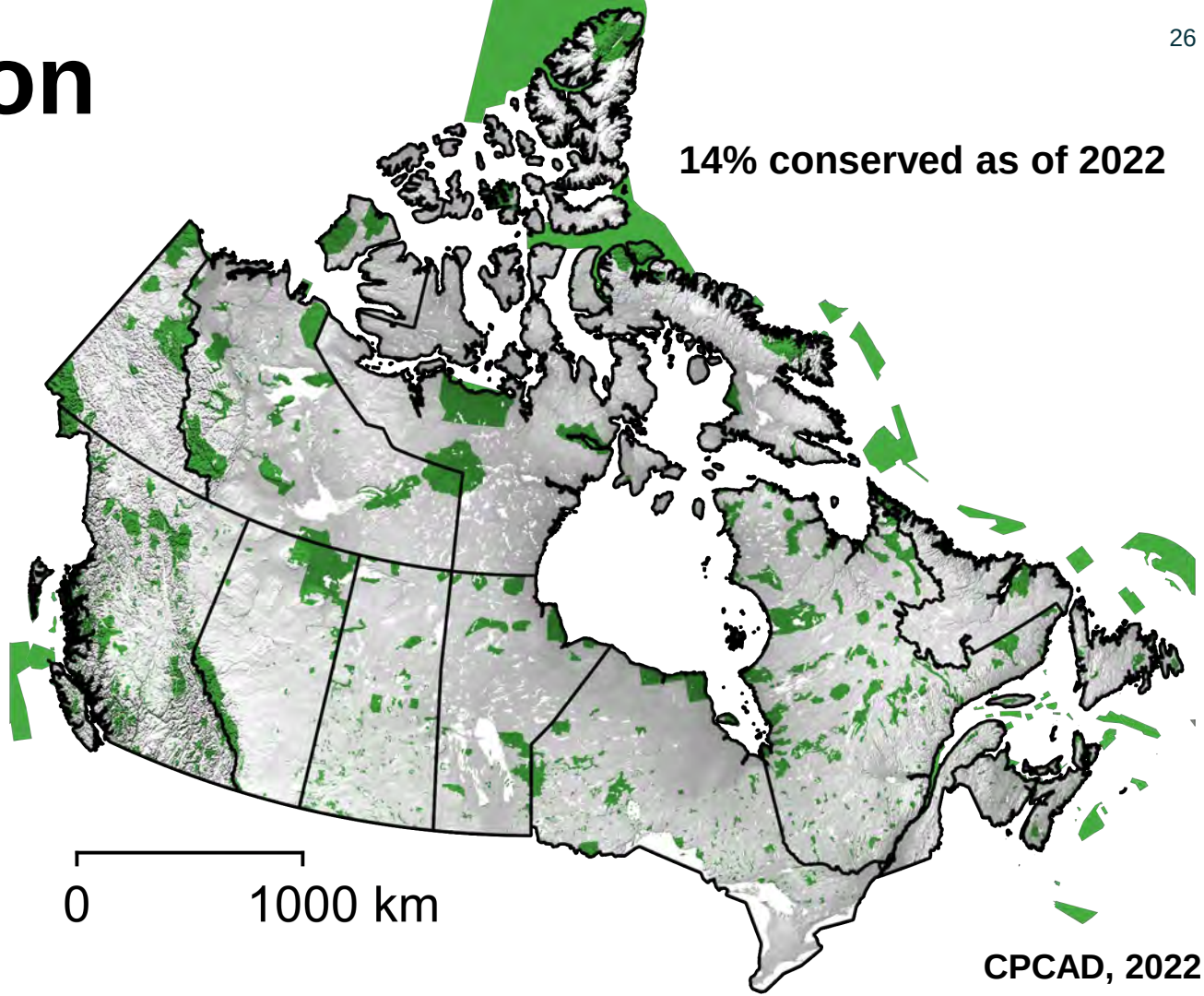
- Combine mineral potential and economic models with ESG principals using multi-criteria optimization to support land-use planning



NPV for a "small" ($0.25B) and "large" ($4B) deposits based on their proximity to infrastructure (Li, Chokshi, Lawley, Thompson)

Conservation priorities

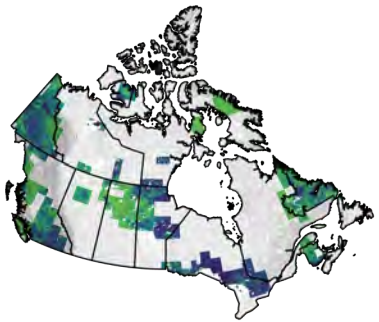
- Must conserve 30% of land and sea by 2030
- Must balance conservation priorities with mineral potential
- Need data-driven decision making



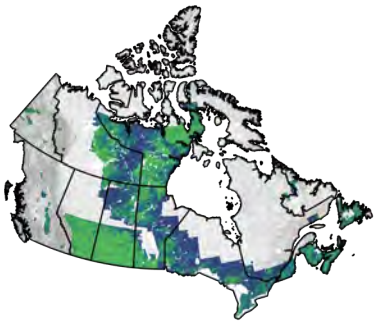
Data gaps and quality

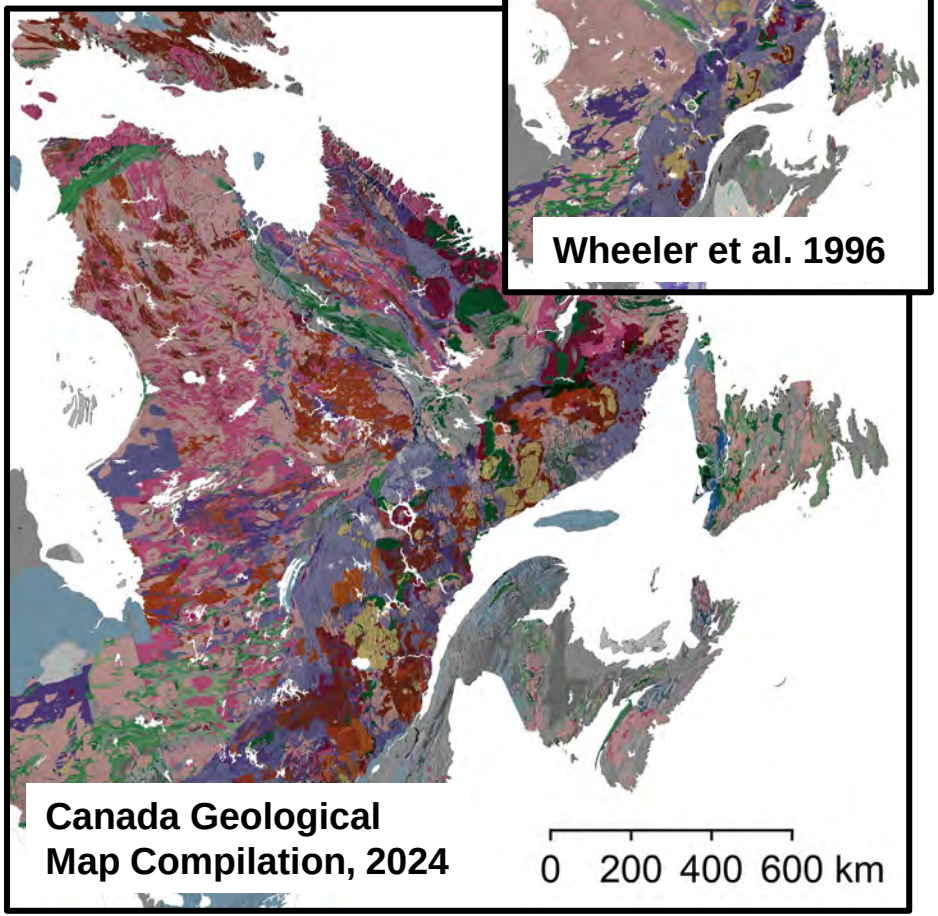
- Data availability and quality highly variable
- Quality of decisions depends on the quality of the data

Geochemistry



Radiometrics





Conclusions

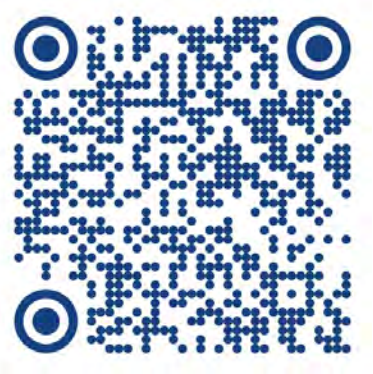
- Public geoscience provides baseline data that is accessible to all
- De-risks exploration and supports policy
- Midwest has high potential for critical minerals both from conventional and unconventional sources

NRCan publication database

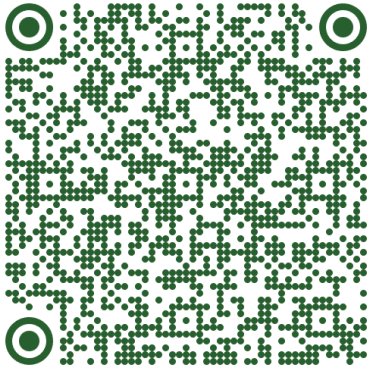
Critical minerals data on www.geo.ca

Resources

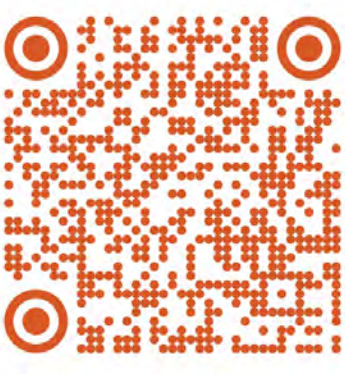
Lithostratigraphy



Geochronology

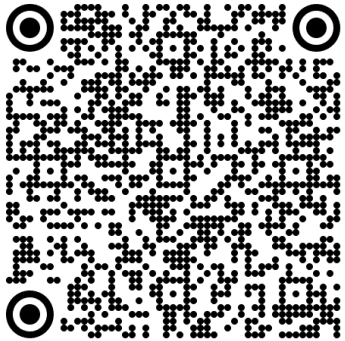


Geochemistry

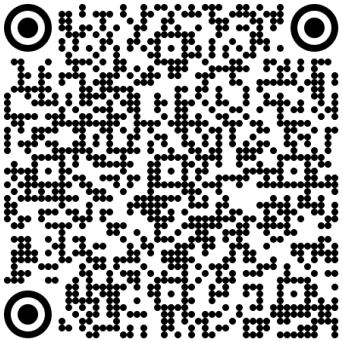


Geophysics

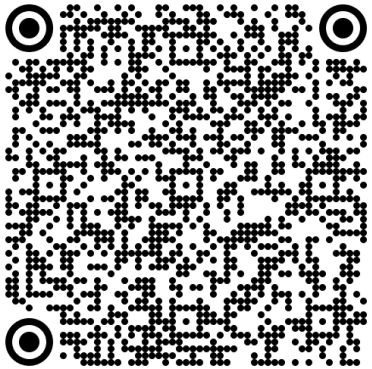
Bedrock geology



Surficial geology



Mining statistics



Geospatial data