Insights into the Usage of AI Tools for Professional Geoscientists - Overview and Best Practices

GEOSCIENTISTS
GÉOSCIENTIFIQUES CANADA®

Geoscientists Canada/Géoscientifiques Canada
55 Metcalfe Street, Suite#300
Ottawa, ON K1P 6L5
www.geoscientistscanada.ca
Email: info@geoscientistscanada.ca

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Preface

About Geoscientists Canada

Geoscientists Canada is the national organisation comprised of the provincial and territorial regulatory bodies (i.e., Members), who regulate the practice of geoscience in Canada and license the country's greater than 14,000 professional geoscientists. Geoscientists Canada exists to serve the profession of geoscience in Canada and works on behalf of the Members.

Disclaimer

Geoscientists Canada's Statements and Guidance Documents are developed by geoscientists in collaboration with the provincial and territorial geoscience regulators. These documents provide general information and guidance on topics related to the practice and regulation of geoscience in Canada.

Geoscientists Canada Statements and Guidance Documents do not establish a legal standard of care or conduct, and they do not include or constitute legal or professional advice.

In Canada, geoscience is regulated under provincial and territorial law by the geoscience regulators. The ultimate authority regarding the propriety of any specific practice or course of conduct lies with the geoscience regulator in the province or territory where the geoscientist is licensed to perform the geoscience work conducted.

This publication was written by live human beings with real intelligence.

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About this Document

The Geoscientists Canada *Insights into the Usage of AI Tools for Professional Geoscientists – Overview and Best Practices* was prepared by the Geoscientists Canada Professional Practice Committee to provide general guidance on the usage of artificial intelligence tools in the practice of professional geoscience. Canada's geoscience professionals should consult the regulators' related geoscience acts, regulations, bylaws, standards, and guidelines for the relevant requirements applicable to the professional's activities within the jurisdiction of their work.

The Geoscientists Canada *for Professional Geoscientists – Overview and Best Practices* does not establish a legal standard of care or conduct and does not include or constitute legal or professional advice.

Professional geoscientists in Canada are responsible to the Code(s) of Ethics of the geoscience regulated provinces and territories in which they are licensed (registered). Provincial and territorial Codes of Ethics are available on the regulators' websites:

Engineers and Geoscientists British Columbia

Northwest Territories and Nunavut Association of Professional Engineers and Geoscientists

Association of Professional Engineers and Geoscientists of Alberta

Association of Professional Engineers and Geoscientists of Saskatchewan

Engineers Geoscientists Manitoba

Professional Geoscientists Ontario

Ordre des géologues du Québec

Engineers and Geoscientists New Brunswick

Geoscientists Nova Scotia

Professional Engineers and Geoscientists Newfoundland and Labrador

Preamble

Insights into the usage of AI Tools – Overview and Best Practices was written at the request of Geoscientists Canada to address the growing concern around incorporating artificial intelligence tools into professional practice generally, and geoscientific practice specifically. The Professional Practice Committee (PPC) undertook this challenge starting in 2024 – during a time when the AI (artificial intelligence) landscape and ecosystem were changing very rapidly – adding to the challenge. The PPC comprises senior geoscientists who have been nominated by their provincial/territorial regulator to serve on the committee. In addition to the AI expertise already on the committee, three subject matter experts (SMEs) were recruited from the regulatory bodies.

The last year has seen an incredible diversity of discussions in PPC meetings, emails and occasionally in person. Choices around where to start, chapter topics, technical depth and breadth, the role of Geoscientists Canada versus the role of regulators - even the title of the publication were framed in the context of geoscientists with a passion for their science and a deep-seated desire to be of service to their profession and the public.

This publication is written to facilitate a certain amount of scan-reading and there is some repetition to emphasize key concepts. Lighter comments and geological examples are intended to mitigate the stress caused by deciphering all the acronyms.

Acknowledgements

The Professional Practice Committee acknowledges and thanks the Member reviewers for their thoughtful and comprehensive comments. This document is the better for their comments and in some cases, suggested additions have been incorporated almost verbatim.

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The Professional Practice Committee is coast to coast with points in between: Tablelands, Newfoundland.

Chapter 1. Introduction

Artificial intelligence is a vast and complex topic. Although there are many definitions of artificial intelligence, one of the most straightforward is: "the capability of computational systems to perform tasks typically associated with human intelligence, such as learning, reasoning, problem-solving, perception, and decision-making" (Russell and Norvig, 2020).

Various standard machine learning (ML) techniques account for the majority of applied statistical learning efforts within the geosciences. Increasingly, large language models are being utilized in the production of reports and other technical documents. These and other techniques will collectively be referred to as "artificial intelligence". The various models, algorithms and statistical techniques covered by the term artificial intelligence are incredibly powerful tools that have facilitated major advancements in the sciences. The tools may be commercial products "off the shelf"; they may be modified to fit specific applications, or they may be completely custom-built.

Consistent with Geoscientists Canada and the Member Regulators' Codes of Ethics, the over-arching theme of this document is Public Safety. Regardless of their existing successes in related disciplines, responsible human oversight of these tools is essential.

The pipeline for application of any ML technique can be seen as having three main components, the first of which is Data. Collecting and curating data is often the most arduous and time-consuming task in the modeling process. The legal requirements around data provenance, acquisition, conditions of usage and security are evolving rapidly. It is incumbent upon all who "touch" data to be aware of data protection laws in all jurisdictions in which they practice. The second component of the pipeline is the application of an appropriate algorithm; the third component is the outputs which require oversight and proper vetting. This last step is critically important and relies upon the expertise of a professional geoscientist. All three components will be addressed in this document.

Purpose

The purpose of this document is to provide an overview of the usage of artificial intelligence tools along with best practice considerations for professional geoscientists, and in so doing, to support the ethical, highly-skilled practices of Canadian Professional Geoscientists at their various career stages.

Typically, professional geoscientists will move through different stages in their career progression. Starting with a purely technical job function, most practitioners will then undertake mixed technical/managerial roles culminating in a mainly managerial role or in a senior technical specialist position.

Those practitioners currently with advanced years of experience both technical and managerial, may include those who started their post-secondary training and careers without AI tools – and in many cases, without computers!

This dichotomy of expertise results in cohorts of geoscientists with very different skill levels related to the usage of AI and AI ecosystems. Each of these groups will have a different view of AI tools and a different understanding of the ethics behind their use. Early career professionals are less exposed to the risks and decision-making around AI outputs, whereas the advanced career professionals will be taking full responsibility for their teams' work products that have been generated with full or partial use of AI.

Ultimately, the professional geoscientist is responsible for their professional work and its outcomes.

The Professional Geoscientist is responsible for the professional work products, regardless of the tools used.

AI Usage in Technical and Managerial Aspects of the Professional Geoscientist's Role

Diving Right In – A few warm-up questions to start:

Technical Aspects

In geoscience exploration and development, the geoscientist is looking for the "least likely" – the anomalies. Large Language Models generate the "most likely". Whether the project is critical minerals exploration, sand reserves for solar panels, oil and gas development or fracture characterization for nuclear waste repositories - the principles, risks and rewards involve the same questions. The technical aspects behind the use of Machine Learning tools can be seen as a pipeline with three main categories: the data, the algorithms and validation of the outputs.

Some questions to ask around the data:

- Where did the data come from, was it legally and ethically acquired, has it been validated/ curated, is it reproducible? (Some dictums just do not change, "garbage in = garbage out".)
- If using data-acquisition technologies such as drones or automated sensors for photogrammetric surveys, can you validate or assess this raw data?
- Does the software require that your own data become part of the training data set?
- Do your organizational policies allow for data-sharing? Are you sharing only the required information as allowed under data classification guidelines or are you over-sharing)?

Some questions to ask around the algorithms and software:

- Do you understand the math and how the algorithms are working?
- What effect are minor variations in the data inputs having on the statistical models?
- Are you using the appropriate software?
- If you are using AI-generated after-market coding, has this been thoroughly tested and validated?
- Does your team keep logs of the coding edits?

Some questions to ask around the outputs:

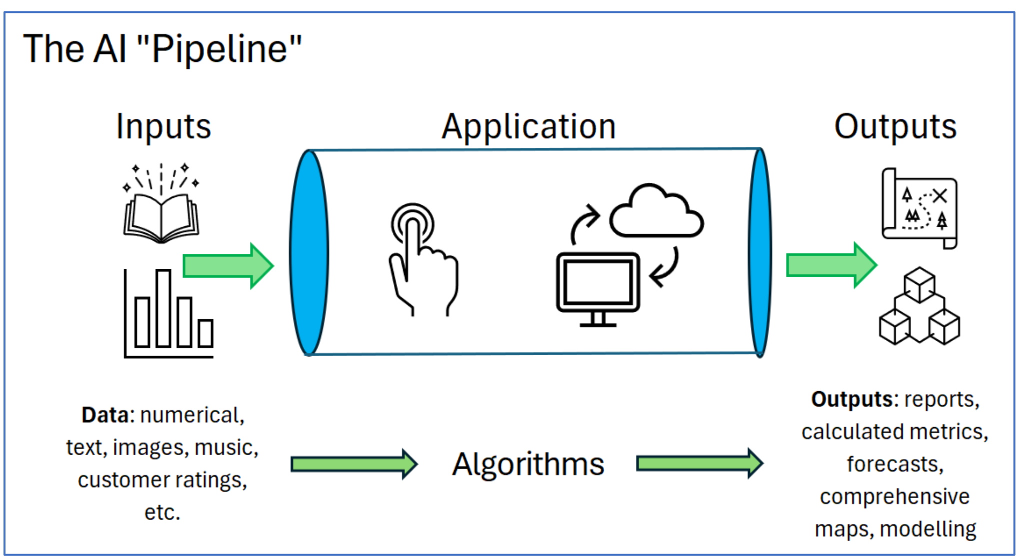
- Is the output reasonable and as expected? Or did the target groundwater reservoir just become shale with brine formation fluid?
- One can turn Niagara Falls into Lake Agassiz in seconds with inappropriate mapping software and inputs – does the team have the expertise to recognize when this is happening? Do they have the expertise to correct the output?
- Generally, is the output geologically consistent?

Managerial Aspects

Professional geoscientists who have a managerial function not only need to be cognizant of the data to output pipeline, they also need to be fully apprised of data privacy and protection laws and their own corporate policies. Of course, much of the data used in the management role is personnel data – individual, group and corporate. These data include day-to-day performance evaluations, compensation bands, promotion data, expense reports, sick leave policies and medical and dental insurance statistics.

The same questions that apply to technical data and applications apply to personnel (and personal) data and applications. Different questions may be relevant to the outputs:

- Is the whole process in alignment with your corporate policies? See the Ethics chapter for more on this.
- Software and training data sets can be vulnerable to the effects of embedded biases. To what degree has your software been impacted? Is there a mitigation protocol?
- What are the checkpoint controls in-place, that helps your organization monitor/identify impacted data sets?
- Are you as the human team leader making decisions or is the application making those decisions? Or is someone less familiar with the applications making the decisions?



Chapter 2. General Overview and History of Artificial Intelligence

This chapter steps back and takes a deeper look at the history of machine learning and large language models, with the focus on geoscience applications. It is intentionally more technical and intended to provide a common understanding of the mathematical and statistical framework underlying the applications and AI tools.

Historical Development

Machine learning, defined in this instance as statistical algorithms that can reveal patterns in complex, higher-dimensional data with minimal prompting, generate solutions for testing data and perform tasks without explicit instruction, is a field of computer science that began shortly after the invention of the first electronic computation devices. While its current implementation is less than a century old, it is based on probability theory and other statistical and mathematical techniques that have been in use since the 18th century. In geosciences, these foundational techniques laid the groundwork for critical methods like kriging, a statistical interpolation method formalized by Georges Matheron in the 1950s, which remains essential for resource estimation and environmental assessments. Additionally, early geophysical companies in the 1980s began using AI for oil and gas exploration, primarily for refining seismic data interpretation.

Machine learning techniques can be subdivided into four rough categories, which are described below with examples of use cases:

1. Unsupervised: Find natural clusters of data in higher dimensional problems. (e.g. estimating bedrock source from a set of surface geochemical assays).
2. Supervised: Providing a label for a data point based on training data (e.g. predicting lithology based on core-scan data at a mine, trained on historical logging).
3. Reinforcement: Determining optimal reward in a scenario. (e.g. planning a drilling campaign to maximize information gained from each drill hole).
4. Generative: Generating text or images from prompts (e.g. summarizing a geological report with a large-language model).

There is a significant push today for robust, artificial intelligence.[1] For clarity, AI is the superset of all forms of intelligent computer systems, while machine learning is a specific subset. AI encompasses the philosophy and implementation of the theoretical and practical concepts of sensing, thinking, and acting that are equal to (or surpassing) a human being. Examples such as Schlumberger's Dipmeter Advisor in the 1970s showcased early AI applications in geoscience, providing rule-based interpretations of seismic data. These early developments, although basic by today's standards, paved the way for applications in subsurface exploration and decision support systems. In the geosciences,

[1] It is important to note that there is no generally acknowledged precise definition for machine learning, with the term "AI" being even more ambiguous. (https://en.wikipedia.org/wiki/Machine_learning, https://www.ibm.com/think/topics/machine-learning)

AI and Machine Learning are often used interchangeably but serve distinct purposes depending on the problem.

Machine learning techniques that do not rely on massive computational power or datasets are still routinely applied against relatively straightforward geological problems.

Deep Learning

A more modern and flexible development in machine learning is "deep learning," which utilizes artificial neural networks. These are based on the concept of a "perceptron" which was itself modelled on biological neurons. The perceptron was invented in 1957 by Frank Rosenblatt at the Cornell Aeronautical Laboratory, consisting of one or more inputs, a processor, and a single output. Many perceptrons can be combined to form a network, represented mathematically as a tensor. The output of the final perceptron in such a network accomplishes a pattern recognition or classification task. Data are fed into the first layer of this network, with each perceptron passing information through multiple nodes to the next layer. This technique has revolutionized fields requiring feature extraction from large datasets, such as geoscience remote sensing, seismic inversion and lithology prediction. It improves upon previous techniques as it is able to make inferences from the data or identify patterns in data that have not been explicitly programmed in as decision points.

Natural Language Processing[2]

Natural Language Processing (NLP) is a sub-discipline of machine learning that focuses on enabling computers to understand, interpret, and generate human language. Recently, the addition of self-attention mechanisms, specifically the transformer architecture, to neural networks has led to the development of highly functional large language models (LLMs). These generative techniques utilize large amounts of natural language data to generate systems capable of understanding and generating text and audio. Being trained on a significant proportion of all the digital text and images in existence, the models can learn, store and later infer many of the semantic relationships contained within these data. Users interact with these models through relatively simple text or audio prompting; in general, when prompted by a user, a model generates a string of text or images with the highest probability of matching the semantic intent of the prompt. In a simplified sense, this is done by converting a user's input to a numerical vector that then operates on the model tensor to iteratively generate words or sub-tokens. Many outputs from these systems are indistinguishable from human-generated content.

In the geosciences, NLP has been applied to analyze vast amounts of unstructured text data, such as geological reports and publications. For example, researchers have utilized NLP techniques to extract meaningful semantic relationships between rock types, aiding in mineral exploration by reducing the search space for critical raw materials. Additionally, LLMs can summarize intricate geological reports, generate detailed geological maps, or simulate subsurface formations, aiding exploration and reservoir management.

[2] https://www.ibm.com/natural-language-processing, https://link.springer.com/article/10.1007/s11053-023-10216-1

Predictive Modelling and Simulation

Predictive modelling and simulation are essential tools in geoscience, helping to analyze and predict geological and environmental outcomes. By combining historical data, real-time observations, and machine learning algorithms, these methods provide valuable insights for decisions in areas like resource exploration, hazard assessment, and environmental management. For example, machine learning models like convolutional neural networks (CNNs) process seismic data to identify subsurface formations, such as hydrocarbon reservoirs or aquifers, reducing the risks involved in exploration. Similarly, combining geochemical, geophysical, and satellite data helps pinpoint potential mineral deposits more efficiently. Advanced tools like generative models can even simulate geological scenarios, offering new ways to visualize and explore subsurface structures.

Using predictive modelling isn't without challenges. The accuracy of predictions depends heavily on the quality of the data. Incomplete or sparse datasets can lead to less reliable results. Complex models, like deep learning networks, are also challenging to interpret, which can be problematic when results must be explained to others. Running these models often requires a lot of computing power, which comes with higher energy costs and environmental impacts.

Real-time Monitoring and Automated Quality Control

Real-time monitoring involves continuously observing and analyzing data as it's collected, allowing for immediate detection and response to any changes or issues. This approach is crucial in various fields, including geosciences, where timely information can significantly impact decision-making.

Real-time monitoring has been instrumental in understanding and mitigating natural hazards. For instance, developing early warning systems for earthquakes and tsunamis relies on immediate seismic data analysis. By monitoring seismic activity in real-time, scientists can quickly identify significant tremors and issue warnings to potentially affected areas, thereby reducing the risk to human life and property.

Automated Quality Control (AQC) refers to using technology to automatically monitor and assess the quality of products or data, minimizing human intervention. IBM defines AQC as leveraging artificial intelligence and automation to reduce defects and downtime, enhancing inspection processes without the need for coding.

In geosciences, AQC has been instrumental in improving data accuracy and reliability. An historical example is the development of Quantitative Evaluation of Minerals by Scanning Electron Microscopy (QEMSCAN) in Australia in the 1970s by the Commonwealth Scientific and Industrial Research Organization (CSIRO). This technology automated the analysis of mineral samples using scanning electron microscopy, providing detailed mineralogical data that was more accurate and consistent than manual methods.

By integrating automated quality control systems, geoscientists can achieve more reliable data, leading to better analysis and decision-making in their research and applications.

Operational Efficiency and Safety

Most unsupervised and supervised machine learning applications in geoscience are based upon straightforward, published and repeatable algorithms. The use of large language models present safety and efficiency concerns that may not yet be fully understood. As the frequency of use increases, the risks associated with inappropriate use commensurately increase. Critical thinking is an essential skill for accepting the outputs of large language models.

Due to the massive training cost for creation of an LLM, the models themselves are generally proprietary and not available as open source. Additionally, the complexity of their architecture makes interpreting output challenging, particularly in high-stakes scenarios like hazard assessment or resource allocation. Model outputs are generally stochastic and not generally repeatable. This can be somewhat alleviated by combining outputs from multiple prompts (with the assumption that important information will be returned more frequently in response than spurious information). However, it is important to note that model inference is not a deterministic process.

Language models for specific tasks can be based on a large, foundational model that has been trained on a very large data corpus then fine-tuned to a particular application. This involves utilizing a task-specific corpus to modify the model tensor weights through a standard training process to increase their precision when applied to particular problems. There are multiple examples in the geosciences of larger models (e.g. Google's BERT model) being trained to answer geologically specific questions (e.g. GeoBERT). This precision often comes at the cost of reduced generalization and text prediction accuracy in broader contexts.

Model outputs can be constrained through prompting to become more factual. However, it is important to note that models are simply token generators and can return believable and grammatically correct content that is nonetheless completely factually incorrect or misleading. **One should never assume that the output of an LLM is suitable for publication or distribution without thorough review.**

Most commercial models will have safety mechanisms that disallow them from returning problematic content (e.g., racist, sexist, violent, etc.). These are programmed into the model through extensive human feedback programs, which are generally only within the capacity of large commercial organizations. As such, interacting with commercial LLMs is usually safer than models without this post-training feedback.

It is also essential to consider the environmental costs of inference with an LLM. These models are run on clusters of graphics processing units (GPUs) that individually draw hundreds of watts. There is an energy and carbon cost to consider when using these tools.

Chapter 3. Ethical Considerations

All professional geoscientists are required to practice professionally and ethically. In the Canadian professional geoscience context, these governing principles are usually established in jurisdictional (provincial or territorial) regulations or bylaws as Codes of Ethics. A geoscientist is meant to interpret and incorporate these ethical principles within their daily decision-making situations in a dynamic manner, responsive to the needs of the situation.

“Professional ethics are more than a minimum standard of conduct; but rather a set of principles which should guide geoscientists in their daily work and relationships.”[3] In all cases the Codes of Ethics require the professional to be responsible for their work and to ensure that they are meeting their duties to protect the public, the profession, their clients, and their employers.

The use of AI can take many different forms and is becoming commonplace. While it is generally considered to be greatly beneficial within professional practice, AI tools are evolving rapidly and there are potential risks. It is critical that professional geoscientists consider the ethical (as well as legal) implications when using these tools in light of the uncertainties.

The following discussion is largely around the professional geoscientist in technical practice, as that is more of a typical career path. Specific impacts of using AI for the professional geoscientist in managerial practice follow this section.

The Professional Geoscientist in Technical Practice

Professional Responsibility

A professional geoscientist must “…Be accountable, honest, and act responsibly and with integrity.” As such they must maintain responsibility, accountability and liability for their professional work, regardless of which tools they use. Having the ability to verify and test answers to ensure that their derivation is understood and ensuring the results meet the requirements of professional practice is fundamental to being a professional.

Therefore, when relying on AI tools in exercising their professional practice, a professional geoscientist needs to identify and understand the risks associated with the use of AI tools and manage or mitigate those risks. An important check is to verify the AI results, or a subset of them, by deriving those results through another means, including additional realizations or varying the algorithms. Relying on a singular approach to a result is rarely accepted as good practice.

This concept extends to the use of AI. Can the answer be independently derived by other means? This is an important test and would be expected by a peer reviewing the work of another professional. Regardless of all attempts to confirm results, the responsibility for the work remains that of the professional who conducts the activity. The responsibility for a wrong answer or a fault cannot be delegated to others, nor can it be diminished by identifying a faulty tool or calculation. The use of AI to

[3] Ethical Considerations in the Professional Practice of Geoscience Geoscientists Canada Board Approved June 4, 2022 https://geoscientistscanada.ca/source/2022/20220604%20FINAL%20Ethical%20Considerations%20in%20the%20Professional%20Practise%20of%20Geoscience.pdf

develop an answer does not absolve the professional of the responsibility for that answer if it is used in professional work and relied upon by others.

The professional geoscientist's obligations also extend to knowledge of the federal and provincial/territorial privacy and data usage laws of their jurisdiction, and of their organization's policies and procedures.

Competency

A professional geoscientist has an obligation to "…Undertake and accept work, and provide opinion, only when competent to do so by knowledge and experience." This can be interpreted as a requirement to be competent within their area of practice, which includes a requirement to stay current with the evolving tools and technology that are relied upon in their professional practice. If a professional geoscientist does not have the competency to identify, understand and manage the risks associated with the use of AI tools within their practice, then those tools should not be used.

A geoscientist who is competent in AI in general will be able to explain the fundamentals of AI, how AI-based tools are created and evaluated, the critical regulatory and ethical issues of the AI-based tools, and the current and emerging roles of AI in geoscience. While the details of the calculations and algorithms being applied may not be fully mastered, understanding the degree of certainty and the limitations of the results must be the starting point for the professional's use of AI-based tools. Technical "wizardry" and professional competence are not the same. Effective communication of the assumptions and uncertainties is critical.

Risk Factors

As emphasized within each jurisdiction's Code of Ethics, a professional geoscientist is to hold paramount the safety, health and welfare of the public and protection of the environment. When applying new technologies, such as AI, any potential risks to public welfare or environment would need to be evaluated. Potential risk factors associated with the reliance on AI tools and technology that a professional geoscientist is ethically obligated to consider may include:

a. **Transparency and Explainability** - The underlying processes behind AI algorithms are complex and the results are not always intuitive (i.e., "the black box"). This lack of transparency on the part of the AI tool has the potential of eroding the public's trust in the Professional Geoscientist. It is the role of the Professional Geoscientist to maintain the public's trust by disclosing AI usage, assumptions, methods and a measure of confidence when presenting results generated by AI. It is crucial for geoscientists to be able to ensure the transparency of the methods used and the explainability of results derived from AI tools to their clients and other stakeholders. How does the professional geoscientist manage "noise" or potential biases in massive datasets to ensure objective and substantiated conclusions?
b. **Reproducibility** - Reproducibility is paramount to good science. The use of AI is no exception to this cornerstone of science. Changes in AI algorithms, parameters and training sets can lead to varying results. The application of AI is rapidly evolving, including methods to enhance and quantify reproducibility of AI results. The application of AI by a competent Professional Geoscientist that is knowledgeable in AI best practices should decrease the variance between AI produced results.

c. **Biases** - Biases could be inherited from the training data into the AI model and could lead to skewed results and have an effect on interpretations and decision-making. It is the responsibility of the Professional Geoscientist to recognize any potential biases (or discuss with the developer), their potential impacts and mitigate them if possible, or at minimum, disclose them to the public or client.

d. **Accuracy** - A Professional Geoscientist is ultimately responsible for the final work product, including any results produced by AI. Accuracy and relevance are both essential for domain-specific Subject Matter Expertise (SME). Professional Geoscientists are the SMEs who can bridge the gap between AI capabilities and real world applications to provide domain-specific insights. AI hallucinations or erroneous results are well known to occur within generative AI's, and all AI-generated results need to be fact-checked by the Professional Geoscientist responsible for the piece of work.

e. **Data Security and Confidentiality** - Robust measures to ensure the security and confidentiality of sensitive digital data (geological, geophysical, drilling) are needed for collection and storage, especially when hosted on cloud platforms. The duty of confidentiality extends to digital data, and the risks of cyberattacks or leaks are real.

f. **Intellectual Property** - The training data for an AI may not all be publicly available information and could include proprietary data, copyrighted information or other's intellectual property that is owned by a third-party. Legal advice may be needed to determine any legal ramifications for the use of this information within AI models. In addition to understanding the data that is used to train a system, reference or attribution of the source of the results should be included with any form of presentation of those results. Referencing the use of an AI program should be disclosed and referenced. Presenting it as professional work without reference or attribution could be construed as plagiarism.

g. **Judgement** – AI cannot completely replace professional judgement or human decision making. AI is limited by the information to which it is exposed. AI may fail to appropriately incorporate the ethical, moral and other intangible human factors that are required to make informed decisions. In addition, research shows that AI designed to mimic human decision-making sometimes results in overly conservative or harsh outputs.

Disclosure

Although currently there are few explicit requirements or guidelines on the disclosure of AI-generated results, the professional geoscientist should still apply general best practice guidelines as outlined by the Code of Ethics and bylaws of their jurisdiction. The principle is to "….acknowledge limitations to knowledge and understanding in the field of geoscience." This is summarized as "The geoscientist must present professional opinion and counsel to any recipient in the context of the limitations to knowledge and the uncertainty in the field of geoscience, and the resulting effect on the work product and the counsel provided. As part of the work product, the stakeholder is to be informed by the geoscientist, in simple but accurate language, of the limitations to knowledge and the potential implications to the work product." Any disclosure of AI-generated results, at a minimum, includes:

a. State **authorship** by the professional geoscientist who supervised the work and assumes responsibility for the disclosure, including any AI-generated results. AI cannot be an author or be held responsible for any disclosed results.

b. State key **assumptions**, parameters, methods and limitations used to generate the AI results. AI is a tool that is treated like any other third-party software, and any results must be accurate and reproducible. An example of a limitation includes the use of proprietary information in the training of the AI model.

c. Document any potential **risks** associated with the application of any AI-generated results, including potential biases, lack of transparency, lack of repeatability and issues associated with privacy and intellectual property.

Other ethical requirements for the professional geoscientist to consider in this regard include the requirements to "Distinguish facts and observations from interpretations, and explicitly state any assumptions, when reporting or presenting". This is explained as "The geoscientist may rely on data, facts, and observations provided by others or may generate this information independently. These data, facts, and observations are used to produce the professional opinion, work product, or report. The source of facts, observations, and potential interpretations relied upon in carrying out of the geoscientist's assignment must be clearly identified".

The Professional Geoscientist in Managerial Practice

When the role of the professional geoscientist includes managerial responsibilities, additional risks arise. Many of these risks are around personal (individually identifiable) data and include:

- Failure to understand the conditions under which an application functions: for example, the automatic incorporation of personnel (group) data into the application's training dataset, where it is available to all subscribers. This may be in violation of the data privacy legislation of that jurisdiction as well as organizational policies.
- Providing an individual's data to third-party background checking organizations. Is the data you provided being sold to other clients? Is the personal data provided being used to inform the background checks for others? In either case, is this transparent and fully disclosed to the applicant? Does the applicant understand that they are under no obligation to provide a Canadian social insurance number? The Office of the Privacy Commissioner of Canada is the entity that launches investigations into compliance.
- The inadvertent usage of personnel applications and datasets that have embedded biases – for example, in recruitment when using AI to reduce the number of applicants. This leaves the professional geoscientist open to missing qualified applicants, and vulnerable to biased recruiting concerns.
- The usage of Large Language Models to write employee evaluations, provide references to employers or validate work experience for professional registration. Large Language Models are just that – they are not and have never been intended to accurately represent a discrete human being. Typically, Codes of Ethics contain directions that professionals shall conduct

themselves with fairness and honesty. Recommended best practices would preclude using inappropriate applications for these purposes.

Practical Suggestions for Ethical Considerations

Adhere to an Ethics Framework – Ethics Checklist

- Refresh on professional ethics generally by reading your regulator's Code of Ethics. Reach out to the regulator for clarity if needed.
- Subscribe to free newsletters from trusted organizations or review website postings. Caveat – not all AI websites themselves adhere to ethical standards. Ethical norms do change with technological advances.
- Access publications on AI ethics and geoscience practice.
- Be transparent about the AI tools and outputs used (detailed disclosure).
- Engage with stakeholders and communities.
- Adhere to professional and scientific standards.
- Check for and address the biases and limitations in AI systems.
- Promote sustainable and responsible use of AI technologies.
- Be mindful of critical thinking and the practical real-world experience gained over time to guide younger tech experts.

Committee members from Ontario. Home of the Frontenac Axis, a UNESCO bioreserve.

Chapter 4. Education and Training

Geoscientists are inherently continuous learners. The fields of machine learning and AI don't traditionally comprise a majority of continuous professional development (CPD) offerings in the geosciences, though both the field in general and its application to the geosciences are evolving at a remarkable pace. In order to utilize AI tools and technology in a beneficial and ethical manner, training and education should include a foundational understanding of how AI works, its application within geoscience practice, ethical considerations (see Chapter 3) and the practical skills to implement AI tools responsibly. Some Canadian geoscience programs may now include education and training on AI technology; most geoscientists learn of the benefits and consequences of utilizing AI during the course of their professional career.

When seeking out AI training sources, geoscientists should ensure that the training sources come from reputable institutions that offer high-quality, peer-reviewed content, with instructors who are industry professionals or come from industry partnerships. Examples include (but are not limited to): Coursera, edX, Udemy, Microsoft Learn, Amazon Web Services, LinkedIn Learning, and DataCamp. These platforms regularly update their content and have reviews and ratings to help maintain quality and provide feedback for improvements.

Geoscientists could also look for opportunities to engage in community discussions and network with others in the field. Once the basics have been mastered, geoscientists can elevate their knowledge through on-the-job learning via projects.

Understanding Usage Limits

Before engaging in the use of AI technology within geoscience practice, geoscientists should familiarize themselves with any legal, regulatory or employer limitations regarding the use of AI. Government, regulators and employers may have rules or guidance on the appropriate use of AI technology and geoscientists must be aware of and adhere to these limitations. For example, the Federal Government provides an online Guide on the Use of Generative Artificial Intelligence (https://www.canada.ca/en/government/system/digital-government/digital-government-innovations/responsible-use-ai/guide-use-generative-ai.html).

Before AI and Large Language Models, there was Math

AI Knowledge Fundamentals

To gain a foundational understanding of how AI tools work and their potential applications in the geosciences, it is important to grasp several key concepts, techniques, and knowledge areas.

The basics of AI encompass a variety of concepts and techniques, supported by a strong foundation in mathematics including linear algebra, probability and statistics, calculus and optimization.

Historically, these topics have not always received much attention in undergraduate science programs. Aside from many textbook and classical references, popular publications provide entry-level (and entertaining) applied statistics education. Such publications include A Field Guide to Lies – Critical Thinking with Statistics and The Scientific Method, and Algorithms to Live By – the Computer Science of Human Decisions (both listed in References).

The fundamental AI workflow begins with data collection and processing including data cleansing, feature engineering and normalization/standardization. The processing applied to this data include machine learning (learn from data to make predictions or decisions), deep learning (subset of ML using neural networks), Natural language processing (use of machines to understand, interpret and respond to human language), and computer vision (interpret and analyze images and videos). To generate results, techniques employed may include supervised learning (from labeled data), unsupervised learning (unlabeled data), semi-supervised learning (combination of labeled and unlabeled data), reinforcement learning (learning through the interaction with environment), and generative models (creation of new data including images).

By understanding the fundamentals, geoscientists can better appreciate and leverage the power of AI in their field. The intersection of AI and geoscience offers exciting opportunities for innovation and advancement.

Before Math, there were Rocks

Ground-truthing

The next section, Applications in Geoscience, covers the geoscientific advances made possible by Large Language Models and AI in general. These are major advances which are transforming the field. Restating the old dictum the "best geologists have seen the most rocks" is a humble reminder of the importance of ground-truthing – literally! In a world that is increasingly remotely-sensed, nothing compares with the experience gained through real life, hands-on examination of outcrops, drill cores, samples, thin sections – and simply walking different terrains and terranes. The best best-practice of all is to gain and develop this experience. The development of an innate ability to assess for reasonable answers and make informed decisions for the most appropriate applications is critical to fully utilizing the power that AI tools bring to a project.

Applications in Geoscience

There are a variety of applications of AI technology within the practice of geoscience. The following are examples of how geoscientists might use or incorporate AI into their professional work:

- Text and Image Generation/Recognition – AI can both produce and recognize text and images based on inputted data.
- Design and Modelling – AI can optimize design and modelling by using generative algorithms and simulations that are based on specified constraints and objectives. This can enhance the entire design process, from ideation to implementation.
- Predictive Maintenance – AI can anticipate and therefore prevent failures in facilities and equipment, which results in optimized operation, reduced downtime, and improved performance.
- Quality Control and Inspection – AI can identify and classify defects, anomalies, or deviations from desired specifications using visual automation.
- Process Optimization – AI can analyze data and identify patterns to improve efficiency and reduce waste in several applications, such as supply chain management and energy consumption.
- Summarization – AI can summarize large volumes of text or information from one or more sources. For example, AI could summarize text from several sources on the Internet.

Applications from (Practice Advisory: Use of Artificial Intelligence (AI) in Professional Practice Engineers and Geoscientists British Columbia Version 1.0, November 22, 2024). Used with permission from EGBC.

Practical Suggestions for Education and Training

Continuous Training and Upskilling

- Take online courses and certifications for your skill level; look for reputable institutions with peer-reviewed content and instructors who are industry professionals.
- Attend industry-specific conference sessions, workshops, webinars, and luncheons by your local or national geology, geophysics or related disciplines, such as engineering organizations (i.e., regulators, CEGA, AAPG, SPE, PDAC).
- Partner with data scientists within your organization or field.
- Read and share interdisciplinary research papers or online articles that discuss AI-driven geoscience projects most applicable to task at hand.
- Locate professional communities and networks to stay up to date on trends and tools in the field.
- Develop risk awareness of the major benefits and common pitfalls as base knowledge.

Engage in Interdisciplinary Collaboration

- Co-develop projects with AI driven solutions for geoscientific problems.
- Create cross-departmental curriculum and promote joint research programs in universities.
- Include data scientists as team members for committees and working groups.

Chapter 5. Human Oversight by Licensed Qualified Professionals

Artificial intelligence is a tool to complement humanity, not to replace it. Geoscientists have the opportunity to lead by example through responsible and transparent integration of humans and AI. The judicious and planful usage of AI tools enables geoscientists to manage vast amounts of data in a short timeframe, recognize trends that couldn't be seen by a human, provide data-driven insights and even run through predictive models to compare environmental impacts.

AI reduces the need for highly trained professionals in many disciplines to spend much of their time doing tedious, repetitive work – which is often not done that well, because it is tedious and repetitive. For example, in the accounting profession, AI tools are now used to examine the accounting information that supports financial statements and to flag anomalous entries for further review. The accountant's time can then be spent investigating more of the red flags (fraud, money-laundering?) than wading through office supplies invoices.

As with any powerful tool, AI has to be applied properly and mindfully. Human oversight is now a widely used term; in this document it applies to a licensed professional working within their scope of practice. Human oversight ensures that AI systems are operating in ways that are "transparent, accountable and aligned with human values". https://www.cornerstoneondemand.com/resources/article/the-crucial-role-of-humans-in-ai-oversight/.

Human oversight is the necessary step to show that proper verification protocols have taken place by a registered and qualified professional, whether that person is a professional geoscientist or registered in another profession. This oversight is a major component of the quality control and technical review process generally and should occur at all stages of a project. Oversight becomes even more vital when AI tools are employed, as it serves to add layers of human reflection/perspective, verification regarding the outcomes (anticipated vs. actual), and checks for inherent bias.

Human Oversight by early-career Geoscientists

Early career geoscientists not only bring fresh skill sets, they also bring fresh insights. Even at an entry-level job stage, their oversight has considerable value. Their role in human oversight is often that of seeing what no one else has seen or has simply taken for granted. These geoscientists may not yet be fully licensed, so are working under the supervision of a registered professional geoscientist. They are still developing experience in ethics and professionalism along with their technical skills, such as critical thinking.

Human Oversight by mid-career Geoscientists – both Technical and Managerial Roles

Mid-career geoscientists have gained considerable experience, had exposure to a variety of projects and are well positioned to influence the usage and adoption of AI tools. At all junctures, with or without direct reports, the best practice for your human colleagues is encouraging open dialogue and shared learning to bridge gaps in AI familiarity. The mid-career professional can have a key role in providing ongoing training and resources to empower professionals at all levels of expertise. AI tools are changing the scientific landscape hourly.

The mid-career geoscientist is close to the data being used for the project or work and needs to be familiar with the inner workings and appropriateness of the AI tools. For instance, checking on the "data-cleaning" may result in staff mutterings about "down in the weeds". However, more than one data anomaly has resulted in significant mineral and hydrocarbon discoveries, while many others have represented false positives which presented expensive failures for the company.

Professional geoscientists frequently work as part of, or as leaders of, a project team. The team will likely be multi-disciplinary; comprising professional engineers, accountants, lawyers, biologists, etc. The team will be engaged in critical minerals exploration, energy project development, groundwater aquifer delineations, perhaps declarations of reserves and resources, construction of infrastructure or other industrial applications. Both the professional geoscientist as technical specialist and as manager will have roles. All the registered professionals will be operating under the Codes of Ethics and Guidelines of their own regulatory organizations regarding the use of AI and the technical and ethical requirements.

The project managers and team leaders will be relying upon the work of others and making outsourcing decisions. Many geoscience regulators have specific Standards for these situations. Best practices would involve an AI due diligence plan constructed by the discipline leads for their scope of technical expertise. One consideration is to delegate a staff member as the AI Auditor who is responsible for documenting and tracking the applications used, any modifications to the applications, ensuring that the data and datasets are clean and legitimately in use.

Practical Suggestions for the Multi-Disciplinary Collaborative Environment

Maintain Transparent Communication of AI results

- Document data source provenance and quality, preprocessing and cleaning steps, and if possible, provide access to datasets.
- Document algorithms details, methodologies employed, hyperparameters and tuning applied, and assumptions.
- Communicate model confidence, assumptions and uncertainty.
- Provide AI results in a manner that is accessible for nontechnical stakeholders in plain language reports and visualizations.
- Address ethical concerns and social or environmental impacts and how they can be managed or mitigated.
- Maintain versioning so model changes can be tracked over time.

Human Oversight by advanced-career Geoscientists

The senior geoscientist or the one who "signs off" has always been, and continues to be, responsible for the work products. Depending on the technical nature of the work and the background of the team/author(s), the level of senior review required will vary. However, the senior review should be undertaken by a professional geoscientist with the appropriate knowledge, skills and experience related to the specific AI tools involved (i.e., within their scope of practice). This is an opportunity for those who have deeper knowledge of AI to gain mentoring experience.

Technical Oversight

The main elements requiring senior-level technical oversight can be considered in tandem with the chapter on Ethical Considerations and the embedded practical suggestions. These elements with their attendant checkpoints are:

The Data: provenance, legitimate usage, ownership issues, free from misinformation (deliberate or accidental), confirmation that the data usage and documentation protocols are robust.

The data collection process may have resulted in inherent biases that need to be considered and acknowledged.

The data should never be used to coerce or force something to occur in relation to financial gain or for personal belief or disposition. For example, purposely building a bias into a data set to influence potential investors and inflate the value of something. Likewise, the outputs of an AI tool should not be improperly obtained or misconstrued so as to influence public policy or mindsets.

The algorithms/AI tools: transparency, traceability, unbiased, repeatability, versioning, legitimate usage of the commercial tools, knowledge and approval of code modifications.

The output: reasonable, as expected, repeatable, aligned with previous outcomes (e.g. the reserves math from one year to the next reconciles), consistent with geoscientific principles and accepted practice. There must be a proper model validation pipeline.

Managerial oversight

In addition to the responsibilities already covered, there is the issue of becoming inadvertently enmeshed in money-laundering and financial crime by external organizations.

The registered professional must be educated in, and cognizant of, the potential for financial crime and money-laundering, both of which have become much easier with the generation of fraudulent data and documents. In the petroleum industry for instance, this may involve vetting of potential Joint Venture partners in collaboration with the project landman to ensure that the potential partner organization is real and not a well-perpetuated fraud facilitated by AI-generated Board profiles and photographs, Annual Reports and financial statements.

Practical Suggestions for Human Oversight

Develop Feedback Mechanisms and Protocols

- Incorporate routine oversight procedures into the standard project workflow.
- Conduct AI model trials with multidisciplinary teams to gather domain expert knowledge on the accuracy of the model, allowing for iteration and adjustment before full deployment and subsequent disclosure.
- Perform continuous or phased monitoring of AI model results against established metrics.
- Document feedback and iterations.

Conclusions

This document was written to support the ethical, highly-skilled practice of the Canadian Professional Geoscientist as they move through their career from new registrant to advanced career professional. Most of the language is intentionally accessible so that practitioners in other fields such as accounting, human resources and law will better understand the dynamic AI-geoscience ecosystem and the changes that are occurring in daily practice.

Professional geoscientists are lifelong learners and adventurers, from our early days of swatting mosquitoes in field school to our retirement days of swatting mosquitoes on hiking trips. Artificial intelligence tools are here to enhance our learning journey, not to shortcut it. At every juncture of our careers, we have the opportunity to develop critical thinking, pattern recognition and geological confidence in our work whether that involves rocks, digits or tokens. Artificial Intelligence tools are now part of that learning journey. Although not yet sufficiently developed for inclusion in this document, agentic systems and reasoning models are two of the next steps on that journey.

Our understanding of the potential applications of AI tools to geoscience is growing. Powerful AI tools will enable better and faster groundwater modeling, facilitate resource development with reduced environmental impacts and aid in shoreline erosion planning and mitigations. Highly challenging collaborative projects such as AI-enhanced subsurface infrastructure mapping, predictive modeling of deep disposal well waste plumes and subsurface sequestration imaging are examples of essential projects that would take years without AI capabilities.

The stewardship of AI should not be left solely to those in programming, IT, or cybersecurity. While their contributions are vital, they are often closest to the code, not to the professions or communities that will feel its long-term impact. Just as we wouldn't expect someone outside geoscience to lead decisions on geological risk or field protocols, AI must be informed by a broader community. This includes engineers, geoscientists, ethicists, and those with lived and public experience.

Ultimately, the practice fundamentals of professional geoscientists remain the same: protection of the public and the environment, skilled practice within one's scope of expertise, integrity and honesty, compliance with the law and upholding the ability of the profession to serve the public interest.

Committee Members all the way to the West Coast: Sidney Harbour, British Columbia.

Glossary of Common Terms and Acronyms

AI - Artificial Intelligence: Simulation of human intelligence in machines which enables them to perform tasks such as decision making and problem solving.

ACQ - Automated quality control.

Bias - Systematic error in AI models that results in unfair or inaccurate outcomes due to flawed data or assumptions.

CNN - Convolutional Neural Network – a particular type of artificial neural network that recognizes patterns in images or other grid-like data. It is used primarily for image recognition and processing.

DL - Deep Learning: A type of machine learning with neural networks that model complex patterns in data.

GMM - Gaussian Mixture Model; used in unsupervised machine learning, financial models, etc. Can be used for cluster geological data points, for tasks like mineral classification or identifying different types of rocks or soil compositions.

Hallucinations - When an AI model generates content or predictions that seem coherent but are factually incorrect or nonsensical, common in generative models like GPT.

LLM - Large Language Model. This is a type of AI model designed to receive human language text inputs, train on massive amounts of these inputs, process by learning patterns and relationships and then output human-like text.

LM - Language Model. Simply a statistical model that analyzes text data and predicts a sequence of words occurring next.

LNM - Large Nature Model. This is a generative model focused solely on nature.

ML - Machine Learning: A subset of AI focuses on algorithms that enable systems to learn from data without being explicitly programmed.

NLP - natural language processing. This is a multi-disciplinary field of artificial intelligence behind for example, chatbots. It enables computers to interpret, respond to and generate human language. Except for "I want to speak to a REAL PERSON".

Prototyping - literally, the process of building a prototype. In this case, robust, reliable commercial-grade applications that may or may not use AI-assisted coding to speed up development.

RAG - Retrieval Augmented Generation; framework for retrieving facts.

Scraping - the process of scavenging data from online resources and websites, usually using automated tools. These data are then stored for later use e.g. In your Netflix profile.

Sycophancy: when the responses of a large language model start to become increasingly and overly aligned with the user's point of view – even when that viewpoint is demonstrably false or harmful. Also called "glazing".

Token - this is the Lego building block of AI. It's a fundamental unit of text processed by models like those used in large language models. "Text" can be words, segments of text, syllables, characters or even punctuation. Tokens are the smallest units of data.

Reasoning Token - Reasoning models use reasoning tokens to break down the query or prompt so that the model can consider using multiple approaches to generating the response. Basically to "think" about the response.

Training Data - A dataset is utilized to train a machine learning model, enabling it to acquire knowledge and make predictions.

VAD - voice activity detection (e.g. "Alexa, turn up the volume.")

VAE - variational autoencoder; an artificial neural network architecture.

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Educational Resources: quality, low- or no-cost resources that can be accessed online.

Amazon Web Services https://aws.amazon.com/free

Coursera www.coursera.org

DataCamp www.datacamp.com

Deep Learning, AI newsletter. Principal: Andrew Ng. Free newsletter, fee-for-course offerings.

https://www.deeplearning.ai/

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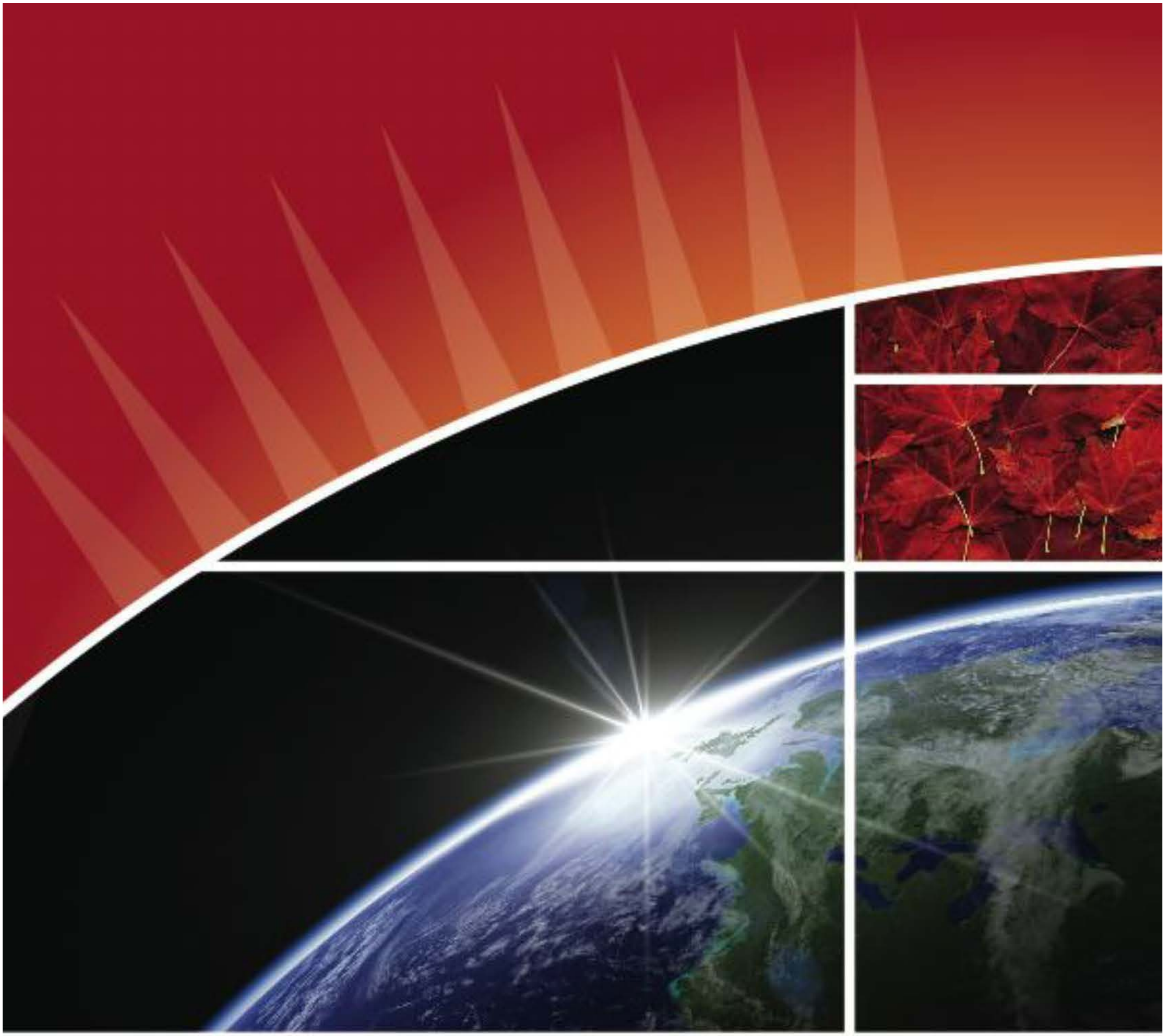

GEOSCIENTISTS GÉOSCIENTIFIQUES CANADA®

T: 613-499-2586
info@geoscientistscanada.ca
#300, 55 Metcalfe Street
Ottawa ON K1P 6L5
www.geoscientistscanada.ca