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Geological Survey of Canada

Report on Results and Delivery 2020-2021

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Canada

Foreword

Throughout its long history, the Geological Survey of Canada (GSC) faced countless challenges and obstacles and still delivered world class geoscience. I am proud to say that 2020-21 was no different.

2020 heralded the start of the global COVID-19 pandemic, and by March 2020 federal employees were asked to work remotely, throwing carefully laid research plans into disarray. Our perspective changed drastically, as we peered through computer screens into a world filled with anxiety and turmoil. We grieved the loss of many, but like others, we adapted to a new reality.

With the help of partners and collaborators, we took steps to address obstacles and moved towards our goals. In June 2020, in collaboration with colleagues from the USGS and the EuroGeosurveys, we launched the new 'World Community of Geological Surveys' (WCOGS). With ~80 fellow survey leaders, we discussed the future of geological survey organisations in a post-COVID world and posted the resulting webinar on YouTube, entering a new era of remotely working. This was one of countless webinars and videoconferencing meetings that took place during the pandemic.

GSC staff supported the COVID effort by providing personal protective equipment to essential workers, adapting sampling programs and field work, building on existing science, reaching out to their colleagues and networks, and upholding the GSC principles of knowledge, excellence, and integrity. Building on these principles, GSC climate change scientists worked with the residents of Aklavik, Tuktoyaktuk, and Inuvik Indigenous communities to deploy seabed instruments to ensure continuity of an observational time series, while through our partnership with the Hakai Institute on the west coast, we deployed a new seismometer at a key location for studying marine geohazards. Other staff forged strong partnerships with local Indigenous communities to complete geoscience field work to support marine spatial planning; collaborations between GSC and the Canadian Hydrographic Service resulted in marine surveys in all four of Canada's Bioregions. We also tapped local university partners to collect samples to study the geothermal resource potential at Mount Meager. Through strategic networking initiatives, GSC scientists were able to achieve project goals, building on an established network of esteemed partners.

With laboratories across Canada also affected by COVID, GSC staff showed great adaptability. Scientists used existing data and innovative numerical modeling to produce journal papers and open files, and laboratory staff updated safety documents, lab manuals, methodologies and databases. As a result, 494 publications were released by GSC in 2020-21 (available through GEOSCAN).

Sharing GSC geoscience goes beyond publishing. Living up to our reputation as an international centre of geoscience excellence, in the past year GSC staff contributed to numerous domestic and global knowledge sharing initiatives. GSC converted the *Understanding Risk BC Symposium* to a series of virtual events, attracting over 1,000 attendees. The Canada3D project hosted a webinar with international partners on how to respond to societal needs with 3D geology. In collaboration with our federal TerraCanada partners, GSC launched an ongoing series of Virtual Science Talks. Although knowledge sharing this year may have been limited to digital spaces, GSC scientists are already incorporating lessons learned in planning future digital, face to face, and hybrid gatherings.

Progress in advancing the governance and infrastructure for GSC data, information systems and earth material collections was made, including expanding cloud computing capabilities. To enhance our digital capabilities, GSC geoscience experts are working with MILA[1] to apply artificial intelligence and machine learning to GSC data assets, to support mineral exploration in Canada. While we strived to stay ahead and gain from new efficiencies and extract new scientific insights from the continued transformation of the digital environment, GSC's physical assets remained equally important. Modern and accessible physical infrastructure are critical to support GSC geoscience. In Ottawa, the Earth Materials Collections group reviewed, catalogued, and moved more than 1,200 pallets and 1,500 cabinets of GSC samples to a new, state-of-the-art facility.

The GSC, through the Groundwater Geosciences Program, has been contributing to the discussion towards the establishment of the Canadian Water Agency, including a draft Freshwater Science Assessment Report and inputs to a data inventory for the Data Assessment.

GSC is a key player in the TerraCanada science hub, part of the Laboratories Canada 25-year strategy to strengthen federal science in Canada. A multi-partner network anchored by modern infrastructure, TerraCanada will attract and retain global talent and promote opportunities for diverse researchers and students, building the next generation of federal science leadership. As co-lead among TerraCanada's five federal partners, NRCan's participation includes scientists from three GSC divisions (Northern, Central, and Quebec), as well as CanmetMINING and CanmetMATERIALS.

This focus on ongoing scientific excellence and expertise is reflected in the $135 M federal government investment over seven years to renew two of the GSC's flagship programs: Geo-Mapping for Energy and Minerals (GEM-GeoNorth) and the Targeted Geoscience Initiative (TGI). GEM-GeoNorth and TGI support the Canadian minerals GeoNorth and metals industries' recovery, ensure the competitiveness of the Canadian mining sector and support community engagement in land-use planning. In a first for the GSC, GEM-GeoNorth has launched a dialogue to co-develop research priorities with participation of 10 provinces and territories, and nearly 60 Indigenous Governments and representative organizations, building upon strong relationships established over the past 12 years. This dialogue will guide the program in providing new, public geoscientific data, knowledge and maps for northern Canada, focusing on natural resource economic development areas, and related infrastructure, in the context of a changing climate. This past year, TGI conducted 34 studies that set the foundation for longer-term research beginning in 2021-22. TGI research focuses on enhancing understanding of the processes that formed Canada's critical metal and other economically important mineral deposits at depth through the development of next-generation geological models, as well as leading-edge mineral targeting methods that will guide exploration in emerging and existing mining areas.

In support of the federal Canadian Minerals and Metals Plan (CMMP) Action Plan, the GSC is working collaboratively with provincial/territorial geological surveys on a Pan-Canadian Geoscience Strategy to produce better data to find the mines of tomorrow, lower exploration risk, boost competitiveness,

[1] Montreal Institute for Learning Algorithms

support land-use decisions, and enhance public safety by reducing risks from natural hazards.

Next year will be a year of transition as we consider the future of work at GSC. As we look to the safety and welfare of our valued staff, we also need to continue planning for the long-term success of GSC. We will continue to nurture and grow a resilient and high-performing workforce, founded upon the principles of diversity, inclusion, and collaboration. Future work at the GSC will build upon our new Indigenous Relations Network, designed to support a vision of enhancing Indigenous relations through collaborative geoscience. We will continue to identify key human resource management pressures, assess capacity and resources, and shape the future of the GSC workplace.

The GSC would be nothing without the dedication, determination, and drive of its people. Thank you to all GSC staff who rose to the challenges of the past year -- supporting Canada and advancing the mandate of NRCan, and the GSC. We helped each other, reached out to our surrounding and virtual communities across Canada and the world, with strength, empathy, and professionalism. Our efforts have not gone unnoticed, and we can all be proud to head into the next year as we continue to uphold the GSC as a global centre of geoscientific excellence. On behalf of all GSC staff, I am honoured to present this 2020-21 Report on our Results and Delivery.

Daniel Lebel, Ph.D.
Director General of the Geological Survey of Canada
Lands and Minerals Sector, Natural Resources Canada
Ottawa, Canada

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Report Overview

The Geological Survey of Canada (GSC) is Canada's national organization for public geoscientific 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. Its expertise focuses on the sustainable development of Canada's mineral, energy, and water resources; the stewardship of Canada's environment; the management of natural geological and related hazards; and the development of technological innovation and support for the competitiveness of Canada's geological resources.

In this annual *Report on Results and Delivery* you can find information on:

- The GSC's mandate, mission and organizational structure (page 13);
- The GSC's strategic priorities and associated programs and services (page 20); and
- Success stories from each program's 2020-21 projects (page 27).

Most GSC science programs are developed as inputs to support federal policy, or are instruments of federal policy. The annexes of this report include detailed information on:

- How the GSC supports NRCan's departmental reporting obligations through three Performance Information Profiles (PIPs) (page 85); and
- The science programs, projects and activities (page 85).

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 help to keep Canadians safe.

GSC Mandate

The GSC has a number of legislated obligations under various federal acts. The mandate of the GSC includes the following legislated requirements:

- Making a full and scientific examination and survey of the geological structure and mineralogy of Canada (*Resources and Technical Surveys Act*, 1985);
- Enhancing the responsible development and use of Canada's natural resources and the competitiveness of Canada's natural resources products (*Department of Natural Resources Act*, 1994);
- Supporting the sustainable development and management of Canada's natural resources (*Department of Natural Resources Act*, 1994); and,
- Providing expert information to support federal environmental assessments (*Impact Assessment Act* (2019)).

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. In addition, 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.

To better serve Canadians and make its geoscience more easily accessible, the GSC launched a revamped website in 2021. In addition to information about the GSC's programs, according to thematic focus areas, the website includes Popular items, Resources (tools, data, research) as well as Featured items.

The GSC directly contributes to the four main priorities laid out in the 2020 Speech from the Throne and 2020 Fall Economic Statement:

- Protecting public health (PSG; CCGP);
- Ensuring a strong economic recovery (GEM-GeoNorth; TGI);
- Promoting a cleaner environment (GNES; EGP; GGP; EAIS); and,
- Standing up for fairness and equality (IRS; Generation 8).

CCGP – Climate Change Geoscience Program
EIAS – Environmental Impact Assessment Service
EGP – Environmental Geoscience Program
GGP – Groundwater Geoscience Program
GEM-GeoNorth – Geo-Mapping for Energy and Minerals GeoNorth
GNES – Geoscience for New Energy Supply
IRN – Indigenous Relations Network
PSGP – Public Safety Geoscience Program
TGI – Targeted Geoscience Initiative

To support Canada's commitment to open science, GSC's geoscience is published in the GEOSCAN database. GEOSCAN features over 85,000 records (various reports, maps, presentations and data), as well as records on external publications authored by NRCan scientists and specialists.

GSC Mission

The GSC's Mission is to provide authoritative geoscience knowledge to inform the stewardship of Canada's onshore and offshore lands, to sustain responsible resource development for future generations, and to keep Canada safe from natural hazards and related risks.

GSC Organizational Structure

The GSC is led by a Director General who provides overall leadership on GSC files. Six regional divisions across Canada share program delivery and provincial and territorial liaison responsibilities for the GSC. The GSC also has an office led by a Director dedicated to helping Canada meet its commitments under the United Nations Convention on the Law of the Sea (UNCLOS).

Table 1: *Geological Survey of Canada Management Team (as of March 31st, 2021)*

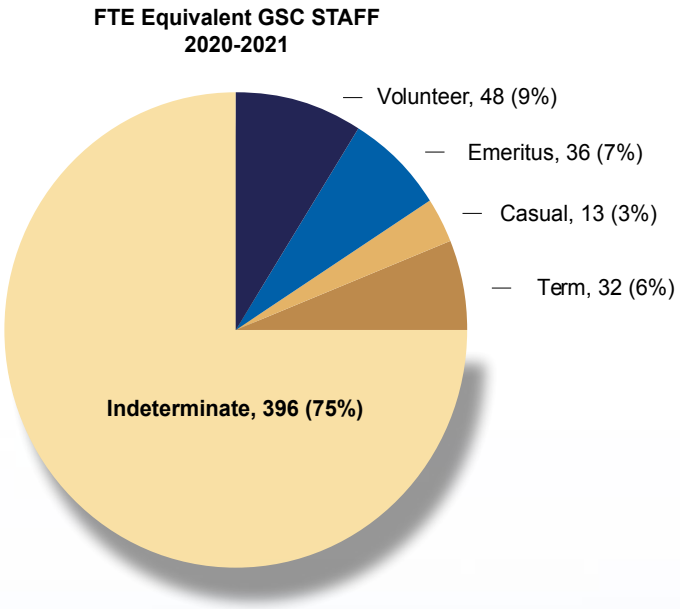
DIRECTOR GENERAL: DANIEL LEBEL				
GSC Division	**Director**	**Program / Service files**	**Provincial / Territorial Liaison**	**International Liaison**
Pacific Division: 9860 West Saanich Road Sidney BC V8L 4B2 1500–605 Robson Street Vancouver BC V6B 5J3	Sonia Talwar Sonia.Talwar@nrcan-rncan.gc.ca	Public Safety Geoscience	British Columbia	Asia, Latin America
Calgary Division 3303 33 Street NW Calgary Alberta T2L 2A7	Sonya Dehler Sonya.Dehler@nrcan-rncan.gc.ca	Geoscience for New Energy Supply; Marine Conservation Targets	Alberta, Saskatchewan	India, Russia
Northern Division: 601 Booth Street Ottawa ON K1A 0E8 Canada-Nunavut Geoscience Office 1106 Ikaluktuutiak Drive Iqaluit NU X0A 0H0	Linda Richard Linda.Richard@nrcan-rncan.gc.ca	Geo-mapping for Energy and Minerals-GeoNorth; Environmental Impact Assessment Service; Science Laboratory Network	Nunavut, Northwest Territories, Yukon	Africa
Central Division: 601 Booth Street Ottawa ON K1A 0E8	Geneviève Marquis Genevieve.Marquis@nrcan-rncan.gc.ca	Targeted Geoscience Initiative; Open Geoscience Network; Canada in 3D	Ontario, Manitoba	Australia, United States, China

DIRECTOR GENERAL: DANIEL LEBEL				
GSC Division	**Director**	**Program / Service files**	**Provincial / Territorial Liaison**	**International Liaison**
Quebec Division: 490, rue de la Couronne Québec QC G1K 9A9	Réjean Couture Rejean.Couture@nrcan-rncan.gc.ca	Groundwater Geoscience Program; Environmental Geoscience Program	Quebec, New Brunswick	Europe
Atlantic Division: 1 Challenger Drive Dartmouth NS B2Y 4A2	Stephen Locke Stephen.Locke@nrcan-rncan.gc.ca	Climate Change Geoscience; Marine Geoscience for Marine Spatial Planning	Nova Scotia, Prince Edward Island, Newfoundland and Labrador	Ocean initiatives, United Nations Framework, Convention on Climate Change (UNFCC), Intergovernmental Panel on Climate Change (IPCC)
United Nations Convention on the Law of the Sea: 1 Challenger Drive Dartmouth NS B2Y 4A2	Mary-Lynn Dickson Mary-Lynn.Dickson@nrcan-rncan.gc.ca	United Nations Convention on the Law of the Sea (UNCLOS) Program		A5 nations: Denmark, Norway, Russia and the United States; US Great Lakes Bottom Mapping SC; GEBCO-Seabed 2030

GSC Staff

The GSC is committed to developing and maintaining a resilient, high-performing, and diverse workforce and is committed to implementing the Government of Canada's Employment Equity goals and targets. In 2020-21 the GSC employed 474 individuals across Canada in various part-time and full-time tenures. In addition to permanent and contract employees, the GSC also employs students as part of a targeted approach to developing highly qualified personnel. In addition, the GSC has the honour of hosting 35 emeritus scientists – former GSC scientists who, amongst other things, continue to mentor GSC scientists and complete work they began while they themselves were GSC scientists – along with 48 volunteers who make varied contributions to support the organisation.

Figure 1: *Full time equivalent (FTE) GSC staff, 2020-21*



Results and Delivery

GSC Reporting Structure within the Government of Canada

The Government of Canada's Policy on Results sets out the fundamental requirements for Canadian federal departmental accountability. It highlights the importance of results and ensures open and transparent public reporting.

Under the *Policy on Results*, each department in the Government of Canada develops a Departmental Results Framework (DRF) identifying core areas of responsibilities. Departmental Results Reports (DRRs) are individual department and agency accounts of results achieved against planned performance expectations as set out in respective Departmental Plans. NRCan's three core areas of responsibilities are:

- Natural Resource Science and Risk Mitigation;
- Innovative and Sustainable Natural Resources Development; and,
- Globally Competitive Natural Resource Sectors.

The GSC supports the NRCan priority, "Natural Resource Science and Risk Mitigation" and reports against it in the NRCan Performance Information Profiles (PIPs); more specifically the GSC reports against the following areas under this priority:

1. Geological Knowledge for Canada's Onshore and Offshore Lands;
2. Geoscience for Sustainable Development; and
3. Geoscience for Keeping Canada Safe.

The GSC contribution to Natural Resources Canada (NRCan) results and delivery processes can be found in Annex I and II, as follows:

Annex I:

- Department Results Framework (DRF);
- Performance Information Profiles (PIPs);

Annex II:

- GSC Science programs/services and activities.

> Find more information on results, financial and human resources related to the 2019-20 Departmental Plan here.

GSC Strategic Priorities

To fulfil 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 the priorities' implementation.

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

1. Geological Knowledge for Canada's Onshore and Offshore Lands;
2. Geoscience for Sustainable Development;
3. Geoscience for Keeping Canada Safe;
4. Geoscience for Society; and
5. Our Science, Our People.

Priorities 1-3 outline the key scientific contributions to NRCan's strategic priorities by producing new geoscience knowledge and are aligned with NRCan DRF and LMS PIP priorities. Priorities 4 and 5 describe organizational and business objectives to sustain capacity and foster a healthy work environment that is required to conduct efficient, effective, and relevant work. The table below demonstrates linkages and alignment.

Table 2: *Geological Survey of Canada's Results & Delivery Reporting Structure*

NRCan DRF Core Responsibility	NRCan DRF Program, LMS PIP, and GSC Strategic Priority (SP)	LMS PIP Projects	GSC Science Programs / Services
Natural Resource Science and Risk Mitigation	SP-1: Geological Knowledge for Canada's Onshore and Offshore Lands	Geo-mapping for Energy and Minerals Canada's Extended Continental Shelf Program	Geo-mapping for Energy and Minerals-GeoNorth (GEM-GeoNorth) United Nations Convention on the Law of the Sea (UNCLOS) Program Canada in 3D (C3D)
	SP-2: Geoscience for Sustainable Development	Environmental Studies and Assessment Groundwater Geoscience Targeted Geoscience Initiative Geoscience for New Energy Supply	Environmental Impact Assessment Service (EIAS) Environmental Geoscience Program (EGP) Groundwater Geoscience Program (GGP)

NRCan DRF Core Responsibility	NRCan DRF Program, LMS PIP, and GSC Strategic Priority (SP)	LMS PIP Projects	GSC Science Programs / Services
			Targeted Geoscience Initiative (TGI) Geoscience for New Energy Supply Program (GNES) Marine Conservation Targets Program (MCT) Marine Geoscience for Marine Spatial Planning Program (MGMSP)
	SP-3: Geoscience for Keeping Canada Safe	Geo-hazards and Public Safety	Public Safety Geoscience Program (PSGP) Climate Change Geoscience Program (CCGP)
N/A	SP-4: Geoscience for Society *(Not part of DRF or PIPs)		Open Geoscience Network (OGN) Indigenous Relations Network (IRN)
	SP-5: Our People, Our Science *(Not part of DRF or PIPs)		Science Laboratory Network (SLN) TerraCanada Pan-Canadian Geoscience Strategy

More information about NRCan's DRF can be found online.

GSC Science Programs and Initiatives

The GSC develops S&T and other geoscience information products to support government policy, regulatory decision-making, or policy implementation. Like other policy instruments, the uses of S&T are as varied as the purposes of the policies themselves; for example, over the years GSC S&T has been used to:

- Support economic development;
- Support regulatory and policy development;
- Demonstrate compliance with international agreements;
- Develop national and international standards;
- Supply public-good products and services;
- Support public health and welfare for civil and national safety, and environmental protection;
- Provide knowledge and technologies to anticipate and respond quickly to national priorities;
- Support domestic and international diplomacy;
- Assert sovereignty at home;
- Support nation building;
- Meet domestic and international obligations;
- Incent behavioural change; and
- Ensure that international policy is based on scientific principles.

In order to conduct its S&T, the GSC collaborates with scientists across Canada and the world. For example, over the last five years, GSC scientists have published peer-reviewed papers with coauthors from over 110 different countries.

GSC science information is open and distributed through the Government of Canada's GEOSCAN bibliographic database and various social media venues.

The GSC delivers its science through programs/ initiatives which are broken down into projects and activities (Annex 2, page 97):

Table 3: *Geological Survey of Canada's Programs and Initiatives*

PROGRAM/ INITIATIVE	OBJECTIVES
Strategic Priority 1: Geological Knowledge for Canada's Onshore and Offshore Lands	
Canada in 3D (C3D)	Developing a national surface and subsurface compilation of the surficial, bedrock and mantle geology of Canada to help better understand the geological structures and dynamic processes below Canada's territory.
Geo-mapping for Energy and Minerals-GeoNorth (GEM-GeoNorth)	Producing and providing 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, and to incorporate more 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.

PROGRAM/ INITIATIVE	OBJECTIVES
Strategic Priority 1: Geological Knowledge for Canada's Onshore and Offshore Lands	
United Nations Convention on the Law of the Sea (UNCLOS) Program	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 continental shelf beyond 200 nautical miles using robust scientific data.
Strategic Priority 2: Geoscience for Sustainable Development	
Environmental Geoscience Program (EGP)	Distinguishing the environmental effects of natural resource development from those produced by natural processes, and to develop new approaches to support the sustainable use and development of Canada's natural resources through informed decision-making.
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, ensuring timely and effective delivery of geoscience information and advice pursuant to department's legislated obligations.
Geoscience for New Energy Supply Program (GNES)	Supporting 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.
Groundwater Geoscience Program (GGP)	Better understanding groundwater distribution, quantity, and flow dynamics within integrated water models for sustainable water management and natural resource development.
Marine Conservation Targets Program (MCT)	Providing resource assessments for offshore and coastal areas under consideration for conservation measures in support of the Marine Conservation Strategy. The MCT program received approval for a next phase of funding from the Treasury Board of Canada in September 2021.

PROGRAM/ INITIATIVE	OBJECTIVES
Strategic Priority 2: Geoscience for Sustainable Development	
Marine Geoscience for Marine Spatial Planning Program (MGMSP)	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.
Targeted Geoscience Initiative (TGI)	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 destination for exploration investment. By focusing on key mineral systems and enhanced analytical, laboratory, and field methods, TGI improves mineral exploration effectiveness through next-generation geological modelling, as well as leading edge tools, innovative techniques, and predictive models.
Strategic Priority 3: Geoscience for Keeping Canada Safe	
Climate Change Geoscience Program (CCGP)	Better understanding the impacts of climate change in Canada by providing cutting-edge information and data to improve our understanding of how Canada's landmass is affected by climate change in order to support land-use planning, infrastructure development, and to help industry and at-risk communities 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.

PROGRAM/ INITIATIVE	OBJECTIVES
Strategic Priority 4: Geoscience for Society	
Open Geoscience Network (OGN)	Making geoscience outputs readily and easily available to Canadians with minimal restrictions through five nodes: Open Access and Public Engagement Node; Information Systems and Data Node; Information Technology Node; Collections Node; and, Governance and Collaboration Node.
Indigenous Relations Network	Working with Indigenous communities to increase our shared understanding of geoscience, including through advisory bodies, hunters and trappers organizations and game councils, and Elders and other knowledge holders. The GSC is increasing and strengthening its internal Indigenous relations capacity and is codifying ethical and respectful ways to co-develop projects with Indigenous communities.
Strategic Priority 5: Our People, Our Science	
Generation 8	Ensuring GSC science remains relevant and impactful through: • Increased science-policy relevance and impact; • Strategic partnerships/collaborations; • Targeted user needs; • Empowered staff (innovation, development & renewal); • New approaches, methods, ideas; • Efficient and effective systems and infrastructure; and • Improved internal and external communications.
Pan-Canadian Geoscience Strategy	Working collaboratively across jurisdictions on shared priorities to provide geoscience information that underpins the responsible development of Canada's geo-resources and serve the public good.

PROGRAM/ INITIATIVE	OBJECTIVES
Strategic Priority 5: Our People, Our Science	
Science Laboratory Network (SLN)	Providing 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. SLN is composed of five functional and horizontal laboratory groups across the six GSC divisions.
TerraCanada	Providing new buildings and laboratory infrastructures through the TerraCanada Science and Innovation hub to bring together five federal partners (including the GSC and NRCan), with complementary mandates, to jointly experiment, discover, and develop scientific knowledge and solutions.

Science and Technology Success Stories

The following GSC 2020-21 success stories are aligned with the GSC's strategic priorities (Annex I) and highlight some of the ways GSC S&T is supporting Canada's policy objectives. Annex II presents a high-level overview of the GSC programs/initiatives.

Strategic Priority 1: Geological Knowledge for Canada's Onshore and Offshore Lands

There are three GSC S&T programs within GSC Strategic Priority 1:

- Geo-Mapping for Energy and Minerals-GeoNorth (GEM-GeoNorth);
- United Nations Convention on the Law of the Sea (UNCLOS); and
- Canada in 3D.

Canada in 3D (C3D)

Program description

Core geoscience knowledge is critical to 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 the surficial, bedrock and mantle geology of Canada to help better understand the geological structures and dynamic processes below Canada's territory. C3D is a collaboration between Canadian federal, provincial and 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 publically viewable online, and freely and openly available for download. C3D is thus creating a synthesis of the geology of Canada and acting as an online gateway to its access and use.

Recent successes include:

Re-engineering the Canada3D web portal

With the transition to the cloud computing environment, the C3D web portal underwent a significant re-tooling in 2021/2022. The launch of the portal will take place in a phased approach during 2021/2022 in collaboration with Provincial and Territorial partners.

Completing new online Bedrock and Surficial Geology maps of the North

GSC experts have compiled over 200 bedrock and surficial geology maps to create a new synthesis of the geology of the North in the online interactive platform. This work combined advanced scientific and technical methods to generate a uniform scientific understanding, as well as a seamless and well-described database of the geology of the North. As an evergreen application, the synthesis will be continually updated with new mapping data from the GSC and from Provincial and Territorial counterparts.

Figure 2: *C3D web portal landing page which provides an entry point to interactive map delivery and hyperlinked bibliographic content*

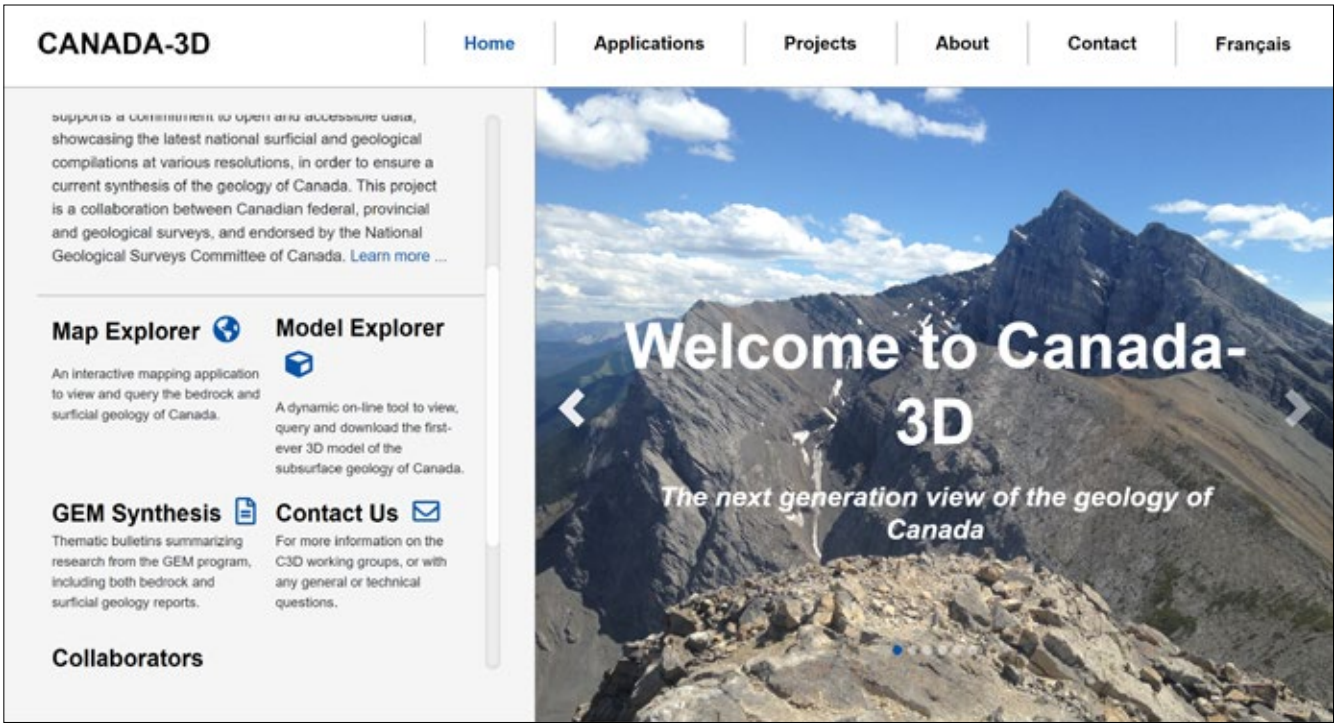
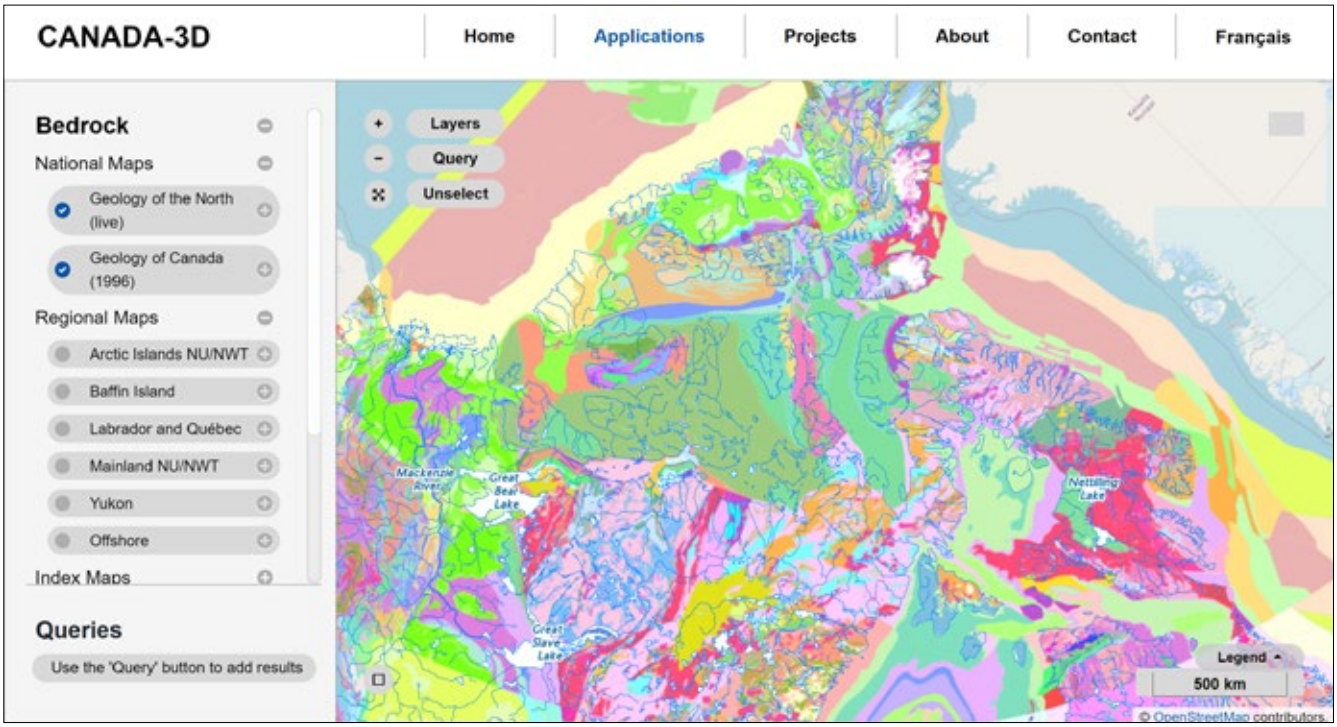


Figure 3: *Current Interface presented for bedrock geological map compilation of Arctic Canada*

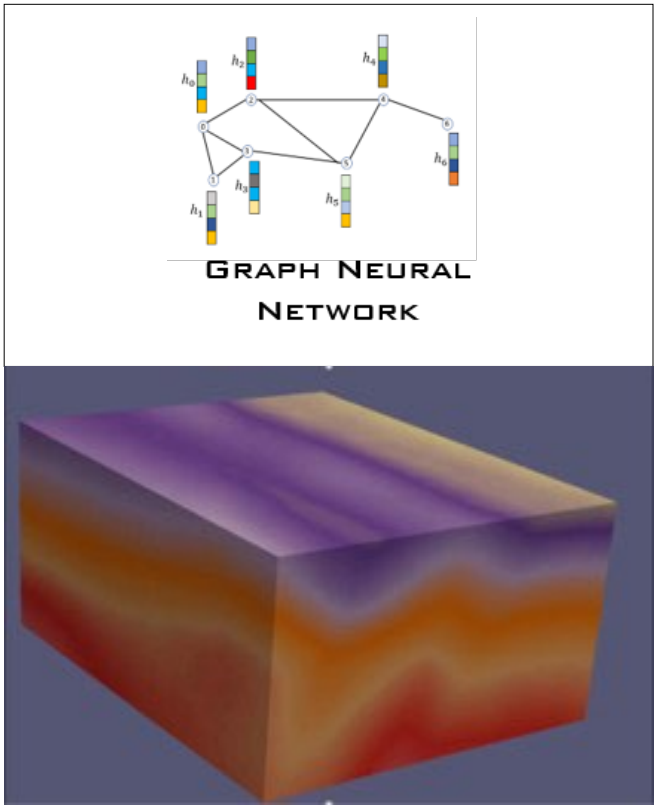


Advancing 3D methods

In addition to map representations of the geology of Canada, GSC scientists are working on a national subsurface 3D model to represent the latest spatial and temporal distribution of the geology of the country. To achieve this, GSC scientists are developing advanced AI (Graph Neural Network) methods for

3D modelling to help fill areas with sparse data with rich knowledge found in maps, reports, and other sources. These methods will be critical to overcoming significant barriers to modelling and visualizing the massive amounts of geological data available for a country the size of Canada.

Figure 4: *Representation of a Graph Neural Network*



Updating the regional southern Ontario 3D model

GSC scientists from the Groundwater Geoscience Program (GGP) and the C3D team collaborated to develop a 3D model of southern Ontario spanning 110,000 square kilometers. The model encompasses both the Phanerozoic geology and supports a fully-coupled groundwater-surface-water model.

This advanced model development was instrumental in obtaining collaborative funding of $500,000 from the Nuclear Waste Management Organization (NWMO) for the C3D project, with an objective of supporting impartial regional scale context for more site specific activities and public communication.

Sharing 3D modeling knowledge across the globe

C3D team members shared results of their work in many forums this past year. These include international conferences in Canada, the US, Europe and Australia. GSC scientists organized and presented at international webinars for the global geoscience community. Publication of research results, as well as data and model developments, have been completed through peer-reviewed journals and GSC open file reports. C3D work contributed to advancing international data standards and ontologies, putting the GSC in a position of influence and ensuing our interests are well represented globally.

What's next for C3D?

In the coming year, C3D will continue research efforts on 3D models and methods development and deploy these methods in advancing the first complete 3D geological model for the Canadian subsurface, with an emphasis on an integrated geological model of the Prairies.

C3D will also continue to host online the Geo-Mapping for Energy and Minerals Program's Synthesis, and will increase the GEM content available through the portal. This Synthesis is a compendium of all the geoscience data and

information garnered over the course of the program and provides a coherent story of Canada's northern geology. The Synthesis is organized in 'GSC Bulletins,' which include both bedrock and surficial geology reports.

Geo-Mapping for Energy and Minerals-GeoNorth (GEM-GeoNorth)

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 attractiveness of Canada's North for mineral resource economic development in a context of 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 coasts in 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 and 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 regarding the first iterations of the GEM program.

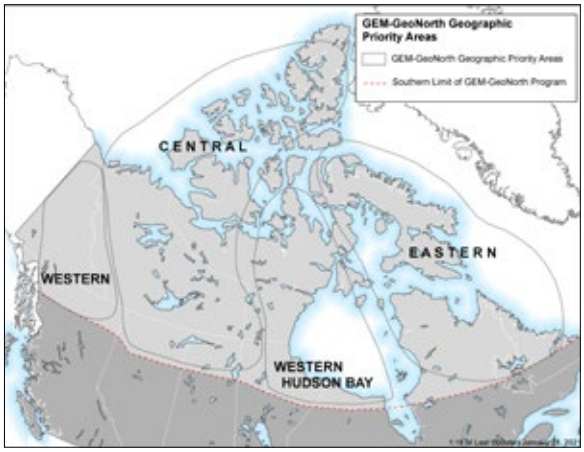
Recent successes include:

Co-developing research priorities with jurisdictions and Indigenous groups

Building upon strong relationships established over its past 12 years of geoscience research, GEM-GeoNorth is actively collaborating with ten provinces and territories (P/Ts), as well as 60 Indigenous Governments and Indigenous organizations (IGs and IOs), to create a new, formalized process to co-develop research priorities. The program's co-development approach is multi-stage and iterative:

1. **Creating a working framework:** GEM-GeoNorth and the Directors of the P/T Geological Surveys have regular meetings to create a collaborative and transparent approach to co-development.
2. **Identifying research priorities:** In 2020, GEM-GeoNorth held a series of regional workshops with federal, provincial and territorial scientists to identify an initial set of draft geographic and thematic priorities. As a result, GEM-GeoNorth has framed Canada's North into four geographic priority regions (Western, Central, Western Hudson Bay and Eastern), plus pan-North thematic priorities.

Figure 5: *GEM-GeoNorth Priority Areas*



These priorities guided the first series of internal research activities (Step 3), and continues to inform dialogue with IGs and IOs (Step 4).

3. **Defining the first research activities:** NRCan launched an initial call for proposals in Winter 2021, open to all NRCan scientists, to define an initial slate of research activities that are transitional/foundational to the program and aligned with the draft priorities identified in collaboration with P/Ts (Step 2). This initial call for proposals yielded 64 proposals from four NRCan sectors. Thirty-six proposals have been approved for funding for the 2021-2022 fiscal year. Additional calls for proposals will follow as the priority-setting dialogue with IGs and IOs continues.

4. **Dialoguing with IGs and IOs:** GEM-GeoNorth and P/T Indigenous Engagement practitioners have identified IGs and IOs to collaborate on setting draft priorities. This dialogue will seek to include the perspectives and priorities of interested IGOs and to maximize benefits for Northerners within the mandate of GEM-GeoNorth, and establish a fruitful and collaborative relationship that can continue throughout the lifecycle of the program.
5. **Adding areas of collaboration and research:** GEM-GeoNorth and the P/Ts agreed to continue their collaborative dialogue on priority-setting. New draft priorities will be included in the dialogue with IGs and IOs and
6. **Adding areas of collaboration and research:** GEM-GeoNorth and the P/Ts agreed to continue their collaborative dialogue on priority-setting. New draft priorities will be included in the dialogue with IGs and IOs and future calls for proposals.
7. **Continuing dialogue:** This new approach with P/Ts and IGs and IOs, and its regular assessment, will continue for the duration of GEM-GeoNorth and may inform the design of future programs.

This collaborative, iterative approach has already received accolades from P/Ts regarding its openness and transparency in the priority-setting process.

Bringing 400 geoscientists together

In October 2020, GSC scientists co-hosted the *Cordilleran Geoscience: A 2020 Perspective* workshop with the British Columbia Geological Survey, the Yukon Geological Survey, and Global Affairs Canada. The virtual event was devoted to the latest research about the geology, geophysics, metallogeny, and mineral deposits of the Cordillera. The workshop highlighted geoscientific work conducted in the Cordilleras at both the federal and provincial/territorial level, and identified existing scientific knowledge gaps and potential avenues for future research.

What's next for GEM-GeoNorth?

GEM-GeoNorth will continue with Steps 4 to 6 of the newly-established collaborative priority-setting process with P/Ts and IGs and IOs, incorporating diverse perspectives and priorities to maximize benefits for Northerners within the GEM-GeoNorth mandate.

GEM-GeoNorth will also continue to convene an Advisory Group of Northerners (AGN), representing the diversity of the North (Indigenous socio-economic development organizations, private sector and territorial governments). This approach builds on the role of the AGN in past program iterations. The AGN will continue to provide key advice on building respectful and sustainable relationships with Indigenous and Northern peoples, communities, and organizations, as well as maximizing the uptake of data and knowledge by Northerners.

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 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 km² 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.

Recent successes include:

Strengthening collaboration domestically and internationally

The UNCLOS Program undertook extensive consultations with GAC and DFO on scientific issues related to the extended continental shelf in the Arctic Ocean. Work progressed on the development of Canada's presentation on its Arctic Ocean submission that will be given to the UN Commission on the Limits of the Continental Shelf during a future plenary session. Scientists with the program continue to collaborate with international collaborators in the United States Geological Survey, the Geological Survey of Denmark and Greenland, Dalhousie University (Canada) and the University of Oslo (Norway).

Continuing to contribute important marine research

Scientific papers published in the last year include:

- Boggild, K., Mosher, D.C., Travaglini, P., Gebhardt, C. and Mayer, L. 2020. Mass wasting on Alpha Ridge in the Arctic Ocean: new insights from multibeam bathymetry and sub-bottom profiler data. Geological Society, London, Special Publications, 500, 323–340, https://doi.org/10.1144/SP500-2019-196
- Dossing, A., Gaina, C., Jackson, H.R. and O.B. Andersen. 2020. Cretaceous ocean formation in the High Arctic. Earth and Planetary Science Letters, 551: 116552
- Jakobsson, M., Mayer, L.A., Bringensparr, C. et al. 2020. The International Bathymetric Chart of the Arctic Ocean Version 4.0. Sci Data 7, 176, https://doi.org/10.1038/s41597-020-0520

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.

Strategic Priority 2: Geoscience for Sustainable Development

There are seven GSC S&T programs within GSC Strategic Priority 2:

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

Geoscience for New Energy Supply (GNES) and Marine Conservation Targets (MCT)

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 GSC program success. For example, GNES collaborations resulted in considerable direct and in-kind support from industry and other agencies. These leveraged funds and data sets enable the program to expand its scope into new and exciting innovative areas such as cloud computing/machine learning/AI, an increased national knowledge base for the exploitation of geothermal energy, and offshore energy mapping through partnership with the province of Nova Scotia. Collaborations also give GNES researchers access to knowledge from other national and international scientific institutions.

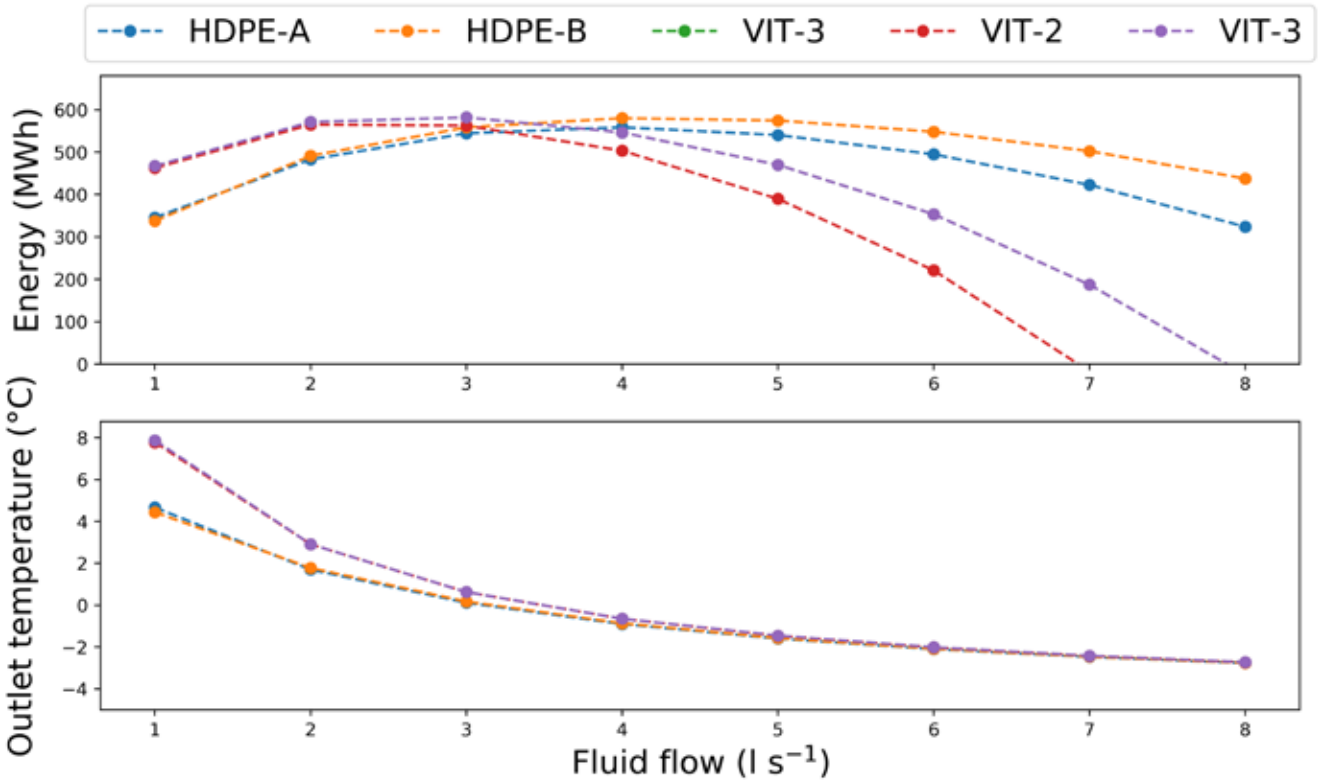
The program is actively providing opportunities in projects with university partners, building on Memoranda of Understanding. Training of highly qualified personnel (HQP) and shared lab capacities contribute greatly to delivery of innovative science and will continue through the program's remaining three years.

Recent successes include:

Repurposing oil and gas wells for geothermal heating

This project investigated the potential for heat production in sedimentary basins with low geothermal gradients. GSC researchers focused on Deep Borehole Heat Exchangers (DBHEs) in the St. Lawrence Lowlands (Bécancour), Quebec. The project demonstrated that the proof of concept for repurposing and retrofitting an oil and gas well for geothermal heating is feasible when using existing well infrastructure.

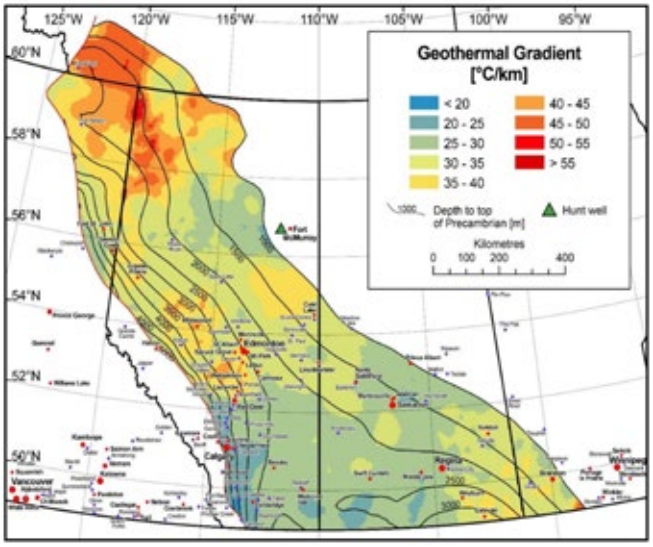
Figure 6: *Net energy (top) and outlet temperature after 1 year of operation (bottom) simulated using the following case: a 1500 m inactive O&G well with a 1000 m casing and a minimum diameter of 152 mm re-purposed to a deep borehole heat exchanger. Net energy corresponds to the energy produced by the Borehole Heat Exchange (BHE) minus energy used to run the pump. The different types of configurations show the use of different types of materials (HDPEA = high-density polyethylene Type A, HDPEB = high density polyethylene Type B, VIT1 = vacuum insulated tubing Type 1, VIT2 = vacuum insulated tubing Type 2, and VIT3 = vacuum insulated tubing Type 3) that have different insulating properties and pipe thicknesses*



Assessing geothermal energy potential in Western Canada

GSC researchers conducted a feasibility study of geothermal energy from the Western Canada Sedimentary Basin (WCSB) to support communities (with populations larger than 3,000), in northeastern British Columbia (BC), southwestern Northwest Territories (NWT), southern Saskatchewan (SK), southeastern Manitoba, and previously studied communities of Alberta (AB). The geothermal energy potential of the WCSB is largely determined by the basin's geometry; the sediments generally range in thickness from 0 m in the east to over 6 km east of the Canadian Rockies. Direct geothermal heating is most promising for the western and southern parts of the basin. Electrical power production is limited to the deepest parts of the WCSB (southwestern NWT, northwestern AB, northeastern BC and southeastern SK). For the regions where electrical power production is feasible, estimates indicate that geothermal power of up to 2 MWatts (electrical), and 20 MWatts (thermal) are possible.

Figure 7: *Map showing the geothermal gradient in the Western Canada Sedimentary Basin*



Understanding hydrogen sulfide source and formation to assess economic and environmental impact concerns

In order to understand the impact of hydrogen sulfide (H_2S), as it pertains to public health and industry environmental stewardship and economics, we need to understand the fundamentals of this dangerous gas' sources and migration pathways in the subsurface. GSC scientists produced the first trans-provincial H_2S distribution map of Alberta and British Columbia's Montney Formation by compiling and critically reviewing large public data sets, including seismic and geophysical data, as well as analyzing elemental and isotopic geochemistry on 600 samples from three full-length cores. This project's success was the result of strong collaboration with the University of Calgary and the GSC training several Research Affiliate Program students at both PhD and MSc levels.

Figure 8a: *H_2S distribution in the Montney Formation in the Western Canada Sedimentary Basin (WCSB)*

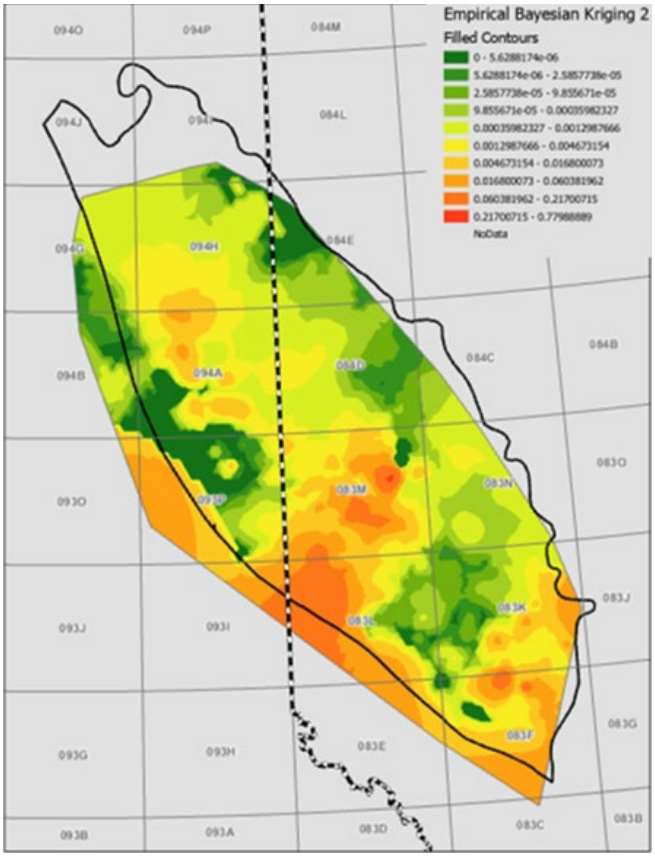
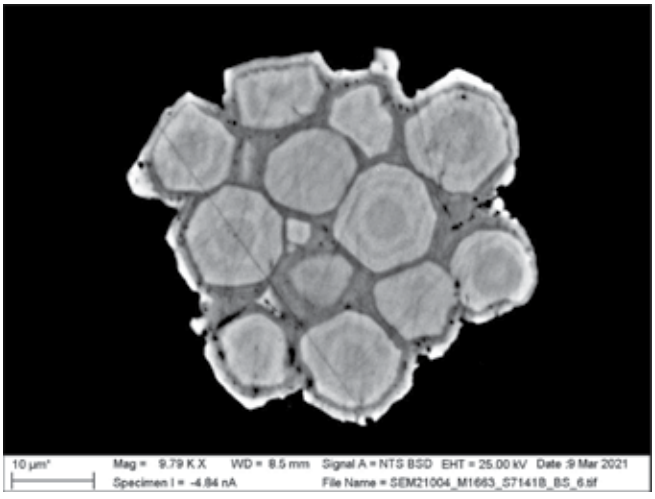


Figure 8b: *Backscattered SEM image of poly-crystalline pyrite from in-situ $\delta^{34}S$ analysis*



Identifying hydrocarbon sources through improved gas chromatography– mass spectrometry (GC–MS) methods

It is critical to "fingerprint" hydrocarbons in order to identify sources and track hydrocarbon migration from spills. GSC scientists collaborated with Schlumberger Canada to improve traditional hydrocarbon fingerprinting methods and develop new GC-MS methodology. This new methodology improves the separation of hydrocarbon molecules of different – but very close – chemical structures and properties. The additional information gained provides improved capability for identifying the sources of hydrocarbons either from an underground oil pool or in cases of surface oil spills.

Transforming tight oil and unconventional gas (TOUG) resources into renewable geothermal energy

In our attempts to meet Canada's net-zero 2050 goals, it will be important to optimize and integrate the complete energy systems available at an energy extraction site (e.g. natural gas well site augmented by geothermal energy extraction). GSC researchers developed a co-production model of hydrocarbon and geothermal resources using an existing shale gas horizontal well. This study examines the entire energy performance using existing hydrocarbon production facilities; researchers used the numerical model to conduct simulations coupling shale gas production with heat extraction from hot water and natural gas under various scenarios for geothermal resource augmentation.

Figure 9: *Graphs showing hydrocarbon 'fingerprints' that are used to identify and track hydrocarbon migration*

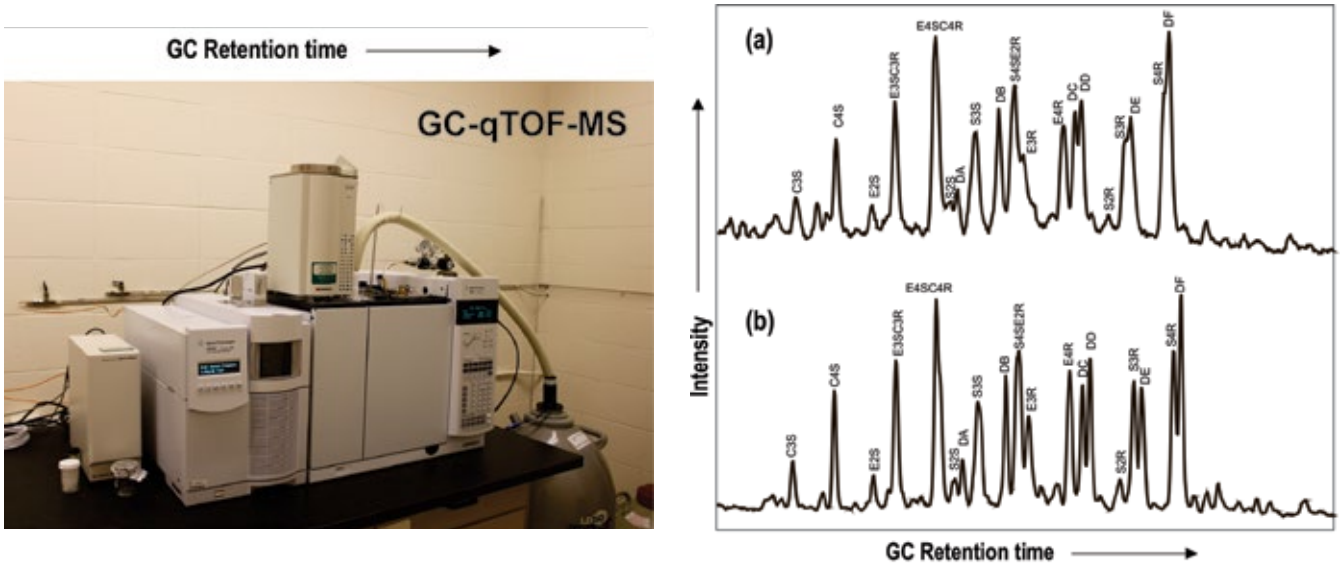
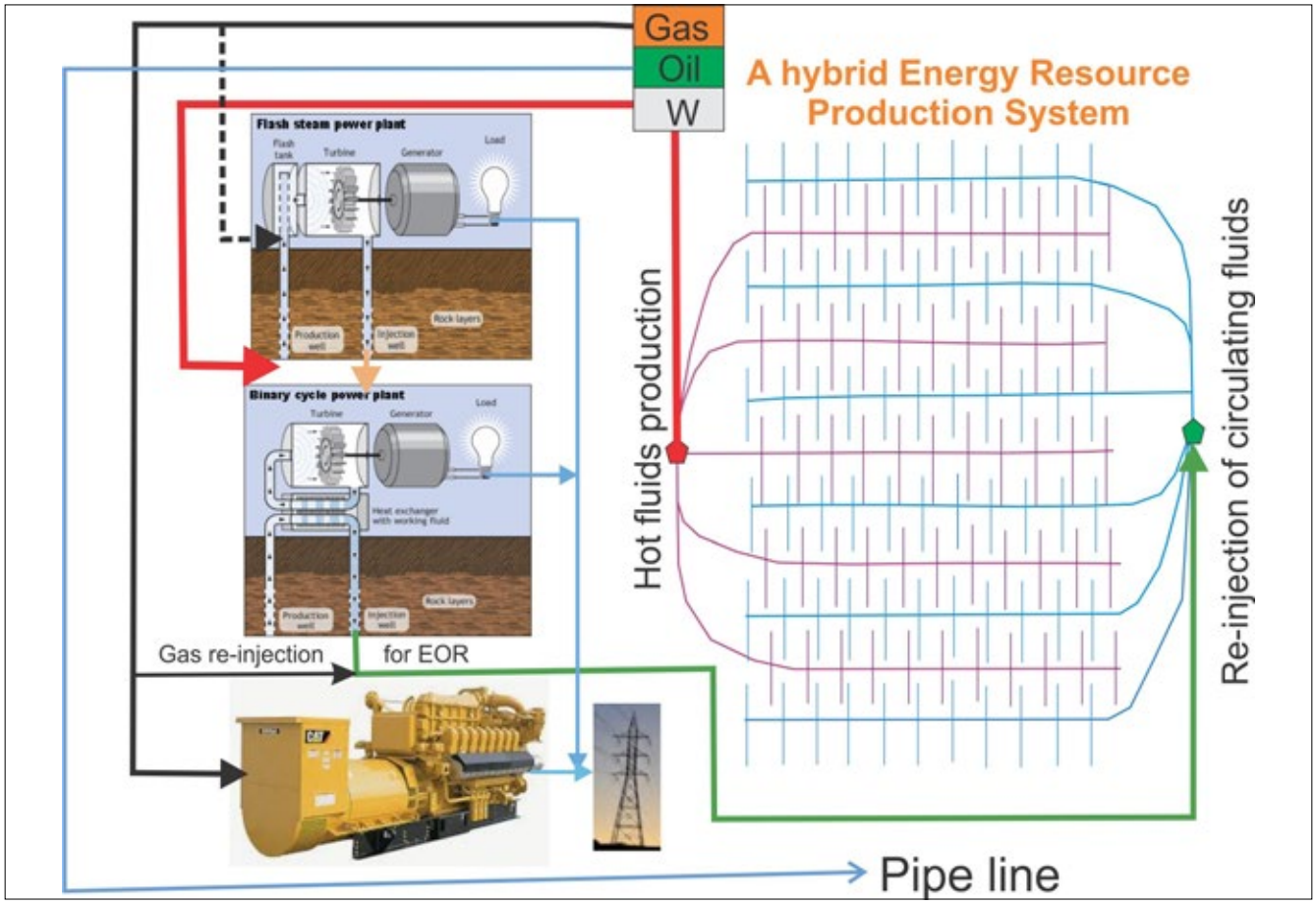


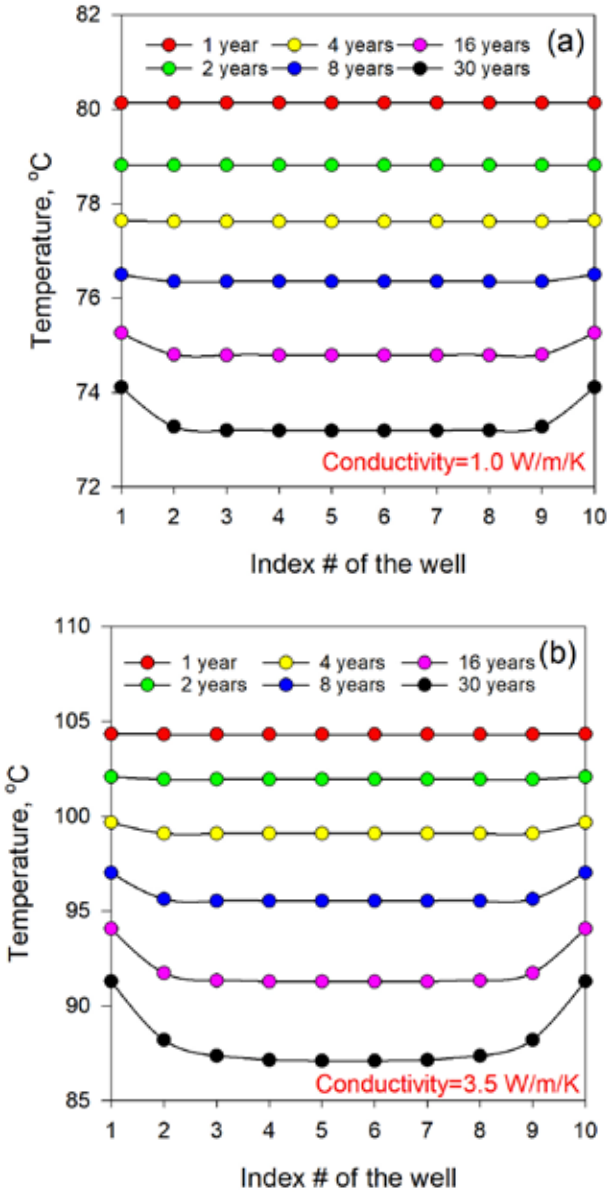
Figure 10: *Hybrid energy resource production system*



Closed-loop geothermal energy recovery from deep systems

To improve the chances of success for industry's development of geothermal resources in Canada, fundamental geoscience information regarding subsurface heat conduction and the influence of cooler injection waters must to be understood. The interaction between cooler injection waters and the geothermal heat reservoir at depth will determine the lifespan and economics of viable geothermal output. By modeling these interactions, GSC researchers provide insights to our industry collaborators regarding design and impact of their closed-loop geothermal recovery technologies on the earth's heat resources. GSC researchers developed a closed-loop model for heat production through heat exchange by circulating working fluid in long and deep horizontal wellbore, then applied numerical simulations under different geological settings and well designs in sedimentary basins of Alberta. This research evaluated the efficiency of this system and identified the key factors affecting the geothermal energy production and lifespan. The results of this project provides useful insights for supporting government project funding decisions to industry in Canada and elsewhere.

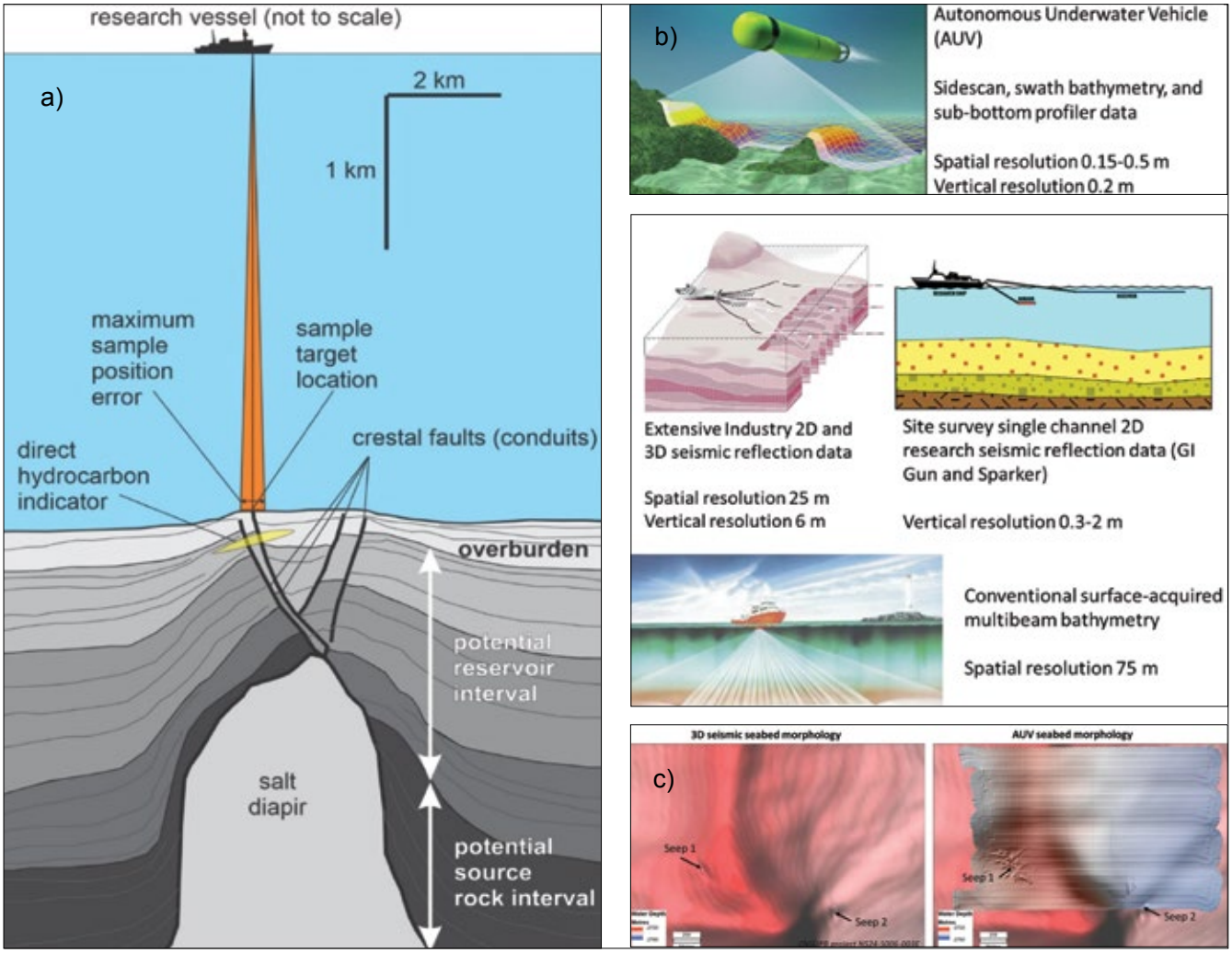
Figure 11: *a) Temperatures after 30 years for a 10 lateral well system under 25 m well spacing with a) 1.0 W/m/K thermal conductivity; b) 3.5 W/m/K thermal conductivity c); and 5.0 W/m/K thermal conductivity*



Acquiring superior data through Autonomous Underwater Vehicle (AUV) surveys

Cold seeps are poorly understood geological features that host unique ecosystems, contribute to seabed instability, and act as conduits for reservoir fluids migrating from depth to the seabed. Analyzing the migrating fluids provides a low-cost method to assess aspects of the petroleum system and its impacts on the local environment and ecosystem. In 2018, GSC led a successful proof-of-concept survey that demonstrated the superiority of seabed morphology data acquired using AUVs as compared to to conventional survey methods. In 2020, the GSC and the Nova Scotia Department of Energy and Mines built on this successful foundation and collaborated in surveying 15 cold seep locations in water depths from 2000 to 3000 meters. These data will be used to plan a Remotely Operated Vehicle (ROV) seep-sampling program scheduled for summer 2021.

Figure 12: *a) Cold seeps; b) Seafloor data acquisition; and c) Seabed morphology and cold seeps at > 2000 m*



What's next for the GNES program?

GNES will continue to work with external partners to study porosity and fluid pathways, applicable to Carbon Capture Utilization and Storage (CCUS) and related applications. The program will continue to explore the sources and migration pathways for H_2S gas emissions by detailed analysis of structural and stratigraphic controls on its distribution/ migration in the Montney Formation of British Columbia and Alberta.

In addition to the geothermal research taking place in the Garibaldi volcanic belt (geothermal electrical) and the St. Lawrence Lowlands (geothermal heat), GNES will explore other geothermal options such as heat extraction from waters. Scientists will also investigate the nature, the extent, and the hot water extraction potential from basal gravels in collaboration with the Deep Earth Energy Production (DEEP) geothermal project in Saskatchewan.

We will continue to seek fundamental understanding of hydraulic fracking flowback water chemistry and its environmental impacts through collaborations with industry and CanmetENERGY Devon.

The GSC has established an Energy Geoscience Working Group to identify priority energy themes and projects across programs.

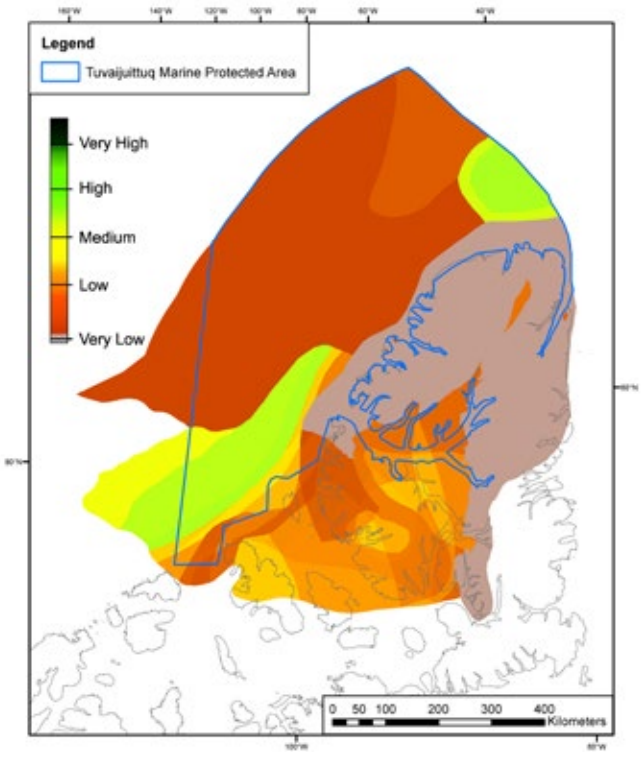
GSC will continue to prepare resource assessments under the Marine Conservation Targets program to support DFO, ECCC and PCA in the identification and establishment of areas for conservation and protection to help Canada achieve its goals for 2025.

Supporting marine protected areas through resource assessments

The Marine Conservation Target resource assessment team compiled and assessed disparate datasets from the Arctic Ocean north of Ellesmere and Axel Heiberg islands to produce a comprehensive assessment of the potential hydrocarbon occurrences at various locations. The GSC continues to work with DFO and PCA to provide resource information to inform conservation decisions.

MCT resource assessments directly influence DFO and Parks Canada Agency (PCA) evaluation and promotion of marine and coastal protected areas. These efforts represent NRCan's contribution towards Canada's UN commitments of 25% and 30% coverage by 2025 and 2030 respectively.

Figure 13: *Qualitative assessment of conventional hydrocarbon resources. Green indicates higher resource potential, red indicates lower potential. Grey areas have no potential*



What's next for the MCT program?

Marine Conservation Targets received 5 years of funding in Budget 2021 to continue developing resource assessments to contribute to Canada's conservation goals of 25% offshore/coastal regions by 2025, and looking forward to 30% by 2030.

GSC will work with other groups in NRCan to provide assessments of petroleum, mineral and other resources for offshore areas identified by DFO, PCA and ECCC for conservation consideration.

Funding includes salary for 10 employees in GSC (5 FTE in year 1) and operating costs to conduct data analysis and interpretation, for a total of $9.5M over 5 years.

Marine Geoscience for Marine Spatial Planning (MGMSP)

Program description

GSC's Marine Geoscience for Marine Spatial Planning (MGMSP) 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. MGMSP contributes to Department of Fisheries and Oceans Canada (DFO) effort 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. The MGMSP 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.

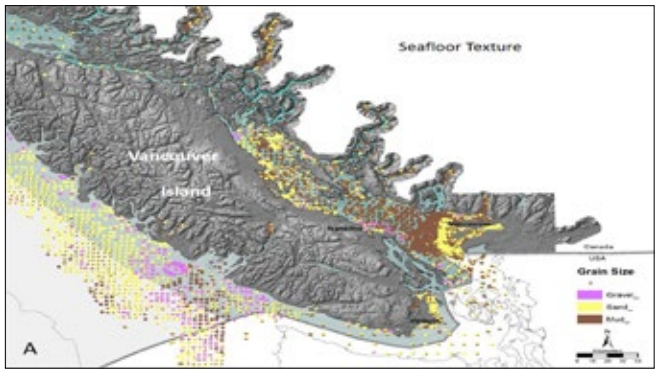
Overall, the GSC will produce marine geoscience deliverables at the broad bioregion scale (seabed morphology, geology, and stability), as well as more targeted studies to inform specific marine spatial-planning objectives in the Atlantic and Pacific offshore. The general outcome for MGSMP is that GSC's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

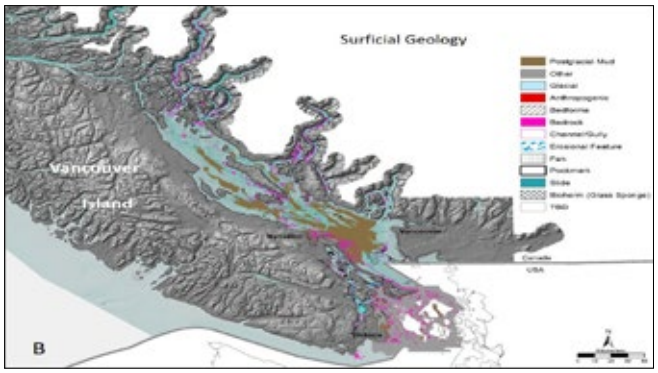
Recent successes include:

A "one stop shop" for decision-making in the Salish Sea Bioregion

Approximately seven million people live adjacent to the Salish Sea Bioregion in British Columbia. MGMSP has created marine surficial geology base layers of the bioregion through integrating more than 14,000 legacy grainsize measurements, other geological samples, and high-resolution bathymetric data. These map products and associated data create a "one stop shop" for geoscience knowledge to support land-use decisions in the bioregion, including offshore mineral resource and renewable energy projects.

Figure 14: *a) Seabed texture in the Salish Sea Bioregion caption derived from discrete seabed grainsize samples; b) Surficial geology map of the Salish Sea Bioregion based on the integration of detailed bathymetry, sub-bottom profiler data and seabed samples*





Assessing seabed conditions on the Northeast Newfoundland Shelf

The Northeast Newfoundland Shelf, part of the Newfoundland Shelves Bioregion, is subject to overlapping interests in use of the seabed space. This includes a significant commercial ground fishery, potential oil and gas resources, and marine conservation. In addition, the area is in a complex geological environment located in a continental shelf and slope setting near the limit of Canada's Exclusive Economic Zone (EEZ). MGMSP mapped 5,900 km² of seabed and established 50 seabed sample stations in this area in 2020. Despite the socioeconomic importance of the region, this is the first time detailed seabed mapping data has been acquired in this area, resulting in the generation of fundamental information on seabed morphology, geology and stability to support marine spatial planning.

Variable maritime geology poses challenges for potential offshore wind energy

Offshore wind energy in Canada is in its infancy; however, it is forming an increasing share of global electricity generation capacity. Offshore wind energy could contribute to Canada's low-carbon future. Seabed geology is an important constraint on the development of offshore wind energy. MGMSP conducted an assessment of Maritime shelf seabed conditions, showing that the shelf geology is highly variable, and that areas amenable to conventional anchoring systems may be relatively limited. The offshore wind industry and a natural resources organization are currently using this knowledge and data for project planning and assessment.

Breaking barriers to deliver marine geoscience data

A key aspect of MGMSP is to remove barriers to discovery by delivering robust marine geoscience data and scientific knowledge to support evidence-based decision-making. By releasing four key legacy datasets on Open Maps, more than 50 years of research – including seabed grain size analyses, seafloor photographs, radiocarbon dates, and marine seismic reflection data – is now available to the public.

Figure 15: *Study area and some example datasets and methodologies for assessment of seabed conditions on the Northeast Newfoundland Shelf*

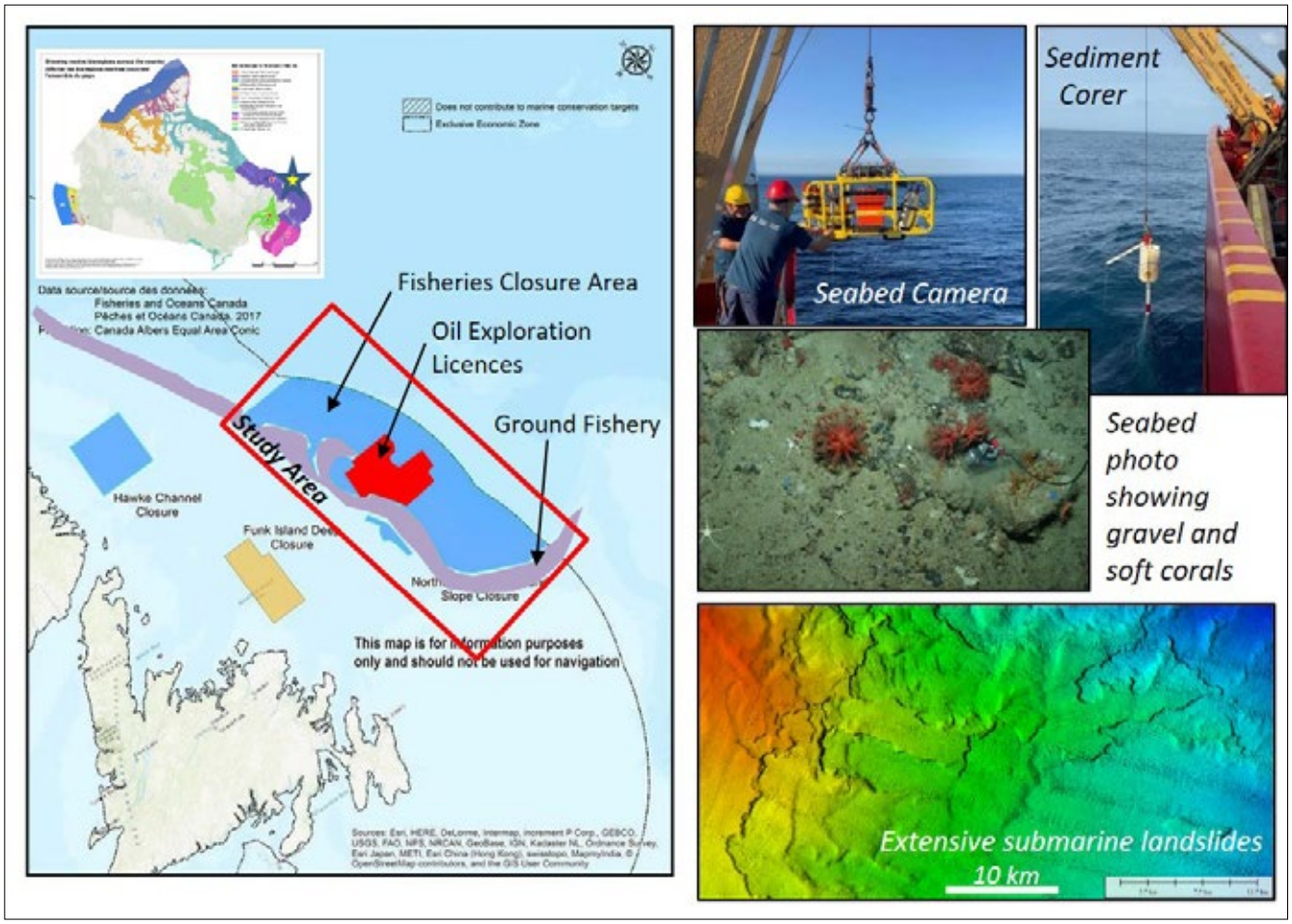
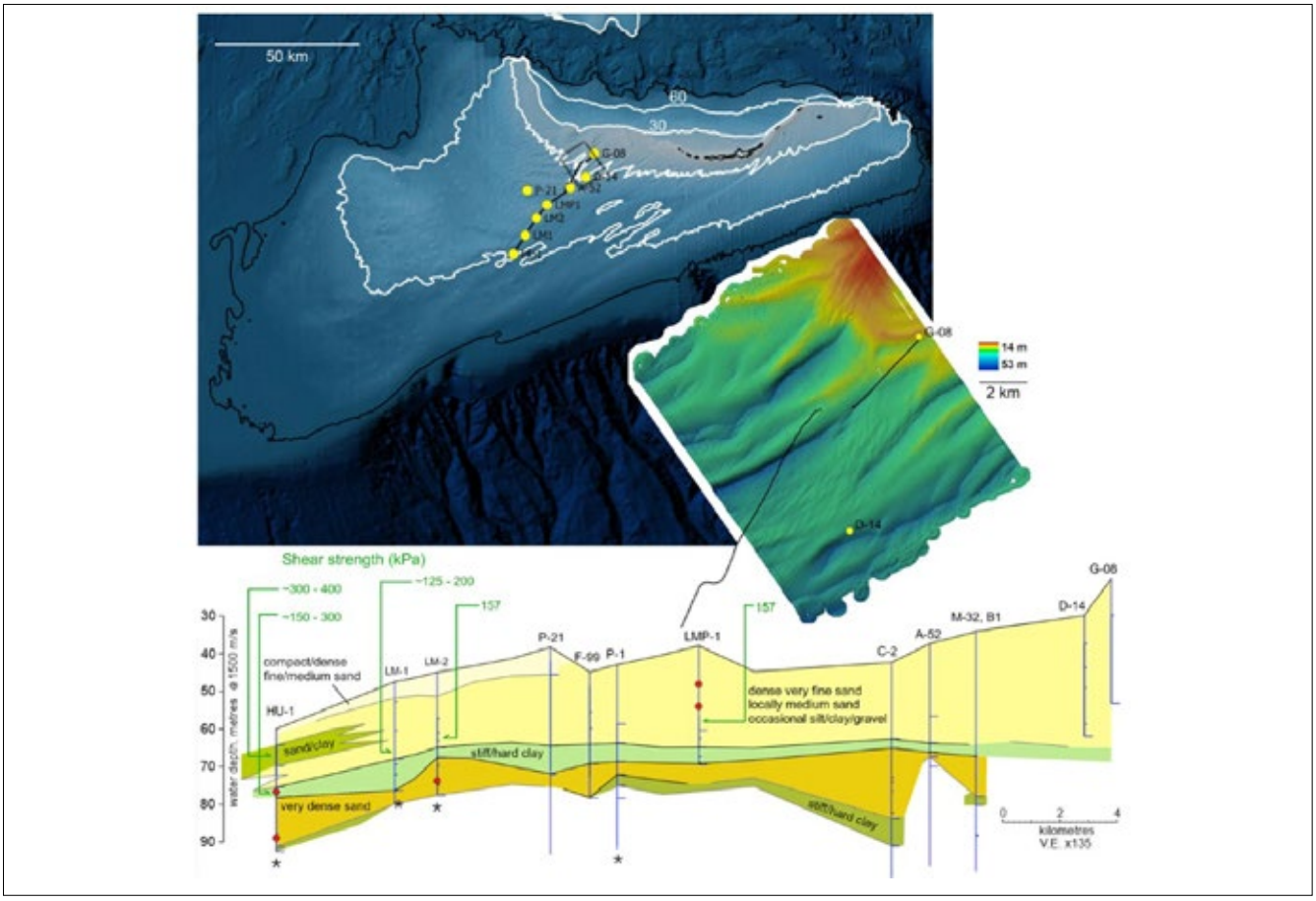


Figure 16: *Bathymetric maps and a geological cross section based on borehole data near Sable Island showing sub-surface physical properties. Figure is modified from Eamer et al. (2020)*



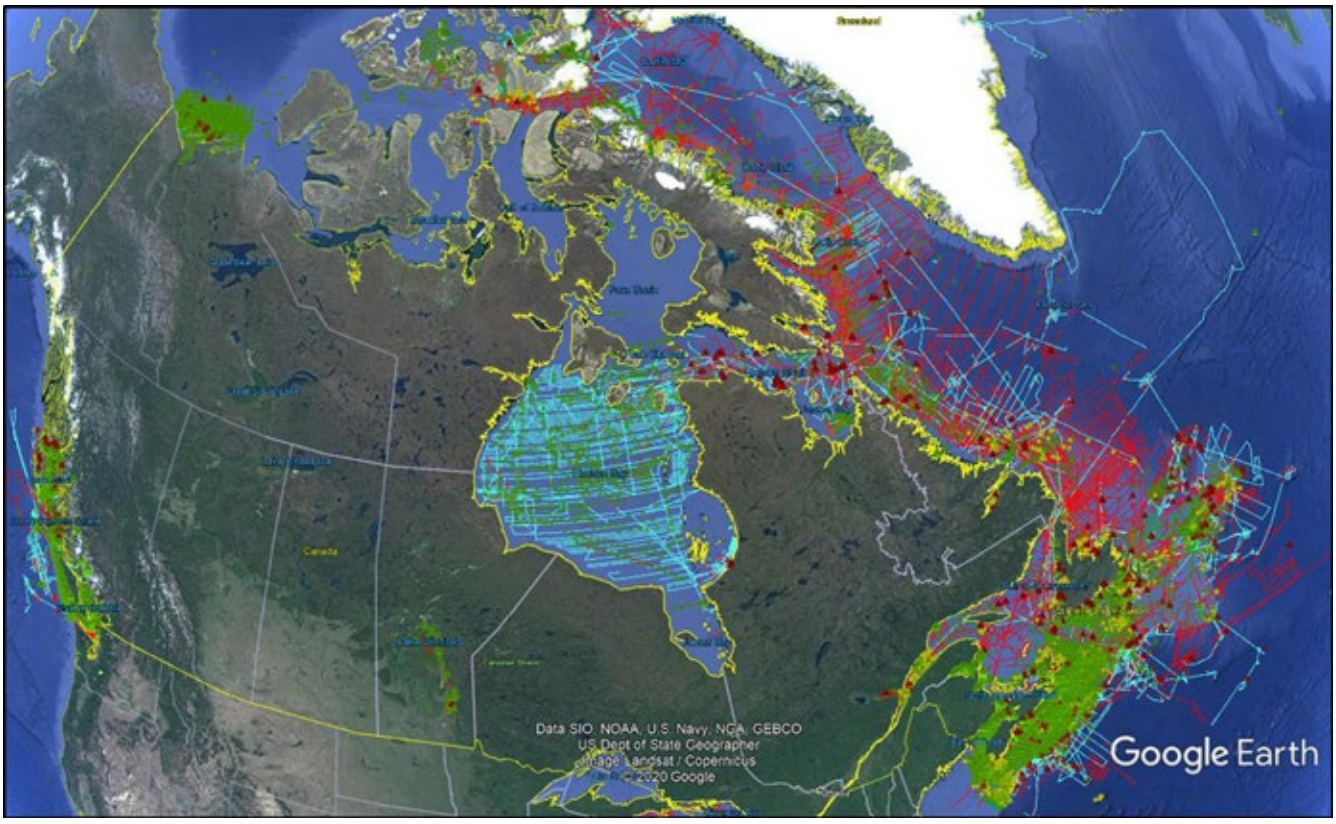
New and ongoing collaboration with Fisheries and Oceans Canada

GSC and DFO have a long history of collaboration, and MGMSP continues to contribute to this legacy. In 2020-21 GSC and DFO co-hosted more than 35 meetings focused on Marine Spatial Planning priorities, and GSC made new connections with DFO Oceanography and DFO Habitat Ecology. Formal and informal inter-departmental agreements resulted in significant field data acquisition in all four MGMSP bioregions in areas of mutual interest, and DFO is currently using GSC knowledge and data for marine spatial planning, project screening, and marine conservation decisions.

What's next for MGMSP?

The MGSP program currently ends in 2023. The near-term focus is to generate knowledge products and deliverables for program stakeholders. The longer-term focus is to develop new research plans related to targeted studies within the four current bioregions and expand into other bioregions, in concert with DFO. The announcement of the Government of Canada's Blue Economy Strategy is a strong indicator that MGMSP is aligned with emerging government priorities and will lead to increased demand for evidence-based decisions on use of marine space.

Figure 17: *Distribution of marine seismic reflection data coloured by data type displayed in Google Earth*



Groundwater Geoscience Program (GGP)

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.

GGP for the phase 2019-2024 is focused on five activities: (1) Archetypal aquifers (including Canada One Water or C1W); (2) Fox Creek aquifer systems; (3) Water resources characterization and modeling; (4) Groundwater Information Network (GIN); and, (5) Regional assessment for the Ring of Fire. These activities are associated to research themes defined as groundwater inventories, cumulative effects, methods for assessing groundwater, data modelling, and dissemination. In the short term, the goal of GGP 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 outcome is to incorporate more effective/efficient regulations and oversight, and the ultimate outcome is better management of groundwater resources by responsible jurisdictions.

Recent successes include:

Pioneering a national dialogue on groundwater science

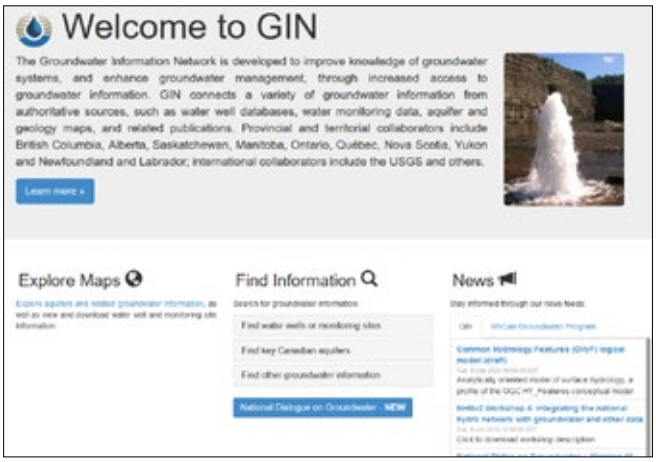
Ongoing collaboration with the Canadian provinces and territories on the National Dialogue on Groundwater (NDGW), to better understand, and collaborate on, groundwater science in Canada. GSC scientists have been meeting bimonthly with all provinces, territories and other federal departments to share knowledge about both jurisdictional and GGP work. Meeting material is available on the NDGW GitHub site and provides information about the goals of NDGW.

Developing a global groundwater information system

Along with international partners, GSC scientists are contributing to the Global Groundwater Information System (GGIS), a database for groundwater information, using the existing Groundwater Information Network (GIN). After following the GWML's development over the last few years, UNESCO's IGRAC has recently informed GSC of their intent to implement GWML in the GGIS. IGRAC's plan is to re-design the GGIS to store groundwater related data and define a standard methodology for exchanging groundwater-related information between agencies. The latest version of GWML, GWML2, was created by collaborators from Canada, USA, Australia, France, and Germany, and has been officially recognised by WMO.

GGIS: Global Groundwater Information System
GIN: Groundwater Information Network
GWML: Groundwater Markup Language
IGRAC: International Groundwater Assessment Center
UNESCO: United Nations Educational, Scientific and Cultural Organization
WMO: World Meteorological Organization

Figure 18: *GIN landing page*



Supporting the creation of a new federal agency in Canada

In the federal budget of 2021, the federal government committed to establish the Canada Water Agency (CWA) to strengthen collaboration between the federal government, the jurisdictions, Indigenous peoples and other partners to find the best ways to safeguard our freshwater. Publications by GSC Chief Hydrogeologist Dr. Rivera's (now retired) exploring issues related to shared water resources and water security between Canada and USA, were used in a CWA investigation document to inform the creation of CWA.

The GSC has contributed freshwater expertise towards the establishment of the CWA; contributing to the review of discussion papers, participating in internal and external working groups, committees and workshops, and advising senior management on the freshwater file.

Sharing cutting-edge groundwater geoscience

Nuclear Magnetic Resonance (NMR) is an emerging tool in hydrogeology, which allows easy estimations of aquifer properties. Knowing that GSC scientists are producing cutting-edge NMR science, the Director for Research and Policy at Freshwater (an NGO) contacted GSC for more information about the effectiveness of the NMR. GSC scientists provided published research and supplemental information so that Freshwater could provide additional information to the Minnesota Geological Survey (MGS). GSC continues methods development of the NMR technique for groundwater through collaboration with the G360 Group at the University of Guelph (MOU) and the use of the NRCan Bells Corners bedrock calibration site.

Figure 19: *Equipment to perform high-resolution hydraulic testing in well for the calibration of the NMR tool in the Vars-Winchester esker system in Embrun, ON. Pneumatic perturbation using nitrogen is used to induce large stress in the well while recording the aquifer responses in the well at different intervals*

Figure 20: *Drilling operations with a portable dual-rotary rig for the installation of a well in an unconsolidated aquifer near Ottawa, ON. The drilling technique was adapted to allow high-resolution profiling of hydraulic properties in granular aquifers*

What's next for GGP?

The GGP will continue its dialogue with all provinces and territories, as well as other federal departments, to increase groundwater science knowledge in Canada for the safety and security of Canadians. The GGP will also provide insights to, and will collaborate with, counterparts from ECCC and AAFC to support the new CWA.

The GGP will implement the C1W project as it will lead to a better understanding of the effect of climate change on surface and groundwater resources within Canada. C1W is a collaborative initiative of NRCan, AAFC, Aquanty Inc., and the Universities of Toronto and Waterloo. The project is co-funded by Defence Research Development Canada (DRDC) Canadian Safety and Security Program (CSSP).

Environmental Geoscience Program (EGP)

The aim of the Environmental Geoscience Program (EGP) is to distinguish the environmental effects of natural resource development from those produced by natural processes, and to develop new approaches to support the sustainable use and development of Canada's natural resources through informed decision-making.

The ultimate outcome of EGP is to increase the effectiveness and efficiency of Canadian environmental regulation and oversight. By developing innovative geoscience for environmental stewardship and increasing public and private sector access to research findings, decision-makers have greater capacity and are more empowered to carry out and review environmental assessments.

Recent successes include:

Adapting to COVID-related challenges through Indigenous partnerships

The Mackenzie River basin project will provide knowledge on long-term natural variability of baseline water quality and quantity of Canada's largest watershed, the Mackenzie River Basin (MRB). The MRB has experienced the highest temperature increase in Canada over the last half century. Warming has affected streamflow and is causing permafrost and ground ice thaw, which is altering land-freshwater-ocean transfer of particulates, elements, and organic carbon. Due to Covid-19 restrictions, GSC scientists were not able to conduct fieldwork for the project. The scientists forged a strong partnership with local Indigenous communities to complete the entire field program (consisting of 4 peat cores and over 100 vegetation samples). Engagement in two-way knowledge sharing between the research team, community members, decision makers, and stakeholders ensured the research met the needs of northerners and end-users. Training opportunities designed for northerners are a key component of this project. This enhanced capacity will contribute to more knowledge and better predictions of future changes in water quality and quantity for warming scenarios.

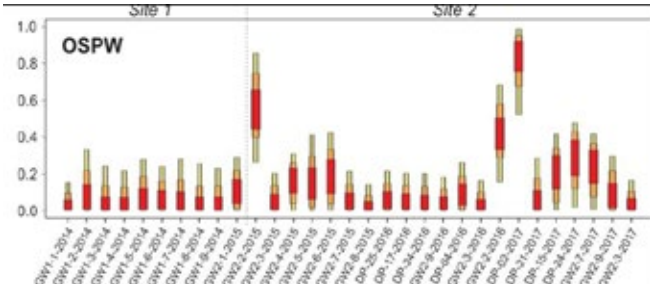
Figure 21: *Sarah Lord of the Gwich'in Renewable Resources Board (GRRB) during the summer 2020 season. Chipesia and Lord collected peat cores, vegetation samples and depth-to-water table measurements in the Gwich'in Settlement Area. These samples form a dataset to tell us the relationship between the ameobae communities and hydrology. With enough samples, this relationship can be statistically quantified and will provide a basis for GSC to reconstruct how hydrology has changed in the basin over the past hundreds to thousands of years*

Supporting environmental investigations into leaking tailing ponds with innovative science

Tailings ponds in Alberta contain wastewater, sand, silt and petrochemical waste from the oil sands mining process. In 2020, the North American Commission for Environmental Cooperation (CEC) launched an investigation following a complaint

that the federal government was allowing toxic water to make its way into the Athabasca River. Amongst others, the CEC used GSC data and interpretations to assess the environmental profiles of tailing ponds and four scientific articles published by the GSC between 2012 and 2018 are cited. The report concluded that there was strong evidence of liquid from the ponds seeping into nearby groundwater. GSC work is still ongoing on tailing ponds. One article published in 2020 and focusing on tools to distinguish natural from anthropogenic source of contaminants can be found here: *Ahad et al*, 2020. (https://doi.org/10.1021/acs.est.9b06875)

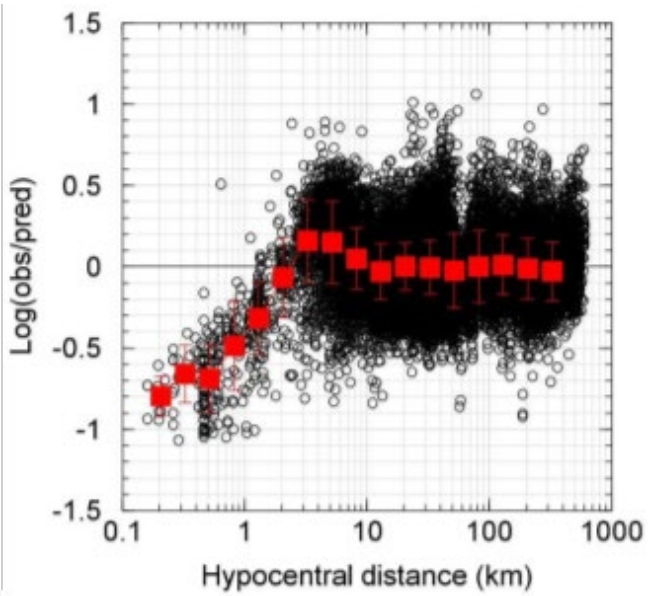
Figure 22: *Discrimination of oil sands tailings pond water in natural environments*



Creating a win-win-win scenario for the oil and gas industry, regulators, and the public

The Induced Seismicity Research (ISR) project has a national scope with team members from NRCan offices in Sidney, Ottawa, and Quebec City. The Project establishes close collaboration with both public and private sectors, including provincial and local governments, crown corporations, professional organizations, and academia, to address critical knowledge gaps in the source process of induced earthquakes and to provide observation-based science to improve regulations on the development of unconventional hydrocarbon resources. Reliable determination of local magnitude (M_L) is crucial for monitoring of induced seismicity. Because NRCan reported magnitude values are routinely used by regulatory agencies in Alberta and British Columbia to ensure proper assessment and mitigation of seismic hazard caused by induced seismicity, modification to the Richter magnitude formula to better reflect the local attenuation characteristics of the Western Canada Sedimentary Basin (WCSB) was important and necessary. In this study, we present an update on the M_L formula using the most comprehensive dataset of earthquakes in WCSB between 2014 and 2018. The revised M_L formula provides a consistent estimate of M_L from stations over a wide distance and magnitude range. Energy industry and regulators use this magnitude value in the case of a significant/felt induced earthquake to decide if the responsible injection operation(s) should be shutdown or suspended. By eliminating or minimizing the chance of controversial shutdown or suspension orders, GSC scientists have directly improved the regulations on oil and gas operations, allowing the energy industry to lower their operation costs while ensuring public safety.

Figure 23: *This figure shows the difference between observed and predicted correction term as a function of distance for earthquakes in the Western Canada Sedimentary Basin (WCSB) using the formula GSC published first in 2018 and later updated in 2020. Each circle represents one observation, and the red squares are the corresponding average values*



Releasing long-awaited guidance on geologic carbon storage

Injected carbon dioxide (CO_2) is used in enhanced recovery operations for oil and other hydrocarbons and for geological carbon storage. GSC scientists contributed to writing document ISO 27916 *Proof of Storage*, recently used by the US Department of Treasury for its proposed regulations regarding the credit for carbon oxide sequestration. This long-awaited draft guidance pertains to long-term secure geologic storage of injected CO_2.

What's next for EGP?

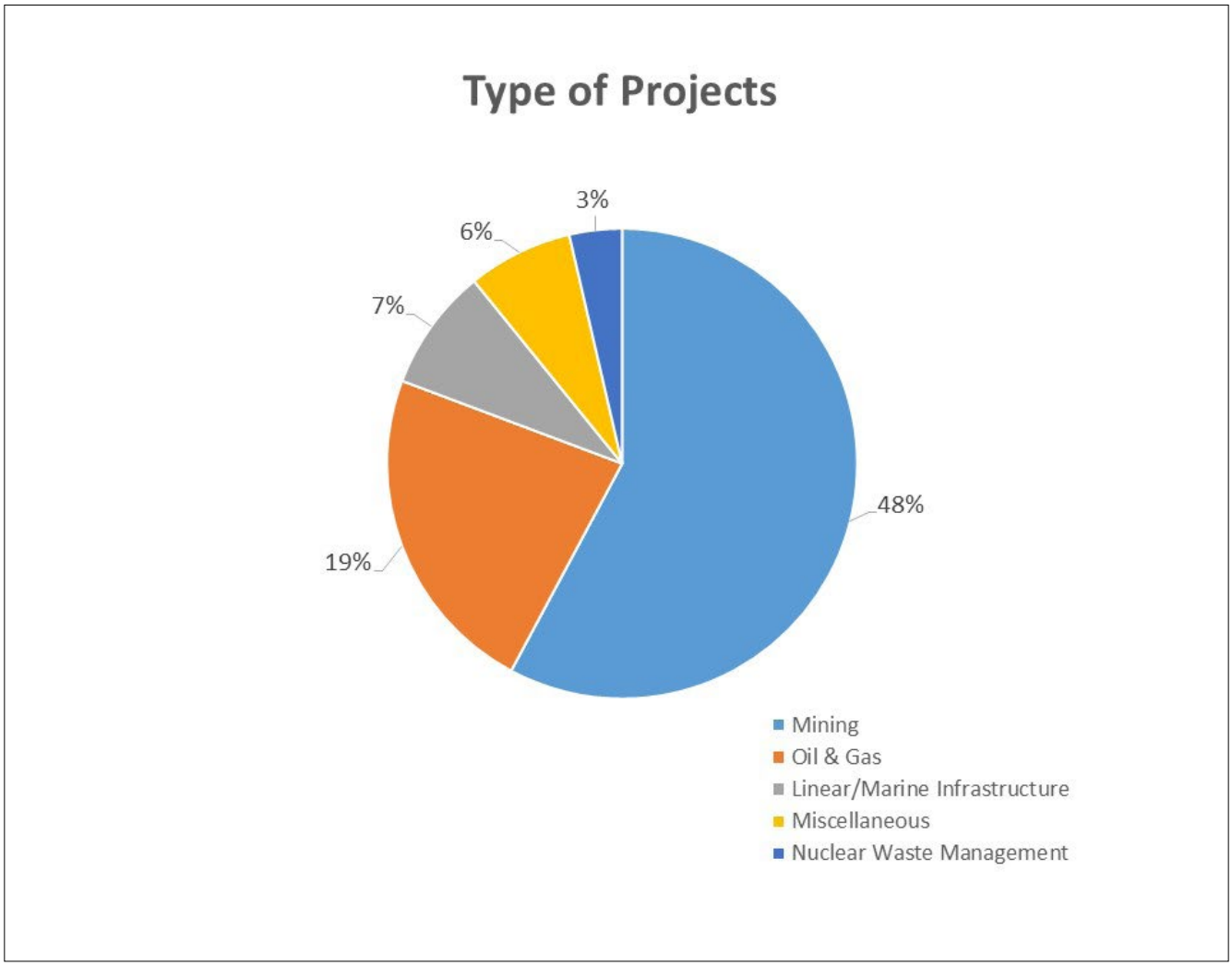
In May 2021, five EGP scientists delivered a live public web presentation to an audience of 89 attendees. These public presentations are held annually; the next one will be in May 2022. Following the annual tradition, the presentations will be included in the EGP YouTube page and available in GEOSCAN.

Environmental Impact Assessment Service (EIAS)

An Impact Assessment is a Federal planning and decision-making tool used to assess positive and negative environmental, economic, health, and social effects of proposed projects and impacts to Indigenous groups and rights of Indigenous peoples. The *Impact Assessment Act* outlines a process for assessing the impacts of major projects. With the implementation of the new *Impact Assessment Act* (IAA 2019), some projects continue to be assessed under the pre-2019 *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, ensuring thorough, impartial, timely advice is provided before projects proceed for the northern EA regimes and southern Environmental Assessment (EA) pursuant to the Impact Assessment Agency of Canada, pursuant to department's legislated obligations. EIAS also provides advice and technical support to experts participating in quasi-judicial Joint Review Panels following the impact assessments.

Figure 24: *GSC EIAS Contribution – FY 2020-2021*



The GSC provides impartial scientific data (honest broker) and supports land use planning and environmentally sound resource development, both on land and in our coastal and offshore waters.

In 2020-21, the GSC contributed geoscientific expertise to 38 projects at different stages of the project life cycle. It also supports client needs, assists in informed economic and environmental federal decision-making process.

Recent successes include:

Supporting safety and sustainability in Canada's mining sector

The proposed Grassy Mountain mine is a 2,800 hectare open-pit mine in Alberta, projected to produce 4.5 million tonnes of coal annually during its 25-year lifespan. GSC scientists provided scientific expertise on hydrogeology, terrain hazards and seismicity at the Joint Review Panel (JRP) Hearings in October 2020.

Protecting aquifers on Indigenous land

The Trans Mountain Expansion Project (TMX) is subject to 156 enforceable conditions, designed to mitigate risks, respect the rights of those directly affected and operate safely. A GSC hydrogeologist provided post-environmental scientific review to satisfy condition #39 – a hydrogeological study relating to the aquifer at the Coldwater Indian Reserve in British Columbia, including quantifying the risks posed to groundwater supplies in the event of leaks, accidents or malfunctions.

What's next for GSC EIAS?

GSC EIAS will continue to respond to all geoscience aspects of EA reviews in a timely manner as and when requested from the Impact Assessment Agency of Canada and other boards/departments. This includes all technical components as well as non-technical, legislative/ policy aspects related to the EAs throughout the project's life cycle.

Targeted Geoscience Initiative (TGI)

Program description

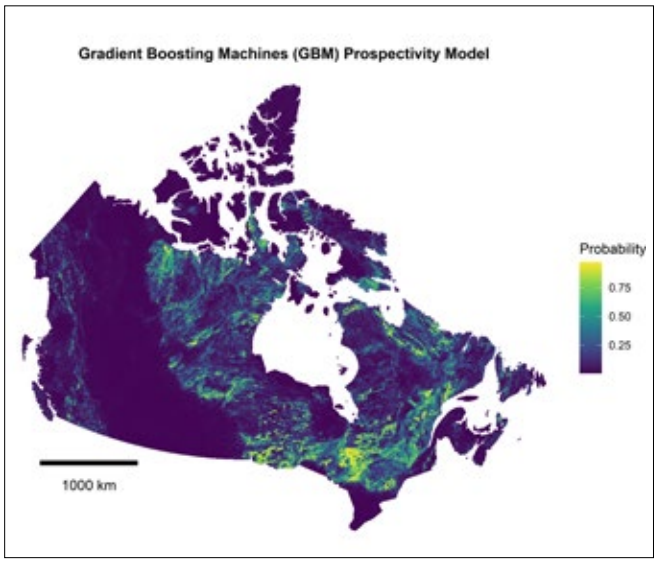
The Targeted Geoscience Initiative (TGI) addresses the ongoing government priorities of leading strong economic growth and responsible resource development. The program provides innovative public geoscience to help the mineral exploration industry identify and develop mineral deposits in emerging and existing mining areas across the country, further enhancing Canada's reputation as a 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 focus on critical minerals and metals.

Desired TGI outcomes include: Stakeholder use of new geoscience informs mineral exploration approaches and natural resource management decisions; stakeholder use of program's outputs to conduct their own geoscience research (e.g. to generate predictive models of mineral potential), with the desired ultimate outcome - attractiveness of Canada for investment in sustainable mineral exploration and development.

TGI 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 enhanced analytical, laboratory, and field methods, TGI improves mineral exploration effectiveness through next-generation geological modelling, as well as leading edge tools, innovative techniques, and predictive models.

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

Figure 25: *Prospectivity results for magmatic nickel (Ni) (+ copper (Cu) + cobalt (Co) + platinum group elements (PGE)) sulphide mineral systems using a gradient boosting machine (GBM) model (Lawley et al. 2021). Model results are based publically available geophysical, geological, and geochemical datasets. Magmatic Ni deposits are shown for reference (Good et al. 2015)*



Recent successes include:

Leveraging Artificial Intelligence (AI) to create a Mineral Potential Engine

At the end of March 2021, GSC scientists completed one of the most significant contracts for the public service using AI for natural language processing. The work involved innovative methods to accurately search and sort large data libraries of text-based scientific publications (3 million words in tens of thousands of publications), using semantic search, keyword prediction, and document similarity in a near instantaneous time frame. Results demonstrated, for the first time, that using the AI-based language models with a library of geology-specific publications significantly improved search results and increased access to information and data. Following engagement with the mineral exploration industry, this project will contribute to the growth of the Canadian economy by encouraging industry to unlock their own unstructured text data and continuing to increase access to leading-edge geoscience knowledge.

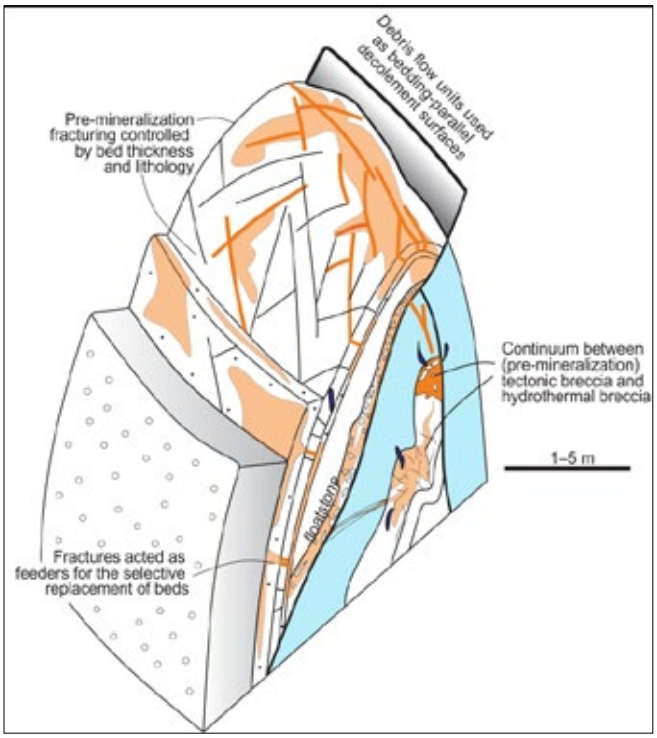
Synthesizing geoscience research to showcase five years of success

In fiscal year 2020-21, TGI completed five synthesis reports showcasing the results of five years of research within the five research projects of TGI-5. At this point, two open files and one bulletin have been published (available on GEOSCAN) and two more bulletins are in press. Below are details on each bulletin:

- **TGI-5, Gold Project:** a summary of contributions to the understanding of Canadian gold systems (Open File 8712, Editors: Mercier-Langevin, P.; Lawley, C.J.M.; Castonguay, S.): This synthesis volume contains 20 individual papers that discuss craton to deposit-scale characteristics of auriferous deposits, plus some support material pertaining to the TGI-5 Gold project, which spanned five years. This report provides transformative tools that will aid in the discovery of gold and associated critical mineral exploration in a wider range of geological settings than previously known. Results from this work will generate new exploration opportunities, supporting Canada's mineral exploration industry, and contribute to economic growth. A strongly positive review of this report was published in Economic Geology in February 2021.

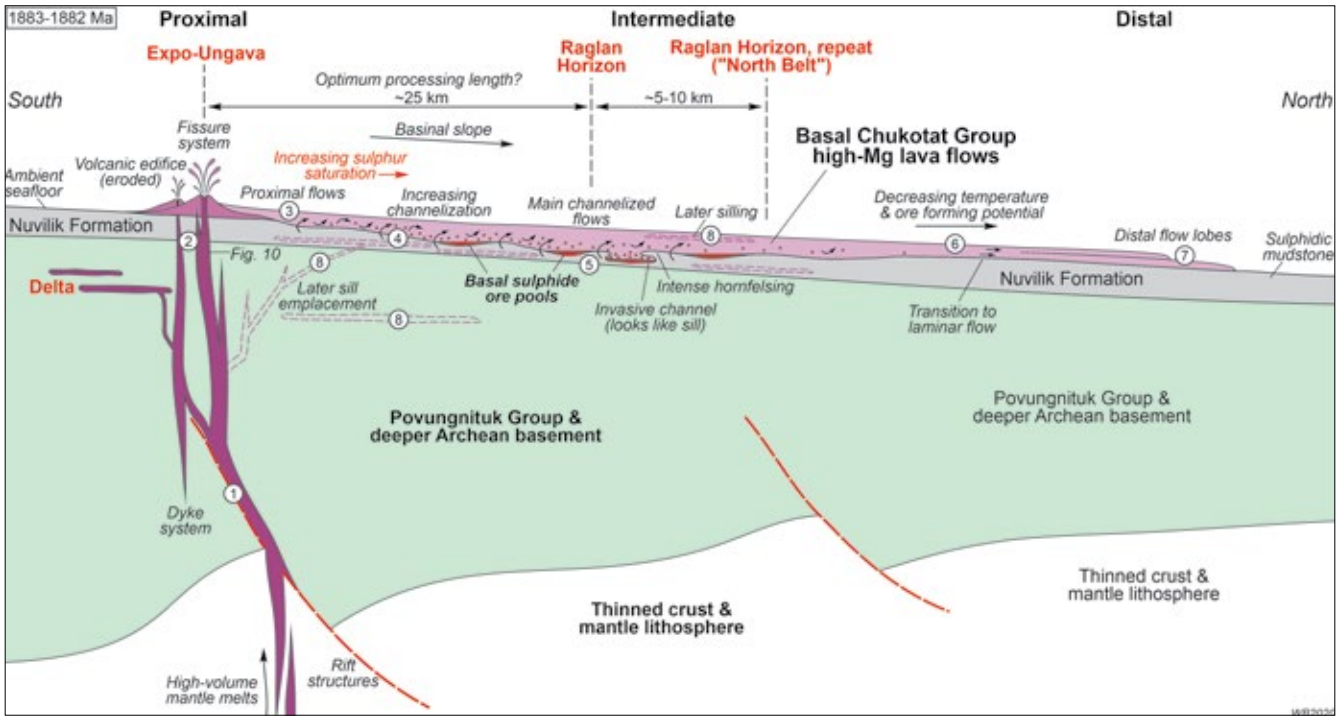
Figure 26: *GSC, Yukon Geological Survey and ATAC Resources geologists in the field in Yukon, Nadaleen gold trend, Central Yukon*

Figure 27: *Summary of the sedimentological and structural features and controls on gold distribution in the Rackla belt, Central Yukon. From Pinet et al. (2020), TGI-5 Gold Project synthesis, Open File 8712*



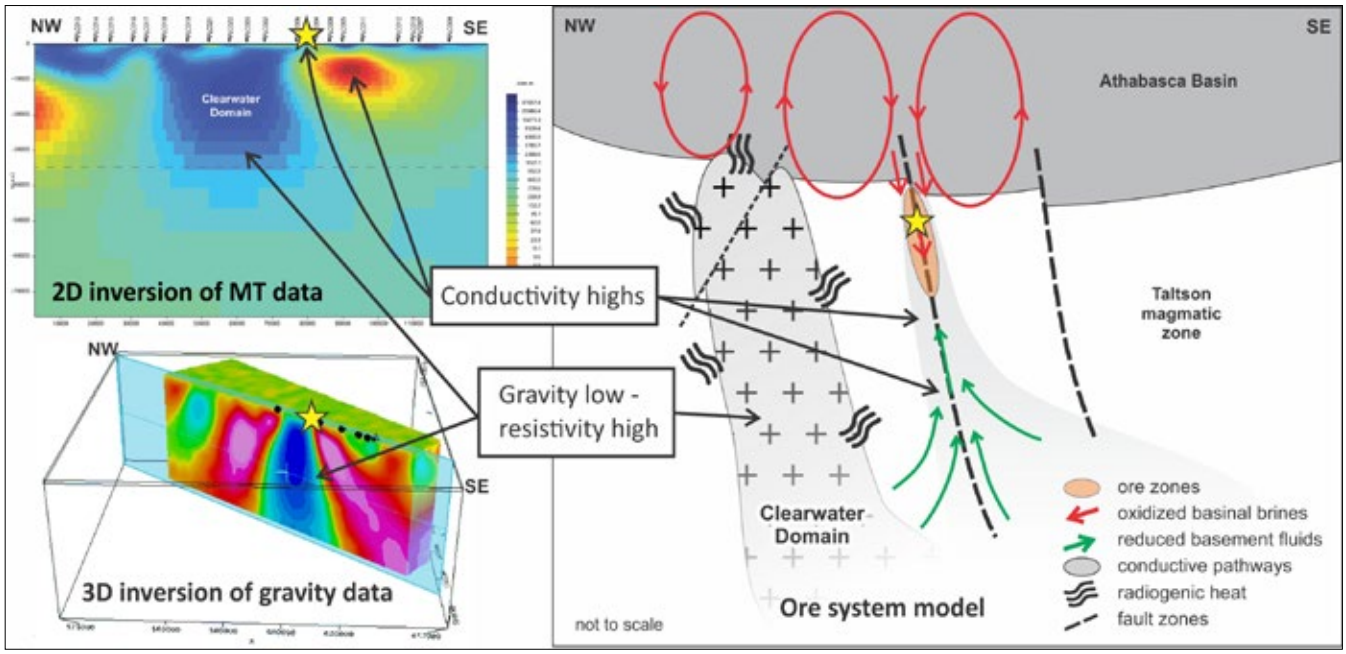
- **TGI-5:** Advances in the understanding of Canadian Ni-Cu-PGE and Cr ore systems - Examples from the Midcontinent Rift, the Circum-Superior Belt, the Archean Superior Province, and Cordilleran Alaskan-type intrusions (Open File 8722, Editors: Bleeker, W. and Houlé, M.G.): This synthesis volume contains nine individual papers that discuss deposit scale to magmatic system fundamentals from various Canadian examples pertaining to the TGI-5 nickel-copper-platinum group elements-chromium (Ni-Cu-PGE-Cr) project. This publication provides key research findings from five years of research across the country on Canadian nickel, copper, platinum (and other platinum group elements), and chromium. These deposits form the backbone of established and emerging mining camps and all are considered critical and essential for new technology, clean electric vehicles, and a low-carbon future.

Figure 28: *TGI-5 research has reconstructed the critical components that make up the economically important ore system of very high temperature, high-Mg (magnesium) lava flows and their volcanic feeder system. Sulphide ores lenses (red lenses in the image) of high grade Ni-Cu-PGE and minor Co form in pools at the bottom of these turbulently flowing lava flows, due to interaction of the lava flows with underlying sulphur-rich sedimentary rocks (Nuvilik Formation), which formed the ambient seafloor at the time, 1882 million years ago. The driving magmatic system of deep mantle melting stretched over 1000s of kilometres, forming these kind of ore deposits in northern Quebec (Raglan), and Manitoba (Thompson). Reference: Bleeker, W. and Kamo, S., 2020. Structural-stratigraphic setting and uranium-lead (U-Pb) geochronology of Ni-Cu-Co-PGE ore environments in the central Cape Smith Belt, Circum-Superior Belt; in Targeted Geoscience Initiative 5: Advances in the understanding of Canadian Ni-Cu-PGE and Cr ore systems – Examples from the Midcontinent Rift, the Circum-Superior Belt, the Archean Superior Province, and Cordilleran Alaskan-type intrusions, (ed.) W. Bleeker and M.G. Houlé; Geological Survey of Canada, Open File 8722, p. 65–98*



- **TGI-5:** Integrated multidisciplinary studies of unconformity-related uranium deposits from the Patterson Lake corridor, northern Saskatchewan (Bulletin 615, Authors: Potter, E G ; Tschirhart, V.; Powell, J.W.; Kelly, C.J.; Rabiei, M.; Johnstone, D.; Craven, J.A.; Davis, W.J.; Pehrsson, S.; Mount, S.M.; Chi, G.; Bethune, K.M.): This report highlights the findings of 5-years of study in the Patterson Lake corridor. Located along the southwestern margin of the Athabasca Basin in Saskatchewan, the corridor hosts high-grade uranium deposits (Triple R and Arrow) that differ from the traditional Athabasca Basin uranium deposits. The results of the study support classification of the deposits as unconformity-related but highlight the role of high-heat producing granitic intrusions in driving the hydrothermal fluid cells that formed the deposits.

Figure 29: *Integration of geophysical, geochemical, isotopic, thermodynamic and structural data to generate an ore systems model for the recently discovered Patterson Lake corridor uranium deposits, southwestern Athabasca Basin. Modified from Tschirhart et al. (2019) and Potter et al. (2020). Location of Arrow deposit indicated by star in geophysical transects*



- **TGI-5: Contributions to the understanding and exploration of porphyry deposits** (In Press, Editors: A. Plouffe and E. Schetselaar): Porphyries are significant producers of a variety of metals, including copper, molybdenum, tin and tungsten. Nine out of the ten papers in this synthesis describe projects conducted in the Canadian Cordillera where most Canadian porphyry deposits occur and a paper on similar, but older deposits in the Appalachians of Atlantic Canada. The main objective of this TGI research was to better define the geological conditions where porphyry deposits form and test techniques to detect buried porphyry deposits in support of mineral exploration. Results from these studies present innovative methods for the discovery of copper, gold and other commodities in the Canadian Cordillera and the Appalachian region.

Figure 30: *Chalcopyrite and molybdenite in Mine phase tonalite at Gibraltar Mine, south central British Columbia*

Figure 31: *Supergene mineralization of native copper, chalcocite and hematite at New Afton mine, south central British Columbia*

- **TGI-5: Volcanic and sediment hosted massive sulfide deposit genesis and exploration methods** (In Press, Editors: Peter, J.M. and Gadd, M.G.): This contribution summarizes the results of a 5-year study of multiple mineral deposit types: polymetallic hyper-enriched black shale; sedimentary exhalative lead-zinc (Pb-Zn); carbonate-hosted Pb-Zn, magnesite; fracture-controlled replacement Zn-Pb, rare-earth element–fluorine-barium; and volcanogenic massive sulfides. Studies employed field geology, combined with geochemical (lithogeochemistry, stable and radiogenic isotopes, fluid inclusions, and mineral chemistry) and geophysical (rock properties, magnetotelluric, and seismic) methods. Collectively, the research provides advanced genetic and exploration models for volcanic- and sedimentary-hosted base-metal deposits, together with new laboratory, geophysical, and field techniques.

Planning for a new phase of geoscience research

- TGI completed a program evaluation in fiscal year 2020-21. In response to recommendations in the evaluation report, TGI developed the following documents: a Mineral Intelligence Engine proposal; a TGI Information Management/Information Technology (IM/IT) Action Plan; a TGI Stakeholder Engagement Plan; and a TGI Performance Management Plan. These documents will help guide program research, processes, engagement, and reporting as it enters a new phase.

What's next for TGI?

With the program's renewal in fall 2020, TGI began short-term studies to lay the foundation for longer-term program research beginning in fiscal year 2021-22 under two research pillars: the Ore Systems Project and Development Project. In early 2020, the program also held a call for proposals to its grant program, which will support complementary studies by external institutions taking place up to March 2023. These research projects will support the goals of TGI, extending the reach of the program and broadening its results.

Strategic Priority 3: Geoscience for Keeping Canada Safe

There are two GSC S&T programs within GSC Strategic Priority 3:

- Public Safety Geoscience Program; and
- Climate Change Geoscience Program.

Public Safety Geoscience Program (PSGP)

The Public Safety Geoscience Program (PSGP) develops 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. The program is working closely with Public Safety Canada and other federal departments in the development of 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 are in the provision of a base of evidence to understand potential losses from earthquakes across the country.

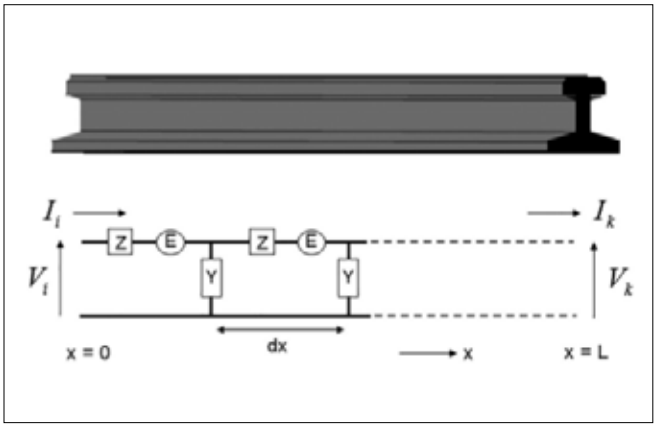
The short-term outcome for PSGP is that Federal, Provincial, Territorial, municipal and industry decision-makers (such as policy makers, project proponents, emergency managers, community planners, utility owners) have scientific evidence and quantitative tools to evaluate risk of geohazards leading to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

Recent successes include:

Investigating geomagnetic interference on railway signals

PSGP has worked to understand the vulnerabilities faced by the rail system to space weather and support rail operators in reducing risk. Railway signals are activated by circuits in railway tracks that detect the presence of a train in a particular rail section. However, there are a number of examples where geomagnetically induced electric fields have interfered with track circuit operation, consequently displaying an incorrect railway signal. GSC scientists developed a new model for track circuit operation to include the induced geoelectric fields produced by geomagnetic field variations, providing insight into conditions that produce signaling problems and tools to assess geomagnetic hazards.

Figure 32: *Rail and its transmission line model (from Boteler, D. H. (2021). Modeling geomagnetic interference on railway signaling track circuits. Space Weather, 19, https://doi.org/10.1029/2020SW002609)*



Assessing threat scores for Canadian volcanoes

There are hundreds of potentially active volcanoes in western Canada, approximately fifty of which have erupted in the last 10,000 years. GSC scientists adapted a United States Geological Survey (USGS) methodology to assess 28 Canadian volcanoes and determined that two volcanoes – Mt. Meager and Mt. Garibaldi – have "*very high*" threat scores nearly identical to Lassen Peak in California and St. Augustine in Alaska, both of which are considered highly active and have had several, large 20th century eruptions. "*High*" threat volcanoes such as Mt. Cayley, Mt. Edziza and Mt. Price score similarly to Mt. Churchill in Alaska and Mt. Adams in Washington. Mt. Churchill is believed to be the source of the ~1250 BP White River Ash, a tephra deposit covering a large portion of northern Canada. Mt. Adams last erupted around one thousand years ago and has a recent history of large lahar and debris

flow events. This 2021 paper helps understand the relative threat of Canadian volcanoes and prioritize future research and monitoring, and contribute in the future to Canada's National Risk Profile under the Emergency Management Strategy.

Understanding what is at risk

In order to assess the potential impacts of hazard events, we must understand what is exposed to these hazards. To respond to this fundamental need in risk assessment, GSC researchers developed a national GIS layer that provides information on buildings and people at the neighbourhood level. This data layer is based on satellite imagery that delineates the extent of settlement across Canada; dissemination area boundaries from Statistics Canada; community profile statistics from Census data; information on land use type; and, characteristics of the building stock derived from site surveys. This provides the data required to understand who and what are exposed to natural hazards, and what their potential vulnerability to those hazards might be. This layer is fundamental to modelling natural hazards risk, and has been developed at a scale that could support community level planning and emergency management.

Figure 33: *Threat levels of Canadian volcanoes (in colour) compared with volcanoes in the United States*

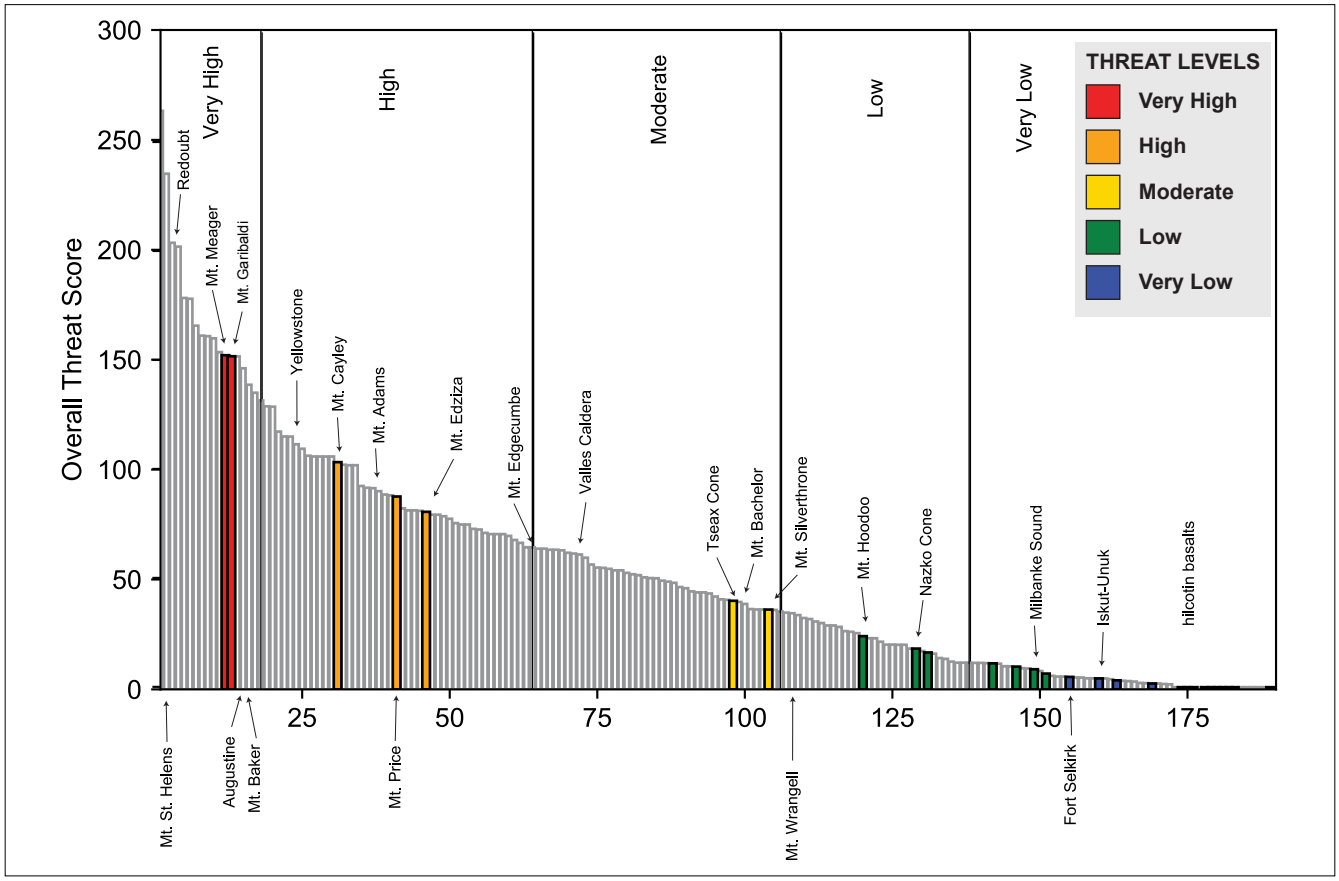
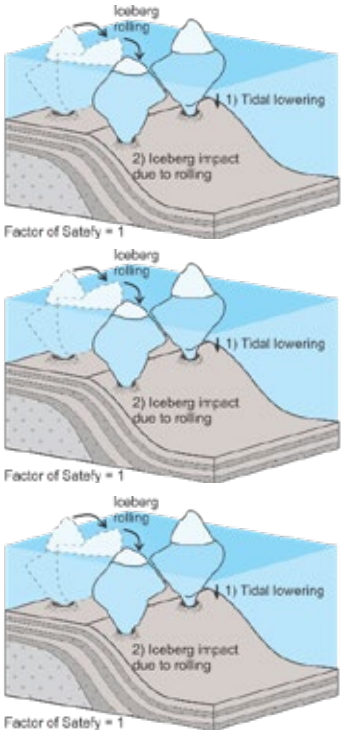


Figure 34: *The components of the national natural hazards exposure model, and fundamental geospatial information to underpin risk assessment*

New discovery on the impacts of icebergs on the seafloor

As part of GSC research in Baffin Bay supported by Crown-Indigenous Relations and Northern Affairs Canada to evaluate geohazards near Baffin Island coastal communities, a first-ever observation was made of an iceberg colliding with the seafloor and triggering a submarine landslide. A submarine landslide triggered by iceberg grounding is a significant discovery, as icebergs ground in many fiords and across the continental margin of Baffin Bay, therefore representing a previously unknown hazard on the seafloor at depth below the iceberg keel depth. These results show that Arctic environments are areas of active seafloor processes that can have consequences on future marine infrastructure as well as nearby communities. Understanding the triggers of marine geohazards will allow stakeholders and decision-makers to properly manage seabed and coastal infrastructure and protect communities in a changing and active marine environment.

Figure 35: *Process by which vertical loading of an iceberg on the seafloor triggers a submarine landslide*



What's next for PSGP?

PSGP will work to include a climate change lens to understand the changing nature of hazards and their associated risks. The program will also develop guidelines for coastal communities in Canada to understand and mitigate coastal flood hazards. PSGP scientists will improve techniques for space weather forecasting, landslide monitoring, and earthquake location, and launch an open source earthquake risk profile for Canada at the neighbourhood scale as part of the National Risk Profile of the Emergency Management Strategy for Canada. Also as part of the National Risk Profile, the program is working with Public Safety Canada to provide evidence-based earthquakes scenario information in support of their risk assessment and capability sessions.

These whole-of-society sessions will provide an understanding of the risks and gaps in the emergency management domain in Canada. This new perspective will be rolled in to a public National Risk Profile report in 2022.

Climate Change Geoscience Program (CCGP)

The GSC's Climate Change Geoscience Program (CCGP) aims to better understand the impacts of climate change in Canada. CCGP scientists conduct geological research on permafrost, coastal erosion, sea level rise, extreme weather events, 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 in order to support land-use planning, infrastructure development, and to help industry and at-risk communities adapt.

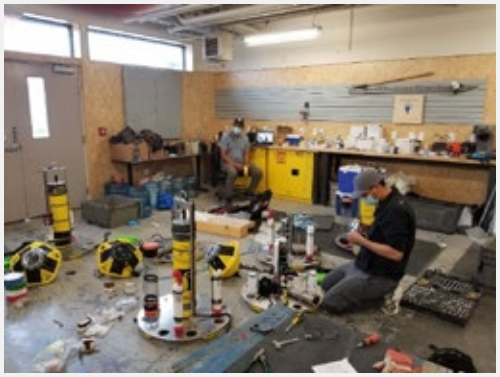
By providing end-users access to CCGP knowledge products to support the identification of priorities for preparedness and adaptation activities in Canada, and users implementing these, the desired long-term outcome is that adaptation measures are implemented through codes, standards, guidelines, and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

New ways of working during COVID-19 pandemic

Fieldwork is an important component of geoscience, but with travel to study sites restricted by COVID-19, CCGP scientists had to be resourceful in figuring out ways to continue their research during the pandemic. In some cases, it involved an increased emphasis on remote sensing methodologies and technologies, while in others, it entailed soliciting the assistance of partners. To minimize data gaps in annual monitoring activities, for instance, permafrost researchers provided federal and territorial colleagues and local contractors in Nunavut and the Northwest Territories with pre-programmed instrumentation, field-data collection protocols, as well as the co-ordinates, descriptions and instructions on the permafrost monitoring sites, and

relied on their partners to assist in collecting the necessary data. The glaciology team enlisted the help of local contractors in the western Cordillera and the high Arctic to conduct measurements for glacier mass balance studies and to service equipment on the glaciers. Coastal scientists were able to pre-program instruments and work with partners in Inuvik to get the equipment assembled and deployed. The success of these collaborations helped ensure continuity in CCGP activities and was due in large part to the strong partnerships that have been built over time with collaborators and communities.

Figure 36: *A technician at the Aurora Research Institute in Inuvik, NT assembles GSC seabed landers while another double-checks the assembly instructions via video conference with GSC staff in Nova Scotia*

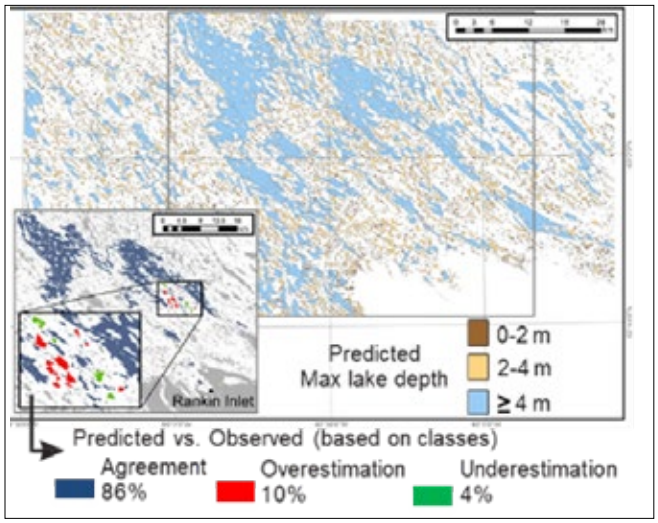


Recent successes include:

Advancing development of talik delineation

CCGP's permafrost researchers are developing new approaches to help delineate open taliks, areas of unfrozen ground that are mainly found beneath large and deep lakes that do not freeze to their bottom. Taliks provide hydraulic connections between surface and groundwater which can affect the development of mining projects because these potential pathways have implications for mine water management and contaminant transport. A CCGP scientist used the Arctic DEM, a high-resolution digital elevation model, to extract topographical variables and develop and validate regional models to determine maximum lake depth for use in assessing the occurrence of taliks below lakes in the Kivalliq and Kitikmeot regions of Nunavut.

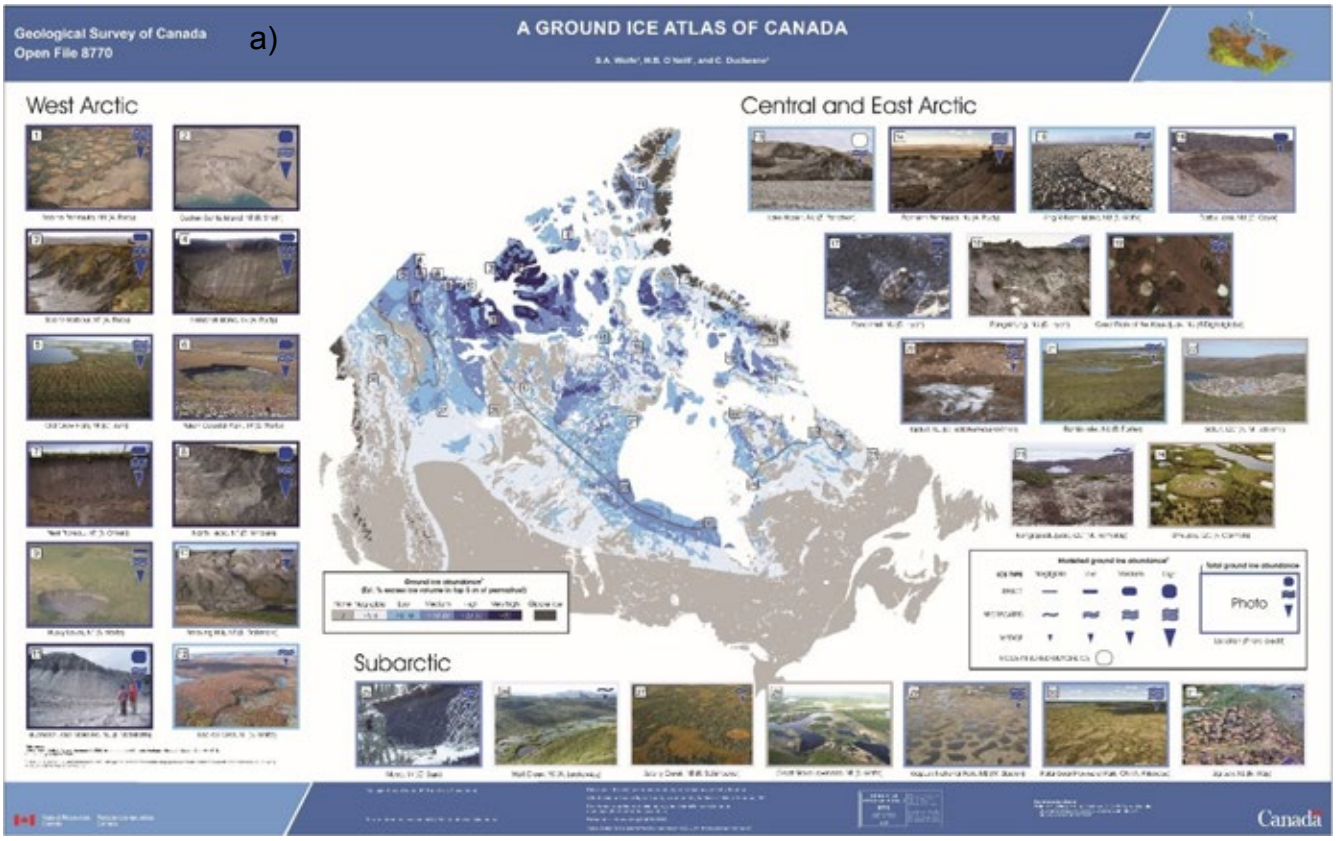
Figure 37: *Maximum lake depth determined for a region in Kivalliq, Nunavut and assessment of model performance*



A ground ice atlas of Canada

CCGP scientists in the Supporting Adaptation in Permafrost Regions Project recently released A Ground Ice Atlas of Canada as a GSC Open File. The Atlas describes the varied ground ice types and abundances in northern Canada, illustrating them with 31 examples from communities, development sites, and natural settings throughout the Canadian Arctic. The sites represent a range of environmental conditions across continuous and discontinuous permafrost zones in Canada. The Atlas compares modelled ground ice abundances to field observations, and discusses the implications of thaw processes in ice-rich terrain (thermokarst), providing guidance for resource development projects, and cost estimates and adaptation measures related to climate change in the North.

Figure 38: a) *Ground Ice Atlas of Canada and b) an inset of Sachs Harbour, NT*



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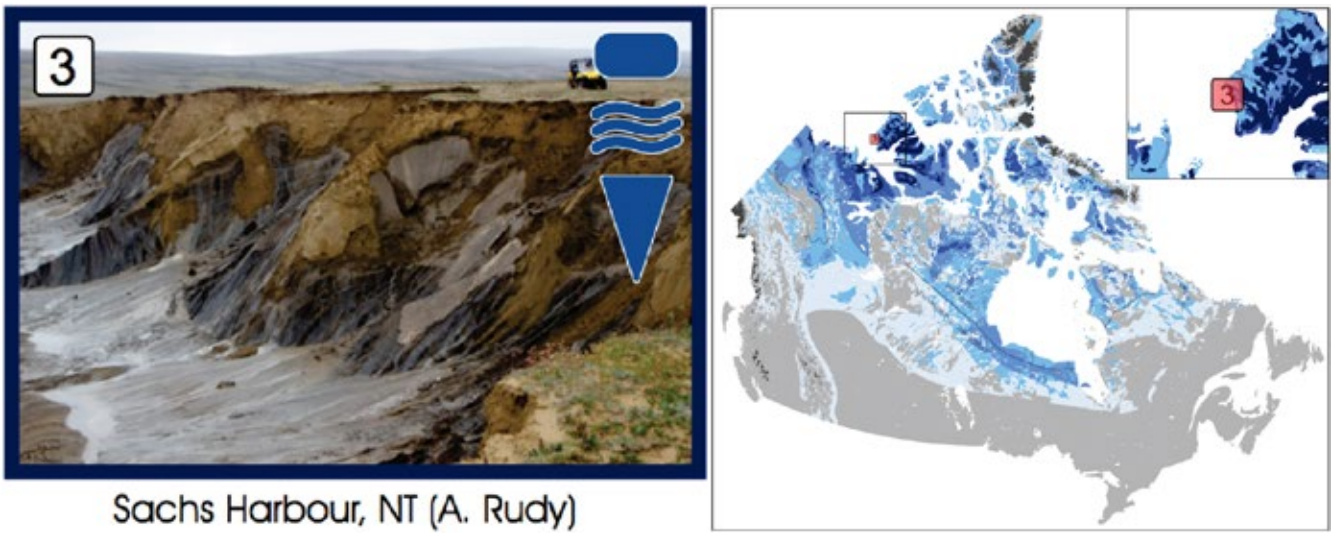
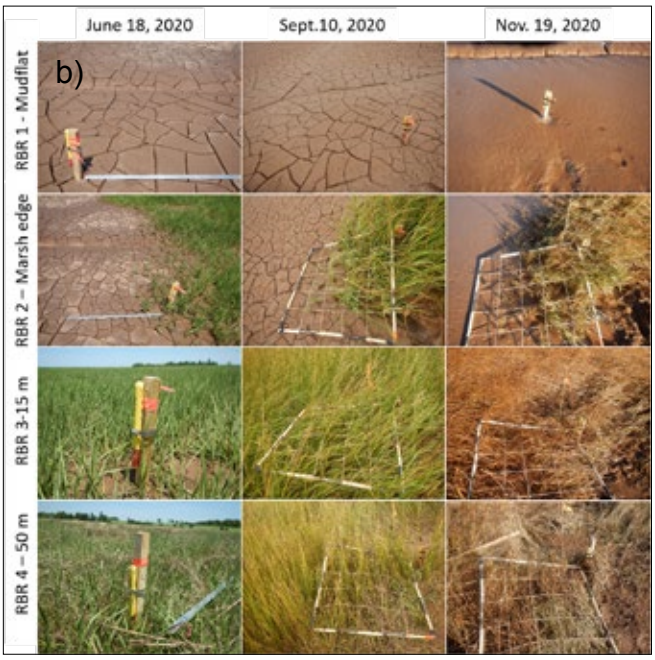


Nature-Based Infrastructure for Coastal Resilience and Risk Reduction

In 2020, the CCGP joined the Nature-Based Infrastructure for Coastal Resilience and Risk Reduction project, a multi-partner initiative (federal, municipal and First Nations government and academia) funded by Defence Research and Development Canada (DRDC) and led by the National Research Council (NRC). Nature-based infrastructure is an underutilized option for combatting Canada's rising flood costs. The project examines the effectiveness of 'soft' coastal infrastructure such as sediments and vegetation to attenuate waves and storm surges, provide flood storage, reduce erosion, attract and stabilize sediment, and sustain stabilizing flora. CCGP scientists are carrying out field work to obtain observations that will inform and constrain modelling and will complement laboratory experiments, and are providing advice on future sea levels. Case studies have been established in three areas: Boundary Bay and Metlakatla in British Columbia, and the upper Bay of Fundy in Nova Scotia and New Brunswick.

Figure 39: *a) Low altitude aerial imagery of natural low marsh with red tidal flats to the left, bright green low marsh in the centre, and pale green high marsh to the right at Clifton Marsh Minas Basin. Pilot Graeme Matheson, NSDA; b) Instrument stations and vegetation quadrats at a Bay of Fundy site in summer and fall 2020, depicting change in vegetation height, density and vigour, and c) The newly constructed breakwaters at Metlakatla are part of a hybrid shoreline protection system incorporating beach nourishment and small ecologically enhanced salt marsh areas. The function of the breakwaters is to attenuate waves at the nourished beach area to ensure stability*

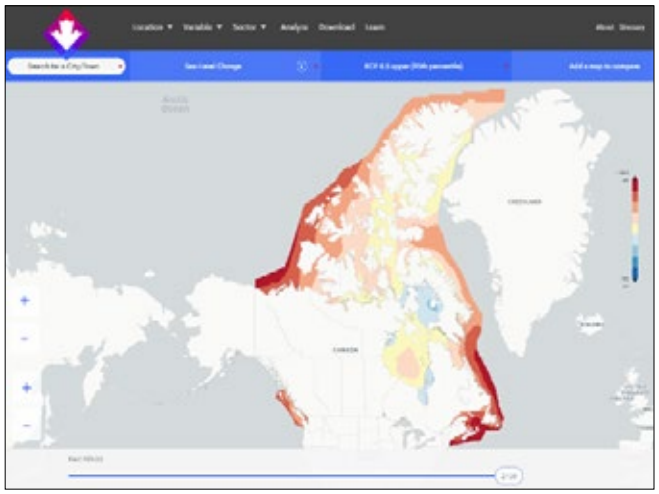


Sea level change data available online

CCGP scientists and NRCan colleagues have developed a gridded dataset of future relative sea levels to help Canadians plan, prepare for, and remain resilient to sea level changes. Relative sea level projections provided by this dataset are foundational information for ensuring coastal communities and ecosystems remain resilient in a changing climate. Projections are available on ClimateData.ca at a resolution of approximately 11 km latitude by 2 to 8 km longitude for 2006 and every decade from 2010 to 2100, relative to 1986-2005 conditions for all coastal regions across Canada. Users can zoom-in to a specific location, view and download the time series data, and compare maps between Intergovernmental Panel on Climate Change (IPCC) emissions scenarios. Combined with other datasets

of storm surge, waves, tides, and additional local-scale vertical land motion, this relative sea level data is expected to contribute significantly to coastal flood risk assessments and adaptation decision-making.

Figure 40: *Projected relative sea-level change at 2100 for the high-emissions RCP8.5 scenario (95th percentile), as provided by the Canadian Centre for Climate Services website climatedata.ca. Projection are relative to a baseline of 1986-2005*



Effects of enhanced glacier melt on primary productivity in Jones Sound

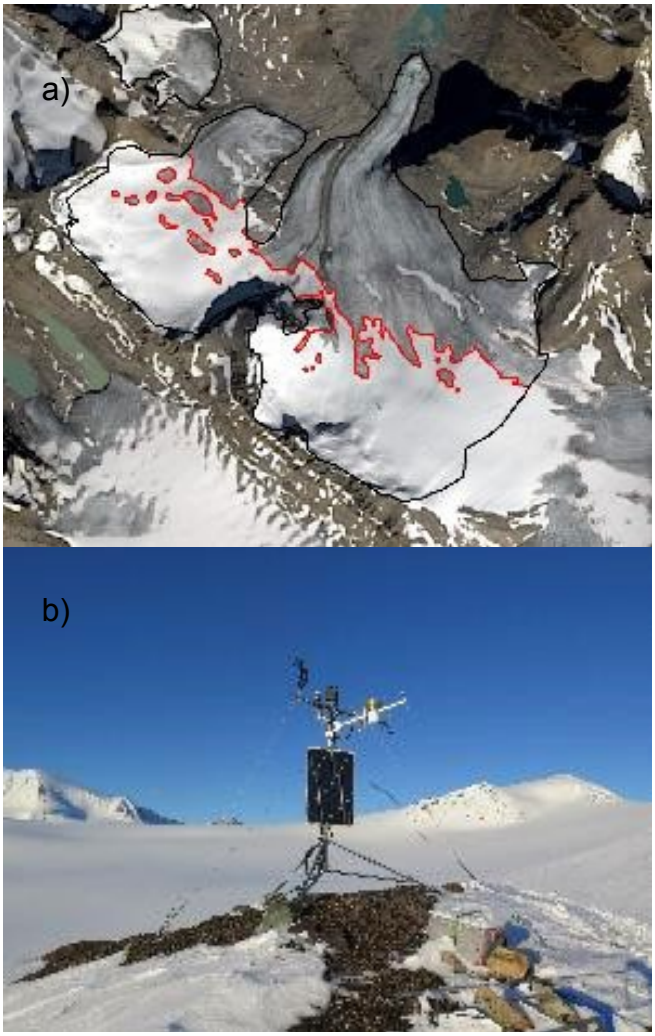
The National Glaciology Project (NGP) collaborated with the Universities of Alberta and Dalhousie to understand the drivers of marine productivity at the base of the food web in Jones Sound, Nunavut. This study combines Indigenous and scientific knowledge to better understand how glacial meltwater inputs affect ecosystem productivity and health in this regionally important environment. Results show that the carbon in glacial melt is potentially more bioavailable than marine carbon. Additionally, with the release of submarine discharge at the terminal ice front, glacial meltwater entrains deeper nutrient-rich marine water and delivers nutrients to the surface as the meltwater plume rises. This research improves our understanding of the impacts of glacier melt runoff due to climate change on primary productivity in Jones Sound, Nunavut where traditional marine food sources are harvested by local Inuit.

Figure 41: *Summer meltwater plumes ejected by the Sverdrup Glacier, Devon ice cap, NU, into Jones Sound*

Measuring equilibrium line altitude (ELA) on Canada's glaciers

GSC glaciologists have been measuring changes in the mass balance of glaciers and ice fields for over a half century - work that is vital in monitoring climate change. Although regular site visits are needed for accurate measurements, it is possible to estimate annual mass balances using glacier-climate indicators such as equilibrium-line altitude (ELA) generated using remotely sensed imagery and climate data downloaded from telemetry-enabled weather stations. The NGP, in collaboration with University of Waterloo, is currently testing the application of RADARSAT-2 imagery to distinguish between dry snow, firn (granular snow, on the upper part of a glacier that has not yet been compressed into ice) and bare ice allowing for superior mapping of the ELA compared to optical imagery.

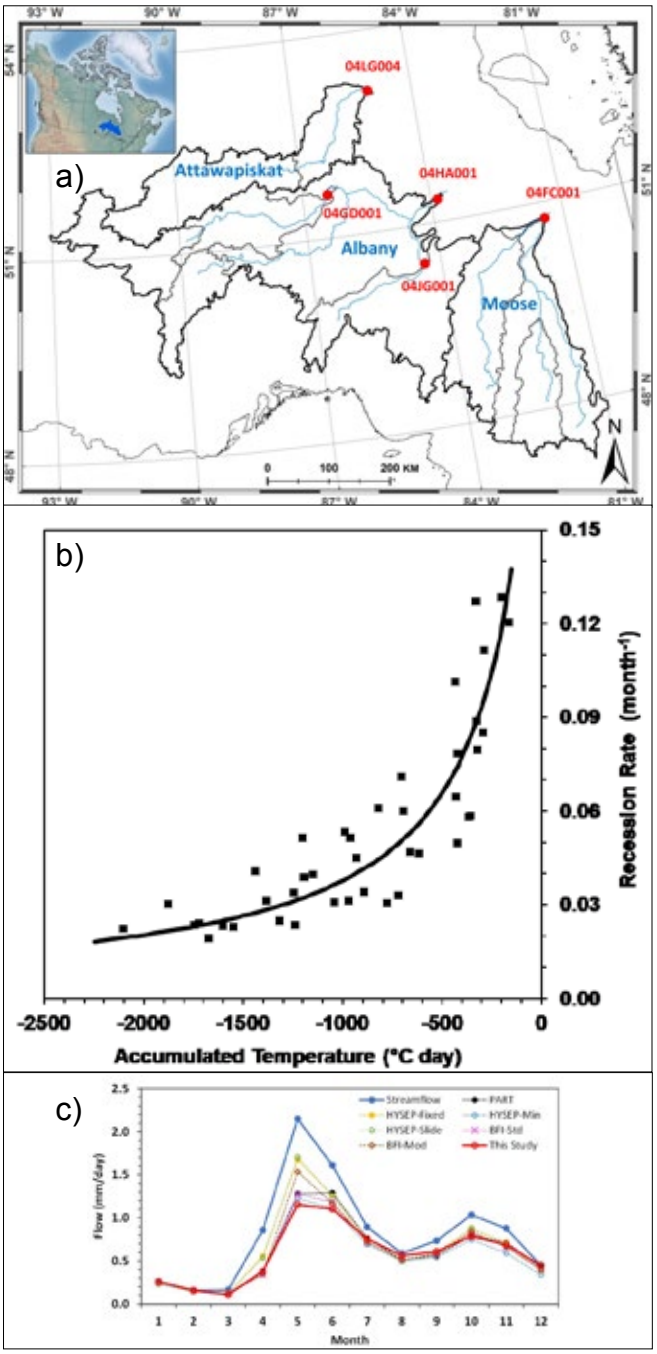
Figure 42: a) *Late summer 2020 Landsat image of Peyto Glacier in Banff National Park used to map the equilibrium line altitude (red) and b) telemetry enabled weather station in Nahanni National Park, Northwest Territories*



A novel method for cold region streamflow hydrograph separation

One of the activities of the CCGP's Extreme Events Project is flood forecasting for Hudson Bay Lowlands. Using NASA's Gravity Recovery and Climate Experiment (GRACE) time series of satellite data, our scientists were able to estimate how much water is lost by aquifer discharge, and how much water is lost by rain/snowmelt induced surface runoff, for a watershed. By simulating aquifer discharge, the new model reveals the relationship between freezing temperature and baseflow recession rate and thus provides an important link between climate warming and aquifer discharge. The model improves flood forecasting for the Hudson Bay Lowlands and provides advance warning to coastal First Nations communities.

Figure 43: *a) Watersheds in the Hudson Bay Lowlands; b) The dynamic change of groundwater recession rate with accumulated freezing temperature in winter (dots: estimated using observed data, line: estimated using GSC model); c) Modelled groundwater discharge and comparison with USGS model results for the Albany Watershed. The issues in overestimating discharge during the snowmelt season by the USGS models are largely resolved*



Standards, guidelines and assessments

CCGP scientists contribute their expertise to the development of Canadian standards and guidelines and provide input for national and international climate change assessment initiatives. For example, permafrost researchers contributed to several standards for the Canadian Standards Association's Northern Infrastructure Standardization Initiative (NISI), work by coastal scientists is included in the sea level section of the National Research Council's Coastal flood risk assessment guidelines for building and infrastructure design, and the glaciology project contributes glacier mass balance data to the World Glacier Monitoring Service. CCGP researchers contributed to international assessments such as the IPCC AR6 Working Groups 1 and 2, the Arctic Monitoring and Assessment Program Update, the State of Climate reports, and the World Climate Research Program Sea-level Grand Challenge.

What's next for CCGP?

In the coming year, the CCGP will focus on the completion of research activities and the dissemination of scientific outputs of the current program. The release of a Special Issue of the Canadian Journal of Earth Sciences on the topic of landscape/seascape responses to Canada's changing climate is planned, as is a comprehensive report synthesising the ARCHIVES project, a multidisciplinary endeavour to reconstruct past hydro-climatic conditions using climate-sensitive natural indicators such as tree rings. Monitoring the climate-induced changes on permafrost, glaciers, and coastlines will continue, and we are planning the next iteration of the CCGP, in collaboration with partners.

Strategic Priority 4: Geoscience for Society

Open Geoscience Network

Program description

The purpose of the Open Geoscience program 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 practiced in full respect of privacy, security, ethical considerations and appropriate intellectual property protection.

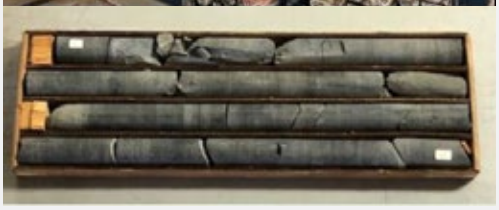
Making GSC geoscience data and information open accelerates the industry's ability to find minerals and metals, improves management of water, energy and mineral resources, helps protect Canadians from natural hazards, facilitates adaptation to climate change, and supports government decision-making and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

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 (**Figure 44**, **Figure 45**).



Recent successes include:

Making GSC Geoscience readily available to Canadians

Central to open geoscience is disseminating our data and communicating our science. The GSC shares various 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.

In 2020-21, the Open Geoscience Network (OGN) supported and promoted GSC geoscience by publishing 494 publications; these include externally-published journal articles as well as GSC publications: 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).

Over 67% of GSC authored articles and information products are open access and all products published by GSC 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 2020-21, GSC geoscience information and data products were downloaded more than 590,000 times from GEOSCAN. Products published in 2020 were downloaded over 60,000 times.

Social media plays an important role in promoting GSC science. Many GSC researchers post information about their own research on various platforms and the GSC Twitter account has a growing audience. In 2020-21, @GSC_CGC posted 266 tweets which received 2242 likes and 837 retweets and making 334,000 impressions. @GSC_CGC was mentioned 676 times by other Twitter users and the number of followers increased 35% to 1,995 by March 31, 2021. GSC science was also featured by NRCan in several internal videos and podcasts.

Want to stay in the loop about cutting-edge geoscience in Canada?

Follow the GSC on Twitter at:

@GSC_CGC

Enabling our digital transformation

A critical role of the Open Geoscience program is to enable digital transformation. Data infrastructure, platforms, and standards are important as these serve as 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 GSC data and assets are managed effectively. OGN has started 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 value to science of our physical collections; and,
- Help document, store and manage the GSC's 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 – especially important as scientists pivoted to re-analysis of existing samples during COVID-19 – and OGN has also continued to update our publications process to best incorporate open science principles.

In 2020-21, OGN catalogued, organized, and moved over 1,200 pallets and 1,500 cabinets of physical samples in Ottawa, Ontario to a more modern facility. This is an early step to increase the accessibility and availability of high quality samples collected across Canada. (**Figure 46**, **Figure 47**)

Prioritizing a national approach to the delivery of Canada's geoscience information

In 2020, during the scoping and development of the Pan-Canadian Geoscience strategy, members of the National Geological Surveys Committee (NGSC) identified geoscience information management and data dissemination as a common challenge and a key factor in making Canada a mineral and energy investment destination. The NGSC also recognized the importance and value of coordinating geoscience data across Provincial, Territorial and Federal public geoscience organizations to meet society's demand for open access to digital data. The GSC collaborated with NGSC's Information Data Management Working Group (IMDWG) to launch the NGSC-wide *Assessment of Data-Readiness and Review of Stakeholder Needs for National Distribution of Geoscience Data*. The assessment identified several datasets highly valued by stakeholders and identified several models for data sharing and integration that have been successfully implemented by other geological surveys. This work will support the identification and prioritization of opportunities to unify and standardize geoscience information and databases from Provincial, Territorial and Federal sources. The NGSC IDMWG will use the report as a reference as they work towards consensus on common priorities to improve national geoscience data availability and accessibility.

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.

Progress will be made towards implementing corporate data governance and standards for managing GSC data.

Publications and technical information will be compiled 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 improving the accessibility, usability and interoperability of geoscience data.

The GSC's digital transformation will continue with the modernization of GSC's applications and broader support for adoption of cloud computing. Development of the GSC publications management tool will be completed, improvements made to respond to client needs and it will be re-hosted to NRCan's cloud environment. Solutions will be explored to support greater discoverability of GSC's physical collections and an IT Architecture framework will be developed to facilitate future science computing and application development.

Indigenous Relations Network

The GSC is active in the field on land and at sea across the country, undertaking geoscientific research to understand Canada's mineral resource endowment, natural hazards, groundwater, energy and changing climate. With more than 630 First Nation communities in Canada, which represent more than 50 Nations and 50 Indigenous languages, GSC's work often takes place within or near Indigenous communities.

The GSC has been conducting geoscience research for over 170 years. During this time, GSC scientists have engaged with, and worked with Indigenous peoples across Canada. As we have become increasingly aware of the importance and value of collaboration and co-development of our geoscience research activities with Indigenous communities, GSC scientists have worked more broadly with Indigenous advisory groups and more closely with individual Indigenous communities. As a result of these connections, GSC science can better support and address Indigenous priorities; empower Indigenous communities with geoscientific knowledge; increase trust and understanding between communities, governments; and, open doors to increase Indigenous participation in GSC geoscience research activities.

Indigenous reconciliation is explicitly recognized as a key part of the GSC, and with its history, relationships, and reach, the GSC has the potential to contribute substantially to reconciliation. The GSC is committed to working with communities to increase our shared understanding of geoscience, including through advisory bodies such as the Advisory Group of Northerners (AGN), hunters and trappers organizations and game councils, and 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.

Since the fall of 2020, the GEM-GeoNorth program has been co-developing its research priorities with provinces and territories, Indigenous Governments (IGs) and Indigenous Organizations (IOs). 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 regarding the first iterations of the GEM program.

You can read more about the GEM-GeoNorth program on page 31.

Recent successes include:

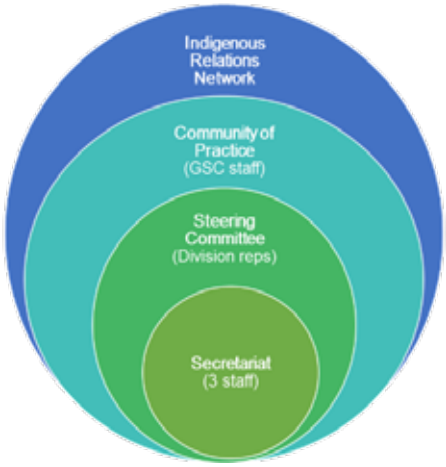
Creating the Indigenous Relations Network

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 towards this goal, the GSC has established the Indigenous Relations Network (IRN), an internal community of practice focused on supporting the organization's capacity to conduct Indigenous engagement. The Indigenous Relations Network Steering Committee provides guidance and leadership to the IRN.

Comprised of representatives from each of the GSC's six geographic divisions the Committee began prioritizing tasks to be carried out. In the remaining months of the fiscal year they:

- Organized training on Indigenous Cultural awareness for 60 GSC staff;
- Developed a Terms of Reference for the Steering Committee;
- Began work on a centralized database of Indigenous engagement activities currently underway in the GSC; and,
- Started development of an Engagement Toolkit with key information for staff on how to approach Indigenous engagement with cultural understanding, awareness, and respect.

Figure 48: *The Indigenous Relations Network*



IRN Steering Committee objectives include:

- Establish a shared awareness and understanding of the GSC's existing relationships with Indigenous communities and organizations, and related engagement activities.
- Support GSC staff to obtain, learn and apply relevant policies, principles or guidance that may affect engagement with Indigenous communities and organizations.
- Foster a culture of collaboration and openness to integrate Indigenous knowledge and perspectives into geoscience, and to understand Indigenous community needs and interests.
- Share leading practices across the organization by creating and/or disseminating tools and making educational and training opportunities available.
- Encourage innovative and mutually beneficial relationships with Indigenous communities and organizations related to geoscience.
- Identify barriers to effective engagement with Indigenous communities on geoscience and work within the organization to begin addressing these barriers, raising issues with senior management, as appropriate.
- Advise the organization on approaches to sustain meaningful relationships with Indigenous communities and organizations in an effective and sustainable manner over the long-term.

What's next for IRN?

In the coming year the IRN will host a virtual workshop for all GSC staff to review what has been achieved to date and to obtain feedback on the plans for moving forward. The IRN will continue to organize Indigenous relations focused training targeted for all staff. Building on past successes, a future aim is to increase the reach of the IRN to include more staff and make further headway into creating an effective Indigenous Relations Community of Practice at the GSC while ensuring that we liaise appropriately within the sector, department, and government as a whole. Leading practices around geoscience and Indigenous communities developed by the GSC provides a solid foundation which, when coupled with the commitment of staff and management, will guide this new GSC initiative in addressing the opportunities and challenges.

Strategic Priority 5: Our People, Our Science

Science Lab Network

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. 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 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 are able to provide innovative solutions. SLN also conducts collaborative research with provincial, territorial, and academic partners, strengthening the scientific excellence of Canada's laboratories.

In 2020-21, SLN contributed to GSC research objectives by delivering laboratory-based research for all GSC programs through 71 Lab Study Agreements, particularly through innovative and specialized laboratory analysis and interpretation.

Recent successes include:

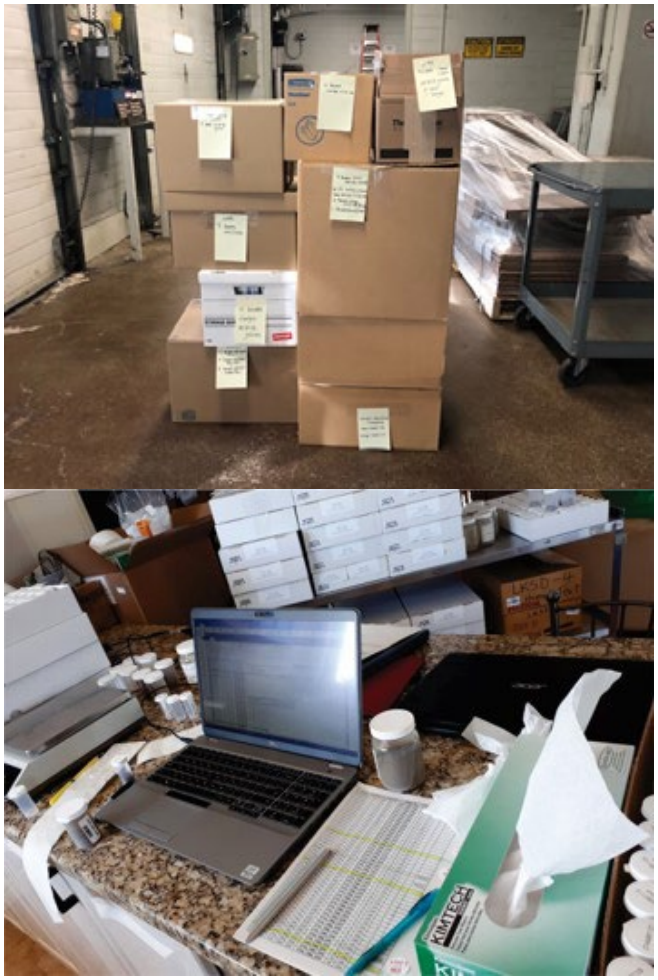
Supporting Canada's response to COVID-19

To help combat the spread of COVID-19 in Canada, SLN organized donations of personal protective equipment (PPE) including gloves, N95 masks, Tyvek suits and lab coats, safety glasses, goggles, face shields, and wipes to local first responders and the Public Health Agency of Canada.

Adapting to the COVID-19 pandemic

All lab-based science and analyses were disrupted due to COVID-19 shutdowns ranging from 45% to over 60% of the fiscal year, which limited access to instrumentation. However, SLN staff adapted in creative ways by completing scientific publications, updating task hazard analysis, safety documents, and lab manuals, some of which will be published as Open Files. SLN scientists completed the digital transformation of the network's Lab Study Agreement process to better support collaboration with GSC programs across Canada.

Figure 49: *Sedimentology sample preparation in the kitchen*



Ensuring the sustainability, reliability, and relevance of SHRIMP data

Sensitive High Resolution Ion MicroProbe (SHRIMP) instruments lead the world in their ability to determine the age of microscopic mineral domains, and GSC Ottawa houses the only SHRIMP laboratory in Canada. Working with international collaborators in Australia and the USA, GSC scientists developed a new platform-independent, open-source, Java-based application for SHRIMP isotopic analyses: SQUID-3. In January 2021, the collaborators successfully launched a beta-version of SQUID-3 through a series of workshops and tutorials on YouTube. The new software updates the SHRIMP data-processing methodology to ensure the sustainability, future improvement, reliability, and relevance of SHRIMP data worldwide.

Reconstructing the past to predict the future of storms

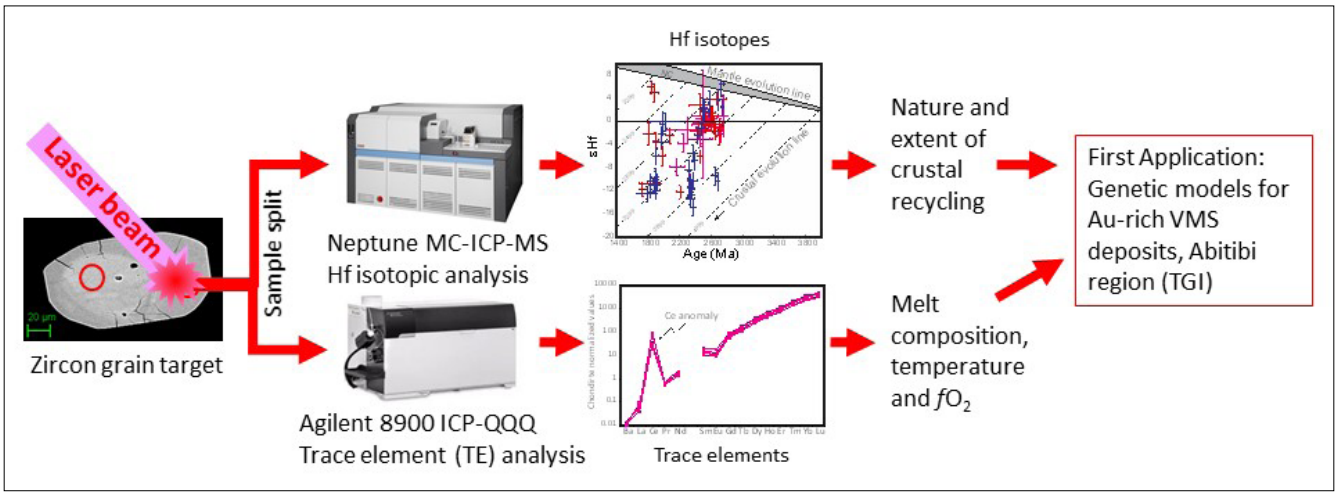
By analyzing legacy rock cores, scientists produced the first reconstruction of an older than 3,500 year record of large storms in the North Atlantic. The impact of abrupt climate change on the storm strength at different latitudes in the North Atlantic in response to changes in overturning circulation strength was described for the first time. This information is fundamental to correctly assess future storm risks along the North Atlantic coastline, especially in densely populated coastal areas where intensity of storms is expected to increase.

Figure 50: *Home of the only SHRIMP lab in Canada, the GSC worked with Australia and the USA to develop & launch new software (SQUID-3) for SHRIMP isotopic analysis*

Zap once, measure twice

Lab scientists have developed a new method for simultaneously measuring isotopes and trace elements in mineral samples, by splitting into two streams the aerosol particles generated when a laser beam is focused on the sample (laser ablation). Each sample stream is then directed to a different Inductively Coupled Plasma Mass Spectrometry (ICP-MS) instrument, permitting different measurements on identical micro-sampling volumes. Flexible, powerful, precise, and efficient, this method was first applied to a TGI project to validate ore system models of gold deposits in the Abitibi region.

Figure 51: *Development of split stream analysis – simultaneous Hf isotopic and trace element analysis of zircon*



Informing international sustainable development

The Commission for Environmental Cooperation (CEC) facilitates effective cooperation and public participation between Canada, USA, and Mexico to conserve, protect and enhance sustainable development in North America. Lab-based research from GSC was cited heavily in a CEC report regarding the contamination of groundwater by oil sands tailings. An online CBC article discussing the results of the report received over 3,500 comments, demonstrating the effectiveness of connecting Canadians with laboratory-based GSC research.

Breaking down silos within NRCan

In collaboration with CanmetMINING, GSC developed the LMS Mineralogical Characterization Facility. By integrating the lab-based mineralogical capabilities of CanmetMINING and the GSC, researchers from both branches have improved access to expertise, instrumentation and trained operators, resulting in better program outcomes and enhanced method development opportunities.

What's next for SLN?

SLN will be undertaking a review of its strategic directions to continue innovating in laboratory-based research and ensure alignment with GSC Programs. This includes looking at new opportunities to create world-class centers of expertise through the acquisition of state-of-the-art instrumentation, and interdepartmental collaboration with our TerraCanada partners.

Generation 8

This goal of this initiative is to ensure a bright future for the GSC as we plan the 8th generation – or major trendline – since its inception in 1842. The Generation 8 Initiative (GEN8) aims to ensure GSC science remains relevant through:

- Increasing science-policy relevance and impact;
- Strategic partnerships/collaborations;
- Meeting targeted user needs;
- Empowering staff (innovation, development & renewal);
- Developing new approaches, methods, ideas;
- Efficient and effective systems and infrastructure; and
- Improving communications – internal and external.

TerraCanada and Laboratories Canada

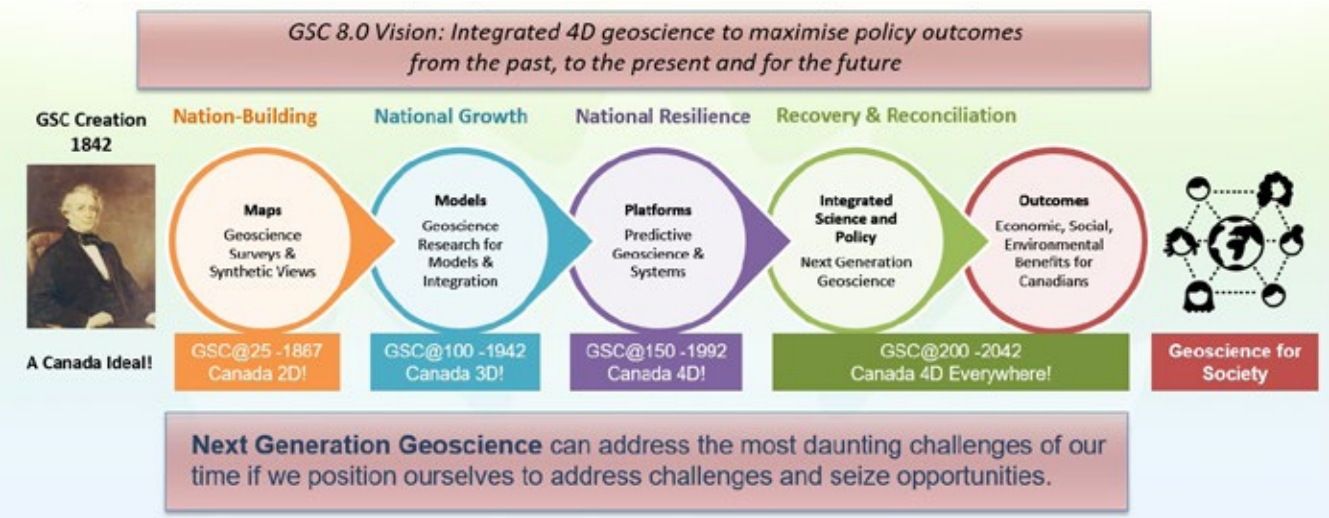
Investing in next generation infrastructure and technology

As part of Phase 1 of the 25-year Laboratories Canada strategy science-based departments and agencies have come together to collaborate on science priority areas. Together, these groups – known as science hubs – are exploring opportunities to strengthen their research through enhanced interdisciplinary work, collaboration, and shared facilities and equipment.

TerraCanada is one of these innovative science hubs, involving five federal partners: Natural Resources Canada (co-lead), National Research Council (co-lead), Health Canada, Environment and Climate Change Canada, and Canadian Nuclear Safety Commission. TerraCanada will promote transdisciplinary research and development and innovation along three themes:

- Sustainable Land and Resource Development;
- Low-Carbon Economy; and
- Safety and Health of Canadians.

Figure 52: *A strategic asset since 1842, the GSC has transformed to meet Canada's evolving public geoscience and policy needs, to turn knowledge to reality and decisions*



Change Management is essential to the success of TerraCanada as it ensures that the people who will be operating in the new environment have the tools and support needed to obtain their buy-in and fully benefit from the changes. The GSC leads Change Management activities related to NRCan staff participation in TerraCanada, working closely with NRCan colleagues in CanmetMINING and CanmetMATERIALS.

In collaboration with NRC and the TerraCanada Hub Management Office, the GSC launched in February 2021 an ongoing series of Virtual Science Events with its TerraCanada partners. By highlighting the scope of science and the breadth of knowledge under TerraCanada, these events are already yielding results in terms of new collaborations explored – and highlighting initiatives that embody the TerraCanada spirit, such as the network for Collaborative Research in Ice, Snow and Permafrost (CRISP). Co-chaired by the GSC and Polar Knowledge Canada, CRISP brings together scientists from eight additional federal partners to share expertise, generate advice, and developcollaboration with NRC and the TerraCanada Hub Management Office, the GSC launched in February 2021 an ongoing series of Virtual Science Events with its TerraCanada partners. By highlighting the scope of science and the breadth of knowledge under TerraCanada, these events are already yielding results in terms of new collaborations explored – and highlighting initiatives that embody the TerraCanada spirit, such as the network for Collaborative Research in Ice, Snow and Permafrost (CRISP). Co-chaired by the GSC and Polar Knowledge Canada, CRISP brings together scientists from eight additional federal partners to share expertise, generate advice, and develop solutions to the complex challenges related to the frozen elements of the earth (ice snow, permafrost)

As well, in 2020 and 2021, scientists from GSC's Northern Division and Central Division participated in workshops to identify specialized science requirements and science affinities that will inform the design of TerraCanada facilities in the National Capital Area.

Creating a healthy, respectful culture in the workplace

The Together for Respect (TfR) Initiative, which spans from 2017 to 2023, is an eight-point plan for contributing to a culture of respectful relationships across sectors, hierarchies, genders, and nationalities. TfR focuses on creating healthy relationships through mutual respect and civility, and enabling well-being and mental health in the workplace. This initiative is an employee-management driven initiative where regular dialogue takes place. TfR objectives include:

- Short-Term: Enhanced leadership best practices and increased engagement through a culture of recognition - from a "Thank You" to a Logan Award (the foremost mark of employee or team recognition in the GSC). Logan Awards were initiated in 2017 to mark GSC`s 175th anniversary, and are awarded annually. In 2020-21, 11 GSC staff received a Logan Award, and 20 GSC staff received recognition on the Wall of Honour. In addition, a GSC employee received a Departmental Impact Award for Living Leadership.
- Medium-Term: Building a better workplace and increasing mental health awareness resulting in increased engagement leading to innovation.
- Long-Term: A workplace of healthy relationships through respect and recognition, ensuring a culturally diverse high performing engaged organization.

Planning the workforce of tomorrow

The GSC is committed to developing and maintaining a resilient, high-performing, and diverse workforce. GSC has multiple initiatives to support this:

Public Service Employee Survey (PSES) working group:

The PSES is a comprehensive survey measuring federal government employees' opinions about their engagement, leadership, workplace, diversity, and inclusion. The GSC's PSES working group synthesized and analyzed results from the 2020 PSES and identified three key areas for the GSC to work:

- Business Processes;
- Career Progression and Advancement; and
- Communication and Involvement: Engagement of staff and Planning.

Human Resource Planning (HR):

In 2021-2022, the GSC focused on three main priority areas related to human resources:

- GSC Branch HR Plan and Divisional Plan updates;
- Career Progression of non-research scientist groups;
- Action Plan to respond to staff's feedback in PSES

GSC Branch HR Plan and Divisional Plan updates; Career Progression of non-research scientist

Official Languages:

We have been working on a Branch Plan regarding official languages training to support succession planning and career opportunities for staff in all Divisions and in our new borderless COVID-19 workforce environment. This contributes to NRCan's official language priorities:

- Reinforcing communications with and services to the public: We will provide services to Canadians in the official language of their choice;
- Strengthening a bilingual workforce: We remain committed to building a workplace that is conducive to the use of English and French; and
- Promoting English and French by sharing our science: We will proactively engage with Official Language Minority Communities to promote bilingualism and scientific research.

Communicating geoscience to Canada and the world

World class geoscience needs a robust communications strategy to ensure that science is accessible and shareable. The GSC has recently developed a communications plan, which will underpin GSC science communications initiatives in a fast-paced, digital world.

The GSC also recently redesigned its website to better communicate GSC geoscience. The website features: popular items, resources (tools, data, research), featured items and provides information about the GSC's programs, according to thematic /focus areas. The GSC also uses Twitter to engage with the public and enhance the GSC's digital presence.

Pan-Canadian Geoscience Strategy

A shared vision for collaboration

The Pan-Canadian Geoscience Strategy (PGS) is a federal/provincial/territorial collaborative effort that is coordinated through the National Geological Surveys Committee (NGSC) in alignment with the Intergovernmental Geoscience Accord (IGA). The PGS helps achieve the targets set out under the Canadian Minerals and Metals Plan (CMMP) and responds to calls from governments and stakeholders to explore options for improving public geoscience coordination and funding. The PGS supports the long-term **vision** to provide geoscience information that underpins the responsible development of Canada's geological resources (geo-resources) and serves the public good.

Under this vision, the PGS seeks to advance the following **mission** initiatives:

- Support a globally competitive mineral and energy exploration and development sector in Canada;
- Provide accessible geoscience data and knowledge to inform sustainable development and land use decisions;
- Reduce environmental and public safety risks associated with resource development and geological hazards (geo-hazards); and
- Be responsive to society's evolving expectations for land and resource management.

The PGS identifies five interdependent **priority areas** for action:

- Advancing framework geoscience;
- Advancing mineral and energy potential modelling;
- Facilitating access to online data;
- Supporting the training of next generation geoscientist; and
- Enhancing public literacy in geoscience.

These priorities support the PGS vision and missions by providing access to data and knowledge, ensuring that these data are sufficiently discoverable and understandable to maximize positive impacts, developing next generation geoscience expertise in Canada as current specialists leave the workforce for retirement, and enhancing the ability of the public to understand and benefit from geoscience. The PGS vision, missions and priority areas were all developed through discussion with a variety of geoscience users and are supported by an NGSC consensus.

From strategy to action

Going forward, the GSC will work with the rest of the NGSC to implement the preliminary actions described in the PGS document, and identify further opportunities to advance the five priorities, in collaboration with Indigenous peoples and stakeholders where possible.

This will be carried out through expert working groups that will be established for each priority area with regionally balanced representation from across Canada.

Funding and Budget Expenditures

Budget Expenditures

In 2020–21, the GSC budget expenditures totaled $57M.

Table 4: *Geological Survey of Canada 2020-21 Budget Expenditures*

GSC 2020-21	A-base ($)	C-base ($)	Total ($)
Vote 1 – Salary	$37 624 118.84	$4 672 757.46	$42 296 876.30
Vote 1 - Operation and Maintenance (O&M)	$2 231 405.29	$10 719 076.72	$12 950 482.01
Vote 5 - Major Capital	-	$1 533 310.30	$1 533 310.30
Vote 10 – Grants	$30 035.50	$215 000.00	$245 035.50
Total All Votes	$39 885 559.63	$17 140 144.48	$57 025 704.11

Program of Energy Research and Development (PERD) funding

The NRCan Office of Energy Research and Development (OERD) funding is the Government of Canada's coordinator of energy research and development (R&D) activities. Thirteen federal departments and agencies receive funds from OERD under the PERD program to undertake R&D and technology demonstrations. Since the 1970s, the GSC has been collaborating with the OERD to develop science to help ensure a sustainable energy future for Canada in the best interests of both our economy and our environment.

GSC received $1M funding for eight projects in 2020-21, under the Federal S&T funding of the OERD. These projects address a variety of strategic priorities around more efficient and cleaner energy.

Other Sources of Funding

The GSC works closely with collaborators to complete geoscientific research in Canada. The GSC would like to acknowledge the contributions of all its partners: from other Government of Canada departments, provincial and territorial governments, non-governmental organisations, industry and academia – from around the world.

Annex 1: Reporting Structure Overview

Natural Resources Canada (NRCan) Departmental Results Framework

NRCan delivers its results through the Departmental Results Framework (DRF) in three core responsibilities (CR): (1) Natural Resource Science and Risk Mitigation; (2) Innovative and Sustainable Natural Resource Development; and (3) Globally Competitive Natural Resource Sectors.

All GSC work falls under the NRCan DRF Core Responsibility 1 (CR-1): *Natural Resource Science and Risk Mitigation*. The objective of CR-1 is to lead foundational science and share expertise for managing Canada's natural resources, reducing the impacts of climate change and mitigating risks from natural disasters and explosives. The expected results are that Canadians have access to cutting-edge research to inform decisions on the management of natural resources; communities and officials have the tools to safeguard Canadians from natural hazards; and communities and industries are adapting to climate change.

This Core Responsibility supports the advancement of the following Government of Canada Strategic Priorities:

- Protecting Canadians from the impacts of natural and human-induced hazards;
- Accelerating the adoption of clean technology and supporting the transition to a low-carbon future; and
- Advancing reconciliation, building relationships, and sharing economic benefits with Indigenous peoples.

This Core Responsibility also contributes to the achievement of the Mandate Letter Commitments of the Minister of Natural Resources.

The GSC programs within the DRF are:

- Geological Knowledge for Canada's Onshore and Offshore Lands (Strategic Priority 1);
- Geoscience for Sustainable Development of Natural Resources (Strategic Priority 2); and,
- Geoscience to Keep Canada Safe (Strategic Priority 3).

See the 2020-21 Departmental Plan for more information.

Performance Information Profiles

Aligned with the Department Results Framework, NRCan uses Performance Information Profiles (PIPs), a tool to organize, co-ordinate and report on performance information relevant to programs. The PIPs enable the collection of data to support monitoring, routine program and policy decision-making, evaluation, reviews, and other activities for programs. The GSC reports annually on the following three PIPs:

1. Geological Knowledge for Canada's Onshore and Offshore Lands;
2. Geoscience for Sustainable Development of Natural Resources; and
3. Geoscience for Keeping Canada Safe.

Strategic Priority 1: Geological Knowledge for Canada's Onshore and Offshore Lands

Through this PIP, NRCan produces geoscientific data and knowledge to map the regional geological context of Canada's onshore and offshore lands (see Figure 53). NRCan provides information on new mineral and hydrocarbon potential to support other sectors and departments with strategic resource assessments, methodologies, and data to make evidence-based decisions. NRCan also increases the availability and use of geoscience data assets and knowledge products by developing value-added analyses and tailoring information to broader audiences. NRCan acquired and interpreted geophysical data that was the basis of a formal submission defining the outer limits of the extended continental shelf beyond 200 nautical miles in the Atlantic and Arctic oceans as part of Canada's obligation to the United Nations Convention on the Law of the Sea. International recognition of this new offshore territory will give Canada sovereign rights over the natural resources on the seabed and subsoil.

Strategic Priority 1: Geological Knowledge for Canada's Onshore and Offshore Lands

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Ultimate outcomes	Effective management and development of Canada's sovereign lands and natural resources	Attractiveness of Canada's North for investment in sustainable mineral exploration and development
Intermediate outcomes	International recognition of Canada's outer limits of the extended continental shelf (ECS) in the Atlantic and Arctic Oceans	Use of new geoscience to inform mineral exploration approaches and natural resource management decisions
Immediate outcomes	Delineated outer limits of the extended continental shelf ECS beyond 200 natural miles in the Atlantic and Arctic Oceans	Increased awareness of new geoscience data, knowledge, and activities, particularly among mineral industry, Northerners, and Indigenous groups
Outputs	Availability of Geoscience Data and Knowledge *(See list of indicators and contributing GSC programs in Figure 54)*	Engagement and Collaboration *(See list of indicators and contributing GSC programs in Figure 55)*

Figure 53: *Logic model for Strategic Priority 1: Geological Knowledge for Canada's Onshore and Offshore Lands Performance Information Profile*

GSC program contributions to LMS PIP indicators

Strategic Priority 1: Geological Knowledge for Canada's Onshore and Offshore Lands

Output 1: Availability of Geoscience Data and Knowledge

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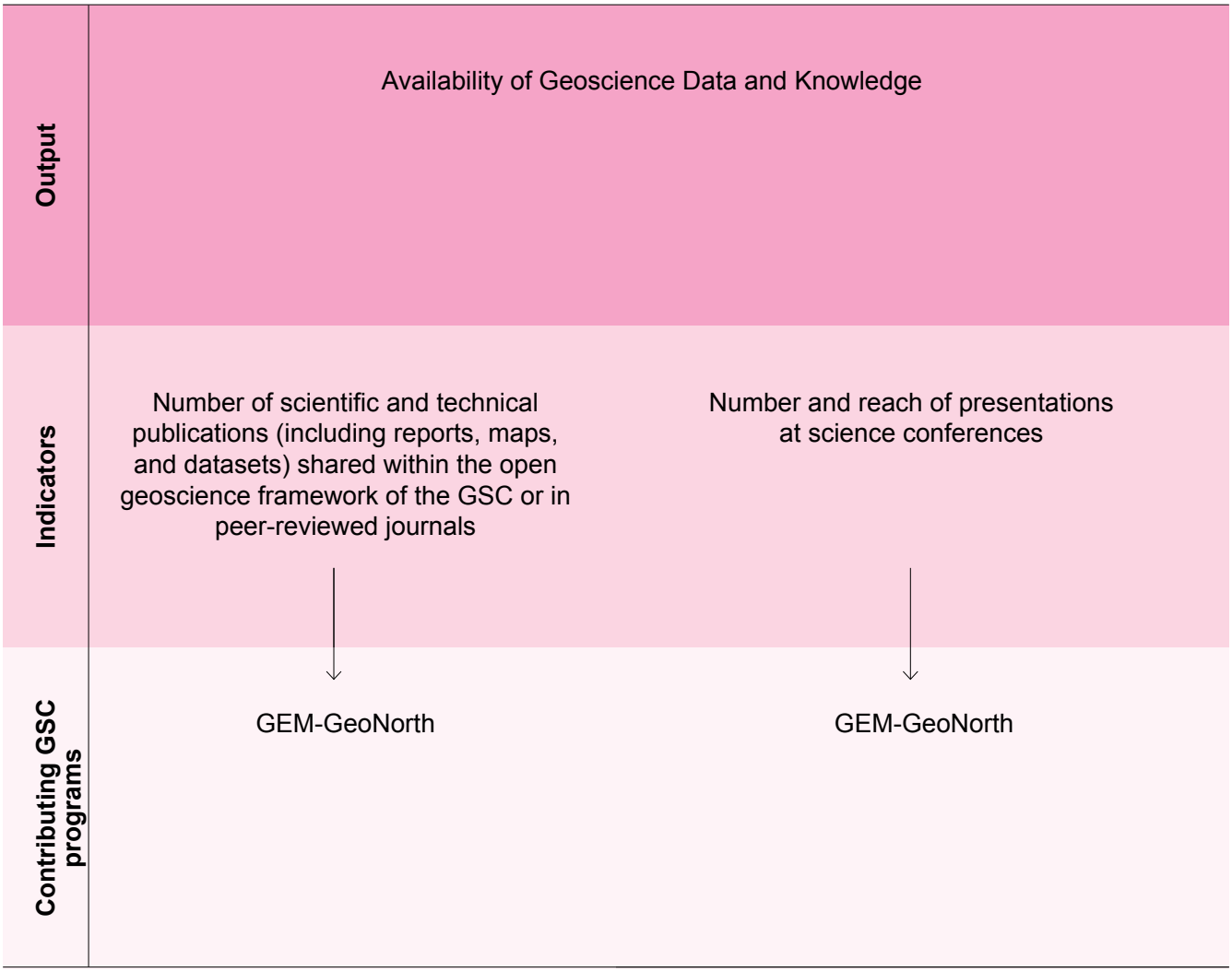

***Program Abbreviations:**
GEM-GeoNorth: Geo-Mapping for Energy and Minerals-GeoNorth

Figure 54: *Strategic Priority 1 (Geological Knowledge for Canada's Onshore and Offshore Lands), Output 1 (Availability of Geoscience Data and Knowledge)*

GSC program contributions to LMS PIP indicators

Strategic Priority 1: Geological Knowledge for Canada's Onshore and Offshore Lands

Output 2: Engagement and Collaboration

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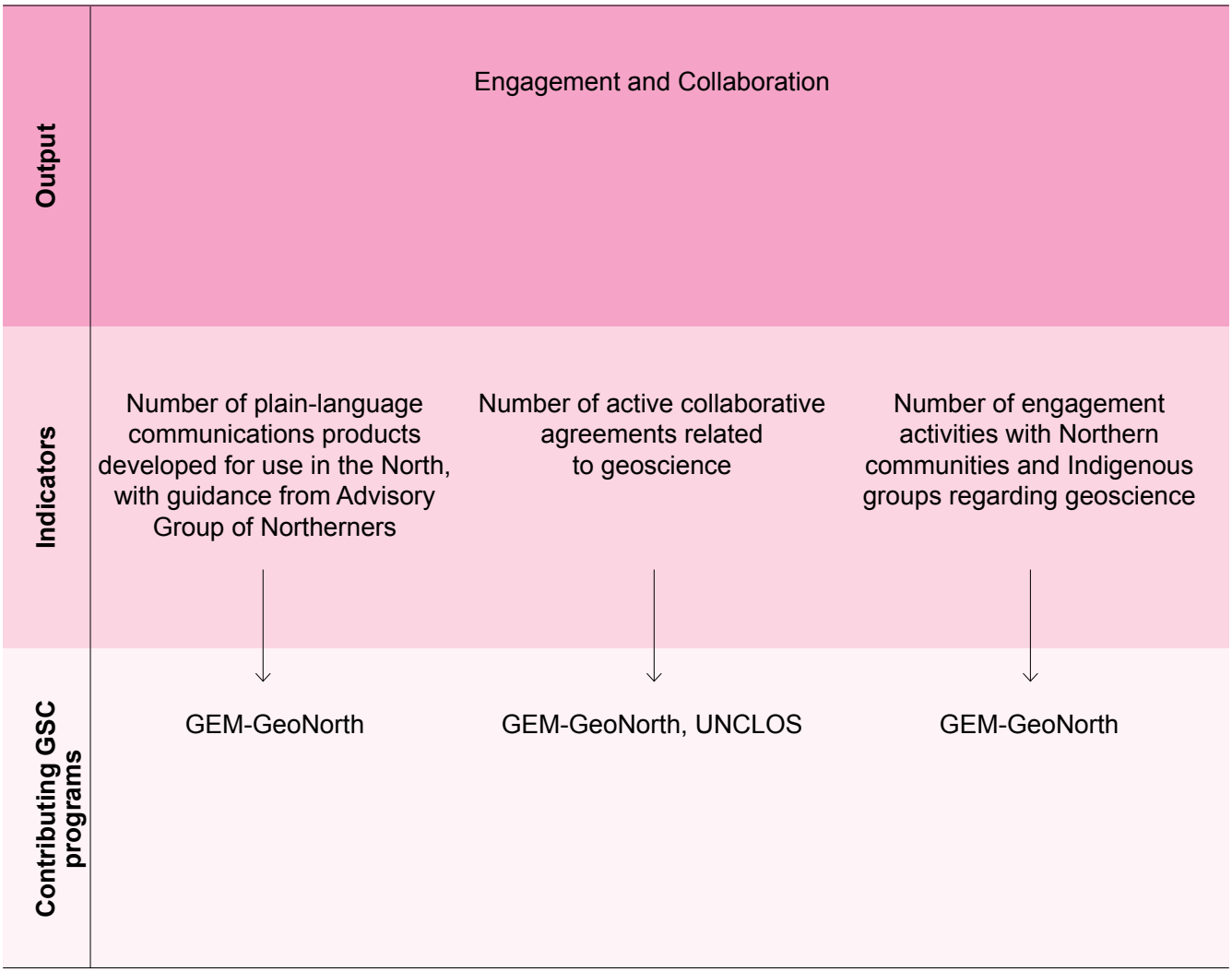

***Program Abbreviations:**
GEM-GeoNorth: Geo-Mapping for Energy and Minerals-GeoNorth
UNCLOS: United Nations Convention on the Law of the Sea

Figure 55: *Strategic Priority 1 (Geological Knowledge for Canada's Onshore and Offshore Lands), Output 2 (Engagement and Collaboration)*

Strategic Priority 2: Geoscience for Sustainable Development of Natural Resources

This PIP creates new geoscience knowledge that supports sustainable development of Canada's land, mineral, energy, and water resources (see Figure 56). Geoscientific knowledge informs land-use decisions such as marine protected areas, pre-exploration geoscience so that companies can efficiently discover new mineral and low-carbon-footprint energy resources, and environmental and groundwater studies so that resource sites can be developed and efficiently remediated post-production. Integrating the results of these studies will increase the efficiency of sustaining mining- and energy-dependent communities, while ensuring that these developments impact the environment and groundwater in the most minimal way. NRCan/LMS provides expert advice to government departments, regulatory bodies, and industry to inform regulatory policies, industry practices, and environmental assessments that contribute to sustainable land-use decision-making and groundwater management. This ultimately serves to improve Canada's global competitiveness and supports the sustainable development of Canadian mining-dependent communities.

Strategic Priority 2: Geoscience for Sustainable Development of Natural Resources

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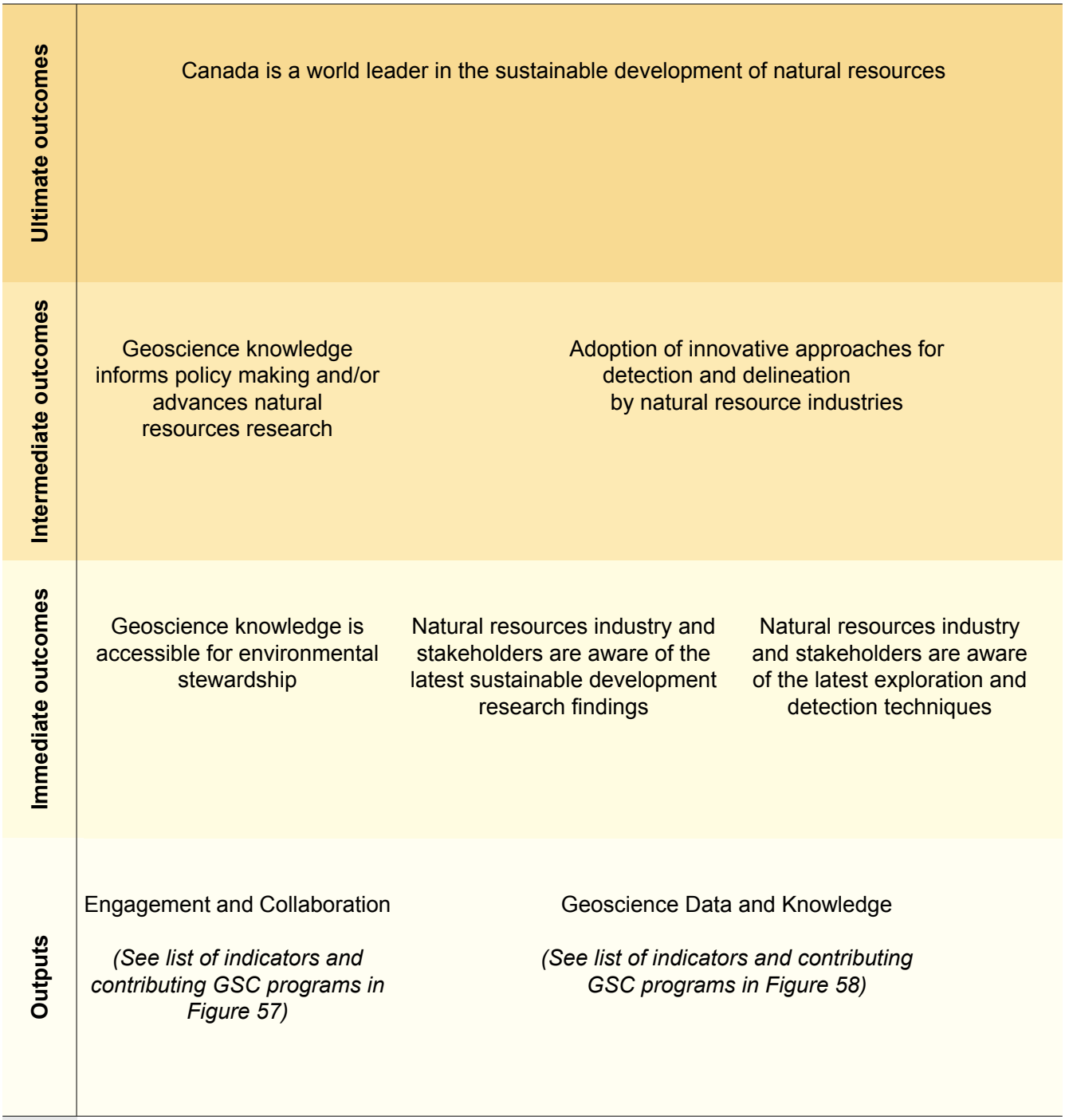

Figure 56: *Logic model for Strategic Priority 2: Geoscience for Sustainable Development of Natural Resources Performance Information Profile*

GSC program contributions to LMS PIP indicators

Strategic Priority 2: Geoscience for Sustainable Development of Natural Resources

Output 1: Engagement and Collaboration

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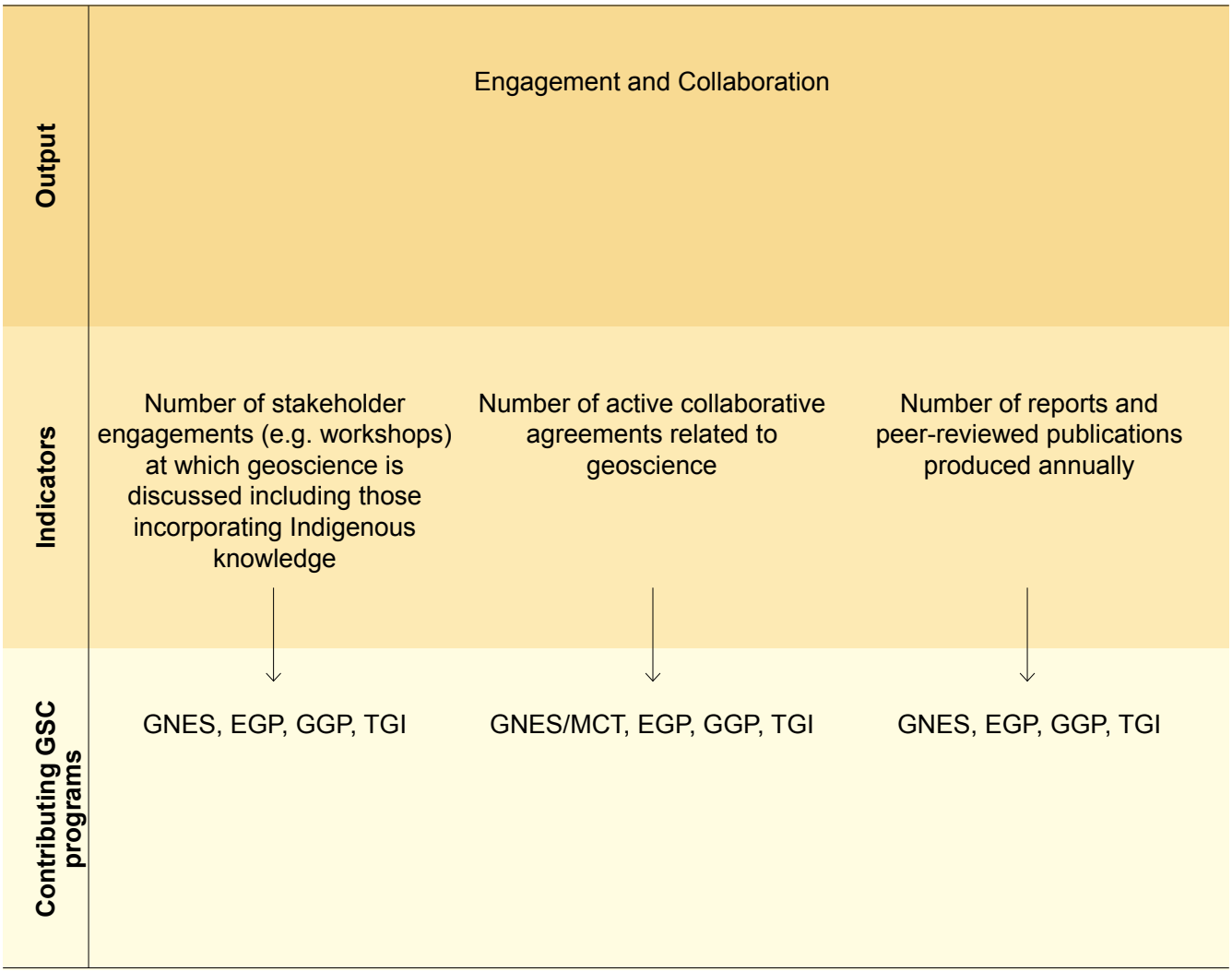

***Program Abbreviations:**
EGP: Environmental Geoscience Program
GGP: Groundwater Geoscience Program
GNES: Geoscience for New Energy Supply
MCT: Marine Conservation Targets
TGI: Targeted Geoscience Initiative

Figure 57: *Strategic Priority 2 (Geoscience for Sustainable Development of Natural Resources), Output 1 (Engagement and Collaboration)*

GSC program contributions to LMS PIP indicators

Strategic Priority 2: Geoscience for Sustainable Development of Natural Resources

Output 2: Geoscience Data and Knowledge

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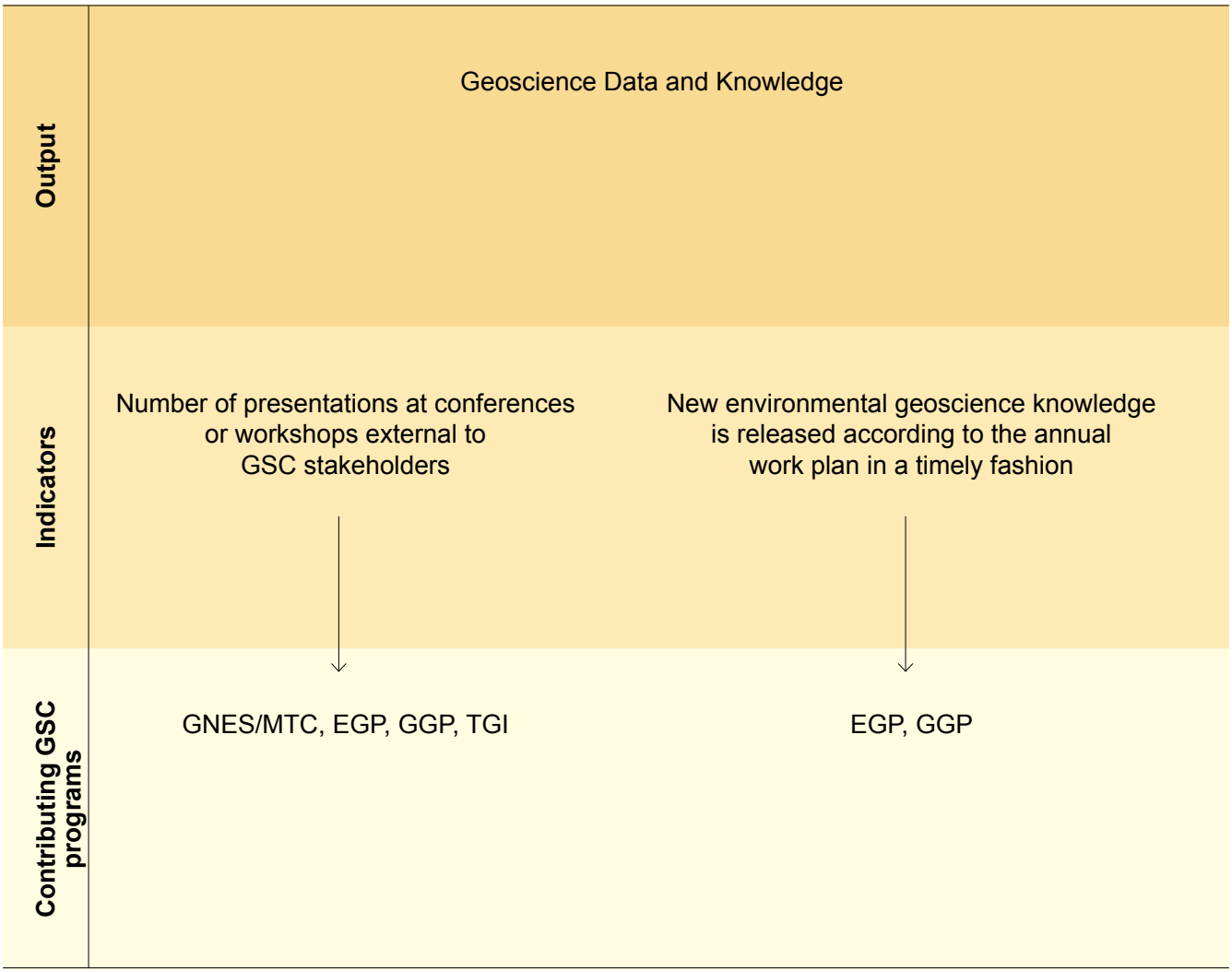

***Program Abbreviations:**
EGP: Environmental Geoscience Program
GGP: Groundwater Geoscience Program
GNES: Geoscience for New Energy Supply
MCT: Marine Conservation Targets
TGI: Targeted Geoscience Initiative

Figure 58: *Strategic Priority 2 (Geoscience for Sustainable Development of Natural Resources), Output 2 (Geoscience Data and Knowledge)*

Strategic Priority 3: Geoscience for Keeping Canada Safe

This program undertakes the monitoring of, research into, and effective planning against various natural and human-induced hazards including earthquakes, tsunamis, landslides, and impacts related to climate change, geomagnetic storms, radiological and nuclear incidents (see Figure 60). Through the provision of hazard information, NRCan helps other levels of government, including international government bodies, the private sector, and professional organizations, to prevent, mitigate, prepare for, respond to, and recover from natural disasters. Similarly, stakeholders use geoscience information to minimize the risks that climate change poses to communities and infrastructure in vulnerable areas.

Strategic Priority 3: Geoscience to Keep Canada Safe

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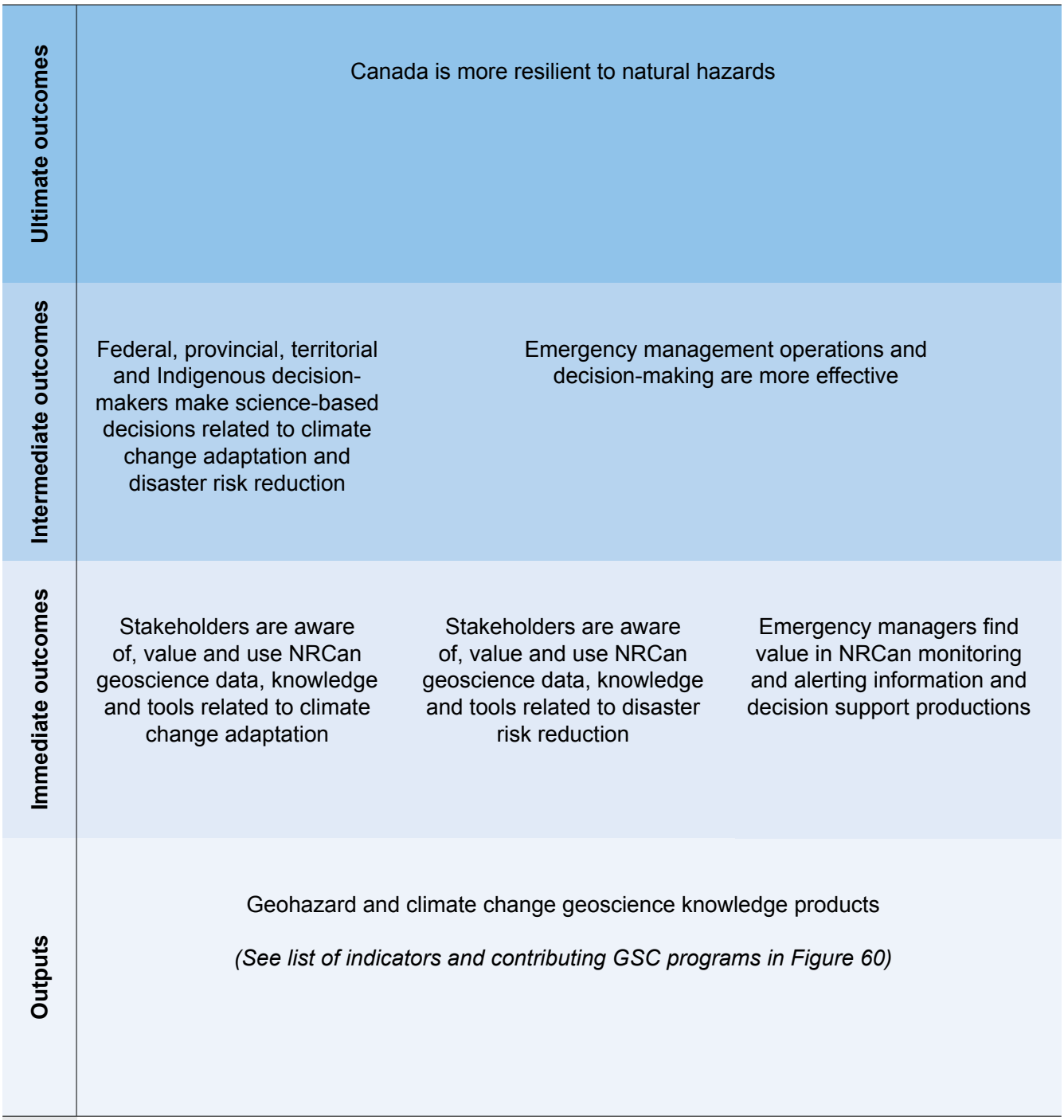

Figure 59: *Logic model for Strategic Priority 3: Geoscience to Keep Canada Safe Performance Information Profile*

GSC program contributions to LMS PIP indicators

Strategic Priority 3: Geoscience to Keep Canada Safe

Output 1: Geohazard and Climate Change Geoscience Knowledge Products

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Output	Geohazard and Climate Change Geoscience Knowledge Products
Indicators	Number of new knowledge products released to open and accessible databases
Contributing GSC programs	CCGP, PSGP

***Program Abbreviations:**
CCGP: Climate Change Geoscience Program
PSGP: Public Safety Geoscience Program

Figure 60: *Strategic Priority 3 (Geoscience to Keep Canada Safe), Output 1 (Geohazard and Climate Change Geoscience Knowledge Products)*

Annex 2: GSC 2020-21 Science Programs, Projects and Activities

GSC 2020-21 Science Programs/ Services, Projects and Activities

Strategic Priority 1: Geological Knowledge for Canada's Onshore and Offshore Lands

The tables below outline the projects and briefly describe the activities for the three GSC S&T programs within GSC Strategic Priority 1:

- Geo-Mapping for Energy and Minerals-GeoNorth (GEM-GeoNorth);
- United Nations Convention on the Law of the Sea (UNCLOS); and,
- Canada in 3D.

Table 5: *GEM-GeoNorth 2020-2021 Science Program Projects and Activities*

Projects & Project Leader	Project Description	Activities & Activity Leader	Activity Description
GEM-GeoNorth Program Coordinator Michel Plouffe	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.	N/A	Funding for the previous iteration of GEM-GeoNorth ended in March 2020. The program was renewed in September 2020. As GEM-GeoNorth is co-developing research priorities with provinces, territories and Indigenous Governments and representative organizations (IGs and IOs), activities for the program had not yet been set.

Table 6: *UNCLOS 2020-2021 Science Program Projects and Activities*

Projects & Project Leader	Project Description	Activities & Activity Leader	Activity Description
Arctic Ocean submission Mary-Lynn Dickson	Canada filed its Arctic Ocean submission to the UN Commission on the Limits of the Continental Shelf in 2019. The program is undertaking science-related activities to support the submission.	Arctic Ocean Presentation David Mosher	Finalizing the Arctic Ocean submission presentation for the UN.
		Database Management Walta-Anne Rainey	Fulfilling the program's obligation to securely maintain the Arctic Ocean submission and data.
		Issues Management Mary-Lynn Dickson	Advising Natural Resources Canada, Fisheries and Oceans Canada and Global Affairs Canada on scientific and technical issues related to the continental shelf.
		Scientific Publications David Mosher Kai Boggild John Shimeld Gordon Oakey Ruth Jackson	Publishing peer-reviewed results in scientific literature.
Atlantic Ocean submission Mary-Lynn Dickson	Canada filed its Atlantic Ocean submission to the UN Commission on the Limits of the Continental Shelf in 2013 and gave its presentation in 2018. The program is maintaining the submission until it is reviewed by the UN.	Database Management Walta-Anne Rainey	Fulfilling the program's obligation to securely maintain the Atlantic Ocean submission and data.

Table 7: *C3D 2020-2021 Science Program Projects and Activities*

Projects & Project Leader	Project Description	Activities & Activity Leader	Activity Description
Canada in 3D Boyan Brodaric	C3D is a collaboration between Canadian federal, provincial and geological surveys, and endorsed by the National Geological Surveys Committee of Canada. It is a national effort to: develop national maps and model of the geology of the country, provide an interactive cloud based portal to access and explore the maps, model, and related information, and research new methods for geoscience mapping and modelling. C3D supports a commitment to open and accessible data, showcasing the latest national surficial and geological compilations at various resolutions, in order to ensure a current synthesis of the geology of Canada.	C3D web portal	Developing, launching and operating the public facing website that hosts data sets, reports, maps; uses advanced techniques to integrate and visualize data sets; and allows users to use a range of advanced tools. This past year the portal migrated to a cloud-based operating environment, which has included complete reprograming in a new development environment and working with internal IM/IT providers in a way that has been a first for NRCan, paving the way for future efforts.
		2D & 3D geological compilation	Interpreting and integrating existing 2D and 3D data sets and models from federal, provincial, and territorial sources. Experts in geological sciences, data management, and computer science are working with legacy data that has varying formats, scales, scientific interpretations, and physical boundaries (e.g. overlap, gaps). Building a system that can scientifically and technologically integrate past and future inputs of this nature has been a major part of the C3D efforts this year.
		Advanced research	Constructing a first-ever 3D model of the subsurface geology of Canada. The initial model will include a national framework including (1) the topographic surface, (2) the bedrock surface, (3) Precambrian-Phanerozoic stratigraphic boundary, and (4) a new interpretation of the boundary between the earth's crust and mantle for Canada. Research into new modelling methods is being carried out to help interpret the subsurface in areas lacking existing models and to tackle the difficult task of interpreting and modelling with sparse data in complex geological terrains.

Strategic Priority 2: Geoscience for Sustainable Development of Natural Resources

The tables below outline the projects and briefly describe the activities for the seven GSC S&T programs within GSC Strategic Priority 2:

- Targeted Geoscience Initiative (TGI);
- Environmental Geoscience Program (EGP);
- Groundwater Geoscience Program (GGP);
- Geoscience for New Energy Supply (GNES) Program;
- Marine Conservation Targets (MCT) Program;
- Marine Geoscience for Marine Spatial Planning Program (MGMSP); and,
- Environmental Impact Assessment Service (EIAS).

Table 8: *TGI 2020-2021 Science Program Projects and Activities*

Projects & Project Leader	Project Description	Activities & Activity Leader	Activity Description
Ore Systems Project Leaders Wouter Bleeker, Patrick Mercier-Langevin, and Jan Peter	This project aims to enhance understanding of Canadian ore deposits and their critical minerals, and the larger mineral systems that generate them in suitable geological environments, from metal sources to ore deposition. A system-scale understanding of ore deposits and ore-forming processes is critical to sustain discovery of additional ore resources, either at depth or in remote areas, and to reduce risk for companies exploring for ore deposits in Canada. This is essential to secure future supply of critical and other economically-important minerals in Canada.	Hydrothermal Ore Systems Jan Peter	Including a diverse group of deposits where the primary depositional mechanism is related to dissolution, transport, and deposition of metals by aqueous fluids such as seawater, basinal brines, and groundwater. These fluids are commonly rich in metals and salts and precipitate critical and economically important metals such as zinc, copper, gold, lead, tin, antimony, germanium, bismuth, and lithium. This activity focusses on the physical and chemical processes that lead to leaching, transport and precipitation of economically important elements and minerals from aqueous fluids.
		Magmatic Ore Systems Wouter Bleeker	Advancing the geoscience knowledge of magmatic ore deposits and their fundamental mineral systems by integrating data across all scales, from the deposit to the full magmatic system scale. Mafic (Mg-Fe-rich) magmatic systems are the dominant ore system to generate deposits of nickel, copper, cobalt, platinum, chrome, titanium and vanadium, most of which are considered “critical”. Felsic (silica-rich) or alkaline systems (silica-poor and alkali-rich, including carbonatites) are the dominant host for numerous other minerals and metals ranging from rare metals (Nb, Ta, Zr) and rare earth elements (REE) to battery metals such as lithium. Research will focus on physical and chemical magmatic processes and research outcomes will include improved understanding of how these deposits form, their distribution in space and time across Canada, what localizes them at the system and district scale, and their complete compositional characterization in terms of critical metals.

Projects & Project Leader	Project Description	Activities & Activity Leader	Activity Description
		Orogenic Ore Systems Patrick Mercier-Langevin	Contributing to improving the knowledge of mineral deposits that are formed as a result of deformation and metamorphism of Earth's crust during orogenesis, with an emphasis on the relationships in space and time to regional tectonic features and their history. Tectonic processes can generate magmas and/or hydrothermal fluids that can mobilize and transport metals and focus them into broad corridors with specific areas or discrete zones where precious and critical metals (e.g., gold, copper, tellurium and bismuth) are concentrated to form ore deposits.
Digital Geoscience and Method Development Project Leaders Simon Bridge and Jack Jensen	This project develops methods for research that is applicable to multiple ore systems and/or original research in support of mineral exploration that is not directly related to an ore system.	Machine Learning/ Artificial Intelligence Applications/ 3D Geological/ Geophysical Modelling Gilles Bellefleur	Developing 1) new methods and/or new applications in artificial intelligence (AI) and machine learning (ML) to support exploration for critical and other economically important mineral systems in Canada; and, 2) geophysical and 3D geological modelling methods to obtain subsurface knowledge of ore systems and enhance the effectiveness of deep exploration. Outcomes will include integrated models of the subsurface constrained by geophysical, geological, petrophysical and geochemical data.
		Mineral Potential Engine Activity Leader Christopher Lawley	Developing innovative laboratory analytical and data acquisition methods (geology/ geophysics/ geochemistry/ remote sensing) in support of critical mineral research. Outputs will provide the geoscience community and exploration industry with new methods to improve the efficiency and targeting capability of the entire mineral exploration work flow.

Projects & Project Leader	Project Description	Activities & Activity Leader	Activity Description
		Spatial Data Infrastructure Ernst Schetselaar	Creating a program-wide digital infrastructure exploiting spatial data infrastructure designs of other GSC programs to: 1) enhance access to TGI's field and laboratory data and derived scientific interpretations; 2) facilitate in-house and external data-driven analysis (e.g., statistics, machine learning, modelling); and, 3) meet the demands for open public data dissemination via the internet to industrial, governmental, academic TGI stakeholders and the general public.

Table 9: *EGP 2020-2021 Science Program Projects and Activities*

Projects & Project Leader	Project Description	Activities & Activity Leader	Activity Description
Volcanic Mercury Emissions – Research in support of the UNEP 2023 Global Mercury Assessment Peter Outridge	This project will help fill key knowledge gaps when accounting for the natural Hg cycle (volcanic system's emissions), supporting the *Minamata Convention on Mercury, 2017*.	N/A	N/A
Long-term hydrological dynamics of Canada's largest watershed: The Mackenzie River Basin Jennifer Galloway	The Mackenzie River Basin in NWT is one of the world's largest (4,200 km long) and most important freshwater ecosystems. Climate change is disproportionately affecting high northern latitudes, especially in NW Canada. This project will examine long-term and cycles to develop predictive ecohydrological models.	N/A	N/A
Cumulative Effects of Resource Development on Mining-Impacted Watersheds Alexandre Desbarats	This project will develop geoscience methods for distinguishing environmental effects of new mining activity from complex existing background conditions in affected watersheds. This information and new data will be synthesized in the first geoenvironmental model for Ag-Ni-Co-As vein type deposits.	N/A	N/A

Projects & Project Leader	Project Description	Activities & Activity Leader	Activity Description
Assessment of potential impacts of oil and gas development activities on shallow aquifers in the Fox Creek area (AB) Christine Rivard	Initially the project scope was to study environmental impacts of hydrocarbon exploration and production activities by studying the potential impacts on shallow groundwater. Now it includes studies on vegetation, forest, snow cover, wetlands, landscape evolution and woodland caribou habitat, in support of new impact assessment legislation for developing regional cumulative effects evaluation methods.	N/A	N/A
Geoscientific Research into Accidentally Spilled Petroleum (GRASP) Jason Ahad	Transporting Canada's energy resources to market is vital to the country's economy. The federal government is committed to ensure the safety of Canadians and their environment, but current uncertainties regarding environmental impacts of accidentally leaked petroleum products limit Canada's capacity to adequately regulate safe transport and effectively respond to spills in both terrestrial and marine	Environmental Impacts of Diluted Bitumen Jason Ahad	Transporting it by pipeline, bitumen is blended with lighter hydrocarbon fractions, yielding a less viscous, diluted bitumen (dilbit). A number of incidents have highlighted the potential environmental risk caused by dilbit pipeline rupture. This project will address the knowledge gap surrounding the transport of dilbit in the environment, particularly shallow groundwater systems.

Projects & Project Leader	Project Description	Activities & Activity Leader	Activity Description
	environments. The project involves lab-controlled and field-based experiments, focussing on terrestrial environments analogous to those found along current and proposed pipeline routes, and on the Douglas Channel area (British Columbia's North Coast), which connects the active port of Kitimat to foreign markets.	Baseline of Natural Variability in Douglas Channel Marine Oil Spill Studies (MOSS) Manuel Bringué	Active port of Kitimat (BC) is a getaway for the export of Canada's energy resources to international markets and an increase of tanker traffic is anticipate. This project will provide a baseline of natural variability in Douglas Channel as well as identifying the capacity of in-situ microbial communities to mitigate accidentally released petroleum products under reduced oxygen and lower pH conditions.
Environmental Impacts of Permafrost Thaw in the Arctic Mathieu Duchesne	As about 50% of the permafrost underlies the Canadian landmass, this project will assess the environmental implications of permafrost degradation and provide a baseline to better appraise the environmental consequences of resource development.	Permafrost Solute Concentrations in an Active Gravel Pit Paul Gammon	The geochemistry resulting from permafrost freeze-thaw processes are poorly understood. This activity aims to refine the current understanding of these processes by investigating the geochemistry of a gravel pit associated with the building of the Inuvik to Tuktoyaktuk Highway (ITH) in NWT.
Geological Carbon Storage Don White	Carbon capture and storage (CCS) is a way to reduce atmospheric emissions of carbon dioxide (CO_2) for a variety of industrial sources. Long-term geological storage of CO_2 involves injecting CO_2 inside deep porous rock formations, such as depleted oil and gas reservoirs or saline aquifers.	N/A	N/A

Projects & Project Leader	Project Description	Activities & Activity Leader	Activity Description
Dredge Disposal at Sea Gwyn Lintern	Canada regulates Disposal at Sea (DAS) through a permit system under the *Canadian Environmental Protection Act* 1999 (CEPA, 1999) and is required to conduct regular monitoring of DAS sites through Schedule 6 of CEPA. This project assesses sediment dispersion at dredge disposal sites in the Pacific Ocean. These disposal sites will be (and are being) used by major infrastructure proponents, particularly energy export ports. The work comprises adding a day onto several existing LMS cruises to deploy and recover current sensors, and to do calculations and report on the dispersion characteristics of sediment to improve national guidelines.	N/A	N/A
Induced Seismicity Research Honn Kao	The exploration and development of shale gas raises questions about potential environmental and public health risks. Geoscience studies provide basic geological context and monitoring data that make it possible to assess potential effects on groundwater and induced seismicity.	N/A	N/A

Projects & Project Leader	Project Description	Activities & Activity Leader	Activity Description
Oil Sands Paul Gammon	Open-pit mining in the tar sands region of the lower Athabasca Valley in Alberta continues to raise questions about sources of contaminants and their potential effects on air and water quality, as well as the possible cumulative effects on water and land ecosystems. This project contributes to developing attribution methodologies for the characterization of atmospheric and aqueous contaminants (potentially toxic metals) by using sophisticated isotopic indicators.	N/A	N/A
Reconstructing long-term environmental dynamics to support regional assessment Josué Jautzy	Project split into 2 components of 2 programs: Groundwater Geoscience Program (GGP) and Environmental Geoscience Program (EGP).	Lake Sediments and Tree Rings Geochemical Compilation in Support of Regional Assessments Josué Jautzy	The purpose of this component is to assess the effect of climate variability on the natural level of metal concentrations in lake sediments and tree rings in order to measure impacts of any new mineral resource development. The tools and methods developed will help future regional assessments under IACC lead.

Table 10: *GGP 2020-2021 Science Program Projects and Activities*

Projects & Project Leader	Project Description	Activities & Activity Leader	Activity Description
Archetypal Aquifers in Canada Hazen Russell	Consolidate GSC knowledge and complete new studies on Canadian Archetypal Aquifer settings.	Aquifers Classification Hazen Russell	Developing aquifer system nomenclature in glacial terrains.
		Archetypal Aquifers Case Studies Hazen Russell	Consolidating literature and complete data collection to support archetypal aquifer descriptions.
		South Nation Aquifers Modelling Hazen Russell	Developing physical based numeric groundwater modelling at watershed to regional scales.
		Borehole Calibration Facilities in Bells Corners Heather Crow	Developing downhole and near surface geophysics, seismic signal processing, machine learning.
		eBook Contribution Hazen Russell	Contributing material as coauthors on a series of free books on hydrogeology.
Canada 1 Water Project Hazen Russell	Develop a groundwater-surface water modelling framework for continental Canada.	Groundwater-Surface-Water Model(s) Hazen Russell	Developing physically based, fully integrated, groundwater-surface-water model(s) coupled with historic climate data and scenario modelling for climate change for six major watershed domains including transboundary watersheds with the USA.

Projects & Project Leader	Project Description	Activities & Activity Leader	Activity Description
Groundwater Information Network Boyan Brodaric	Define norms and standards for the purpose of development and distribution of hydrogeological databases.	Groundwater Information Network (GIN) portal and database Boyan Brodaric	Creating a national groundwater web portal and database for groundwater data (GIN).
		Permafrost Information Network (PIN) Héryk Julien	Continuing the development of a national permafrost information network (PIN), including a web portal and database.
		Groundwater Dashboard Development François Létourneau	Developing dynamic summary dashboards for every aquifer in the groundwater Information Network (GIN) and British Columbia collaboration.
		Standards Development Boyan Brodaric	Maintaining and advance relevant geoscience data standards.
		Linked Data Boyan Brodaric	Prototyping linked data infrastructure for Canada-US water data.
Water Resources Characteri-zation And Modelling Daniel Paradis	Improve characterization methods and techniques, including remote sensing and 3D numerical modeling to develop better geoscience knowledge of large aquifer systems in Canada and to understand regional groundwater flow dynamics.	Southern Quebec Groundwater Modeling Daniel Paradis	Developing a platform supporting surface and groundwater allocations, assessing water resources and forecasting their futures under climate change and anthropogenic stresses.
		Hydrogeo-physics Daniel Paradis	Developing hydrogeological characterization approaches, including learning machines, to translate geophysical data in hydraulic properties and high-resolution hydraulic testing for complex aquifers.

Projects & Project Leader	Project Description	Activities & Activity Leader	Activity Description
		Glaciers and Rockies Regional Groundwater Flow System Daniel Paradis	Quantifying changes in glacial meltwater inputs into the hydrological system, and assess the related impacts on the different water storage compartments (Canadian Rockies).
Fox Creek Aquifers System assessment Christine Rivard	Support provincial water management regulations and policies aiming to protect groundwater and to minimize impacts of these industrial activities on the environment.	Surface Water/ Groundwater Flow Dynamics Christine Rivard	Evaluating potential impacts of oil and gas development activities, including induced seismicity, on non-saline aquifers in the Fox Creek area (Alberta).
Reconstructing long-term environmental dynamics to support regional assessment (Ring of Fire (ROF)) Nicolas Benoit	Improve the understanding of the distribution and mobility of metal(loid)s associated to Cr deposits in the environment.	Definition of the Hydrogeo-logical Context of the RoF Nicolas Benoit	Developing a preliminary hydrostratigraphic understanding through the analysis of existing exploration boreholes, geologic and topographic maps at the McFauld's Lake region in the RoF (2020). This exercise allowed identification of recharge and discharge zones, as well as a regional hydrostratigraphical sequence composed of organic deposits resting over a leaky aquitard, on top of a confined or semi-confined bedrock aquifer.

Table 11: *GNES 2020-2021 Science Program Projects and Activities*

Projects & Project Leader	Project Description	Activities & Activity Leader	Activity Description
Unconv-entional Resources Omid Ardakani	This project aims to advance the fundamental geoscience knowledge of Canada's sub-surface lands with the intent of improving our environmental performance during the development and production of tight oil and unconventional gas. Such endeavours will ultimately support the global steps towards a low carbon economy. Funded by PERD.	CO_2 Enhanced Oil Recovery Omid Ardakani	Studying the interaction of CO_2 in shales to better understand its role for enhanced oil recovery and CO_2 sequestration and storage.
		Montney H_2S Source and Migration Omid Ardakani	Understanding the process by which H_2S is formed in the Montney Formation, a major natural gas producing unit in NW Alberta and NE BC.
Geothermal Resources Steve Grasby	The Geothermal Project supports government goals of reducing CO_2 emissions by a transition to non-emitting energy resources by evaluating regional geothermal resources.	Geothermal St. Lawrence Lowlands Christine Rivard	Characterizing the geothermal energy potential of the Bécancour area of southern Québec and to model heat transfer and fluid flow.
		Regional Geothermal Steve Grasby	Studying the geothermal energy potential of the WCSB for both electricity and head generation.
		Garibaldi Range (Mt. Meager) Geothermal Steve Grasby	Studying the geothermal potential of the Mount Meager region to produce electricity.
		Hybrid Geothermal Zhuoheng Chen	Investigating the feasibility of co-extraction of tight unconventional gas and heat resources for co-generation of power through reservoir modelling.

Projects & Project Leader	Project Description	Activities & Activity Leader	Activity Description
Laboratory Methods Dennis Jiang	Using renewable and low carbon energy geoscience research, this project focuses on innovative and novel laboratory methods. This project integrates and applies Augmented Intelligence/ Machine Learning to advance Canadian geoscience research and development.	Pore Fluid Implications Zhuoheng Chen	Using modelling to better understand pore fluid interactions in shale gas reservoirs, this project investigates how fluids move in shales at the micro- and nano-scale.
		Laboratory Method Development Dennis Jiang	Improving traditional hydrocarbon fingerprinting laboratory methods allows the identification of different but very similar chemical structures and properties. This information improves the identification of source hydrocarbons both from reservoirs and in surface oil spills.
		Hydraulic Fracking Flowback Waters Dennis Jiang	Characterizing the chemical composition of flowback waters from hydraulic fracturing and the environmental impacts associated with these waters.
Nova Scotia Offshore Marine Geoscience Natalie Shea	In collaboration with the province of Nova Scotia, GSC is conducting offshore geoscience research to better understand the depositional environments associated with hydrocarbon deposits. This project is funded by the province of Nova Scotia.	Autonomous Underwater Vehicle (AUV) Surveys of Hydrocarbon Seeps off Nova Scotia Calvin Campbell	Detecting cold seeps from conventional sea surface methods has proven to be a challenge. By using an AUV, superior imaging of cold seeps was possible, improving the quality of data obtained from sites.
		Identifying Upper Jurassic Source Rock Offshore Nova Scotia Using Geochemical Proxies Nikole Bingham-Koslowski	Using geochemical proxies, this activity will identify and constrain the paleoenvironmental and depositional conditions required to produce source rocks during the Upper Jurassic, offshore Nova Scotia.

Projects & Project Leader	Project Description	Activities & Activity Leader	Activity Description
		Play Fairway Biostratigraphic Analysis Rob Fensome	Completion of papers based on the biostratigraphy of the Triassic–Early Cretaceous of the Scotian Margin, including Laurentian channel area, Southwest Nova and Scotian-Moroccan Margin correlation.
		Carbonate Diagenesis and Clumped Isotopes of the Scotian Slope Hydrocarbon Gas Seeps Josué Jautzy	Using cores collected in 2015 and 2018, clumped isotope analysis of carbonate minerals will improve understanding of the geological history of these sediments.
Marine Conservation Targets Keith Dewing	The Marine Conservation Targets project conducts hydrocarbon resource assessments in areas being considered by DFO and others for Conservation as part of Canada's commitment to conserve 10% of its marine and coastal areas through the creation of Marine Protected Areas.	N/A	N/A

Table 12: *MGMSP 2020-2021 Science Program Projects and Activities*

Projects & Project Leader	Project Description	Activities & Activity Leader	Activity Description
Scotian Shelf Bioregion Brian Todd	Marine geoscience knowledge generation in the Scotian Shelf Bioregion. Includes delivery of maps and data at bioregional, regional assessment, and targeted study scales.	Geological Constraints for Offshore Wind Energy Development Jordan Eamer	Assessing surficial geology physical properties in the context of offshore wind energy infrastructure.
		Regional Bathymetric Data Compilation	Compiling bathymetric data requiring the merging and balancing of various datasets and sources to create a seamless geomorphological base.
		Marine Surficial Geology Synthesis Geneviève Philibert	Updating previous surficial geology for offshore Nova Scotia and interpretating new data to create a bioregional scale geology map.
Newfoundland and Labrador Shelves Bioregion Vladimir Kostylev	Marine geoscience knowledge generation in the Newfoundland and Labrador (NL) Shelves Bioregion. Includes delivery of maps and data at bioregional, regional assessment, and targeted study scales.	Regional Modeling of Seabed Sheer Stress and Sediment Transport Michael Li	Calibrating seabed sheer and sediment transport models for offshore NL and NS to support decisions around sediment mobility.
		Marine Surficial Geology Synthesis Gordon Cameron	Synthesizing surficial geology for offshore NL. Consists of updating previous interpretations and interpretation of new data to create a bioregional scale geology map.
		Nearshore Sedimentary Processes Off Labrador Alex Normandeau	Case studies of nearshore sedimentary processes and geological hazards off Labrador.

Projects & Project Leader	Project Description	Activities & Activity Leader	Activity Description
		Slope Stability Assessment Laura Broom	Assessing regional slope stability based on extensive legacy and new sediment core samples and geotechnical analysis.
Pacific North Coast Integrated Management Area (PNCIMA) Bioregion Cooper Stacey	Marine geoscience knowledge generation in the PNCIMA Bioregion. Includes delivery of maps and data at bioregional, regional assessment, and targeted study scales.	Surficial Geology Synthesis Cooper Stacey	Synthesizing surficial geology for PNCIMA. Consists of updating previous interpretations and interpretation of new data to create a bioregional scale geology map.
		Regional Bathymetric Compilation Robert Kung	Bathymetric compilation requires the merging and balancing of various datasets and sources to create a seamless geomorphological base. Covers PNCIMA and Salish Sea bioregions.
Salish Sea Bioregion Randy Enkin	Marine geoscience knowledge generation in the Salish Sea Bioregion. Includes delivery of maps and data at bioregional, regional assessment, and targeted study scales.	Anthropogenic Impacts of Anchorage Sites Karen Douglas	Collaborating on a research project with DFO to study effects on ship anchorage on seabed conditions.
		Surficial Geology Synthesis Randy Enkin	Synthesizing surficial geology for Salish Sea bioregion. Consists of updating previous interpretations and interpretation of new data to create a bioregional scale geology map.
Autonomous Systems Pilot Project Alex Normandeau	Project focused on technological development of applications of autonomous and intelligent marine systems for seabed studies and marine spatial planning.	Acquisition and Operation of New Autonomous Seabed Mapping Instrumentation Robbie Bennett	Developing turnkey operation procedures for NRCan autonomous marine systems.

Projects & Project Leader	Project Description	Activities & Activity Leader	Activity Description
Data Management IM/IT Sheila Hynes	Ensure coordination of program data and geospatial deliverables for public-facing data platforms (Open Maps, Marine Spatial Data Infrastructure).	Legacy Dataset Release Sheila Hynes	Releasing of geospatially optimized legacy marine geology datasets.

Table 13: *EAIS 2020-2021 Science Program Projects and Activities*

Projects & Project Leader	Project Description	Activities & Activity Leader	Activity Description
GSC Environmental Impact Assessment (EA/IA) Service Danny Wright Aruna Dixit	Coordinate federal environmental assessment reviews that require geoscience expertise, ensuring timely and effective delivery of geoscience information and advice for the northern and southern regimes pursuant to NRCan's legislated obligations.	All Aspects of an EA/IA	Covering all geoscientific aspects of an EA for 38 development projects pursuant to federal EA regimes both north and south of 60° within the GSC's mandate. Contributed to Grassy Mountain Coal (AB) Joint Review Panel Hearing. Ongoing contributions to the TMX (Trans Mountain Pipeline, BC) project and participating in Regional Environmental Assessment for the Ring of Fire.

Strategic Priority 3: Geoscience for Keeping Canada Safe

There are two GSC S&T programs within GSC Strategic Priority 3:

- Public Safety Geoscience Program; and
- Climate Change Geoscience Program.

Table 14: *PSGP 2020-2021 Science Program Projects and Activities*

Projects & Project Leader	Project Description	Activities & Activity Leader	Activity Description
Earthquake Geohazards John Cassidy	Research to understand where, how big and how often future earthquakes might occur. This includes understanding how the ground will shake, where active faults exist, and what can be expected in terms of aftershocks following an earthquake. The research undertaken in this project fundamentally informs the national seismic hazard model that underpins the seismic provisions in the National Building Code of Canada.	Intraplate Earthquakes Greg Brooks	Improving the understanding of intraplate earthquakes in Quebec, Ontario, and the Eastern Arctic. This includes paleoseismic investigations, seismic site response, and fault mapping.
		Plate Boundary Earthquakes Joe Henton	Improving assessments of earthquake hazards in Canada's plate boundary region, from southwest BC to the Beaufort Sea. This includes developing new models for earthquake hazard and tsunami generation, and supporting the development of early warning systems.
	Research to understand the hazards and risks associated with volcanoes in Canada. This includes developing outreach materials and models to demonstrate specific hazards at high threat Canadian volcanoes.	Volcanic Hazard Assessment Melanie Kelman	Understanding the hazards and risks associated with volcanoes in Canada. This includes developing outreach materials and models to demonstrate specific hazards at high threat Canadian volcanoes.
Landslides and Marine Geohazards Andrée Blais-Stevens	Targeted assessments of terrestrial and marine geohazards, including tsunamis.	Baffin Bay and Arctic Channels Alex Normandeau	Defining nearshore hazards that could affect Baffin communities, including the recurrence of submarine landslides on the east coast of Baffin Island, and understanding landslides in Pangnirtung.
		Beaufort Sea Ned King	Understanding offshore submarine geohazards, including faults and slope instabilities, in the Beaufort Sea, to ensure the safety and security of communities and any future infrastructure.

Projects & Project Leader	Project Description	Activities & Activity Leader	Activity Description
		Terrestrial Landslides David Huntley	Understanding slow moving landslides in southern BC and on the Saskatchewan-Manitoba border on railway corridors.
		Submarine Landslides and Tsunami Hazard Gwyn Lintern	Understanding these offshore and coastal hazards and how they might impact people and infrastructure.
Space Weather Hazards Ljubomir Nikolic	As concern about space weather is growing and affected industries are looking for more detailed knowledge about the characteristics of space weather disturbances and the effects they can have so they can plan effective mitigation actions.	Ground Effects David Boteler	Understanding geomagnetic effects on ground systems to support informed decision-making.
		Ionospheric Effects Robyn Fiori	Investigating ionospheric effects on radio systems and Global Navigation Satellite System (GNSS) performance.
		Space Weather Hazard Assessment Lidia Nikitina	Establishing a benchmark for worst-case conditions, which could happen once in a certain period of time, or once in several solar cycles, depending on a phenomenon.
		Forecast Development Ljubomir Nikolic	Improving space weather forecasting.
National-Scale Geohazard Risk Assessment Nicky Hastings	Developing tools, knowledge and methodologies to bring together our knowledge of the hazards and people, the environment, and infrastructure exposed to understand the social, economic and physical impacts including, public safety, vulnerability of buildings,	Canadian Safety and Security Program (CSSP) Coastal Flood Mitigation Nicky Hastings	Advancing an understanding to integrate local and scientific knowledge that informs risk reduction strategies against coastal storm surge and tsunami risks across Canada.
		CSSP Disaster Risk Reduction Pathways	Developing science to transform knowledge about systemic risk into policies that strengthen existing

Projects & Project Leader	Project Description	Activities & Activity Leader	Activity Description
	economic losses, and the community capacity to recover.	Murray Journeay	mechanisms for risk governance, mitigation, and resilience in SW BC.
		Emergency Management Strategy - Earthquake Risk Assessment Malaika Ulmi	Providing a national body of evidence to understand seismic risk and inform mitigation action.

Table 15: *CCGP 2020-2021 Science Program Projects and Activities*

Projects & Project Leader	Project Description	Activities & Activity Leader	Activity Description
Supporting Adaptation in Permafrost Regions Sharon Smith	Understanding permafrost-climate-infrastructure interactions. Informs adaptation strategies for major existing and proposed transportation routes in the North.	Improving the Canadian Permafrost Map Sharon Smith	Advancing development of a digital 3-D permafrost model for planning and decision-making. Sub-activities: measuring permafrost thermal state and active-layer conditions, developing a Canadian permafrost data portal to support predictive ground-ice mapping and modelling and enabling the development of decision-making tools, and enabling the development of big-data and artificial-intelligence products.
		Transportation Resilience in the Arctic Informed by Landscape Systems Peter Morse	Analyzing geoscientific data in the vicinity of major existing and proposed transportation routes in the North (Inuvik-Tuktoyaktuk Highway, Dempster Highway, North Slave roads, Nunavut corridors), to inform development of climate-change–resilient transportation and community infrastructure.

Projects & Project Leader	Project Description	Activities & Activity Leader	Activity Description
Supporting Adaptation in Coastal Regions Thomas James	Assessing the sensitivity of Canadian coastal regions to climate change. Informs adaptation strategies for existing and proposed coastal infrastructure and communities.	Sea-level Projections for Canada Thomas James	Refining Canada's sea-level change projections and hazard risks (e.g. flooding, infrastructure, and population risk at shorelines).
		Coastal Dynamics Dustin Whalen	Improving the understanding of coastal erosion on land and the nearshore environment in ice-rich permafrost terrain in the Western Arctic (Beaufort Sea).
		CanCoast Indices: Validation, Refinement and Application of Coastal Sensitivity and Vulnerability Indices Gavin Manson	Developing a national digital database, with nested scalable models that combine data on different coastal physical features, to generate indices of coastal sensitivity to climate change.
		Nature-Based Infrastructure for Coastal Resilience and Risk Reduction Gwyn Lintern	Examining the effectiveness of 'soft' coastal infrastructure such as sediments and vegetation to attenuate waves and storm surges, and provide flood storage.

Projects & Project Leader	Project Description	Activities & Activity Leader	Activity Description
Extreme Events: Forecasting for Hudson Bay Lowlands and Drought Risk Assessment for the Hydro-power Industry Christian Bégin	Advancing climate adaptation through improved drought indices and flood forecasting.	Advancing Climate Adaptation Through Improved Flood Forecasting for Hudson Bay Lowlands Hazen Russell	Improving flood forecasting for the Hudson Bay Lowlands to provide advance warning to First Nations communities through the integration of traditional knowledge and time series of satellite data.
		Improving Drought Risk Assessment Associated With Climate Change For the Hydro-Power Industry of Central and Eastern Canada Christian Bégin	Developing drought indices to provide support for improved hydroelectric water management.
National Glaciology Project David Burgess	Assessing the rate and the causality of glacier changes in Canada's Arctic and Alpine environments.	High Arctic David Burgess	Employing *in situ*, remote sensing and regional climate models to assess synoptic scale glacier change in the Arctic. Canada.
		Western Cordillera Mark Ednie	Employing *in situ* and remote sensing data to assess synoptic scale glacier change in the western Canada.

Strategic Priority 4: Geoscience for Society

Table 16: *OGN 2020-2021 Projects and Activities*

Projects & Project Leader	Project Description	Activities & Activity Leader	Activity Description
IT Infrastructure Mathieu Ouellet/ Glen Newton	Put in place and maintain IT systems to securely generate, store, manage and disseminate GSC data, publications, collections and knowledge.	- Application Modernization and Workload Migration - Cloud Computing Support - Software Optimization	Updating, transforming and relocating applications from legacy locations to the cloud or SSC end-state data centres. Supporting the activities to acquire cloud space and the transition of research projects. Centralizing software purchases to optimize licensing costs.
Information Systems and Data Kathleen Lauzière / Kyler Coutts	Create tools, standards, workflows and governance to manage geoscience data throughout its lifecycle.	- NRCan Datasets Inventory - NRCan Data Strategy - LMS Data Strategy - LMS IM Strategy	Cataloguing datasets provided to Treasury Board and the public to enhance data findability. Contributing to Data and IM Strategies implemented by NRCan and LMS to improve the management of NRCan data.

Projects & Project Leader	Project Description	Activities & Activity Leader	Activity Description
Open Access and Public Engagement Kaz Shimamura / Sonya Banal	Make high quality, authoritative geoscience publications timely and freely available to Canadians and communicate with the public about GSC program outputs.	- S&T Publishing - NRCan Open Science Action Plan - NRCan S&T Publications Guidelines - NRCan Science Commun-ications Guidelines - S&T Publications Official Languages	Managing the business processes and ensuring peer review, editing, layout and release of GSC S&T information products. OGN participated in developing The NRCan Open Science Action Plan, which is required under the GoC Open Science Roadmap. The Roadmap commits the Government to, among other things, making all publications freely available without embargo by 2022. OGN participated in the development of various guidelines that provide advice on how to interpret NRCan's Science Integrity Policy with respect to publication and communications.
Synthesis and Integration Boyan Brodaric	Increase access to new knowledge of the geology of Canada as a whole by integrating various data sets using new and innovative methods, including for dissemination. Increase the capacity for integration of Canadian geoscience knowledge across disciplines and for prediction.	- Canada 3D - Groundwater Information Network (GIN)	Developing national framework geology in 2D and 3D that integrates data from various sources and provide access to these via an online portal. GIN connects groundwater data from various sources and makes it available via a portal to inform decision-making.

Projects & Project Leader	Project Description	Activities & Activity Leader	Activity Description
Synthesis and Integration Boyan Brodaric	Increase access to new knowledge of the geology of Canada as a whole by integrating various data sets using new and innovative methods, including for dissemination. Increase the capacity for integration of Canadian geoscience knowledge across disciplines and for prediction.	- Canada 3D - Groundwater Information Network (GIN)	Developing national framework geology in 2D and 3D that integrates data from various sources and provide access to these via an online portal. GIN connects groundwater data from various sources and makes it available via a portal to inform decision-making.
Earth Material Collections Rhian Evans	Properly document, preserve and curate GSCs physical collections throughout their life cycle.	- Rehousing and Improving Collections Facilities - Collections Loans to Institutions - State of the Collections Review	Rehousing and improving collections facilities are actions undertaken to improve storage and life-cycle management of physical collections. For example, in Ottawa a new warehouse was fitted up and over 1300 tons of material were cleaned, catalogued and relocated. Collections loans are actions undertaken to transfer portions of GSC collections to third parties under long-term loan agreements; e.g. the GSC is in the process of transferring some of its collections to the Canadian Museum of Nature. The state of the collections review is a series of activities to collect and analyze the state of GSC's physical collections holdings to recommend ways to enhance their value to geoscience and education.

Strategic Priority 5: Our People, Our Science

Table 17: *SLN 2020-2021 Services, Projects, and Facilities*

Projects & Project Leader	Project Description	Facilities and Facility Leader	Facility Location(s)
Inorganic Geochemistry Research Lab Group (IGRL) Paul Gammon	Innovative geochemical research and analysis (isotope systems, metal species) to define geochemical processes in ore-forming bodies, crustal processes and to identify the movement and impact of elements in the environment.	Environmental and Surficial Lab Facility Paul Gammon	Ottawa, ON
		Analytical Chemistry Lab Facility Simon Jackson	Ottawa, ON
		Marine Geochemistry Lab Facility Michael Parsons	Dartmouth, NS
Paleontology Lab Group Manuel Bringué and Sofie Gouwy	Expertise in paleontology to provide geological age and paleoenvironmental insights from geological records. Supporting basin analyses for hydrocarbon and mineral exploration, geological mapping, reconstructions of past environmental change over geological time, and in modern settings. Assessing and forecasting the response of ecosystems to cumulative effects of climate and anthropogenic disturbance.	Palynology Labs Manuel Bringué and Jennifer Galloway	Calgary, AB Dartmouth, NS Quebec, QC
		Conodont Labs Sofie Gouwy	Calgary, AB Vancouver, BC
		Macrofossil Lab Facility Jim Haggart	Vancouver, BC

Projects & Project Leader	Project Description	Facilities and Facility Leader	Facility Location(s)
Mineralogy and Physical Properties Group Jeanne Percival	Expertise in mineralogy, quantitative mineralogical analysis and physical properties of rocks, minerals, and unconsolidated materials, to resolve geophysical, geotechnical, sedimentological, stratigraphic and mineralogical research problems.	Marine Core and Sedimentology Lab Facility Alexandre Normandeau	Dartmouth, NS
		Sedimentology Lab Facility Shauna Madore	Ottawa, ON
		Mineralogy Lab Facility Lapidary Facility Jeanne Percival	Ottawa, ON
		Paleomagnetism & Petrophysics Lab Facility Randy Enkin	Sidney, BC
Isotope Geochemistry and Geochronology Group (IGGG) Jason Ahad	Developing analytical techniques and applications of radiogenic and stable isotope-based studies to date geological events and trace crustal, environmental and marine processes. Contributing to research in regional geological studies, ore deposit modelling and environmental stewardship.	Isotopic Geochemistry & Geochronology Lab Facility Bill Davis, Natasha Wodicka, Jeremy Powell	Ottawa, ON
		Delta Lab (Stable Isotope) Facility Jason Ahad	Quebec, QC

Projects & Project Leader	Project Description	Facilities and Facility Leader	Facility Location(s)
Organic Geochemistry and Petrology (OGPet) Group Dennis Jiang and Rachel Robinson	Geochemical and petrographic characterization of (1) conventional and unconventional hydrocarbon systems in the subsurface; (2) existing and potential environmental impacts of fossil resource extraction and development on the surface and underground; (3) the origin and fate of organic matter and its interaction with water and sediments.	Organic Geochemistry and Organic Petrology Lab Facilities Dennis Jiang, Rachel Robinson, Omid Haeri Ardakani	Calgary, AB

Table 18: *IRN 2020-2021 Services, Projects, and Facilities*

Projects & Project Leader	Project Description	Activities & Activity Leader	Facility Location(s)
Indigenous Relations Secretariat Sonia Talwar	Support management in addressing current Indigenous relations issues for the GSC.	GSC Strategic Priority 4 Support Sonia Talwar	Coordinating on behalf of managers.
		Indigenous Relations Network (IRN) Sonia Talwar	Creating and managing an Indigenous Relations Network that will promote the development of a community of practice around Indigenous relations at the GSC.
		Expert advice to management Sonia Talwar	Supporting management on ensuring better integration within the Sector, Department, and government of Canada on Indigenous relations issues.

Projects & Project Leader	Project Description	Activities & Activity Leader	Facility Location(s)
Indigenous Relations Network Steering Committee Mike Ellerbeck	The IRN Steering Committee will build on the GSC's experience to enhance relationships with Indigenous communities and organizations through engagement on geoscience initiatives. It is grounded in the principles of mutual respect and cooperation; recognize the value of Indigenous worldviews and traditional knowledge; and offer benefits to Indigenous communities, where appropriate.	Training Michelle Côté	Recommending and coordinating training to GSC staff to enhance abilities to effectively and respectfully engage with Indigenous communities.
		Engagement Tool Box Mike Ellerbeck	Developing organizational tools to help staff develop and maintain respectful and fruitful relations and collaborations with Indigenous communities.
		Indigenous Engagement Database Michelle Côté	Developing internal systems to aid in better coordination and reporting on Indigenous relations across the GSC.
		IRN Communications Mike Ellerbeck	Evaluating internal and external communications needs for the IRN. Developing communications material for internal (NRCan and Government of Canada) promotion. Identifying other communications needs. Advising the steering committee on Communications needs.

Annex 3: Acronyms

AB - Alberta
AGN - Advisory Group of Northerners
AI - Artificial Intelligence
AUV - Autonomous underwater vehicle
BC - British Columbia
C3D - Canada in 3D
CCGP - Climate Change Geoscience Program
CCUS - Carbon Capture Utilization and Storage
CEC - Commission for Environmental Cooperation
CMMP - Canadian Minerals and Metals Plan
CNGO - Canada-Nunavut Geoscience Office
CO_2 - Carbon Dioxide
CSSP - Canadian Safety and Security Program
CWA - Canada Water Agency
DBHE - Deep Borehole Heat Exchangers
DFO - Fisheries and Oceans Canada
DILBIT - Diluted Bitumen
DRDC - Defence Research Development Canada
DRF - Departmental Results Framework
DRR - Departmental Results Reports
EA - Environmental Assessment
EEZ - Exclusive Economic Zone
EGP - Environmental Geoscience Program
EIAS - Environmental Impact Assessment Service
EIS - Environmental Impact Statements
GAC - Global Affairs Canada
GEM-GeoNorth - Geo-Mapping for Energy and Minerals-GeoNorth
GEN8 - Generation 8 Initiative
GGIS - Global Groundwater Information System
GGP - Groundwater Geoscience Program

GIN - Groundwater Information Network
GNES - Geoscience for New Energy Supply
GNSS - Global Navigation Satellite System
GRRB - Gwich'in Renewable Resources Board
GSC - Geological Survey of Canada
GWML - Groundwater Markup Language
H_2S - Hydrogen Sulfide
HQP - Highly Qualified Personnel
ICP-MS - Inductively coupled plasma mass spectrometry
IGGG - Inorganic Geochemistry Research Lab Group
IGs - Indigenous Governments
IOs - Indigenous Organizations
IGRAC - International Groundwater Assessment Center
IGRL - Inorganic Geochemistry Research Lab Group
IMDWG - Information Data Management Working Group
IPCC - Intergovernmental Panel on Climate Change
IRN - Indigenous Relations Network
IRS - Indigenous Relations Secretariat
ISR - Induced Seismicity Research
JRP - Joint Review Panel
LMS - Lands and Minerals Sector
MCT - Marine Conservation Targets Program
MGMSP - Marine Geoscience for Marine Spatial Planning Program
MGS - Minnesota Geological Survey
MILA - Montreal Institute for Learning Algoritms
ML - Machine Learning
MRB - Mackenzie River Basin
NDGW - National Dialogue on Groundwater
NGSC - National Geological Surveys Committee
NL - Newfoundland and Labrador
NMR - Nuclear Magnetic Resonance
NRCan - Natural Resources Canada
NWMO - Nuclear Waste Management Organization
NWT - Northwest Territories
OGN - Open Geoscience Network
OGPet - Organic Geochemistry and Petrology
P/Ts - Provinces and territories
PCA - Parks Canada Agency
PERD - Program of Energy Research and Development
PIN - Permafrost Information Network
PIP - Performance Information Profiles
PNCIMA - Pacific North Coast Integrated Management Area
PPE - Personal Protective Equipment
PSGP - Public Safety Geoscience Program
R&D - Research and Development
ROF - Ring of Fire
ROV - Remotely Operated Vehicle
SHRIMP - Sensitive High Resolution Ion MicroProbe
SK - Saskatchewan
SLN - Science Laboratory Network
TfR - Together for Respect
TGI - Targeted Geoscience Initiative
TMX - Trans Mountain Expansion Project
TOUG - Transforming tight oil and unconventional gas
UNCLOS - United Nations Convention on the Law of the Sea
UNESCO - United Nations Educational, Scientific and Cultural Organization
UNFCC - United Nations Framework, Convention on Climate Change
WCOGS - World Community of Geological Surveys
WCSB - Western Canada Sedimentary Basin
WMO - World Meteorological Organization

Annex 4: Resources

- Canada in 3D: https://canada3d.geosciences.ca/
- Geological Survey of Canada: https://www.nrcan.gc.ca/science-and-data/research-centres-and-labs/geological-survey-canada/17100
- Geological Survey of Canada - Strategic Plan 2018-2023: https://www.nrcan.gc.ca/science-data/science-research/earth-sciences/geological-survey-canada-strategic-plan-2018-2023/15410
- GEOSCAN: https://geoscan.nrcan.gc.ca/
- Groundwater Information Network: http://gin.gw-info.net/
- Laboratories Canada: https://www.science.gc.ca/eic/site/063.nsf/eng/h_97809.html
- Minister of Natural Resources Mandate Letter (December 13, 2019): https://pm.gc.ca/en/mandate-letters/2019/12/13/minister-natural-resources-mandate-letter
- Minister of Natural Resources Supplementary Mandate Letter (January 15, 2021):https://pm.gc.ca/en/mandate-letters/2021/01/15/minister-natural-resources-supplementary-mandate-letter
- Natural Resources Canada: https://www.nrcan.gc.ca/home
- Natural Resources Canada Organizational Structure: https://www.nrcan.gc.ca/home/about-us/natural-resources-canada-organizational-structure/23054
- NRCan Departmental Plan 2020-21: https://www.nrcan.gc.ca/transparency/reporting-and-accountability/plans-and-performance-reports/departmental-plan-formerly-reports-on-plans-and-priorities/2020-21-departmental-plan/departmental-plan-2020-21/22581

- Office of Energy Research and Development: https://www.nrcan.gc.ca/science-and-data/funding-partnerships/funding-opportunities/office-energy-research-development-oerd/
- Open Maps Canada (Federal Geospatial Platform): http://open.canada.ca/en/open-maps
- Open Science and Data Platform: https://osdp-psdo.canada.ca/en/osdp Permafrost Information Network: https://pin.geosciences.ca/
- Permafrost Information Network: https://pin.geosciences.ca/
- United Nations Convention on the Law of the Sea: https://www.iucn.org/theme/marine-and-polar/our-work/international-ocean-governance/unclos


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