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Geothermal Energy in Canada – Times Are "a Changing"

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ABSTRACT

Geothermal research and exploration in Canada have a long and rich history with many prominent and important early researchers, explorers and developers who worked within Canada and abroad. Geothermal Canada was launched in 1973 as the Canadian Geothermal Association and has been dedicated since that time to supporting the geothermal community in Canada. Now after more than 40 years along, the geothermal landscape is finally beginning to change and it is important to review the current and recent projects, research, and initiatives. Vibrant research groups exist through universities across the country; 464 scientific publications on geothermal energy written by Canadian researchers are reported in Scopus from 2014 to 2018. The focus is on resource assessment, direct-use and adapting technology for remote communities located in arctic to subarctic climatic zones. Provincial governments in Alberta, British Columbia, Nova Scotia, Nunavut, Saskatchewan, and Quebec are supporting projects along with the exchange of ideas. In Canada's north, including the Yukon, Nunavut, Nunavik and the Northwest Territories, there are initiatives to assess the geothermal potential, especially through engineered geothermal systems (EGS), and to support research for development challenges in extreme environments. Canada's federal government, through Natural Resources Canada, awarded a 25.6-million-dollar contribution grant to the DEEP Corp. project in Saskatchewan, and in Alberta a 25.4-million-dollar contribution grant was awarded to Alberta No. 1. Additionally, the Geological Survey of Canada continues to support geothermal research. As the global landscape continues to evolve away from hydrocarbons for heating and electricity generation, Canada is well-placed to fill in the gap mostly with thermal energy, and some more limited electrical generation from sedimentary basins, deep fault and volcanic systems, as well as to be a leader in EGS. Canadian

scientists and engineers are poised to make significant contributions both here in Canada and globally.

1. Introduction

Located in the higher latitudes of the northern hemisphere, Canada has very high heating loads and is prime for geothermal development, in particular, direct-use. Much of the Canadian landmass experiences arctic to subarctic climatic conditions with areas of continuous permafrost and high heating loads that exceed 7000 degree-days. With a mean annual temperature of 1°C, it is ripe for large-scale geothermal development (Figure 1). This significant heating requirement, coupled with a transitioning of the hydrocarbon economy and a need to reduce greenhouse gases, has poised Canada to start seriously looking into geothermal energy.

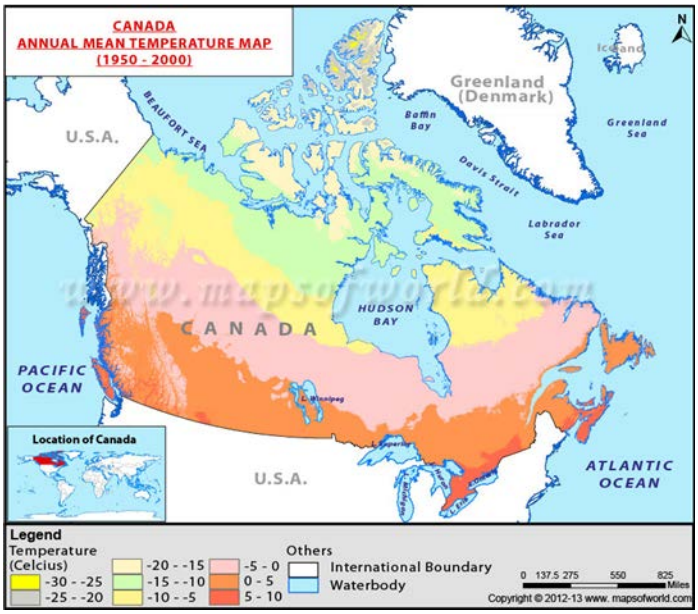


Figure 1: Canada's mean annual temperature is approximately 1°C (Maps of World 2012).

Canada is already a leader in geoexchange (shallow heat pumps) deployment but has lagged in deep geothermal direct-use and power generation.

In Canada, the perception of high costs and the fact that less than 2% of Canada's landmass has access to high quality geothermal fluids that can be pumped at high rates (>90°C, >100 L/s) (Figure 2) has hindered the industry. Sedimentary basins, and in particular the Western Canada Sedimentary Basin (WCSB), are massive hydrocarbon resources and are heavily extracted. According to Natural Resources Canada (NRCan) in 2019, Canada's energy sector directly employed more than 269,000 people and indirectly supported over 550,500 jobs; the energy sector accounts for over 11% of nominal Gross Domestic Product (GDP); government revenues from energy were $14.1 billion in 2017 and more than $799 million was spent on energy research, development, and deployment by governments in 2017-18. Prior to the current pandemic situation, Canada was the sixth largest energy producer, the fifth largest net exporter, and the eighth largest consumer of energy globally. These facts, along with the unknown impacts of geothermal production alongside hydrocarbons, make geothermal a hard sell in Canada. However, with the duel impact of plummeting oil prices and the economic impact of COVID-19, Canada is uniquely positioned to take advantage of its own geothermal resources, idle rigs and crews, as well as export its knowledge and technology for drilling, pumping, handling massive quantities of hot water, and development in extreme climates, globally.

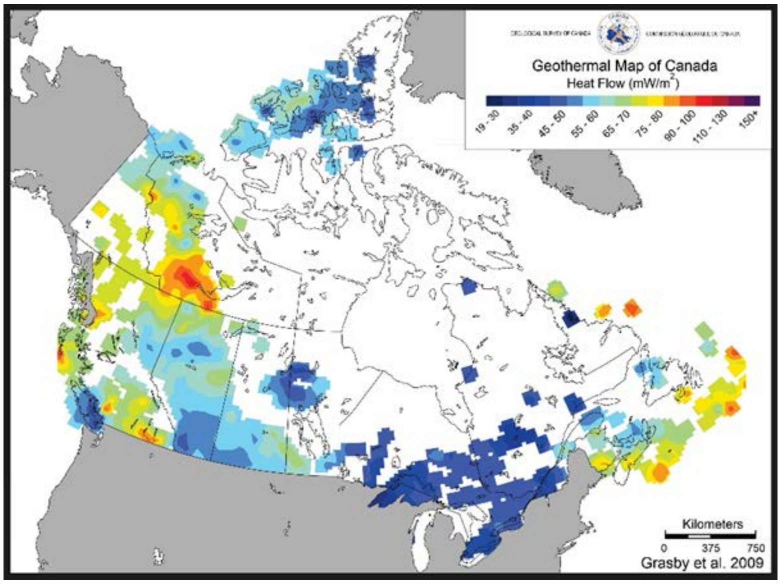


Figure 2: Geothermal map of Canada (Grasby et al. 2009). White areas represent no data, but in central and eastern Canada characterize areas underlain by metamorphic and granitic rocks of the Canadian Shield.

The Government of Canada and many of the provinces and territories are heeding the voices of the populace and making commitments in the field of renewable energy. Governments have stepped up funding geothermal research, development, and innovation (RD&I) over the past three years. In the western basins where the sediments are deep enough and hot enough for power generation, two projects have been funded (Alberta No. 1, Alberta; DEEP Corp. Saskatchewan). Funding is through NRCan's Emerging Renewable Power Program (ERPP). Although these projects are small in terms of proposed electrical power output, they are the test beds for expansion and were awarded from a pool of renewable projects where no extra value was awarded to geothermal projects for base load or heat generation.

However, Canada is a vast country and although high quality resources are found in some parts of Canada (Figure 2), more than 90% of the landmass underlain by crystalline rocks is unsuitable for conventional geothermal development. It is these crystalline rocks that make up what is termed geologically the "Canadian Shield" (Figure 2; Figure 3) and that offer a significant RD&I challenge for Canadian geothermal projects. Combined with very high heat load requirements over much of this region (Figure 1), there is clear impetus for Canadians to invest in engineered geothermal systems (EGS) and cold environment adaptations for geothermal technology. Even subsurface waters a few tens of degrees above zero, present a very significant temperature difference (ΔT) that can be usefully used for heat energy. Developing this technology, along with supporting traditional projects to help the energy transition, is the challenge for governments across Canada.

This paper outlines some of the progress and work done in Canada and abroad by Canadians and Canadian companies and organizations in pursuit of geothermal energy generation – both for electricity and heat.

Figure 3: Researcher from INRS investigates physical rock properties of typical Canadian Shield rocks near Kuujjuaq, Nunavik, Quebec.

2. Academic Research and Education Initiatives

2.1 Geothermal Research and Study Programs at Canadian Universities (contributed by Mafalda Miranda (mfldmiranda@gmail.com))

Several Canadian universities are active with geothermal programs and research, development and innovation (RD&I) projects. Many of these programs are funded in part by Canadian federal grants through the National Science and Engineering Council of Canada (NSERC) in addition to university, provincial and territorial support. Among these, Table 1 highlights the research carried out by Institut national de la recherche scientifique in partnership with Université Laval and École de Technologie Supérieure, the Geothermics Research Group of the University of Alberta, the University of Manitoba, the Vancouver Island University, and the Concordia University. Beyond these universities, several others offer undergraduate and/or graduate programs with options to pursue research within the geothermal energy field.

Table 1. Summary of Canadian universities with active geothermal R&D projects

University	Programs and research projects
Institut National de la Recherche Scientifique (INRS)	Geothermal research program • Aquifers: a natural infrastructure for energy-efficient cooling to fight the urban heat island • Northern geothermal potential research chair • Geothermal resources and technologies for active and closed mines • Analysis of heat transfer processes in favorable geothermal environments • The Grenville Province of southern Quebec: geophysical interpretations and implications for deep geothermal and regional correlations
University of Alberta	Geothermics Research Group: • Imaging, characterizing and modelling Canada's geothermal resources • Fluid/rock interactions in Canada's geothermal systems • Optimizing geothermal energy production and utilization technology • Socio-economic roadmaps to commercial geothermal energy production in Western Canada
University of Manitoba	Groundwater Engineering program: • Geothermal behaviour of the @Source-Energy Pipe System • University of Manitoba Efficient and Renewable Technology Hub (UMEARTH)
Vancouver Island University	Nanaimo campus • District Geo-Exchange Energy System—Phase I
Concordia University	Sustainable Energy and Infrastructure Systems Engineering (SEISE) lab: • Identification of the technical and economic feasibility of geothermal systems in northern Québec region
University of Waterloo	Waterloo Institute for Sustainable Energy • Tools for analyzing power flow of modern microgrids • Compressed air calculations offer energy storage insights • Solutions for greener energy and potable water • Integrating local community knowledge into transitions from fossil fuel to renewable energy systems

2.2 Review of Canadian Scientific Publications Made During the Last 5 Years (contributed by Jasmin Raymond (jasmin.raymond@inrs.ca))

A Scopus search with ‘’geothermal’’ in keywords, title and abstract revealed that 11,872 documents have been published in this field over the past five years, from the beginning of 2014 until the end of 2018. Publications were sorted according to country affiliation of authors. Canada is ranked seven, with 464 publications, after the six countries with most contributions to the geothermal literature over the past five years, namely the United States of America (2,498), China (2,055), Germany (999), Italy (775), United Kingdom (571) and Japan (498). Hence, the Canadian contribution to geothermal science remains outstanding, given that the population of Canada is smaller than all of the above countries, and that geothermal power is not yet produced in Canada, although geothermal direct-use is widespread with utilization of geothermal heat pumps from coast to coast.

The Ontario Tech University, University of Alberta, University of Calgary, University of British Columbia, McGill University, Polytechnique de Montréal, École de Technologie Supérieure, Institut national de la recherche scientifique, Natural Resources Canada and Université Laval are the top ten institutions that published geothermal studies (Figure 4). Broad subject categories of interest to the Canadian geothermal literature are earth and planetary sciences with 29% of publications, followed by energy (26%), engineering (16%), environmental science (13%) and other fields (16%) including agricultural and biological sciences, physics, chemistry, mathematics and computer science, just to name a few.

The publications released by authors with Canadian affiliations that attracted the most interest were evaluated with the number of citations cumulated until July 2019 for each year of publication in the three major subject categories mentioned above. Topics of the papers with high impact concern geothermal heat pump systems, high to low temperature geothermal power plants, geological setting associated to both shallow and deep geothermal resources, renewable and sustainable energy solutions in which geothermal is an important component, as well as integration of geothermal energy in the oil and gas sector. A non-exhaustive review limited to peer reviewed articles in scientific journals is given to identify important research trends.

In terms of important research trends in the earth and planetary sciences category, the work of Dehkordi and Schincariol (2014; 30 citations) on the performance of closed-loop ground heat exchangers impacted by groundwater flow was highly cited. Crustal stress orientation with implications for deep geothermal systems (Reiter et al. 2014; 34 citations), hydrothermal degassing of magma chambers (Kennedy et al. 2016; 33 citations), prediction of ground surface temperature (Ouzzane et al. 2015; 29 citations) and heavy metals in hydrothermal systems (Tardani et al. 2017; 19 citations) were also topics of highly cited journal articles. Work conducted on a decision-making scheme for renewable power (Al Garni et al. 2016; 55 citations), hot water generation for oil sands processing from enhanced geothermal systems (Hofmann et al. 2014a and b; 53 citations) and energetic studies of multigenerational solar-geothermal systems (Al-Ali and Dincer 2014; 52 citations) were of most interest for articles in the energy subject category.

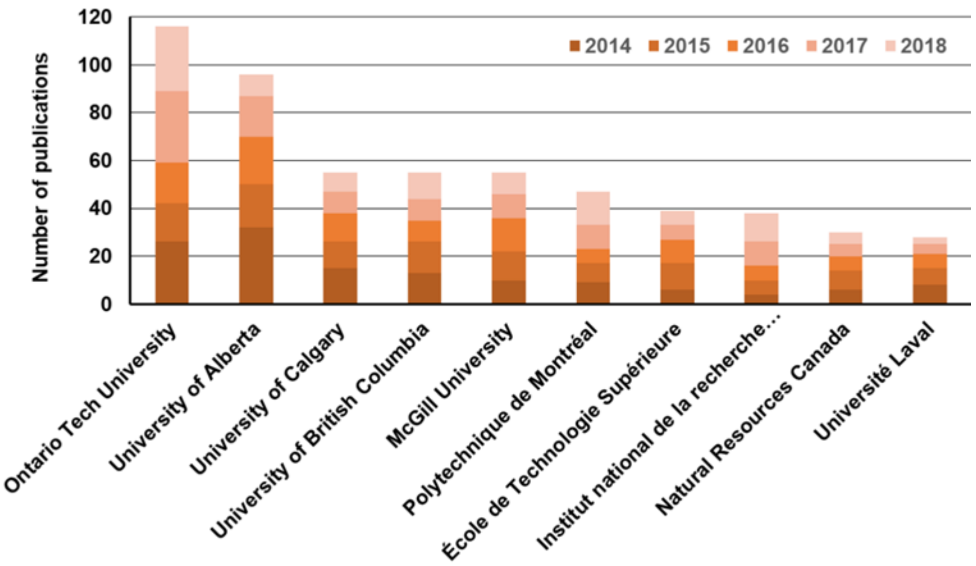


Figure 4: Number of geothermal publications released by the most active Canadian institutions in this field over the past five years.

Cited studies in the engineering category were related to the simulation of ground heat exchangers with a heat injection rate varying along segments of boreholes (Cimmino and Bernier 2014; 61 citations), methods to design geothermal heat pump systems based on cost minimization (Robert and Gosselin 2014; 37 citations) and abandoned petroleum wells as sustainable sources of geothermal energy (Templeton et al. 2014; 33 citations). Dincer and Acar (2015; 127 citations) further completed a study that rates geothermal as the most sustainable energy alternative for power generation when combining economic and environmental factors, such as land use, water contamination and waste issues. All these studies, contributing to a diversified Canadian geothermal literature, clearly show the importance and potential of geothermal energy, which is expected to increase its shares in the future Canadian energy budget to decrease greenhouse gas emissions and reduce the environmental impact of energy production.

2.3 Institut national de la recherche scientifique (INRS) (Contributed by Jasmin Raymond (jasmin.raymond@inrs.ca) and Mafalda Miranda (mfldmiranda@gmail.com))

The Centre Eau Terre Environnement of the Institut national de la recherche scientifique based in Quebec City developed a geothermal research program over the past five years. The objective of the research was to improve the understanding of heat transfer mechanisms that impact the performance of both shallow and deep geothermal system operations in order to reduce installation cost and develop competitive geothermal technologies. A core laboratory to characterize thermal and hydraulic properties of geological materials, named LOG (Laboratoire Ouvert de Géothermie), was put in place with major funding from the Canadian Foundation for Innovation and has been operated in an open source fashion. A research chair supported by the Institut nordique du Québec to study the northern geothermal potential was additionally awarded to INRS.

At INRS, significant scientific developments were achieved in the field of thermal response tests to design geothermal heat pump systems (Koubikana Pambou et al. 2019; Raymond et al. 2014, 2015a, 2016; Raymond et al. 2019; Raymond and Lamarche, 2014; Rouleau et al. 2016; Vélez Márquez et al. 2018), improving the field tests with alternative approaches using heating cables or temperature profiles to better characterize subsurface heterogeneities and the impact of groundwater flow. Work was also made to map the subsurface thermal conductivity distribution and put forward a new a thermostratigraphic concept helping to design geothermal heat pump systems (Raymond et al. 2017, 2019), or decrease the borehole thermal resistance of ground heat exchangers with alternative pipe configurations (Raymond et al. 2015b; Lamarche et al. 2018). This work is to better constrain the length of boreholes and potentially reduce system installation cost.

Sedimentary basins of eastern Canada, such as the St. Lawrence Lowlands, were studied to assess deep geothermal resources suitable for power generation with regional heat transfer models and geophysical well log analysis (Bédard et al. 2014, 2017; Nasr et al. 2018; Langevin et al. 2019; Gascuel et al. 2020). This work has revealed target anomalies with a geothermal gradient as high as 40°C/km. Further studies were conducted to image reservoir properties such as macro porosity distribution with innovative X-ray scanning techniques of dry and saturated core samples (Larmagnat et al. 2019).

The potential development of geothermal heat pumps, thermal energy storage and deep enhanced (engineered) geothermal (EGS) systems in the cold climate of the Canadian Arctic is being studied. The region of focus is Nunavik (Belzile et al. 2017; Comeau et al. 2017; Giordano et al. 2018). Overburden and bedrock thermohydraulic properties near Kuujjuaq were assessed to conduct simulations (Figure 3). These studies show, despite the unbalanced heating loads and an energy demand above 8000 heating degree days below 18°C, that geothermal heat pump systems can be operated in such a subarctic climate. Thermal energy storage can provide space heating to reduce diesel consumption even though solar radiation varies seasonally (Giordano and Raymond 2019) and EGS may be a long-term option for heat and power (Miranda et al. 2018; 2020).

2.4 University of Saskatchewan (contributed by Grant Ferguson (grant.ferguson@usask.ca))

The University of Saskatchewan hydrogeology group has been involved in a series of projects related to geothermal energy. A focus of many of these projects has been to characterize the hydrogeologic properties of various formations within the Western Canada Sedimentary Basin. The permeability of the Cambrian/Ordovician Deadwood Formation and Ordovician Winnipeg Formation, which are currently a target for the Deep Earth Energy Production (DEEP) geothermal project, were characterized in a recent project. The Red River Formation, which may also have geothermal potential, was also characterized in a recent joint project with the Geological Survey of Canada. The permeabilities of various shallower strata have been characterized at a regional scale. Those formations could become important for direct-use projects or for disposal of brines from deeper geothermal energy projects.

In addition to the above-mentioned projects assessing hydrogeologic properties, regional scale assessments of fluid movement are underway as part of a Global Water Futures project. While there is enormous geothermal potential in sedimentary basins, widespread development will require coordination with the oil and gas industry, and consideration of induced seismicity, in addition to the overlying groundwater resources.

2.5 University of Alberta (contributed by Jonathan Banks (jbanks@ualberta.ca) and Martyn Unsworth (unsworth@ualberta.ca))

Pioneering work by University of Alberta (U of A) researcher Dr. Jacek Majorowicz has laid the foundation for the development of geothermal resources in the WCSB (Figure 5). His work and the work of colleagues over several decades is reflected in what we as Canadians know about heat flow in Canada (Figure 1; cf. Grasby et al. 2009; Gray et al. 2012; Jones and Majorowicz 1987; Jones et al. 1985; Majorowicz and Grasby 2010 and 2019; Majorowicz and Jessop 1981; Majorowicz and Moore 2014; Majorowicz et al. 1999). A 2014 publication (Weides and Majorowicz 2014) elegantly outlines the potential of the WCSB for geothermal development (Figure 6).

Building on the foundation of early work at the U of A, the past five years has seen the geothermal energy research program at the U of A evolve from a small group of individual researchers working independently from one another to a unified program spanning five university faculties. This research program is supported through the U of A's Future Energy Systems program (part of the Canada First Research Excellence Fund), with matching and in-kind support from various provincial and local municipal agencies, as well as several industry partners. Cumulatively, the research program is backed by ~$7.5 million in funding through 2023. Research carried out in the program is led by ten co-principal investigators and currently employs about 30 students, post-doctoral fellows and research associates. Research within the program is divided into 4 discrete projects.

Four major projects are the focus of most of the work at the U of A. The first project is focused on identifying and characterizing geothermal resources within the Canadian Cordillera, with target areas in the Rocky Mountain Trench (SE British Columbia), the Tintina Fault (central Yukon) and the Garibaldi Volcanic Belt (SW British Columbia). The second project is focused on exploitation of geothermal resources within the Western Canadian Sedimentary Basin Within the context of this project, the University of Alberta has established a new, state-of-the-art fluid/rock interaction laboratory.

The aim of the third project is to develop novel uses of low-enthalpy geothermal resources. This project has two main areas. The first area involves the development of Stirling engines for geothermal applications. Stirling engines are externally heated, closed cycle heat engines capable of running at 0.5ºC temperature differences. The prototype engines are designed to economically produce electrical power in the 60˚C – 90˚C temperature range. To facilitate the repurposing of the hundreds of thousands of deep wells in the Western Canadian Sedimentary Basin, the second area of this project is focused on the development of deep borehole heat exchangers and novel commercial uses for low-grade heat in cold climates. The fourth project focuses on the socio-economic factors involved with bringing geothermal power to communities. Research in this project focuses on assisting remote and northern communities, as well as communities looking to diversify their hydrocarbon economies, with geothermal power for heat and electricity. Researchers in this project also help mediate negotiated settlements between municipalities and geothermal energy developers. This process provides an opportunity for longitudinal studies on how communities adopt renewable technologies.

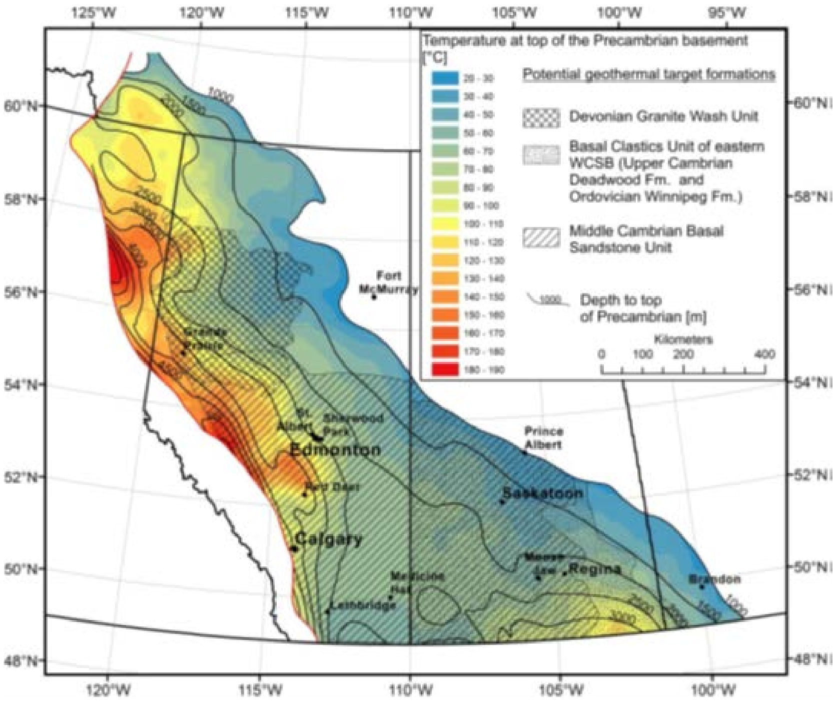


Figure 5: Temperature at the top of the Precambrian basement with potential geothermal target formations. The Precambrian basement is one of the key target zones for development in the WCSB (Figure 5 from Weides and Majorowicz 2014).

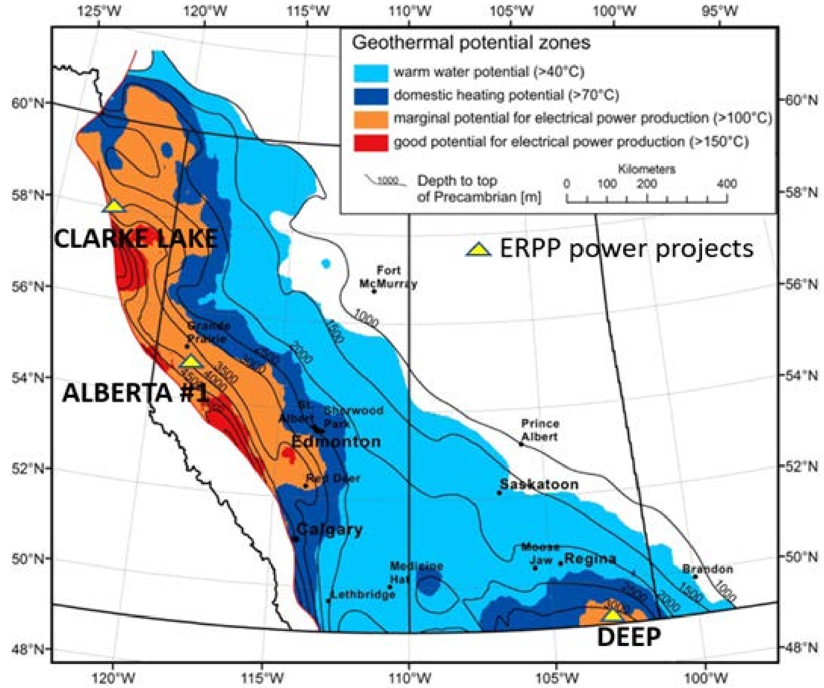


Figure 6: Possible geothermal applications based on the temperature at the top of the Precambrian basement. Also shown as yellow triangles are the three power development projects currently underway in the WCSB (adapted from Weides and Majorowicz 2014, their Figure 13).

2.6 University of Waterloo (Contributed by Maurice Dusseault (mauriced@uwaterloo.ca))

The University of Waterloo (UW) is pursuing the concept of smart hybrid integrated geothermal systems (SHIGS), with a focus on remote communities in Canada’s north (north of where the mean annual temperature is -30 to -25°C; Figure 1). The department noted that high-grade geothermal is available for less than 2% of Canada’s landmass, and that warm fluids at high rates (>90°C, >100 L/s) are generally only available in the western basins where the sediments are deep enough. Therefore, UW decided to limit their geothermal research domain to the rest of Canada (90% of the land area), which includesareas underlain by strong, low-porosity igneous and sedimentary rocks (for example Toronto, Montréal, Halifax, Vancouver, Iqaluit, Yellowknife, and Winnipeg).

The SHIGS that the department is studying involve both shallow and deep aspects. The deep case arises when a reasonably large temperature difference (ΔT) is needed to generate power and supply heat, in some proportion. For example, if temperatures of 60°C can be accessed at depth or in a thermal repository, organic Rankine Cycle (ORC) engines can provide some power for lights and appliances. The shallow geothermal aspect is the implementation of a ground source heat pump and heat repository system so that heat can be stored and used seasonally. To the knowledge of the researchers, this integration is a novel direction, and they are trying to work out all the energy issues (energy production, rates, storage, recovery, etc.). The hybrid aspect is the same as for a hybrid (EV) car: storage of energy for maximum utility, although the scale is different. For EV the storage period is minutes, but for geothermal it would be seasonal. The smart part of SHIGS is the need for sensors and software to optimize the energy available for the particular end-user and climate conditions. Sensor data would be transmitted through the internet to more central locations for smart surveillance and smart decision-making. Because of the vast differences in climate between July and January, systems must operate over a wide range of power and heat demands.

The hybrid car analogy is worth explaining in more detail. Figure 7 clarifies: 1) the concept of a hybrid system (i.e., a system with energy conversion and storage); 2) the hybrid car with a gasoline engine and a battery; and, 3) the hybrid geothermal system. Figure 7(a) could have included a plug-in recharger for the hybrid car, just as we “plugged in” some available waste heat in the SHIGS system (Figure 7(b)) to recharge it seasonally. Figure 7(c), shows the ORC power engine must be able to operate at its peak efficiency in the coldest months, so the optimization approaches must be geared to this period, but for effectiveness, waste heat is not discarded, it is stored whenever possible. The analogy with a hybrid car is clear, but the geothermal system is more complex because of different energy sources, a dramatic seasonality in the energy needs, and the additional complexity associated with geological systems.

In summary, for isolated communities in the north, where the the sun is dark for many months and wind power is not baseload, there are few viable renewable energy options available for the full year. Researchers at UW believe that the SHIGS approach may provide part of the solution to the need for reliable, resilient local energy management in the north, for civilian and for military needs.

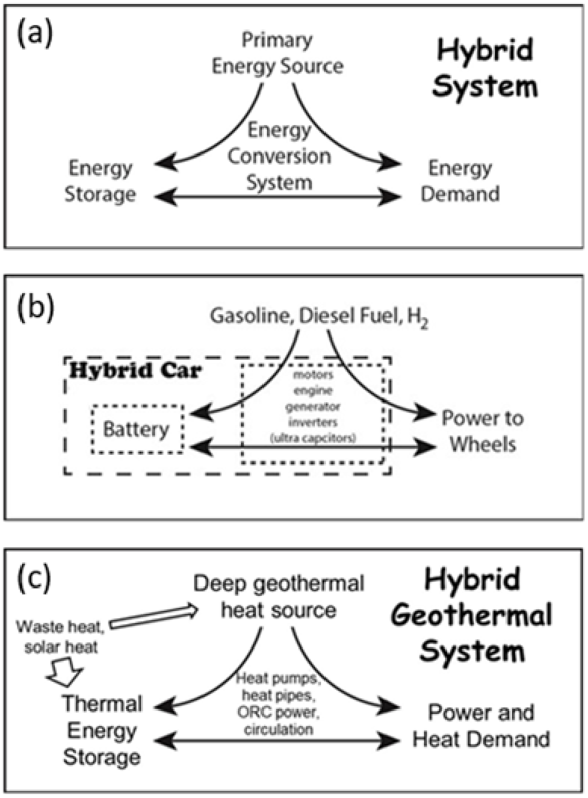


Figure 7: (a) The Hybrid System Concept: Sources – Conversion – Storage – Uses; (b) a hybrid system using a battery for energy storage; (c) a hybrid geothermal system

3. Provincial and Territorial Government Activities and Projects

3.1 Alberta (Contribution by Katie Huang (katieyhuang@gmail.com)

Despite the lack of regulatory framework for drilling geothermal wells in Alberta, there are still several ongoing projects in the province. Tech company Eavor, based out of Calgary, AB, recently announced grants and partnerships to develop a demonstration facility of their closed-loop technology. Among the partners for this CDN$10 M project are the Shell New Energies Research and Technology Team and the Government of Canada via the Natural Resources Canada’s Clean Growth Program and Sustainable Development Technology Canada. Additional updates on Eavor can be found on their website https://eavor.com/.

Razor Energy Corp., another Calgary based company, has also announced funding for a geothermal project in northern Alberta. A $5 million contribution from NRCan’s Clean Growth Program, and a $2 million contribution from Alberta Innovates, demonstrates a commitment by both levels of government to cleaner energy creation. Under the terms of the contribution agreements, NRCan and Alberta Innovates will assist Razor’s development of a technically viable and commercially sustainable solution to recover geothermal waste heat from its hydrocarbon wells. Further updates can be found on their website https://www.razor-energy.com/.

The Municipal district of Greenview (MDGV), located in west-central Alberta has also been working on geothermal initiatives. It commissioned a study of the potential of the Fox Creek area to Terrapin Geothermics (Terrapin), an Edmonton-based company. Terrapin followed this with other studies for local governments including the City of Grande Prairie. The culmination of this work was an application by Terrapin and MDGV to the ERPP funding program (Hickson et al. 2018a) which resulted in a 25.4-million-dollar contribution grant awarded to the Alberta No. 1 project (Figure 6).

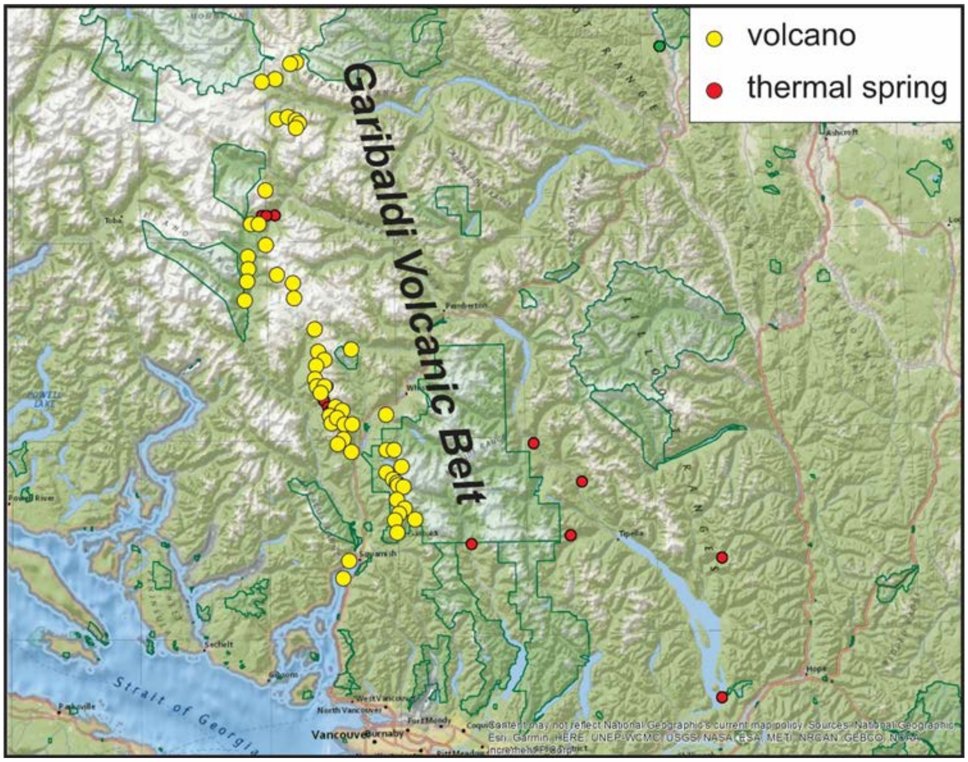
These projects have been built upon over several decades of research for geothermal potential in the province (i.e., Bachu 1988; Gray et al. 2012; Weides et al. 2013; Hofmann et al. 2014a and b; etc.). This research has identified low-medium grade geothermal resources throughout Alberta with high potential for direct heat use as well as EGS.

3.2 British Columbia (contributed by Bastien Poux (bastien.poux@gmail.com))

Geothermal energy exploration got its kick-off in British Columbia's high temperature geothermal systems. In particular, the volcanic Mount Meager (part of the Garibaldi Volcanic Belt), with extensive hot springs, was an early target where exploration took place for more than a decade (Hickson 2017). This volcanic massif is in southern British Columbia and is the site of BC's only wide diameter geothermal drilling. It continues to be of exploration interest today due to the high temperatures (up to 260°C) reached in some of the wells. There are now seven wells, six of which are on a lease held by Toronto-based Polaris Infrastructure. Of these wells, MC1 successfully supported a 250-kW power pilot plant tested for 40 days in 1984. Polaris is interested in ways that the wells and lease area could be used for research purposes. A workshop was held October 13, 2018 to review the available information on the system (Hickson et al. 2018b).

Geoscience BC (GBC), an arms-length entity from government, is a not-for-profit geoscience organization, that has dispersed close to CDN$1Million dollars in research funds since inception of the program. Despite the long history of BC projects and high-quality resources such as Mount Meager, geothermal power generation projects have not advanced in British Columbia over the past decade. In 2016, GBC decided to expand its focus from high temperature systems to also include direct-use. Several projects were funded to provide a roadmap for communities to follow in order to help them initiate and carry out geothermal projects (Hickson et. al. 2017). A website was also established with training material to help developers (Hickson and Proenza 2017).

In 2019 GBC contributed CDN$500,000 in funding along with provincial and federal contributions to a new project in the Garibaldi Volcanic Belt (Grasby 2019; Geoscience BC 2019; Figure 8). This belt, which includes Mount Meager, will focus on reducing the exploration risk in one of the highest potential geothermal regions of Canada. NRCan's Geological Survey of Canada (GSC) is the lead agency while GBC as well as NRCan's Renewable Energy Development Initiative program are providing funding. The project is working with academic partners to apply a range of geoscience tools, including remote sensing, geophysics, tectonics, volcanology, and geochemistry, to better understand the controls on rock permeability while developing new predictive tools for finding permeable aquifers at depth.



Content may not reflect National Geographic's current map policy. Sources: National Geographic, Esri, Garmin, HERE, UNEP-WCMC, USGS, NASA, ESA, METI, NRCAN, GEBCO, NOAA, increment P Corp.

Figure 8: Generalized map of the Garibaldi Volcanic Belt volcanoes (yellow) and known thermal springs (red).

A techno-economic assessment of geothermal energy resources in the sedimentary basin in northeastern British Columbia was also completed by researchers from The University of Victoria who evaluated four areas favourable for geothermal development. The sites are at Horn River, Clarke Lake, Prophet River and Jedney. In the Clarke Lake Gas Field Reservoir Characterization report, researchers from the University of Alberta analysed the potential of the depleted Clarke Lake natural gas field for its potential as a geothermal reservoir. It has been the focus of several other technical studies funded by GBC (Arellano 2018; Palmer-Wilson et al. 2018a; Renaud et al. 2018).

In addition to these research undertakings, two companies are working on commercial development activities in British Columbia. One of these is focused on the Clarke Lake Field (Figure 6) mentioned above. The reservoir is located adjacent to the town of Fort Nelson, a northern Canadian town with long cold winters. The Indigenous people of the region are the Fort Nelson First Nation and it is they who are the proponents for the Clarke Lake Geothermal Project. For this project, NRCan has funded a "Conceptual Design and Feasibility Assessment" through one of its national programs. The other projects are close to the towns of Terrace and Valemount and are being developed by Borealis GeoPower (Borealis). The Lakelse Project is partnered with the Kitselas First Nations and the company reports that a core drilling and field program is in progress. The Canoe Reach project has been dubbed "Sustanaville". See the Borealis website for the latest updates on their project.

3.3 Saskatchewan (contributed by Janis Dale (janis.dale@uregina.ca) & Brian Brunskill (brianbrunskill@sasktel.net))

The success story for geothermal electricity projects in Canada is the DEEP geothermal power project in southern Saskatchewan (Figure 6). The project is being supported by ERPP funding along with private sector investors. The first-of-a-kind in Canada, this Private-Public partnership project is a few miles north of the United States border. In December 2018, DEEP successfully drilled their first geothermal test well. The vertical well reached its target total depth of 3,530m, making it the deepest well ever drilled in Saskatchewan's history. Preliminary data, acquired to assess the geothermal reservoir, indicate bottom-hole temperatures exceeding 125˚C, in addition to positive reservoir pressure and permeability exceeding the minimum threshold for project feasibility. During the 2019-2020 winter season, DEEP completed four more exploration wells to further define the geothermal field reservoir parameters and test 3D seismic and airborne geophysical data. Flow and injectivity testing will be conducted during the summer of 2020. This data will be incorporated into a full-scale simulation model to determine optimal well spacing and additional follow up drilling will be planned for later in the year.

This project builds on early direct-use projects in Saskatchewan. Along with Mount Meager in BC, federal and provincial funding focused on the University of Regina, which led to the drilling of a geothermal test well in the winter of 1978-79. The single test well was cased to 2034m, and open holed to 2226m. Over 40 papers and technical documents reporting on the efficiency of geothermal use for heating on the University of Regina campus have been written (U of R Energy Research Unit, Dr. Laurence Vigrass). The project was not completed, as the second well was never drilled, but very important results were obtained that impact future projects in the WCSB.

The project showed the importance of the "Basal Clastic Unit" of the WCSB (Figure 5). These rocks consist of interbedded sandstones and shales and are of Cambrian-Ordovician age, making up the Winnipeg and Deadwood formations, referred to as the "Deadwood Aquifer". The aquifer is widespread, although varies in geological character as well as temperature. This work has shown that the temperature of the water available at the wellhead on the U of R campus would have a temperature of 58 to 59°C when pumped at a rate of 60 to 100 m^3/h. Reservoir water is a sodium-chloride-sulphate brine with total dissolved solids of 108,500 g/m^3. Corrosion testing showed that the water contains little hydrogen sulphide and carbon dioxide and, if kept free of dissolved oxygen, is not aggressively corrosive (Vigrass et al. 2007).

Pumping tests were also very successful with an indicated productivity index estimated at 0.11 m^3/h per kPa of drawdown (Vigrass et al. 2007). It is known that the water in the Deadwood Aquifer is stagnant, moving likely at a rate of less than one metre per year. Modeling completed for the original well indicates that thermal breakthrough would occur after 35 years of continuous pumping. The geothermal system planned now considers greater pumping rates to increase system capacity, and greater separation between the wells to increase system longevity. Operating at 60% capacity the system can allow over 70 years of exploitation. With this technical knowledge completed, efforts are now underway to resurrect the project to heat Kisik Towers, a new residence, being built on campus.

3.4 Northwest Territories (contributed by Kathryn Fiess (Kathryn_Fiess@gov.nt.ca))

Recent federal and territorial government mandates to reduce GHG emissions associated with the use of diesel to generate electricity in remote communities has resulted in a renewed interest in the development of alternative renewable energy resources, including geothermal energy. The inclusion of this form of energy as a Northwest Territories Geological Survey (NTGS) research focus area will result in the delivery of the geoscience required to understand this resource and its potential contribution to NWT energy needs. To this end, NTGS has identified two geoscience project areas to focus research efforts. These project areas include Fort Liard and Yellowknife (Figure 9).

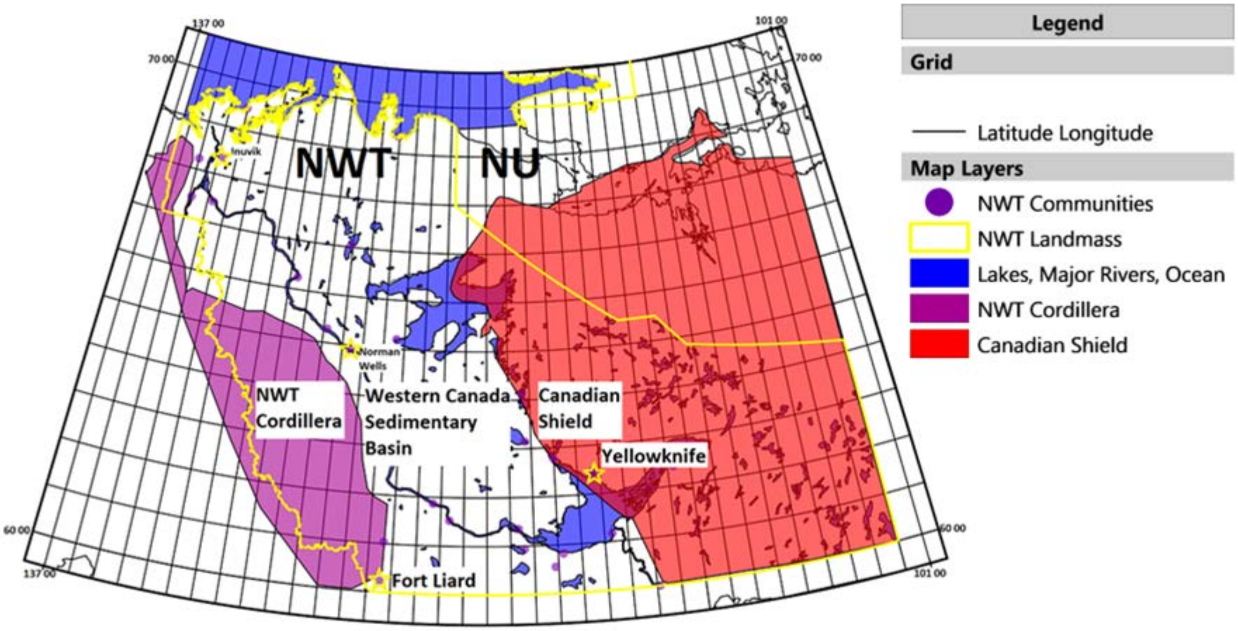


Figure 9: Location Map Northwest Territories (NWT) with outlined projects as yellow stars. Fort Liard is an area associated with deep saline aquifers and has been the focus of hydrocarbon exploration and extraction. (NU=Nunavut).

The hydrothermal resource potential in the Fort Liard area is associated with deep saline aquifers. Such aquifers occur in Paleozoic and Mesozoic age basinal sedimentary rocks that overlie the Precambrian basement in that region. Exploration well bottom-hole temperatures near Fort Liard also indicate that the region is characterized by a higher than normal geothermal gradient of approximately 33 to 37°C/km (Grasby et al. 2013; Figure 5). NTGS will conduct comprehensive reservoir characterization studies of potential resource and injector reservoirs using outcrop and core data, chip samples, geophysical well logs, regional bedrock mapping, and where available, gravity and magnetic susceptibility data. Seismic data will also be used to evaluate local structure and formation continuity, reservoir continuity (where possible), and formation depth and isopach mapping. Where relevant, resource volumes and productivity will be estimated. Reservoir risk associated with the potential resource and injector formations will also be evaluated.

The Con Mine, located in the City of Yellowknife (Figure 9), was the first gold mine developed in the Northwest Territories, Canada. Gold ore was actively mined from 1938 to 2003, and approximately five million ounces of gold were extracted from the mine. After the mine's closure, the City of Yellowknife contracted various technical studies during the early 2000s to examine the potential of the Con Mine as a geothermal heat source for the city. These studies determined that mine waters could have sufficient temperatures (up to and exceeding 30°C) to support a district heating project. NTGS has initiated a geoscience data gap analysis to identify additional research work required to assess project feasibility and geotechnical risk. In addition to these research studies, Borealis has a project under development around the Hamlet of Fort Liard. Their website reports that a Front End Engineering Design (FEED) study has been completed.

3.5 Nova Scotia (contributed by Catherine Hickson (cathie@ttgeo.ca))

In 2020 The Offshore Energy Research Association of Nova Scotia (OERA) put out a request for proposals to update the on-shore geothermal potential of Nova Scotia. As stated in the RFP, the project will "compile and review available information to provide a preliminary opinion on the potential for geothermal development in Nova Scotia and to characterize the favourability of geothermal resource development across the province". This objective is posed for two basic categories of geothermal resource: (i) electricity generation, and (ii) heat production from abandoned mines or mid-depth reservoirs. The project ends in 2020, with results possible by the time of the GRC.

Interestingly, the province hosts one of the most successful long-term geothermal projects in Canada. The Town of Springhill has been utilizing geothermal energy stored in abandoned, flooded mine caverns, since the late 1980s. The Cumberland Energy Authority and the Government of Canada have recently invested in the development of a mine water geothermal business park (https://www.cumberland-energy-authority.ca/minewater-geothermal-business-park-concept-design-underway.html) on the site.

3.6 Nunavut (contributed by Catherine Hickson (cathie@ttgeo.ca))

Nunavut, Canada's coldest jurisdiction (Figure 1) commissioned a geothermal feasibility study in 2018. This study was carried out by Saskatchewan-based Respec, and a geothermal favourability map for Nunavut (Minnick et al. 2018) was completed (Figure 10). Following completion of the report, the Qulliq Energy Corporation asked for a follow-up proposal (Hickson et. al. 2018a) to carry the initial work forward in specific communities (Figure 10). These communities have a higher than average heat flow or significant enough loads (supplied through diesel generation) that the economic and carbon offset potential of replacing some of this generation and heat energy through tapping deep geothermal resources are worth further investigation. The technical work proposed following Phase I was divided into a Phase II and Phase III plan. Phase II work was grouped into two parts: (1) additional data gathering to support the targeting of temperature gradient (TG) well drilling and (2) the drilling itself.

Respec won the Phase II contract and initiated work early in 2020. The proposed work in Nunavut as well as the work going in Nunavik are excellent platforms for technology advancement in Arctic Canada (cf. Raymond et al. 2015a and b). Technology challenges range from extreme temperatures to the challenges of permafrost.

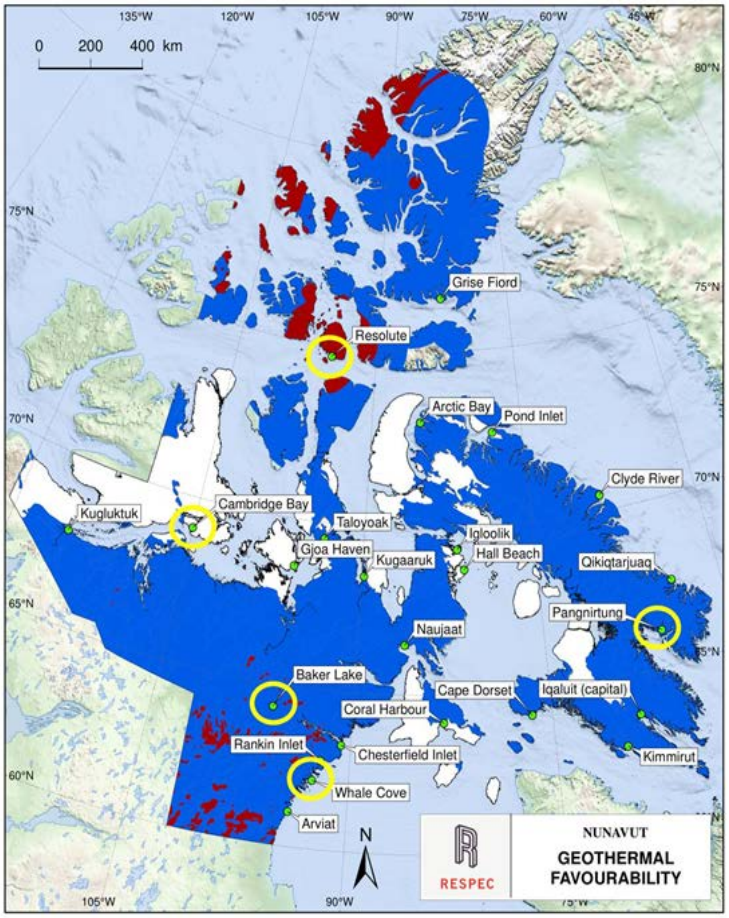


Figure 10: Geothermal favourability map for Nunavut (Topical Study RSI 2828) with the five targeted communities circled in yellow. Blue areas are typically underlain by crystalline rocks considered to have low potential by conventional technologies; white areas are underlain by sediments of the Arctic Basin and areas shown in red have inferred temperature gradients slightly above global averages.

3.7 Yukon (contributed by Tiffani Fraser (Tiffani.Fraser@gov.yk.ca))

Yukon Geological Survey (YGS) is evaluating the geothermal energy potential of the Yukon (Figure 11) to help determine the viability of developing these resources, primarily for communities not connected to the electrical grid and to offset hydrocarbon usage for space heating. All hydrocarbons used in the territory are trucked from the south.

Previous geothermal investigations in the Yukon include numerous regional and site-specific studies by the GSC (Grasby et al. 2012), Yukon Energy Corporation (unpublished studies) and the Canadian Geothermal Energy Association (CanGEA 2016). The current research builds on these studies and has four components:

- Modeling regional heat flow in the mid to shallow crust;
- Calculating potential heat production from young granites;
- Direct measurement of thermal gradient in ground temperature monitoring wells; and,
- Geophysical surveys over an active deep crustal fault structure.

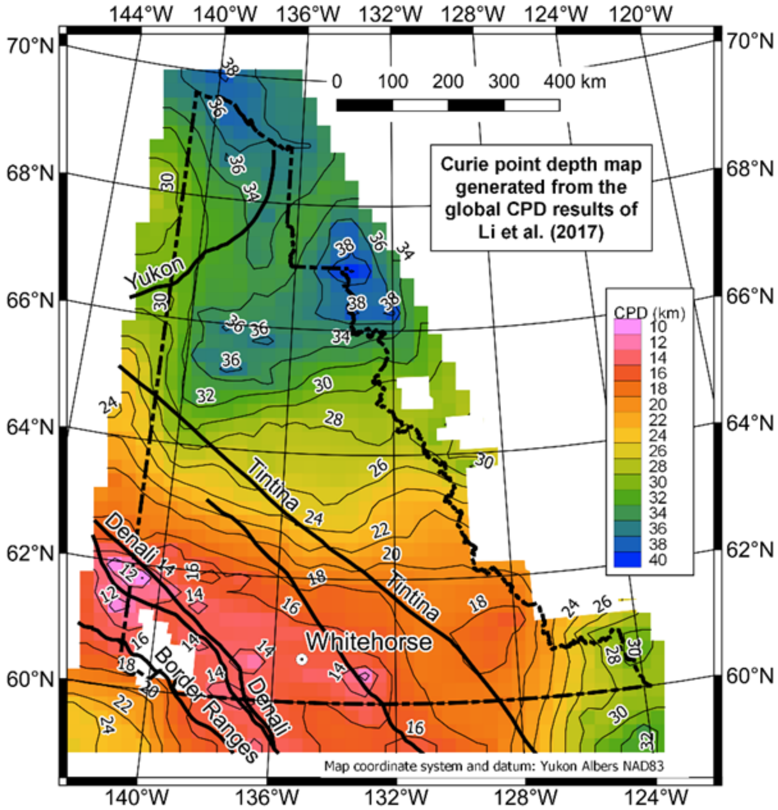


Figure 11: Yukon Curie point depth map. This map has been used to target additional investigations in Yukon (Witter et al. 2018).

Heat flow was modeled by Witter and Miller (2017) by calculating Curie point depths (CPD) using public domain regional aeromagnetic data from NRCan. CPD estimates were subsequently improved upon by Li et al. (2017; Figure 12) using a global EMAG2 magnetic dataset as discussed in Witter et al. (2018). The Curie point, defined as the temperature above which a magnetic substance loses its magnetic properties, corresponds to a temperature of roughly 580°C for the commonly occurring mineral magnetite. CPD calculated for Yukon correspond well with the heat flow map of Grasby et al. (2012), with the shallower CPD occurring across southern Yukon.

Additional, shallow sources of potential heat were identified by calculating the heat generated from the natural radiogenic decay of U, Th and K in granites. Using the technique of Rybach (1981), heat-production values were calculated from existing whole rock geochemical data. Granites in southern Yukon locally have significantly higher heat production values than "average" granites (over 10μW/m^3 vs. 2.45μW/m^3 for an average granite). Notable are Cretaceous granites which have higher heat generation values compared to younger Paleogene ones.

Direct ground temperature data were collected from two 500-metre-deep wells drilled between November 2017 and March 2018. One well is located midway between Takhini Hot Springs

(46°C surface water temperature) and a granite pluton that yielded a heat production value of 5.96µW/m^3. The granite is thought to provide a heat source to infiltrating meteoric waters, possibly in permeable carbonate rocks. The second well targeted the Tintina Fault, a major dextral strike-slip fault that transects the Yukon. This location was selected to assess whether enhanced permeability in the fault creates a locally-elevated geothermal gradient.

In 2019, the YGS acquired ground-based gravity and ELF-EM (Extremely Low Frequency Electro-Magnetics) data over a portion of the Denali Fault, near the community of Burwash Landing, southwest Yukon (a community which is diesel dependent for electricity). The purpose of the surveys was to: 1) help estimate the variations in thickness of glacial overburden and other Quaternary sediments, and, 2) differentiate subsurface lithologies (based on density and electrical resistivity) to aid in the interpretation of the complex structural relationships associated with the Denali Fault and subsidiary faults. The study has produced a number of drill targets which will form the focus of the next stage of a broader multi-agency Denali Fault project.

4. Federal Government Initiatives

The Federal Government has supported geothermal RD&I since the 1970s. This support has been largely awarded to the academic community and has reinforced National Science, Engineering and Research Canada (NSERC) funding, as well as the Geological Survey and Canada’s national laboratories. Since the early 1970s federal funding has waned as more pressing national issues came to the forefront. But, the growing recognition of geothermal’ s base load capacity and overall energy generation potential in a world that is starting to value green energy is starting to produce funding results.

Advocates of geothermal energy development in Canada have long pointed out the advantages other renewables have received and how the development of industries in wind and solar have been supported. Federal recognition of the corporate challenges of geothermal projects from debt financing, high up-front capital costs, low rates of return and long time periods for return on investment (ROI) have been a long time in coming. However, under the recent ERPP, geothermal is starting to get the support it needs to get out of the starting gate. As the economic impact of COVID-19 and the plummeting price of oil has shown, industry advocates are suggesting an increase in the funding of the ERPP program along with an extension of the program time frame. In addition to support for these commercial projects increased RD&I are also being advocated.

5. Conclusions

The foregoing summary of activity and projects in Canada is not complete but should give the reader a sense that activity in Canada is indeed on the increase with three important power generation projects and associated direct-use applications either in or near development. These projects are supportive of, and indeed have been informed by, the significant academic work already completed or being undertaken, as well as the studies at Canadian National Laboratories such as the GSC. We want to emphasize that all of the current work builds on the significant volume of research spawned since the 1970s.

The challenges of geothermal projects from debt financing, high up-front capital costs, low rates of return and long time periods for return on investment have been slowly fading, to be replaced by the growing recognition of the value of base load power with generational timeframes and reducing greenhouse gas emissions (GHG). ROIs might be slow in coming but will continue for decades. The value of the carbon offsets and energy transition in a cold country with a sparse population will continue to manifest themselves as Canadians make efforts to reduce GHG emissions in a country where, for all practical purposes - heat is life. By accessing Earth's naturally occurring heat and putting it to useful work, Canadians will continue to contribute to the global economy and address their commitments to greening that economy.

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