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GEOLOGICAL SURVEY OF CANADA
REPORT ON RESULTS AND DELIVERY

2018-2019

Canada

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Report on Results and Delivery 2018-2019

Geological Survey of Canada

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FOREWORD

Since 1844, when William E. Logan, the first Director of the Geological Survey of Canada (GSC) submitted to the legislature his "*Report of progress for the year 1843"*, a tradition of reports to Canadians and the world on explorations and scientific results was born. This has taken many forms, with a total publication count of over 85,000 titles to date available through the GSC web portal *GEOSCAN* (https://geoscan.nrcan.gc.ca/geoscan-index.html).

As the current Director General of the GSC, I am honoured to present this first of a new series of annual reports to highlight our many and varied results.

The GSC is Canada's national organization for public geoscientific information and research. Its world-class expertise focuses on issues that matter to Canadians such as the sustainable development of Canada's mineral, energy, and water resources; the stewardship of Canada's environment; the management of geological and related hazards; and the development of technological innovation and support for the competitiveness of Canada's geological resources.

Some of this year's GSC highlights include the implementation of the *GSC Strategic Plan 2018-2023* that aligns GSC science with the federal policy agenda. The success of this strategy is evidenced by recognition in the 2018 and 2019 Federal Budgets where the GSC received new funding for new headquarter laboratory buildings, cumulative effects and impact assessment science, the *United Nations Convention on the Law of the Sea - Outer Limits of Continental Shelf Program*, and leadership of a major earthquake risk profile project under the newly announced national *Emergency Management Strategy*.

We continue to strive to make the GSC a workplace of choice and excellence with the implementation of initiatives such as "*Making GSC Ottawa a Better Workplace*", "*Together for Respect", "Kairos Blanket exercise on Indigenous history", Team Building excursions*, and promoting women in science. The past year saw the completion of major $14M renovations in our GSC Calgary laboratory which has well-positioned the GSC for success on Low Carbon Energy futures, with national and international collaborations. In addition, our culling and migration of the GSC rock collection to a new facility is progressing well with completion within the coming year or so.

An organizational modernization initiative entitled "*Generation 8*" has been launched to tackle all aspects of the GSC. In addition, a scientific shift towards increased use of big data, data analytics and digital technologies such as artificial intelligence in our science. This is demonstrated by the ongoing development of a 3D interactive map of Canada under the *Canada3D* initiative carried out jointly with all the provincial and territorial geological surveys of Canada under the *aegis* of the Canada *Intergovernmental Geoscience Accord*.

I wish to acknowledge Celina Campbell and her team who compiled this report with input from across the GSC, no small feat as a first of its kind report.

As the reader will quickly realize in reviewing this report, the results for the last year are impressive. This is in no small measure due to an outstanding team of scientists and support personnel that count on a large network of collaborators nationally and internationally, as well as a depth of support coming from our host department, Natural Resources Canada, and the Lands and Minerals Sector. I offer my sincere thanks to all those contributors to our success.

Your obedient servant,

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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EXECUTIVE SUMMARY

As part of Natural Resources Canada's (NRCan) Lands and Minerals Sector (LMS), the Geological Survey of Canada (GSC) has been providing public geoscience knowledge to Canadians since 1842. NRCan is a science-based organization and works to improve the quality of life of Canadians by ensuring that our natural resources are developed sustainably through evidence-informed policy; and by providing a source of jobs, prosperity and opportunity while preserving the environment and respecting communities and Indigenous peoples.

NRCan is delivering results for Canadians across three core responsibilities mandated to the Department: 1) Natural Resource Science and Risk Mitigation; 2) Innovative and Sustainable Natural Resource Development; and 3) Globally Competitive Natural Resource Sectors.

- All GSC Science and Technology (S&T) falls under NRCan Core Responsibility 1.
- The GSC reports its S&T contributions to NRCan Core Responsibility 1 through a nested corporate reporting structure (NRCan Departmental Results Framework, LMS Performance Information Profiles, and GSC S&T Programs).

The mission of the GSC is to provide authoritative and innovative geoscience information reflected through the following corporate priorities:

- Geological knowledge for Canada's Onshore and Offshore Land;
- Geoscience for Sustainable Development; and
- Geoscience for Keeping Canada Safe.

The GSC develops its science through 13 science programs/services:

1. Geo-mapping for Energy and Minerals Program;
2. United Nations Convention on the Law of the Sea (UNCLOS) Program;
3. Environmental Assessment Service;
4. Environmental Geoscience Program;
5. Groundwater Geoscience Program;
6. Targeted Geoscience Initiative Program;
7. Geoscience for New Energy Supply Program;
8. Marine Conservation Targets Program;
9. Marine Geoscience for Marine Spatial Planning Program;
10. Climate Change Geoscience Program;
11. Public Safety Geoscience Program;
12. Open Geoscience; and
13. Science Laboratory Network.

In 2018–2019, the GSC:

- had budget expenditures that totaled $65.8M;
- employed 401 full-time employees; and
- published 764 publications.

This *Report on Results and Delivery* provides an overview of the GSC, its corporate results and delivery structure, and 2018-19 S&T program highlights.

INTRODUCTION

The Geological Survey of Canada (GSC) is Canada's national organization for public geoscientific information and research. Its world-class 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.

Founded in 1842, the GSC has remained relevant to successive generations of Canadians by:

- working on issues that matter to Canadians;
- networking within the lands and minerals innovation ecosystem;
- supporting a targeted career-long employee learning environment, enabling staff to remain current;
- ensuring employee access to the resources required to remain innovative; and
- enabling a national lands and minerals ecosystem community.

First signed in 1996 and renewed in 2002, 2007, 2012, and 2017, the *Intergovernmental Geoscience Accord* (IGA) provides a framework for co-operation and collaboration among the federal, provincial, and territorial geological surveys. Co-operation and collaboration minimize overlap and duplication, enhance synergies among jurisdictions to resolve regional geoscience problems, and facilitate optimal utilization of resources.

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 reflected through the following main priorities:

- Geological knowledge for Canada's onshore and offshore lands;
- Geoscience for sustainable development; and
- Geoscience for keeping Canada Safe.

Geoscience is the scientific study of the planet Earth and its many different natural geological systems. Geoscience is an important tool in helping decision makers develop science-informed solutions to many of society's complex problems. For example:

- Finding natural resources such as minerals, metals, groundwater, and petroleum.
- Helping ensure that natural resources are developed in a responsible and sustainable manner.
- Reducing loss from natural hazards, (e.g., earthquakes, floods, landslides, hurricanes, tsunamis, volcanoes) and climate change (e.g., melting permafrost, sea level changes).
- Understanding natural baseline environmental conditions and the impact human activities may have on the environment.
- Mapping our landmass to improve our fundamental understanding of the connections and processes between onshore and offshore areas.
- By understanding the history of our planet, geoscientists can better predict how events and processes of the past might influence the future.

Most GSC science programs are developed as inputs to federal policy, or instruments of federal policy. For example *inter alia* the provision of public good geoscience has been used to:

1. Support Canada's economy.

- For example, public geoscience increases private mineral-exploration activity by providing information about areas being considered for more detailed exploration, reducing the costs and risks of private exploration. Estimates indicate that every $1M of government investment to enhance the geoscience knowledge base will likely stimulate $5M of private sector exploration expenditures, which, in turn, will result in discovery of new resources with an average *in situ* value of $125M.

2. Support science-based/informed decision-making.
    - For instance, public geoscience reduces the environmental risks of resource development, informs environmental assessments (e.g., offshore resource assessments), and supports international obligations and relationships through scientific collaboration and science diplomacy (e.g., United Nations Convention on the Law of the Sea Program).
3. Inform the development of standards such as national building and transportation infrastructure codes in areas at high risk of geohazards such as earthquakes, sensitive clays, melting permafrost, coastal erosion, and tsunamis.

Through the provision of targeted public-good geoscience, the GSC continues to help ensure that Canada's land and offshore natural resources and associated sectors (e.g., exploration, mining, and transportation) can help address current and future federal economic, social, and environmental policy priorities.

This document presents a high-level corporate overview of the GSC, its science programs, and program linkages to NRCan and LMS priorities.

MANDATE

The GSC has a number of legislated obligations under various federal acts (e.g., Department of Natural Resources Act [1994], Resources and Technical Surveys Act [1985], Canadian Environmental Assessment Act [2012], Comprehensive Nuclear-Test-Ban Treaty Implementation Act [1998], Emergency Management Act [2007]). In addition, it provides support to the Minister of Natural Resources, as well as to other implicated ministers, to help meet objectives outlined in their mandate letters, horizontal interdepartmental priorities, international processes and federal geoscience commitments outlined in federal budgets.[1]

The principle mandate of the GSC includes:

- "Make a full and scientific examination and survey of the geological structure and mineralogy of Canada" (Resources and Technical Survey Act, 1985);
- "Seek to enhance 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);
- "Have regard to the sustainable development of Canada's natural resources and the integrated management thereof" (Department of Natural Resources Act, 1994); and

[1] For example: Budget 2013 committed to the Geo-mapping for Energy and Minerals program, Budget 2015 committed to the Targeted Geoscience Initiative-5, Budget 2017 committed to the Pan Canadian Framework on Climate Change, Budget 2018 committed to Impact Assessment Act (cumulative effects and impact-assessment research), and Budget 2019 committed to the United Nations Convention on the Law of the Sea Program and the Emergency Management Strategy for Canada.

- Provide expert information to support environmental assessments under the federal government's requirements under CEAA 2012 [*CEA Act 1992*, Section 12 (3)].

The GSC develops geoscience knowledge and geoscientific tools in support of its federal mandate. This is a never-ending task due to the need for new resources (e.g. critical minerals, minerals and metals for a low-carbon future), and evolving/changing federal priorities (e.g. Indigenous knowledge, cumulative effects, new natural-resource development infrastructure).

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.

Figure 1. Photo of CCGS Louis S. St-Laurent (leading) and CCGS Terry Fox (following) in the Arctic.

In Budget 2019, the GSC received new funding for the United Nations Convention on the Law of the Sea (UNCLOS) Program. The UNCLOS Program completed its Canada's Arctic Ocean submission and filed it with the United Nations in spring 2019. More information can be found at https://www.canada.ca/en/global-affairs/news/2019/05/canadas-arctic-ocean-continental-shelf-submission.html.

ORGANIZATIONAL STRUCTURE

The GSC is led by a Director General who provides overall leadership on GSC files. Program delivery and provincial and territorial liaison responsibilities for the GSC are shared by six regional divisions across Canada, in addition to the Vancouver office and the Canada-Nunavut Geoscience Office (CNGO) (Table 1). Each director has corporate (e.g. human, financial, and asset resource management), programs and regional responsibilities.

Table 1. Geological Survey of Canada Management Team

Director General	GSC Division	Director	Program / Service files	Regional contact
Daniel Lebel	**Pacific Division:** Sidney & Vancouver, British Columbia	Philip Hill	Public Safety Geoscience	British Columbia
	Calgary Division: Calgary, Alberta	Sonya Dehler	Geoscience for New Energy Supply; Marine Conservation Targets	Alberta, Saskatchewan
	Northern Division: Ottawa, Ontario & Canada Nunavut Geoscience Office, Iqaluit, Nunavut	Linda Richard	Geoscience for Energy and Minerals; Environmental Assessments; Open Geoscience	Nunavut, Northwest Territories, Yukon
	Central Division: Ottawa, Ontario	Mike Villeneuve	Targeted Geoscience Initiative; Science Laboratory Network	Ontario, Manitoba
	Quebec Division: Québec, Quebec	Andrée Bolduc	Groundwater Geoscience Program; Environmental Geoscience Program	Quebec, New Brunswick
	Atlantic Division: Dartmouth, Nova Scotia	Stephen Locke	Climate Change Geoscience; Marine Geoscience for Marine Spatial Planning	Nova Scotia, Prince Edward Island, Newfoundland and Labrador

In 2018–19, the GSC budget expenditures totaled $65.8M (Table 2). Its workforce included: 401 full-time employees. There were 87% (350) indeterminate employees (permanent), 13% (51) term employees, 17 casuals (workers employed for under four months) and 25 students.

Table 2. Geological Survey of Canada 2018-2019 Budget Expenditures

GSC 2018-2019	A-base ($)	C-base ($)	Total ($)
VOTE 1 – Salary	36,566,721.17	4,571,322.42	41,138,043.59
VOTE 1 - Operation and Maintenance (O&M)	5,016,899.01	15,937,614.04	20,954,513.05
VOTE 5 - Major Capital	270,701.00	1,819,603.00	2,090,304.00
VOTE 10 – Grants	198,983.00	1,395,710.00	1,594,693.00
Total All Votes	42,053,304.18	23,724,249.46	65,777,553.64

GSC RESULTS AND DELIVERY

GSC REPORTING STRUCTURE WITHIN THE GOVERNMENT OF CANADA

The Government of Canada's *Policy on Results* supports a strong focus on results, helps the government track and report progress, assesses effectiveness, and aligns resources to priorities. The GSC results and delivery processes and tools are nested as follows (from the highest level to the most granular, Table 3):

- Natural Resources Canada Department Results Framework (DRF) (Annex I);
- Natural Resources Canada's Lands and Mineral Sector's Performance Information Profiles (PIP) (Annex I);
- GSC Strategic Priorities (Annex I); and
- GSC Science programs/services (Annex II).

GSC STRATEGIC PRIORITIES

To guide its programs/services, the GSC's Strategic Plan identifies the key priorities for 2018 to 2023 and related initiatives to support their implementation. Priorities include:

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;
5. Our Science, Our People.

Priorities one to three outline the key scientific contributions to Natural Resources Canada's strategic priorities by producing new geoscience knowledge and are aligned with DRF and LMS PIP priorities. Priorities four and five describe organizational and business objectives to sustain capacity and foster a healthy work environment that is required to conduct efficient, effective, and relevant work.

GSC SCIENCE PROGRAMS/SERVICES

The GSC develops science and technology (S&T) 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 international obligations;
- incent behavioural change; and
- ensure that international policy is based on scientific principles.

Table 3. Geological Survey of Canada's Results & Delivery Reporting Structure

NRCan DRF Core Responsibility	NRCan DRF Program	LMS PIP	LMS PIP Projects	GSC Strategic Priority (SP)	GSC Science Programs / Services
Natural Resource Science and Risk Mitigation	Geological Knowledge for Canada's Onshore and Offshore Land	Geological Knowledge for Canada's Onshore and Offshore Land	Geo-mapping for Energy and Minerals Canada's Extended Continental Shelf Program	SP-1: Geological Knowledge for Canada's Onshore and Offshore Land	Geo-mapping for Energy and Minerals Program United Nations Convention on the Law of the Sea (UNCLOS) Program
	Geoscience for Sustainable Development	Geoscience for Sustainable Development	Environmental Studies and Assessment Groundwater Geoscience Targeted Geoscience Initiative Geoscience for New Energy Supply	SP-2: Geoscience for Sustainable Development	Environmental Assessment Services Environmental Geoscience Program Groundwater Geoscience Program Targeted Geoscience Initiative Program Geoscience for New Energy Supply Program Marine Conservation Targets Program Marine Geoscience for Marine Spatial Planning Program
	Geoscience for Keeping Canada Safe	Geoscience for Keeping Canada Safe	Geo-hazards and Public Safety	SP-3: Geoscience for Keeping Canada Safe	Climate Change Geoscience Program Public Safety Geoscience Program
				SP-4: Geoscience for Society	Open Geoscience
				SP-5: Our People, Our Science	Science Laboratory Network

The right-most columns feed into the left ones in a hierarchical fashion (from GSC to LMS to NRCan). Columns in darker shades represent actual reporting structures and columns in lighter shades represent umbrella structures that may provide inputs into the actual reporting structures. More information about NRCan's DRF can be found at https://www.nrcan.gc.ca/plans-performance-reports/dp/2019-20/21771.

The GSC delivers its science through 13 programs/services, which further break down into projects and activities (Table 5, Annex II).

GSC programs/services include:

1. Geo-mapping for Energy and Minerals Program;
2. United Nations Convention on the Law of the Sea (UNCLOS) Program;
3. Environmental Assessment Service;
4. Environmental Geoscience Program;
5. Groundwater Geoscience Program;
6. Targeted Geoscience Initiative Program;
7. Geoscience for New Energy Supply Program;
8. Marine Conservation Targets Program;
9. Marine Geoscience for Marine Spatial Planning Program;
10. Climate Change Geoscience Program;
11. Public Safety Geoscience Program;
12. Open Geoscience; and
13. Science Laboratory Network.

Through its programs/services, the GSC engages with Indigenous communities, incorporates traditional knowledge with western science, and supports decision-making by communities.

Program of Energy Research and Development

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

Highlights of GSC 2018-19 PERD related work include:

- Successfully developed artificial intelligence (AI)-based method can now automatically identify seismic signals from induced earthquakes and determine the corresponding phase arrival times. This development significantly improved the efficiency of locating induced events and their repercussions in British Columbia and Alberta.
- New techniques in data analytics and numerical modelling have provided new insight on source-rock reservoirs and fluid dynamics of shale-hosted petroleum that will result in more efficient drilling and resource extraction.
- Researchers from the GSC have established a relationship between injection-induced earthquakes and tectonic strain rate, which indicates that regulations on induced seismicity should consider regional tectonic characteristics.

GSC science information is open and distributed through the Government of Canada’s GEOSCAN bibliographic database and various social media venues (Annex III).

GSC SCIENCE AND TECHNOLOGY SUCCESS STORIES

The following GSC 2018–2019 S&T 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 13 GSC programs/services.

STRATEGIC PRIORITY 1: GEOLOGICAL KNOWLEDGE FOR CANADA'S ONSHORE AND OFFSHORE LAND

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

- Geo-Mapping for Energy and Minerals (GEM); and
- United Nations Convention on the Law of the Sea (UNCLOS) Program.

GEO-MAPPING FOR ENERGY AND MINERALS

NRCan's Geo-Mapping for Energy and Minerals (GEM) Program generates public geoscience knowledge related to Canada's North. GEM knowledge and data informs decision-making by Northerners, Northern institutions, and the natural resources industry, to stimulate a strong northern economy through stable, long-term investment in responsible resource development.

Phases 1 and 2 of GEM ($200M/12 years, 2008–2020) focus on mapping the North to the minimum modern standards needed for effective private-sector exploration. In addition to stimulating resource exploration, uptake of these results has informed land-use planning related to the growing need for infrastructure to support resource development beyond the exploration stage (Figure 2).

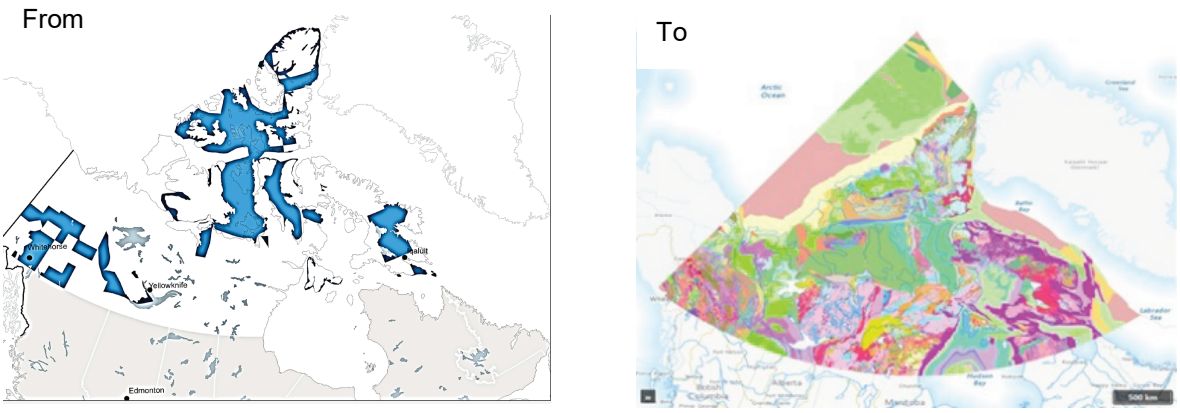


Figure 2. Mapping the geology of the Canadian North. This figure showcases GEM progress from 2008 to 2020.

GEM is conducted in collaboration with provinces and territories as per the principles outlined in the Ministerial Intergovernmental Geoscience Accord. It benefits from an Advisory Group of Northerners (AGN), which includes representatives from territorial governments, the private sector and Indigenous socio-economic development organizations.

The AGN:

- Provides critical advice that helps the program overcome specific challenges related to the North in program implementation and delivery, and improves access by Northerners to GEM training, jobs, and opportunities. AGN members also advise on communicating with Northerners, as well as help directly to communicate opportunities provided by GEM.
- Advises on approaches to maximize the value of GEM knowledge for local decision-making on resource development and land-use, through increased access by Northerners to geoscience knowledge and value-added knowledge products.
- Provides advice on continued communication with Northerners that will maximize the impact of the program on northern prosperity and decision-making, and establish leading practices in engaging Northerners and Aboriginal communities.
- Provides advice to help GEM maximize the involvement of, and benefits to, Northerners and Indigenous peoples by identifying relevant initiatives, tools, products, engagement approaches and collaboration opportunities with communities, all levels of government, industry, and other stakeholders.

Recent successes include:

Climate-Resilient Infrastructure informed by Geoscience
The Northwest Territories Department of Transport used GEM surficial geological knowledge to help plan the route of the Tlicho All-Season Road, an estimated $150 million project. The road will support economic development in the region targeting gold, copper, bismuth, and cobalt; which includes mining opportunities such as the $6M NICO mine (in planning stage).

Mineral Potential in Southern Mackenzie
GEM fieldwork in Southern Mackenzie indicates potential for new, undiscovered base metal mineralization in the region, including zinc, lead, and copper. Exploration companies expressed great interest in the preliminary results presented at the Prospectors and Developers Association of Canada convention.

Diamond Potential
Kimberlite indicator minerals found in Nunavut and Northwest Territories could potentially expand the exploration area for diamonds to Victoria and Banks Islands.

Diversifying Mineral Potential in Northern Labrador
Research in the Ungava Peninsula unearthed potential gold deposits, ushering in new investment opportunities. Previously, exploration in Labrador focused on iron, nickel, or uranium; this new information helps direct gold and additional nickel exploration. In 2018, four companies conducted exploration activities in the Ungava Peninsula.

Additional Gold Potential in Northern British Columbia
Two companies, Grey Rock Resources and Brixton Metals Corporation, cite a joint British Columbia Geological Survey–GEM report that recognizes a new potential bedrock source for placer gold in Atlin, British Columbia. Subsequently, visible gold found by Grey Rock initiated a staking rush over 120,000 hectares of land in the area. Brixton Metals now reports there is additional exploration potential in their 979 km^2 wholly owned Atlin Gold Project, where this bedrock source is situated.

UNITED NATIONS CONVENTION ON THE LAW OF THE SEA (UNCLOS) PROGRAM

Canada ratified the United Nations Convention on the Law of the Sea (UNCLOS) in 2003, and as a signatory 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. In addition to precisely defining the outer limits of its continental shelf following the criteria set forth in Article 76 of the Convention, submissions include robust scientific data and arguments showing the continental shelf extends beyond 200 nautical miles and that it is a natural component and a natural prolongation of our landmass. Canada's two submissions (Atlantic Ocean filed in 2013 and Arctic Ocean expected to be filed in 2019) show entitlement to 2.4 million km^2 of seafloor and subsoil, making it the largest area ever considered by the United Nations under UNCLOS. International recognition of these 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 subsoil.

Drawing a line in the sediment
Geoscientific research in the Arctic Ocean to define the outer limits of Canada's continental shelf was carried out under harsh environmental conditions using ice camps, an Autonomous Underwater Vehicle (AUV), and heavy-duty icebreakers to acquire data and samples. The acquisition of geological, geophysical, and geomorphological datasets and samples was carried out on, under, over, and through thick multi-year ice. This required GSC scientists and technicians to spend their summers working at sea on 42- to 47-day long research expeditions. In addition to the Canadian expeditions, many successful joint missions were conducted with scientists from Denmark and the United States. The Canadian program continues to collaborate with scientists from other Arctic nations and meets annually with them to discuss scientific issues related to improving our understanding of the geology and formation of the Arctic Ocean.

Recent successes include:

Canada's Arctic Ocean Submission
After a decade of research, the GSC finalized Canada's Arctic Ocean submission, which was filed with the Commission on the Limits of the Continental Shelf at the United Nations in New York on May 23, 2019. By filing its submission, Canada has met its legal obligation as a signatory to the UNCLOS to define the outer limits of Canada's continental shelf. Based on robust geoscientific evidence, the 2100-page submission shows unequivocally that Canada's continental shelf extends beyond 200 nautical miles and is a natural prolongation of our landmass. Legacy data collected by past GSC field programs undertaken in the Canadian Arctic Archipelago are an important component of Canada's submission. The onshore and offshore data show that the formation of our continental shelf resulted from a complex series of tectonic and magmatic events. These events tie the geological evolution of the landmass to all elements of the development of the continental shelf. The proposed outer limits are precisely defined by 877 co-ordinates, encompassing an area of over one million km^2, including the geographic North Pole. These outer limits will eventually become Canada's last international boundary, conferring sovereignty over the living and non-living natural resources on the seafloor and in the subsoil.

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);
- Marine Conservation Targets (MCT);
- Marine Geoscience for Marine Spatial Planning (MGMSP); and
- Environmental Assessments (EA).

The GSC is setting international standards in the adoption of digitization and disruptive technologies in the lands and minerals sector**.** The GSC has incorporated cutting-edge research trends such as the use of big data, data analytics, augmented reality and machine learning, including artificial intelligence, in many areas such as 3-D geological, groundwater, and oil and gas modelling.

GSC commitment to land and marine conservation:

- assessed offshore petroleum resources as part of Canada's target of protecting 10% of its offshore by 2020;
- developed new maps and analyses of seafloor geology and active seabed processes to inform evidence-based marine spatial planning and regional environmental assessments; and
- in 2018–19 the GSC provided 42 geoscience-based environmental-impact statements to support land-use planning and environmentally sound resource development, both on land and in our coastal and offshore waters.

TARGETED GEOSCIENCE INITIATIVE

Canada's reserves of metals have been declining for more than 30 years. Deeper exploration for new resources is required to offset the increasing rarity of surface discoveries. The Targeted Geoscience Initiative (TGI) is a collaborative federal geoscience program that provides the mineral exploration industry with new ore-system models and innovative methodologies to enhance effectiveness of deep exploration of Canada's key economic minerals and also aims to reduce some of the risks of mineral exploration and support Canadian mining-dependent communities

In 2019–20 the GSC will complete the Targeted Geoscience Initiative-5 (TGI) program which has improved understanding about the processes underlying Canadian ore systems, such as gold and uranium. This knowledge, through public geoscience, informs mineral exploration and increases the economic sustainability of current mines.

Shining Gold in the North

Building on regional geological knowledge from GEM, TGI public geoscience helped in the expansion of Canada's newest gold-mining district in the Kivalliq region of Nunavut, through the development of updated models for predicting the characteristics of the district's gold deposits. TGI scientists discovered a new control on the distribution of the gold in the district, which led to improvements to the search criteria used to find new deposits in the region, in addition to gold exploration models in other Banded Iron Formation host rocks around the world. This knowledge has helped companies working in the region to make their exploration strategies more efficient and effective. As stated by Alain Blackburn, Senior Vice-President, Exploration, at Agnico Eagle Mines Limited, the recent creation of two new mines in the Kivalliq gold-mining district represents "one of the most significant development projects currently contributing to unlocking Canada's northern resources and supporting job creation in the Arctic."

Recent successes include:

New model for Canada's youngest gold mining district
New public geoscience knowledge generated by TGI has resulted in the expansion of Canada's newest gold-mining district made up of the Meliadine, Meadowbank, and Amaruq deposits in the Kivalliq District of Nunavut. Operated by Agnico Eagle Mines Limited, production began at Meadowbank mine in 2010 and is expected to begin at Meliadine and Amaruq in 2019.

Previous models used to predict the size, shape, and grade of the deposits in this district assumed that the ore zone followed the folds of the banded iron-formation (BIF) host rocks; however, poor gold recovery caused mine geologists to question this model.

Structural mapping and geochronology work by graduate students supported by TGI identified that the distribution of the gold in the district was controlled by discrete faults crosscutting the folds, rather than the fold pattern itself. This influenced the search criteria used to find new deposits in the district and BIF-hosted gold exploration models used around the globe.

Joint research rests big ideas
Gold research conducted jointly by TGI-supported geoscientists at the British Columbia and Yukon geological surveys and GSC is examining the relationships between the Llewellyn fault in northern British Columbia, the Tally Ho shear zone in southern Yukon Territory, and gold mineralization. New field observations coupled with high-precision geochronology indicate there are two spatially overlapping gold mineralization events of different ages and styles. This style matches the timing and structural framework for several gold deposits throughout British Columbia, as well as the Juneau gold camp in Alaska, suggesting a similar first-order genetic process.

Nickel-Copper-Platinum Group Element (PGE) Deposits
Many of the world's major nickel-copper-platinum group element (Ni-Cu-PGE) sulfide deposits, such as Canada's world-class Voisey's Bay deposit, are hosted by small mafic or mafic-ultramafic intrusions that are the remnants of larger magmatic plumbing systems that are closely tied to the magmatic evolution of continents.

Like pieces of a giant jigsaw puzzle, fragments of ancient crust have moved over the surface of the Earth for millions of years, driven by magmatic activity in the upper crust, providing the heat and fluids that create continents and form modern mineral deposits. By studying the location, composition, age, shape, and interrelationships between these mafic and ultramafic rocks, TGI geoscientists are building a clearer picture of how and where these valuable deposits form.

Deeper Potential in Sudbury
The Sudbury area is host to some of the world's largest Ni-Cu-PGE magmatic sulfide deposits. In a partnership with geologists at the Ontario Geological Survey, TGI researchers and students are updating geological maps and creating new cross-sections for the Sudbury area.

Historically, mining has occurred on the margins of the mafic and ultramafic intrusions; however, new mapping and age data have generated new targets. Considering the influence of one of Earth's largest preserved impact craters, and the additional heat it would have provided, TGI researchers suspect that the sulfide melts migrated deeper than previously thought.

Modelling by TGI researchers has identified a new set of mineralized veins several hundred metres below the existing known mineralization.

New Technology Explores Deep Roots at New Afton
At the New Afton copper-gold mine in British Columbia, TGI researchers and staff from New Gold, the operator of the mine, completed one of the first applications of Distributed Acoustic Sensing (DAS) - Vertical Seismic Profile (VSP) for mineral exploration to visualize the conduit/feeder system below the deposit.

Using a fibre-optic cable rather than traditional geophones, the team collected high-quality seismic data that enabled them to 'see' more clearly and deeper than by drilling or other geophysical methods can reach.

Mining at New Afton commenced in 2012 and is an operating block cave mine. This project will generate an unparalleled image of the deep roots of this ore deposit to help plan future exploration activity and mining operations.

Fingerprinting Porphyry Deposits Using Indicator Minerals in Glacial Sediments
TGI researchers are refining a cost-efficient geochemical exploration tool for finding porphyry copper deposits: indicator minerals in glacial sediments. Certain chemical elements and minerals are more abundant in glacial sediments that have scoured over a porphyry deposit, than those that have not. The advantage of investigating the composition of glacial sediments is that the extent of the region with high copper concentrations in glacial sediments is much larger than the derivative bedrock source.

Examining sediments from near four porphyry copper deposits in British Columbia — Gibraltar, Mt. Polley, Highland Valley Copper, and Woodjam — TGI researchers found that elements concentrate in certain minerals leaving a porphyry "fingerprint" on the glacial sediments. Epidote and zircon were found to have potential.

The sediments were analyzed using equipment and methods available at commercial laboratories so that the process could be replicated by industry.

Understanding Uranium Deposits in the Patterson Lake Corridor, Saskatchewan
In 2012, two large, high-grade uranium deposits were discovered in the basement rocks in the Patterson Lake corridor on the southwestern margin of the Athabasca Basin. Exploration activity increased, but little was known about how or why these newly discovered deposits had formed outside of the basin. The companies working in the area encouraged and supported TGI-4 and TGI-5 researchers to develop new tools to better understand why these deposits occur where they do.

At Patterson Lake, the deposits are associated with regional fault systems, so researchers used new geochemical, geophysical, and geochronology tools to identify the source of the uranium and what causes the ore fluids to deposit uranium.

One study integrated visible–near infrared–shortwave infrared (VNIR-SWIR) spectroscopy, gamma-ray logs, and magnetic-susceptibility measurements taken on drill core samples to investigate the role that reactivated faults played in the formation of these deposits, while another used isotopes and principal component analysis (PCA) of whole-rock geochemistry to better understand the redox conditions that control ore deposition. A geochronology study used argon-argon dating, low-temperature thermochronology potassium-argon dating, and fission track data in apatite to examine the timing of fault movements.

ENVIRONMENTAL GEOSCIENCE PROGRAM

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

Recent successes include:

Induced Seismicity Study: Fracking and Earthquakes in Western Canada
Hydraulic fracturing, or fracking, is the injection of pressurized liquids to fracture rock formations that host unconventional oil and gas resources. These processes have different effects in different areas, and one of the key concerns is induced seismicity.

Scientists at the Geological Survey of Canada have found a link between the injection-induced earthquakes and the deformation rate of the tectonic plates. The majority of induced earthquakes occurred in an area where the tectonic strain rate is relatively large, a 150 km wide band immediately to the east of the Canadian Rocky Mountains, essentially the border between British Columbia and Alberta. Farther to the east, where the geological deformation rates are low, earthquakes of this type are much less frequent.
Seismologists now know that there is no one-size-fits-all approach to the regulation of hydraulic fracturing. The regional tectonic background has to be considered. Knowledge of this connection is important for both regulators and hydraulic-fracturing operators to help them avoid causing larger, more damaging earthquakes by controlling the level of injection operations in high-risk areas.

GSC Leadership of United Nations 2018 Assessment of Mercury in the Global Environment
Continuing our long-standing leadership in studies of mercury in the environment, GSC contributed scientific expertise and leadership to the 2018 Global Mercury Update Assessment produced by the United Nations Environment Program. Because of its high toxicity to humans and wildlife via food webs, especially in Canada's Arctic, emissions of mercury are regulated under the 2013 UN Minamata Convention, which Canada has ratified. The GSC also played a major role in producing the 2013 Global Technical Assessment that provided the scientific rationale for the Minamata Convention. The 2018 Update report, which will be repeated again in five years, provides a state-of-the-science assessment that will guide future multinational research and policy objectives, and includes two chapters led by a GSC scientist.

Geochemical monitoring: An essential tool for establishing baseline conditions and defining gas origin in water wells
Regular monitoring of several water wells has been extremely helpful to ascertain the source of methane when individual samples provided ambiguous results. In addition, monitoring has shown that large variations in both methane concentration and isotopic composition can occur naturally. These findings demonstrate that a single sampling campaign, which is what regulations require in most cases, may lead to erroneous interpretation of gas origin and imply that monitoring should be carried out over at least one or two years prior to hydrocarbon development to establish the potential natural variations of both methane concentration and isotopic composition. The methodology developed during two projects related to potential impacts of shale-gas activities on shallow aquifers (2012–2019) will help support the regulatory process for the protection of shallow groundwater in the context of unconventional resources development.

What are the Natural Versus Human Contaminants in the Athabasca Oil Sands Region?

The Athabasca Oil Sands Region (AOSR) economic sector has been criticized, often in the absence of scientific evidence, for its potential environmental impacts**.** Understanding the natural contaminant background conditions is essential before being able to recognize and attribute what the impact of natural versus human induced contamination is in an environment. This is particularly important for informed decision-making to improve regulatory efficiency and reduce the environmental risks of resource development. The Geological Survey of Canada scientists developed new environmental indicators for fingerprinting sources of contaminants and studied environmental processes aimed at separating out human-induced versus natural contaminants in the AOSR. This research will help inform stakeholders how best to measure source contributions in any environment including the AOSR, which in turn can improve regulatory efficiency and reduce the environmental risks of resource development.

GROUNDWATER GEOSCIENCE PROGRAM

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.

The culmination of many years of work and international partnerships have resulted in the submission of a groundwater data standard to the World Meteorological Organization.

Recent successes include:

Groundwater Information

Groundwater does not stop at political borders, but its data often does. This impedes scientific and decision-making activities with cross-jurisdictional partners. The Groundwater Information Network (GIN) is a collaboration of NRCan, provinces and territories for sharing groundwater data using international standards led by GSC. The network developed and ratified a new international standard for groundwater data. It prototyped new approaches to connecting water data within an international consortium and under the federal climate science plan, and it also linked to the global groundwater information monitoring system, becoming its Canadian supplier of groundwater data.

The Groundwater Information Network serves over a thousand unique web users every month, and for the first time enabled groundwater data from the US and Canadian national systems to be used seamlessly. This facilitates many scientific activities that draw on data from GIN, and influence the design of several groundwater data systems internationally.

National Aquifer and Groundwater Accounting

After more than twenty years of aquifer-scale mapping, GGP scientists still do not have a full understanding of the groundwater resources in Canada. A shift of scales, and tools with new and innovative approaches to groundwater assessment and accounting is required.

The GSC designed the National Aquifer and Groundwater Accounting (NAGA) project as a platform for a national assessment. From Earth Observations and hydrogeology, NAGA developed the application of satellite imagery for aquifer mapping and dynamic groundwater assessments. Amongst their applications are the numerical models and glacier mass balances constrained with satellite imagery.

Water is as a system underpinning other drivers (e.g. glacial melt, climate change). These drivers are important to inform management of water resources, adaptation practices to climate variability and to cumulative effects. This project has already produced results about the annual groundwater storage

changes in the Great Lakes Basin, as well as the glaciers from the Rockies and meltwater transfer into the Canadian Plains.

Southern Ontario Groundwater
Southern Ontario (S-ON) generates 40 % of the Canadian gross domestic product, has 80% of Ontario's population, and two million people reliant on groundwater. The GSC's work in S-ON supports the bi-national Great Lakes Water Quality Agreement (GLWQA) and the Canada-Ontario Agreement (COA). A gap analysis in 2015 identified the need for legacy data capture, fieldwork, conceptual model development, and numeric modelling and analysis. A state-of-the-art three-dimensional geological model was developed and converted into a hydrostratigraphic framework to support a groundwater–surface-water flow model. To supplement numeric modelling, a conceptual framework for groundwater–surface water interaction was developed to support watershed managers' decision-making.

Southern Ontario has the most advanced geological and hydrogeological modelling framework of any jurisdiction in the Great Lakes Basin. The model will contribute to the GLWQA by providing insight into the groundwater contribution to the Great Lakes from streams as well as direct shoreline and lake-bottom discharge.

GEOSCIENCE FOR NEW ENERGY SUPPLY

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 research and development and the promotion of non- and low-emitting energy resources using advancements in the fundamental understanding of Canada's subsurface landmasses.

Recent successes include:

GNES has developed international partnerships and active collaborations to build a strong innovation ecosystem for clean energy development
GNES Program was developed to increase the geoscience knowledge base needed to facilitate responsible, clean-energy development and to support clean-energy policy and standards development. In the first 15 months of the GNES Program, strong partnerships have been forged with international organizations (e.g. Japan Oil, Gas and Metals Corporation [JOGMEC], Korean Institute of Geoscience and Mineral Resources [KIGAM]), provincial and territorial geological surveys, and other NRCan sectors.

Research partnerships & collaborations are fundamental to GSC program success. For example, GNES collaborations have resulted in increased funding to $1.3M that will bolster the $225k/year A-base budget. This will enable the program to expand its scope into new and exciting innovative areas like cloud computing/machine learning/AI, an increased national knowledge base for the exploitation of geothermal energy, and innovative offshore energy mapping through a $500k partnership with the province of Nova Scotia. Collaborations also give GNES researchers access to a larger swath of cutting-edge laboratory facilities and highly specialized scientific equipment housed in other research facilities.

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 remaining four program years.

New technologies to improve the success of sustainable clean-energy development in Canada
In 2018, GNES researchers embarked on an innovative use of cloud computing, machine learning and augmented intelligence (AI) to advance our geoscience knowledge of Canada's subsurface landmasses. Using scanning electron microscope images from seven shale-core samples, the team trained an application to identify pore spaces, organic matter, and clay minerals on the images. The images were then re-analysed to refine the nanoscale mapping on a pixel-by-pixel basis thus greatly improving the identification of nanoscale pore structures. This improved mapping of shale organic-material content and of porosity and permeability will increase the accuracy of hydrocarbon resource assessment and greatly improve fluid-flow models. Better geoscience knowledge of the resource and its host formations will ultimately lead to higher resource recovery while decreasing extraction costs.

The work has garnered interest from international partners (JOGMEC, KIGAM), industry (e.g. Husky Energy), provincial and territorial surveys (Alberta, Saskatchewan, British Columbia, and Northwest Territories), and academia. New methodologies like this promise to improve accuracy and save hundreds of hours of researcher time, thereby allowing more time to focus on the analysis and interpretation. This methodology can be expanded for use in any basin fluid-flow model and will improve understanding of the thermal maturity evolution in the basin.

This innovative methodology promises to be the first of many uses of cloud computing, machine learning and AI to better understand the petrophysical characteristics of fluid-filled formations.

MARINE CONSERVATION TARGETS

The Marine Conservation Targets (MCT) Program provides estimates of offshore petroleum resource potential to inform decisions related to Canada's target of protecting ten per cent of its offshore land by 2020.

Recent successes include:

Resource Assessment Heat Map
The Marine Conservation Targets (MCT) team mapped areas of high, medium, and low hydrocarbon potential to support federal decision-making. The team developed tools, maps, and reports for decision-makers with varying geoscience backgrounds. Heat maps developed by MCT using new geographic information system (GIS) methodologies clearly portray a region's overall petroleum potential (Figure 3).

The heat maps have been presented favorably to other government departments, non-governmental organizations, First Nations, and community groups. The MCT has assessed broad regions, thereby providing context and planning options, and increasing the value of the GSC work. Completed assessments are publicly available so that GSC products for decision-making are accessible and transparent.

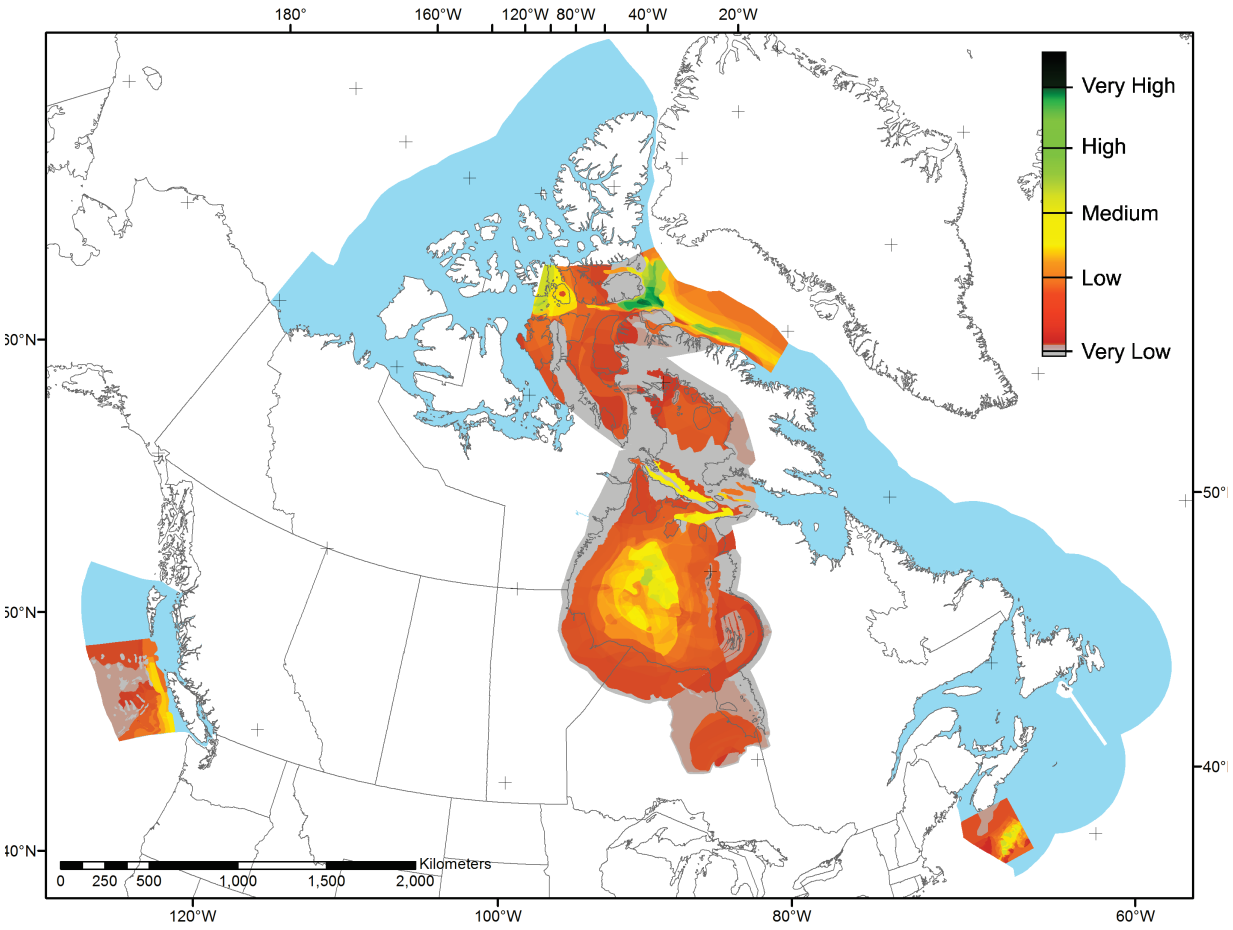


Figure 3. Completed MCT resource assessment report areas to March 2019

MARINE GEOSCIENCE FOR MARINE SPATIAL PLANNING

The Marine Geoscience for Marine Spatial Planning (MGMSP) is developing new maps and analyses of seafloor geology and active seabed processes to inform evidence-based marine spatial planning and regional environmental assessments.

Recent successes include:

Scoping of new program

This new program was scoped with the Department of Fisheries and Oceans (DFO). The GSC will produce three scales of marine geoscience deliverables: bioregional (seabed morphology, geology, and stability), regional (compilations and seabed assessments), and targeted (new geoscience data to inform specific marine spatial-planning objectives) assessments in selected Atlantic and Pacific regions.

ENVIRONMENTAL ASSESSMENTS

The GSC Environmental Assessments (EA) Service supports land-use planning and environmentally sound resource development, both on land and in our coastal and offshore waters. The GSC is the lead agency for evaluating geoscience in environmental impact statements (EIS). In 2018–19 the GSC provided geoscience expertise for 42 EIS reviews. Areas included: mining (23.6%), oil and gas (7.2%), lands and minerals related infrastructure (6.1%), hydroelectric (1.2%), and miscellaneous (5.2%).

STRATEGIC PRIORITY 3: GEOSCIENCE FOR KEEPING CANADA SAFE

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

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

PUBLIC SAFETY GEOSCIENCE

The Public Safety Geoscience (PSG) program focuses on understanding hazards and risks associated with earthquakes, tsunamis, space weather, volcanoes, submarine and terrestrial landslides, and marine geohazards, and working with stakeholders to inform safe resource development, land use planning, conservation efforts, and regulations.

GSC remains committed to keeping Canadians safe. The GSC conducted public safety research on earthquake and landslide hazards that will eventually be incorporated into the next version of the National Building Code. Lands and Minerals Sector has partnered with the Global Earthquake Model Foundation to channel international expertise towards refining Canada's earthquake hazard model and building a new national risk model that will contribute to Public Safety Canada's National Risk Profile.

Recent successes include:

Assessing the Risk of Earthquakes at Regional and National Scales

Responding to the need for modern hazard and risk assessment tools, the PSG Program led an initiative with partners across the government of Canada (including Public Safety Canada, Insurance Bureau of Canada, Defence Research and Development Canada, and the Institute for Catastrophic Loss Reduction) to become a member of the Global Earthquake Model Foundation (GEMF). The partnership contributes to assessment of earthquake risk using modelling tools to support disaster risk reduction (DRR) planning across Canada.

Improving Aviation Operation by Better Forecasting Space Weather

Space weather can affect Global Navigation Satellite Systems and high-frequency radio communications, which are both important for aircraft flying over the pole. Because of this, the International Civil Aviation Organisation has introduced new requirements for aviation operations, which requires better information on space weather events. Lands and Minerals Sector was one of the centres chosen to provide space-weather advisory information (Figure 4). Through their research, LMS scientists have developed tools that are being used to develop forecasts of space weather effects on the Global Navigation Satellite Systems.

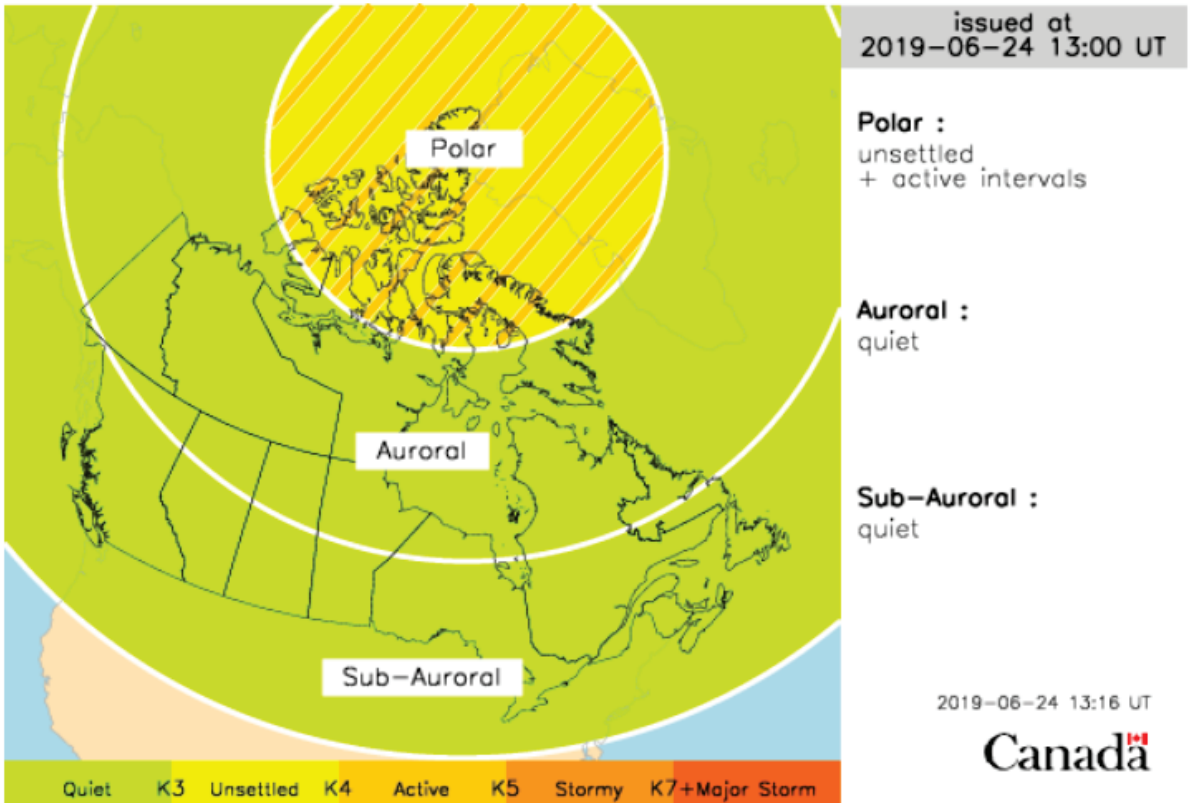


Figure 4. Example of space weather maps provided by the Government of Canada based on GSC data and analyses.

Reconstruction Past Marine Mass Movements to Inform Infrastructure Building On British Columbia North Coast

Tsunamis have swept through Kitimat Arm in 1974 and 1975 damaging the Northlands Navigation dock at Kitimat and the Haisla First Nation docks at Kitamaat Village. Several large infrastructure projects are proposed for the Kitimat Arm coastal area, and some have already been approved, but they might be at risk of impacts from submarine mass movements. Using multidisciplinary techniques, NRCan scientists study the magnitude and frequency of past submarine mass movements in this fjord system to provide information regarding the risk of future events, and the mitigation measures that might reduce this risk. The work has discovered paleo-tsunami evidence, and produced geoscience knowledge such as seabed maps which illustrate hazards, geological history and unique habitats; sub-seabed profiles indicating previous delta failures; geological mapping on land to determine landslide susceptibility; geotechnical testing of the fjord slopes; tsunami modelling; and real-time tracking of seismic activity and seafloor movement. The results of this initiative will provide information useful to communities and other stakeholders to determine hazard potential, particularly with regard to frequency and magnitude of submarine and subaerial landslides, and ensuing tsunamis.

CLIMATE CHANGE GEOSCIENCE PROGRAM

The aim of the Climate Change Geoscience Program (CCGP) is to better understand the geological impacts of climate change in Canada for land-use planning and government regulation to help at-risk communities adapt. Climate Change Geoscience research is providing cutting-edge information in the areas of climate change hazards, mitigation, and resilience. For example, the GSC conducted science and research to help understand the impacts of climate change and climate-change adaptation on aspects such as permafrost, coastal erosion, sea level rise, extreme weather events, and monitoring of Canada's glaciers.

Recent successes include:

Supporting Adaptation in Permafrost Regions Project
Canada's North is rich in largely underexplored and undeveloped natural resources. Sustainable development of these resources could contribute to the North's economy, but infrastructure resilient to permafrost conditions is required. The Supporting Adaptation in Permafrost Regions (SAPR) Project is advancing our knowledge of permafrost. Using a new approach to improve the national permafrost map, better information on ground-ice conditions is available for infrastructure planning, land use, and climate change adaptation. The Permafrost Information Network (PIN), a public portal, is now available to stakeholders for infrastructure and adaptation planning. Newly developed models, methodologies and mapping protocols improve regional landscape-susceptibility modelling. Models shows how Canada's northern landscape (key northern transportation corridors are noteworthy) will respond to climate warming. The SAPR Project research also involves the combining of local knowledge with scientific field-based studies and Earth Observation data to improve the knowledge of permafrost conditions in northern communities. This information sharing means better knowledge products and improved climate-change risk-reduction strategies.

In collaboration with the territorial governments, the work related to the development of protocols for mapping (from Earth Observation data) has been used to advance the understanding of how permafrost-related hazards and landscape instability have influenced decision-making in the maintenance of transportation corridors such as the Inuvik-Tuk Highway and the Dempster Highway in Northwest Territories and Yukon.

Understanding of the Sensitivity of Canada's Coastal Regions to Climate Change
A substantial portion of Canada's population and infrastructure is located along its marine coasts. Knowledge of present and projected coastal sensitivity contributes to better understanding of the impacts of climate change on Canada's coasts. Mitigation Impacts along coasts requires knowledge of projected sea level and coastal sensitivity. Sea-level projections help to predict future flooding and assess risk to infrastructure and populations. NRCan's Canadian Geodetic Survey and CCGP scientists partnered to create a national crustal velocity grid, allowing for the generation of relative sea-level projections for all coastal areas. Now, 485 national and regional maps of projected relative sea-level change, through the 21st century, are available for municipal and provincial planning. Using an innovative statistical technique, derived national-scale coastal sensitivity indices (Figure 5) are part of the recent release of CanCoast 2.0, an online national-scale coastal database. Northern coastlines are among the fastest changing areas in the world. NRCan scientists monitor the environmentally sensitive Beaufort Sea region to gain more knowledge of climate-driven change. Improved knowledge helps decision-makers develop effective adaptation strategies for existing and proposed infrastructure and communities.

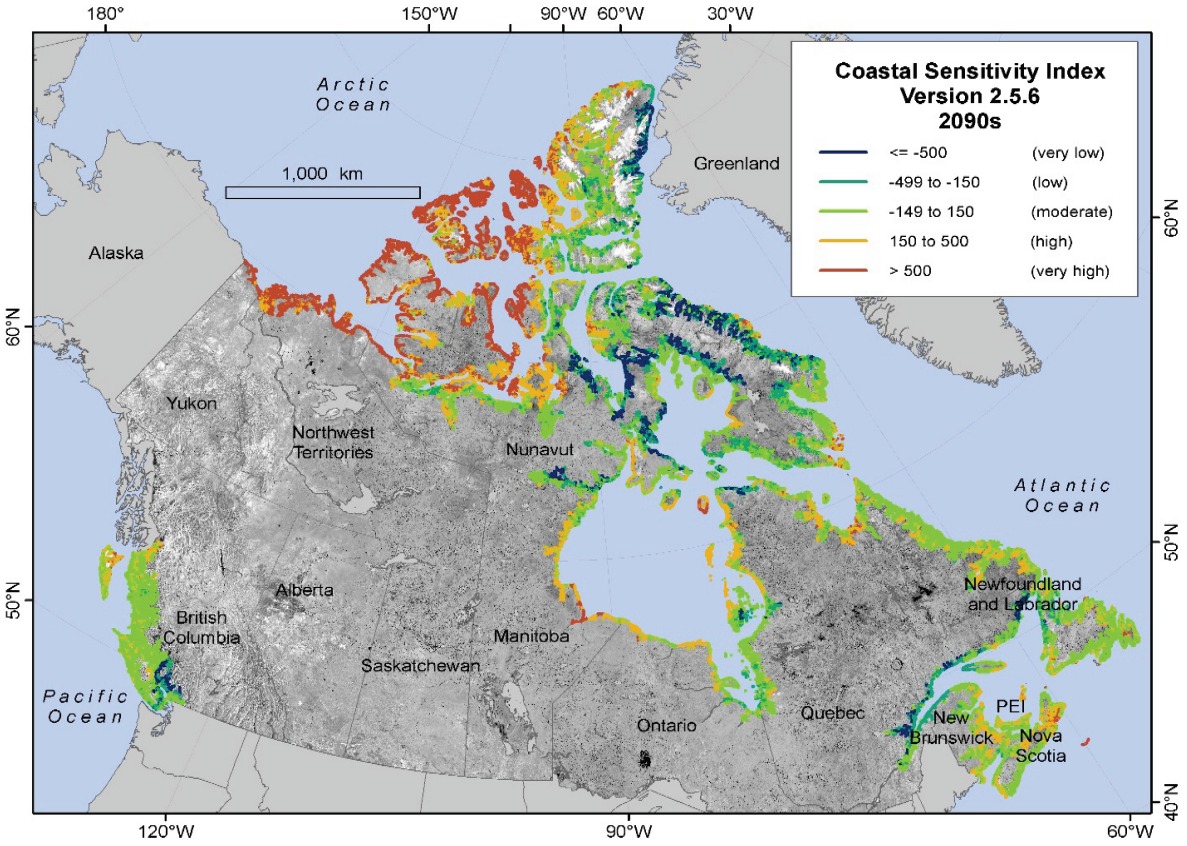


Figure 5. CanCoast 2.0: Coastal sensitivity index map of Canada

Geoscience Supporting the Advancement of Climate Adaptation Using Past Drought History

All Canadian economic sectors are impacted by climate change, including the energy sector. To assess potential climate-change effects on future water regimes, the hydro-power industry is using available data to simulate hydroclimatic variability and estimate future drought risks. Unfortunately, existing climatic data cover a very short time period, making forecasts unreliable. To overcome this lack of data, CCGP researchers use isotopic analysis of old trees to reconstruct the hydrological conditions of the last two centuries. The first isotope-based hydroclimate reconstruction from eastern Labrador was recently published. A second field campaign conducted in northern Manitoba is expected to generate improved hydroclimatic reconstructions. A better understanding of the evolution of these water regimes will be used to forecast potential climate-change effects, with anticipated benefits for the Canadian hydro-power industry.

Measuring Canada's Glaciers to Enhance Understanding of the Causes and Consequences of the Rapidly Changing Northern Environments

As a circumpolar nation, Canada has international commitments to enhance understanding of the causes and consequences of the rapidly changing Arctic environment. Canada has the largest area of glacier ice (~200,000 km^2) after the Greenland and Antarctic ice sheets; ~75% of Canada's glaciers and ice caps are in the Arctic. Monitoring Canada's glaciers is critical to assess global glacier change and to inform decisions on adaptation in the Arctic where change is most rapid. Current research focuses on the development and application of remote-sensing techniques and modelling to assess broad-scale patterns of glacier change. The systematic long-term glacier-change observations reveal Canada's glaciers as the third most important contributor to sea-level rise in the northern hemisphere. A three-year research collaboration with the University of Alberta and the hamlet of Grise Fiord, NU will contribute to

understanding the impact of enhanced glacier melt on Arctic marine ecosystems productivity and health, on which the community relies. Many of the glaciers in this region terminate at tidewater where marine mammals gather, particularly during summer months, suggesting glacier discharge likely stimulates primary productivity in these near-shore ocean environments. Also, a new, first-ever empirical glacier mass-balance model for the Canadian Rockies and Southern Interior Ranges, is a valuable contribution to western Canada water-availability studies.

CCGP Science Contributed to National Climate Change Assessment 2019
Natural Resources Canada scientists at the Geological Survey of Canada are on the frontier of understanding the effects of climate change on Canada's sea levels, permafrost, and glaciers. Their work contributed to the Environment and Climate Change Canada publication, *Canada's Changing Climate Report 2019* (CCCR2019) which provides, for the first time, an overview of how and why Canada's climate is changing and the projections for the future. Climate Change Geoscience Program scientists provided relative sea-level change projections across Canada's coasts, reported on glacial mass balance from field and satellite observations, and gave ground temperatures and the trends in Canada's permafrost regions. The impacts of these changes, such as the expected increase in extreme high water-level events where relative sea level is projected to rise, and the effects on infrastructure where permafrost is warming and thawing, will help inform adaptation decision-making and increase public awareness and understanding of Canada's changing climate.

STRATEGIC PRIORITY 4: GEOSCIENCE FOR SOCIETY

OPEN GEOSCIENCE

Open Geoscience (OG) ensures that federal geoscience data and information are findable, accessible, and reusable. It addresses the how rather than the what of GSC science. An important component of implementing Open Science is to continue to ensure that information systems are in place and maintained to securely generate, store, manage and disseminate GSC data, publications, collections and knowledge. To assist in this, measures are being implemented to modernize publication management and dissemination tools.

Recent successes include:

The next-generation synthesis of Canadian geology
Core geoscience knowledge is critical to overall management of the country's landmass and to decision-making related to natural resource development. Geological Survey of Canada scientists are working with national and international partners to develop the next generation of 3D geological modelling tools and to explore new approaches to data visualization. The results are being integrated into Canada in 3D (C3D), a national surface and subsurface compilation of the geology of Canada to help better understand the geological structures and dynamic processes below ground. C3D is more than a series of maps, however. It includes the latest geological knowledge and provides visualization of/and access to three dimensional data on surficial geology, bedrock geology, and information about the mantle layer. The GSC is working to make C3D publically viewable online and freely and openly available for download. Essentially, C3D is not only creating a synthesis of the geology of Canada, but will also act as an online gateway to it.

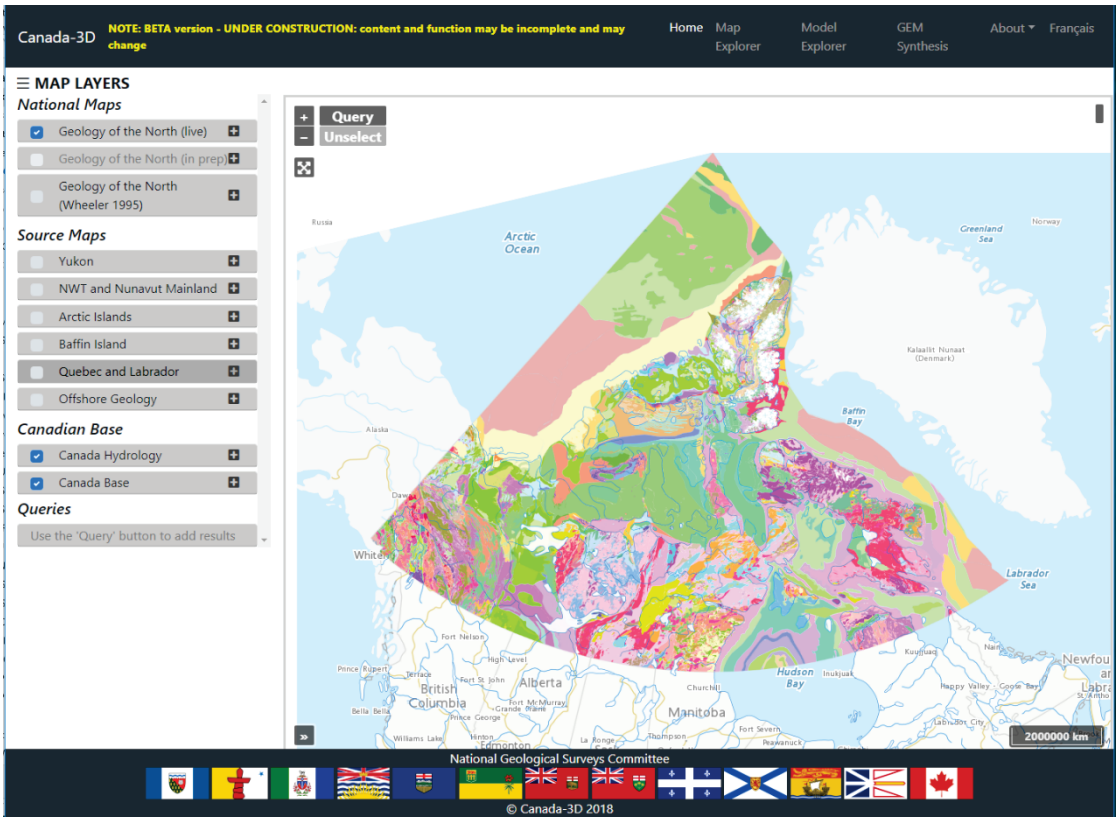


Figure 6: Prototype of the C3D website.

STRATEGIC PRIORITY 5: OUR PEOPLE, OUR SCIENCE

SCIENCE LABORATORY NETWORK

The Science Laboratory Network (SNL) provides innovative lab-based leadership for all GSC programs and increases effectiveness, connectivity, and efficiency in GSC laboratories.

Recent successes include:

Development of analytical techniques to provide insights on the geochemistry of ore-forming fluids

Analyses of fluid inclusions from quartz overgrowths on detrital quartz grains from the Athabasca Basin reveal the presence of uranium concentrations more than two orders of magnitude higher than most naturally occurring geofluids, providing evidence for the role of basinal brines in the formation of the giant Athabasca uranium deposit.

Evaluation of marine geohazards in Pond Inlet, Nunavut

Integration of physical and geotechnical properties of sediment cores in Pond Inlet allow the most complete evaluation of marine geohazards for a Nunavut community to date, providing northern coastal communities with better knowledge for improving public safety.

ANNEXES

ANNEX I: GEOLOGICAL SURVEY OF CANADA REPORTING STRUCTURE OVERVIEW

NATURAL RESOURCES CANADA (NRCAN) DEPARTMENTAL RESULTS FRAMEWORK

NRCan delivers its results through the Departmental Results Framework (DRF) in three core responsibilities: (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 DRF under CR-1 are Canadians have access to leading-edge scientific and technical products on natural resource management that can be used to inform decisions.

Within the DRF, the LMS programs that encompass GSC programs are Geological Knowledge for Canada's Onshore and Offshore Land, Geoscience for Sustainable Development, and Geoscience for Keeping Canada Safe.

For more information: https://www.nrcan.gc.ca/plans-performance-reports/dp/2019-20/21771

2019–20 Departmental Report Highlights
NRCan will complete the Geo-mapping for Energy and Minerals Program, which will continue to advance our geological knowledge of the North. This will contribute to better exploration investment decisions in the Arctic and more informed land-use decisions within northern communities.

NRCan finalized Canada's Arctic Ocean submission to the Commission on the Limits of the Continental Shelf in 2019, which met our legal obligation under the United Nations Convention on the Law of the Sea to define our continental shelf beyond 200 nautical miles. Canada's Arctic Ocean submission proposed outer limits covering an area of over one million km^2, including the North Pole. The outer limits will eventually become Canada's last international boundary, giving Canada sovereignty over the natural resources on the seafloor and in the subsoil.

NRCan's Climate Change Geoscience Program will conduct science and research to help understand the impacts of climate change and climate-change adaptation on aspects such as permafrost, coastal erosion, sea level rise, extreme weather events and monitoring of Canada's glaciers.

NATURAL RESOURCES CANADA'S LANDS AND MINERAL SECTOR'S PERFORMANCE INFORMATION PROFILES

NRCan has 11 sectors/offices which include the Lands & Minerals Sector (LMS). LMS has seven branches including the GSC. Aligned with the DRF Programs, LMS has 11 Performance Information Profiles (PIPs) and associated PIP Programs. The PIPs are a management tool for program officials to organize and co-ordinate performance information relevant to their program. The PIPs are evergreen documents that 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 LMS PIPs. At the LMS program level, GSC science programs report under the following three LMS PIP programs:

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

1. GEOLOGICAL KNOWLEDGE FOR CANADA'S ONSHORE AND OFFSHORE LAND

Through this program, NRCan produces geoscientific data and knowledge to map the regional geological context of Canada's onshore and offshore lands (*see* logic model in Figure 6). 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.

2. GEOSCIENCE FOR SUSTAINABLE DEVELOPMENT OF NATURAL RESOURCES

This program creates new geoscience knowledge that supports sustainable development of Canada's land, mineral, energy, and water resources (*see* logic model in Figure 7). 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 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.

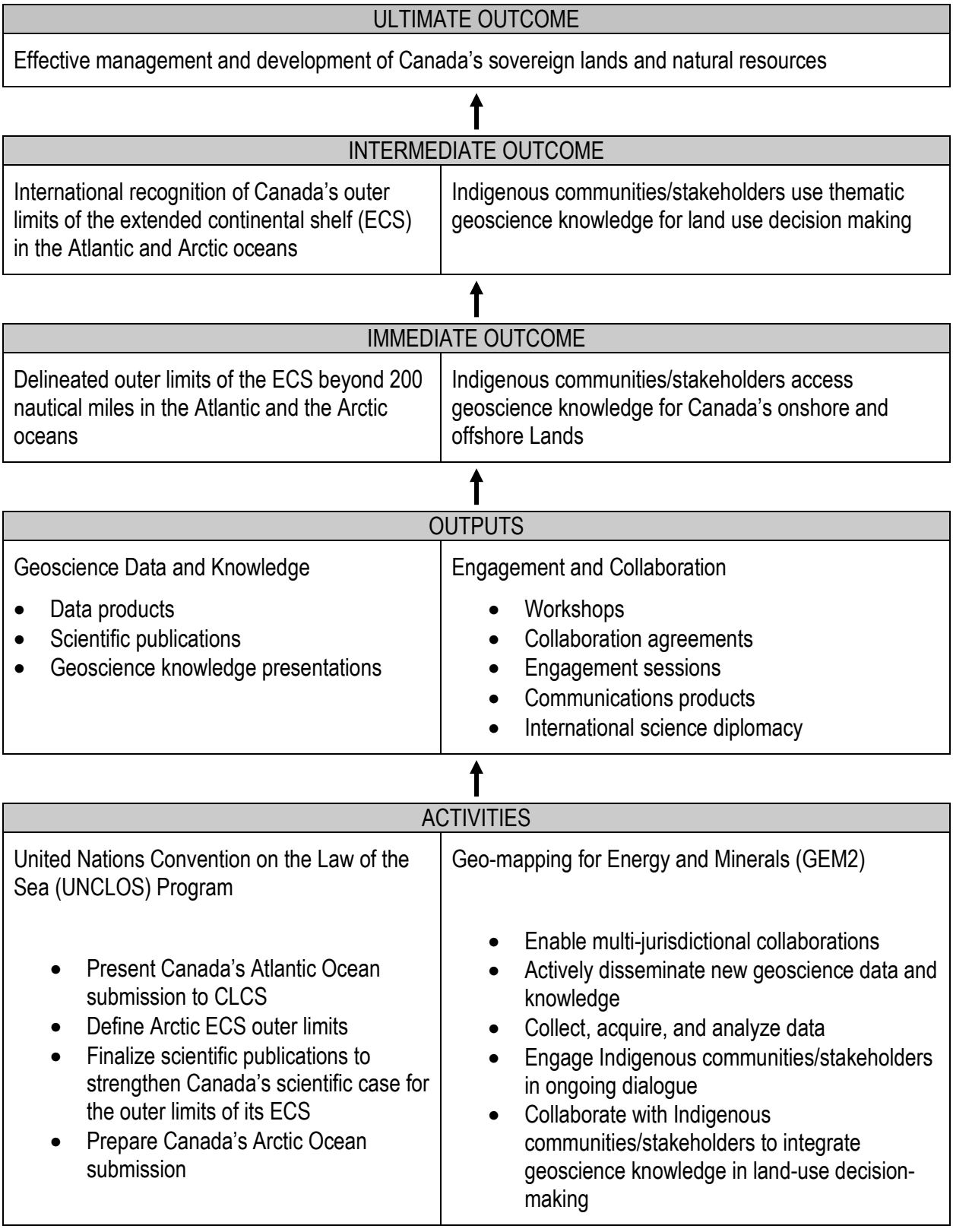


Figure 7. Logic model for the geological knowledge of Canada's onshore and offshore land Performance Information Profile

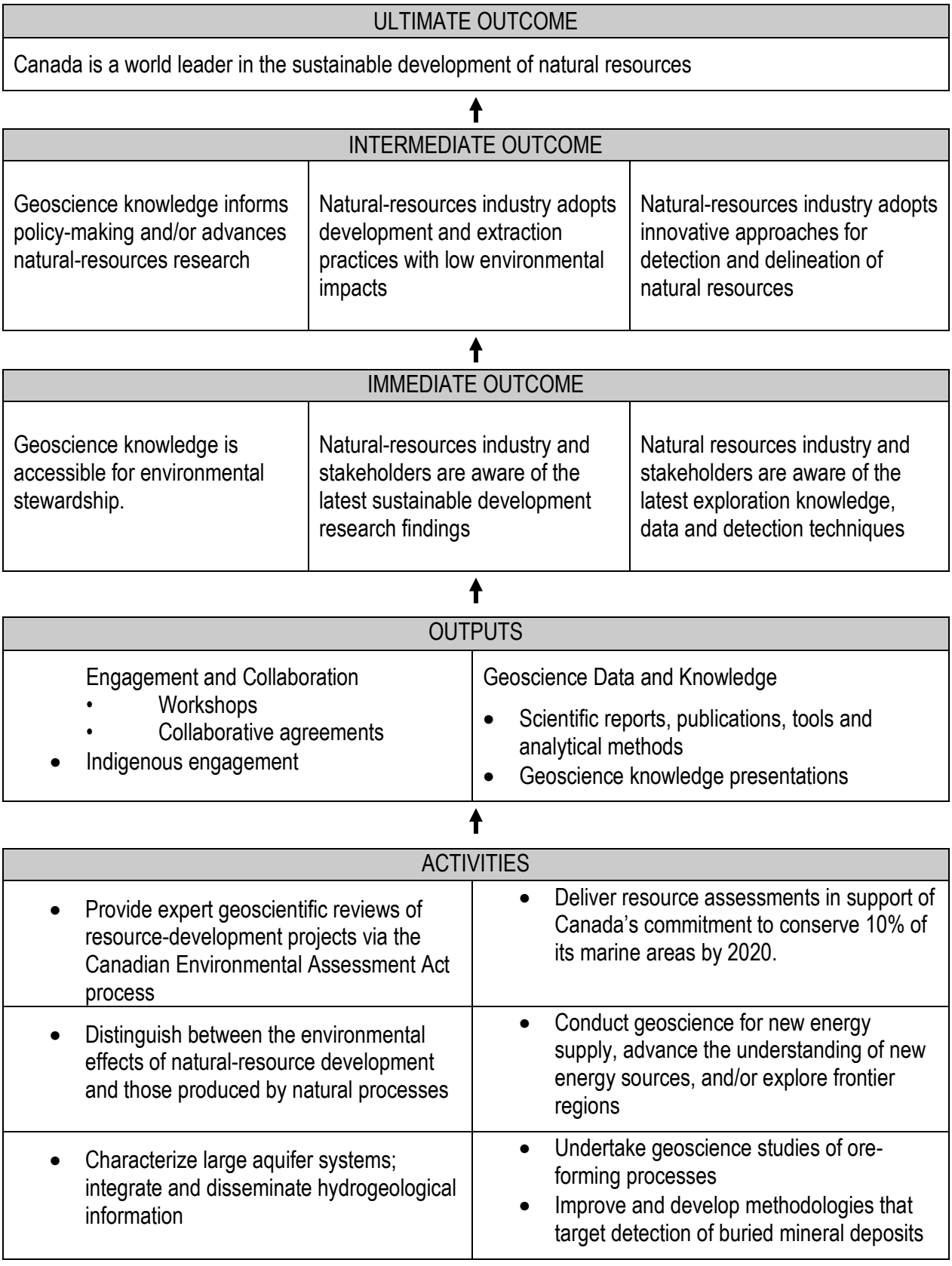


Figure 8. Logic model used for the Geoscience for Sustainable Development of Natural Resources' Performance Information Profile

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* logic model in Figure 8). 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, geoscience information is used by these stakeholders to minimize the risks that climate change poses to communities and infrastructure in vulnerable areas.

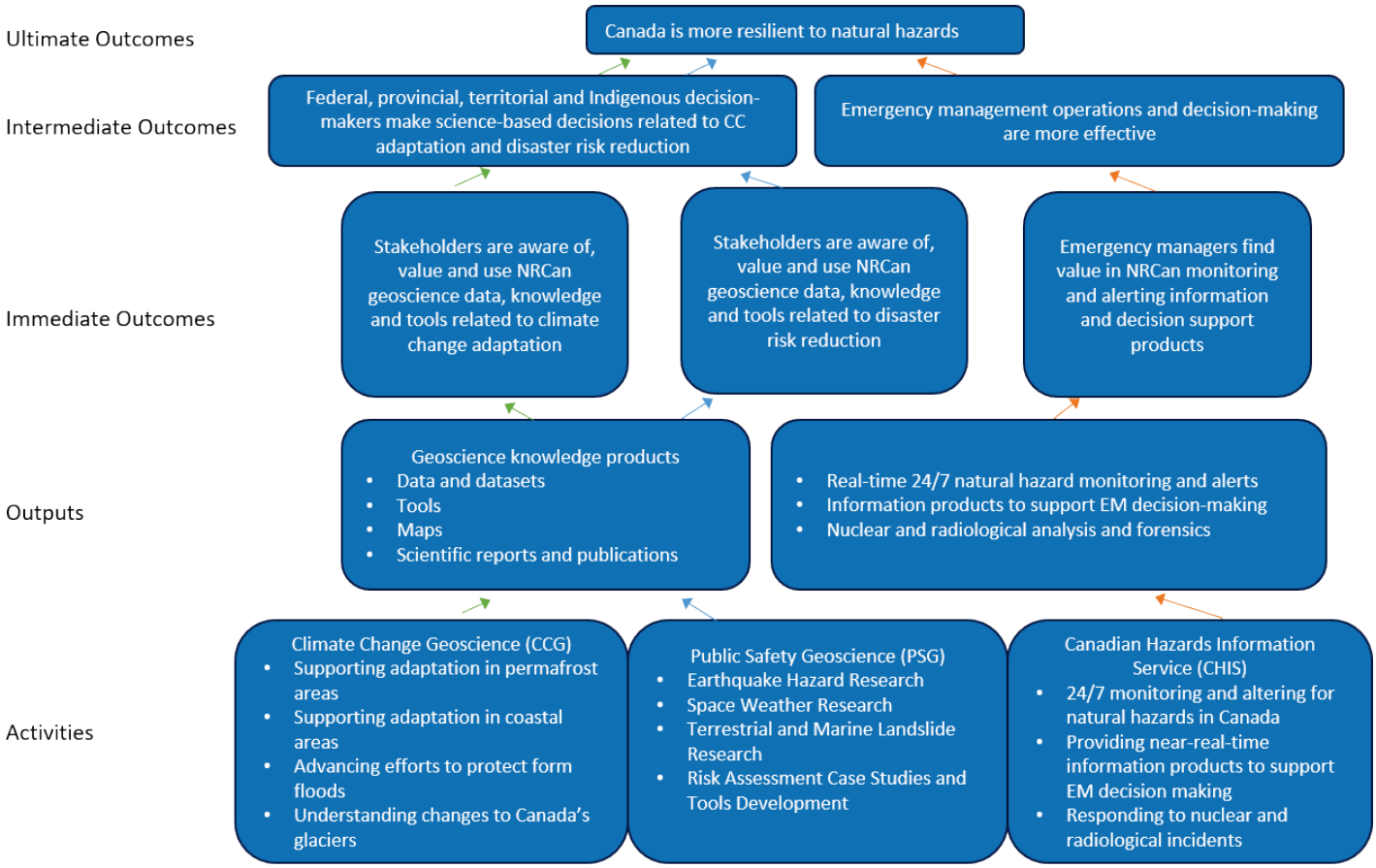


Figure 9. Logic model used for the Geoscience for Keeping Canada Safe

GSC STRATEGIC PRIORITIES

The GSC provides Canada with a comprehensive geoscience knowledge base contributing to economic development, public safety, and environmental protection by acquiring, interpreting, and disseminating geoscience information concerning Canada's landmass, including the offshore. Through its programs and activities, the GSC engages with Indigenous communities, incorporates traditional knowledge with western science, and supports decision-making by communities.

To guide its programs and activities, the GSC's Strategic Plan identifies the key priorities for 2018 to 2023 and related goals to support their implementation (Table 4). Priorities one to three outline the key scientific contributions to Natural Resources Canada's strategic priorities by producing new geoscience knowledge and are aligned with DRF and LMS PIP priorities. Priorities four and five describe organizational and business objectives to sustain capacity and foster a healthy work environment that is required to conduct efficient, effective, and relevant work. Table 5 presents the directors and program manager associated with each item.

Table 4. Geological Survey of Canada 2018-2019 Strategic Priority goals

Strategic Priority	Strategic Priority (SP) goals
Strategic Priority 1: Geological knowledge for Canada's Onshore and Offshore Land	SP-1-1: When the GEM-2 program ends in 2020, we will publish new knowledge of Canada's geology in frontier areas of Arctic onshore and offshore land. The knowledge will supply critical information to decision-makers to ensure that future management of lands and resources in the North is guided by scientific evidence.
	SP-1-2: Through our contribution to the completion of Canada's UNCLOS submission for the Arctic in 2019, we will have completed the delineation of the outer limits of Canada's extended continental shelf, thus fostering international recognition of Canada's last frontier.
	SP-1-3: We will implement new programs, including a program to respond to the Arctic Policy Framework, as well as tools and methods to discover, model, visualize, and interpret the 3-D geology of Canada's lands. In both onshore and offshore domains, we will integrate traditional mapping of the land surface and seabed with geophysical-survey and observatory data from below ground. This work will help us to develop 3-D models of Canada's geological framework and a deeper understanding of Earth processes.
Strategic Priority 2: Geoscience for Sustainable Development	SP-2-1: We will develop new mineral deposit models through research on how geological processes in ore-generating systems evolve through time. We will also support technological innovation within the exploration industry, with the combined aim of stimulating the discovery of new subsurface deposits.
	SP-2-2: We will advance research to combine knowledge of groundwater aquifers and their links with surface water systems to build integrated models of water systems for sound, comprehensive water management by the provinces and territories.
	SP-2-3: We will continue to deliver authoritative geoscience, including research on cumulative effects, to support land-use planning and environmentally sound resource development, both on land and in our coastal and offshore waters.
	SP-2-4: To facilitate development of low-carbon energy sources, we will support the fledgling geothermal industry and other renewable energy industries to assess resource potential, enhance energy recoverability, and support environmental assessments.
	SP-2-5: We will develop methodology to better characterize shale-hosted resources and transfer knowledge to industry, regulators, and other stakeholders.
Strategic Priority 3: Geoscience for Keeping Canada Safe	SP-3-1: We will develop advanced hazard models for earthquakes, tsunamis, landslides, and space weather to support regular updates of building codes and emergency planning.
	SP-3-2: We will assess the impacts of climate change on the water cycle, permafrost, and coastal erosion and inundation to enable planning of resilient communities and infrastructure.
	SP-3-3: We will continue to work with the Canadian Hazard Information Service and Ocean Networks Canada to build an earthquake early-warning system for southern British Columbia.
	SP-3-4: We will integrate our geoscience with socioeconomic analysis and engineering data to provide a comprehensive understanding of risk from natural hazards and climate change to critical infrastructure and urban centres.
	SP-3-5: We will focus on transferring this knowledge of hazards and risk to a wide range of stakeholders, including the provinces and territories, professional associations, and the insurance industry, to support actions that will decrease Canada's exposure to natural disaster and climate change.

Strategic Priority	Strategic Priority (SP) goals
Strategic Priority 4: Geoscience for Society	SP-4-1: We will establish a governance structure to manage geoscience information through best practices and processes based on recognized standards. Through this approach, we will document, store and manage the GSC's data. We will ensure that we have a robust and modern data infrastructure that will ensure sustainability and will work effectively with external tools such as the Federal Geospatial Platform and the open data initiative. The infrastructure will also facilitate the discovery and dissemination of our data.
	SP-4-2: In the spirit of Canada's open science initiative, we will establish a modern publication process that incorporates open science principles and is responsive to client needs. We will work with provincial and territorial surveys to synthesize Canada's geoscience knowledge and data and develop open and dynamic web portals to share geoscientific information.
	SP-4-3: We will develop an approach to land-use planning that is informed by geoscience by initiating dialogue and building relationships with federal, provincial, and territorial counterparts, Indigenous groups, and non-governmental professional organizations. Through pilot projects, we will build a methodological framework for providing accessible multidisciplinary geoscience to inform land-use planning.
	SP-4-4: We will build on past engagement to facilitate and guide our relationships with Indigenous communities based on recognition of traditional knowledge, respect, and co-operation. Based on needs identified by Indigenous communities, we will put special emphasis on working with several of those communities to co-develop prototype projects by using traditional and geoscientific knowledge for land-use planning, management, and decision-making. With provinces, territories, universities, and professional associations, we will investigate ways to build geoscience capacity within Indigenous communities to enhance incorporating geoscience knowledge into land-management decision-making by communities.
Strategic Priority 5: Our People, Our Science	SP-5-1: We will proactively support and develop a resilient, high-performing and diverse workforce skilled in emerging and traditional areas of geoscience research by encouraging cutting-edge skill sets and continuous learning. We will modernize our workforce and acknowledge the continued efforts of our staff to advance public geoscience in Canada.
	SP-5-2: We will foster a modern work environment that balances sound scientific infrastructure and a healthy workplace; offers world-class laboratories, collections, and facilities; and provides opportunities for employees to contribute meaningfully to the development of Canada.
	SP-5-3: We will lead and advance the geoscience research agenda in Canada and internationally by advancing a scientific research agenda that demonstrates scientific and technical leadership, challenges paradigms, and makes a difference to Canadian society.
	SP-5-4: We will serve as the hub of geoscience research in Canada through collaboration with other federal departments, other levels of government, universities, the private sector and international research institutes.

GSC 2018-19 SCIENCE PROGRAMS/SERVICES, PROJECTS AND ACTIVITIES

Table 5. Directory of the GSC 2018-2019 Science Programs/Services, Projects and Activities

Strategic Priority Board	GSC Program / Service & Program Manager	Projects & Project Leader	Activities & Activity Leader
SP-1	Geo-mapping for Energy and Minerals Michel Plouffe	Baffin Natalie Shea	Mary River, North Baffin Natalie Shea
			Mapping of Onshore Cretaceous Stratigraphies Natalie Shea/Jim Haggart
			Baffin Region Synthesis Nikole Bingham-Koslowski
		Cordillera Steve Irwin	Crustal Structure of Southeast Yukon Jim Ryan
			Stikinia Bedrock Alex Zagoreski
			Yukon Tectonic Evolution — Late Mesozoic to Tertiary Dawn Kellett
		Hudson-Ungava Daniel Wright	Saglek Block — Canada–Greenland Connection and Metallogeny David Corrigan
			Geophysics — MT Southampton and Kaskattama Highlands Jim Craven
		Mackenzie Carl Ozyer	Coppermine River Transect Rob Rainbird/Tom Skulski
			Mackenzie–Selwyn Geo-Transect Robert McNaughton/Karen Fallas
			Southern Mackenzie Surficial Mapping Roger Paulen/Rob Smith
			North Bear Surficial Mapping Dan Kerr/Brendan O'Neil
		Rae Genevieve Marquis (Lorne McKee, acting)	Rae—Glacial Synthesis Isabelle McMartin
			Boothia–Somerset Mary Sanborn-Barrie
		Western Arctic Carl Ozyer	Tertiary onshore–Smoking Hills Rob Smith/Jennifer Galloway
			Richardson Mountains Thomas Hadlari

Strategic Priority Board	GSC Program / Service & Program Manager	Projects & Project Leader	Activities & Activity Leader
SP-1	United Nations Convention on the Law of the Sea (UNCLOS) Program Mary-Lynn Dickson (Director)	Atlantic Ocean submission Mary-Lynn Dickson	Geomorphology David Mosher/Kai Boggild
			Seismic reflection John Shimeld
			Seismic refraction Ruth Jackson
			Potential fields and geological samples Gordon Oakey
			Geological samples (Alpha Ridge) Marie-Claude Williamson
			Geochronology Dawn Kellett
			GIS and Database Management Walta-Anne Rainey
			Geomorphology David Mosher/Kai Boggild
SP-2	Environmental Assessments Danny Wright		
	Environmental Geoscience Program Gilles Cotteret (Éric Boisvert in acting role)	Metal Mining Mike Parsons	Critical Metals Alexandre Desbarats
			Northern Baselines Jennifer Galloway
			EGP legacy work synthesis Mike Parsons
		Carbon Capture and Storage Don White	
		Shale Gas: Induced Seismicity Project Honn Kao	
		Shale Gas: Assessing Groundwater Vulnerability to Deep Industrial Activities Christine Rivard	
		Sources of Contaminants Near the Oil Sands Martine Savard	Waterborne contaminants Martine Savard
			Airborne contaminants Martine Savard

Strategic Priority Board	GSC Program / Service & Program Manager	Projects & Project Leader	Activities & Activity Leader
SP-2	Environmental Geoscience Program Gilles Cotteret (Éric Boisvert in acting role)	Dredge Disposal at Sea Gwyn Lintern	
		Special Projects	Fluid Storage and Circulation in Carbonates Denis Lavoie
			Mercury in the Environment Peter Outridge
	Groundwater Geoscience Yves Michaud	Southern Ontario Project Hazen Russel	
		Groundwater Information Network Boyan Brodaric National Aquifer and Groundwater Accounting Alfonso Rivera Groundwater Information Network Boyan Brodaric National Aquifer and Groundwater Accounting Alfonso Rivera	
	Targeted Geoscience Initiative Geneviève Marquis	Gold Patrick Mercier-Langevin	System Controls on Gold Through Space And Time (Source to Trap) Patrick Mercier
			Tectonic Influences on Gold (Tectonic Drivers and Conduits) Patrick Mercier
		Nickel-Copper-Platinum Group Elements Systems Wouter Bleeker	System-Scale and Deposit-Scale Controls on Nickel-Copper-Platinum Group Elements Mineralization in Cratonic Areas and Their Margins Wouter Bleeker
			Magmatic Architecture of Cr-bearing Ore Systems Wouter Bleeker
		Porphyry-Style Mineral Systems Neil Rogers	Arc-related Porphyry Mineralization in Space and Time Neil Rogers
			Mineral Markers of Porphyry Processes Neil Rogers
			Post-orogenic porphyry systems in space and time Neil Rogers

Strategic Priority Board	GSC Program / Service & Program Manager	Projects & Project Leader	Activities & Activity Leader
SP-2	Targeted Geoscience Initiative Geneviève Marquis	Uranium-Rich Ore Systems Eric Potter	Uranium Fluid Pathways Eric Potter
			Uranium-Rich Deep Metasomatic Processes Eric Potter
		Volcanic- and sedimentary-hosted base metal mineralization (SEDEX-VMS) Jan Peter	Seafloor Ore Deposition through Space and Time Jan Peter
			Base Metal Sources and Mineralizing Processes Jan Peter
	Geoscience for New Energy Supply Edward Little	Clean Transitional Energy Resources Edward Little	Tight Gas Development Andy Mort
			Frontier Oil and Gas Omid H. Ardakani, Zhuoheng Chen, Keith Dewing
			Decreasing Environmental Risks to Tight Gas Development Zhuoheng Chen, Dennis Jiang, Pavel Kabanov, Andy Mort, Yin
		Geothermal Energy Edward Little	Regional Geothermal Resource Evaluation Steve Grasby
			Reducing Exploration Risk for Geothermal Resources: Garibaldi Volcanic Belt Steve Grasby
			Regional Geothermal Resource Evaluation
			Reducing Exploration Risk for Geothermal Resources: Garibaldi Volcanic Belt Anovitz, Chen, Steve Grasby, Yin
		Innovation and Renewable Energy Edward Little	Nano-Pore and Pore Fluids – Implications for Tight Formations Zhuoheng Chen
		Interactions between Nano-Pores and Pore Fluids: Improvements in Environmental Performance in Tight Reservoirs (NG and CO_2)	Machine Learning Application Zhuoheng Chen
			Lab Method Development Lawrence M. Anovitz, Dru Heagle, Stanislav R. Stoyanov
			Modeling Stanislav R. Stoyanov
			Case Studies Zhuoheng Chen, Dru Heagle

Strategic Priority Board	GSC Program / Service & Program Manager	Projects & Project Leader	Activities & Activity Leader
SP-2	Geoscience for New Energy Supply Edward Little	Novel Geochemical Method Development and Applications to Sustainable Energy Resource Advancement D. Jiang	
	Marine Conservation Targets Gary Sonnichsen		
	Marine Geoscience for Marine Spatial Planning Gary Sonnichsen		
SP-3	Climate Change Geoscience Program Réjean Couture	Supporting Adaptation in Permafrost Regions Sharon Smith	Improving the Canadian Permafrost Map Sharon Smith
			Transportation Resilience in the Arctic Informed by Landscape Systems Peter Morse
		Supporting Adaptation in Coastal Regions Thomas James	Sea-level Projections for Canada Nicky Hastings and Tom James
			Coastal Dynamics Dustin Whalen
			CanCoast Indices — Validation, Refinement, and Application of Coastal Sensitivity and Vulnerability Indices Gavin Manson
		Extreme Events: Advancing Climate Adaptation through Improved Drought Indices and Flood Forecasting Christian Bégin	Flood Forecasting for Hudson Bay Lowlands Hazen Russell
			Improving Drought Risk Assessment Associated with Climate Change for the Hydro-power Industry of Central and Eastern Canada Christian Bégin
	Public Safety Geoscience Adrienne Jones	Earthquake Geohazards Adrienne Jones	Earthquake Geohazards John Cassidy
			Intraplate Earthquakes Heather Crow
			Plate Boundary Earthquakes Joe Henton
		Landslides and Marine Geohazards Adrienne Jones	Landslides and Marine Geohazards Andrée Blais-Stevens
			Baffin Bay Celina Campbell

Strategic Priority Board	GSC Program / Service & Program Manager	Projects & Project Leader	Activities & Activity Leader
SP-3	Public Safety Geoscience Adrienne Jones	Landslides and Marine Geohazards Adrienne Jones	Beaufort Sea Ned King
			Terrestrial Landslides David Huntley
			Arctic Channels Robbie Bennet
		Space Weather Hazards Adrienne Jones	Space Weather Hazards David Boteler
			Ground Effects David Boteler
			Ionospheric Effects Robin Fiori
			Satellite Effects Larisa Trichtchenko
			Forecast Development Ljubomir Nikolic
		National-Scale Geohazard Risk Assessment Adrienne Jones	Risk Assessment Nicky Hastings
			National-Scale Geohazard Risk Assessment Murray Journeay
			Interactive Web Application — ER2 Risk Tool Michel Parent
SP-4	Open Geoscience Nicole Couture	Open Geoscience Governance Nicole Couture	
		Information Management (IT) Geneviève Marquis	
		Information Management (IM) Kathryn Coyle	
		Collections Véronique Séguin	
		Open Access and Public Engagement Kathryn Coyle	
		Geoscience Synthesis and Integration (Canada in 3D) Boyan Brodaric	

Strategic Priority Board	GSC Program / Service & Program Manager	Projects & Project Leader	Activities & Activity Leader
SP-5	Science Laboratory Service Vicki McNicoll	Inorganic Geochemistry Research Lab Group Paul Gammon	Environmental and Surficial Lab Facility Paul Gammon, Isabelle Girard, Pierre Pelchat, John Serkerka
			Analytical Chemistry Lab Facility Raymond Chung, Isabelle Girard, Simon Jackson, Pierre Pelchat, Duane Petts, Zhaoping Yang
			Marine Geochemistry Lab Michael Parsons and Lori Campbell
			Labo-CGQ INRS Kathleen Lauzière
		Paleontology Lab Group Manuel Bringué Jennifer Galloway	Palynology Lab Esther Asselin, Lori Campbell, Jennifer Galloway, Rob Fensome, Leanne Tingley, Graham Williams
			Conodont Lab Mike Orchard, Hillary Taylor, Leanne Tingley
			Micropaleontology Lab Leanne Tingley
			Macrofossil Lab Facility Owen Brown , Jim Haggart, Jenna Higgins
		Mineralogy and Physical Properties Group Jeanne Percival	Marine Core and Sedimentology Lab Facility Alexandre Normandeau
			Sedimentology Lab Facility Carrie Bolton, Alain Grenier, Shauna Madore, Claudia Moore, Miriam Wygergangs
			Mineralogy Lab Facility Igor Bilot, Jeanne Percival, Jacques Pinard, Katherine Venance
			Paleomagnetism & Petrophysics Lab Facility Randy Enkin
		Isotope Geochemistry and Geochronology Group Bill Davis	Isotopic Geochemistry & Geochronology Lab Facility Ron Christie, Raymond Chung, Bill Davis, Nancy Joyce, Dawn Kellett, Carole Lafontaine, Vicki McNicoll, Julie Peressini, Tom Pestaj, Nicole Rayner
			Delta Lab (Stable Isotope) Facility Jason Ahad, Jade Bergeron, Marc Luzincourt, Joelle Marion, Martine Savard, Anna Smirnoff
		Organic Geochemistry and Petrology Group Dennis Jiang	Organic Geochemistry Lab Facility Dale Issler, Dennis Jiang, Marina Milovic, Andy Mort, Julito Reyes, Rachel Robinson

ANNEX II: GSC PROGRAM SUMMARIES

This section presents a high-level summary of each of the 13 programs and services of the GSC, their logic models, and highlights of their activities in the 2018–2019 year.

Land and Minerals Sector
Geological Survey of Canada

Who are we?

The Geological Survey of Canada's (GSC) is part of the Land and Minerals Sector and its mission is to develop **geoscience knowledge and data** to support decisions about the **responsible development of natural resources** and the **safety of Canadians**.

We study Canada's vast onshore and offshore lands to improve scientific understanding of the dynamic processes that shape the world around us, from mountaintop to seafloor.

Mandate: "make a full and scientific examination and survey of the geological structure and mineralogy of Canada"

As Canada's longest-standing scientific organization, we've "read the rocks" and know what's under our feet and beneath our ocean floor. We bring this foundational knowledge to our partnerships with experts in other disciplines to tackle some of Canada's 21st-century challenges, including searching for deeply hidden resources, better understanding climate change and its impacts, and studying the effects of natural resources development on

- 400 staff in seven centres across Canada
- >30 specialized science laboratories

Read the full strategic plan at https://doi.org/10.4095/313405

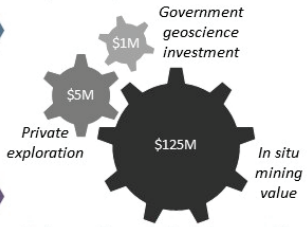
Cooperating across Canada

Since 1996, the *Intergovernmental Geoscience Accord* provides a framework for cooperation and collaboration among the federal, provincial and territorial geological surveys.

GSC science supports:

- **Canada's economy**

Public geoscience increases private mineral exploration activity by reducing the costs and risks of private exploration.



- **Science-based decision-making**

Public geoscience reduces the environmental risks of resource development, informs environmental assessments and supports international negotiations.

- **Informed development of standards**

Public geoscience informs national building and transportation infrastructure codes in areas at high risk of geohazards.

Natural Resources Canada: Departmental Results Framework

A-base budget 2015-2020: $250M

Geological Knowledge of Canada's Onshore and Offshore Land
C-base budget 2015-2020: $124M

Geo-Mapping for Energy and Minerals (GEM)
- Launched in 2008, this addresses the insufficient geological understanding of Canada's north.
- Produces geological knowledge for the benefit of the minerals and energy exploration sectors, residents of the North and their institutions, as well as provincial and territorial jurisdictions with resource management responsibilities.

United Nations Convention on the Law of the Sea (UNCLOS)
- Maps the continental shelf beyond 200 nautical miles as an obligation of the Government of Canada to the United Nations Convention on the Law of the Sea.

Geoscience for Sustainable Development
C-base budget 2015-2020: $32M

Targeted Geoscience Initiative (TGI)
- Provides the mineral exploration industry with new ore system models and innovative methodologies to enhance effectiveness of deep exploration for Canada's key economic minerals.
- Reduces some of the risks of mineral exploration and supports Canadian mining dependent communities.

Environmental Geoscience and Environment Assessments (EGP, EA)
- Establishes natural environment baseline.
- Develops methodologies to understand and distinguish anthropic impacts from natural processes.
- Reviews for the federal Environmental Assessment process and for proposed protected areas.

Groundwater Geoscience (GGP)
- Characterizes aquifers to understand groundwater distribution, quantity and flow dynamics.
- 3D data integration and information dissemination.

Marine Conservation Targets (MCT)
- Assesses petroleum resources for offshore Canada as part of Canada's target of protecting 10% of Canada's offshore by 2020.

Geoscience for New Energy Supply (GNES)
- Supports strategies to transition to low-carbon economy with clean energy R&D
- Furthers energy geoscience to promote the use of non-emitting energy resources.

Marine Geoscience for Marine Spatial Planning (MGMSP)
- Provides maps and analyses of seafloor geology and conditions for integrated environmental assessments.

Geoscience for Keeping Canada Safe
C-base budget 2015-2020: $13M

Public Safety Geoscience (PSG)
- Studies hazards and risks associated with earthquakes, tsunamis, space weather, submarine and terrestrial landslides, and marine geohazards.
- Works with stakeholders to inform safe resource development, land use planning, conservation efforts, and regulations.

Climate Change Geoscience (CCG)
- Provides geoscience expertise for land-based and coastal infrastructure in the North in collaboration with federal, territorial, provincial, Indigenous, and academic partners to reduce risks arising from climate change.
- Studies permafrost, coastal erosion, sea-levels changes and other climate change risk and supports adaptation in at-risks region

Horizontal networks

Science Lab Network Increasing effectiveness, connectivity, and efficiency in GSC labs

Open Geoscience Ensuring that federal geoscience data and information are findable, accessible, and reusable. Visit geoscan.nrcan.gc.ca

Geoscience is an important policy instrument to help governments meet their objectives.

Looking to the future

Geoscience Renewal | Terra Canada | Emergency Management Strategy

Geo-Mapping for Energy and Minerals (GEM)

GSC STRATEGIC PRIORITY 1: GEOLOGICAL KNOWLEDGE OF CANADA'S ONSHORE AND OFFSHORE LANDS

Why? Collaborative initiative (2008-2020) that provides the public, including the natural resources industry, with modern geoscience knowledge needed to promote exploration and long-term economic development for vast and untapped resources of Canada's North.




Region	Objective	Highlights & Successes
Cordillera	The Cordilleran region has a substantial mineral endowment. It hosts a multitude of mineral deposits (gold, copper, lead, and zinc). New geoscience knowledge in this area will drive the discovery of new mineral deposits and help increase known resources.	**A New Klondike Gold Rush** • Collaborative research between GEM and the United States Geological Survey (USGS) found a historically important gold bearing geological unit (Klondike-like) in western Yukon extends into eastern Alaska. Recognizing the new extents of this unit will be of interest to companies exploring for sources of placer gold at the international level. **Stikinia Bedrock** • GEM research indicates that previous interpretations of faults and terrane boundary relationships require significant reassessment. Proper recognition and understanding of these relationships can help identify new areas with resource potential for minerals that are known to occur in the region, such as copper and gold. **Additional Gold Potential in British Columbia** • Two companies, Grey Rock Resources and Brixton Metals Corporation, cite a joint BCGS-GEM report that recognizes a new potential bedrock source for placer gold in Atlin, British Columbia. Subsequently, visible gold found by Grey Rock initiated a staking rush over 120,000 hectares of land in the area. Brixton Metals now reports there is additional exploration potential in their 979 km^2 wholly owned Atlin Gold Project, where this bedrock source is situated. **Pioneering new fault direct-dating technique** • In collaboration with Portsmouth University, UK, GEM is conducting one of the first studies to use a new technique dating calcites found on fault surfaces. A better understanding of this geological information can help locate new areas with resource potential for minerals, known to occur in the region such as copper and gold.
Mackenzie	A lack of geologic knowledge has been a significant detriment to the economic development across the Mackenzie region. Taken the proven oil and gas potential of the region to the next level and discovering new economic mineral resources require improvements in our understanding of the stratigraphic and structural relationships across	**Permafrost In the NWT** • Surficial mapping in the Great Slave Region and glacial sediment mapping in thaw-sensitive terrain, identified extremely useful information for land-use planning, infrastructure and resource development. • The Northwest Territory Department of Transport used GEM surficial geological data to help plan the route of the Tlicho All-Season Road, an estimated $150 million project. In turn it might create mining opportunities, such as the $600 million dollar NICO mine targeting gold, copper, bismuth and cobalt, still in planning stage. **Copper Potential in the Mackenzie** • Fieldwork identified two geological units previously unknown in the region, potentially extending areas with known copper mineralization potential. This work will complete the first regional effort to place the region into a modern framework and allow Northerners and industry to responsibly develop mineral resources to maximize their socio-economic benefits. **Defining the Darnley Bay Anomaly** • GEM research helped to define the nature, size and depth of the Darnley Bay anomaly – the largest gravity and magnetic anomaly in North America, potentially expanding the resource considerations for nickel, copper and platinum group, as claimed by Darnley Bay Resources Ltd. (now, Pine Point Mining). This work supported their decision to extend their exploration permits in the region until 2023.

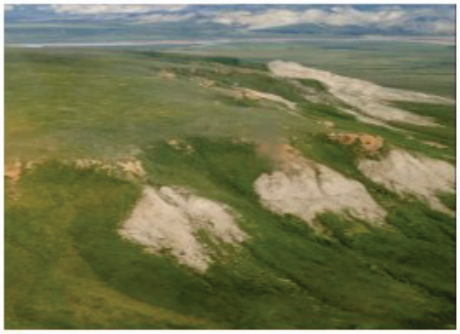
Geo-Mapping for Energy and Minerals (GEM)

GSC STRATEGIC PRIORITY 1: GEOLOGICAL KNOWLEDGE OF CANADA'S ONSHORE AND OFFSHORE LANDS

Region	Objective	Highlights & Successes
Rae	The Rae region is a large, remote, part of the Canadian Shield, west of Hudson Bay, with a complex geological history. It hosts several mines and numerous nickel, uranium and diamond prospects. While perceived to have additional mineral potential, geological knowledge is lacking presenting significant exploration challenges. GEM work aims to better understand the geology and glaciation patterns of the Rae region and how it can enhance mineral exploration.	**Glacial Synthesis** • The integration of large volumes of ground-based and remote surface geology and age dating helped piece together the glacial history of the region, providing new knowledge essential for geochemical and heavy mineral surveys. **Integrated Geoscience along the Northwest Passage** • GEM discovered unique differences underlying the Boothia Peninsula indicating that mineral exploration strategies used in other Rae areas are likely inappropriate for Boothia Peninsula. • This research provided relevant data and knowledge for this isolated region of Nunavut regarding resources assessment and economic development opportunities associated with potentially dramatic increases in shipping due to climate change impacts. **Mineral Potential of the Chantrey-Thelon Area** • Fieldwork identified three main areas with economic potential in three different geological domains: newly recognized copper-nickel-platinum group elements and massive sulphide (copper-zinc-gold-silver) resource potential. **Mapping in the Tehery Region** • Multiple kimberlite (diamond) indicator minerals were found in glacial sediments south of Meen Lake, north-west of Hudson Bay, indicating a clear diamond potential. • Working with the University of New Brunswick, researchers developed a more accurate classification method for remote mapping of surficial materials, helping to improve the geological assessment of the region at lower costs. **Finding Traces of Space** • GEM research facilitated a rare discovery: the presence of impact spherules in fieldwork samples, an indication of a meteorite strike. The composition of the spherules suggest they originate from an exoplanet – a planet outside of the Solar System – and constitute the first recognized interstellar impactor.
Baffin	This region covers the offshore and onshore areas around Baffin Island. The goal is to complete comprehensive geological framework mapping of these of the North that have the highest resource potential.	**Onshore Mapping** • Four new stratigraphic sections depicting how rock layers are deposited, including succession and age, were measured on Bylot Island., Northern Baffin Island. Common stratigraphic succession allow identification of regional and local unconformities, and help sequence a stratigraphic framework for the offshore succession. **Baffin Bay Petroleum Systems** • A GEM study provided a good understanding of the geological history and plate tectonic evolution of the sedimentary basins and the factors that control the petroleum resource potential in the area. **Filling Knowledge Gaps** • Southern Baffin Island represent some of the last major missing tectonic pieces in our understanding of Nunavut geology. Targeted bedrock mapping was conducted to resolve this uncertainty.

Geo-Mapping for Energy and Minerals (GEM)

GSC STRATEGIC PRIORITY 1: GEOLOGICAL KNOWLEDGE OF CANADA'S ONSHORE AND OFFSHORE LANDS



Region	Objective	Highlights & Successes
Western Arctic	Covering the Western Canadian Arctic Archipelago, research in this region uses data acquired by GEM, the United Nations Convention on the Law of the Sea (UNCLOS) and industry seismic surveys. Integration of recent Arctic mapping projects will improve the understanding of bedrock geology and geological history.	**Smoking Hills** • GEM work is helping clarify the bedrock units within the Smoking Hills, information that is necessary for correlation to other GEM Arctic Margins study areas, including the offshore Canada Basin. Fieldwork determined that earlier mapping was incorrect. Observations now help resolving questions about kimberlite (diamond) indicator mineral studies on Banks and Victoria Islands, and are critical to supporting the continued success of regional mineral exploration. • Fieldwork along Horton River was able to identify 'smoking' bocannes at numerous sites, providing a characterization of them, and discovered naturally occurring hyper-acidic waters down to a pH of -1.44, stronger than sulphuric acid. **Richardson Mountains** • Scientists recognized a different rock formation, in the Richardson Mountains, providing an unknown link between Arctic Alaska to Canada's Sverdrup Basin. • Identification of an outcrop in the White Mountains uplift, shows a clearly different geological formation than the rest of the Richardson Mountains. Researchers can now determined fault mechanisms to explain how it was uplifted.
Hudson Ungava	The Hudson Bay region represents a large, poorly known part of Canada from both energy and mineral potential perspectives. New mapping and geochemical studies will better resolve petroleum potentials within the basin.	**Saglek Block** • An airborne high-resolution geophysical survey was completed and together with aeromagnetic maps provide nearly seamless coverage from the Labrador Trough to the Labrador coast. Early results indicate a substantial expansion of potential gold-hosting rocks, as well as prospective areas for rare-earth deposits. • These new findings will provide an improved body of information for better assessing the geological framework and mineral potential of the area. **Southampton Island** • A magnetotelluric survey was completed to map the extent of hydrothermal dolomites, an important factor contributing to the petroleum prospectively within the Hudson Basin. **Gold Potential in Northern Labrador** • Research in the Ungava peninsula unearthed potential gold deposits, ushering in new investment opportunities. Previously, exploration in Labrador was focused on iron, nickel or uranium, and this new information helps direct gold and additional nickel exploration. • In 2018, four companies conducted exploration activities in the Ungava Peninsula.

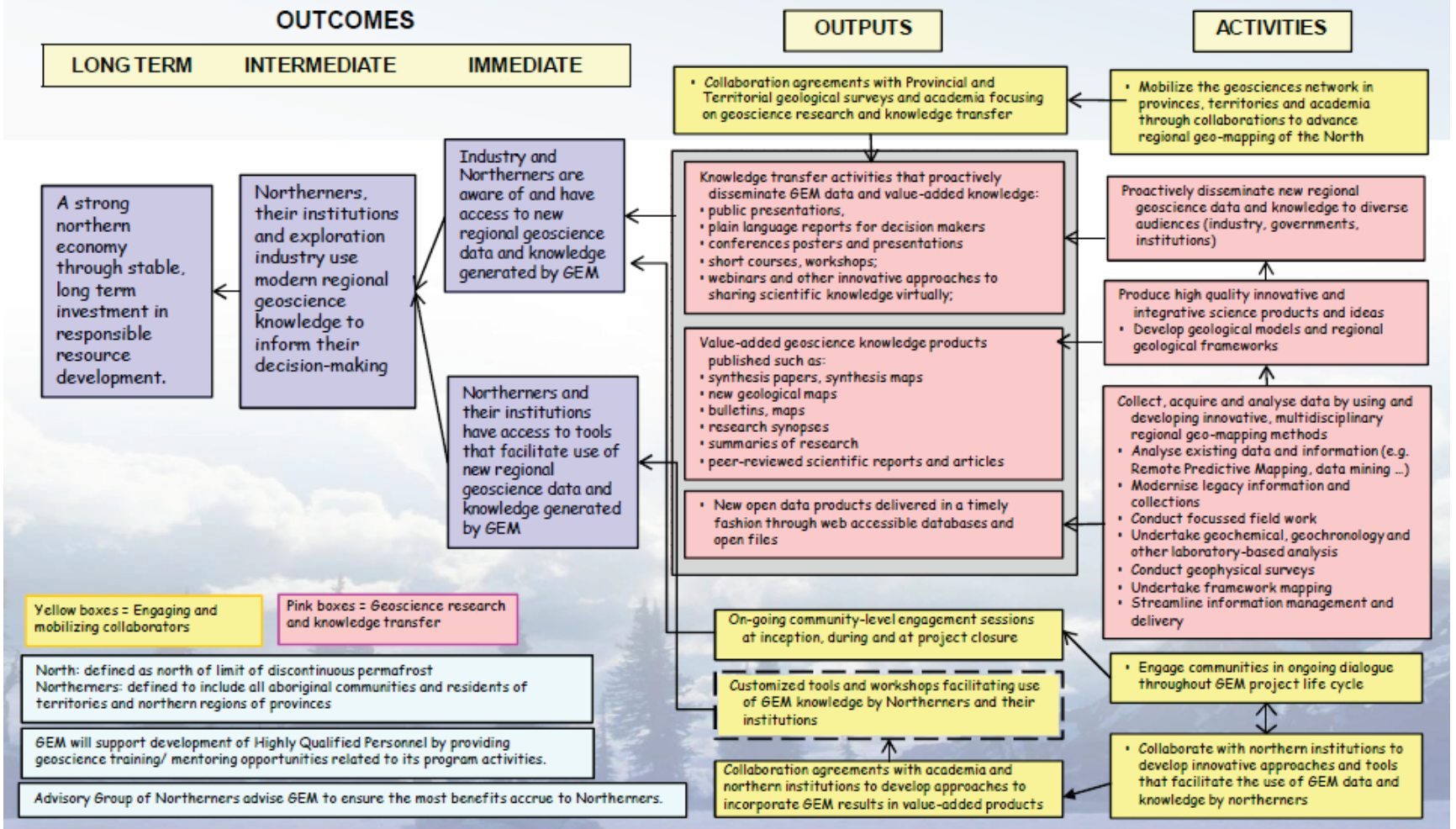
Geo-Mapping for Energy and Minerals (GEM)

GSC STRATEGIC PRIORITY 1: GEOLOGICAL KNOWLEDGE OF CANADA'S ONSHORE AND OFFSHORE LANDS

Region	Objective	Highlights & Successes
Collaboration with Communities	One component of the GEM program is to provide geological knowledge to residents of the North and their institutions, as well as provincial/territorial jurisdictions with land-use and resource management responsibilities. GEM is expanding its community engagement activities in recognition of the need to engage Northerners and their institutions at all stages of GEM activities.	**Advisory Group of Northerners** • GEM established an Advisory Group of Northerners, representatives from territorial governments, the private sector and Indigenous socio-economic organizations to provide advice on approaches that can be implemented to successfully deliver geoscience knowledge to Northerners. • GEM has conducted 7 annual meetings to date across the North to solicit feedback and ideas to benefit the delivery of geoscience knowledge to northern communities. **Engagement with Communities** • Since 2013, GEM scientists and engagement officers have conducted 62 trips, visiting a total of 41 communities and holding over 100 meetings/events with representative organizations, hunters and trappers committees, community corporations, public meetings, and other public events. **Community Research-Sharing** • With the completion of GEM research, scientists and engagement officers have been touring communities to present research results, so landholders have relevant information about inform decision making about land-use. • Through dialogue and information sharing, GEM research sharing sessions have been helping building positive relationships with communities. An on-going responsibility of the program and critical for continued successful geoscientific initiatives in the North. **Geoscience Field School** • GEM held a geoscience field school in the community of Toloyoak, Nunavut in 2016. More than 160 community members of all ages took part in the geological field school, occurring over five days. • The field school presented a unique opportunity for residents to learn more about the geological features of their land, and it expanded on local and traditional knowledge. • The geoscience lessons were broken down into teachable blocks, covering topics such as rocks and minerals, ancient ice sheets, geophysics, geocaching with GPS, and mapping with GIS software. **Grants & Contributions** • Collaborating and funding regional organizations through grants and contributions to integrate geological knowledge to traditional knowledge in the creation of tools, like maps, that help clarify mining and energy development probability to allow inform land and resource development decisions. • In 2018, over $840,000 dollars were provided to northern organizations and academia through grant distributions. Since 2013, up to $4,640,000 were provided.

Geo-Mapping for Energy & Minerals (GEM)

Government Issue: Helping the North realize its full economic and social potential by improving regional geological mapping for responsible resource exploration and development



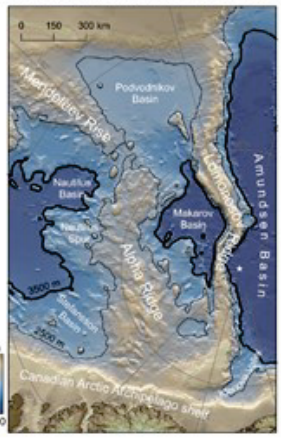
Natural Resources Canada | Ressources naturelles Canada

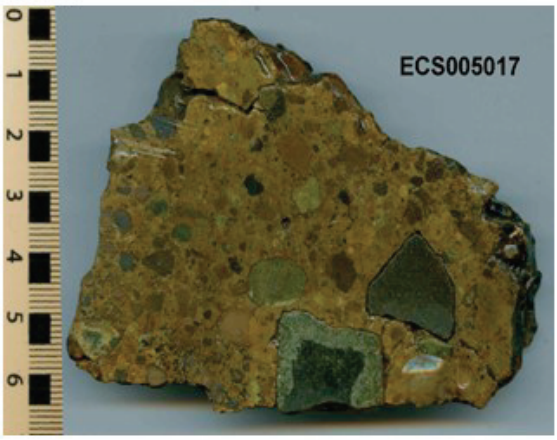
Canada

GSC STRATEGIC PRIORITY 1: GEOLOGICAL KNOWLEDGE OF CANADA'S ONSHORE AND OFFSHORE LAND

United Nations Convention on the Law of the Sea

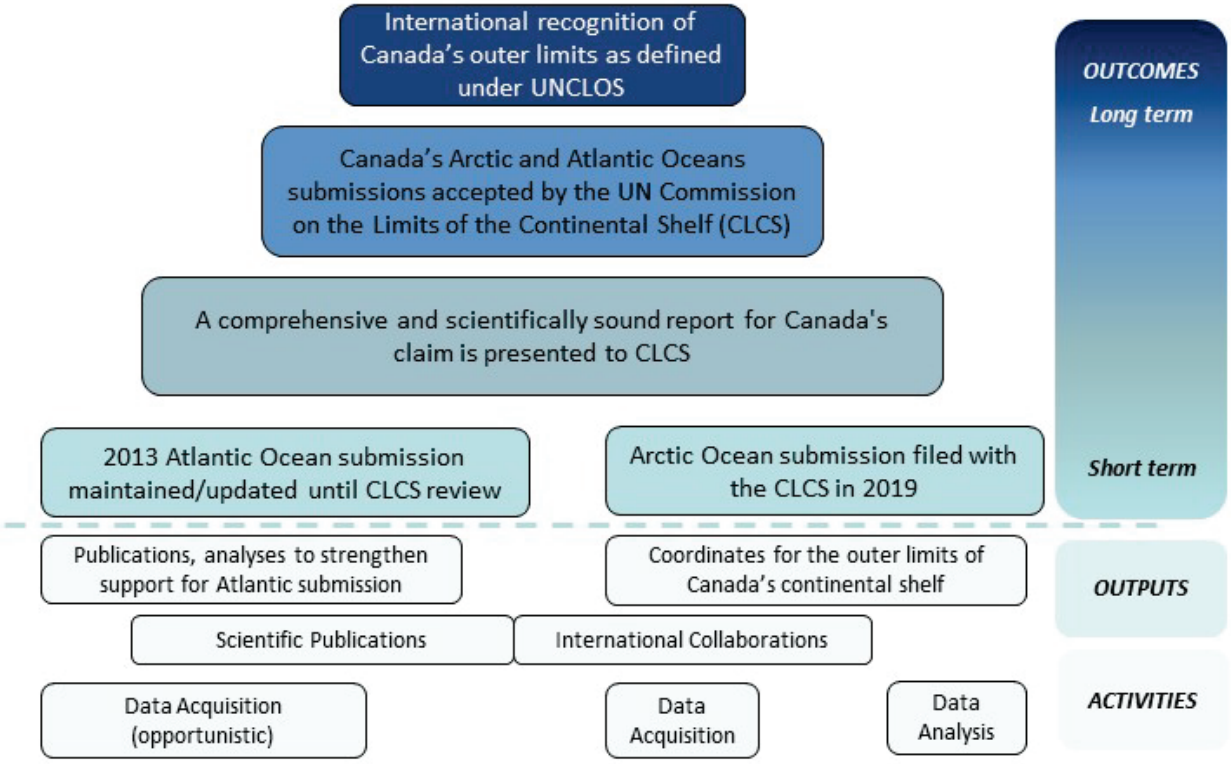
Why? To map the continental shelf beyond 200 nautical miles as an obligation of the Government of Canada to the United Nations Convention on the Law of the Sea.





Project	Success Stories
Canada's Arctic Ocean submission	• The continental shelf is precisely defined by 877 coordinates from Canada Basin to Amundsen Basin, including the geographic North Pole, which encompasses an area of 1.2 million square kilometers beyond the Canada's exclusive economic zone. • A total of 20 documents representing: -2100 pages -870 figures/maps -10 large format (A0) maps -13 large format regional seismic profiles -1 Executive Summary in English and French (publicly available)
Data collection	• 18,709 km of multi-channel seismic reflection data. • 773 recordings of seismic wide-angle reflection and refraction. • 90,000 km single and multi-beam bathymetric, subbottom profiler and shipborne gravimeter data. • 800,000 km² of aero-gravity and aero-magnetic data. • More than 800 kg of geological samples dredged from 6 sites. • Piston cores acquired at three sites
Scientific results	• The Central Arctic Plateau (Lomonosov Ridge, Alpha Ridge, Mendeleev Rise) is an interconnected submarine elevation with continental origins that is composed of thickened crust (20-30 km thick). • The development of Alpha Ridge has been shaped in large part by plume-related events in the High Arctic Large Igneous Province (HALIP) that can be traced back to the Canadian Arctic islands. • On the North American side, the Central Arctic Plateau is morphologically continuous with the landmass of Canada across the narrow geological shelf north of Ellesmere Island. • Conclusions: -The Central Arctic Plateau is an interconnected submarine elevation with demonstrated continental affinities. It has geomorphological and geological continuity with the Canadian continental margin and landmass. -Canada regards all elements of the continental margin as being in geological continuity. As a result, the application of both the distance and depth constraints of UNCLOS Article 76 have been invoked to delineate the outer limits of Canada's continental shelf.

UNITED NATIONS CONVENTION ON THE LAW OF THE SEA (UNCLOS) PROGRAM (2019-2024)

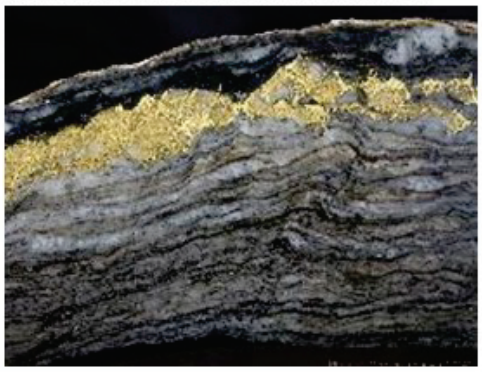


GSC STRATEGIC PRIORITY 2: GEOSCIENCE FOR SUSTAINABLE DEVELOPMENT

Targeted Geoscience Initiative Program

Why? To provide the mineral exploration industry with new ore system models and innovative methodologies to enhance effectiveness of deep exploration for Canada's key economic minerals and to reduce some of the risks of mineral exploration and support Canadian mining-dependent communities.





Objective	Goals	Success Stories
Modelling Ore Systems at depth	Better understand the processes underlying and the development of five ore systems in Canada to inform mineral exploration and increase the economic sustainability of current mines. This ore systems are: • Gold • Nickel-Copper-Platinum Group Element (PGE) deposits • Porphyry • Uranium • Volcanic- and sedimentary-hosted base metal	• Identification of new distribution pattern of gold (controlled by discrete faults cross-cutting the folds, rather than the fold pattern itself) is redefining search criteria in the Banded Iron Formation (BIF) host rocks. • New field observations and age calculations carried out on volcanic sedimentary hosted hyper-enriched black shale deposits located in Yukon have re-defined the accepted exploration model these deposits in Canada and abroad.
Developing the new generation of highly qualified personnel	Participate in the training and mentoring of students to increase the number of Highly Qualified Personnel (HQP) available to the mineral industry	• 45 students and 9 post-doctoral fellows were trained to lead the future search for mineral deposits in Canada and worldwide. • Structural mapping and geochronology work by MSc and PhD students redefined the distribution pattern of gold from the Banded Iron Formation host rocks which improves the search criteria used to find new deposits.
Developing transferable models	Integrate multi-scale scientific knowledge of sources of metals and the pathways they take to become an ore deposit in a way that is transferable across locations and that can be used by industry to innovate their exploration approaches	• Co-development between multi-sectorial partners of a new style of uranium ore genesis that is distinct from the standard model present elsewhere in the Athabasca. • Co-created public geoscience knowledge has resulted in the expansion of Canada's newest gold-mining district of the Meliadine, Meadowbank, and Amaruq deposits in the Kivalliq District of Nunavut.

Targeted Geoscience Initiative (Phase 5) Logic Model

Source-to-ore geoscience for effective exploration

Issue	NRCan SO 1 – Canada's natural resource sectors are globally competitive PA 1.3 – Investment in natural resource sectors		
Ultimate Outcomes	**Economic prosperity and job opportunities improve** in mineral producing regions of Canada through increased discovery and development of mineral resources	**Global competiveness** of Canada's exploration industry is enhanced through decreased costs and risks of mineral discovery.	
Long-term outcomes *(2020 and beyond)*	New knowledge, methodologies and models enhance the exploration industry's ability to detect buried ore deposits.	Integrated, multi-scale scientific knowledge of source-to-ore formation that is both authoritative and accessible results in industry innovating exploration approaches.	A replenished pool of highly qualified personnel equipped with state-of-the-art knowledge, is available for employment in the mineral exploration industry.
Intermediate Outcomes *(by 2019)*	Innovative methodological approaches for detection and delineation of ore deposits begin to be adopted by industry.	Exploration industry starts to apply new public geoscience knowledge to explore for Canada's major mineral deposit types.	
Immediate Outcomes *(by 2017)*	Mineral exploration industry can efficiently discover recent and emerging public geoscience knowledge and methodologies relevant to discovery of new mineral resources	Collaborative geoscience research groups, that engage students, are formed to leverage expertise and capacity to effectively solve research questions about genesis of ore systems.	

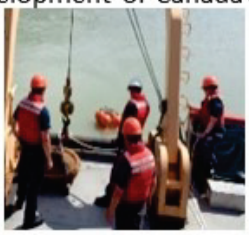
Source-to-ore geoscience for effective exploration

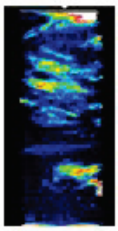
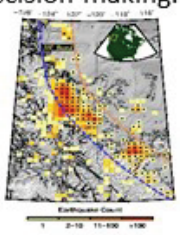
Ultimate Outcomes	**Economic prosperity and job opportunities improve** in mineral producing regions of Canada through increased discovery and development of mineral resources	**Global competiveness** of Canada's exploration industry is enhanced through decreased costs and risks of mineral discovery.	
Outputs	Results of proof-of-concept testing of methodology *- Publicly available results from field tests of innovative methodologies that target markers of ore forming processes.* *-Innovative geochemical, geophysical and mineralogical indicators that target buried ore environments*	Open Public Geoscience Knowledge Products *- Expedited scientific publications that make available data sets and preliminary interpretations relevant to mineral exploration.* *- New authoritative syntheses of leading-edge knowledge of Canada's economically important mineral systems.* *- Presentations at workshops, field and short courses, seminars and online publications, targeted to stakeholder needs.*	Student theses, projects, reports and databases that address geoscience questions related to ore deposits.
Activities	Develop methodologies targeted to measureable markers of ore system processes (New and Improved Methodologies) *- Improve and develop methodologies that target detection of buried mineral deposits* *- Carry out proof-of-concept testing.*	Carry out public geoscience research on ore system processes (New Geoscience Knowledge) *- Collaborate on geoscientific studies with industry, academia (including students) and Provincial-Territorial Geological Surveys.* *- Compile existing and collect new data, scientifically analyze, interpret and synthesize data into new ore system knowledge* *- Develop new geological models and identify measureable markers of ore deposit formation*	
	Disseminate public geoscience (Open Geoscience) *- Develop expedited, publicly-accessible, national framework for discovery of data and knowledge pertinent to mineral exploration* *- Produce and provide to industry the latest scientific knowledge of ore systems and their genesis* *- Develop and test new methodological approaches for detection and delineation of buried ore deposits.* *- Train new student HQP in innovative approaches to ore systems geoscience*		

GSC STRATEGIC PRIORITY 2: GEOSCIENCE FOR SUSTAINABLE DEVELOPMENT

Environmental Geoscience Program

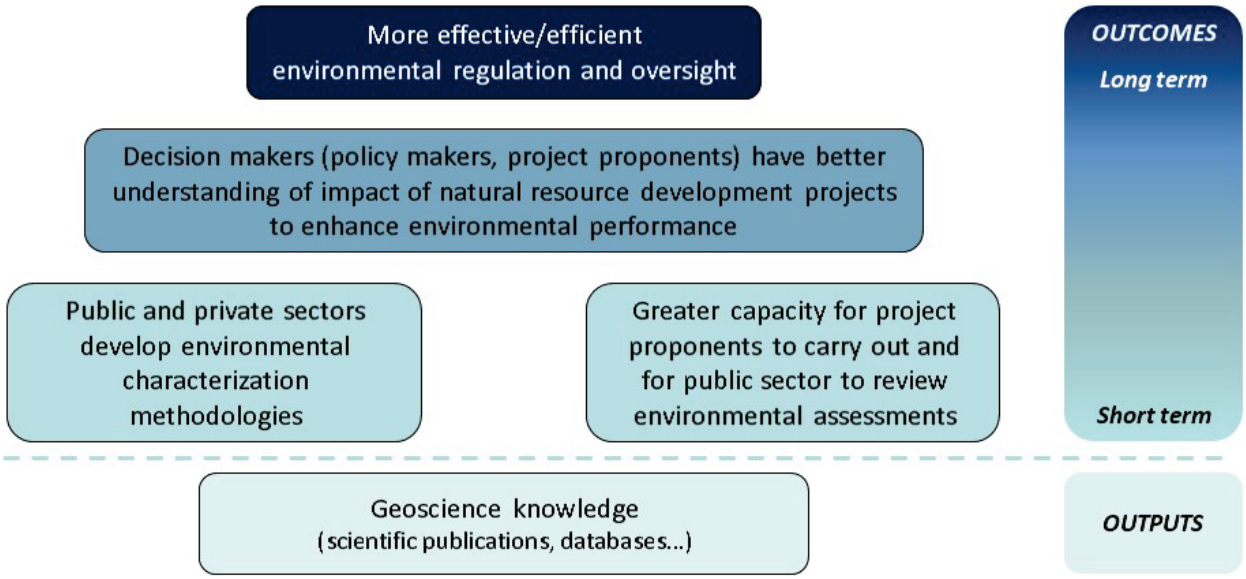
Why? To distinguish between the environmental effects of natural resource development and those produced by natural processes, and to develop new approaches in geoscience to support the sustainable use and development of Canada's natural resources through informed decision making.

Project	Project Goal	Success Stories
Metal Mining	Provide baseline geochemistry data and knowledge of key geochemical processes that control the environmental signature of gold and critical metal deposits across Canada.	• Research on gold mines in the subarctic has produced a new conceptual model on the role of climate change and organic matter in the biogeochemical cycling of arsenic in northern lakes. • GSC data and knowledge on pit lake water quality, tailings seepage chemistry and radioactive slag leachate chemistry have been shared with Ministère de l'Énergie et des Ressources naturelles and are informing the development of their site remediation plans for the St. Lawrence Columbium Mine.
Carbon Storage	To develop, test, and calibrate methods for monitoring of geological storage of carbon.	• 4 years of seismic monitoring in SE Saskatchewan demonstrating that the appropriate site selection and injection procedures for CO2 storage can reduce injection-related seismicity.
Shale gas	To assess of impact of hydraulic fracturation on regional seismicity and groundwater in shallow aquifers.	• Western Canada research concludes that the geological deformation rate is an important controlling factor for the occurrence of induced earthquakes. But if frequent occurrence of induced earthquakes persists over time, it could lead to a reduction of natural earthquake occurrence in the long term. In the east, no connection were found between fracturation and seismicity. • A holistic approach provided no evidence of the presence of large-scale connections between gas reservoirs and shallow aquifers.
Oil Sands (Source)	Geochemical developments for the identification of contaminant sources in water and air.	• In water, dual isotope approach allows for quantification of oil sands process-affected water (OSPW) from tailings ponds. • Tree-ring Nitrogen isotopes suggest that local soil conditions and specific microbial communities control the response of trees to emissions from mining operations.
Fluid Storage	Apply conventional reservoir characterization to low temperature geothermal play type.	• Novel application of CT-Scan analyses shows strong correlation with conventional porosimetry and opens new possibility in 3D imaging and continuous metric scale porosity measurement.
Dredge	Assessing sediment dispersion at dredge disposal sites in the Pacific Ocean.	• Novel technique determined that Five Finger Disposal site (Central Salish) is Non Dispersive.
Mercury	Help produce 2018 Global Mercury Assessment for UNEP.	• GSC leading authorship of 2 geochemistry chapters of Global Mercury Assessment for the United Nations Environment Programme.

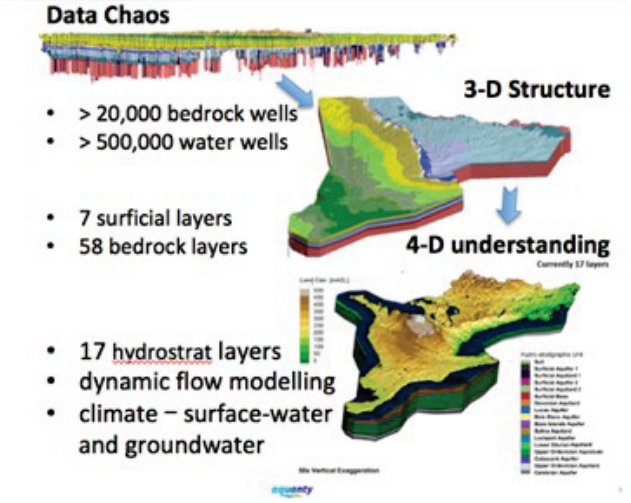
ENVIRONMENTAL GEOSCIENCE PROGRAM LOGIC MODEL (2014-2019)
Responsible natural resource development

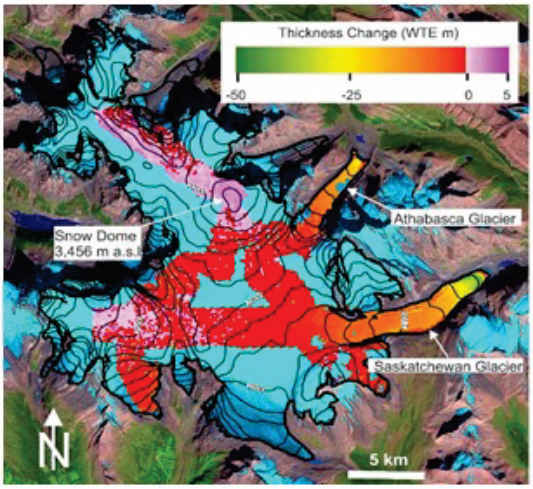


GSC STRATEGIC PRIORITY 2: GEOSCIENCE FOR SUSTAINABLE DEVELOPMENT

Groundwater Geoscience Program

Why? To better understand groundwater distribution, quantity and flow dynamics within integrated water models for sustainable water management.

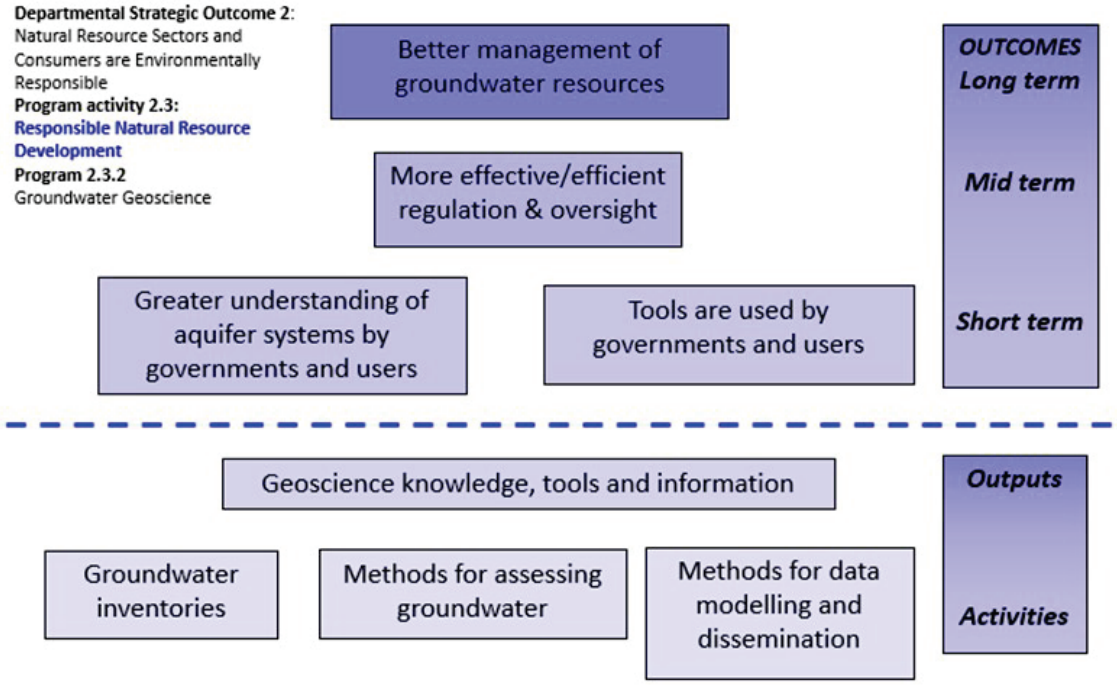




Project	Project Goal	Success Stories
Southern Ontario	Data collection, capture and modelling along with methods development for sustainable groundwater management in Southern Ontario.	• Geological modelling of Southern Ontario including well data, bedrock topography, karst mapping and development of a fully coupled SW/GW flow model. • A framework for conceptualizing SW/GW interactions and identifying potential impacts on water quality, quantity and ecosystems. • High resolution soil moisture mapping via multi-satellite data fusion.
Groundwater Information Network (GIN)	Federal / Provincial – Territorial collaboration for groundwater data sharing. Enables data availability online, provides uniform national data based on international standards. GIN is at the forefront of Open Science initiatives contributing to a variety of significant activities.	• Significant advances in conceptualizing and digitally representing water related entities such as aquifers, rivers and lakes through the Linked Data concept. • Culmination of years of work and many international partnerships for the development of OGC and WMO data standards on groundwater (GWML2). • Enhance data delivery through the GIN web portal.
National Aquifer and Groundwater Accounting (NAGA)	Canada-wide groundwater assessment and accounting using modern tools. Earth Observation using remote sensing gravity and radar imagery are used in support of aquifer mapping and groundwater accounting.	• Scientific innovations using numerical solutions filtering GRACE satellite data to monitor total water variability and trends. • Assessing the impact of glaciers ice mass losses and their effects on the Canadian Plains groundwater flow systems.

GROUNDWATER GEOSCIENCE PROGRAM
Logic Model 2014-2019

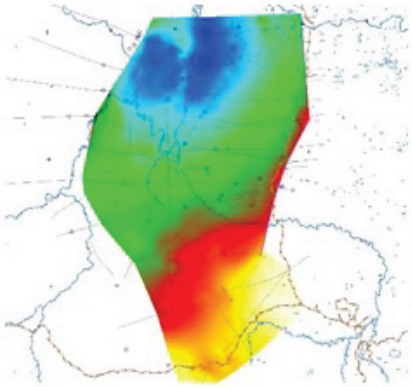
PAA 2014-15
Departmental Strategic Outcome 2: Natural Resource Sectors and Consumers are Environmentally Responsible
Program activity 2.3: **Responsible Natural Resource Development**
Program 2.3.2 Groundwater Geoscience

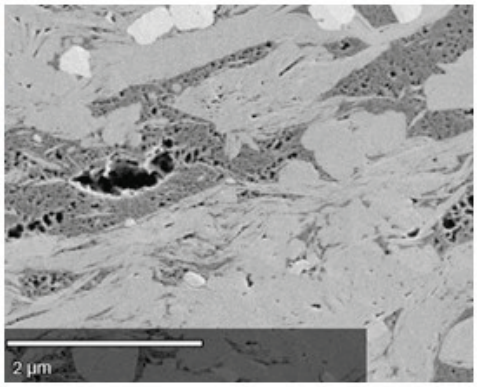


GSC STRATEGIC PRIORITY 2: GEOSCIENCE FOR SUSTAINABLE DEVELOPMENT

Geoscience for New Energy Supply

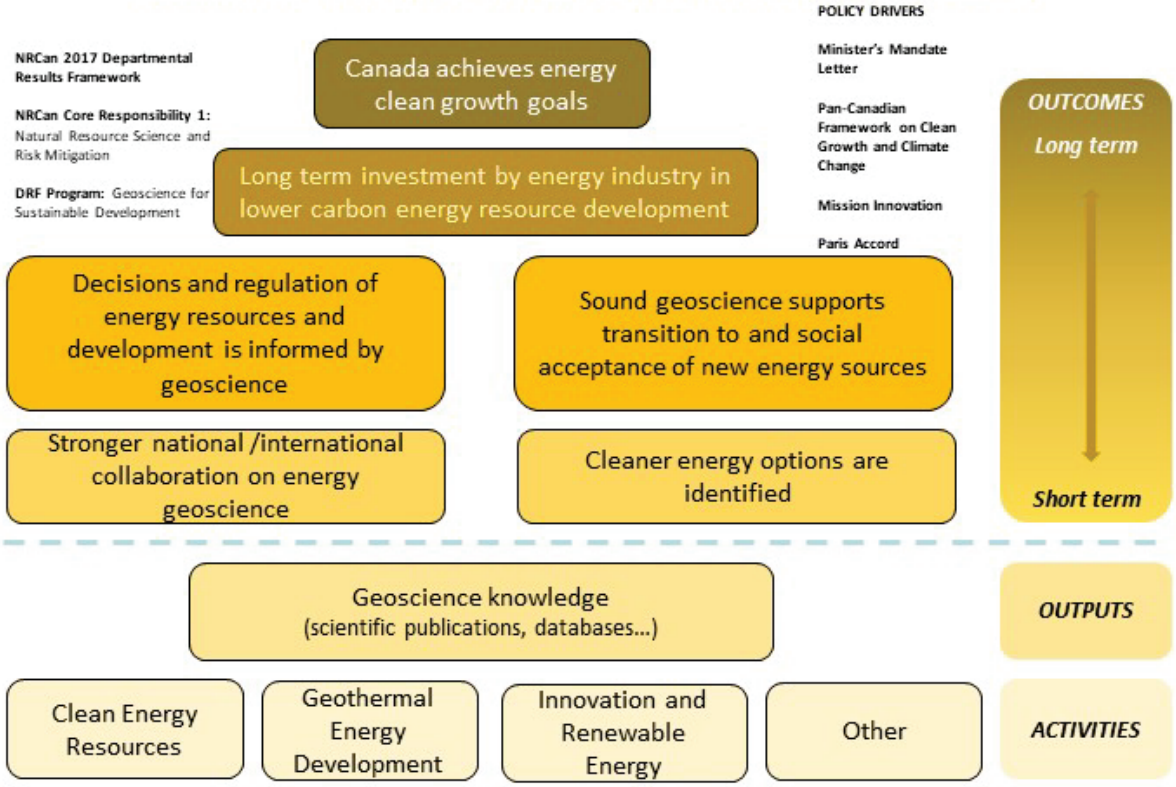
Why? To support strategies for our transition to a future low-carbon economy through clean energy research and development (R&D) and the promotion of non- and low-emitting energy resources using advancements in the fundamental understanding of Canada's sub-surface landmasses.





Project	Project Goal	Success Stories
Geothermal Energy	Supports government goals of reducing CO2 emissions by a transition to non-emitting energy resources by evaluating regional geothermal resources.	• Assessment of net geothermal energy potential in sedimentary basins (producible proportion with net energy gain). • Assessment of geothermal potential in the Garibaldi Range (20 participants from 6 universities and collaborations with industry, Geoscience BC and Energy Sector).
Clean Energy Resources	Advancement of 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 (TOUG). Such endeavours will ultimately support the global steps towards a low-carbon economy.	• Decreasing environmental risk to tight gas development project using field and core lab research combined with conventional field geology, advanced instrumental surveys and multipurpose sampling. • Basin analysis using seismic interpretations from 33 newly acquired seismic lines to create 2-D intepretation of the basin as well as a 3-D grids, isochron and formation thickness maps. • Uptake by industry of the characterization of organic matter fractions in unconventional reservoirs. • Defined specific parameters for ion-milling to improve our understanding of lab-induced factors influencing scientific results
Innovation and Renewable Energy	Captures renewable energy geoscience research focusing on innovative and novel laboratory methods and the integration and application of Augmented Intelligence/Machine Learning in Canadian geoscience R&D.	• Application of machine learning techniques to improve the geoscientific characteristics of tight formations and the migration of liquid/gas (water, gas, oil, CO_2) through them. • Adoption of improved analytical methods by industry for in-situ composition and characteristics of TOUG energy resources. • Successful deployment of the NRCan Explorer Class Autonomous Underwater Vehicle (AUV) to >2500 m water depth to identify new seabed fluid escape features.

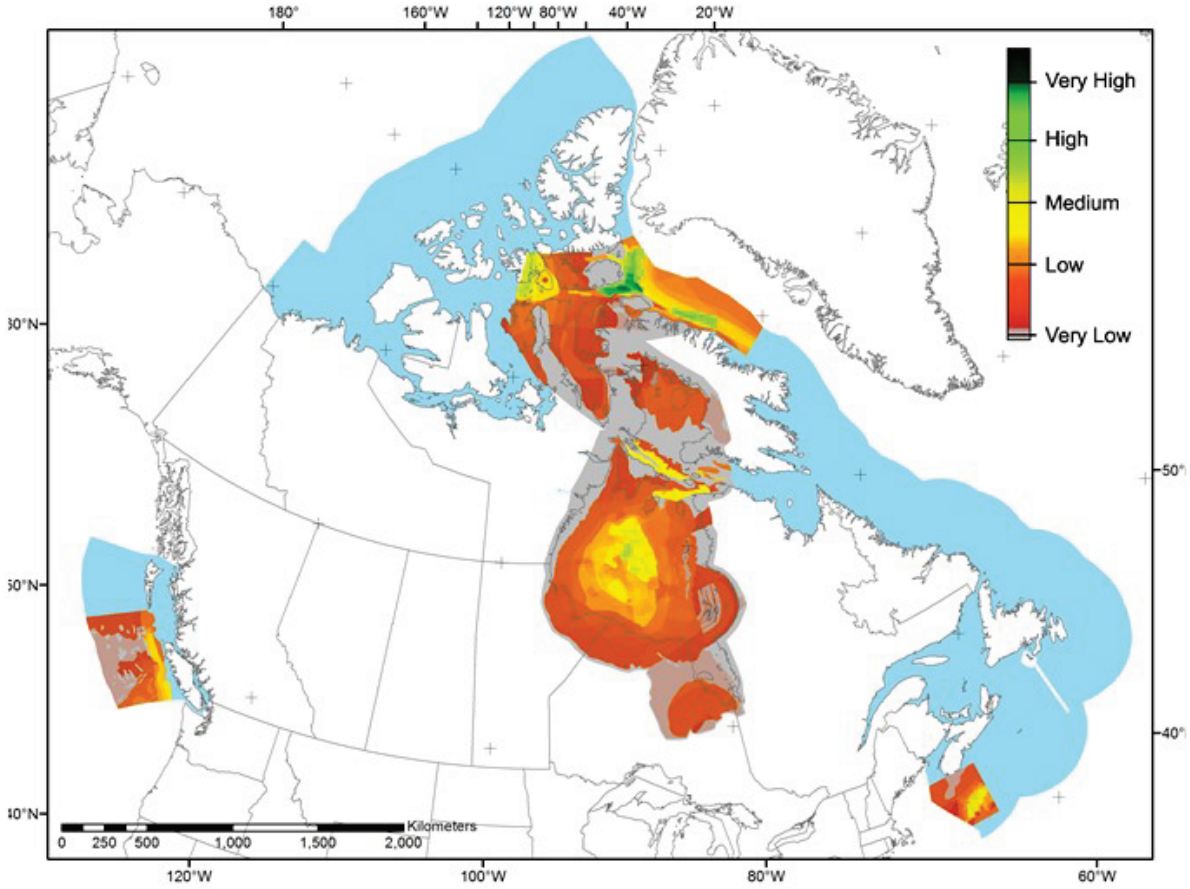
GEOSCIENCE FOR NEW ENERGY SUPPLY PROGRAM (2018-2023)



GSC STRATEGIC PRIORITY 2: GEOSCIENCE FOR SUSTAINABLE DEVELOPMENT

Marine Conservation Targets Program

Why? Assesses offshore petroleum resources as part of Canada's target of protecting 10% of its offshore by 2020.

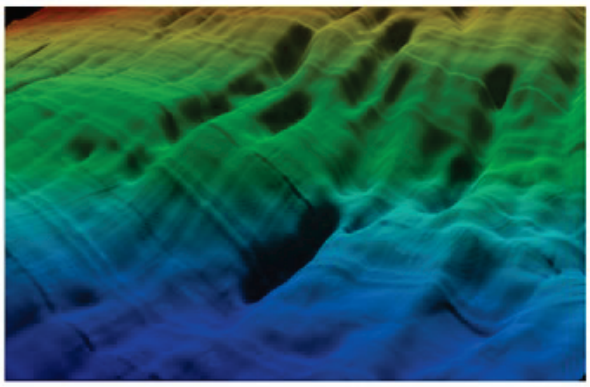


Project	Success Stories
Marine Conservation Targets	• Innovative mapping of areas of high, medium and low hydrocarbon potential to support Government of Canada's decision-making. • Development of tools, maps and reports for decision-makers with varying geoscience background, including new heat maps to portray a region's overall petroleum potential. • Assessments of the broader regions, thereby providing context and options, and increasing the value of the GSC work. • Release GSC Open Files of the MCT work so that GSC products for decision making were accessible and transparent.

GSC STRATEGIC PRIORITY 2: GEOSCIENCE FOR SUSTAINABLE DEVELOPMENT

Marine Geoscience for Marine Spatial Planning Program

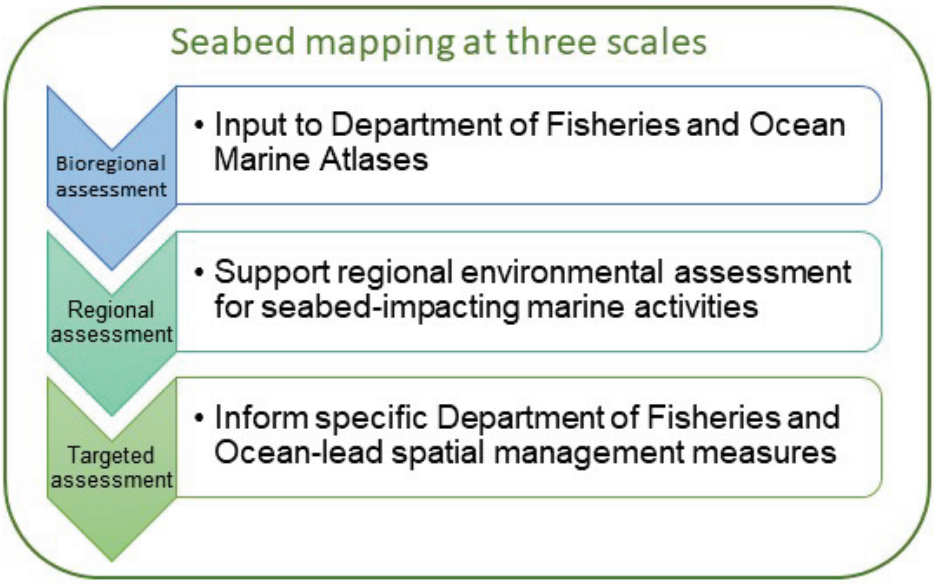
Why? New maps and analyses of seafloor geology and active seabed processes will inform evidence-based marine spatial planning and regional environmental assessment.



Project goals

Marine Geoscience for Marine Spatial Planning

- To contribute marine geoscience to integrated, regional assessment of environmental conditions so that projects can be planned and approved with a full understanding of site suitability and potential cumulative impacts, especially regarding:
  - (1) What is on the seabed?
    - e.g. *bedrock, sand, sediment, etc.*
  - (2) What are the geological processes affecting the seabed?
    - *e.g. sediment transport, sediment erosion, sediment deposition*
  - (3) Is the seabed unique, sensitive, or unstable?

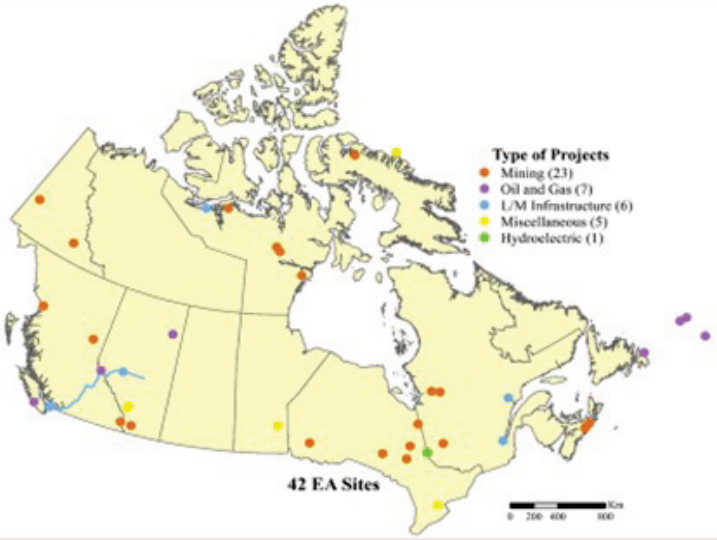


GSC STRATEGIC PRIORITY 2: GEOSCIENCE FOR SUSTAINABLE DEVELOPMENT

Environmental Assessment Service

Why?

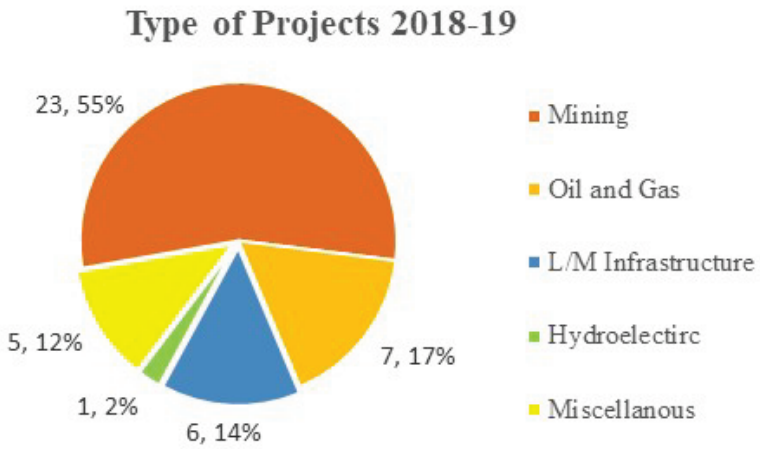
To support land-use planning and environmentally sound resource development, both on land and in our coastal and offshore waters. The GSC is the lead agency for evaluating geoscience in environmental impact statements (EIS).



Project Success Stories

EA reviews

- Timely delivery of geoscience expertise for 42 EIS reviews, including:
  - During the technical review of Roberts Bank Terminal 2 project (BC), NRCan's science informed BC guidelines that "a 0.5 m sea level rise adjustment to the 1-in-100 year estimated design sea level would be considered reasonable".
  - Based on GSC-EIS technical review Nunavut Water Board (NWB) added commitments in its decision for the In-Pit Tailings disposal Meadowbank project (Nunavut).
  - Frontier oil sands project in Alberta completed its panel hearings in October 2019. GSC hydrogeology expert participated in this hearing and responded to FNs questions.
  - This GSC service contributed two months time to TransMountain Expansion Pipeline Project called upon by "NRCan TMX Task Team" preparing for additional consultation.



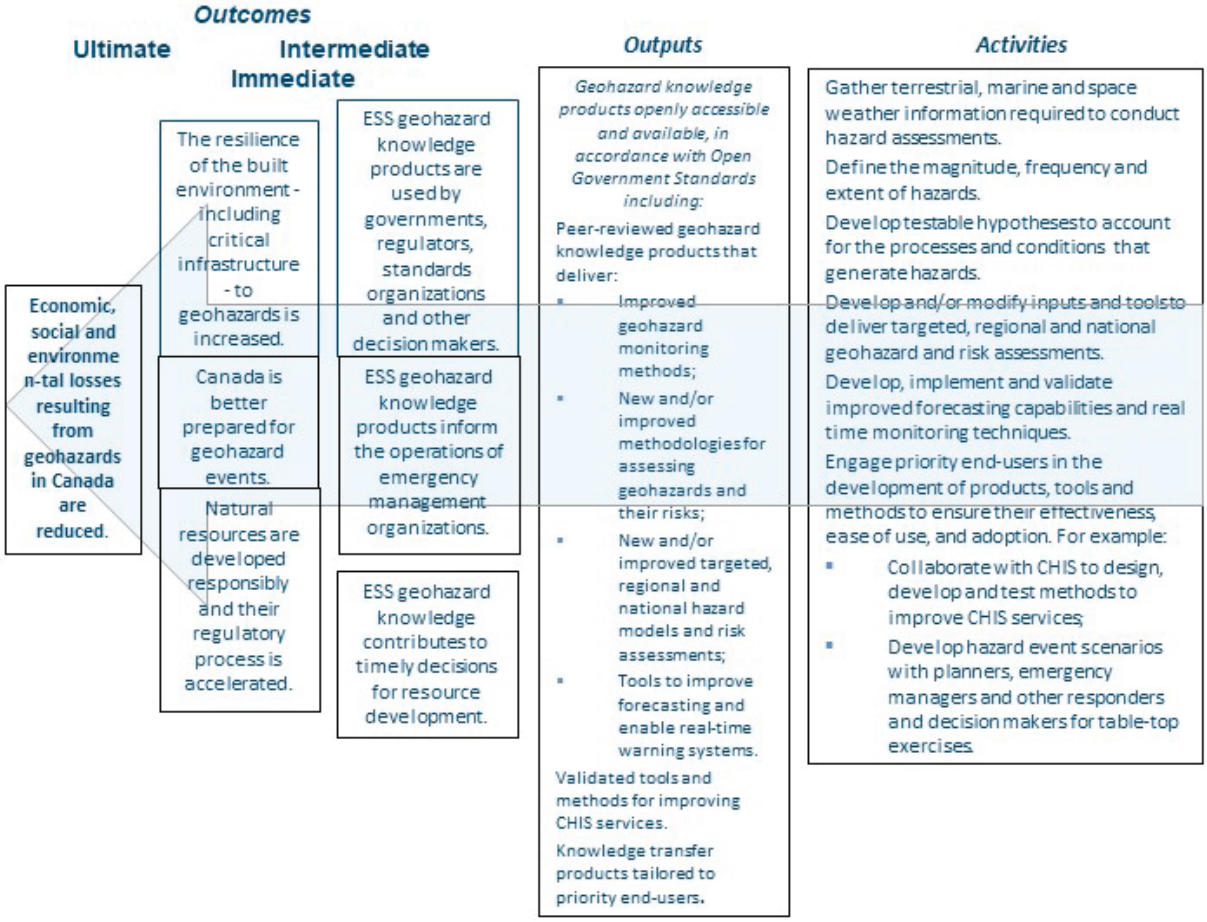
GSC STRATEGIC PRIORITY 3: GEOSCIENCE FOR KEEPING CANADA SAFE

Public Safety Geoscience Program

Why? To understand hazards and risks associated with earthquakes, tsunamis, space weather, volcanoes, submarine and terrestrial landslides, and marine geohazards and to work with stakeholders to inform safe resource development, land use planning, conservation efforts, and regulations

Project	Project Goal	Success Stories
Earthquake Geohazards	Studying earthquake sources, propagation, and site effects as well as volcanic and tsunami hazards to inform mitigation planning, including the national building code, and the development of earthquake early warning systems.	• Integrated earthquake risk assessment for BC and contribution to BC Earthquake Risk Information Portal – an interactive web-mapping application designed to inform pre-event emergency planning by EMBC staff. • Research that contributes to refining the national seismic hazard model that informs seismic provisions in the National Building Code of Canada.
Landslides and Marine Geohazards	Regional and targeted assessments of slope stability hazards on the seafloor (mainly in Arctic areas) and on land in key areas of development or infrastructure corridors.	• Legacy data syntheses and regional marine geohazard assessments for the Beaufort Sea and Baffin Bay are being completed following multi-year funding. • Innovative monitoring techniques of potential landslides sites near Ashcroft (BC) to support broader efforts in applying technology to support decision making by train operators.
Space Weather Hazards	To improve monitoring and forecasting of geomagnetic storms and other space weather hazardous events.	• New requirements for aviation operations and NRCan is one of the centres chosen to supply space weather services. • Establishment of a relationship between geomagnetic activity and Global Navigation Satellite System (GNSS) scintillation that is being used to develop forecasts of space weather effects on GNSS.
National-Scale Risk Assessment	To develop, apply and assess methods and bring awareness to tools and methods for regional and national geohazard risk assessments in collaboration with multi-sectorial partners.	• The tools, methods and outputs of this project supported the District of North Vancouver in developing policies and plans to reduce earthquake risk. • Development of a spatial decision support system based on a set of automated tools and protocols for rapid risk assessment associated with seismic hazards. • Assessment of earthquake risk using OpenQuake software modelling in support of disaster risk reduction (DRR) planning across Canada.

Public Geoscience Logic Model



GSC STRATEGIC PRIORITY 3: GEOSCIENCE FOR KEEPING CANADA SAFE

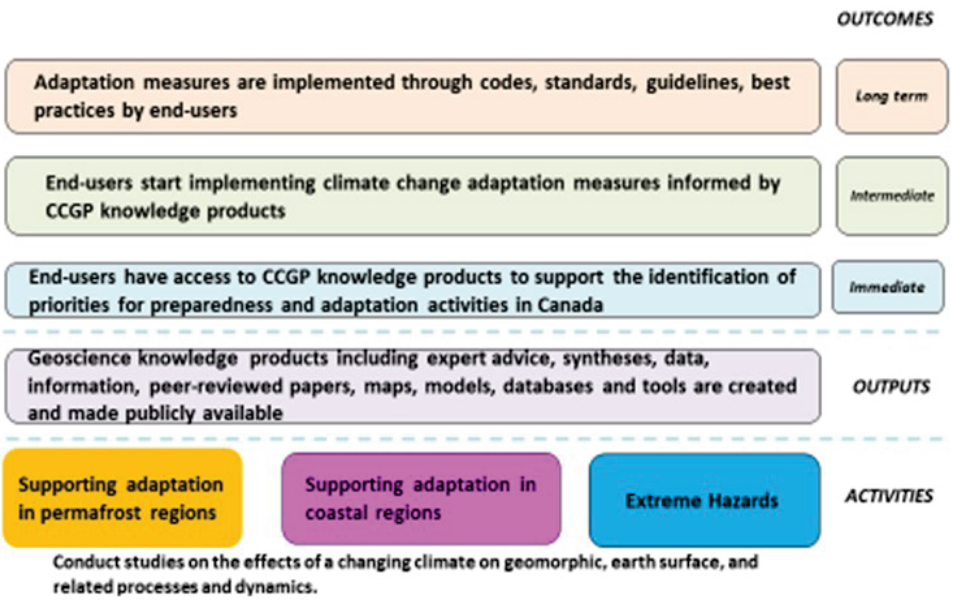
Climate Change Geoscience Program

WHY? To better understand the geological impacts of climate change in Canada for land-use planning and government regulation to help at-risk communities to adapt.

Project	Goal	Success Stories
Supporting Adaptation in Permafrost Regions	To improve the understanding of permafrost-climate-infrastructure interactions, to inform the development of climate-change adaptation strategies for major existing and proposed transportation routes in Arctic and subarctic environments.	• Development of the Permafrost Information Network to ensure permafrost data are available to stakeholders for infrastructure and adaptation planning. • New approach developed to improve the national-scale permafrost map and provide better information on ground ice conditions for infrastructure planning and climate change adaptation. • Protocols for mapping permafrost landscape features along key northern transportation corridors to inform adaptation decisions.
Supporting Adaptation in Coastal Regions	To better understand the sensitivity of Canadian coastal regions to climate change, for the development of effective adaptation strategies for existing and proposed coastal infrastructure and communities.	• CanCoast, a national-scale database allowing innovative analysis of coastal sensitivity. • Coastal monitoring in Tuktoyatuk, NWT, and surrounding regions to aid local decision-making related to coastal change impacts • Development of national sea-level projections, based on an updated national model of crustal uplift.
Extreme Events	To improve flood forecasting of the Hudson Bay Lowlands to provide advance warning to First Nations communities and a long-term hydroclimatic record for improved hydroelectric water management.	• Document past river flow in eastern Labrador to benefit the Canadian hydro-power industry through a better understanding of the evolution of hydraulic regimes and to foresee potential climate change effects. • Development of a drone-based hyperspectral system for land cover validation providing improved knowledge of land surface change and implications for water storage.
Glacier Mass Balance	To quantify the rate and assess the causality of glacier-climate change in Canada's Arctic and Alpine environments.	• Development of a glacier mass balance model for the Canadian Rockies and Southern Interior Ranges to support decadal-scale water availability studies in western Canada. • Systematic glacier change observations reveal Canada's glaciers as the 3rd most important contributor to sea-level rise in the northern hemisphere.

Contribution to National Climate Change Assessment: Significant contributions to the ECCC's *Canada's Changing Climate Report 2019:* a first-time overview of how and why Canada's climate is changing as well as providing projections for the future

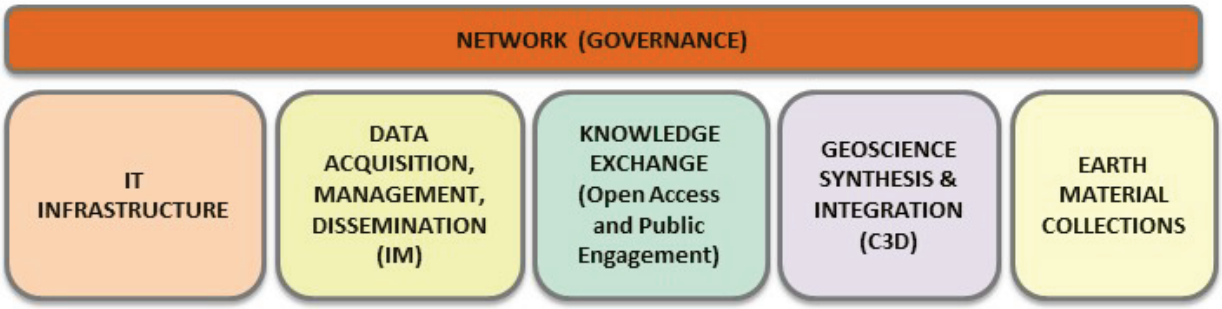
CLIMATE CHANGE GEOSCIENCE PROGRAM (CCGP)
LOGIC MODEL (2016-2021)



STRATEGIC PRIORITY 4: GEOSCIENCE FOR SOCIETY

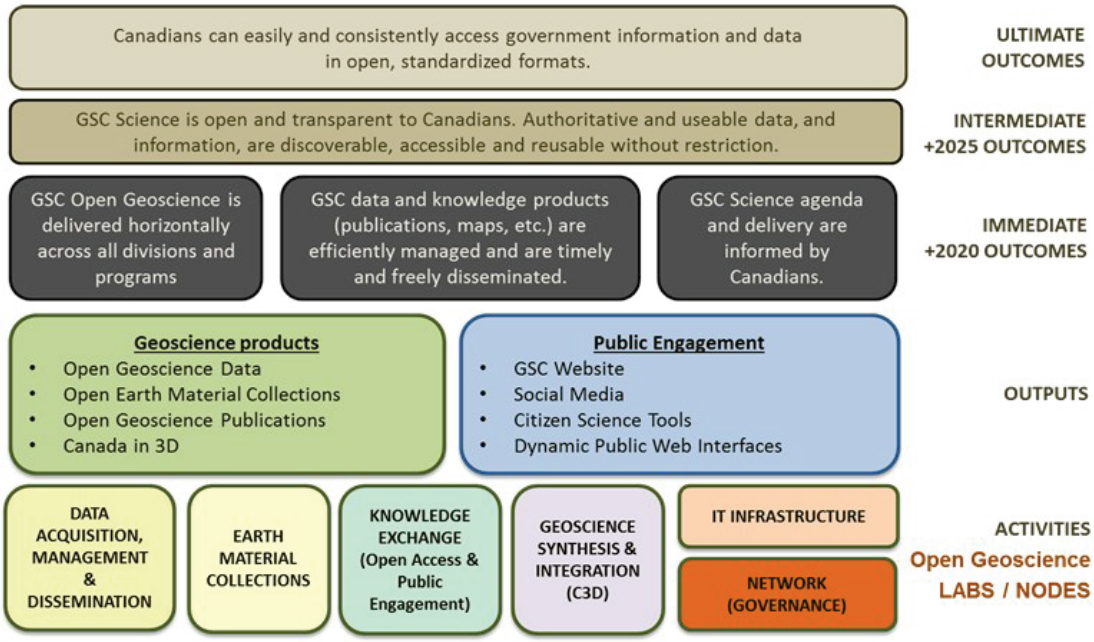
Open Geoscience

Why? To ensure that federal geoscience data and information are findable, accessible, and reusable. Open Geoscience addresses the how rather than the what of GSC science. It aims at improving collaboration and increasing the impact of GSC science.



Project	Success Stories
Social and traditional media	• Almost 1000 followers of the GSC Twitter account. 1500 tweets and re-tweets. • 67 Canadian Geoscience Maps which included descriptive notes, abstract, résumé, accompanying notes (up to 66 pages), figures, tables and legends. • Canadian Geoscience Map series launched and release of 47 CGM maps and data. • Treatment, technical review and quality control of : -180+ manuscripts - 108 Open Files - 30 CGM maps and data - Translation of 60 summaries of external publications -35 geophysical maps (consisting of 105 map sheets) -16 scientific posters/presentations -16 information products
Canada 3-D (C3D)	• A prototype of the C3D website has been developed and it is being adopted for the delivery of the GEM scientific synthesis. • Continue to make technical advancements in 3D modelling and augmented reality. • Good progress on deep sub-surface interpretation from geophysical data. • Have reincorporated Yukon bedrock geology into database and have begun incorporating surficial maps into the database.

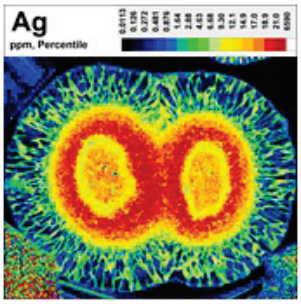
Open Geoscience Logic Model



STRATEGIC PRIORITY 5: OUR SCIENCE, OUR PEOPLE

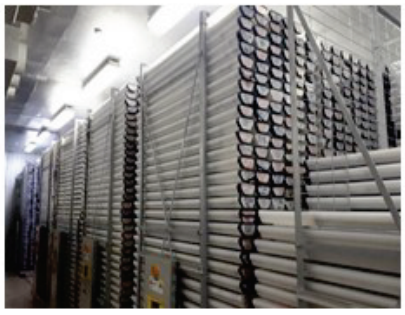
Science Laboratory Network

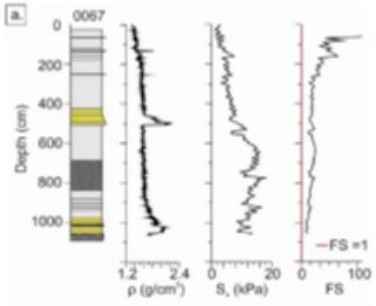
Why? To provide innovative lab-based research leadership for all GSC programs, and to increase effectiveness, connectivity, and efficiency in GSC labs



Project	Success Stories

Lab-based scientific innovations/ method development	• Development of analytical techniques for in-situ chemical analysis of individual fluid inclusions in the LA-ICP-MS (laser ablation inductively coupled mass spectrometry) lab, providing insights on the geochemistry of ore forming fluids.
	  • Analyses of fluid inclusions from quartz overgrowths on detrital quartz grains from the Athabasca Basin reveal the presence of U concentrations more than two orders of magnitude higher than most naturally occurring geofluids, providing evidence for the role of basinal brines in the formation of the giant Athabasca uranium deposit (TGI project).
	• Development of clumped isotope analytical techniques and protocols, a new and growing field of isotopic research, that provides critical information on the temperature of paleofluid systems applicable to research in basin analysis, diagenesis and paleoclimate studies.
	  • Hudson Bay Basin (GEM project): Δ_{47} thermometry of the Upper Ordovician Red Head Rapids Formation: an evaluation of the thermal history of a porous reef reservoir.
	• Integration of physical and getechnical properties of sediment cores to evaluate marine geohazards.
	  • Integration of physical and geotechnical properties of sediment cores in Pond Inlet allow the most complete evaluation of marine geohazards for a Nunavut community to date, providing northern coastal communities with better knowledge for improving public safety.
	• Development of a new geochronology tool in the LA-ICP-MS (laser ablation inductively coupled mass spectrometry; Agilent 7700x) lab for in-situ U-Pb dating of calcite to constrain the evolution of ore forming systems.
	  • U-Pb dating of hydrothermal calcite associated with Carlin-type gold mineralization, north-central Yukon (TGI project).





Example of data from a sediment core where physical properties and geotechnical properties are combined to establish the likelihood of sediment to fail.

ANNEX III: 2018–19 GEOLOGICAL SURVEY OF CANADA SCIENCE PROGRAM COMMUNICATION PRODUCTS

External vs. Internal	Specific type of publication	Number
External publications	External peer-reviewed publication published	290
Internal publications	GSC Open Files published	296
	GSC Maps published	101
	Other internal GSC publications	77
Other	New databases put online	20
	Webinars	10
	Interviews	178
	Press articles	29
	Tweets	13,512
	Presentations to industry / stakeholders (e.g., at open houses, conferences, workshops, meetings)	409
	Presentations made to indigenous associations / communities / partners	57
	Science-based briefing notes to senior LMS management (DG And Above)	20
	Presentations made to senior management (DG and above)	24
	Other (e.g., outreach videos, summary reports, updating guideline report, policy meetings)	30

To view GSC open geoscience publications please visit GEOSCAN https://geoscan.nrcan.gc.ca/geoscan-index.html