

## Peer Review Report

# Review Report on Mapping Canada's green economic pathways for battery minerals: Balancing prospectivity modelling with conservation and biodiversity values

Original Research, Earth Sci. Syst. Soc.

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### EVALUATION

#### **Q 1** Please summarize the main findings of the study.

This study presents a workflow that reduces the search space for magmatic Ni sulfide deposits by a significant percentage. The workflow is based on prospectivity models coupled with natural resources management datasets and strategies. This aligns critical mineral exploration and mining with conservation and biodiversity values.

#### **Q 2** Please highlight the limitations and strengths.

Strengths:

- (1) This study explores large-scale datasets at the country scale for mineral exploration prospectivity analysis for some fundamental critical metals;
- (2) This exercise applies the mineral system approach to its mineral exploration model;
- (3) It uses machine learning algorithms to assist the prospectivity exercise; and
- (4) This research has a holistic approach linking critical mineral exploration and mining with conservation and biodiversity values.

Weaknesses:

- (1) The literature presented to support many of the statements made and the workflow presented could be more complete;
- (2) The conceptual model used to apply the mineral system model could be described in more detail;
- (3) Key elements of the mineral system model were not analysed and discussed (e.g., ore preservation, trap);
- (4) The layers used for the prospectivity analysis could be discussed in more detail to provide the reader with a more precise view of the work and interpretations provided in the paper; and
- (5) The prospectivity analysis does not provide an uncertainty quantification and discussion of the results.

#### **Q 3** Please comment on the methods, results and data interpretation. If there are any objective errors, or if the conclusions are not supported, you should detail your concerns.

Please see the comments provided in Q4.

#### **Q 4** Check List

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Is the English language of sufficient quality?

Yes.

Is the quality of the figures and tables satisfactory?

Yes.

Does the reference list cover the relevant literature adequately and in an unbiased manner?

No.

Are the statistical methods valid and correctly applied? (e.g. sample size, choice of test)

No answer given.

If relevant, are the methods sufficiently documented to allow replication studies?

No.

Are the data underlying the study available in either the article, supplement, or deposited in a repository? (Sequence/expression data, protein/molecule characterizations, annotations, and taxonomy data are required to be deposited in public repositories prior to publication)

No.

Does the study adhere to ethical standards including ethics committee approval and consent procedure?

Not Applicable.

If relevant, have standard biosecurity and institutional safety procedures been adhered to?

Not Applicable.

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**Q 5** Please provide your detailed review report to the editor and authors (including any comments on the Q4 Check List):

I have read with interest the paper titled: "Mapping Canada's green economic pathways for battery minerals" by Lawley et al.

This paper is about using a prospectivity approach as part of natural resources management strategies to improve Environmental, social, and governance performance as a tool to help plan the aspirational goal of zero emissions for Canada in 2050. To this end, they map the potential prospective regions in Canada for magmatic Ni ± Cu ± Co ± PGE mineral systems (not related to impacts; e.g., excluding the Sudbury Ni system) using machine learning approaches in combination with five ecosystem services (freshwater, carbon, nature-based recreation, species at risk, and climate change refugia).

The manuscript is well-structured and well-written. It contributes to mineral exploration from the point of view that it links mineral exploration protocols with environmental, cultural and societal contexts and datasets. This is very welcome and an excellent example of how to better enhance mineral exploration at a large scale in the fluid and more holistic context we are in these times.

However, as presented, in my view, the paper needs significant changes to better convey the message and enhance its impact.

(1) Introduction

(1.1) The Introduction sets up the stage well for the issues related to biodiversity, environmental impact and factors that play a significant role in the new international policies of the Governments to context mineral exploration and the extraction of mineral resources.

(1.2) Lines 96–103, Not sure if the Introduction is the best place to list the results of this study.

(1.3) The authors may consider briefly discussing the potential impact on the critical metal forecast predictions for batteries of technology disruption (e.g., batteries of graphite and Vanadium). This can significantly impact the amount of Ni–Co needed for future batteries and for countries to meet zero emissions.

(1.4) Line 94 and 107–109, maybe the authors mean Critical Metals more than Critical Minerals for this specific exercise since the paper only refers to Ni, Cu, Co and PGE.

(2) Canada's battery mineral sources

I believe this section would significantly improve and be much more informative to the reader if the authors extended it and summarised several essential aspects of the study as well as milestone references in the subject.

(2.1) It would be good if the authors present the global context related to the fundamental battery metals (e.g., production, resources, and minerals systems associated with Ni, Co, and Li). Then, present the reader with the general global view of Ni source, which is ~30% from magmatic Ni deposits whereas ~70% comes from lateritic Ni deposits. Since the environmental impact of extracting Ni from the former is much lower than in the latter deposits, this enhances the importance of looking for more magmatic Ni sources.

(2.2) Lines 106–107. "Canada is the sixth largest producer of Ni in the world (USGS 2021). A significant amount of Cu, Co, and Platinum Group Elements (PGE) are produced as by-products of these Ni mining activities."

(2.3) Quantifying these statements with total global contribution production and tonnage would be good.

(2.4) Does Canada want to play a role for the critical metals as a reliable supplier (e.g., Australia) or a mainly as a consumer (e.g., EU, USA)?

(2.5) Why did the authors not include the third largest Ni mine in their exercise in the country?

(2.6) The authors mention several times Mineral Systems without explaining to the reader what this concept means and its importance for designing the prospectivity analysis on magmatic Ni sulfide deposits.

(2.7) Lines 111–132, This paragraph could be coupled with a Figure to display the conceptual model the authors are using for this study. This will allow the reader to better understand how the authors used the datasets available and why. And better explain the importance of the mineral systems elements and ore footprints that were mappable and utilised for the prospectivity exercise.

(2.8) Lines 127–132,

Mineral systems are based on the result of the co-existence of all fundamental elements. Having the depositional architecture/traps not considered certainly has a significant impact on the prospectivity results. The authors could rationalise the case and justify using the Mineral Systems approach even if one of the fundamental components could not be mapped.

(2.9) The authors may consider that a fundamental aspect of the mineral system is the preservation of the deposit. All the essential elements to produce a magmatic Ni deposit might be present, but that does not mean the deposit was formed. If it was, it might have been removed.

(2.10) Table 2 in the supplementary material mentions traps interpreted from geological and geophysical datasets. However, in the text, it says that this was not assigned.

(2.11) Table 2. mentions preservation and is linked to the metamorphic dictionary. This is not explained in the text.

(2.12) It is very challenging to assess this section of the paper with the limited information about the datasets used and how they were interpreted.

(2.13) It would benefit the reader to see how the authors interpreted and used the collected datasets. Which type of exploration proxy represents each dataset after their processing and interpretation?

(2.14) the prospectivity analysis for the magmatic Ni system seems to be heavily based on the author's previous study but with a more accurate dataset selection. What are the main differences and similarities between the earlier outputs for Lawley et al. (2021) and the magmatic Ni outputs of this exercise with the new dataset/?

### (3) Prospectivity data and methods

(3.1) Different data analysis methodologies have been used to develop Prospectivity analysis applied to Mineral Systems for the last 20 years. Different methods have different pros and cons and limitations in their application outputs based on the data availability and density. The authors could explain to the reader the pros and limitations of the methodology they chose to apply and why they decided to use it.

(3.2) Lines 159-161,

More information about what the authors are referring would be helpful (e.g., large igneous provinces events, break up of supercontinents associated with rifts and mantle plume events, archean versus post-archean crustal evolution processes, etc.)

(3.2) Lines 163-165,

It would be good to be more specific about how the datasets were used to interpret the pathways.

(3.2) Lines 172-175,

Which kind of "further processed" was used?

(3.3) Lines 181-182,

A brief description of the platform and method used with its pros and cons would be informative.

Why was this method used? Any advantages of other ML approaches tried in the literature. A background explanation and details would be helpful for the reader to understand the methodology applied in this study and its reasoning.

There is little reference to the literature on mineral systems, mineral exploration of magmatic Ni sulfide deposits and prospectivity analysis. The article should be self-contained and not depend on other articles to be understandable since the reader may not have access to some literature that is not open access.

When the authors test the reliability of the results by testing the outputs in known areas not used in the training of the algorithm, which was the results?

Many researchers working in mineral exploration and prospectivity analysis are exploring different approaches and comparing results between supervised and unsupervised methods.

(3.3) Lines 220-229,

Mapping uncertainty? Another critical aspect of the output of geophysical interpretations and prospectivity exercises is quantifying the uncertainty of the outputs. This offers an excellent layer of information to the explorers to better estimate the risk in some areas compared to others. The authors could comment on these important aspects of the study and how this study approached the element of uncertainty in the datasets, interpretations of datasets and prospectivity outputs.

(4) Ecological representation data and methods

(5) Conservation data and methods

(5.1) Line 266,

References?

(6) Results

(6.1) Out of the datasets used for the prospectivity analysis for magmatic ni sulfide deposits, which were the features and which is the uncertainty associated with the dataset interpretation?

(6.2) Lines 401–403,

Is it differentiated in the model mafic versus ultramafic rock suites?

Since the maximum geological period is displayed as a significant prospectivity factor, which is the relationship of the known Ni discoveries in Canada with time? This would indicate how important or not are different geological periods for this mineral system type in Canada.

Is this not a repetition of (1)?

In many contexts, major faults can be seen in DEM datasets more clearly than in magnetic and gravity.

(7) Discussion

(7.1) Line 459,

There is not much discussion in the last part of the article on Co deposits, not a debate about how Ni and Co elements link to get whether are ni system relates to Cu, Co and PGE grades associated.

(7.2) From 453 to 490, as presented, this section reads as Results, not a discussion.

(7.3) Green mining starts with green exploration.

An excellent point to highlight in the discussion

(7.4) It would be worth mentioning that the significant adverse environmental impact of mineral exploration and mining in many areas of the world is not due to a lack of cleaner and low-impact technologies available that can minimise the adverse effects. Still, the choices made but the decision-making chain that ultimately decides what, where and how to carry out the exploration and mining activities.

(7.5) It would be very interesting to see in the discussion a short section with a reflection on how the authors can see this type of work exported in areas such as Australia, the EU and the USA since they have similar frameworks to apply this approach.

**Q 6** Originality

**Q 7** Rigor

**Q 8** Significance to the field

**Q 9** Interest to a general audience

**Q 10** Quality of the writing

**Q 11** Overall quality of the study