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Reading the Rocks Reloaded: A Celebration of the Geological Survey of Canada 175th Anniversary with a View to the Future

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See table of contents

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Article abstract

In 2017, the Geological Survey of Canada (GSC) celebrated its 175th anniversary, just as the 150th anniversary of the Canadian Confederation was celebrated. In many ways, the development of this organization over its long history parallels the exploration and economic development of our country, and these two stories are very closely intertwined. In its early days, the GSC was involved in charting the essential geography of Canada's landmass, and early GSC geologists were involved in some of the discoveries that laid a foundation for our modern resource economy. In the 21st century, the GSC remains at the forefront of geoscience research across the nation, collaborating with many Provincial and Territorial partners and also with academic and industry researchers to expand our knowledge and find ways to sustainably develop our resources. Like all organizations, GSC has evolved over the years, and must continue to do so in response to technological innovation and societal demands. This article provides an overview of where we came from, where we have been, where we are today, and where we hope to go in the future. It is hoped that it will provide a starting point for other articles highlighting some of GSC's more specific scientific contributions over the years, and exploring some of the many characters who colourfully populate its long history.

ARTICLE

Reading the Rocks Reloaded: A Celebration of the Geological Survey of Canada 175th Anniversary with a View to the Future

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SUMMARY

In 2017, the Geological Survey of Canada (GSC) celebrated its 175th anniversary, just as the 150th anniversary of the Canadian Confederation was celebrated. In many ways, the development of this organization over its long history parallels the exploration and economic development of our country, and these two stories are very closely intertwined. In its early days, the GSC was involved in charting the essential geography of Canada's landmass, and early GSC geologists were involved in some of the discoveries that laid a foundation for our modern resource economy. In the 21st century, the GSC remains at the forefront of geoscience research across the nation, collaborating with many Provincial and Territorial partners and also with academic and industry researchers to expand our knowledge and find ways to sustainably develop our resources. Like all organizations, GSC has evolved over the years, and must continue to do so in response to technological innovation and societal demands. This article provides an overview of where we came from, where we have been, where we are today, and where we hope to go in the future. It is hoped that it will provide a starting point for other articles highlighting some of GSC's more specific scientific contributions over the years, and exploring some of the many characters who colourfully populate its long history.

RÉSUMÉ

En 2017, la Commission géologique du Canada (CGC) a célébré son 175ème anniversaire, alors que l'on célébrait le 150ème anniversaire de la confédération canadienne. De plusieurs façons, le développement de cette organisation au cours de sa longue histoire suit en parallèle l'exploration et le développement économique de notre pays, et ces deux histoires sont très intimement inter-reliées. Dans ses premiers jours, la CGC a été impliquée dans la cartographie géographique essentielle de la masse continentale du Canada, et ses premiers géologues de la CGC ont été impliqués dans certaines des découvertes qui ont jeté les bases de notre économie moderne des ressources. Au XXIe siècle, la CGC reste à l'avant-garde de la recherche géoscientifique à travers le pays et collabore avec de nombreux partenaires provinciaux et territoriaux ainsi qu'avec des chercheurs universitaires et industriels afin d'élargir nos connaissances et de trouver des moyens de développer nos ressources de manière durable. Comme toutes les organisations, la CGC a évolué au cours des années, et doit continuer de le faire en réponse à l'innovation technologique et aux besoins sociétaux. Cet article fourni un aperçu de nos origines, de notre cheminement, de notre situation actuelle et de nos objectifs futurs. On espère que cela fournira un point de départ pour d'autres articles mettant en lumière certaines des contributions scientifiques plus spécifiques de la CGC au fil des ans et explorant certains des nombreux personnages qui peuplent de manière colorée sa longue histoire.

INTRODUCTION

The 2017 GAC–MAC meeting held in Kingston, Ontario, included a special session in honour of the 175th anniversary of the Geological Survey of Canada (GSC), founded in 1842. This session, within the inspiring meeting theme *'Where it all began,'* included several presentations about different aspects of the GSC's long history, and thoughts about its future. This article represents an adaptation from a keynote address that formed part of this session. It is my hope, shared by the editors at Geoscience Canada that other presentations from this session will in time move to formal publication.

The presentation originally held a longer title: "*Reading the Rocks Reloaded: Canada's and the GSC's Flight on the Arrow of Time, From Eyes on the Stars to Boots on the Ground, and Into the Future.*" This evocative and somewhat poetic title celebrated not only the GSC's momentous achievements but also by extension those of the wider geoscience community in this country, in a year that was also the 150th anniversary of the Confederation of Canada. I will begin by evoking the epic history of the GSC and Canadian geoscientists through a multi-generational perspective. Then, I will summarize the geographical and geological exploration of Canada over many decades, and the discoveries of some of the most spectacular landscapes and diverse, long-ranging geological records in the world. Finally, I will offer some perspectives on the challenges ahead for geoscience in this country and the direction that the GSC is taking to address them.

Recently, the GSC celebrated its 175th anniversary with joyful in-house gatherings of employees and friends, naturally coupled with some music and speeches. We did this to mark the traditional April 14th 'birthday' of the GSC, commemorating the day in 1842 on which William Logan accepted his letter of employment from the Province of Canada, following the recommendation of several eminent British geologists. He subsequently traveled to Canada and turned up at the government office in Kingston in late August 1842, nearly a year after the Legislature approved the funding of the survey in 1841. It was to fulfill an ambitious legislated mandate:

> *"… be it resolved that a sum of money not exceeding £1500 sterling be granted to Her Majesty to defray the probable expense in causing a Geological Survey of the Province of Canada."* (Canada (Province), Legislative Assembly 1841).

The original intent was to have a completed survey in a couple of years, but given Canada's vast geography, changing geologically-based priorities and the wisdom of successive parliaments, the work has taken longer than originally thought, and is still ongoing. 175 years later, there does not seem to be an end in sight to the geological surveying of Canada. In conjunction with the Provincial and Territorial geological surveys, the GSC has now mapped the majority of Canada`s landmass, describing the surface of our land from the American border to its coastal frontiers at a broad regional scale. Nevertheless, we have yet to probe it systematically and substantially at depth and fully document its offshore extensions. In spite of the fact that there is much left to do, we made many discoveries along the way that have served as foundations for the Canadian economy. The understanding of Canada's geological architecture and resources involved many organizations, people and cultures. The initial efforts of the GSC were aided greatly by the deep indigenous traditional knowledge about the geography of this vast land. Indigenous people traded native copper from the Great Lakes region, as well as chert from Labrador, millennia before Europeans even dreamed of sailing this far west. These indigenous people also played a key role in supporting the exploration of Canada, in teaching survival skills in the difficult boreal wilderness, in sharing their own knowledge of the geography of the continent, and in accompanying the explorers as guides, hunters, warriors, and as co-leaders. This body of knowledge combined over time with the technology of European newcomers, and with the ideas of natural philosophy that emerged and evolved in the late 18th century to form the principles of modern Geological Science.

Let`s reflect on why we celebrate these 175 years. What does such an anniversary mean? It is another slice of 25 years in the history of an organization. It is common to think of 25 years as the length of a typical human generation, so we are celebrating seven generations of geoscience in Canada, and entering the eighth. This is a chance to look at the past, consider the present and peek into the future. In the span of seven geoscience generations, we have achieved great things that we can reflect upon, and find in them the inspiration to forge ahead towards a future of sustainable land and resource development that will sustain generations to come.

The present-day GSC is home to some 400 employees, spread from coast to coast to coast, from Dartmouth in Nova Scotia to Sidney in British Columbia, and to Iqaluit in Nunavut. Friends of the Royal Canadian Geographical Society (RCGS) awarded the GSC with a Gold Medal in November 2016 at their annual Gala held at the Canadian War Museum. The event, attended by a great assembly of friends, was a very moving and joyful occasion. Highlights included awards to present and former GSC employees of three more Gold Medals, to Paul Hoffman, Denis St-Onge and Marc St-Onge. The Massey Medal was awarded to Stephen Blasco. Having had the honour of receiving the Gold Medal on behalf of the GSC from the Minister of Natural Resources, the Honorable Jim Carr, and the President of the RCGS, Paul Ruest, I made it my mission for the year to bring it to our staff to hold as I visited all the GSC offices. It was my way of underlining their contributions and to acknowledge the importance of the professionalism embraced by the present employees of the GSC. Many enjoyed a 'selfie' with their Gold Medal, from which a great mosaic was made (Fig. 1). This medal is not only for the current GSC generation, but also for the past generations, those before us, and is a reminder that we stand on the shoulders of giants in science, whose achievements will hopefully be outlined and assessed by other papers.

FROM RAGS TO RICHES: THE ROLE OF MINERALS IN CANADA'S PROSPERITY

Through the hard work of generations, Canada's geology has become the foundation of our economic prosperity including minerals, oil and gas, soils, fertilizers and construction materials for our roads, harbours, buildings and so many other things. Every Canadian knows, or should know, the value of our natural resources in economic development.

Understanding the geology of some 17 million square kilometres of onshore and offshore territory is a never ending task – What do history and geology tell us of how we got from where we were 175 years ago to where we are now? Recall that in 1842, when the government started a one-person geological survey, Canada had no substantial mining production beyond minor coal seams in Nova Scotia, and no certain knowledge of whether it had any potential. Today, Canada has a thriving

Figure 1. Some of the GSC staff holding the Royal Canadian Geographical Society (RCGS) Gold Medal awarded to the GSC in November 2016. A 'GSC and William Logan' medallion was also distributed at the time to all the RCGS gala participants. It has since been turned into a 'golden' version that is awarded annually to meritorious staff of the GSC.

economy; ranked as the second best mining exploration destination in the world, with the majority (57%) of global mining finance in 2016 coming from the Toronto and Vancouver Stock Exchanges. Canada ranks in the top five countries for the global production of 13 major minerals and metals: we are first in potash, second in uranium, nickel and niobium, third in cobalt and platinum group metals, fourth in salt, sulphur and tungsten, fifth in diamonds, graphite and gold, and we are the sixth largest global producer of oil. Current production is close to four million barrels per day, and we have the third largest oil reserves in the world. In addition to mineral production, Canada is also important in the processing of resources from elsewhere, such as aluminum. The difference between what we knew of in 1842 and what we now enjoy is so vast that it is hard for the layperson to imagine that it all began when Logan set out on a simple field expedition to Nova Scotia and Gaspé in 1843 to look for coal and other minerals. Did geoscience and the GSC have a major role to play in Canada's development as a resource giant? The answer is of course complicated but also interesting, and in essence, it is a solid 'yes.'

The GSC's long history can be found in several interesting accounts, including the detailed and well-researched book "Reading the Rocks" (Zaslow 1975). I strongly encourage readers to explore Zaslow's fascinating accounts of the epic expeditions and resulting discoveries of the 'founding five Directors'. From Logan to his successors Alfred R.C. Selwyn, who led the GSC for 25 years, (see Figure 2 for an example of early GSC innovative technology application led by him), George M. Dawson, who surveyed the southern Prairies, British Columbia and Yukon, (Fig. 3), Robert Bell, famous for his great northern expeditions, (Fig. 4), and Albert P. Low. Low's famous Quebec and Labrador expeditions were the subject of a recent article in Geoscience Canada (Wilton 2018), and we hope that other pioneers in our geoscience will soon be celebrated in a similar fashion.

A GSC tale that has not yet been fully told is that of its achievements and travels on the twisted road of organizational life from the late 20th century to the present day. I will offer here that the GSC and geoscience remain to this day a very important part of who we are as a nation, and have been critical elements of what Canadians have achieved in building this country.

LOOKING DEEP THROUGH CANADA ON THE ARROW OF GEOLOGICAL TIME

My quick and partly metaphorical 'field trip' across Canada will travel on the arrow of geological time and will highlight some interesting facts and observations about our geography, our human history and our geology. Geoscientists have worked long and hard to tease out and document the long geological history of our land, and we have learned a lot, as summarized in Figure 5. Before we depart on this rapid journey, I will refer the lay reader, whom might wish to learn more, to the superb

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Figure 2. Example of early Geological Survey of Canada (GSC) economic geology investigations. In 1880 the GSC contracted for a number of drill holes on the southern prairies to investigate the extent of the lignite deposits exposed on the Souris River. After experiencing considerable difficulty in obtaining suitable timber for the derrick and an engine bed, this hole near Roche Percée was drilled to a depth of 295 feet. Photo Credit: A. Selwyn, second director of the GSC.

book "*Four Billion Years and Counting: Canada's Geological Heritage*" (Fensome et al. 2014) published by the Canadian Federation of Earth Sciences to mark the International Year of Planet Earth.

Canada has a fabulous geological endowment, matched by few other countries in the world. It holds the records of at least 4 billion years of geological history, comprising continental collisions, uplifts, mountain building and continental erosion into vast and long past seas, as well as relics of giant volcanic belts rich with metals. The 'land' was enriched by metallogenic processes that occurred deep in ancient oceans, and was deeply carved by more recent multiple glaciations. Large meteorite impacts scarred it on many occasions, and some of these enriched our legacy of metals and minerals. Few countries in the world have nearly as many layers of rocks, or provide such a nearly continuous record from the early days of Earth to its recent perturbations. From a modern natural hazards perspective, few countries share such a quiet and lucky setting with very few and infrequent large earthquakes, and few active volcanoes. Nevertheless, we are increasingly aware of the risks of major earthquakes and/or tsunami in Canada, and GSC personnel assess and monitor such hazards, just as we

Figure 3. G.M. Dawson and party standing in front of building in Fort MacLead, Alberta, 1879. Dawson became the third Director of the Geological Survey of Canada (GSC) in 1895 after an epic career as a staff geologist that started in 1875 when he joined the organization. He wrote several milestone reports based on extensive field work with parties such as this one. Dawson worked for the British North American Boundary Commission surveying the International Boundary. His GSC reports based on surveys of very remote areas of BC and Yukon were used by prospectors and government geologists during the Yukon Klondike gold rush. Dawson City, Yukon, was named in his honour, as was Dawson Creek, British Columbia.

Figure 4. The Geological Survey of Canada (GSC) has a long history of exploring Canada`s frontier areas and hiring indigenous people for field support, often visiting distant communities such as this one on the shore of Hudson Bay, Manitoba. Photo credit: Robert Bell, fourth Director of the GSC.

seek to understand the past.

Looking much further beyond Earth, and deeper into time, we can see the elemental particles that dominated the moments after the Big Bang and which led ultimately to the coalescence of stars, galaxies and planets. Forces from beyond Earth still reach our planet and can have major influences upon it. As the Earth orbits the Sun, it is bombarded by solar wind particles that can have detrimental effects on infrastructure such as power lines, pipelines, satellites and modern digital communication systems. Every day, GSC geophysicists monitor the solar wind and its effects on the geomagnetic field to issue 'space weather' forecasts to mitigate these impacts. This

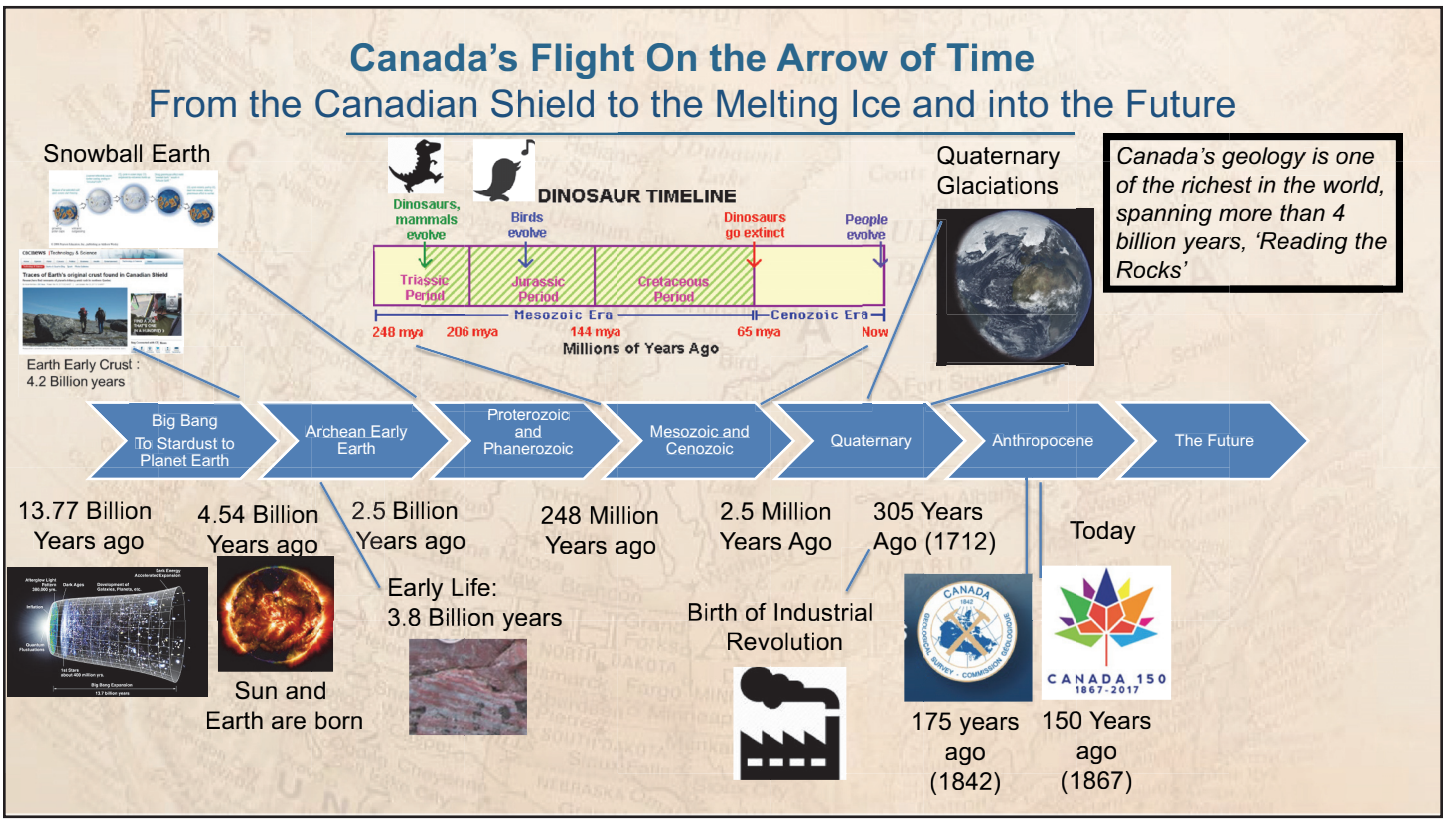

Figure 5. Highlights of Canada's geology and history presented on the "Arrow of time."

advanced system has evolved through several generations, starting in the 1920s with our early basic observations of Canada's geomagnetic field to support magnetic compass-based navigation.

Going back to the Earth's formation as part of solar system, we know that Canada contains the oldest recorded rocks, represented by the 4.0 Ga Acasta Gneiss in the Northwest Territories (Bowring et al. 1989). There may be still older materials, as O'Neil and Carlson (2017) suggest an age of 4.3 Ga for metavolcanic rocks in Northern Quebec. Although based on indirect methods involving extinct radioactive isotopes, and actively discussed in the geoscience community, such results hint at the possible extent of ancient crust in the Canadian Shield. From the same general area comes a report of putative fossilized microorganisms that are at least 3.8 Ga and perhaps as old as 4.3 Ga (Dodd et al. 2017). If the latter inferences and the organic origins of these tiny structures are confirmed, these will place the origins of life on Earth 500 million years earlier than previously suggested by researchers.

If we continue our journey on the arrow of time, we reach the Proterozoic, a long interval of at least 1.5 billion years, marked at its beginning and end by periods of planet-wide glaciation that may have threatened life on Earth, but may also have played a critical role in its development. The longest and oldest of these glaciations, the Huronian glaciation, extending from 2.4 to 2.1 billion years ago, was described in Ontario by Coleman (1907). The relationship between these frigid intervals and the appearance of oxygen in Earth's atmosphere, through the evolution of primitive photosynthetic organisms, is a subject of much keen debate in the geoscience community. Subsequent global glaciations towards the end of the Proterozoic form part of the events labelled as the 'Snowball Earth' (e.g. Hoffman et al. 1998), and may have stalled photosynthesis on Earth, leading to near-collapse of the biosphere. The record of Neoproterozoic global glaciation is well displayed in both northwestern and eastern Canada. However, life survived this crisis, and volcanic gas emissions eventually raised temperatures enough to release the Earth from ice, and begin a new epoch in its long history. The times of the Snowball Earth form the older of two new geological periods added to the global time scale – the Cryogenian and the Ediacaran. The Ediacaran Period witnessed the appearance of the first complex multicellular organisms, including animals. The record of the Ediacaran biota is worldwide, but the earliest and best preserved of these remarkable organisms are in Canada, where they are now preserved as part of the newly declared World Heritage Site at Mistaken Point in southeastern Newfoundland.

Canada has a rich fossil record, which spans the long period from the most primitive unicellular life, to the first multicellular creatures, fossil trees, and many vertebrate forms including dinosaurs, early mammals and the megafauna of the ice ages. We can trace the march of evolution through diversifications and mass extinctions from this remarkable legacy. In Alberta, we have some of the richest dinosaur fossil beds in the world and the richest oil deposits, the oil sands.

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GSC geologists have minutely documented and synthesized the richest global records of past glaciations (e.g. Dyke 2003). These are of critical importance in understanding the natural fluctuations of our planetary climate, but also played a significant role in the discovery of mineral resources, as discussed below.

From prehistoric times to the mid-19th century, natural resources extraction and trade through the territory that is now Canada was mainly represented by the harvesting of wildlife (fur trade and cod fisheries), agriculture and forestry. No substantial metal mines, gem, or petroleum deposits were developed until the middle of the 19th century, aside from coal in Nova Scotia. The discovery and development of numerous mineral and petroleum deposits in the mid and late 19th century and in the 20th century propelled Canada's economy into an enormous expansion, and translated into rapid GDP growth, allowing the country to fund the significant infrastructure and socioeconomic benefits that we enjoy today. Canada contains the largest component of the Canadian Shield (also known as the Laurentian Shield) which many would consider the most resource-endowed section of the Earth's crust. Exploration of the Canadian Shield, has unearthed some of the richest gold and base-metals camps in the world, and it also contains substantial deposits of nickel, uranium, cobalt and many other valuable industrial commodities. Exploration continues today, guided by our knowledge of the origins and distribution of metal deposits, and discoveries of many types are still being made. Beyond the confines of this ancient core to our country, valuable resources occur in the Appalachian mountains of eastern Canada, and throughout the Rockies and other western Canadian regions, where huge deposits of copper and molybdenum are related to past volcanic and igneous processes that resemble those operating today in western South America. The quest for minerals sometimes leads to totally new developments, such as the discovery of valuable diamond deposits in Canada's north, notably in the Northwest Territories, Ontario and Quebec. The story of Canada's arctic diamonds is a great example of detective work by geologists and prospectors, but the wider knowledge of our ice-age history was equally important in finding mines such as Diavik, which produces gems worth $2 billion every year.

Early mineral discoveries in Canada commonly involved traditional indigenous knowledge of the land, and our First Nations communities continue to play an important role in prospecting for resources. The development of resources brings benefits to indigenous communities, through impacts and benefits agreements and direct employment opportunities. In the modern world, the successful and environmentally sustainable development of resources requires consultation and cooperation between stakeholders, and much progress has been made in this respect.

This field trip through deep geological time has highlighted the great knowledge derived through scientific and technical efforts over the last 175 years, and the Geological Survey of Canada has played an important role throughout that time. We have not been alone in this, and cannot claim credit for every discovery or insight, but we have provided much foundation knowledge, and a framework for the research and exploration efforts of many others. Canada is a unique geological destination from the perspective of fundamental scientific research, and it is one of the world's most active mineral exploration destinations. This reflects its many natural geological endowments, and its welcoming investment climate, but it also reflects the quality and availability of geoscientific data, and a history of technical innovation in these fields. These same attributes have made Canada the largest source of worldwide funding for mineral exploration, and make Canadian exploration and service companies important all across the globe.

EYES ON THE STARS: EXPLORING AND MAPPING THE OUTLINE OF CANADA BEFORE 1842

The quest for mineral resources and their exploitation started long before European explorers came to the eastern reaches of Canada. Indigenous people traded native copper from the Great Lakes region, chert from Labrador and many other commodities for thousands of years. The Ramah chert quarry in northern Labrador and the Fleur-de-Lys soapstone quarry in northern Newfoundland are amongst the oldest mining ventures known anywhere in the so-called 'new world.' In the 19th century, much remained to be systematically reported in terms of scientific examination, and even the basic geography of many remote areas was not established from surveying. Early maps and exploration efforts depended to a large extent on the traditional knowledge and support of the indigenous people of Canada, a foundation that the GSC built upon, and continues to value.

Shoalts (2017) notes that the early geographic exploration and mapping of Canada, to the mid-19th century, was done through momentous expeditions led by the likes of the Viking Eric the Red , Jacques Cartier, Samuel de Champlain, Samuel Hearne, John Franklin, le Sieur de La Vérendrye, and Alexander McKenzie. These expeditions were fraught with danger and challenges, and were aided by the support and guidance of indigenous peoples, such as Matonabbee and his clan, who guided Samuel Hearne's expeditions.

Common among early European explorers were several drivers: a desire for recognition, fame or 'stardom,' an avid curiosity and thirst for knowledge, and an appetite for wealth (extending territory for fur trade, or finding a trade route to the Pacific). In addition, separate from those seeking fame and wealth, missionaries and other explorers sought religious converts. It is unlikely that they could have sought such goals without indigenous peoples teaching them survival skills in the difficult boreal wilderness, sharing their own geographical knowledge, and accompanying them as guides, hunters, and sometimes as co-leaders. The mapping achieved through these expeditions is impressive, given that through most of the 17th and 18th centuries, the bulk of the exploration was undertaken using birch bark canoes, navigating up and down streams and coasts, using only crude celestial navigational instruments.

These early geographic explorations, continuing into the mid-19th century, achieved three important outcomes. Such efforts provided a broad outline of the coasts, major rivers and mountains, and limits of the continent, as we know it now,

with the exception of the Arctic Islands. They led to a series of large settlements in southeastern Canada, serving as bases for later establishing the small communities and fur trade posts that dotted the land in the west and the north. Last, but not least, a relatively prosperous colonial economy and society grew up based on agriculture, forestry, fur, and fisheries, with an ever-expanding land base. This territorial expansion was, of course, driven by a fierce competition between Britain and the emerging American Republic, based on the colonial demand for resources and immigration.

By 1842, there were still little or no mineral resources developed in Canada apart from some coal, quarried stone and various artisanal uses of clay and sand. Only a few instances of metalliferous ores, such as the bog iron of Trois-Rivières and the native copper deposits that served to make tools and jewellery used by indigenous peoples, had been developed economically on a small scale. Coal mining had begun in the early 18th century near Louisbourg, Nova Scotia, but its exploitation remained at a similarly small scale.

PUTTING BOOTS ON THE GROUND: THE CREATION OF THE GEOLOGICAL SURVEY OF CANADA

Between 1825 and 1850, coal mining in Nova Scotia expanded, spurred by an appropriate licensing scheme and industrial demand. An equivalent boom in coal mining in the British Isles was driven by the steam engine and the industrial revolution. This led to the first meticulous mapping of the geology of Great Britain through the efforts of William Smith, whose first national-scale geological map, by far the most accurate of its time, was published in 1815. This map showed the usefulness of mapping to predict and locate the mineral resources of the country (see Winchester 2001 for the story of the "*Map that Changed the World*") and most certainly set the stage for the creation of the Geological Survey of Canada and geological surveys across most industrialized countries through the 19th century and into the early 20th century.

William Logan, who had participated in the mapping of Great Britain with his mentor Henri de La Beche, was chosen to found the GSC. Canadian-born, but educated in Britain, he was hired to further the economic expansion of the Province of Canada (present-day Ontario and Quebec), by identifying and assessing its mineral resources. Coal, known to occur in Nova Scotia but not yet in the Province of Canada, was of special interest, because it was clearly essential for economic expansion.

William Logan must surely had a humbling experience in considering the challenge ahead in surveying a country as large as the Province of Canada. As he wrote in 1842:

> *"The extent and nature of the territory will render the task a most laborious one; but I am fully prepared to spare no exertion of which I am capable, to render the work, when it is completed, satisfactory to those who have instituted the examination, and creditable to myself. I am especially anxious to bring the investigation to a conclusion in as short a time as a due regard to geological truth and the applications of the science will permit"*(Logan 1843).

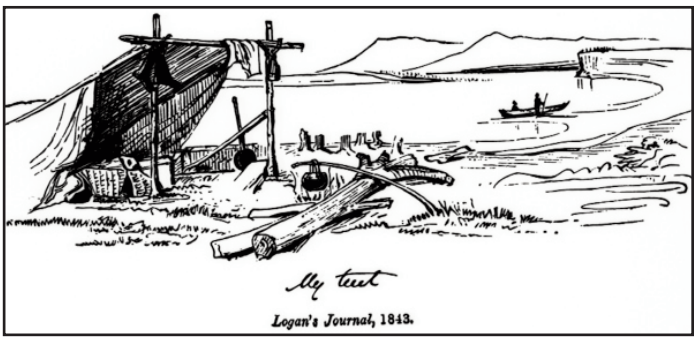

Figure 6. Drawing by William E. Logan entitled "My tent" excerpted from his journal, 1843. The reader can find more on this and other interesting facts about the Geological Survey of Canada on a new website entitled *The History of the Geological Survey of Canada in 175 Objects*.

Logan met this task head-on, taking up his duties in Kingston, Ontario, on April 14, 1842 (which we now mark as the GSC's traditional 'birthday'), starting his fieldwork in the summer of 1843, and surveying geology along the coasts, lakes and streams of Quebec, Ontario and Nova Scotia. This was done by canoe and foot traverses across fields, forests, and mountain ranges. Logan used only a tarpaulin as a tent (Fig. 6), had only a few bags for his possessions, carried just a compass and a hammer, and had the assistance of only a few local hires. After roaming the coasts and rivers of parts of Nova Scotia and Quebec, and up the St. Lawrence Valley, he was not able to report finding any coal seams in the Province of Canada. He was, however, able to report on a number of mineral occurrences and much geology worthy of further investigation.

As we look at todays more elaborate and structured GSC field practices, the simplicity of the tent retains an appeal for many. It is a way to move around lightly and quickly, and to gather data efficiently on the land. We now have computers and all sorts of technological marvels such as GPS and portable X-ray fluorescence devices, but fundamentally, we still rely on direct observations to gather data, collect rock samples and tell the story of 'what's out there.' Even with sophisticated remote surveying and detection techniques, field work remains vitally important to the GSC and it is a method that we prioritize to this day. Although other types of data are undeniably valuable in what we do, field work remains an efficient empirical approach to unravelling many geological puzzles.

THE GEOLOGICAL MAP OF CANADA: THE WORK OF MANY GENERATIONS

By 1864, in less than 25 years or one generation, Logan had produced a map of the southern part of Canada and the adjacent United States, which was a remarkable achievement (Logan 1864; Fig. 7). This map, like so many of the objects described in a new portion of the *science.gc.ca* website - *The History of the Geological Survey of Canada in 175 Objects* (George Plant and collaborators 2017) – is an iconic part of the history of Canada. If Smith's geological map of England 'changed the world,' we can safely say that Logan's geological map changed Canada's future. In fact, his map, made jointly with US geolo-

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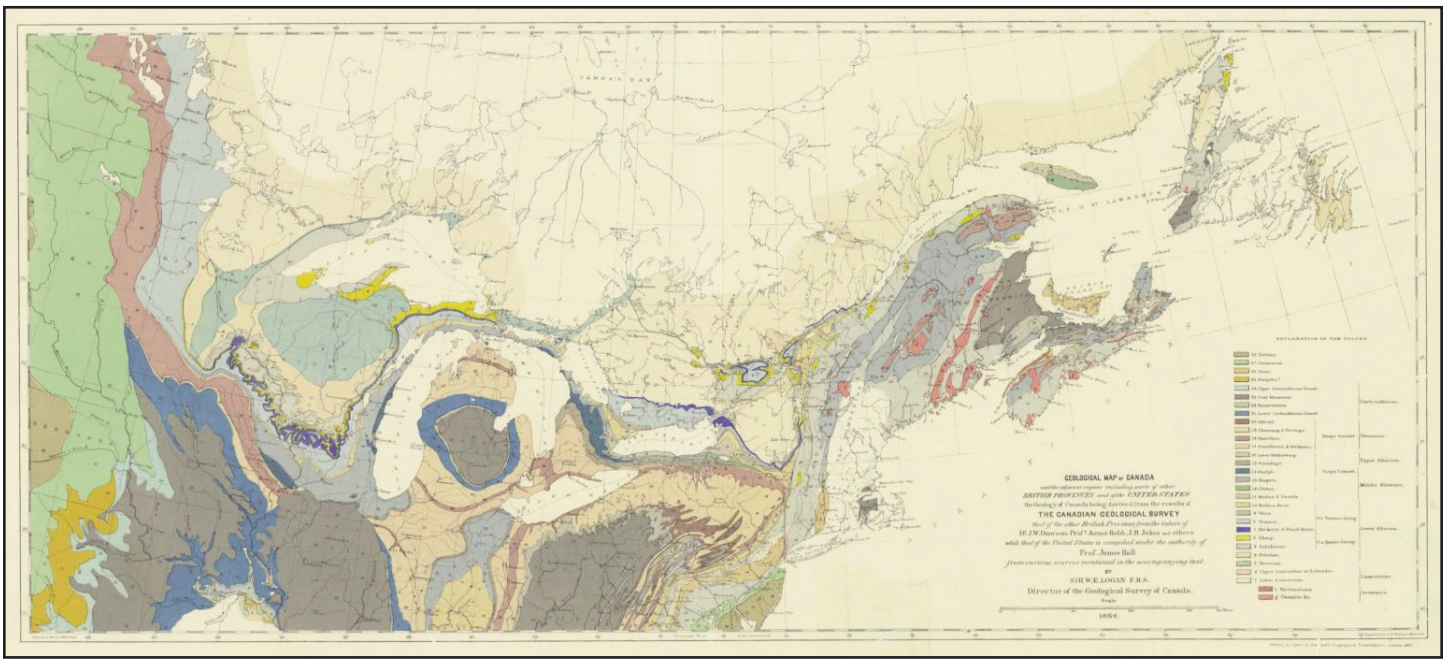

Figure 7. Geological map of Canada by Logan (1864).

gist James Hall, is a fully integrated cross-border map of Canada and the USA. The map features all the main elements of the geology of Eastern North America: the Appalachian fold and thrust belt, the St. Lawrence Lowlands, and the great basins of the Midwest. It is an amazing feat given that it was done with only the help of a compass, a hammer, and some basic surveying tools such as a simple wheel to measure distances and generally without the benefit of any topographic base map. He produced one map at 1" to 150 miles and another one at 1" to 25 miles, which compares to the maps of William Smith that one can see today at the British Museum of Natural History.

Logan and his scientists also had a knack for striking the imaginations of the public and policy-makers by putting together collections and displays for events such as the Great Exhibitions of London and Paris in 1851 and 1852. In 1855, only 13 years after he founded the GSC, Logan earned a knighthood from Queen Victoria, one would think in large part because his geological contributions to the exhibitions were so well presented and captivating on the world stage.

Since 1864, the GSC has produced several new versions of the geological map of Canada, one every 25 years or so. The most recent version published in 1996 was under the supervision of past Chief Geologist John Wheeler (Wheeler et al. 1996). The GSC is now looking at the development of the next generation of the map of Canada, under a project that we have labelled 'Canada 3D.' Having reached the frontiers of the land in two dimensions at a broadly regional near-surface level, we are starting to map deeper and project the geology under our feet, moving to another frontier. It is the GSC's primary mission to document and understand Canada's long geological history, but knowledge of the geology of Canada has not been achieved by the GSC alone. It is the culmination of joint efforts over multiple generations by the community of geoscientists from the geological surveys of the provinces and territories of Canada, academia and the private sector. The provincial and territorial surveys only really took flight after the constitutional arrangements of 1867 that devolved responsibilities over natural resources to these jurisdictions. Every Province and Territory in Canada, aside from Prince Edward Island, has a geological survey. After some consideration of abolishing the GSC in the 1870's and again in the 1990's (Findlay 2010), sound thinking prevailed, and agreements were forged to instead foster federal-provincial cooperation centred on common geoscientific objectives. Although there were naturally some disagreements about priorities, the intent and workings of the Intergovernmental Geoscience Accord (Canada Mines Ministers 2012) now ensures cooperation and complementary roles for the federal and provincial/territorial surveys, and has proved successful in doing so (Fig. 8). This cooperation is strengthened by the participation of geoscientists from the private sector and academia in many larger projects.

A VIEW TO THE FUTURE

Lebel (2010) presented some views on drivers that will shape Canadian geoscience in the 21st century. These include a renewed race for minerals and energy on the Canadian frontiers in a resource-hungry world, stock market swings and economic cycles in times of financial and commodity price upheavals, globalization and the growth of junior mining companies. Wider influences include concern over climate change and other environmental issues, the globalization of science, onshore and offshore indigenous land claims, and the increasingly global competition for the tight supply of scientific professionals.

Some new drivers have emerged since 2010, and others have changed in importance, but I suggest that this list still applies today. We can perhaps add the decline of the traditional print news media and the emergence of social media, and a

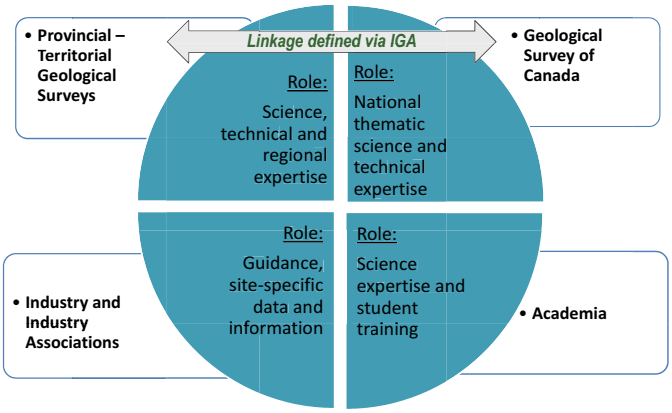

Figure 8. Canada`s geoscience 'ecosystem' in relation to the Intergovernmental Geoscience Accord 2012 (IGA). As described in the IGA, Canada's geological surveys were: "*Initially established to encourage and regulate the development of mineral and energy resources, the geological surveys in the 21st century deliver public geoscience programs that contribute to a broad spectrum of economic, health and safety, environmental, and other public policy issues. The Intergovernmental Geoscience Accord provides a framework for cooperation and collaboration among the federal, provincial and territorial geological surveys. Cooperation and collaboration minimize overlap and duplication, enhance synergies among jurisdictions to resolve regional geoscience problems, and facilitate optimal utilization of resources.*"

general decline in the public's confidence in public and private institutions and authorities (Johnston 2017). Technological change will continue to drive innovation and the need for new geoscience, because new technologies increase the demand for some minerals and metals (e.g. lithium and rare-earth elements), and new exploration methods and models require specific information that may not have been acquired by earlier work.

Geoscientists are making increasing use of revolutionary technologies. For example robotics, drones, microsatellites and distributed sensor networks are revolutionizing remote sensing, and handheld XRF devices provide analyses 'at the outcrop' rather than waiting months for lab analyses to be completed. Three-dimensional basin mapping allows increased understanding of the geology required for petroleum exploration, but also for carbon capture and sequestration. Biology and geoscience intersect in the evaluation of DNA fingerprinting of oil eating bacteria and Genetically Modified Organisms that could mitigate pollution problems from resource extraction. Modern computer and digital processing allows easier three-dimensional geological modelling, and neural networks, machine learning and artificial intelligence help us to find and understand patterns in our data.

Geoscientists are 'knowledge integrators' who read the rocks and discover in them stories and hidden treasures that they can relate in words and illustrations. These stories still need to be published as open data sets and scientific papers for the scientific community to build upon, but other media (e.g. YouTube videos) give us new tools and ideas for public education and data dissemination. These new approaches need to continue and grow if we are to form bonds between scientists and the wider communities that can benefit from geoscience surveys (Groulx et al. 2017). Without renewed and innovative efforts in Earth Science public education, it is likely that social consensus on difficult issues such as the subsurface sequestration of waste carbon, hydraulic fracturing ('fracking'), or enforcement of standards and regulations for construction on flood plains and coastal areas will remain elusive. Special attention will need to be given to social-media approaches and modern methods to present Earth Science and Engineering concepts in a manner that is meaningful to citizens who do not have scientific backgrounds.

A STRATEGIC PLAN FOR THE GEOLOGICAL SURVEY OF CANADA FOR 2018–2023

The first goal for the GSC stated in its new five-year strategic plan (Geological Survey of Canada 2018) is the sustainable development of Canada's natural resources. This links the long-established mandate of understanding Canada's remarkable geology to the practical application of such knowledge to generate socio-economic benefits through sustainable resource development and environmental protection. This continues the long tradition of scientific research to understand geological processes and develop new scientific methods, and combines it with the use of new technological methods for surveying and detection. We will continue to develop the core geoscience knowledge that will remain critical to the success of sustainable mineral exploration, support the development of low carbon energy such as geothermal, and inform land decisions regarding the management and protection of water resources. The geoscience data from such efforts is also critical to other stakeholders, such as indigenous peoples and communities that need such knowledge to manage their land base and make decisions about mineral and other resource developments, and understand the impact and cumulative effects of development.

A second important goal for the GSC is to continue investigations aimed at natural hazard risk reduction, including floods, earthquakes and landslides, to reduce the steadily increasing human and infrastructure costs of natural disasters in Canada. In addition to potential hazards related to the natural geological environment, we must increasingly assess the effects of climate change on the potential for such events, and on the vulnerability of affected locations.

A third objective for the GSC is to pursue the advancement of framework geoscience knowledge, in the form of targeted maps and ancillary databases, to provide a sound basis for decision-making and policy initiatives for both onshore and offshore areas. The initial objectives include first completing the Geomapping for Energy and Minerals (GEM) program aimed at Canada's northern regions, and completing Canada's submission to the UN Commission on the Limits of the Continental Shelf. The GSC's role in marine geology is a very important one, and is well illustrated by Figure 9, which highlights our cooperation with Sweden, even in the face of the legendary rivalry of our countries in ice hockey! In the longer term, we seek to develop the terms of a new flagship public geoscience program that could be delivered jointly with provinces, territories, and universities.

In all these areas, the GSC intends to remain at the leading edge. Just as we pioneered protocols for the use of portable XRF in the field, and have been a leader in remote predictive

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Figure 9. (a): Photograph of the Canadian icebreaker Louis St. Laurent and the Swedish icebreaker Oden near the North Pole in 2016. These ships and their Geological Survey of Canada-led scientific crews took part in the last of several joint international survey expeditions to the Arctic Ocean that advance the state of knowledge of this remote region, and secure geological and bathymetric data required by the United Nations in order to prepare the upcoming 2019 Arctic Ocean extended continental shelf submission by Canada under the United Nations Charter Law of the Sea, Article 76. (b) Some of the crew involved in this expedition. Photo credits: Asa Lindgen (a) and Lars Lehnert (b).

mapping and 3-D mapping, we will continue to make new investments in the application of artificial intelligence, geo-modelling, and the wider uses of geoscience in tackling controversial environmental and societal problems. In working toward the implementation a new strategic plan (Fig. 10), we will engage with Canada's geoscience community to help address the issues of today and the many exciting challenges of tomorrow.

Figure 10. The main goals of the 2018–2023 Strategic Plan of the Geological Survey of Canada (Geological Survey of Canada 2018).

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As the world changes around us, we will change with it; we will "skate to where the puck is going to be", not where it is now. In the process we wish to develop partnerships with other leading scientific organizations in Canada to identify new areas where science can contribute to Canada's economic, environmental and social well-being.

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