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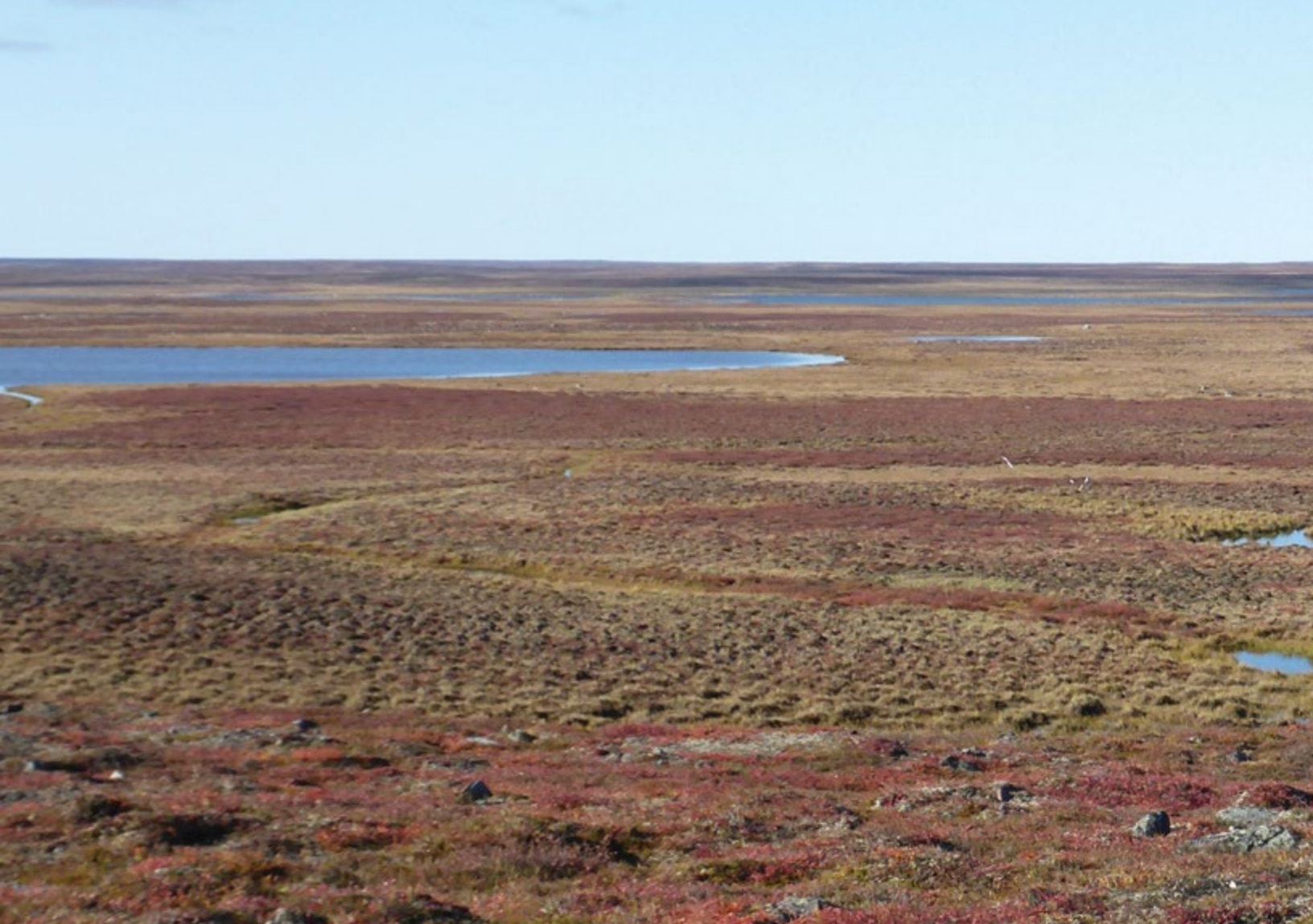
Ressources naturelles  
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Canada

# Geological Survey of Canada

**Year in Review:  
2021–22**





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Geological Survey of Canada

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# Foreword

As the Director General for the Geological Survey of Canada (GSC), it is a privilege to present this first *Geological Survey of Canada Year in Review* report, a snapshot report of select scientific accomplishments in 2021–22. These Year in Review reports will highlight the GSC’s achievements and provide a few key illustrations of its geoscience activities and products, while additional information presented in the companion report [Year in Review \(supplemental report\): 2021–22](#) will serve as one of many public records of organizational accountability and transparency for the people in Canada. As part of Natural Resources Canada, the GSC has been entrusted by the Government of Canada with a growing list of priorities and programs to serve the public good that are continually updated and renewed to align with national and global needs. By undertaking priority geoscientific activities and providing authoritative research results, GSC programs are designed to support the sustainable and inclusive economic development of northern and remote communities, inform sound decision-making for land use both onshore and offshore, protect the environment, and reduce risks from natural disasters and climate change.

This report provides an overview of key GSC activities in the 2021–22 fiscal year. During this time, the world had entered its second consecutive year of a global pandemic, and the GSC was not immune to the uncertainty and challenges to traditional ways of working. We continued to underscore the importance of supporting and celebrating the human side of science—both within the GSC and with our collaborators—as exemplified by the resiliency, creativity, and fortitude of the people dedicated to advancing and promoting geoscience in Canada and around the world.

Faced with restrictions to in-person interaction, whether with coworkers in regional offices, international colleagues at remote study sites, or community partners in the Arctic, staff across the GSC were asked to continue adapting and evolving to ensure that the GSC delivers world-class geoscience. As with all challenges throughout our long history, our people rose to the occasion. Scientists devised creative alternatives to fieldwork, collaborating with colleagues across the country to write synthesis papers and bulletins, and drawing from physical sample collections and data obtained over many decades to apply to new research directions and to analyze with new tools and methods. Managers kept teams motivated and engaged while consulting on the future of hybrid work. Administrators scheduled and rescheduled thousands of virtual meetings while staff across the country grappled with changes in their family routines. And while guiding the organization through daily operations, GSC executives also started shaping the next phase of federal geoscience by laying the groundwork for the GSC’s *Strategic Plan 2023–2028*.



During this challenging time, the essential attributes of perseverance and dedication were embodied in collaborative projects with rural and Indigenous communities in Canada's North. Scientists and community members worked together to face complex and ever-changing logistical challenges with agility, endurance, and determination, while ensuring project success and forging ever-stronger bonds.

In 2021–22, the GSC also strengthened relationships with our provincial and territorial Survey counterparts. The National Geological Surveys Committee, with members consisting of the GSC and Canada's other 12 provincial and territorial geological survey organizations, formalized an approach to coordinate and integrate public geoscience activities with the launch and ministerial endorsement of the [Pan-Canadian Geoscience Strategy](#) in February 2022. With five distinct priority areas, this strategy supports a long-term vision to foster greater efficiency and innovation in geoscience by advancing framework geoscience, making geoscience data more readily available and interconnected, and enhancing geoscience training and literacy in Canada.

The GSC has always celebrated cooperation and shared geoscience knowledge, and the string of cancelled in-person events in 2021–22 did not change this paradigm. Across Canada, GSC staff championed GSC geoscience virtually at the International Online Workshop on Mineral Chemistry in Systems with IOCG, IOA and affiliated Critical Metal Deposits, with more than 360 participants from 34 countries; participated in the annual Québec Mines + Energy conference, with over 1,000 participants and more than 120 events; and co-hosted the inaugural Critical Minerals Mapping Initiative Forum, to name but a few events.

The GSC continues to be a world leader in geoscience because of its people. I am proud of the adaptability, perseverance, and passion of all GSC staff and look forward to another year of excellence in multi-partner collaboration to achieve positive outcomes for Canadians and the world.



Daniel Lebel  
Director General  
Geological Survey of Canada



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# Report overview

The Geological Survey of Canada (GSC) is Canada's national organization for public geoscience information and research. As an integral part of Natural Resources Canada's (NRCan) Lands and Minerals Sector (LMS), the mission of the GSC is to provide authoritative and cutting-edge geoscience information across Canada for the benefit of all Canadians.

GSC geoscience is cross-cutting, linking programs and services across the organization to provide integrated and relevant knowledge, tools, and data to stakeholders ranging from academia and industry to Indigenous groups, Canadian provincial and territorial surveys, and international collaborators. In this annual *Year in Review report*, information on GSC geoscience is broadly classified into the following focus areas:

- [Minerals](#) (page 9)
- [Geoscience for the North](#) (page 12)
- [Climate change](#) (page 15)
- [Marine and coastal](#) (page 18)
- [Hazards and public safety](#) (page 22)
- [Groundwater and aquifers](#) (page 24)
- [Energy resources](#) (page 27)
- [Geoscience tools and data](#) (page 30)
- [Laboratories and collections](#) (page 33)

Underpinning the geoscience at the GSC are the fundamental principles of:


- [National and international science policy collaboration](#) (page 36)
- [Staff and organizational support](#) (page 39)

[Annex 1](#) contains a description of each of the 2021–22 GSC geoscience programs and services. Additional information on the GSC's projects and activities, departmental reporting obligations, and contacts is available in the complementary annual [Year in Review \(supplemental report\): 2021–22](#).

Through the provision of directed geoscience, the GSC continues to help ensure that Canada's lands and offshore natural resources are managed effectively and sustainably according to the best scientific knowledge, and to help keep Canadians safe.

For more information on the GSC and its geoscience, visit us on the web or follow us on Twitter at [@GSC\\_CGC](#).

See our previous annual reports [here](#).



# Geoscience at the Geological Survey of Canada

## The GSC in the 21<sup>st</sup> century

The GSC is underpinned by the principles of the Government of Canada's [Values and Ethics Code for the Public Sector](#), as well as scientific excellence, with five fundamental pillars:

- Respect for Democracy
- Respect for People
- Integrity
- Stewardship
- Excellence

The GSC uses cutting-edge research methods and technologies to develop geoscientific information that can be used to address urgent challenges for Canada and Canadians such as adapting to climate change, managing risks from natural hazards, and building competitive and responsible mineral and energy supply chains.

The GSC embodies strong communication and collaboration, which is the foundation of how we work. To ensure that our research is easily found, used, and understood by the people who need it, we must manage our data, communicate our science, and engage with potential science users effectively. We can also create important synergies by collaborating with other parts of the federal government, provincial and territorial geological survey organizations, academia, industry, Indigenous organizations and communities, non-governmental organizations, and trusted international partners.

Regardless of the geoscience topic, big data and powerful new predictive tools are empowering increasingly sophisticated numerical models of the Earth's complex air, land, and water systems. The GSC is leveraging these cutting-edge approaches, continually redefining the art of the possible—as in the case of the [Canada1Water](#) project. In the spirit of social justice and reconciliation, the GSC also aims to be at the forefront of inclusive growth, collaboration, and co-creation with communities, as well as a champion of collaboration with and between provincial and territorial geological survey organizations.



Every year, the GSC publishes hundreds of maps, Open Files, peer-reviewed papers, and other reports. GSC scientists are recognized worldwide and sought after for their expert advice on locating mineral, energy, and groundwater resources, reducing risk from natural hazards, and reviewing environmental assessments.

Finally, science is ultimately a human endeavour. Scientific excellence relies on skilled scientists, and the impact of that science relies on potential users knowing that it exists and their ability to find and apply it. The GSC's fundamental organizational principles and supporting priorities aim to address these areas.

As a distinguished part of Natural Resources Canada (NRCan), the GSC publishes in NRCan's **GEOSCAN** bibliographic database.

GEOSCAN features over 90,000 publication records, from maps and bulletins to scientific presentations and general information products. GEOSCAN also contains records of external publications authored by NRCan scientists and specialists or supported by NRCan.

GEOSCAN also provides links to publications available online or free download, as well as information on NRCan programs.





## GSC strategic priorities

The GSC provides support to the [Minister of Natural Resources](#), as well as to other Ministers, to help meet objectives outlined in their [mandate letters](#), horizontal interdepartmental priorities, international processes, and federal geoscience commitments.

As Canada's national geoscience organization, the GSC develops geoscience knowledge and tools in support of its federal mandate, constantly evolving, innovating, and adapting to new scientific advances and changing federal priorities.

To fulfill its departmental reporting requirements and guide its programs and services, the GSC develops a Strategic Plan every five years. The [most recent Strategic Plan](#) identifies five key priorities for 2018–2023, along with related initiatives to support implementation of the priorities.

The GSC's strategic priorities for 2018–2023 are:

1. [Geological knowledge for Canada's onshore and offshore lands](#)
2. [Geoscience for sustainable development of natural resources](#)
3. [Geoscience for keeping Canada safe](#)
4. [Geoscience for society](#)
5. [Our science, our people](#)





## GSC programs

The GSC delivers its geoscience through 15 main programs and initiatives. Program and project architecture is designed to address the priorities outlined in each cycle of the GSC's Strategic Plan. Programs and plans in this report are aligned with the 2018–2023 Strategic Plan, while programs and plans from 2023 to 2028 will align with the 2023–2028 Strategic Plan, published in early 2023.

For an overview of the GSC, check out our [short video](#) showcasing the breadth and variety of geoscience at the GSC.

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### **STRATEGIC PRIORITY 1: Geological knowledge for Canada's onshore and offshore lands**

#### **Geo-mapping for Energy and Minerals-GeoNorth (GEM-GeoNorth):**

Producing and providing new, public geoscientific data, knowledge, and maps for northern Canada. The focus of this program is on areas where economic and/or infrastructure development is likely to benefit northern communities. GEM-GeoNorth will incorporate complementary climate change research into studies to enhance our understanding of the rapidly changing environments, landscapes, and coasts in the North, and how to mitigate these changes.

**Canada in 3D (C3D):** Developing a national surface and subsurface compilation of data and information in a way that empowers the development of 2D and 3D maps at a national scale, and allows users to download aggregated and complex datasets in a way previously unavailable.

**United Nations Convention on the Law of the Sea (UNCLOS):** Fulfilling the Government of Canada's obligation as a signatory to the United Nations Convention on the Law of the Sea (UNCLOS) to define its national boundary at the sub-sea continental shelf beyond 200 nautical miles using robust scientific data.

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### **STRATEGIC PRIORITY 2: Geoscience for sustainable development of natural resources**

**Targeted Geoscience Initiative (TGI-6):** Providing innovative public geoscience to help the mineral exploration industry identify and develop mineral deposits in emerging and existing mining areas across the country, further enhancing Canada's reputation as a trustworthy destination for sound exploration investment. TGI improves mineral exploration efficiency and reduces costs by focusing research efforts on high value and strategic mineral systems, the development and use of advanced analytical, laboratory, and field methods, predictive models, and technologies.

**Environmental Geoscience Program (EGP)**: Distinguishing the environmental effects of natural resource development from those produced by natural processes and developing new approaches to support the sustainable use of Canada's natural resources through informed decision-making.

**Groundwater Geoscience Program (GGP)**: Gaining a better understanding of groundwater distribution, quantity, and flow dynamics within integrated water models for sustainable water management and natural resource development.

**Geoscience for New Energy Supply (GNES)**: Supporting strategies for Canada's commitment to transitioning to a low-carbon economy through clean-energy geoscience research and development, and the promotion of non-emitting and low-emitting energy resources, using research to advance our fundamental understanding of Canada's subsurface landmasses.

**Marine Conservation Targets (MCT)**: Providing resource assessments for offshore and coastal areas under consideration for conservation measures in support of the Marine Conservation Strategy. The Marine Conservation Targets program received approval for the next phase of funding from the Treasury Board of Canada in September 2021.

**Marine Geoscience for Marine Spatial Planning Program (MGMSPP)**: Developing new maps and analyses of seafloor geology and active seabed processes to inform evidence-based decisions around marine spatial planning and regional environmental assessments, as well as cumulative effects assessments.

**Environmental Impact Assessment Service (EIAS)**: Evaluating geoscience information in environmental impact statements (EIS), managing the coordination of federal environmental assessment reviews that require geoscience expertise, and ensuring timely and effective delivery of geoscience information and advice pursuant to the department's legislated obligations.

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### **STRATEGIC PRIORITY 3: Geoscience to keep Canada safe**

**Climate Change Geoscience Program (CCGP)**: Developing a better understanding of the impacts of climate change in Canada by providing new and continual information and data, thus improving our understanding of how Canada's landmass is affected by climate change and providing support to land-use planning, informing infrastructure development, and assisting industry and at-risk communities to adapt.

**Public Safety Geoscience Program (PSGP)**: Developing new and innovative knowledge and tools to support emergency management, development, planning, and regulatory decisions that increase resilience and decrease risk to keep Canadians safe from earthquakes, terrestrial and submarine landslides, volcanoes, tsunamis, coastal flooding, and space weather.

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## **STRATEGIC PRIORITY 4: Geoscience for society**

**Open Geoscience Network (OGN):** Making geoscience outputs readily and easily available to Canadians with minimal restrictions, including establishing a robust and modern digital and physical infrastructure to better store, manage, and disseminate GSC data, publications, sample information, and coding. The GSC's scientific research outputs include peer-reviewed science articles and publications, as well as scientific research and technical data, including GSC sample collection catalogues in the longer term.

**Indigenous Relations Network (IRN):** Working with Indigenous communities to increase our shared understanding of geoscience and traditional knowledge, particularly through advisory bodies, hunters and trappers organizations and game councils, Elders, and other knowledge holders. The GSC is also increasing and strengthening its internal Indigenous relations capacity and is codifying ethical and respectful ways to co-develop projects with Indigenous communities and to engage in GSC programs.

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## **STRATEGIC PRIORITY 5: Our science, our people**

**Science Laboratory Network (SLN):** Providing innovative lab-based research leadership and state-of-the-art analysis and interpretation instruments and techniques for all GSC programs, and increasing effectiveness, connectivity, and efficiency across all five GSC laboratory groups.

Several GSC services and initiatives also promote **science policy collaboration** and **support the organization and its staff**.





## GSC geoscience at a glance: 2021–22

Since 1842, the Geological Survey of Canada has produced cutting-edge, authoritative geoscience to support mineral exploration, climate change research, marine and coastal resilience, and natural hazards mapping. From horse-drawn wagons and hand sketches to helicopters, digital modelling, and artificial intelligence, the GSC continues to evolve and adapt to changing national and global priorities to ensure GSC geoscience is relevant, accessible, and useful.

Highlights of 2021–22 GSC geoscience collaboration include:

- Inaugurating the Secretariat for the [World Community of Geological Surveys](#) (WCOGS), an informal best practice community reaching 130 national and regional geological survey organizations, co-founded by the GSC;
- Co-organizing the International Workshop on Critical Minerals with Geoscience Australia and the United States Geological Survey (USGS), which features the most advanced research on critical minerals geoscience around the world and attracts more than 1400 participants;
- Releasing the [Targeted Geoscience Initiative](#)'s final synthesis of a five-part series on advances in genetic and exploration models for base metal deposits in Canada and on innovative laboratory, geophysical, and field techniques to support mineral exploration;
- Collaborating with Spexi Geospatial Inc. to test a scalable unoccupied aerial vehicle (UAV) platform to inventory and monitor slow-moving landslides, merging real-time global navigation satellite system measurements, UAV photogrammetry, and satellite-based synthetic aperture radar interferometry datasets to achieve centimetre-scale accuracy;
- Awarding over \$700,000 in funding to academic and multidisciplinary groups for one- and two-year projects to build geoscience capacity in Canada's North through the [GEM-GeoNorth](#) program;
- Awarding eleven new multidisciplinary grant and contribution agreements totalling \$500,000 through the [Targeted Geoscience Initiative](#) to develop next-generation geological knowledge, leading-edge tools, innovative techniques, and predictive models of Canada's mineral potential for key commodities, including critical minerals;
- Installing a new 3D lab for computer vision research to support AI-generated mineral modelling and validation of augmented reality data; and,
- Receiving a glowing evaluation of the [Public Safety Geoscience Program](#) from the NRCan Audit and Evaluation Branch.



# Minerals

Mineral exploration plays a key role in ensuring the long-term viability of Canada's mining industry. It leads to the discovery and development of mineral deposits that could become future mines, creates jobs—often in remote and northern communities—and attracts significant investment. In 2021, the direct contribution of Canada's minerals and metals sector to its gross domestic product (GDP) was \$97 billion, which represented 4% of Canada's total GDP.

In addition to its mineral endowment of the more traditional commodities such as gold, base metals, and diamonds, Canada carries out mineral exploration for commodities used in highly valued applications in both the clean technology and the information technology sectors, such as rare earth elements, graphite, lithium, scandium, and others. With the World Bank forecasting that the production of some critical minerals will need to increase by 500% to 4,000% by 2050, Canada is primed to capitalize on the generational opportunity presented by the rising global demand for these critical minerals. Although the lists of critical minerals may differ among countries, owing to a variety of factors, there is significant overlap between jurisdictions.

To support mineral exploration and development in Canada, the GSC:

- **Decreases investment risk** by developing new, and improving existing, predictive models and maps;
- **Increases efficiency and efficacy of research** by enhancing analytical, laboratory, and field methods and techniques;
- **Emphasizes digital transformation** by leveraging artificial intelligence and other disruptive technologies;
- **Promotes innovation, global competitiveness, and environmentally sound practices** by offering grants to academia, Indigenous groups, and organizations to support complementary research.

Mining is one of Canada's **most important economic sectors**, with Canada currently producing 60 minerals and metals at 200 mines and 6,500 sand, gravel and stone quarries across the country.



## Determining footprints, endowment, origin, and prospective settings in critical mineral deposits

**Targeted Geoscience Initiative** (TGI) research was recently published in Geological Association of Canada Special Paper number 52, which includes two chapters on Olympic Dam, the world's largest example of iron oxide copper gold ore deposits (IOCG). These chapters include over 150 diagrams and more than 50 maps highlighting how Australian and Canadian IOCG and affiliated deposits are endowed in critical metals. This project used global comparisons to demonstrate how each evolutionary stage of mineral systems can lead to very distinct critical metal associations, contents, and deposit types. These results highlight the importance of the Critical Mineral Mapping Initiative (CMMI) collaboration with Geoscience Australia and the USGS.

### Reference publications:

Corriveau, L., Montreuil, J-F., et al. Geological Survey of Canada, Scientific Presentation 127, 2021, 105 pages, <https://doi.org/10.4095/329093>.

Corriveau, L., Potter, E. G., Mumin, A. H. (eds.). Mineral Systems with Iron Oxide Copper-gold (IOCG) and Affiliated Deposits, Geological Association of Canada, Special Paper 52, 2022, ISBN: 978-1-897095-96-6.

Gadd, M., Lawley, C., et al. Public geoscience solutions for diversifying Canada's critical mineral production. Geological Society, London, Special Publications, Volume 526, 2022, <https://doi.org/10.1144/SP526-2021-190>.

Hofstra, A. H., Listin, V., Corriveau, L., et al. Deposit Classification Scheme for the Critical Minerals Mapping Initiative Global Geochemical Database. USGS Open-File Report 2021-1049, <https://doi.org/10.3133/ofr20211049>.



The **CMMI Portal** is a free interactive mapping tool showing outputs from the geoscientific collaboration between the GSC, Geoscience Australia, and the United States Geological Survey (USGS).

The Critical Minerals Mapping Initiative (CMMI) focuses on building a diversified critical minerals industry in Canada, Australia, and the United States.

Through this international collaboration, the CMMI is developing a better understanding of:

- known critical mineral resources;
- geological conditions under which critical mineral deposits were formed, and thereby where they are most likely to be found; and,
- how to infer new sources through potential mapping and quantitative mineral assessments.

The **CMMI Portal** is a free interactive mapping tool showing outputs from the geoscientific collaboration between the GSC, Geoscience Australia, and the United States Geological Survey (USGS).

## Determining the cumulative effects of resource development on mining-impacted watersheds

At this time, global critical mineral production is dominated by regions with low environmental, social and governance (ESG) requirements, given the costly and often environmentally challenging nature of extracting and refining these minerals. Therefore, extracting natural resources, while simultaneously protecting Canada's wilderness and promoting sustainable development, provides Canada with an international competitive advantage.

In this project, [Environmental Geoscience Program](#) (EGP) researchers are providing evidence of the historical cumulative impacts of mining on receiving watersheds around the Cobalt area in northeastern Ontario. Researchers sampled mine tailings, mine effluent waters, and lake sediment cores to evaluate the concentrations and speciation of silver, arsenic, cobalt, nickel, antimony, and mercury. Additionally, researchers are using age-dating (arcellaceans, diatoms, pollen) of lake sediments to evaluate the ecological response to legacy metal(loid) contamination and the cumulative effects of mining on aquatic biota.

This research highlights the difference between the impacts of past unregulated mining and those of modern, more sustainable critical mineral resource development. This work also contributes to the development of new geoscience methods for assessing the cumulative environmental effects of critical metal mining in watersheds where previous resource development activities have left a complex legacy of pervasive background contamination in waters and sediments. In the long term, this research will support the process of fast-tracking critical mineral exploration by helping to improve the use and attainment of ESG criteria within the mining industry and among regulators.

The release of [Canada's Critical Minerals Strategy](#) promises to help advance the development of critical mineral resources to power the green and digital economies at home and around the world.

Through this strategy, Canada pledges to become a global leader in the responsible, inclusive, and sustainable production of critical minerals, from discovery to mines to manufacturing.



Core sampling of lake sediments on Lake Timiskaming in March 2022

# Geoscience for the North

Through **continuous dialogue** with interested Indigenous landholders, governments and representative organizations, the GSC's GEM-GeoNorth program aims to include their perspectives and priorities in the planning of research on their territories.

In addition, GEM-GeoNorth's full-time engagement officers build **long-term relationships** with communities. Finally, GEM-GeoNorth disburses grants to academic, northern and Indigenous organizations that conduct geoscience research or want to develop their capacity to use the program's data.

Mineral and energy exploration and production are primary economic drivers in Canada's North, providing opportunities for sustainable employment and skills development as well as the development and expansion of infrastructure to support wider economic growth. To undertake exploration activities in the North, mining companies rely on pre-competitive and foundational geoscience maps and information to help them identify prospective areas of resource potential. Often, companies would typically not invest in the production of such basic geoscience research, especially in Canada's North where the costs of conducting exploration are very high.

GSC geoscience explores the structure and evolution of geology in the North and helps address an insufficient understanding of the geology of vast tracts in Canada's North. GSC scientists lead and conduct research in collaboration with Canadian provinces and territories and research institutions in Canada and around the world, as well as northern and Indigenous institutions and organizations. In addition, the GSC supports and promotes effective engagement with local communities to obtain consent for work, to identify and respond to concerns regarding proposed research activities, and to communicate research findings back to the community as an important component of land use decision-making.

To support geoscience for the North, the GSC:

- **Collaborates with provinces, territories, and Indigenous Governance Organizations (IGOs)** to create a new, formalized process to co-develop geoscientific research priorities;
- **Increases resiliency to climate change** by producing new geoscientific research, knowledge, and data;
- **Expands access to geoscientific resources and tools** to support decision-making by communities and governments;
- **Provides grants to northern educational institutions and organizations** to conduct geoscience and develop capacity; and,
- **Helps train the next generation of highly qualified personnel**, including northern and Indigenous geoscience professionals and students.



## Empowering northern mapping by Northerners

Historically, the accessibility and uptake of geoscience knowledge by Indigenous groups in Canada have been limited by the technical nature of geological publications and expensive licensing requirements to view and analyze data. To facilitate collecting and archiving field observations, [Geo-Mapping for Energy and Minerals-GeoNorth](#) (GEM-GeoNorth) worked with the Arctic Eider Society to determine the feasibility of incorporating geoscience into the [Indigenous Knowledge Social Network](#) (SIKU), the Inuit-developed web platform and mobile app that allows Northerners to digitally document and share their observations of the land.

User-friendly, mobile-app-supported mapping will allow access to, and participation in, collecting data in and about Canada's North, such as changing permafrost conditions; prospecting within new infrastructure corridors; and identifying rocks, minerals, and landforms. This partnership also serves as a blueprint for how GEM-GeoNorth collaborates with northern and Indigenous governments and organizations to align research priorities and continue to help build geoscience capacity in the North.



The [Indigenous Knowledge Social Network](#) (SIKU) has four guiding principles:

- **Respect:** As the only social media platform putting Indigenous rights first, SIKU is a safe space for sharing and mobilizing Indigenous knowledge.
- **Self-determination:** SIKU helps document the data that has always formed the basis for Indigenous knowledge and mobilize it for use in community-based monitoring, [guardian programs](#), and self-determination in research, education, and environmental stewardship.
- **Intellectual property:** No one can use your data without permission. Intellectual property ownership is maintained through an informed data stewardship framework.
- **Integrity:** The terms of use require real names and real data—critically important for safe travel, knowledge transfer, language, and cultural preservation.

Thawing permafrost releases greenhouse gases. This includes both carbon dioxide—which arises from the carbon in decaying organic materials that have been locked in permafrost for thousands of years—and methane, a greenhouse gas estimated to be 30 times more potent than carbon dioxide.

Once these two major greenhouse gases are released into the atmosphere they can contribute to, or accelerate, the pace of climate change globally, in turn causing more permafrost thaw.

## Understanding permafrost conditions on infrastructure stability and water quality

Understanding the effect of permafrost freeze-thaw processes in northern Canada is integral to ensuring the stability and safety of northern infrastructure such as roads, bridges, and mines, especially in the face of climate change. To better understand this phenomenon, [Environmental Geoscience Program](#) (EGP) researchers redesigned standard groundwater monitoring sensor systems to withstand the extreme cold of northern winters, and subsequently deployed them in the fall of 2021.

The initial data from these deployments indicate that groundwater within the soils overlying permafrost is a more important component of Arctic hydrologic systems than previously thought, and that groundwater movement during Arctic winters is likely much more extensive than previously anticipated. Both of these findings have significant implications for major infrastructure that relies on stable permafrost and winter ice, such as highways and bridges. Furthermore, in the sites investigated to date, groundwater geochemistry undergoes strong seasonal changes, which are subsequently reflected through impacts on summer surface water quality.

Overall, this project has created a hydrogeological sensor system, which is a suite of standard tools for understanding groundwater-ground stability issues in non-permafrost areas that has been tailored for northern areas. In addition, results of this research have led to a more holistic view of hydrogeological systems in permafrost regions. Sharing these research outputs supports the adaptation of northern communities to climate change by improving

infrastructure stability as well as protecting water quality. Furthermore, the sensor system will enable northern communities to measure and monitor their local environmental systems as climate change continues to reshape Canada's North.



Setting up the first installation of the newly designed and built datalogger and sensor network in the fall of 2021. The dataloggers were periodically maintained and data was downloaded by Inuvik-based workers.

# Climate change

As a northern country, Canada is experiencing climate change at twice the rate of the world's average. In the Canadian Arctic, the rate is three times the world average. Increasing temperatures mean that glaciers are melting, and permafrost is warming and thawing. The effects are dire in Canada, which has the third-largest area of glacier ice in the world (~200,000 km<sup>2</sup>). Moreover, a full 50% of Canada contains permafrost.

Canada's northern coastlines are also among the fastest-changing areas in the world. Permafrost thaw and coastal erosion threaten existing infrastructure and development projects and accompanying sea-level rise floods land and enlarges rivers and lakes. As almost all Indigenous communities in Canada's North are located on the coast, they are most at risk of experiencing climate change impacts. These include risks to infrastructure, water supply, livelihoods, housing, food sources, and ultimately the health and safety of the citizens.

By understanding historical changes in climate, as preserved in both the geological record, and by assessing the current climatological effects, geoscience helps us understand current climatic trends and predict future conditions.

To support climate change geoscience, the GSC:

- **Assesses the rate and cause of permafrost, ground ice, and glacier changes** in Canada's North;
- **Clarifies the causes and consequences** of rapidly changing northern environments, including coastal areas experiencing erosion due to sea-level rise, permafrost degradation, reduced sea ice, and an increase in storm surges;
- **Informs adaptation strategies** for existing and proposed infrastructure, coastal communities, and major transportation routes in the North; and,
- **Provides advance warning to Indigenous communities** that are vulnerable to the effects of climate change.

**Climate change adaptation** is any activity that reduces the negative impacts of climate change or helps people cope with them, or one that takes advantage of new opportunities that result from climate change.

**Mitigation activities** reduce the rate and magnitude of climate change, while adaptation addresses current and future impacts. Successful adaptation does not mean that negative impacts will not occur, only that they will be less severe than without adaptation.



The reduction of water runoff from melting glaciers can impact water tables, agricultural practices, and even the availability of drinking water downstream.

Click [here](#) to learn more about how GSC scientists measure changes to Canada's glaciers.

## Monitoring Canada's glaciers through mass balance measurements

The GSC has been monitoring the state and evolution of Canada's glaciers for more than half a century. Assessing changes to the mass of water contained in Canada's glaciers supports freshwater and climate change studies in Canada's Arctic and alpine environments, and maintaining annual observations produces a highly valuable long-term record. In 2021, [Climate Change Geoscience Program](#) (CCGP) scientists focused on resuming annual glacier mass-balance measurements at the long-term glacier reference sites in the Arctic and in British Columbia, following a year of missed fieldwork due to the COVID-19 pandemic.

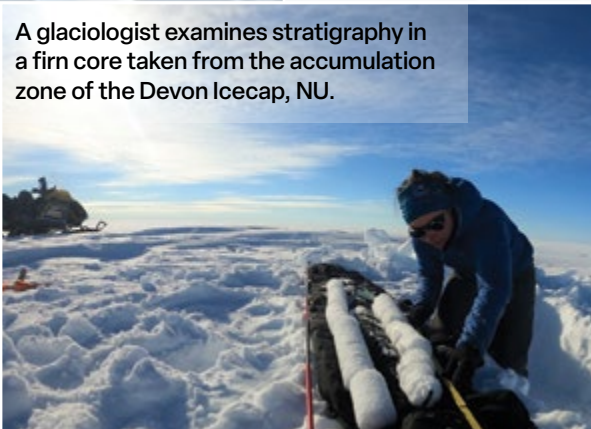
Observations show that the previous year had been exceptionally warm, leading to melt-out of many measurement stakes and weather stations which are established on the glaciers. In addition to collecting data and repairing damaged weather stations, the researchers drilled and examined cores, dug deep snow pits within the ice cap accumulation areas, and employed satellite technology to provide data critical for reconstructing the net mass balance that could not be measured via standard methods. Results from the 2021 fieldwork campaign are being used to prepare an annual report on the status of glacier mass balance for the World Glacier Monitoring Service, part of Canada's obligations to international agreements on climate monitoring.

### Reference publications:

Burgess, D. and B. Danielson. 2022. Changes in geometry, mass, and climatic response since 1959. Meighen Ice Cap: Canadian Journal of Earth Sciences. doi: [10.1139/cjes-2021-0126](#).

WGMS 2021. Global Glacier Change Bulletin No. 4 (2018–2019). Zemp, M., Nussbaumer, S.U., GärtnerRoer, I., Bannwart, J., Paul, F., and Hoelzle, M. (eds.), ISC(WDS)/IUGG(IACS)/UNEP/UNESCO/WMO, World Glacier Monitoring Service, Zurich, Switzerland, 278 pp., publication based on database version: doi: [10.5904/wgms-fog-2021-05](#).

A glaciologist examines stratigraphy in a firn core taken from the accumulation zone of the Devon Icecap, NU.





## Quantifying long-term permafrost thaw and surface subsidence

The GSC has operated a network of thaw tubes in the Mackenzie Valley since 1991. These thaw tubes allow researchers to assess permafrost thaw penetration relative to a fixed datum, active layer thickness, and surface elevation change. [Climate Change Geoscience Program](#) (CCGP) researchers analyzed these records to quantify the amount of thaw and surface settlement that has occurred in response to climate change.

The results indicate that overall, thaw has progressed by 0.8 cm per year, and ice-rich ground has subsided 0.4 cm per year. In some areas, up to 80 cm of permafrost thaw has occurred since the 1990s. By considering subsidence, the measurements from the thaw tubes provide a better indication of permafrost loss than active layer thickness derived through mechanical probing. Incorporating landscape response associated with permafrost thaw will improve climate-permafrost models and help ensure that decision makers have the best information to inform adaptation planning in Canada.

The variability of maximum active layer thickness in permafrost has **important implications** for hydrological processes, terrestrial and aquatic ecosystems, and the integrity of northern infrastructure.



## Marine and coastal

Canada's coastlines are extremely diverse.

Approximately **70% of Canada's coastline** borders the Arctic Ocean to the north and is very sparsely populated, with most residents being Inuit, First Nations, or Métis. Sea ice is a defining element of the coast for much of the year.

In eastern Canada, the region bordering the Atlantic Ocean is characterized by several cities and an abundance of small towns and hamlets, with a diverse economy in which coastal resources continue to play an important role.

In western Canada, the population of the region bordering the Pacific Ocean is concentrated in British Columbia's lower mainland and southeastern Vancouver Island, with the number of residents and built-environment asset value of the greater Vancouver area far exceeding that of any other part of Canada's marine coast.

Canada is the second-largest country in the world, but a full 40% of the country's landmass is under the ocean. A changing climate is increasingly affecting the rate and nature of change along Canada's three highly dynamic coasts, with widespread impacts on natural and human systems. Concurrently, extreme weather events, particularly in the 21<sup>st</sup> century, demonstrate the vulnerability of coastal infrastructure in Canada.

As such, there is an urgent need for a better understanding of climate risks and adaptation in coastal areas, and it is imperative that future development be undertaken with an understanding of the dynamic nature of the coast and changing coastal risks. Geoscience helps guide decisions about the use of Canada's coastlines and offshore waters, on topics ranging from conservation to hazard assessment and resource extraction. We provide critical information to decision makers at Fisheries and Oceans Canada, Transport Canada, Environment and Climate Change Canada, the Parks Canada Agency and regulators, as well as provincial and territorial governments, Indigenous communities, and organizations and municipalities across the country.

The GSC also helps Canada uphold its obligations as a signatory to the United Nations Convention on the Law of the Sea (UNCLOS). Our research has been fundamental in defining the continental shelf and understanding the links between our landmass and submerged lands in the Atlantic and Arctic oceans. Two submissions to date (Atlantic Ocean, filed in 2013, and Arctic Ocean, filed in 2019) show that Canada is entitled to 2.4 million km<sup>2</sup> of seafloor and subsoil, making it the largest area ever considered under UNCLOS. Often this work was done under harsh conditions, especially in the ice-covered central Arctic Ocean near the North Pole and along the Canadian Arctic Archipelago. We continue to work with our colleagues in other Arctic nations to define the boundaries of the continental shelf through UNCLOS.



To support marine and coastal geoscience the GSC:

- **Develops new maps and analyses** of seafloor geology and active seabed processes to support marine spatial planning and regional environmental assessments;
- **Contributes to Canada's marine conservation targets** of conserving 25% of its offshore areas by 2025 and 30% by 2030;
- **Defines Canada's international boundaries** as a member of the United Nations; and,
- **Provides geoscientific advice and expertise** on major resource development projects and their potential environmental effects.



While geoscience generally focuses on the physical characteristics of Canada's coasts, the effects of climate change are much broader in scope, touching ecosystem sustainability, renewable resources, food security, health and well-being, energy, economic prosperity, cultural integrity, and other facets of these [coastal systems](#).

## Increasing coastal resiliency and risk reduction through nature-based infrastructure

This project aims to address key factors and data gaps limiting the uptake of nature-based infrastructure for coastal flood and erosion risk reduction. [Climate Change Geoscience Program \(CCGP\)](#) researchers are using a combination of field experiments and modelling to assess the effectiveness of salt marsh growth and beach nourishment in reducing flooding and erosion at sites on both the Pacific coast (Metlakatla and Boundary Bay, BC) and the Atlantic Coast (Chignecto Isthmus on the New Brunswick/Nova Scotia border).

CCGP researchers deployed a variety of field instruments, such as wave sensors, tide gauges, current metres, and interval cameras to document wave attenuation. The continuous data collected will form the basis of future physical and numerical modelling. Throughout the project, CCGP scientists have worked closely with First Nation communities to exchange knowledge and information and to develop field plans that meet the unique needs of community partners, while also addressing the project's science objectives.

This research will contribute to an improved understanding of the performance of nature-based infrastructure in Canadian coastal environments, and will serve as the foundation for developing a "Knowledge Base and Design Guide," the first national guidance on implementing nature-based infrastructure for coastal hazard risk management purposes in Canada.



GSC researchers prepare an instrument on the deck of a hovercraft in Boundary Bay on the west coast.

## Characterizing foundation conditions for marine renewable energy

Marine renewables, in particular offshore wind energy, are seeing rapid adoption worldwide. These structures require regional- and site-scale characterization of what is on, and under, the seabed. [Marine Geoscience for Marine Spatial Planning](#) (MGMSP) researchers are focusing on the shallow geology of the continental shelf on Canada's Atlantic and Pacific coasts to help with future science-based decision-making regarding location, foundation design, and layout for infrastructure from the shelf to the coast. MGMSP outputs from this project provide important input data for relevant geological models to support this decision-making, including updated bathymetry, surficial geology, shallow subsurface geology, depth of sediment mapping, seabed sediment mobility/shear modelling, geotechnical characterization of marine soils, and geohazard mapping.

### Reference publication:

Eamer, J. B. R., Levisky, Z., and MacKillop, K. Geotechnical parameters important for offshore wind energy in Atlantic Canada; Geological Survey of Canada, Open File 8873, 2022, 41 p. <https://doi.org/10.4095/329688>.

Wind turbines are a well-known technology, and offshore wind offers **stronger and more predictable** energy than onshore wind resources. While offshore wind levels vary, they are more easily forecast, up to several days in advance, making offshore energy easier to integrate into grid operations in parallel with other energy sources.

Geophysical gear being deployed from the CCGS Louis S. St-Laurent in the Arctic Ocean.



# Hazards and public safety

Floods are the **most costly** natural disasters in Canada in terms of property damage. For example, flooding in southern British Columbia in November 2021 resulted in \$675 million in insured losses.

Floods can occur in any region, in the countryside or in cities, at virtually any time of the year.



The impacts of climate change are already being felt across Canada, with increased frequency and intensity of hazards such as floods, wildfires, drought, extreme heat, tropical storms, melting permafrost, coastal erosion, and, in northern Canada, damage to seasonal ice roads. These hazards pose significant risks to communities, individual health and well-being, the economy, and the natural environment. Moreover, many Indigenous communities are among the most vulnerable to climate change due to their remote and coastal locations and reliance on natural ecosystems.

At the same time, non-climatological disasters, such as earthquakes, space weather, and volcanic eruptions also warrant risk reduction strategies to ensure preparedness and rapid and effective response. By creating or strengthening capacity in both the human and built environments, communities in Canada will be able to cope with, adapt to, respond to, and recover and learn from disasters. Land-use planning, policies, emergency management, and regulations, based on modern and authoritative science, can help at-risk communities adapt to the effects of climate change and natural hazards and support all levels of government in understanding the risks posed by hazards so they can plan appropriately.

To support public safety across Canada, the GSC:

- **Conducts research to understand where and how major events** such as flooding, earthquakes, terrestrial and submarine landslides, volcanoes, tsunamis, and space weather might occur in Canada;
- **Assesses the potential impacts of natural hazards** to prioritize risk-reduction activities;
- **Develops risk assessments, case studies, frameworks, and tools** that support risk-related decision-making; and,
- **Works with Indigenous communities** to incorporate science and Indigenous knowledge into risk-related decision-making.

## Assessing seismic hazards for proposed nuclear waste repositories

In 2021, [Public Safety Geoscience Program](#) (PSGP) scientists completed sub-bottom geophysical surveys at Lake Kipawa and Lake Timiskaming in Ontario and Quebec. The work at Lake Kipawa investigates the spatial extent of subaqueous landslides triggered by the 1935 magnitude 6.1 Timiskaming earthquake. This helps to understand the relationship between the area impacted by landslides and the magnitude of the triggering earthquake. The work at Lake Timiskaming investigates the origin of faults in young glacial lake deposits to determine if they are caused by melting of buried ice or by faulting in the underlying bedrock. This research improves the understanding of long-term seismic and neotectonic activity in the region and, ultimately, will help inform a seismic hazard assessment for areas proposed for use as a deep geological nuclear waste repository.

### Reference publication:

Brooks, G.R. Evidence of early postglacial paleoearthquakes from mass transport deposits buried within glaciolaustrine sediments in northeastern Ontario-western Quebec, Canada [Abstract], in GAC®-MAC 2021, London, Canada: Exploring Geosciences Through Time and Space/GAC®-MAC 2021, London, Canada: Explorer les géosciences à travers le temps et l'espace; Geological Association of Canada-Mineralogical Association of Canada, Joint Annual Meeting, Programs with Abstracts vol. 44, 2021 p. 53Open Access (NRCan Cont.# 20210480)

[Online - En ligne \(complete volume - volume complet, PDF, 2.45 MB\)](#)

Supplying about 15% of Canada's electricity, the nuclear industry **offsets over 50 million tonnes of carbon emissions** across the country each year while also providing critical medical isotopes that diagnose diseases, treat illnesses and sterilize medical equipment around the world.



# Groundwater and aquifers

The total volume of groundwater worldwide is estimated to be about **100 times the volume of surface water** in rivers and lakes.



Groundwater is vital for Canada's health, environment, and economy. Nearly 30 percent of Canada's population (almost 10 million Canadians) depends on groundwater to supply drinking water, and more than 80 percent of the country's rural population relies on groundwater for its entire water supply. Groundwater is often the preferred source for communities, farms, and individual households since it can be close to users, is relatively inexpensive, and is often of better quality than heavily used surface waters.

Canada's groundwater, however, is increasingly under threat from factors such as urbanization, climate change, burgeoning energy production, intensification of agriculture, and contamination. When precipitation carries contaminants into underground aquifers, it can render them deficient or unfit for human use, putting communities and economies at risk. Understanding how groundwater moves in the ground is key to managing its availability and clarifying how contaminants are transported.

To support groundwater geoscience across Canada, the GSC:

- **Assesses and characterizes Canada's main aquifer systems** through geological mapping, regional hydrogeological assessments, and groundwater modelling;
- **Monitors the seasonal changes** in groundwater, freshwater, and wetlands on a regional and national scale;
- **Identifies contaminant sources** in water and air using geochemistry; and,
- **Helps municipalities increase resiliency** of their built structures to prevent contamination by informing the location, design, and operations of new structures.



## Leading a global workshop on developing groundwater standards

Groundwater data have historically been challenging to find and use because they are diversely structured and fragmented. Overcoming data heterogeneity requires a common data format; however, no appropriate international standard was suitable until the development of Groundwater Markup Language 2 (GWML2).

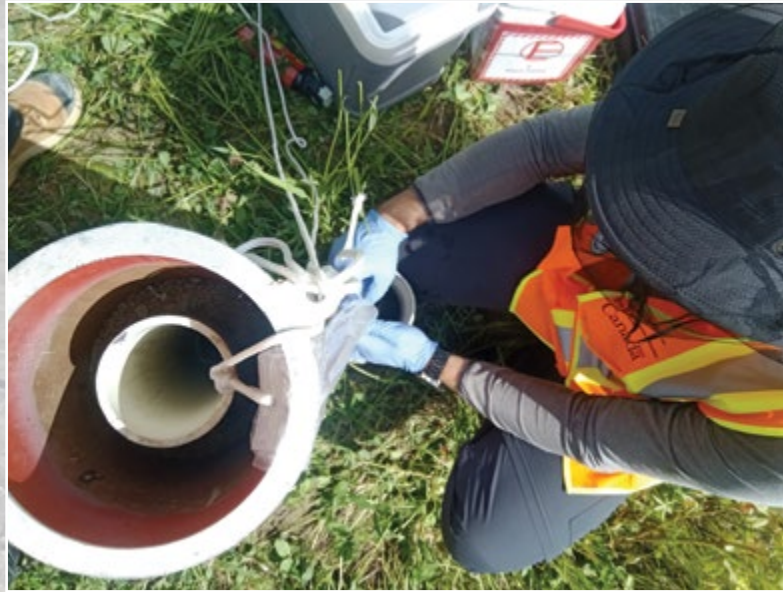
An international team, led by [Groundwater Geoscience Program \(GGP\)](#) researchers, developed the GWML2 data exchange standard and is spearheading its adoption as an international standard for groundwater data.

In March 2022, the World Meteorological Organization (WMO) held an international workshop demonstrating how GWML2 has been implemented in several countries, including France, Australia, New Zealand, the USA, and Canada. As part of this year's UNESCO Water Day theme, [Groundwater: Making the invisible visible](#), WMO showcased how GWML2 is currently being used in some jurisdictions, and opened discussions on how it can be improved to enhance groundwater geoscience around the globe.

One of the major barriers to sustainable management of groundwater in Canada is access to data. Standards are key to making water data usable across jurisdictions and platforms. Data standards is one of the components required to discover and exchange data between groundwater data providers both within Canada and around the globe.

GWML2 is an international standard for the online exchange of groundwater data that addresses the problem of data heterogeneity, representing key hydrogeological entities such as aquifers and water wells, as well as related measurements and groundwater flows.

GWML2 has already been adopted into the WMO's [Manual on Codes](#).



**C1W** is a three-year collaborative partnership between Aquantia Inc., Natural Resources Canada, and Agriculture and Agri-Food Canada. The principal source of funding is from the Public Safety and Security Program of Defence Research Development Canada (DRDC).

The project will provide a framework to assess the impact of climate change on water resources. This will be of value (social, cultural, geographic, and economic) to communities and decision makers across Canada. It will help Indigenous and rural communities, as well as the agriculture and natural resource extraction industries (forestry and mining), to adapt to climate change, particularly in Canada's North.

The C1W datasets will facilitate future, regional, and local scale analysis anywhere within continental Canada using a nested modelling approach.

## Canada1Water: Continental scale groundwater-surface water modelling

Initiated in 2021, the Canada1Water (C1W) project is a three-year project that aims to model the response of Canada's groundwater and surface water resources to climate change for mid- and end-century timeframes. This is the first time that such results will be available for continental Canada and the Canada-USA transboundary river basins.

Through C1W, [Groundwater Geoscience Program](#) (GGP) researchers are collaborating to integrate results from land surface modelling (to capture the land-atmosphere energy balance), dynamically downscaled regional climate models, and physics-based groundwater-surface water modelling. For computation efficiency, and to accommodate distinct regional differences in physiography and hydrogeological processes and issues, Canada has been divided into seven major catchment areas with groundwater-surface water model domain areas ranging from 800,000 to 2.3 million km<sup>2</sup>. Model spatial resolution varies from 1 km to 5 km.

Model calibration and validation utilize a wide array of terrestrial and remote sensing data, including provincial groundwater monitoring networks, national hydrological network stations, and data from the Gravity Recover and Climate Experiment (GRACE). Model datasets and outputs will be published under an Open Government Data Licence.

**Reference website:** [Canada 1 Water](#).



# Energy resources

There is a growing demand in Canada for clean energy sources and environmentally sustainable energy resource development to reach the Government of Canada's target of net-zero CO<sub>2</sub> emissions by 2050. Canada, with its large landmass and diverse geography, has substantial renewable resources that can be used to produce energy, including water, wind, biomass, solar, geothermal, and ocean energy. Usable energy can be produced in the form of electricity, industrial heat, thermal energy for space and water conditioning, and transportation fuels.

The GSC supports this critical shift and is working to improve the chances that industry will succeed in energy resource extraction (helium, natural gas, and the earth's geothermal heat) and injections (sinks such as carbon capture, utilization, and storage [CCUS]). The GSC is redirecting research efforts from frontier petroleum basins toward less conventional energy-related research and development, including geothermal and offshore renewable energy solutions. The resulting information should allow Canada to meet its energy needs while reaching environmental targets.

To support clean energy resource development across Canada, the GSC:

- **Improves mapping methods and geoscience knowledge** to better detect, understand, and model the impact of resource development;
- **Assesses low-emission, clean-energy sources and geothermal potential** to support the renewable energy industries; and,
- **Continues to differentiate** between made-made and natural contamination.

**Carbon capture, utilization, and storage (CCUS)** involves capturing CO<sub>2</sub> from facilities, such as factories and power plants, or directly from the atmosphere.

Once the CO<sub>2</sub> is captured, it is compressed and transported to be permanently stored in geological formations underground or used to create products such as concrete and low-carbon synthetic fuels.



Computed tomography (CT) scans are a powerful extension to traditional petrographic analysis, as it allows observations and measurements to be **extended into three dimensions**. The scans create virtual slices through objects and layer them to create 3D models.

## Developing a 3D porosity imaging methodology using a medical CT scan

The success of technologies using deep geological formations, such as geothermal energy production and CO<sub>2</sub> storage, is mainly controlled by the permeability of the geological unit. Permeability, in turn, depends on effective porosity which includes only the connected pores in a rock matrix (as this is where the fluid can circulate). The [Geoscience for New Energy Supply](#) (GNES) project developed a methodology to image 3D porosity of connected pores using a medical CT scan, by scanning both dry and water-saturated core sample 3D pore networks—an improvement over a simple average total porosity value from a conventional lab.

This advanced characterization work provides a better understanding of how the fluid (brine or CO<sub>2</sub>) flows through the reservoir. Combined with thermal conductivity and permeability measurements, this advanced characterization work forms the fundamental basis for ongoing multi-scale fluid flow and heat transfer modelling work, increasing the chances of success in selecting the best candidates for geothermal energy production and CO<sub>2</sub> storage.

This project also included numerical simulations to study the performance of two different types of geothermal systems: deep borehole heat exchangers (DBHEs) and well doublets. Two cases for DBHEs were studied: Case #1, repurposing of an oil and gas well, and Case #2, drilling a new borehole. These simulations and a preliminary cost analysis showed that repurposing existing wells over a 30-year period can be advantageous, even compared with gas and hydroelectricity.

### Reference publication:

Gascuel, V., Raymond, J., Rivard, C., Marcil, J-S., and Comeau, F-A., Design and optimization of deep coaxial borehole heat exchangers for cold sedimentary basins, *Geothermics*, Volume 105, 2022, <https://doi.org/10.1016/j.geothermics.2022.102504>.



## Triggering new industry interest in the geothermal potential of volcanic belts in western Canada

**Geoscience for New Energy Supply** (GNES) researchers successfully completed geological fieldwork in the Mount Cayley area, with support from the Squamish First Nation. The project included helicopter-supported gravity surveys, new bedrock mapping, fracture analyses, thermal property analyses, and age dating of some of the most recent volcanic eruptions in Canada. This project also included a new installation of ground temperature probes for use as a low-cost geothermal exploration tool, exploiting the insulation effect of snow cover that allows direct, shallow measurement of the Earth's heat flux during the winter (a unique opportunity for geothermal exploration in higher latitude snow-covered regions).

In addition, this project included the first use of thermal imaging drones and the first sampling of one of the highest temperature thermal springs in Canada. The results of this project have spurred new industry interest in the geothermal potential of the volcanic belts in western Canada, including the purchase of the Mount Meager Geothermal Lease, and support Canada's goal of achieving net-zero energy by 2050 through reducing the risk of renewable geothermal energy exploration.

### Reference publication:

Grasby, S.E., Ansari, S.M., Barendregt, R.W., Borch, A., Calahorrano-DiPatre, A., Chen, Z., Craven, J.A., Dettmer, J., Gilbert, H., Hanneson, C., Harris, M., Hormozzade, F., Leiter, S., Liu, J., Muhammad, M., Quane, S.L., Russell, J.K., Salvage, R.O., Savard, G., Tschirhart, V., Unsworth, M.J., Vigouroux-Caillibot, N., Williams-Jones, G., and Williamson, A., Vestrum Z.E. Garibaldi Geothermal Energy Project – Phase 1 – Final Report. Geoscience BC Report 2021-08, 276 p.

**Geothermal energy** is a source of clean, reliable, stable baseload power, and can also be used to provide direct heat for a number of purposes, including district heating and greenhouses. Canada has enormous geothermal energy resources, varying in quality, across the country.



## Geoscience tools and data

The objective of [open science initiatives](#) in the federal government is to provide Canadians with greater accessibility to learn about and participate in scientific processes and research while maximizing the health and well-being of the country.



Historically, science across the globe was underpinned by tradition, culture, and incentives, creating an environment where scientific inputs, outputs, and processes were either closed, accessible for a fee, or only available to researchers and/or collaborators. Open science is a movement to make scientific processes and practices, including research methodology and outputs, more open and transparent. The Government of Canada is committed to making federally funded science open to Canadians by helping to generate research ideas, making data and publications readily available, and making research understandable and useful.

The GSC has been dedicated to geoscience research and science communication in Canada since its inception in 1842. GSC activities have always included regional geological mapping, based on fieldwork, laboratory observations, and the synthesis of available knowledge. However, recent technological advances and the federal policy commitment to open science are rapidly transforming the way the GSC collects information and data, stores data, and uses data in modern ways, such as numerical modelling for decision support activities. Modernizing the GSC's information management and communication practices with clients and stakeholders has become imperative in today's rapidly changing societal and technological environment.

To support [open and accessible geoscience tools and data](#) across Canada, the GSC:

- **Develops and maintains digital geoscience tools** for use in terrestrial and marine geoscience;
- **Publishes scientific data, information, maps, journal articles, and other publications** on multiple open access data repositories; and,
- **Contributes to open science policies and initiatives** to ensure and improve public access to, and literacy in, geoscience knowledge.

## Prioritizing a national approach to accessible geoscience

Disseminating our data and communicating our science are central to open geoscience. The GSC shares different types of data using various portals, such as the Open Data Platform or the [Geoscience Data Repository for Geophysical Data](#). Science communication takes many forms, from peer-reviewed articles to social media posts. The GSC publishes products that are available online free of charge through [GEOSCAN](#). In addition, other libraries and content aggregators (such as the [Federal Science Libraries](#) and the new [Open Science and Data Platform](#)) harvest the records and republish them, providing multiple online portals for readers to find and access GSC information products.

In 2021–22, the [Open Geoscience Network](#) (OGN) supported and promoted GSC geoscience by publishing 524 publications. These include externally published journal articles as well as GSC publications, such as Open Files (containing various types of data and reports, such as geophysical surveys and maps), bulletins, scientific presentations, general information products, and Canadian geoscience maps (surficial and bedrock).

In 2021, OGN also completed a Canada-wide *Assessment of Data-Readiness and Review of Stakeholder Needs for National Distribution of Geoscience Data*, in collaboration with the National Geological Surveys Committee (NGSC). The assessment identified several datasets that are highly valued by stakeholders and identified several models for data sharing and integration that have been successfully implemented by other geological surveys. This supports the identification and prioritization of opportunities to unify and standardize geoscience information and databases from provincial, territorial, and federal sources. The NGSC will use this report as a reference in its efforts to build consensus on common priorities to improve the availability and accessibility of national geoscience data.

**Reference website:** [GEOSCAN](#).

OGN consists of five nodes built around cross-cutting themes:

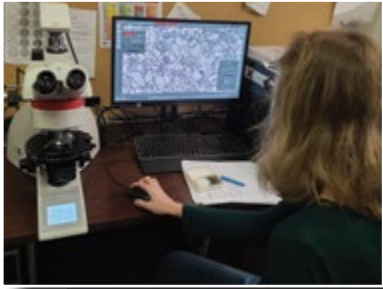
- Open Access and Public Engagement node
- Governance and Collaboration node
- Information Technology node
- Information Systems and Data node
- Collections node

These nodes support GSC geoscience by consistently managing and safeguarding GSC's physical and digital assets across all divisions.



Canada-3D (C3D) is a National Geological Surveys Committee of Canada project focused on developing methods and models for building a 21st-century national-scale 2D and 3D geological map.

A 3D geological model allows us to visualize and attempt to make predictions of geological conditions in depth.



## Modelling Canada in 3D

[Canada-3D](#) (C3D) includes a public, interactive web portal to disseminate and promote collaborative geological knowledge and data. The primary purpose of this web portal is to share the vision and imagine the future of the NGSC-C3D project, and perhaps one day serve as the foundation for a more full-featured conduit for our national geoscience data stores, maps, cross-sections, and 3D models. The web portal currently includes the geology of the three territories (Yukon, Northwest Territories, and Nunavut) and the older (1995-96) national reference maps.

The portal also includes a host of publication links from the GSC's Geo-Mapping for Energy and Minerals ([GEM](#)) program synthesis volume and snapshots of published 3D models. Several publications on 3D methodology can be downloaded from open source journals and GEOSCAN.

In 2021-22, C3D increased the ability of industry and academia to do complex and big data modelling, modernizing Canada's approach to natural resource characterization with advanced AI methods. Researchers developed a new mathematical methodology to include observations of rock unit and structural anisotropy, using emerging deep learning methods to create geologically reasonable models. This improvement allows for considerable flexibility to use more geological constraints within the modelling process, with a methodology that is scalable to massive datasets within a cloud computing infrastructure.

[Canada-3D](#) (C3D) researchers also developed several 3D regional models representing a range of modelling challenges arising from complex geology with sparse data, including deeper lithospheric models using earthquake information from across the globe, shallow near-surface models supporting climate change adaptation, and prediction of water budgets in vulnerable communities. These regional models incorporate big data integration principles, allowing the models to be useful and applicable for carbon storage, geothermal energy, and nuclear waste research, as well as providing users with a deeper understanding of Canada's critical mineral systems.

C3D researchers are now in the process of compiling current and geologically relevant public maps from provinces and territories to upgrade geological knowledge, enhance relationships, and modernize scientific language to create the next generation geological framework for Canada. This new framework will ensure up-to-date information with common standards, and a richer digital search method for more specific geological information.

**Reference website:** [C3D](#).



# Laboratories and collections

NRCan owns and/or occupies major laboratories and science centres across Canada, providing controlled conditions in which scientific research, experiments, and measurement may be performed. NRCan's laboratories also provide a national presence and support regional and local systems of innovation, contributing to Canadian competitiveness and economic development.

The GSC's [Science Laboratory Network](#) consists of five lab groups spread out across six divisions, each with a unique capacity to provide specialized laboratory results in support of programs and dedicated to developing new methods, technologies, and techniques to analyze and interpret information for scientists. Laboratory staff also collaborate with international partners as well as other laboratories across Canada, particularly in academia and other government departments.

GSC field researchers bring samples of earth material—such as rocks, minerals, sediments, cores, organic material, and water samples—to the GSC labs for analysis and interpretation. Scientists also use the GSC's extensive collection of earth material samples to inform and support their geoscience work. The earth material collection includes collections of original geological material spanning the GSC's entire existence, from 1842 to the present. Access to the GSC's vast collection reduces the risks and costs associated with exploration activities, particularly in remote regions. Scientists can also use this collection to conduct reanalysis projects using modern geoscience knowledge, concepts, and analytical techniques.

To support laboratories and collections across Canada, the GSC:

- **Develops improved laboratory methodologies and processes** to push the frontiers of cutting-edge geoscience analysis;
- **Collaborates and partners with jurisdictional partners, academia, and industry groups** to ensure collaborative, synergistic centres of excellence; and,
- **Maintains and improves physical sample collections** to preserve legacy information and enhance accessibility.

More than 60 employees work at over 30 of the GSC's specialized science laboratories and collections facilities across the country, developing new methods, technologies and techniques to analyze and interpret information for scientists in the GSC's geoscientific programs.

GSC scientists also collaborate with international partners as well as other laboratories across Canada, particularly in academia and other government departments.



In 2021–22, collections management teams from across the country accessioned, triaged, inventoried, and/or catalogued 87,000 units (e.g., samples, pails, and boxes) as part of digital transformation exercises to increase the discoverability and accessibility of GSC sample material.

In 2021–22, 25,000+ samples were loaned or made accessible by the GSC to internal and external stakeholders to contribute to research activities.

## Enabling the digital transformation of new and legacy resources

A critical role of the [Open Geoscience Network](#) (OGN) is to enable digital transformation. Data infrastructure, platforms, and standards are important because they provide the foundation for storing and disseminating geoscience information to clients and stakeholders. Data refers to our collections of physical geological material as well as digital data. The Open Geoscience Network has created a collaborative approach to ensure effective management of GSC data and assets. In 2021–22, the OGN continued to lay the foundation to:

- Establish governance structures to better manage geoscience data and information;
- Develop a robust and modern data infrastructure that will facilitate discovery and access to our data;
- Increase the scientific value of our physical collections; and,
- Help document, store, and manage GSC data.

To improve security and functionality, the GSC has started moving some of its key applications to the cloud and has increased support capacity for cloud computing. Physical collections are being reorganized to improve accessibility, which is especially important as scientists shifted to re-analysis of existing samples during COVID-19. The OGN has also continued to update our publication process to optimize the incorporation of open science principles.

**Reference website:** [Geological Survey of Canada – Labs and the earth material collection](#)



The GSC earth material collection includes collections of geological material (rocks, minerals, fossils, soil, stream and lake sediment, as well as other earth materials) gathered by researchers during geoscience field mapping. It spans the GSC's entire existence, from 1842 to the present.

## Pushing the boundaries of geoscience laboratory analysis

In 2021-22, the [Science Laboratory Network](#) contributed to GSC geoscience across Canada through specialized lab services, including:

- Completing a major taxonomic revision of the iconic Jurassic dinocyst *Gonyaulacysta*, focussing on the biostratigraphic utility of the genus and making it more useful in solving applied geological problems
- Determining a comprehensive organic carbon budget for an exhumed ancient delta clinothem preserved in Upper Cretaceous (~75 Ma) deposits in the Magallanes Basin, Chile, with results representing an annual burial yield of 9 to 90 tons of organic carbon per square kilometre, on the same order of magnitude as present-day yields calculated for deltas such as the Amazon
- Updating the Kiel System at GSC's Delta-Lab with a major improvement unique in the world: to handle the acidification of refractory carbonates—for example, siderite, magnesite, and ankerite—at temperatures up to 115°C, allowing researchers to explore the clumped isotopic composition of refractory carbonates on small samples (1-2 mg instead of 5-8 mg)
- Using a newly installed laser system that hosts a cryostage to complete initial testing to demonstrate the success of a new laser ablation system, and designing further improvements to the system that—once manufactured—will be implemented over the next few months, which in turn will reveal significant new information on how the ice formed and what controlled its formation to inform issues such-as permafrost hazards or subsurface hydrogeological conditions that can negatively impact northern infrastructure.

### Reference publication:

Hage, S., Romans, B.W., Peplow, T.G.E. et al. High rates of organic carbon burial in submarine deltas maintained on geological timescales. *Nat. Geosci.* 15, 919–924 (2022). <https://doi.org/10.1038/s41561-022-01048-4>; <https://www.nature.com/articles/s41561-022-01048-4>.

The GSC has **five specialized laboratories** with expertise in:

- Inorganic geochemistry
- Organic geochemistry and petrology
- Isotope geochemistry and geochronology
- Mineralogy and physical properties
- Paleontology



# National and international science policy collaboration

NRCan research and science are guided by NRCan's [Science Integrity Policy](#), which identifies NRCan science as contributing to three main areas:

- Public Good
  - Supporting innovation in order to improve the economic and social well-being of Canadians
  - Anticipating and responding to national priorities
- Policy and Re'gulatory Frameworks
  - Supporting regulatory functions within the department and other governments
  - Developing standards, codes, techniques, and guidance to support industry practices and ensure safety and well-being of Canadians
  - Supporting innovation and pre-commercial technology developments
- Expert Advice and Science Diplomacy
  - Providing expert advice and guidance to decision makers, as well as assessments related to risk management
  - Cooperating and collaborating internationally on natural resources issues

Both pan-Canadian and international collaboration is necessary to identify emerging geoscience issues across Canada and around the globe, thereby creating a shared vision of the future of geoscience. Engaging with diverse stakeholders groups ensures that GSC geoscience is addressing the most critical questions and benefiting Canadians from coast to coast to coast.

Embedded in the GSC's collaborative approach to science policy is the fundamental need to develop, exchange, enhance, and advocate for modern and effective geoscience, to create and consult on best practices, and to incorporate diverse views and experiences. The GSC is also committed to supporting and promoting geoscience to audiences across Canada and the world.

To support science policy collaboration, the GSC:

- **Creates and leverages partnerships in Canada and across the world** to foster synergy, efficiency, and innovation in geoscience,
- **Collaborates to identify knowledge gaps in geoscience** to advance framework geoscience; and,
- **Develops, leads, and contributes to science-policy improvement** through conferences, workshops, and communications initiatives.



## Enhancing geoscience collaboration across jurisdictions

Through its role in the National Geological Surveys Committee (NGSC), in 2021–22 the GSC:

- Finalized and published the Pan-Canadian Geoscience Strategy (PGS), a framework for collaboration across federal-provincial/territorial jurisdictions that represents unprecedented consensus on geoscience goals;
- Led PGS promotion through news releases, social media, conference presentations, and specialized materials (e.g., infographics);
- Supported working groups to advance priority areas for collaboration identified in the PGS;
- Developed and launched a more user-friendly and accessible [NGSC website](#); and,
- Supported development of an updated Intergovernmental Geoscience Accord—which includes enhanced commitments toward collaboration and modernized language regarding Indigenous peoples—for Ministerial consideration.

By breaking down silos, sharing knowledge, and coordinating work through efforts like the ones outlined above, geological survey organizations across Canada can increase the efficiency and impact of geoscience and better serve the public good.

**Reference website:** [Pan-Canadian Geoscience Strategy](#).

The [National Geological Surveys Committee](#) (NGSC) is a group of senior executives from Canada's 13 geological survey organizations who coordinate and integrate public geoscience activities across Canada.

The GSC Director General is always one of the two NGSC co-chairs. GSC policy staff are responsible for the NGSC Secretariat. GSC Directors, managers, and scientists also contribute to implementing the Pan-Canadian Geoscience Strategy and Intergovernmental Geoscience Accord.



WCOGS is open to all geological organizations and associations across the globe.

Participation is voluntary and free and is comprised not only of individual national geological surveys, but also survey organizations such as the Coordinating Committee for Geoscience Programmes in East and Southeast Asia, EuroGeoSurveys and The Association of Iberoamerican Geological Mining Surveys.

## Co-founding a global network of geoscientific excellence

Co-founded by the GSC, the World Community of Geological Surveys (WCOGS) brings together national and regional geological survey organizations around the world, connecting people and organizations, generating synergies, sharing best practices, and providing mutual support to promote global geoscience dialogue and address both national and global geoscience issues.

In 2021–22, the GSC contributed to WCOGS activities by:

- Acting as the inaugural WCOGS Secretariat;
- Co-developing and launching a user-friendly [WCOGS website](#);
- Participating in a presentation to the Association of Iberoamerican Geological Mining Surveys about global geomapping;
- Participating in a presentation to the Organization of African Geological Surveys (OAGS) about global geoscience; and,
- Chairing the WCOGS Activities Committee to develop and coordinate future WCOGS activities and events.

By fostering international collaboration around the world, the GSC will continue to not only produce and publish, but also share and build on authoritative and relevant geoscience.

**Reference website:** [World Community of Geological Surveys](#).



## Organizational and staff support

The nature of federal government mandates and funding means that government organizations need to implement new programs quickly and adeptly while continuing to achieve exceptional results. Programs and projects need to have robust and effective management, planning, and reporting systems, supported by policies and processes that foster critical and strategic evaluation and innovation. At the same time, successful organizations need to develop, maintain, and reconsider best practices to have an inclusive, equitable, and accessible workplace of choice, attracting the best minds and a diversity of talent, and to provide frameworks and opportunities within which our staff can grow.

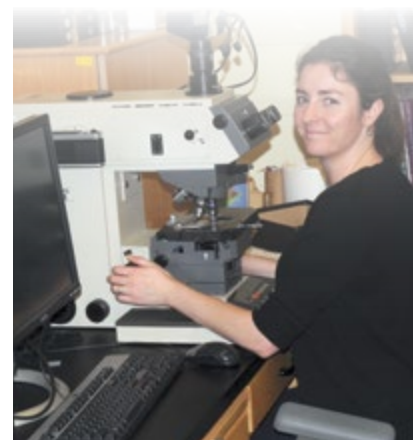
The GSC prides itself on providing a positive and modern workplace, balanced between organizational excellence and staff health and wellness. With regional offices across the country (Dartmouth, NS; Quebec City, QC; Ottawa, ON; Calgary, AB; Vancouver, BC and Sidney, BC), and many different types of internal and external stakeholders, programs and projects are designed to address a wide variety of geoscience issues tailored to, and respectful of, regional and local needs and nuances while contributing to national geoscience priorities. To support these programs, and the organization as a whole, GSC staff are supported and encouraged to continue their professional development and career progression, whether through language and skills training or mentoring and advancement opportunities.

To contribute to organizational and staff support and development, the GSC:

- **Develops, aligns, evaluates, and improves corporate initiatives** to ensure that organizational priorities are reflective of the science-policy environment as well as staff and organizational considerations;
- **Implements career development programs, knowledge transfer strategies, and succession planning efforts** to ensure and sustain collaboration, mobility, and motivation;
- **Builds capacity** with strategic recruitment, diverse representation, current digital technology, and streamlined internal processes; and,
- **Promotes geoscience communication** to showcase Canada's expertise and leadership in federal science, increase public geoscience knowledge and interest, and help build the workforce of tomorrow.

**Integrated planning** is an important building block in continuously improving and building the human capacity of the Public Service to deliver services to Canadians.

Integrated, rigorous planning can mitigate risks associated with aging workforces, tight labour markets, and technological change, and can help identify optimal strategies for recruitment, retention, learning, development, employee engagement, promotion, succession, employment equity, and official languages.



The **United Nations Declaration on the Rights of Indigenous Peoples** (UNDRIP) is about the respect and recognition of the human rights of Indigenous peoples.

On June 21, 2021, the **United Nations Declaration on the Rights of Indigenous Peoples Act** received Royal Assent and came into force. This Act provides a roadmap for the Government of Canada and Indigenous peoples to work together to implement the Declaration based on lasting reconciliation, healing, and cooperative relations.

## Promoting and building capacity in Indigenous engagement

The Indigenous Relations Steering Committee, part of the **Indigenous Relations Network**, collects and promotes available leading practices, tools, and other resources for use by GSC staff to aid in Indigenous engagement. In 2021–22, the Indigenous Relations Network (IRN) Toolbox Working Group developed a draft six-step engagement guideline and associated resources to support GSC staff engagement activities, including the preparation of the first draft of the “GSC Program Fieldwork Map,” a tool for GSC management and staff to be aware of projected activities in the field and to plan for Indigenous engagement.

In addition to the Indigenous Engagement Toolbox, the IRN also serves as a resource for GSC staff and management to:

- Develop a community of practice for mutual support;
- Foster collaboration among programs and divisions on Indigenous engagement issues;
- Facilitate co-planning of engagement activities between staff; and,
- Serve as a single point of contact through the **IRN mailbox**.

In 2021–22, the **Indigenous Relations Network** (IRN) also organized a workshop to help shape the future of Indigenous engagement at the GSC, facilitated several Indigenous training sessions for staff across the GSC

and in other NRCan sectors, and helped to co-develop a customized course, Archeology and Indigenous Science for Geoscientists, with GeoArcheo Consultants, to be delivered in the 2022–23 fiscal year.





## Supporting geoscience with a workplace of excellence

As good science communication inspires non-geoscientists and geoscientists alike, highlighting the importance, diversity, and excitement of geoscience is crucial. In 2021–22, the GSC updated its [web presence](#) to improve and facilitate access to GSC geoscience; developed and released a six-minute plain-language [outreach and promotion video](#), “The Geological Survey of Canada: An overview,” which highlights the scope and variety of GSC geoscience by program; promoted and publicized GSC science, upcoming geoscience events, and general interest geological knowledge through the [@GSC\\_CGC](#) Twitter account; and co-created a Twitter training session for 75 GSC staff members, including how to design and use personal professional accounts to promote geoscience.

In an effort to bolster Canada’s commitment to support both official languages, in 2021–22 the GSC provided French and English language training staff across the GSC to continue building capacity, ensuring that the GSC can promote and share its science in official language minority communities and provide quality services and geoscience in both official languages across Canada.

To support inclusion, diversity, equity, and access (IDEA), in 2021–22 the GSC’s Together for Respect initiative continued to focus on the mental well-being of staff and providing a safe space for voicing opinions, ideas, and concerns on wide-ranging issues, thus ensuring an inclusive environment that fosters collaboration and engagement. Other priorities and initiatives to ensure that the GSC is a modern, forward-thinking workplace of excellence include a Public Service Employee Survey (PSES) working group, designed to take into account the opinions of GSC employees on their engagement, leadership, workforce, work environment, workplace well-being, and compensation, and to align GSC HR plans with Lands and Minerals Sector (LMS) and Treasury Board (TB) HR plans, trends, and policies.

GSC science is routinely featured in NRCan’s [Simply Science](#) podcasts, articles, videos, photo galleries, and tweets.

In addition, the [@GSC-CGC](#) Twitter account actively promotes geoscience from the GSC and beyond. In 2021–22, [@GSC-CGC](#)—which has 2,916 followers—posted 172 tweets, which received 1,684 likes and 831 retweets and made 281,100 impressions.





# Annex 1: GSC 2021–22 program descriptions

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## **STRATEGIC PRIORITY 1:** Geological knowledge for Canada’s onshore and offshore lands

The following information outlines the projects and briefly describes the activities for the three programs within GSC Strategic Priority 1: Geological knowledge for Canada’s onshore and offshore lands:

- [Geo-Mapping for Energy and Minerals-GeoNorth](#) (GEM-GeoNorth)
- [Canada-3D](#) (C3D)
- [United Nations Convention on the Law of the Sea](#) (UNCLOS)



## Geo-mapping for Energy and Minerals-GeoNorth (GEM-GeoNorth)

### Program description

In September 2020, the Geo-Mapping for Energy and Minerals (GEM) program was renewed for \$100M over 7 years (2020–2027). GEM-GeoNorth will produce and provide new, public geoscientific data, knowledge, and maps for northern Canada, focusing on areas where economic and/or infrastructure development is likely to benefit northern communities. This national, multidisciplinary, and collaborative research will help inform land-use decisions, exploration for geological and mineral resources, and environmental assessments. The ultimate desired outcome of GEM-GeoNorth is the attractiveness of Canada's North for economic development of mineral resources in the context of a changing climate.

Additionally, GEM-GeoNorth scientists will incorporate more complementary climate change research into their studies, which will enhance our understanding of the rapidly changing environments, landscapes, and coastlines of the North, and how to mitigate these changes. This complementary climate change research will consider existing and future infrastructure related to mineral resource development, along with associated projects. Since the fall of 2020, GEM-GeoNorth has been co-developing its research priorities with provinces, territories, and Indigenous Governance Organizations (IGOs). Representing a first for NRCan's Geological Survey of Canada, this collaborative formal approach responds to

feedback received from northern and Indigenous governments, organizations, and institutions on the first iterations of the GEM program.

### What's next for GEM-GeoNorth?

Now in its second year, GEM-GeoNorth continues to align its research priorities with provinces and territories, as well as Indigenous governments and organizations. This process will also continue with consultation and engagement with Indigenous communities aiming to improve fieldwork plans in the North for the summer of 2023. A second call for grant proposals, aimed at increasing capacity building in the North, will be launched in the fall of 2022.



## Canada-3D (C3D)

### Program description

Core geoscience knowledge is critical to the overall management of the country's landmass and to decision-making related to natural resource development. Canada in 3D (C3D) scientists are working to develop a national surface and subsurface compilation of Canada's surficial, bedrock, and mantle geology to gain a better understanding of the geological structures and dynamic processes that lie beneath Canada.

C3D is a collaboration between Canadian federal, provincial, and territorial geological surveys, under the auspices of the National Geological Surveys Committee of Canada. To generate the compilation, GSC scientists are collaborating with national and international partners on the next generation of 3D geological modelling tools and new approaches to data visualization. The GSC is also working to make C3D products and methods publicly viewable online, and freely and openly available for download.

C3D is a 21st-century vision for the GSC, along with its territorial and provincial partners, for creating a synthesis of the geology of Canada and for imagining new ways of sharing this information to support our future sustainable low carbon economy.

### What's next for C3D?

The challenge for the near future is to build on foundational work and make C3D operational. The team will continue working in close collaboration with our partners to conduct geoscience research, disseminate information, and solve problems in an open, transparent, and accessible manner.

In the next few years, C3D will provide examples of this vision with new 3D models, map and data compilations, and integrated geological-geophysical products. This work will require improved workflows for leveraging legacy geo-information, new methods for handling large multi-property datasets with Artificial Intelligence driven approaches, and coordinating, standardizing, and upgrading our Information Technology/Information Management resources.



## United Nations Convention on the Law of the Sea (UNCLOS)

### Program description

Canada ratified the [United Nations Convention on the Law of the Sea](#) (UNCLOS) in 2003, and as a party to the treaty, has a legal obligation to define its continental shelf beyond 200 nautical miles by filing submissions, making formal presentations, and engaging with the Commission on the Limits of the Continental Shelf during the review process. The program is the joint responsibility of Global Affairs Canada (GAC), Natural Resources Canada (NRCan), and Fisheries and Oceans Canada (DFO). The program within the GSC is located at the Bedford Institute of Oceanography in Dartmouth, Nova Scotia, where scientific personnel with geological and geophysical expertise advise GAC on scientific and technical issues related to the continental shelf.

In addition to precisely defining the outer limits of its continental shelf following the criteria set forth in Article 76 of the Convention, submissions by coastal states must include robust scientific data and arguments showing that the continental shelf extends beyond 200 nautical miles and that it is a natural component and a natural prolongation of the landmass. Canada's two submissions (Atlantic Ocean, filed in 2013, and Arctic Ocean filed in 2019) show entitlement to 2.4 million km<sup>2</sup> of seafloor and subsoil, making it one of the largest areas considered by the United Nations under UNCLOS. International recognition of the outer limits will eventually become Canada's last boundaries on the map, conferring sovereign rights over the living and non-living resources on the seafloor and in the subsurface.

### What's next for UNCLOS?

The UNCLOS Program will continue to advise on scientific and technical issues related to the extended continental shelf, undertake marine geoscience research, and maintain Canada's two UNCLOS submissions. The Program will also continue to undertake science-related activities, finalize Canada's Arctic Ocean presentation for the UN, facilitate collaboration with international scientific partners, and advise the government on continental shelf issues.



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## **STRATEGIC PRIORITY 2: Geoscience for sustainable development**

The following information outlines the projects and briefly describes the activities for the seven programs within GSC Strategic Priority 2: Geoscience for sustainable development:

- [Targeted Geoscience Initiative \(TGI\)](#)
- [Environmental Geoscience Program \(EGP\)](#)
- [Groundwater Geoscience Program \(GGP\)](#)
- [Geoscience for New Energy Supply \(GNES\)](#)
- [Marine Conservation Targets \(MCT\)](#)
- [Marine Geoscience for Marine Spatial Planning \(MGMSP\)](#)
- [Environmental Impact Assessment Service \(EIAS\)](#)



## Targeted Geoscience Initiative (TGI)

### Program description

The Targeted Geoscience Initiative (TGI) supports the Government of Canada's priorities of leading strong economic growth and responsible resource development. The program provides innovative public geoscience to help the mineral exploration industry identify and develop mineral deposits in emerging and existing mining areas across the country, further enhancing Canada's reputation as a premier destination for exploration investment. In September 2020, TGI received program renewal on an ongoing basis at an incremental funding level of approximately \$5M per year, with a focus on critical minerals and metals.

Desired TGI outcomes include the use of the program's geoscience research by stakeholders to inform mineral exploration approaches, natural resource management decisions, and industry geoscience research (e.g., to generate predictive models of mineral potential), and to ultimately increase Canada's attractiveness for investment in responsible mineral exploration and development.

The TGI program supports Canada's mining sector by reducing investment risk through the delivery of world class public geoscience that promotes innovation, global competitiveness, and environmentally sound practices. By focusing on key mineral systems and novel analytical, laboratory, and field methods, TGI improves mineral exploration effectiveness through the creation of next-generation geological models, and the development of leading-edge exploration tools, innovative techniques, and predictive models.

To keep pace with scientific advances and emerging data-related technologies, TGI also places a strong emphasis on the effective delivery of public data and applications of artificial intelligence and related disruptive technologies. The TGI program builds on its ore systems research and leverages its data assets to create digitally driven, public-facing systems capable of creating predictive models and maps of Canada's mineral potential for key commodities.

### What's next for TGI?

With the program's renewal in the fall of 2020, TGI funded one- and two-year studies to lay the foundation for longer-term research activities under two research pillars: (1) Ore Systems, and (2) Digital Geoscience and Method Development. Studies under these two pillars have successfully met their short-term objectives, and in late 2022, TGI management will initiate a second call for internal research proposals to extend the current studies until March 2025, and to invite new internal research proposals for two-year studies.

In September 2022, the program will hold a second call for proposals for its grant program, which will support complementary studies by external institutions running from April 2023 to March 2025. These research projects will support the goals of TGI, extending the reach of the program and broadening its results.



## Environmental Geoscience Program (EGP)

### Program description

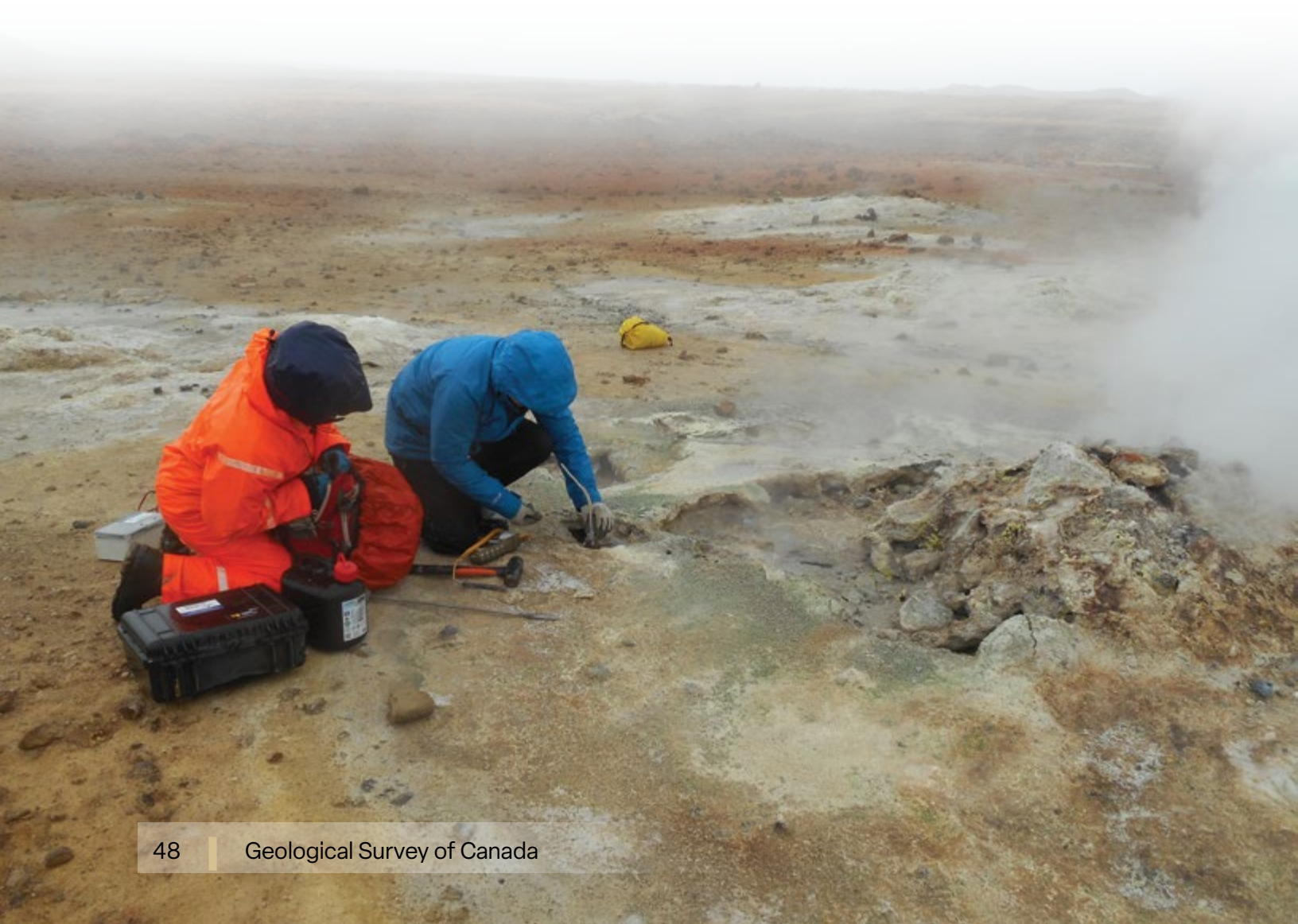
The goal of the Environmental Geoscience Program (EGP) is to provide innovative scientific information that makes it possible to distinguish between the environmental effects of natural resource development and those produced by natural processes. As part of this mandate, developing new approaches in geoscience supports the responsible use and development of Canada's natural resources through informed decision-making.

The ultimate desired outcome of the EGP is to increase the effectiveness and efficiency of Canadian environmental regulation and oversight.

By developing innovative geoscience for environmental stewardship, and by increasing public and private sector access to research findings, decision makers have a greater capacity to carry out and review environmental assessments.

### What's next for EGP?

Public presentations are held annually in May and made available on [EGP's YouTube page](#) and in [GEOSCAN](#). The next series of presentations will be in May 2023. The EGP is entering the final phase of its current program cycle (2019–2024). Over the coming year, scientists involved in 15 different projects will focus on finalizing the key deliverables of the program.





## Groundwater Geoscience Program (GGP)

### Program description

The goal of the Groundwater Geoscience Program (GGP) is to better understand groundwater distribution, quantity, and flow dynamics within integrated water models for sustainable water management.

During the 2019–2024 phase, GGP is focusing on five projects: (1) Archetypal aquifers (including Canada One Water or C1W); (2) Fox Creek aquifer systems; (3) Water Resources Characterization and Modelling (WRCM); (4) [Groundwater Information Network](#) (GIN); and, (5) Regional Assessment for the Ring of Fire. These projects are associated with research themes defined as groundwater inventories, cumulative effects, methods for assessing groundwater, data modelling, and dissemination.

In the short term, GGP's goal is to provide geoscience knowledge, tools, and information to understand aquifer systems, and to encourage governments and clients to use these tools. The medium-term goal is to incorporate more effective/efficient regulations and oversight, and the ultimate goal is better management of groundwater resources by responsible jurisdictions.

### What's next for GGP?

GGP will initiate discussions with stakeholders to define the new phase of the program for fiscal year 2024–2025.



## Geoscience for New Energy Supply (GNES)

### Program description

The goal of the Geoscience for New Energy Supply (GNES) Program is to support strategies for our transition to a future low-carbon economy through clean-energy geoscience research and development and the promotion of non- and low-emitting energy resources using advancements in the fundamental understanding of Canada's subsurface landmasses.

Research partnerships and collaborations are fundamental to the success of GSC programs. For example, GNES collaborations resulted in considerable direct and in-kind support from industry and other agencies. These leveraged funds and datasets enable the program to expand its scope into new, exciting, and innovative areas,

such as cloud computing/machine learning/AI, an expanded national knowledge base for the exploitation of geothermal energy, and offshore energy mapping through a partnership with the province of Nova Scotia. Collaborations also give GNES researchers access to knowledge from other national and international scientific institutions.

The program is actively providing project opportunities with university partners, building on Memoranda of Understanding. This includes training of highly qualified personnel (HQP) and shared lab capacities. This contributes greatly to delivery of innovative science and will continue throughout the program's life cycle.

### What's next for GNES?

With current program funding coming to a close, GNES will aim to successfully extend the program beyond March 2023.



## Marine Conservation Targets (MCT)

### Program description

The Marine Conservation Targets (MCT) program provides science-based estimates of offshore petroleum resource potential to inform decisions related to Canada's target of protecting 25% of its offshore lands by 2025 and 30% by 2030. The GSC is responsible for conducting the resource assessments in areas being considered by either the Department of Fisheries and Oceans Canada (DFO), Environment and Climate Change Canada (ECCC), and the Parks Canada Agency (PCA). GSC works very closely with the energy sector's Offshore Petroleum Management Division (OPMD) as it is responsible for the economic assessment of any petroleum potential in Canada's offshore territory. The GSC's MCT Program has a 5-year mandate, ending March 31, 2026.

### What's next for MCT?

The Marine Conservation Targets program will continue to develop and apply geological methods and assessment tools to provide scientific knowledge on offshore natural resources in support of Canada's conservation targets for 2025.



## Marine Geoscience for Marine Spatial Planning (MGMSPP)

### Program description

GSC's Marine Geoscience for Marine Spatial Planning (MGMSPP) Program is developing new maps and analyses of seafloor geology and active seabed processes to inform evidence-based decisions around marine spatial planning and regional environmental assessments. MGMSPP contributes to Fisheries and Oceans Canada (DFO) efforts to develop marine spatial plans and atlases for four of thirteen large offshore areas that DFO defines as Canada's bioregions.

The GSC's marine geoscience also supports Regional Environmental and Cumulative Effects Assessment processes. MGMSPP is producing new maps of seabed geology for offshore British Columbia (Salish Sea and Pacific North Coast) and offshore Atlantic Canada (Newfoundland and

Labrador, and Nova Scotia) that will be uploaded to Open Maps Canada/the Federal Geospatial Platform and accessible through the Marine Spatial Data Infrastructure.

Overall, the GSC will produce marine geoscience deliverables at the broad bioregion scale (seabed morphology, geology, and seabed disturbance), as well as more targeted studies to inform specific marine spatial planning objectives in the Atlantic and Pacific offshore. The general desired outcome for MGMSPP is that GSC's marine geoscience knowledge is used to support evidence-based decisions around the safe, effective, and sustainable use of the seabed.

### What's next for MGMSPP?

MGMSPP has prepared a Treasury Board Submission, to be delivered in the fall of 2022, that will enable the continuation and renewal of the program.



## Environmental Impact Assessment Service (EIAS)

### Program description

An impact assessment is a federal planning and decision-making tool used to assess the positive and negative environmental, economic, health, and social effects of proposed projects, as well as impacts on Indigenous groups and the rights of Indigenous peoples. The Impact Assessment Act outlines a process for assessing the impacts of major projects. Although the new Impact Assessment Act (IAA) was implemented in 2019, some projects continue to be assessed under the Canadian Environmental Assessment Act (2012).

The GSC is the lead federal agency for evaluating geoscience information in environmental impact statements. It is responsible for managing the coordination of federal environmental assessment reviews that require geoscience expertise. This includes ensuring that thorough, impartial, and timely advice is provided before projects proceed to the environmental assessments of the northern EA regimes and the Environmental Assessment (EA) under the Impact Assessment Agency of Canada,

pursuant to the department's legislated obligations. The EIAS also provides advice and technical support to experts all through the EA process and when participating in quasi-judicial Joint Review Panels following the impact assessments.

The GSC provides impartial scientific knowledge (honest broker) and advice and supports land use planning and environmentally sound resource development, both on land and in our coastal and offshore waters. In 2021–22, the GSC contributed geoscientific expertise to 44 projects at various stages of their life cycle. It also supports client needs and assists in informed federal economic and environmental decision-making.

### What's next for EIAS?

The EIAS continues to respond to questions and provide clarifications requested by various organizations during the EA process. A Memorandum of Understanding between NRCan and ECCC will underpin future hydrogeological considerations in the IA process. Efforts are also underway to develop and streamline guidelines for impact assessments, which will include groundwater/surface water interaction, to meet the needs and mandate of the GSC, DFO, and ECCC.



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### **STRATEGIC PRIORITY 3: Geoscience for keeping Canada safe**

The following information outlines the projects and briefly describes the activities for the two programs within GSC Strategic Priority 3: Geoscience for keeping Canada safe:

- [Climate Change Geoscience Program \(CCGP\)](#); and
- [Public Safety Geoscience Program \(PSGP\)](#).



## Climate Change Geoscience Program (CCGP)

### Program description

The GSC's Climate Change Geoscience Program (CCGP) aims to better understand the impacts of climate change in Canada. CCGP scientists conduct geoscientific research on permafrost, coastal erosion, sea-level change, extreme events such as droughts, and glacier melting. The program provides cutting-edge information and data to improve our understanding of how Canada's landmass is affected by climate change, to support land-use planning and infrastructure development, and to help industry and at-risk communities adapt.

By providing end users with access to CCGP knowledge products to support the identification of priorities for adaptation activities in Canada, and users implementing them, the desired long-term outcome is that adaptation measures are implemented by end users through codes, standards, guidelines, and best practices.

### What's next for CCGP?

The Climate Change Geoscience Program will continue and enhance its environmental monitoring activities in core research areas related to permafrost, coastal processes, and glacier changes; provide historical context for contemporary changes to support modelling of future conditions, including carbon cycling; and, work with partners to consider hazards and risks related to climate change.

CCGP will be guided by two significant ongoing national efforts: the National Adaptation Strategy (NAS), which provides a shared vision for climate resilience in Canada, and Climate Science 2050 Plan (CS2050), which identifies priority activities and coordinates national science investment and research planning. CCGP will continue its established collaborations with federal, provincial/territorial, Indigenous, and academic partners, and work to strengthen these partnerships and build new ones.



## Public Safety Geoscience Program (PSGP)

### Program description

The Public Safety Geoscience Program (PSGP) develops innovative knowledge and tools to support planning, emergency management, land-use development decisions, and regulatory approaches that increase resilience and decrease risk to keep Canadians safe from earthquakes, terrestrial and submarine landslides, volcanoes, tsunamis, and coastal flooding. The program works closely with Public Safety Canada and other federal departments to develop the National Risk Profile, a first-ever national-scale picture of disaster risks in Canada to support strategic investment in risk reduction. The Program's contributions provide an evidence base for understanding potential losses from earthquakes across the country.

The short-term desired outcome for PSGP is that federal, Indigenous, provincial, territorial, municipal, and industry decision makers—such as policy-makers, project proponents, emergency managers, community planners, and utility owners—have scientific evidence and quantitative tools to evaluate risk from geohazards, leading to all levels of government and Indigenous communities making evidence-based decisions for risk reduction, with the ultimate desired outcome of Canada being more resilient to natural hazards.

### What's next for PSGP?

In 2022–23, PSGP will launch a platform to share results from a neighbourhood-scale national risk assessment, which will include “what if” scenarios for seismically active regions of Canada. In addition, PSGP will work with partners from Germany and Japan to deploy ocean-bottom seismometers and pressure sensors on the seafloor on Canada's west coast to improve our understanding of the earthquake and tsunami regime in this region.

PSGP will work with partners, including the Canadian Hazards Information Service and the Canadian Centre for Mapping and Earth Observation, to execute an initiative funded by Defence Research and Development Canada to assess volcanic hazards and risks at volcanoes in southern BC, and to develop a workflow for monitoring these volcanoes through satellite-based remote sensing.

PSGP will also use drones, satellite imagery, and other innovative technologies to identify and assess landslides and earthquakes. The program will continue to work with communities in the North to better understand the hazards that affect them, particularly in the face of climate change.





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## **STRATEGIC PRIORITY 4: Geoscience for society**

The following information outlines the projects and briefly describes the activities for the two services within GSC Strategic Priority 4: Geoscience for society:

- [Open Geoscience Network \(OGN\)](#)
- [Indigenous Relations Network \(IRN\)](#)



## Open Geoscience Network (OGN)

### Program description

The purpose of the Open Geoscience Network is to enable digital transformation—that is, to evolve our traditional business models to meet the needs of today’s science and tech-savvy users, with technology playing an enabling role. This includes establishing a robust and modern digital and physical infrastructure to better store, manage, and disseminate GSC data, publications, sample information, and coding. The digital infrastructure will work with external federal tools such as Open Maps and the Open Science and Data Platform to facilitate discovery, access, and use. The GSC publication process will be modernized to incorporate open science principles and use new ways to compile information into useful formats and disseminate it effectively to diverse clients.

Open Geoscience is the practice of making geoscience outputs readily and easily available to

Canadians with minimal restrictions. The GSC’s scientific research outputs include peer-reviewed science articles and publications, scientific research, and technical data, including, in the longer term, GSC sample collection catalogues. Open Geoscience is enabled by our people, technology, and infrastructure. It is practised in full respect of privacy, security, ethical considerations, and appropriate intellectual property protection.

Making GSC geoscience data and information open accelerates the industry’s ability to find minerals and metals, improves management of water, energy, and mineral resources, helps protect Canadians from natural hazards, facilitates adaptation to climate change, and supports government decision-making and policy development regarding natural resources. The GSC works with provincial and territorial partners in a cooperative national approach to delivering Canada’s geoscience information.



## What's next for OGN?

The OGN will continue to expand its collaborative approach to addressing Open Geoscience issues, increasing participation in the areas of Open Access and Public Engagement and Synthesis and Integration. The network will further enhance the ability of clients and stakeholders to find, access, integrate, and reuse GSC publications and data, including our physical collections.

The OGN will continue making progress toward implementing corporate data governance and standards for managing GSC data, including compiling publications and technical information into more usable formats, using new ways to disseminate them effectively and openly to diverse clients. The OGN will continue to promote the efficient processing and sharing of geoscience data and information—as openly as possible and as securely as necessary—with our partners in

the National Geological Surveys Committee and beyond, by breaking down technical barriers and finding solutions to improve the accessibility, usability, and interoperability of geoscience data.

The GSC's digital transformation will continue with the modernization of GSC applications and broader support for the adoption of cloud computing. The OGN will complete the development of the GSC publications management tool, responding to client needs and rehosting the tool in NRCan's cloud environment. The OGN will also explore solutions to support greater discoverability of GSC's physical collections and develop an Information Technology (IT) architecture framework to facilitate future science computing and application development.



## Indigenous Relations Network (IRN)

### Program description

The Geological Survey of Canada (GSC) is continuing its work to build and maintain respectful, cooperative, and mutually beneficial relationships with Indigenous communities through its geoscience initiatives. As part of the work to move toward this goal, the GSC established the Indigenous Relations Network (IRN), an internal community of practice focused on supporting the organization's ability to build relations with Indigenous Peoples and conduct Indigenous engagement related to our mandate. The Indigenous Relations Network Secretariat and Steering Committee provide guidance and leadership to the IRN.

The Steering Committee is composed of divisional representatives who work collaboratively across the organization to support a national vision for Indigenous engagement at the GSC.

### What's next for IRN?

The IRN plans to continue to build on these successes and further strengthen this emergent community of practice by supporting the IRN Steering Committee, staff, and management with targeted training, further elaboration of tools, and organizing more staff engagement on Indigenous relations issues. The IRN will also assess the feasibility of transitioning the community of practice into a GSC Indigenous Engagement Office to provide coherence in approach across the GSC.



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## **STRATEGIC PRIORITY 5:** Our people, our science

The following information outlines the projects and briefly describes the activities for the service within GSC Strategic Priority 5: Our people, our science:

- **Science Laboratory Network (SLN)**



## Science Laboratory Network (SLN)

### Program description

The Science Laboratory Network (SLN) provides innovative lab-based research leadership and state-of-the-art analysis and interpretation for all GSC programs, increasing effectiveness, connectivity, and efficiency in GSC laboratories. The SLN is composed of five functional and horizontal laboratory groups across the six GSC divisions, based on research expertise. Each group has unique scientific areas of focus and a thematic range of research activities that support the GSC's geoscience programs. The operating model is a consultative/collaborative approach between lab-based scientists and other researchers, and SLN science leadership is embedded in GSC programs, providing integration with program outcomes. Lab-based scientists participate at the start of the project/program planning cycle and can provide innovative solutions. The SLN also conducts collaborative research with provincial, territorial, and academic partners, strengthening the scientific excellence of Canada's laboratories.

In 2021–22, the SLN contributed to GSC research objectives by delivering lab-based research for all GSC programs through 147 Lab Study Agreements, particularly through innovative and specialized laboratory analysis and interpretation.

### What's next for SLN?

Through major capital funding, the SLN is acquiring a state-of-the-art Multicollector Noble Gas Mass Spectrometer and ultra-high vacuum extraction line to develop new high precision methods to modernize the Noble Gas Laboratory. In addition, the existing instrument and extraction line will be repurposed for clay geochronology. These instruments will support essential research and analytical advances in the GSC Noble Gas Geochronology Laboratory and help meet the requirements of current and future GSC programs and activities.





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