Northwest BC Geothermal & CCUS Assessment Project – Phase 1

Geoscience BC Report 2025-06

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EXECUTIVE SUMMARY

Executive Summary

Geothermal energy utilization has been ongoing since time immemorial with humans using Earth's naturally occurring (endogenous) heat to improve their physical and spiritual wellbeing. In many parts of the globe, naturally occurring hot water and fumaroles are places of sacred importance because they are unusual in the landscape and before easy access to fuel to heat water, provided a luxurious option for heating, bathing and washing.

Although use of Earth's naturally occurring energy has been going on for millennia, it has only been in the past 100 years or so that this energy has been convertible into electrical power. This electrical conversion first took place in Larderello, Italy in 1904 on a small (10kW) scale and expanded to the first geothermal power plant at the same location in 1913 with 250kW of capacity This expanded the ability to utilize geothermal energy as electrical power has the advantage of being transportable over 1000's of km, whereas thermal energy (heat) is much more limited in range, with use typically limited to approximately 10 km of distance from the source wells. This is not to say that heat use cannot impact a more distant area such as when it is used for an industrial process (e.g. wood pellet drying) and the resultant product is shipped vast distances.

Canada, despite its extreme climate, geothermal resource potential and high energy needs has not produced electrical energy from geothermal energy at scale. The first geothermal electrical generation in Canada took place at Mount Meager, British Columbia, in 1984 with a 20kW temporary generator, however the site was never developed beyond temporary testing (Ghomshei et al., 2004). Currently, the only geothermal facility operating in Canada is in Alberta's Swan Hills area, co-producing geothermal and natural gas electricity. In British Columbia, there has been potential identified for geothermal electricity production in the southwest (Mount Meager) and in the northeast (near Clarke Lake) and this potential is currently being explored for commercial development in these locations. Identifying areas with geothermal resource potential will assist commercial entities in the evaluation and potential siting of future geothermal energy projects. Therefore, this scoping desktop study was initiated to provide a regional review of potential geothermal resources in the northwest region of British Columbia. In addition, the study undertook a high-level assessment of geological carbon storage potential of the region, including deep saline aquifer sequestration and carbon mineralization in shallow basaltic or ultramafic rocks.

The project area outline (Figure 1) and scope for this study was generated through discussions with the British Columbia Ministry of Energy and Climate Solutions (MECS) and encompasses more than 83,000 sq km. This area includes a region of British Columbia referred to as the "Golden Triangle" based on the significant mineral exploration in this area. In general, the region represents an area where industrial activity (i.e. mineral extraction) has occurred in the past, is currently occurring and is anticipated to expand in the future, provided the resources to support continued development exist. MECS is responsible for British Columbia's electricity, alternative energy and petroleum resource sectors, and supporting work to align energy policies with climate goals. The review of geothermal resource and carbon sequestration data, and improvement in understanding in regions with limited current data is an important aspect of supporting the Ministry's mandate.

Figure 1: The northwestern British Columbia project area is shown outlined in red along with the approximate area of the "Golden Triangle".

From a geological perspective the area chosen for study has potential for naturally occurring geothermal systems, which are necessary to have geothermal resources. Situated along the western margin of British Columbia, plate tectonic forces have created a region of complex geology, extreme topography, recent volcanism and significant mineralization potential (Figure 2). The older basement architecture of the region is part of the Intermontane assemblage of terranes (c.f Ootes et al., 2017). The basement to the project area is mostly a rock package called Stikinia (Figure 2). Stikinia has its origins in continental rifting and is made up of volcanic and sedimentary rocks ranging in age from the Paleozoic to the Mesozoic. On top of this more ancient geology, geologically young volcanoes and hot springs dot the project area, indicative of the occurrence of naturally occurring geothermal systems that warrant further investigation.

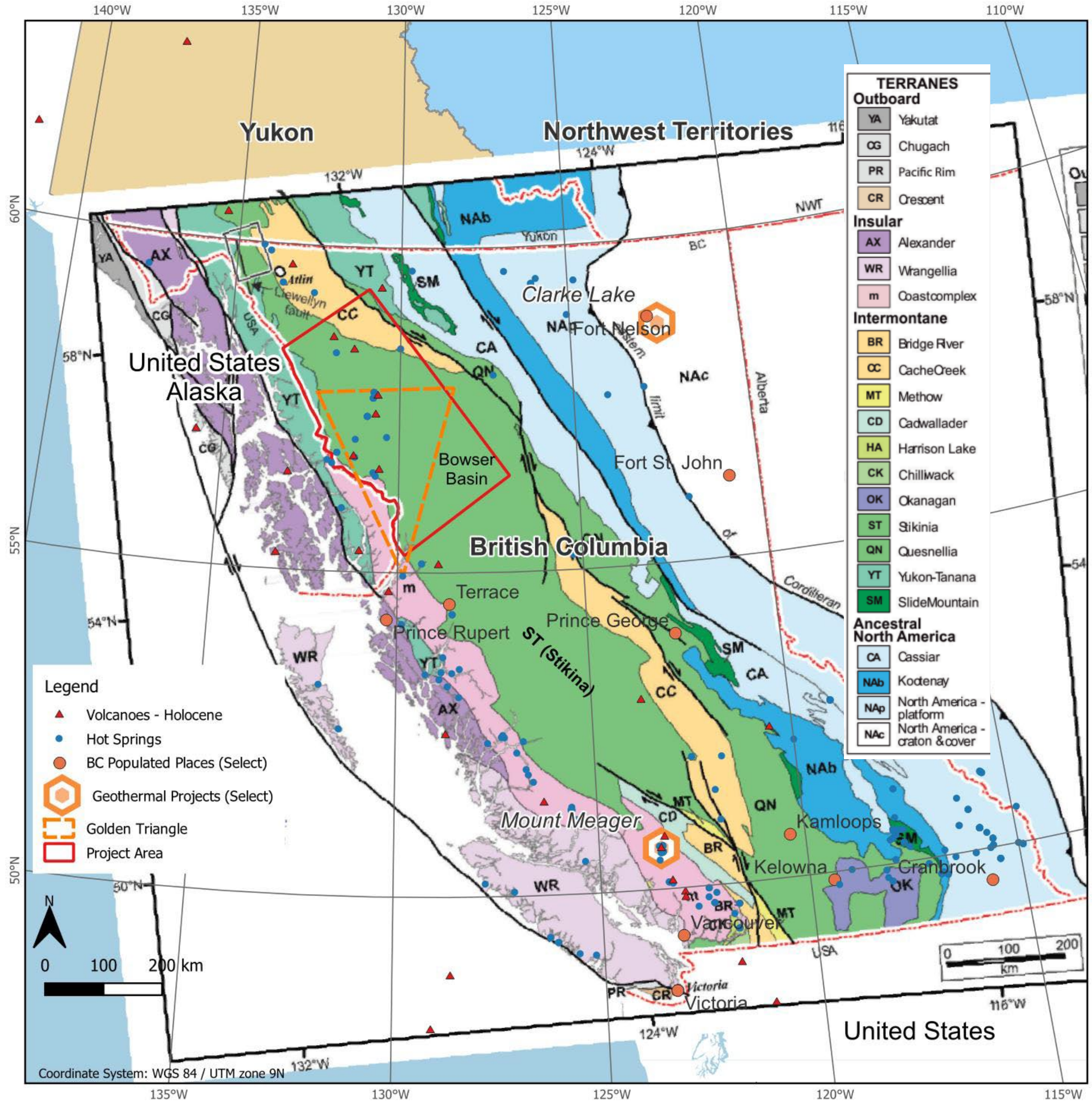

Figure 2: The project area is shown superimposed on a geological terrane map of British Columbia (Ootes et al., 2017)

In this study, our goal was five-fold – (1) gather and evaluate geological and geophysical information that provides better understanding of the subsurface where naturally occurring geothermal systems may have formed; (2) integrate this subsurface information into a digital platform that allows for data analytics to be performed to evaluate the data; (3) take the gathered geoscience information and using data analytics, create favourability maps that identify areas where naturally occurring geothermal systems might have formed; (4) report these finding and provide recommendations for filling data gaps and provide a framework for future evaluations; (5) provide a high-level overview of the geological carbon (CO_2) mineralization and deep saline sequestration (CCUS) possibilities of the region.

This scoping study summarizes the current state of geothermal technologies and provides an overview on geothermal exploration techniques and processes while focusing on a specific type of resource exploration tool – a “Play Fairway (PF) Analysis” – which originated in the oil and gas industry but has been recently applied to geothermal energy exploration, in particular in the Great Basin region of the US. This study focuses on the analysis of currently available data and its applicability to naturally occurring geothermal energy systems which include volcanic hosted; structurally (i.e. fault and fracture) controlled; and sedimentary basin plays. From an analysis of these data, geothermal favourability maps have been created. **It must be noted that this “favourability” is relative to areas only within the study area and for the particular assessment criteria, not to global geothermal systems.** Areas identified as favourable would require additional research and assessment to determine their suitability and potential to host geothermal resources. Finally, the study gives an initial overview of the potential for geological CO_2 storage in the project area.

Overall, this research provides a valuable first step in determining the geothermal potential of the project area and what additional data is required to improve the outcome of developing the geothermal resources. The study demonstrates, through the PF analysis methodology, that there are areas within the region that have a higher potential (more favourable) of hosting naturally occurring geothermal systems than other areas. In particular the study identified the Mount Edziza/Spectrum Range and the Iskut-Unuk River areas as having high relative favourability for the presence of both volcanic hosted and structurally controlled geothermal systems. These areas should receive additional investigation including an analysis of the economic feasibility of geothermal resource development.

Despite the limitations of the data and the methodology, this work provides sufficient information to suggest that robust geothermal systems exist within the project area. The exact location, size and resource potential of these systems (and whether they may be developable by either conventional or unconventional technologies) awaits further data and investigation. A set of recommendations is provided in this report for additional work that could be carried out as desk top studies (Phase II) as well as recommendations for additional field-based studies (Phase III).

The Bowser Basin and its near neighbour, the Sustut Basin, covers an area of approximately 65,000 sq km, of which approximately one-half is within the project area. The Bowser Basin is a large sedimentary basin in the interior of British Columbia, and although potentially containing more than 6,000 metres in thickness of sediment, these results suggest that it is unlikely to be a good candidate for hosting sedimentary basin geothermal systems or for CO_2 sequestration in saline aquifers.

Acknowledgements

The project partners acknowledge that this research concerns the territories of many First Nations in the Northwest region of British Columbia. We encourage anyone considering new development or activities in their territories to engage early and engage often with appropriate Indigenous groups. The Province of British Columbia's Consultative Areas Database can be used to identify potentially impacted First Nations and their respective contacts. https://www2.gov.bc.ca/gov/content/data/geographic-data-services/land-use/contacts-for-first-nation-consultation-areas

This research was facilitated through access to the numerous public geoscience databases that exist due to public funding. The collection of datasets such as regional geochemistry, magnetics, gravity and seismicity, are all funded by federal and provincial governments. In fact, virtually all the data used in this study has been funded through the public sector. Without these datasets, this study would not have been possible to the level of certainty and credibility that it has achieved. Although much more needs to be done, the researchers thank government officials for supporting the collection of “public good” geoscience data and making it freely available.

The research team thanks the anonymous peer reviewers for their constructive and insightful comments and criticism. Their input improved the report. Additionally, comments received from members of the Project Advisory Committee were helpful and they are thanked for their input assisting in creating a clearer and improved final document. Graphic artist F. Marwick is thanked for assistance with some of the figures.

Geoscience BC is grateful to the Province of British Columbia through the Ministry of Energy and Climate Solutions for funding this project. This project had a Steering Committee and a Project Advisory Committee facilitated by Randy Hughes of Geoscience BC, and the project partners extend a sincere thank you to the anonymous peer reviewers and the committee members for their time and valuable input.

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Ootes, L., Elliott, J.M., Rowins, S.M., 2017. Testing the relationship between the Llewellyn fault, gold mineralization, and Eocene volcanism in northwest British Columbia: A preliminary report (No. 2017–1), Geological Fieldwork 2016. British Columbia Ministry of Energy and Mines.

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Appendices (Provided Separately)

Appendix 1 – Report Maps (PDF)
Appendix 2 – Report Maps (GeoPackage)

Note: For this report, the spatial dataset outputs have been published as GeoPackages (*.gpkg files) for ease of data manipulation and visualization. The only exceptions are TIF and Surfer GRID files saved under Geophysics/Aeromag & Geophysics/Gravity due to some limitations with the GeoPackages raster format.

GeoPackages were selected due to the following reasons:

- can store default symbology and labels
- can store multiple datasets within a single GeoPackage to simplify data management
- can store vector & raster datasets within a single GeoPackage

The authors of this report recommend accessing the GeoPackages using QGIS

If a different spatial format is required, QGIS can be used to export a GeoPackage dataset to a different format such as shapefiles, GeoTIFFs, and many others.

Report Structure

This report is presented in five chapters. Chapter One provides background and contextual information. It is comprised of three sections, the first of which introduces geothermal energy systems and technology. It outlines the difference between naturally occurring geothermal systems and the technologies used to extract and utilize the heat energy. The second section provides background information on how geothermal exploration is carried out and the data required to develop a geothermal prospect. The third section is a description of the methodology used to assess the project area for the presence of areas of elevated geothermal heat. This methodology, a "Play Fairway" (PF) analysis" (PFA), integrates geoscientific datasets, using data analytics to produce a "favourability" map.

Chapter Two presents the eighteen datasets compiled and reviewed for the project. These data are laid out as to their source and applicability to the PF analysis. Each section has an overview, followed by information on where the data was sourced from, the format of the data, how the data was used in the data analytics, and, finally, recommendations concerning improvements to the datasets for future investigations. This section is laid out as an atlas with maps displaying data as used in the analysis.

Chapter Three provides the details of the data analytics used to integrate and evaluate these various datasets. It concludes with presentation of favourability maps for volcanic hosted, structurally (fault/fracture) hosted, and sedimentary hosted geothermal systems. Noting that the favourability is relative to the project area, not relative to known geothermal systems elsewhere in the world.

Chapter Four lays out the recommendations for further research by highlighting the limitations of the methodology and the datasets used. This Chapter presents specific recommendations related to each of the datasets, as well as further desk-top studies that could be carried out. Some guidance is given for field studies that would be required to determine the suitability of any specific area for geothermal energy development.

Chapter 5 outlines currently available data and a high-level assessment of the potential of the project area for carbon capture and underground storage.

Spatial Data Collections

These eighteen discreet datasets were sought and where possible, data collected:

1. Spatial distribution of geological units.
2. Heat flow mapping
3. Fracture/fault (structural control) mapping
4. Regional stress field information
5. Seismicity data
6. Fluid geochemistry (Hot springs and thermal features) data
7. Quaternary volcanism (Neogene and Quaternary volcanic outcrops)
8. Regional gravity data
9. Regional magnetic data
10. Magnetotelluric data
11. Physical rock properties of specific geological units (transmissivity and conductivity).
12. Geochemical analysis that includes (U, Th and K) for radiogenic plutons and spatial distribution
13. Petrological/geochemical whole rock XRF analysis
14. Regional geochemical survey analyses

15. Curie Point Depth mapping
16. Hyperspectral/ASTER satellite images, Landsat or other image sets
17. Bowser Basin sedimentary stratigraphy
18. Existing borehole (drillhole and well) locations and relevant data

Topography and bathymetry datasets were used as reference layers for various maps in this report, mainly as semi-transparent hillshade layers. Two topography datasets were utilized:

1. GEBCO – The GEBCO_2024 dataset was published in July 2024. It is a global digital elevation model including topography and bathymetry with a resolution of 15 arcseconds (roughly 450 m). ("GEBCO's global gridded bathymetric data sets," 2024)
2. JAXA – The JAXA (Japan Aerospace Exploration Agency) - ALOS World 3D - 30m dataset is a global digital elevation model for topography with a resolution of 1 arcsecond (roughly 30 m). ("ALOS Global Digital Surface Model (DSM)," 2024)
3. ETOPO - The ETOPO 2022 dataset is a global digital elevation model including topography and bathymetry. The 60 arcseconds (roughly 1800 m) resolution version was used in the project. (NOAA National Centers for Environmental Information, 2022)

Chapter 3 of the report documents the data integration assessment. All spatial information was compiled into a GIS data system. QGIS ("Download · QGIS Web Site," n.d.) is an open source, free downloadable software package to allow spatial visualization of data and provide decision making tools to everyone. QGIS allows the user to create, edit, visualize, analyze and publish geospatial information. The outputs are publishable in a variety of formats including WMS, WMTS, WFS, and WCS. For this report, the outputs have been published as GeoPackages (*.gpkg files) for ease of data manipulation and visualization. Maps within Section 2 are created using a project template providing a standardized output.

The data analytics is done using a program called Spotfire. Spotfire ("Spotfire," n.d.) combines visualizations and advanced analytics to solve complex problems. 4th Resource Corp, members of which are co-authors of this study, has been developing the data analytics for more than a decade to provide solutions to complex geological problems such as PF analysis.

Non-spatial data collections

A significant number of reference documents were accessed and used in the data collection and analysis. References were organized using another free software platform called Zotero. Zotero ("Zotero | Your personal research assistant," n.d.) assists in the collection, organization, annotation and citing of shared research papers and documents. As far as possible, all source material was downloaded and made available to the team compiling and writing the report. Due to copyright restrictions, this document data set can't be provided with the report, but all citations made are fully referenced.

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1.1 Geothermal Systems and Technology

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Section 1.1 Figure 1: Five classes of heat extraction (and storage) are shown in this schematic diagram first published in 2022 (Hickson and Smejkal, 2024). Class 2 systems are historically what make up the bulk of the global geothermal electrical generation. 16

Section 1.1 Figure 2: Conventional geothermal systems (Class 2: Figure 1) form in a variety of geological settings: VH – volcanic hosted; FF – structural (fault and fractures); RP – radiogenic pluton; HSA – sedimentary basin. Depths and temperatures are approximate, based on a 34°C regional geothermal gradient. The gradient close to the volcano or intrusive dykes and sills, may be much higher as indicated by the 180°C isotherm. (Khodayar and Björnsson, 2024, modified from their Figure 1) 17

Section 1.1 Figure 3: Conventional geothermal systems (Class 2) use naturally occurring fluid (either liquid or steam) to create electrical energy. The type of system deployed is dependent on the specific characteristics of the resource as to temperature and liquid quality (i.e. dry or wet steam). (Moya et al., 2018, modified from their Figure 1) 18

Section 1.1 Figure 4: Hydrothermal systems have naturally occurring brines and are depicted in this diagram as the open porous framework in the lower section. Typically, with depth, there is a loss of permeability in these natural systems. Superimposed on permeability is heat. The heat source may be the geothermal gradient, radiogenic plutons, or magmatic intrusions. Petrothermal systems are essentially "hot dry rock" – showing schematically in the upper part of the diagram from warm to very hot. To extract thermal energy from petrothermal systems (hot rock with low permeability), they must be engineered, either by creating a fracture network (permeability) and providing a working fluid (engineered or enhanced systems EGS), or by using a closed-loop (Advanced Geothermal System AGS) system. The creation of an EGS or AGS represents increasing technological intervention. As noted in Figure 4, petrothermal systems (Class 3), as opposed to hydrothermal systems (Class 2), require hydraulic, chemical or thermal stimulation (Figure 4). In real world exploration for geothermal 20

Section 1.1 Figure 5: Unconventional geothermal developments: Enhanced or Engineered Geothermal Systems (EGS) in hot dry rock between 3 Km and 6 Km depth. EGS technology uses mostly hydraulic fracking to create fractures as natural heat exchangers in rock or adjacent to the borehole. AGS systems rely on a large surface area from many wellbores or groups of wellbores (a subsurface radiator) to extract thermal energy (Khodayar and Björnsson, 2024, modified from their Figure 4) 21

Section 1.1 Figure 6: The geothermal technologies shown in Figure 1, are not suited for all regions of Canada due to geological as well as climatic constraints. The area outlined in red is the Canadian Shield, made up of geological provinces that are dominated by crystalline plutonic and high-grade metamorphic rocks known to lack permeability (are “tight”)(Huang and Hickson, 2024) 22

Overview

Although use of Earth's naturally occurring energy has been going on for millennia, it has only been in the past 100 years or so that the energy has been convertible into electrical power. Electrical power has the advantage of being transportable over 1000’s of km, whereas thermal energy is much more limited in range unless it can be used for an industrial process (e.g. wood pellet drying) and the resultant product is shipped long distances.

In this section of the report, we first define naturally occurring “geothermal systems”. We then discuss the various thermal extraction technologies. Because of the changing technology landscape, this report focuses on spotlighting naturally occurring geothermal system exploration targets, i.e. locations where endogenous heat is concentrated due to various geological factors. By breaking the analysis into three primary geological criteria – heat, permeability, and fluids - areas where natural geothermal systems are more likely to occur are identified and ranked as to favourability.

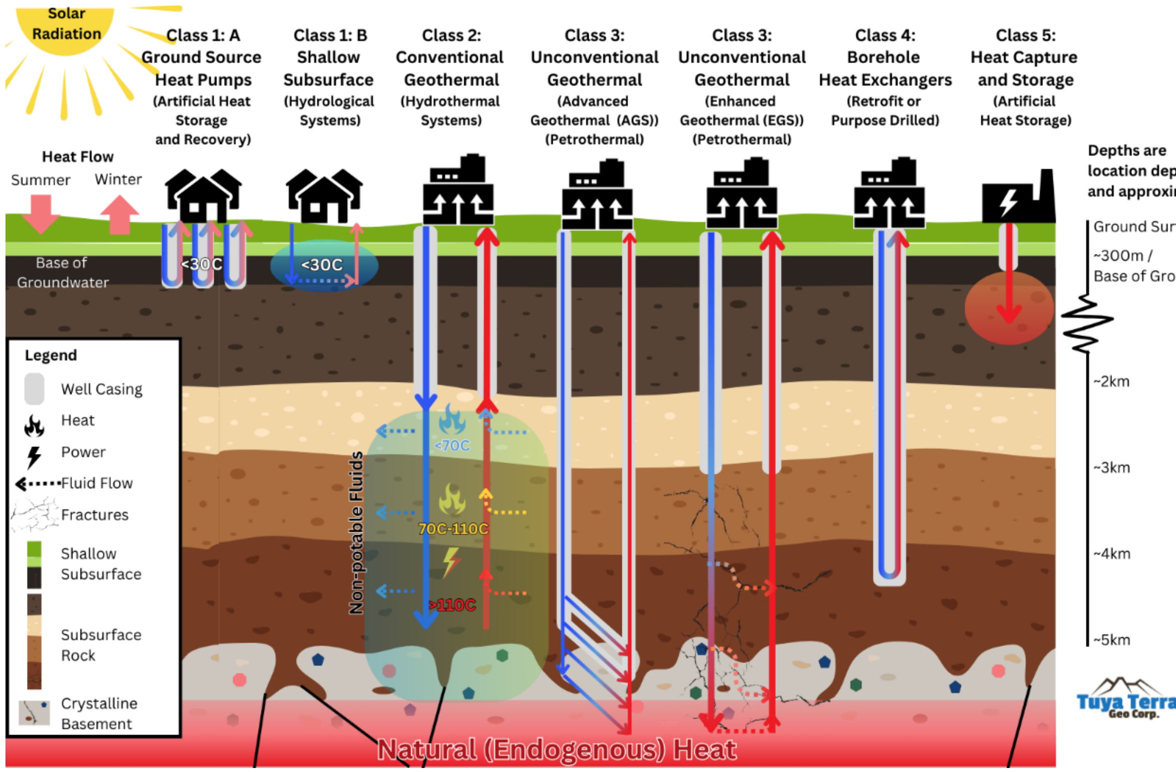
Five types of naturally occurring geothermal systems (“plays”) are analyzed in this report using the PF analysis methodology – volcanic hosted, structurally controlled, radiogenic plutons, sedimentary basin plays and ultradeep/ultrahot rock. The determination of which technology best suites the potential “geothermal plays” identified in this report is beyond the scope of this study and is left for future assessment.

Naturally Occurring Geothermal Energy Systems

The earth increases in temperature with depth, with the rate of temperature increase (geothermal gradient) varying from place to place. Naturally occurring (endogenous) high geothermal gradient thermal energy is easy to see in the form of volcanoes, fumaroles and hot springs. Elsewhere the endogenous thermal energy is not as visible at the surface, however temperature gradient wells, deep drilling and deep mine shafts provide information to assess geothermal gradient and areas with high thermal energy.

In the past the only type of natural geothermal system that could be exploited were simply referred to as “deep geothermal” or “conventional” geothermal systems. The main characteristic of these types of systems, referred to as “Class 2” in Figure 1 (Hickson and Smejkal, 2024), is that endogenous heat is concentrated in a reservoir of permeable, fluid saturated rock permitting the convective circulation of heat within the reservoir. The heat source could be a radiogenic pluton, a magma body, or Earth’s endogenous heat (Figure 2).

Naturally forming permeable hot systems have sufficient fluid (sometimes referred to as brine), that it can be used as the working fluid for the technological system used to bring the heat to the surface, either as a liquid (or steam if hot enough). Depending on the temperature and the form of the fluid (liquid, dry or wet steam) differing types of technology are used to extract the heat and turn it into useful energy. These

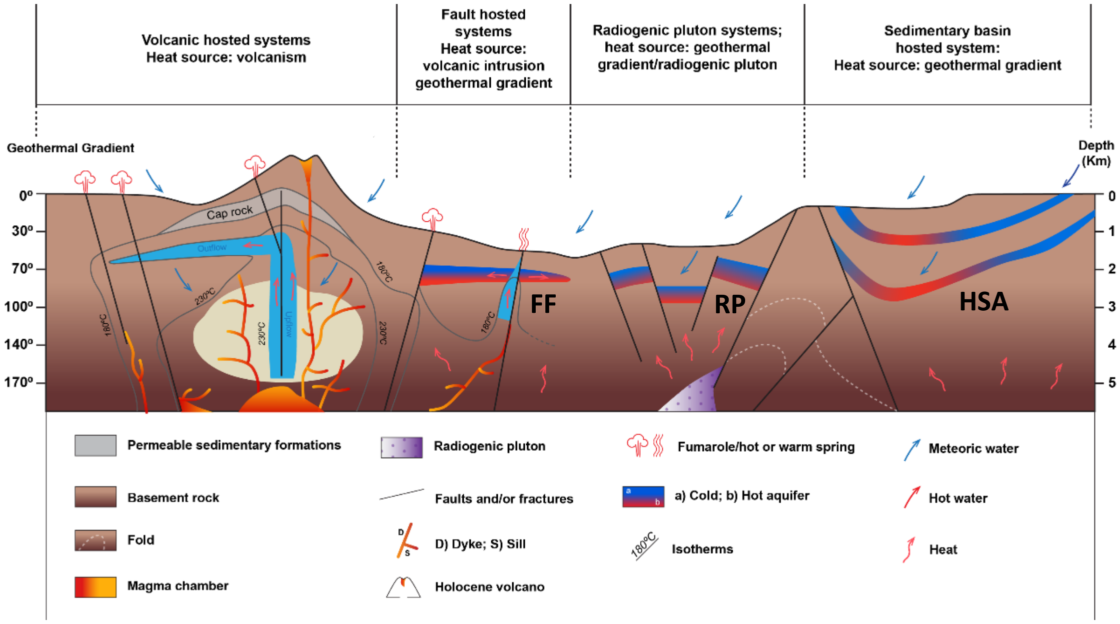


Section 1.1 Figure 1: Five classes of heat extraction (and storage) are shown in this schematic diagram first published in 2022 (Hickson and Smejkal, 2024). Class 2 systems are historically what make up the bulk of the global geothermal electrical generation.

systems could utilize heat exchangers for low temperature fluids, or at higher temperatures, Organic Rankin Cycle (ORC) electrical generators or flash turbine systems. Each reservoir will have a unique technological solution for heat conversion to useable energy (Figure 3).

The type of surface and subsurface technology required at each site is not considered in this report as it is an engineering solution dependent on many factors. Additionally, there are rapid changes in energy conversion technology being made at the present time. Currently, a resource temperature lower than 100°C is considered only marginally commercial, however there have been cases where lower temperature fluids are commercially viable such as Chena Hot springs, Alaska (Kolker et al., 2007). At this site they are able to convert 73°C fluid into 400kW of electricity using ORC technology. However, the location is in the far north with a significant temperature difference (ΔT) between the ambient air temperature and the resource temperature, significantly improving performance of the technology. The development uses the hot fluid directly for bathing, greenhouses and space heating in addition to generating sufficient electricity to meet the needs of the inhabitants and visitors. The geological setting of the Chena Hot spring geothermal system is a short fracture segment within a radiogenic pluton (Kolker et al., 2007). The system would likely exist as a cold spring if it were not for the radiogenic energy provided by the pluton.

In addition to geothermal systems associated with radiogenic plutons, geothermal reservoirs can be found associated with volcanic fields, deep circulating fault systems and in sedimentary basins. These are all termed "geothermal resource plays" and are shown schematically in Figure 2. A fifth play type is "ultra deep/ultra hot" which is both a technology and a natural system play. It relies on the fact that the geothermal gradient of the earth is sufficient that drilling to depths greater than seven kilometers will result in contacting rocks hot enough to produce electricity using appropriate technology. "Ultra hot" may also be achievable at shallower depths close to volcanoes. "Ultra hot" (supercritical) refers to temperatures that are at or above the triple point of water.



Section 1.1 Figure 2: Conventional geothermal systems (Class 2: Figure 1) form in a variety of geological settings: VH – volcanic hosted; FF – structural (fault and fractures); RP – radiogenic pluton; HSA – sedimentary basin. Depths and temperatures are approximate, based on a 34°C regional geothermal gradient. The gradient close to the volcano or intrusive dykes and sills, may be much higher as indicated by the 180°C isotherm. (Khodayar and Björnsson, 2024, modified from their Figure 1)

Geothermal Energy Extraction Technologies

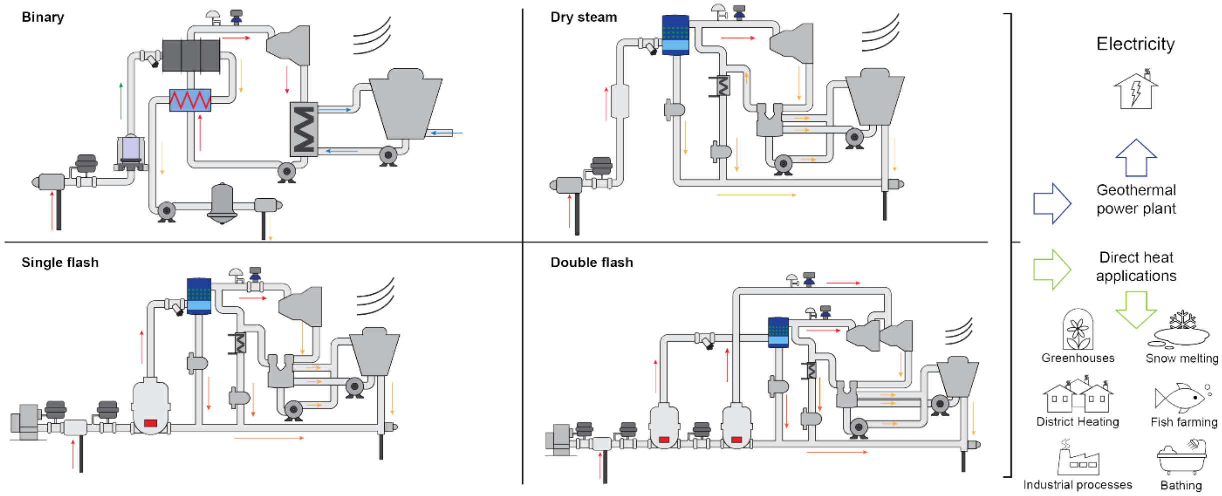
One aspect of "geothermal systems" must be clarified and that is the difference between geological thermal resources that exist in the sub-surface and the technologies that might be used to extract energy from those systems, or hot rock in general. Figure 1 shows five technology classes that can be used to extract thermal energy. Of these, Class 1, uses the earth for heat storage (geoexchange) no endogenous heat energy is extracted, Classes 2 – 4 extract endogenous heat, and Class 5 uses the earth as a heat storage medium. Of these, Class 1 and 2 systems have been in commercial use for decades. Most of the worlds currently produced geothermal resources are Class 2 "conventional" systems (Rybach, 2022; Soltani et al., 2019). Conventional geothermal systems require heat, transmissivity (permeability) and fluids. The technology used to generate electricity is either an Organic Rankin Cycle (ORC) or a flash system (Figure 3). Soltani et al. (2019) provides an extensive review of the history of geothermal development globally.

Class 1: Geoexchange systems

Geoexchange systems use earth as a heat storage medium, removing heat from the air, or in some cases water, using a heat pump (Hickson et al., 2022). They require a ground source heat pump to extract heat and store it. Because they do not rely on naturally occurring (endogenous) heat, for the purposes of this study, these systems have been excluded. Their installation is specific to the very shallow subsurface (upper 100 m), so requires site specific investigations specific to the shallow subsurface, but these systems are relatively easy to deploy. They do require electricity to run the ground source heat pump.

Class 2: Conventional geothermal systems

Class 2 (Figure 1) technology is the oldest heat exploitation technology in existence and remains the dominate development approach globally. As discussed above, the surface installation for heat extraction is the main technological difference between low temperature (100 – 170°C) and high temperature systems (170°C and greater). Heat exchangers at the low end of the thermal spectrum to flash systems as the highest temperatures Figure (Moya et al., 2018)



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Class 3: Enhanced or Engineered Systems (EGS) and Advanced Geothermal Systems (AGS)

Class 3 (Figure 1) technologies, in particular EGS (enhanced or engineered geothermal systems) have seen significant development and research efforts over the past few decades. EGS have been operating in Europe with the Soultzsous-Forêts geothermal project (Vidal and Genter, 2018) likely the most well-known. In the USA, the government has invested significant funds into technological development of EGS systems. The most notable is the Utah Frontier Observatory for Research (FORGE) where the University of Utah runs a field scale laboratory (Jones et al., 2024). Significant advances in EGS technology have been brought about that both decrease the development risk, as well as reduce the costs (Kneafsey et al., 2021), in particular drilling costs.

Advanced geothermal systems (AGS) are defined as “closed loop” systems where no natural fluids enter into the borehole. Heat transfer to the surface is through conductive heat transfer to the artificial working fluid within the borehole. Several research papers modelling the long term thermal response of the system suggest that a rapid decline in produced fluid temperature at the surface that will need to be carefully engineered to continue to produce power or thermal energy over a substantial period of time (Adhikari et al., 2024; Yuan et al., 2023). Other work on costing of these systems suggests that significant advancements in drilling technologies (more than 50% cost reduction), are required to enable cost-competitive AGS implementations. “Despite these challenges, the economic viability and societal acceptance potential of AGS are significantly raised when considering that negative externalities and their costs, so common for most other power plants, are practically non-existent with AGS”(Malek et al., 2022)

Class 4: Downhole Borehole Heat Exchangers (DBHEs)

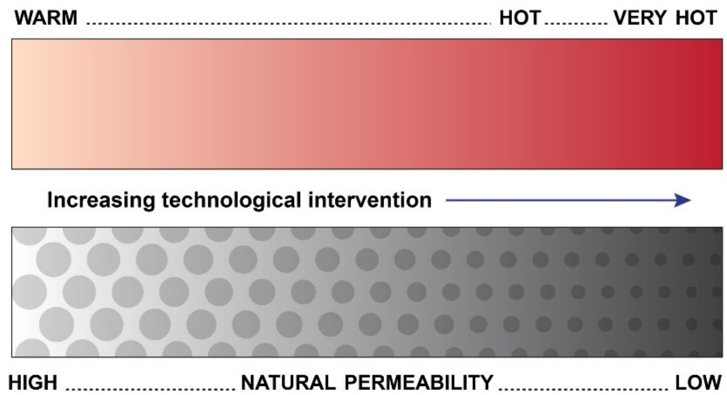
Class 4 (Figure 1) systems are still under development. The technology has been experimented with (Pokhrel et al., 2022) for several years and a number of companies have been created or pivoted to use the technology, for example Ceraphi, Greenfire, GeoThermal Inc. Renewable Energy Systems (RES), Veolia, and others. The potential to use Downhole Borehole Heat Exchangers (DBHEs) in boreholes presents an interesting challenge being pursued by a few companies. DBHEs offer the potential to put a formally productive well that no longer flows (due to scaling or pressure draw down or other factors) but is still hot, into production. Greenfire Energy experimented with the DBHE technology using liquified CO_2 as the working fluid at the Coso Geothermal Field with promising results (Higgins et al., 2020). An up-to-date review of DBHEs can be found in (Kolo et al., 2024).

Class 5: Underground thermal energy storage – UTES

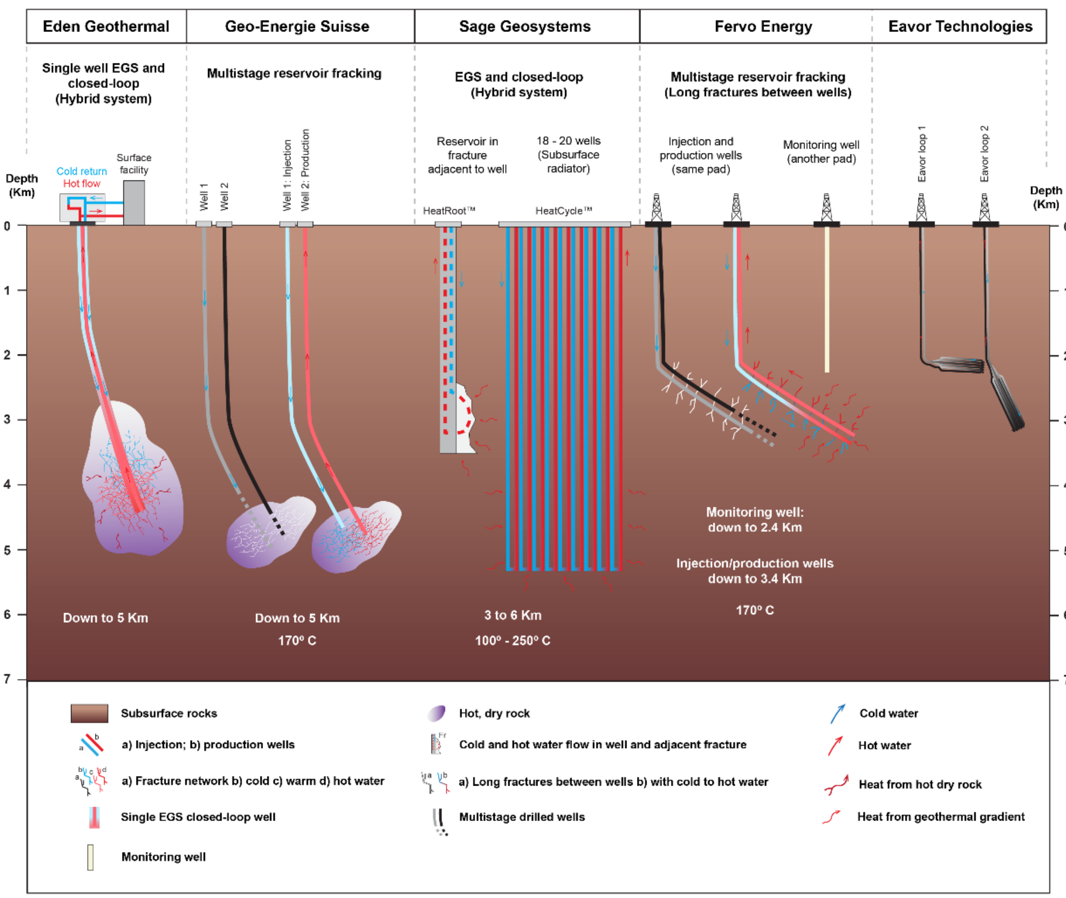
Class 5 (Underground thermal energy storage – UTES) is also relatively new and is still in the technological development stage. HEATSTORE is a European project aimed at lowering the cost, and improving the storage capacity of high [sic] temperature (~25°C to ~90°C) systems (Koornneef et al., 2020). The study has demonstration projects in six countries experimenting with the storage of excess and waste heat energy from solar thermal, biomass, concentrated solar thermal, and other sources.

Technology deployment

It must be stressed that Figure 1 represents varying technological solutions to extract (and store) heat in the subsurface. The heat extraction technology deployed at a specific site will be dependent on local conditions, energy requirements of the users/developers and their risk tolerance, and most likely cost considerations. With the growing proliferation of terminology, several authors have tried to better define some of the language to more clearly differentiate between systems that occur in natural reservoirs and those that have been engineered. For example, for this study Class 2 systems are defined as hydrothermal and Class 3 systems as “petrothermal systems” (Huenges, 2025) (Figure 4). Khodayar and Björnsson (2024) provide additional information and definitions of “Enhanced” and “Engineered” EGS systems as well as “Unconventional systems” (Figure 5; our Class 3).



Section 1.1 Figure 4: Hydrothermal systems have naturally occurring brines and are depicted in this diagram as the open porous framework in the lower section. Typically, with depth, there is a loss of permeability in these natural systems. Superimposed on permeability is heat. The heat source may be the geothermal gradient, radiogenic plutons, or magmatic intrusions. Petrothermal systems are essentially "hot dry rock" – showing schematically in the upper part of the diagram from warm to very hot. To extract thermal energy from petrothermal systems (hot rock with low permeability), they must be engineered, either by creating a fracture network (permeability) and providing a working fluid (engineered or enhanced systems EGS), or by using a closed-loop (Advanced Geothermal System AGS) system. The creation of an EGS or AGS represents increasing technological intervention. As noted in Figure 4, petrothermal systems (Class 3), as opposed to hydrothermal systems (Class 2), require hydraulic, chemical or thermal stimulation (Figure 4). In real world exploration for geothermal



Section 1.1 Figure 5: Unconventional geothermal developments: Enhanced or Engineered Geothermal Systems (EGS) in hot dry rock between 3 Km and 6 Km depth. EGS technology uses mostly hydraulic fracking to create fractures as natural heat exchangers in rock or adjacent to the borehole. AGS systems rely on a large surface area from many wellbores or groups of wellbores (a subsurface radiator) to extract thermal energy (Khodayar and Björnsson, 2024, modified from their Figure 4)

resources (i.e. hot rocks), often the presence of heat is easier to demonstrate than permeability. When drilling, targeting a hot, highly permeable reservoir, issues related to drilling such as inadequate clearing of cuttings, clay, improper mud balance, and other factors may result in permeability issues. Additionally, the hydrothermal zone may be missed or was underestimated, and the well, though hot, may require stimulation of some sort (e.g. cold-water thermal cracking, deflagration or hydraulic fracturing).

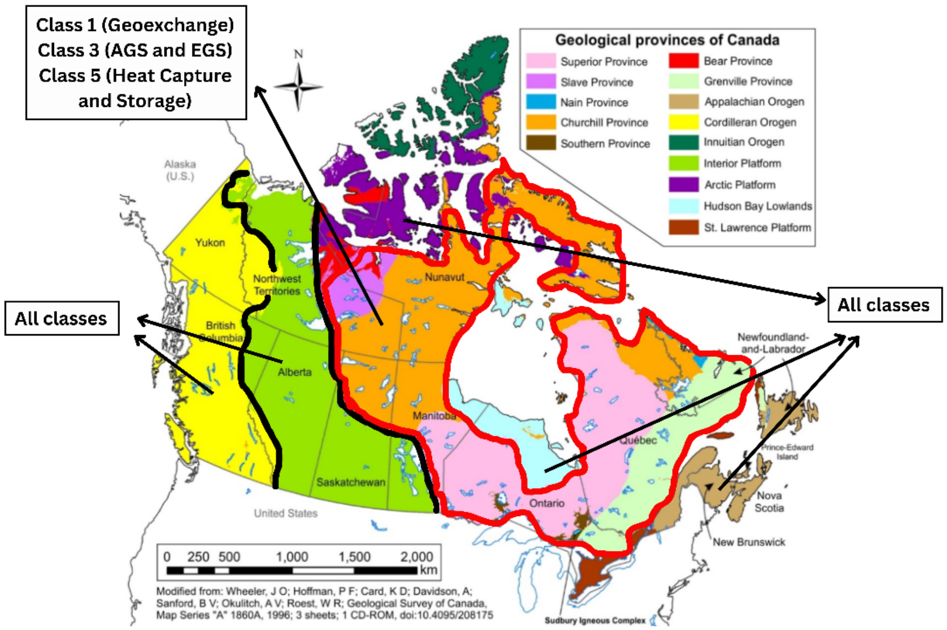
Recent literature (for example Hickson and Smejkal, 2024) have been referring to Class 3 (EGS and AGS) as "unconventional" systems (Figure 1) as these systems extract the energy in ways not previously considered in "conventional" systems (Class 2). Many companies around the world are investigating unconventional energy extraction, some examples are shown in Figure 5. By design, the "unconventional technologies" shown in Figure 5 are essentially geologically agnostic (to a certain degree) – meaning they can be deployed in most environments, requiring only heat. This is an important factor when creating a favourability map. Factors such as permeability, important for conventional Class 2 systems, may be irrelevant or potentially detrimental for unconventional systems.

Unconventional EGS Systems may benefit from natural fractures (Huenges, 2025; Vidal and Genter, 2018) and understanding the stress regime is important for well bore stimulation (Li et al., 2022). EGS systems are also known to induce seismic events (Zhou et al., 2024), so understanding the regional stress field (Section 2.4) is an important consideration. In fact understanding the risks of induced seismicity is important for any kind of geothermal system (Yaghoubi et al., 2022). AGS technological systems on the other hand appear to be moving toward "hot-dry-tight-rock". For these systems to be optimal, and for development cost to be lowered, they need to be uncased but minimize working fluid losses. This is best achieved in tight crystalline rocks without fractures.

Regardless of the permeability, geothermal resource extraction is enhanced by higher temperatures across all technologies. Areas of higher temperatures and higher temperature gradients require less drilling and are therefore less costly to develop. In high temperature zones, boreholes are typically shallower, and fewer boreholes are required to extract the same amount of energy. Defacto, areas of high favourability for heat are also areas that could be developed using Class 3 systems (unconventional) more cost effectively than colder areas. Figure 6 shows what technologies are most likely to be deployed across Canada based on geological provinces (Huang and Hickson, 2024). This diagram demonstrates the lack of naturally occurring permeability in Canada's crystalline shield, making the deployment of Class 2 technologies unlikely there. However, in other areas, all classes are possible, but the likelihood of deployment of a specific class of geothermal technology will depend on local geological conditions and socio-economic factors.

Because of the changing technology landscape, this report focuses on Fairways spotlighting naturally occurring geothermal system – i.e. locations where endogenous heat is concentrated due to various geological factors. By breaking the analysis into three primary geological factors – heat, permeability, and fluids, areas where natural geothermal systems are more likely to occur are identified and ranked as to favourability on a relative basis within the context of the project area.

Within the constraints of the data, five types of naturally occurring geothermal systems ("plays") have been analyzed using the PF analysis methodology – volcanic hosted, structurally controlled, radiogenic plutons, sedimentary basin plays and ultradeep/ultra hot rock. The favourability of these geothermal systems has not been ranked relative to similar systems outside the project area. Additionally, utilization of a specific class of development technology as outlined above, would require additional technical and financial analysis as to which technology class best suites the specific site assessment and development goals.



Section 1.1 Figure 6: The geothermal technologies shown in Figure 1, are not suited for all regions of Canada due to geological as well as climatic constraints. The area outlined in red is the Canadian Shield, made up of geological provinces that are dominated by crystalline plutonic and high-grade metamorphic rocks known to lack permeability (are "tight")(Huang and Hickson, 2024)

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Section 1.2 Figure 2: Flow chart showing the elements of a phased exploration program adapted from Yehia and Suemnicht (unpublished). Which aspects of this program are carried out are dependent on the type and size of the project, geology, past exploration and the results from each phase of the exploration process. Target identification informs the decisions made as to whether it is worthwhile to proceed to Prospect Evaluation and finally the investment of capital needed for Project Appraisal (Hickson and Yehia, 2014). 29

Overview

In this study, our goal has been five-fold – (1) gather and evaluate geological and geophysical information that provides better understanding of the subsurface of the study area where naturally occurring geothermal systems may have formed; (2) integrate this subsurface information into a digital platform that allows for data analytics to be performed to evaluate the data; (3) take the gathered geoscience information and using data analytics, create favourability maps that identify areas where naturally occurring geothermal systems might have formed; (4) report these finding and provide recommendations for filling data gaps and provide a framework for future evaluations; and (5) provide a high-level overview of the carbon sequestration (CO_2) and underground storage (CCUS) possibilities of the region.

In this section of the report, the focus is on providing a framework for geothermal exploration. By reviewing geothermal exploration practices the datasets that follow will more obviously fit into an exploration planning structure. Which of the various exploration methodologies are applicable depends on many factors Including the scale of the region under investigation, existing studies, type of geothermal play being explored for, etc.

Five types of naturally occurring geothermal systems ("plays") have been analysed using the Play Fairway analysis methodology – volcanic hosted, structurally controlled, radiogenic plutons, sedimentary basin plays and ultradeep/ultra hot rock. Exploration for these different types of geothermal systems varies just as the weighting and data analytics analysis outlined in Section 3.1 varies depending on the type of system being explored for. The "evidence layers" are the basic geological and geophysical data used to explore. The PF analysis process has reduced the exploration region from more than 83,000 sq kms to a few areas hundreds of hectares in size. This is an extremely valuable 1st step, but it must always be remembered that the result is a geospatial-statistical study with no recognized geothermal systems in the region (other than those of unknown size associated with the hot springs) to validate the results. The study has not been benchmarked in any way. The results are based on expert judgement. Expert judgement suggests that the "high" favourable areas are the best place to start exploration as these areas have the highest likelihood of success of finding a geothermal system.

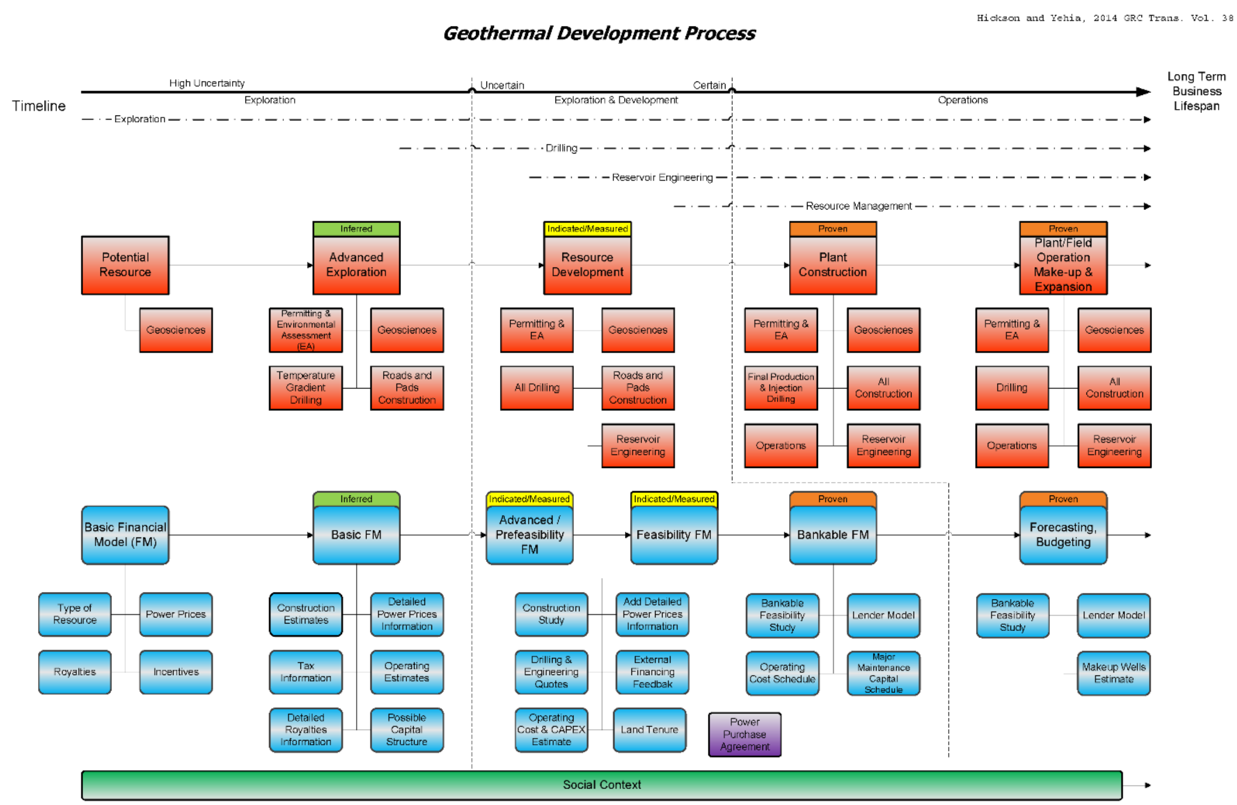
Geothermal exploration requires a specific set of data inputs to guide the exploration process. Once an area has been selected that shows promise ("more favourable") than other areas in the region of exploration interest, a review of existing geoscience information is first carried out. Although at a high level, this study constitutes "Phase 1" of the exploration plan and the high-level results are provided in Section 3.1 of this report. Each of the 18 datasets reviewed is provided with context as to its applicability for use, weighting and ranking, in the PF analysis. The resulting favourability maps can be used to guide future exploration, helping reduce costs by focusing on more limited geographic areas and specific geological constructs however, they can also be very misleading, providing a sense of confidence in the results that is unjustified. The datasets collected in this study are at a regional scale, and with the exception of the fluid data (hot springs) were not originally gathered with geothermal exploration in mind. The favourability maps should be considered crude markers to focus exploration but may have missed important areas where no or limited data exists.

In addition, unconventional geothermal energy extraction technologies (see Section 1.1 Figure 1) may require different sets of subsurface conditions than conventional extraction technologies. These differences have not been taken into consideration in this overview of geothermal exploration practices nor in the favourability maps provided.

Exploration Practises:

Regardless of what type of naturally occurring geothermal systems is being explored for, or what type of technology is being considered for deployment, the process involves a number of specific steps (Hickson and Yehia, 2014). The PF analysis is an exercise in targeting the most favourable locations for geothermal exploration: it does not provide a resource size estimation. The analysis should be of assistance in finding funding to finance exploration in specific areas, but there are still a number of overarching considerations.

Putting geothermal exploration into the development context is a critical aspect of project development. Without the resource there is no development; without the financing there is no project. Managing these two aspects (resource and financing) of development and the interplay between the geoscience side of the equation and finance side is critical for a successful project. Helping the finance side understand the geoscience side and vice versa plays a vital role in ensuring that projects are "right sized" and "right technology fits" to meet the goals of the developer, whether that be the private sector, government or a local municipality. Figure 1 outlines these parallel paths. The upper path outlines the various aspects of the geoscience and engineering required, while the bottom path shows the roll of financing and budgeting. A critical element, shown in purple is the Power Purchase Agreement., which is a contract entered into between a utility or commercial entity (for example BC Hydro) and a power generator for the sale of electrical energy.

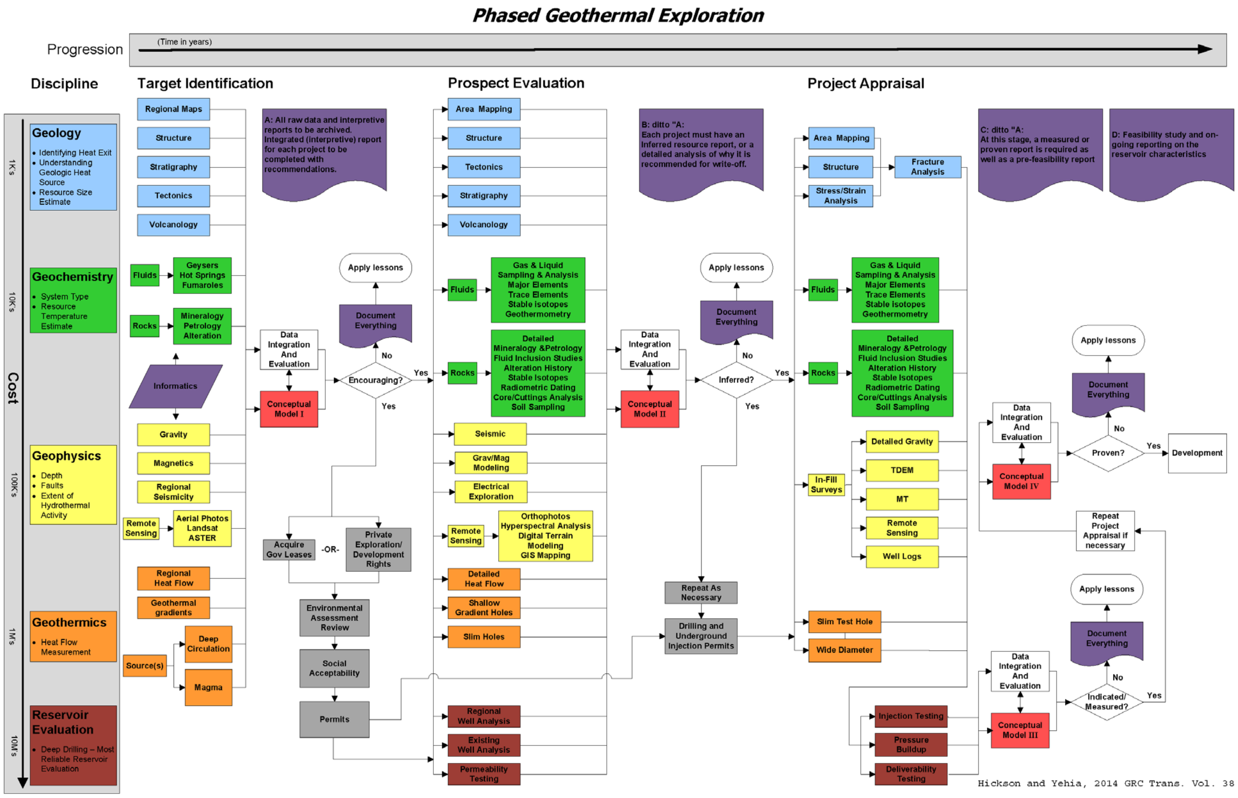


Section 1.2 Figure 1: The parallel geoscience/engineering and financial pathways that a geothermal energy project takes on the path to development (Hickson and Yehia, 2014)

Thoughtful analysis, expert driven, will support a successful project. A successful project is one that meets the expectations and preset outcomes the financiers have built into the financial models. This may be stated in MWe (megawatts electric) or MWth (megawatts thermal), or it may simply be a technically successful outcome if research and development is the goal and funding is based on grants or other non-repayable financial instruments. Note that the funding required for a thermal only (direct use) project is 10 to 20% of a project whose goal is electrical generation.

In Nevada, where PF analyses were first carried out, tracks of land for geothermal exploration are acquired through nomination of land packages by legal entities as defined by the States Geothermal laws (State of Nevada, 2025). Once a land package is nominated, it is held until a land auction is carried out (BLM US Dept of Interior, 2024). An open bidding process is then held to auction the rights to carry out geothermal investigations (BLM US Dept of Interior, 2024; State of Nevada, 2025). The PF analysis encouraged companies to nominate land in specific areas that appeared more favourable than other land (Section 1.3, Figure 2). Companies used the PF analysis to target their acquisition efforts and nominate land packages, but this is just the first step in the process. Following nomination and disclosure of the land packages included in the auction, company exploration teams set out to review available data as to the potential temperature and resources size contained within the land package. These estimates are then provided to the company's financial team who set limits on the maximum price to be bid for the land package. In Nevada's data rich environment, relatively sophisticated estimates can be made as to the potential value of a given land package based on available data benchmarked against developed geothermal fields.

Within the project area, as noted above, the data is mostly at a scale that is not appropriate for resource size estimation. However, the PF analysis as a geospatial analytical tool, has narrowed the exploration areas down to a few 100s of sq km from the 83,414 sq km of the project area. This narrowing provides better focus to proceed to the next step in exploration, which is locating specific geoscience information as outlined in Figure 2 (target identification). This is the least costly aspect of exploration. As shown in Figure 2, each stage – target identification, prospect evaluation and project appraisal – has specific data requirements in order to make decisions to progress to the next stage. Both Figure 1 and 2 indicate the growing need for capital investment as the exploration advances and decisions on project development are made. It may take multiple years to reach the project appraisal stage (Figure 2), as boreholes are required for direct testing of the resource.



Section 1.2 Figure 2: Flow chart showing the elements of a phased exploration program adapted from Yehia and Suemnicht (unpublished). Which aspects of this program are carried out are dependent on the type and size of the project, geology, past exploration and the results from each phase of the exploration process. Target identification informs the decisions made as to whether it is worthwhile to proceed to Prospect Evaluation and finally the investment of capital needed for Project Appraisal (Hickson and Yehia, 2014).

What is new to the exploration pathway outlined in Figure 2, is considering the new technologies and how they integrate into exploration. Some technologies may only be suitable for hot-dry rocks (radiogenic plutons), but other technologies may require significant natural permeability to be successful. Thought of in another way, if unconstrained by any other factors, exploration for favourable locations to develop Class 2 (conventional) systems will be the lowest cost option. These Class 2 systems, reliant on heat, permeability and fluids, have proven to be successful over decadal time frames. These systems, whether power is produced by an ORC or flash technology are commercially proven systems providing baseload generation, low cost per kilowatt hour, low OPEX and proven multi-decadal sustainability. However, if the location of the development is constrained by factors such as proximity to infrastructure or population centers, then evaluation of the potential for a technological solution might be worth pursuing (Section 1.1).

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1.3 Play Fairway Methodology and Resource Estimation

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Section 1.3 Figure 3: Diagram shows the yearly output from the 600MWe geothermal electricity produced by Nevada, using a conservative Capacity Factor (CF) of 85%. 600 MWe deployed wind (34% CF) would only generate 25% and a 600 MWe Solar (CF 15.4%) 5% of the yearly output of the geothermal facility. To produce the equivalent amount of electricity the wind installation would need to be 1,500 MW and the solar PV 3,312 MW in size. Note that the Solar PV CF is derived from the annual photovoltaic potential value at Dease Lake https://nrcan-rncan.maps.arcgis.com/apps/webappviewer/index.html?id=0de6c7c412ca4f6cbd399efedafa4af4&_gl=1*lo5ojt*_ga*MjM1NzM5MzgxLjE2OTg4NTcxNTE.*_ga_C2N57Y7DX5*MTczOTgyMzk2My42LjAuMTczOTgyMzk2My4wLjAuMA.. 36

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Overview

Five types of naturally occurring geothermal systems ("plays") have been analyzed using the PF analysis methodology – volcanic hosted, structurally controlled, radiogenic plutons, sedimentary basin plays and ultradeep/ultrahot rock. Section 1.1 discusses the characteristics of these naturally occurring geothermal systems and provides context for "systems" vs "technology". The PF analysis is a methodology for targeting areas that have characteristics conducive to the formation of naturally occurring geothermal systems; but the presence of a geothermal system is not validated by the methodology – only a geospatially constrained area where there is the potential for a system to have developed. Unlike other areas where PF analysis has been applied, there is no benchmarking data in northwestern British Columbia to validate the geospatial results.

Each type of system (volcanic hosted, structurally controlled, radiogenic plutons, sedimentary basin plays and ultradeep/ultrahot rock) has specific attributes that make their formation more favourable. For example, volcanic hosted systems must be associated with geologically young volcanism. Similarly structurally hosted systems require deep crustal penetrating faults that are permeable enough that meteoric water can circulate to hotter zones at depth, then rise to the surface fast enough to retain the thermal energy. Sedimentary basin geothermal plays require a number of geological controls; (1) a deep sedimentary basin, (2) capping stratigraphic formation(s) to allow trapping of the endogenous, conductively transmitted thermal energy, (3) have high transmissivity (permeability) and (4) are brine saturated. Radiogenic plutons have sufficient heat production that in the presence of meteoric water can host a geothermal system. Ultradeep/ultrahot systems either take advantage of high thermal energy near volcanoes, magmatic intrusions, or elevated temperatures by deep drilling in a region with a higher-than-average geothermal gradient.

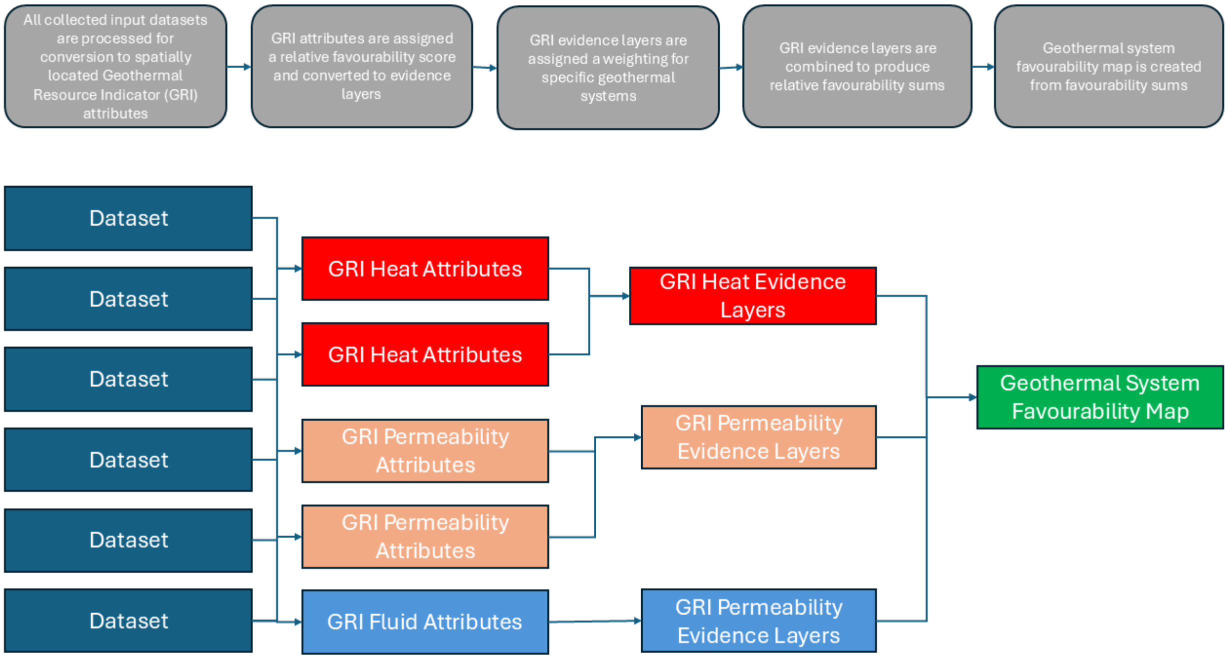
The Geological characteristics that favour these various types of naturally occurring geothermal systems, are known with relative certainty. These characteristics can be grouped into three attributes: heat, permeability and fluid. The PF analysis methodology uses interactive data analytics and offers a method for evaluating the attributes (characteristics) and providing a geospatial favourability map as an outcome. The results are expert driven and rely on the data types and data quality used. The results give a unit-by-unit favourability (within the region being considered) for the specific geothermal system being analyzed for, based on the evidence layers. It provides "more favourable" to "less favourable" results relative to the other units in the map area being analyzed. Thus "high" is "high" relative to near neighbours within the map area and does not indicate that there is in fact a geothermal system in a "high favourability" area, only that it is more likely in these areas relative to "low favourability" areas.

Play Fairway Analysis

Methodology

Play Fairway (PF) analysis was borrowed from the Oil and Gas exploration sector as an approach to reduce geothermal exploration risk and identify the most prospective areas for further exploration and potential development (Faulds et al., 2016; Fraser and Gawthorpe, 2003). Fraser and Gawthorpe (2003) defined PF analysis as a "basin scale assessment to reduce risk in exploration". As used by them and other authors in the geothermal context (c.f. Faulds et al., 2016; Hart-Wagoner et al., 2024; Lindsey et al., 2021) the PF analysis is highly statistical involving a large number of datasets (Figure 1). The datasets are queried for their applicability to the three attributes (heat, permeability and fluid) and assigned numerical values and weightings creating "evidence layers" which are combined to produce final feasibility (favourability) maps

(Figure 2). These maps are highly dependent on the expertise of the evaluation team and the quality and quantity of the datasets.



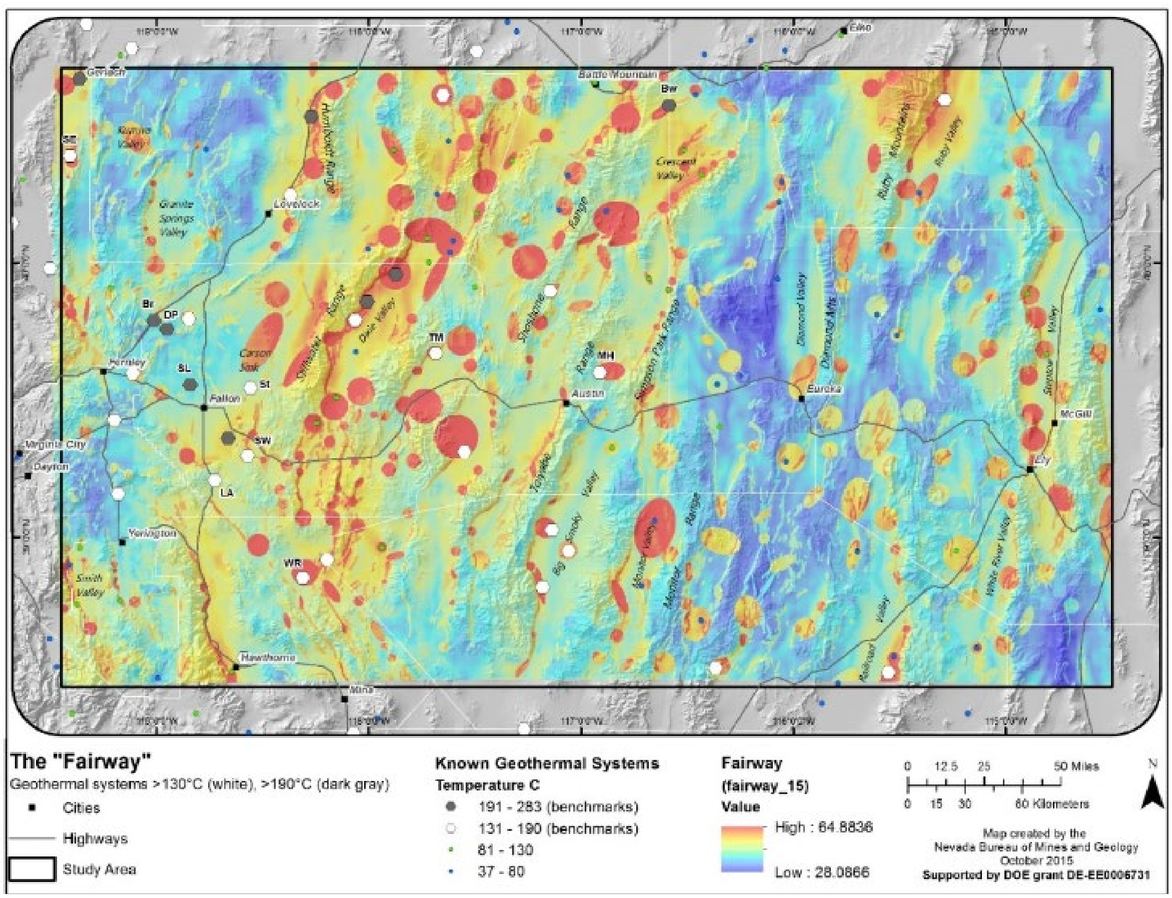
Section 1.3 Figure 1: Schematic representation of the PF analysis. A specific dataset may contribute to all three attribute categories. For example hot spring fluid chemistry and location informs heat, permeability and fluid attributes. Adapted from Lindsey et al., 2021

PF analysis use "fuzzy logic" ("Fuzzy logic," 2025) expert-guided, to make decisions based on incomplete and non-numerical information. PF analysis, using "Fuzzy models or fuzzy datasets" is a mathematical means of representing imprecision and incomplete information (hence the term fuzzy). Although the analysis provides an exact numerical solution, the result can only be construed in a broad and overarching context In this study, the analysis has been binned, and the numerical results formed into rankings of "low", "moderate" and "high" favourability. In the case of Faulds et al. (2016) they represented the most favourable areas as gradational colours, with red representing the most favourable areas (Figure 2). The authors note "The fairway model produced in [Faulds et al. 2016] is a significant improvement over previous models, because compared to past efforts it 1) incorporates a greater dimensionality of input data (greater diversity of input layers), 2) uses more up-to-date and more accurate data (e.g. earthquakes and Quaternary fault slip and age data), and 3) marks the first comprehensive inclusion of structural data, which is critical given its key role in controlling systems in the Great Basin region and elsewhere. The modeled fairway clearly provides a dynamic prediction over multiple scales (local, intermediate, and regional scales), and it is a target-rich model, with numerous favourable locations identified in a variety of settings throughout the project area." Since the first analysis, PF type systematic reviews of regions for geothermal potential in many parts of the world have been carried out (Hinz et al., 2016; Lindsey et al., 2021).

The European Union Project "DESTRESS" came up with a list of properties for reservoir characterization (Chavot et al., 2019). These include characterization of the geological, fluid, hydraulic, mechanical, and structural conditions of the subsurface along with borehole testing. Faulds et al. 2016 used a similar set of properties to characterize "heat", "fluid" and "permeability" (Figure 1). In this study, each data set was assigned values related to heat, fluid and permeability. Each of the datasets used in this analysis are presented in its own section with specific reference to the source of the data as well as comments on data gaps and recommendations to upgrade or update the data set to be more useful for geothermal exploration and resource estimation.

The favourability mapping results are presented based on the five types of natural geological systems known to exist. These subsurface geothermal systems are defined as the “plays” in this PF analysis. The “fairway” is the project area. There are five geothermal play styles – volcanic, sedimentary, structural, radiogenic plutons and ultra deep/ultra hot. Based on available data, favourability maps were generated for volcanic, structural and sedimentary systems. The geology of a specific location will drive a specific technological solution (Section 1.1) for that location. For example, the Canadian shield will require an EGS or AGS technology solution (Class 3), simply because there is little likelihood of finding permeable rocks where energy extraction might be possible with a Class 2 system (Conventional).

The specific details of the methodology used to produce the favourability maps are described under Section 3.1. Rankings and weightings are not transferable from other studies as there is significant variation in datasets and there is no Benchmark data for the project area. Benchmark data was heavily relied on in the Nevada studies (Faulds et al., 2016; Hart-Wagoner et al., 2024) and guided much of their analysis and final favourability maps. Modifications are also necessary to try to balance data gaps, lack of consistent datasets across the region, and where no data exists, proxies for that data set have been suggested and experimented with. The results are consistent with current understanding of the geological framework of the region and provides clear direction regarding where the more favourable areas for geothermal exploration are but provides no information on potential resource size.



Section 1.3 Figure 2: The PF analysis model of the Great Basin study area showing areas of higher favourability as red zones. Also plotted are known geothermal systems and their temperatures from production boreholes.(Faulds et al., 2016)

Resource Size Estimation

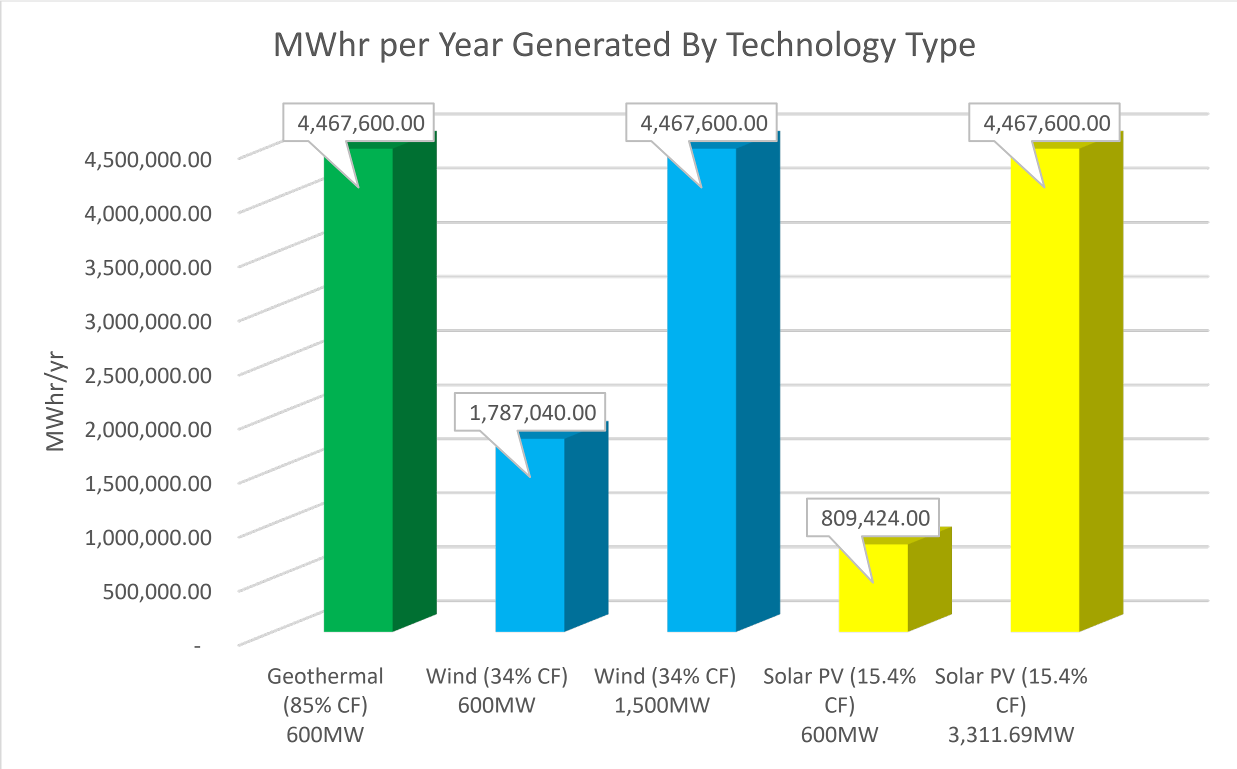
A Play Fairway (PF) analysis does not provide an estimation of resource size. In regions such as Nevada, resource potential can be estimated based on known geothermal system size, measured subsurface temperatures (Figure 2) and resource sizes. The PF analysis as completed for this study, only provides guidance as to where the best places for further exploration, within the project area, might be; it also does not incorporate recovery technology type as a variable for geothermal energy extraction. Specific datasets at appropriate scale are required in order to evaluate the geothermal potential of a specific area. Northwestern British Columbia, despite the significant mineral exploration that has taken place over the past 100 or more years, is still a vast, rugged, underexplored area. A PF analysis provides a framework upon which to build an understanding of the data and the limitations of that data for the purposes of geothermal resource estimation.

In Faulds et al., (2016) the production capacity of Nevada's geothermal facilities was just over 600 MWe. In 2008, an estimate of 4,300 MWe was published (Williams et al., 2009). This built on an early information leaflet distributed by the USA Department of Energy (Department of Energy, 2001) where a forecast potential for 2,500 to 3,700 MWe of electrical generation was given. These forecasts along with the PF analysis prompted significant investment and the development of new geothermal fields in Nevada. Between 1986 (first geothermal electrical production in Nevada) and 2001, production peaked at just under 1.5 million MWh per year. Between 2001 and 2019, production steadily grew to just under 4 million MWh per year. It was during this time period that 22 new facilities were put into production (Nevada Division of Minerals, 2021).

The resource potential for geothermal electricity production in Nevada is currently speculative for two reasons. Firstly, the PF analysis shows that there are additional favourable areas that have not yet been explored and secondly, new technologies (Class 3, Unconventional) have not yet been factored into the resource estimates. At this juncture, it is not clear whether new technologies will spur additional exploration and development efforts in the Great Basin as most EGS experiments taking place in the USA have not yet shown commercial viability or were not intended to be commercial (e.g. FORGE). An example is the Fervo experimental site at Blue Mountain (Horne et al., 2025) as well as the work of FORGE in Utah (Jones et al., 2024; Kneafsey et al., 2021)

Despite the lack of certainty over Class 3 unconventional technologies and whether they will be commercially viable (i.e. can attract investment capital to complete projects) the reasoning behind the PF analysis in the USA, was to provide guidance to the private sector so they might better focus their exploration efforts in order to carry out more cost-effective exploration; new technologies provide additional development options.

All things being equal, fully understanding the difference between baseload geothermal power (regardless of technology deployed for extraction) and intermittent renewable power provides a context for supporting geothermal exploration and development. Comparing the electricity produced by a geothermal facility on a yearly basis to solar and wind generation facilities shows the significant differences between baseload and intermittent power production. Baseload power is available 24 hours of the day, such as that generated by geothermal, hydroelectric, nuclear, or natural gas energy sources. Wind and solar are examples of intermittent power generation, only available when the sun shines or the wind blows unless backed up by technologies like smart grids and/or battery storage..



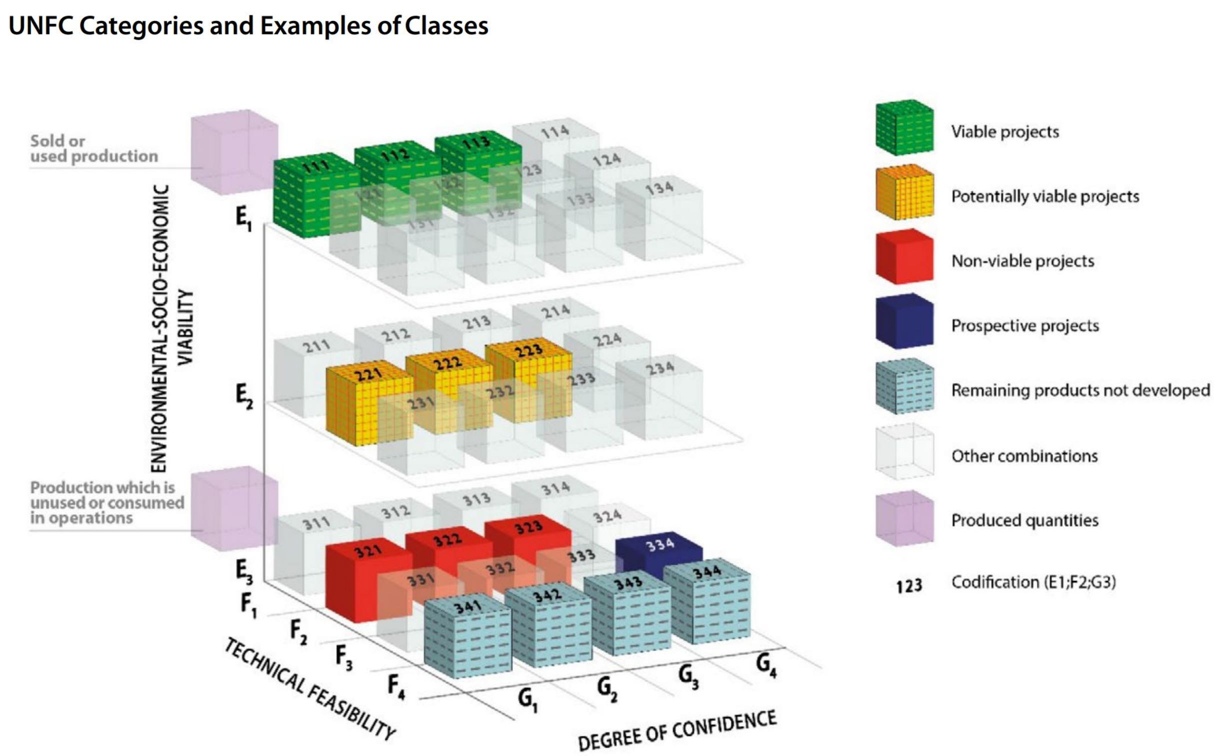
*Section 1.3 Figure 3: Diagram shows the yearly output from the 600MWe geothermal electricity produced by Nevada, using a conservative Capacity Factor (CF) of 85%. 600 MWe deployed wind (34% CF) would only generate 25% and a 600 MWe Solar (CF 15.4%) 5% of the yearly output of the geothermal facility. To produce the equivalent amount of electricity the wind installation would need to be 1,500 MW and the solar PV 3,312 MW in size. Note that the Solar PV CF is derived from the annual photovoltaic potential value at Dease Lake https://nrcan-rncan.maps.arcgis.com/apps/webappviewer/index.html?id=0de6c7c412ca4f6cbd399efedafa4af4&_gl=1*lo5ojt*_ga*MjM1NzM5MzgxLjE2OTg4NTcxNTE.*_ga_C2N57Y7DX5*MTczOTgyMzk2My42LjAuMTczOTgyMzk2My4wLjAuMA..*

Framework Classification for Geothermal Energy Resource Reporting

Resource estimations for commodities have come under increased scrutiny for publicly traded companies seeking to raise capital on public stock exchanges. The trigger for this increased scrutiny started with the BRE-X corporation mining industry fraud that resulted in a call for greater legislative control (Lehman, 1999). In 2002 the National Instrument 43-101 was adopted by the Toronto Stock Exchange (TSX) for mining reserves and in 2003 National Instrument 51-101 was adopted for oil and gas reserves. The Australian Stock Exchange (ASX) is another active exchange for raising resource exploration capital. They have a similar code requirement called JORC (Mineral Resources and Ore Reserves). Their code was first published in 1989. In 2010 a voluntary reporting code for geothermal projects was adopted by the TSX based on the Australian geothermal reporting code. Neither the Australian or Canadian codes had wide adoption and are now considered obsolete (Hickson et al., 2020).

In 2019, the United Nations Framework Classification for resources (UNFC) was published (Tulsidas and Griffiths, 2019). This document laid the foundation for resource reporting based on the UNs sustainability goals (Figure 4) and 3-dimensional matrix where the E Axis is degree of favourability of environmental-socio-economic conditions; F Axis Maturity of technology, studies, and commitments; and G Axis Degree of confidence in estimate of quantities of products (Figure 4).

Section 1.3 Figure 4: UNFC Sustainability goals as presented in 2019 (Tulsidas and Griffiths, 2019)



Section 1.3 Figure 5: 3-Dimentional framework for resource estimations (Tulsidas and Griffiths, 2019)

Fortunately the geothermal community has completed several important documents under the guidance of the International Geothermal Energy Association (IGA), the International Renewal Energy Agency (IRENA and IGA, 2021) (Beardsmore et al., 2021; United Nations, 2018) as well as the World Bank (Energy Sector Management Assistance Program, 2021). Using these documents as guidance an inferred resource estimate for the project area could be in the 100's of MWe, if new technology (Class 3) is considered along with conventional (Class 2) technology.

Recommendations for Additional Work

Within the time frame and scope provided for this report and analysis, it has not been possible to provide a deep dive into estimating the resource potential of the area. By analogy and additional research, it may be possible to make some estimates of the potential for volcanic hosted, structurally hosted and sedimentary hosted systems and priorize the potential success vs efforts and expenditures of finding geothermal resources. Additional work could be done evaluating the potential for ultradeep/ultrahot systems other than just assuming that the most favourable areas to explore for these types of systems are volcanic areas.

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2.1 Geological Data: Rock Types and Ages

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Overview

Geothermal favourability is strongly associated with specific types and ages of rocks. For volcanic hosted systems, most favourable are geologically young (<1 million years old), felsic, high viscosity volcanic rocks that tend to form magma chambers shallow in the earth's crust, or cryptodomes (magma intruded to shallow levels in the crust, but don't erupt), and/or extensive dykes and sills. These rock types and magmatic processes can be associated with extensive high temperature hydrothermal systems that include surface manifestations such as hot springs and fumaroles. More mafic volcanic rocks (for example basaltic rocks) tend to transit the crust from the upper mantle rapidly and do not tend to develop hydrothermal systems, unless the system is large and long lived.

For carbon (CO_2) capture (CCUS) applications ultramafic rocks, especially serpentenized material have been shown to have capacity for carbon sequestration (Dipple et al., 2009) and are included in this compilation. The sedimentary sequence that makes up the Bower Basin, are treated separately (See Section 2.15). However, if brine-based disposal in a sedimentary basin in being investigated, high permeability is required. Similarly, sedimentary basin geothermal systems require reservoir rocks with high transmissivity (permeability). Limited information on rock properties is available (See Section 2.10), so this limited the usefulness of "sedimentary units" to be adequately evaluated in the context of the PF analysis.

Dataset created by:

Bastien Poux

Dataset Source:

Geological Survey of British Columbia https://www2.gov.bc.ca/gov/content/industry/mineral-exploration-mining/british-columbia-geological-survey/geology/bcdigitalgeology (Cui et al., 2017)

Built from the compilation of maps of: (Heung et al., 2022)

Data Format

GIS shapefiles for British Columbia bedrock geology, fault lines and quaternary alluvium. A simplified overview of the British Columbia Bedrock dataset, with geological units classified by rock type, and the fault dataset are shown on Figure 1 for the project area.

Project use case:

Geology: projection to WGS84 coordinate system, clipping to project area. The geology shapefile was filtered and exported in new shapefiles to three separate datasets:

- Neogene and Quaternary volcanic rocks
- Paleogene and Older volcanic rocks
- Intrusive rocks

For this study, the analysis is focused on volcanic and intrusive rocks, due to their favourability for hosting high temperature geothermal systems. However, the regional lumping of stratigraphic units and the lack of detailed mapping in areas underlain by volcanics, are a limitation to these data.

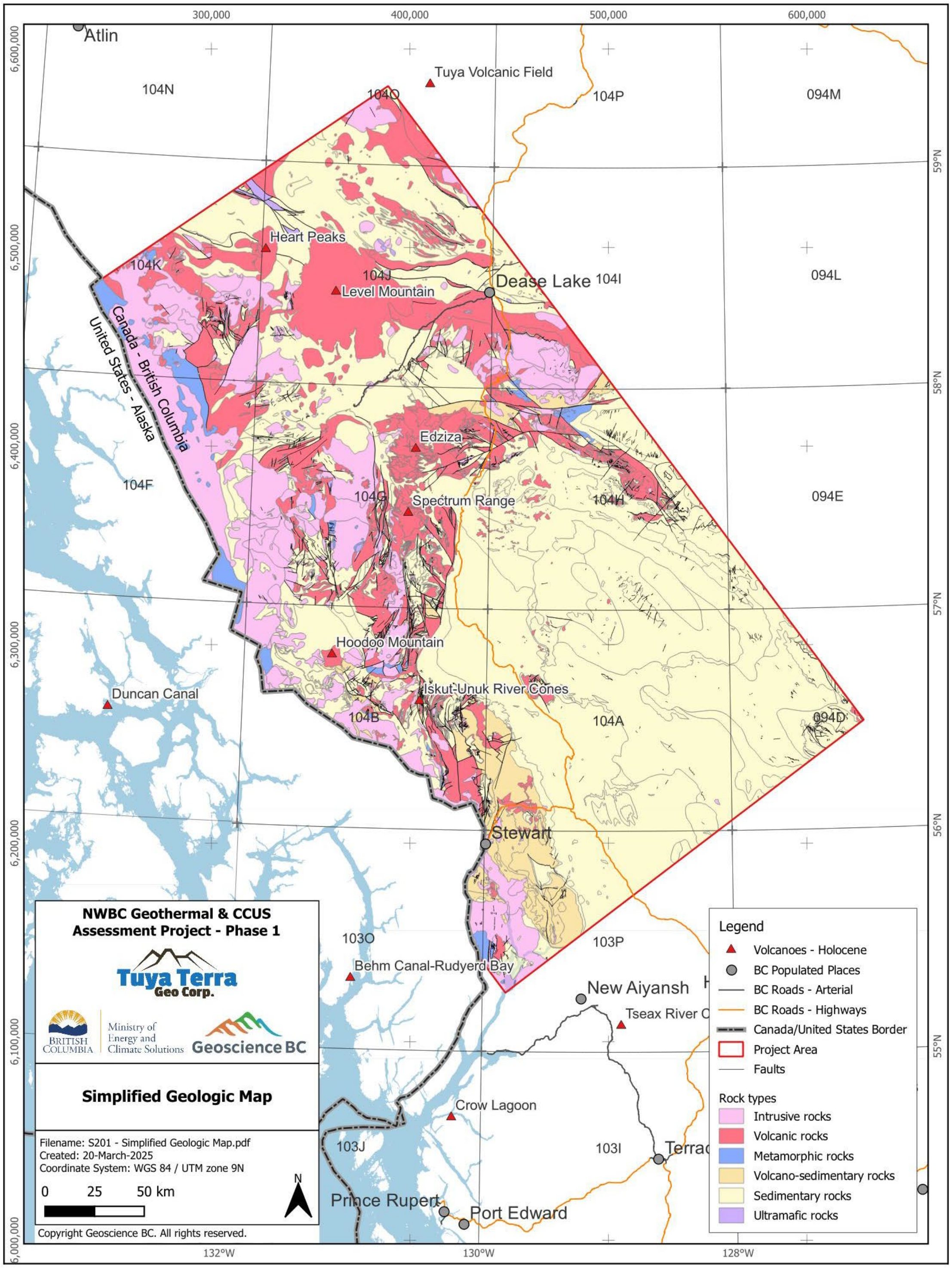
Data distribution:

Data covers the whole province; current digital version is dated **2019-12-19 (See** https://www2.gov.bc.ca/gov/content/industry/mineral-exploration-mining/british-columbia-geological-survey/geology/bcdigitalgeology**).** There have been 10 updates to this map since January 2010. The previous version was from 2005 (Massey et al., 2005). Even though more detailed, larger scale, geological maps exist for some parts of the project area these have not yet been integrated into the British Columbia geological map. The 2019 compilation is considered sufficient for this study. This map permits delineation with enough precision of the main sectors of recent (Neogene and Quaternary) and older (Paleogene and older) volcanic activity and the zones of plutonic intrusions.

To evaluate the geothermal favourability of the project area, the lithologies represented in the British Columbia Bedrock geology map were filtered to create new selective layers containing relevant information. The volcanic formations in the area were further filtered by age, resulting in three new layers:

- Neogene and Quaternary volcanics
- Paleogene volcanics
- Older volcanics

For each layer, volcanic rocks were classified by type based on attributes provided in the British Columbia Bedrock digital geology map.

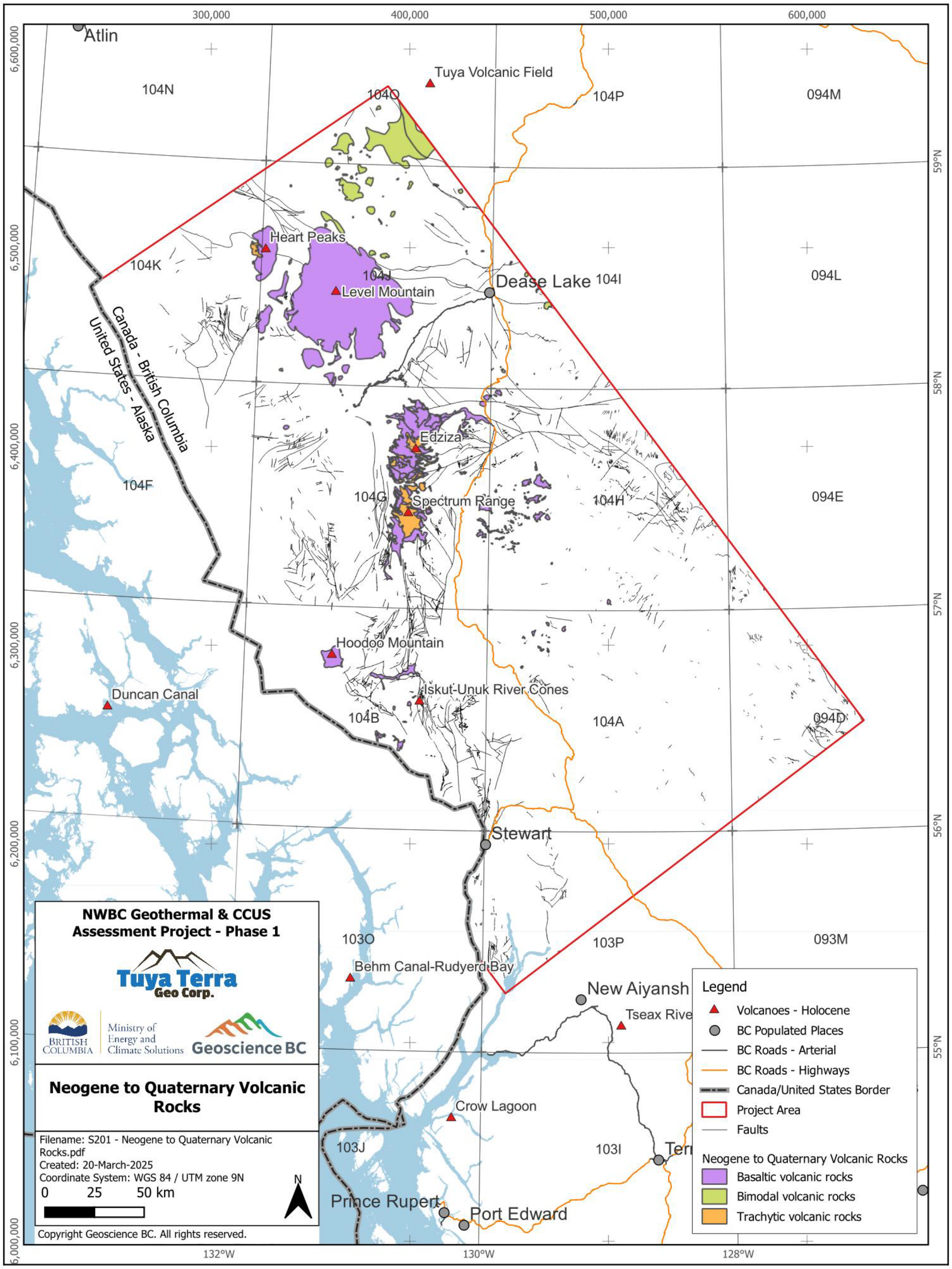


Section 2.1 Figure 1: Simplified geological map of the project area (modified from Cui et al, 2019)

Neogene and Quaternary Volcanic Rock Formations

Volcanic rocks from these periods predominantly have mafic to intermediate compositions, including alkali basalt series, trachybasalts, and minor trachyte and rhyolite. A more detailed description and discussion on the implications of chemistry can be found in Section 2.7. These younger volcanic formations are located near well-known volcanic centers:

- Hoodoo Mountain and Iskut-Unuk River cones (central-south area): Basaltic flows, tuff, and scoria with olivine and plagioclase phenocrysts.
- Spectrum Range and Mount Edziza: Diverse lithologies due to multiple eruptive periods (Miocene to Holocene, ~7.5 Ma–2000 ybp). Alkali olivine basalt and hawaiite dominate the flanks, while trachybasalts, trachyte, and rhyolite form lava domes and flows in the stratovolcano cores (Souther, 1992).
- Maitland Volcanics (Klappan Range): Pliocene-aged olivine basalts with minor trachyte necks and flows (Evenchick and Thorkelson, 2004).
- Level Mountain: Primarily alkali basalts and trachybasalts, with minor trachyte and rhyolite. Initially a shield volcano, it transitioned to a stratovolcano during volcanic activity spanning the Miocene to Pliocene (Hamilton and Scarfe, 1977).
- Heart Peaks: Similar in age to Level Mountain, with a bimodal distribution of basaltic and felsic lavas (Casey and Scarfe, 1978).
- Tuya Volcanic Field (northeast corner): Pliocene-Holocene volcanic rock consisting of basaltic flows, ash, and minor rhyolitic tuff and flows. Noted for the interaction of continental scale glaciation with volcanism. Type location for “Tuya” subglacial volcanic landform (Moore et al., 1995).



Section 2.1 Figure 2: Map of the Neogene to Quaternary volcanic rocks in the project area, with faults and main volcanic centers (modified from Cui et al, 2019)

Paleogene Volcanics

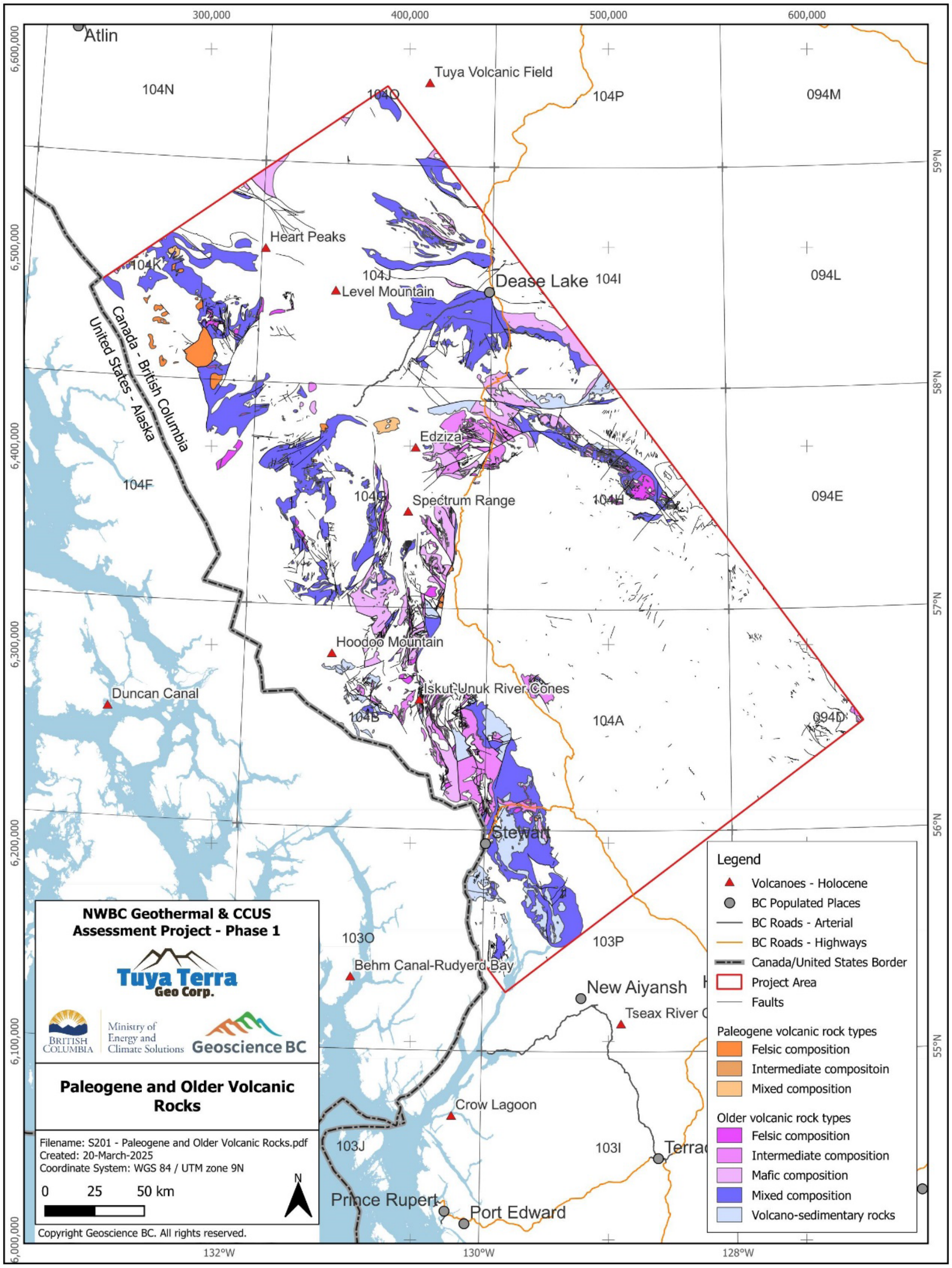
Paleogene volcanic rocks are limited to a few areas, primarily from the Early Eocene:

- Mt. Edziza vicinity: Volcaniclastic rocks of the Sloko Group.
- Boundary Range (west of Heart Peaks and Level Mountain): Early Eocene rhyolite, dacite, and volcaniclastics of the Sloko Group.

Older Volcanic Rock Formations

Older volcanic formations can be classified by rock type and stratigraphic group:

- Stikine Assemblage: Paleozoic-aged mafic to intermediate lavas, tuffs, and breccias. Includes metamorphosed units near 40 Mile Flats (Paleozoic-Mesozoic).
- Hazelton Group: Triassic-Jurassic volcanic rocks of mafic to felsic composition around the Bowser Basin edge
- Stuhini Group: Widespread Triassic-aged mafic to intermediate tuff, ash, breccias, and volcaniclastic sediments.
- Cache Creek Complex: Carboniferous-Permian basalts and tuffs northeast of Level Mountain near Dease Lake.
- Takla Group: Undivided Triassic volcanic rocks near the Tuya Volcanic Field.

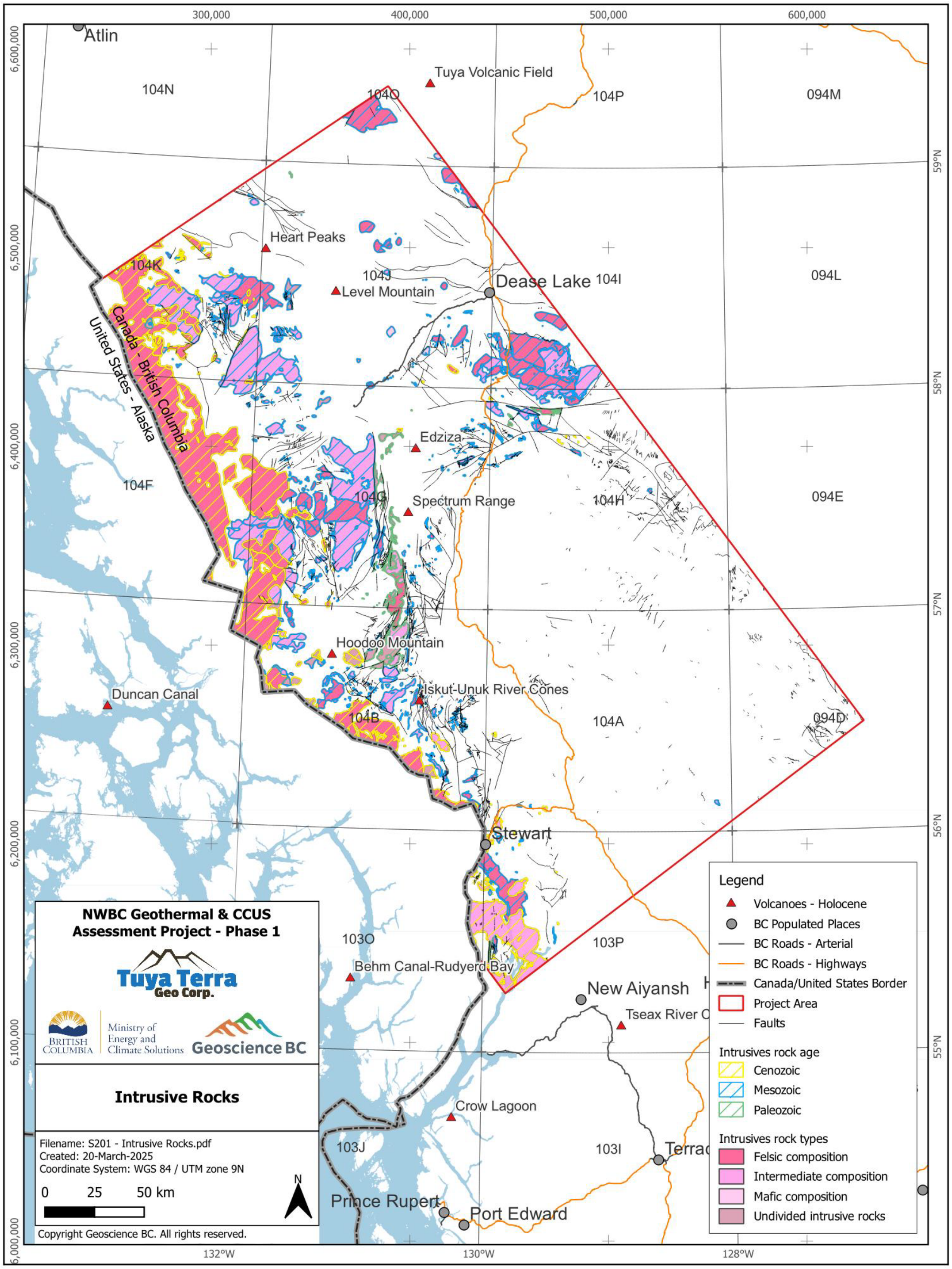


Section 2.1 Figure 3: Map of the Paleogene and Older volcanic rocks in the project area (modified from Cui et al, 2019)

Intrusive Rocks

Intrusive rocks in the project area were similarly classified by geologic era and rock type (mafic, intermediate, felsic, and undivided). The rock type classification was complemented by comparing with the mafic whole rock value (FeO+MgO wt%) as provided in the Global whole-rock geochemical database (see below). The Cenozoic intrusive rocks all have a low mafic index, although most of the chemical analyses available are for the rocks located on the western side of the map area in Alaska, USA.

- **Cenozoic Intrusive rocks**: Predominantly along the western project boundary, extending northwest-southeast into Alaska. Major plutonic suites include the Sloko-Hyder Plutonic Suite, Major Hart Pluton, Coast Plutonic Complex, Saddle Lake Pluton, Hyder Pluton, and Boundary Stock. These intrusions consist of granite, granodiorite, quartz diorite, monzogranite, monzodiorite, and quartz monzonite, reflecting high silica content.
- **Mesozoic Intrusive rocks**: these rocks are distributed throughout the project area with the exception of the southern part where they are likely covered by sediments of the Bower basin. Most Mesozoic intrusive rocks are found between the Boundary Range and the volcanic centers, including the Seraphim Mountain Pluton, the Texas Creek Plutonic Suite, the Cone Mountain Plutonic Suite and more unnamed ones. To the south of Dease Lake, the Three Sisters Plutonic Suite complex covers a large area. Mesozoic intrusive rocks consist of intermediate to felsic rock types, including granite, granodiorite, diorite, quartz monzonite and monzodiorite.
- **Paleozoic Intrusive rocks**: The oldest intrusive rocks in the area are located west of Mt Edziza and Spectrum range and extend in an elongated shape to the south, just east of the Hoodoo Mountain. The Forrest Kerr and the McClymont Plutonic Suites are composed of various granite and diorite and some gabbro.



Section 2.1 Figure 4: Map of the intrusive rocks in the project area (modified from Cui et al., 2019)

Ultramafic rocks

Few outcrops of ultramafic rocks are indicated on the British Columbia Bedrock Geology map based on the mapping done by (Mihalynuk et al., 1996). Ultramafic rocks are rocks that are high in Magnesium and Iron, and low in Silica. Understanding the distribution of these rocks is important to characterize the favourability of the region for carbon sequestration using mineralization (Dipple et al., 2009) (see Section 5.1). Small occurrences are noted in the center of the project area, to the west of Mount Edziza. These occurrences have been mapped as belonging to the Polaris and to the Copper Mountain Suites and consist of pyroxenite and dunite. A larger ultramafic body is found east of Dease lake just outside of the project area and continues farther west between Heart peaks and is part of the Cache Creek Complex of the Paleozoic era. The lithologies reported correspond to oceanic crustal ultramafic rocks such as peridotite, dunite, pyroxenite, there rocks are generally serpentenized.

Limitations of Datasets

This dataset represents the geological formations mapped as occurring on the surface only. Relevant formations for this study might be covered by recent quaternary sediments (glacial deposits) volcanic deposits or exist below thicker sedimentary formations. For example, the lithologies that compose the basement to the Bowser basin are unknown and need to be investigated as well. This provincial geological map was built by compiling numerous large-scale maps and detailed geological models, it may not incorporate recent drilling data, remote sensing, or geophysical surveys, leading to outdated or generalized interpretations. Converting the detailed geology for representation on a small-scale map requires a degree of simplification that can obscure some geological features relevant to evaluating the geothermal potential of the project area. It will be critical to use the higher resolution geological maps when working on the selected areas for further exploration work.

Data Gaps

The geological map provides comprehensive, but regional (small scale) coverage of the entire area of interest, ensuring that no data gaps exist. All relevant geological features, including lithology and faults are well-documented at a resolution suitable for this high-level geothermal assessment. These data are not suitable for detailed, focused or site-specific work.

Recommendations for Additional Work

Foundational geoscience work carried out by the Geological Survey of British Columbia and the Geological Survey of Canada, along with their academic and private sectors partners and contractors, has provided British Columbia with an enviable set of data rich geoscience maps. Further, the availability of these maps and their databases in a publicly available digital format provides researchers and explorationists a significant advantage to other jurisdictions. It is because of this foundational geoscience research that a study such as this one, can provide an assessment of the area under investigation.

Though these data are suitable for the high-level assessment carried out for this report, they are not suitable for detailed, focused or site-specific work. Large scale mapping may be available through mineral exploration companies and when focused areas are found, additional relevant mapping may be available that could be evaluated. See Section 2.17 for additional information on mineral exploration taking place in the project area.

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2.2 Heat Flow Map

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Section 2.2 Figure 1: This heat flow map was created by Jacek Majorwicz for inclusion in Geoscience BC Report 2016-07 (Hickson et al., 2016). The project area in red was overlain on the map 55

Section 2.2 Figure 2: Heat flow map gridded from heat flow sites found in GBC Report 2016-07_GIS_Geothermal.zip data files. Due to the sparse data, little inference can be made, but heat flows within the project area appear higher on a regional basis when compared to other areas of British Columbia (Figure 1). 56

Overview

Heat Flow maps are maps that provide estimates of the heat emanating from the earth. These maps are useful at both a regional and local scale. Regional scale heat flow mapping has been carried on in many parts of the world to aid in geothermal exploration. Geothermal gradient boreholes are drilled to depths of 100 m to as much as 1000 m. The boreholes are small diameter and when completed, tubing is inserted, capped at the end, and the tubing filled with water. The tubing is left for hours to days to equilibrate and when equilibrated, a temperature log of the well is taken. The temperature log establishes the geothermal gradient. This provides information on the geothermal gradient in proximity to the drilled borehole.

On a regional basis, the heat flow provides a measure of the favourability of a region to host geothermal systems. On a local scale, the mapping can aid in targeting exploration drilling sites. High heat flow at a local level is a good indicator of a geothermal system but also complex or highly variable heat flow values are good as they may be indicating the local presence of moving thermal fluid. The more complexity of the heat flow values both laterally and vertically (due to moving thermal water) the more interesting the area is as a geothermal prospect. However, this assessment requires many boreholes in close proximity.

Heat flow is ideally calculated using physical rock properties and the bottom hole temperature. Less ideally, the average gradient from a single bottomhole temperature of the well and the average annual surface temperature can provide the overall temperature gradient of the entire well. On a regional scale, as available for this study, these data are sparse and variable. These data may therefore not be reliable on a regional scale.

Dataset Created by:

C.J. Hickson

Dataset Source:

The most recent update of the heat flow map for British Columbia was completed by Jacek Majorwicz in 2016 for inclusion in a Geoscience BC report that reviewed the potential for direct use geothermal in British Columbia (Hickson et al., 2016). Since this update, no new heat flow data could be found.

Data Format:

The heat flow sites used in the Majorwicz 2016 heat flow map were gridded and extrapolated between boreholes where the calculations were derived for the purposes of this report to provide a regional digital dataset.

Project use case:

Heat Flow is an important parameter in assessing the favourability of an area for hosting geothermal resources under the right geological conditions. In this study, the heat flow is considered fairly uniform over the entire area and is elevated relative to areas east of the study area (Figure 1).

Data distribution:

There are gaps in the distribution of boreholes used to measure geothermal gradients and heat flow. For the purposes of this report, only the regional data was considered.

Data from adjacent areas:

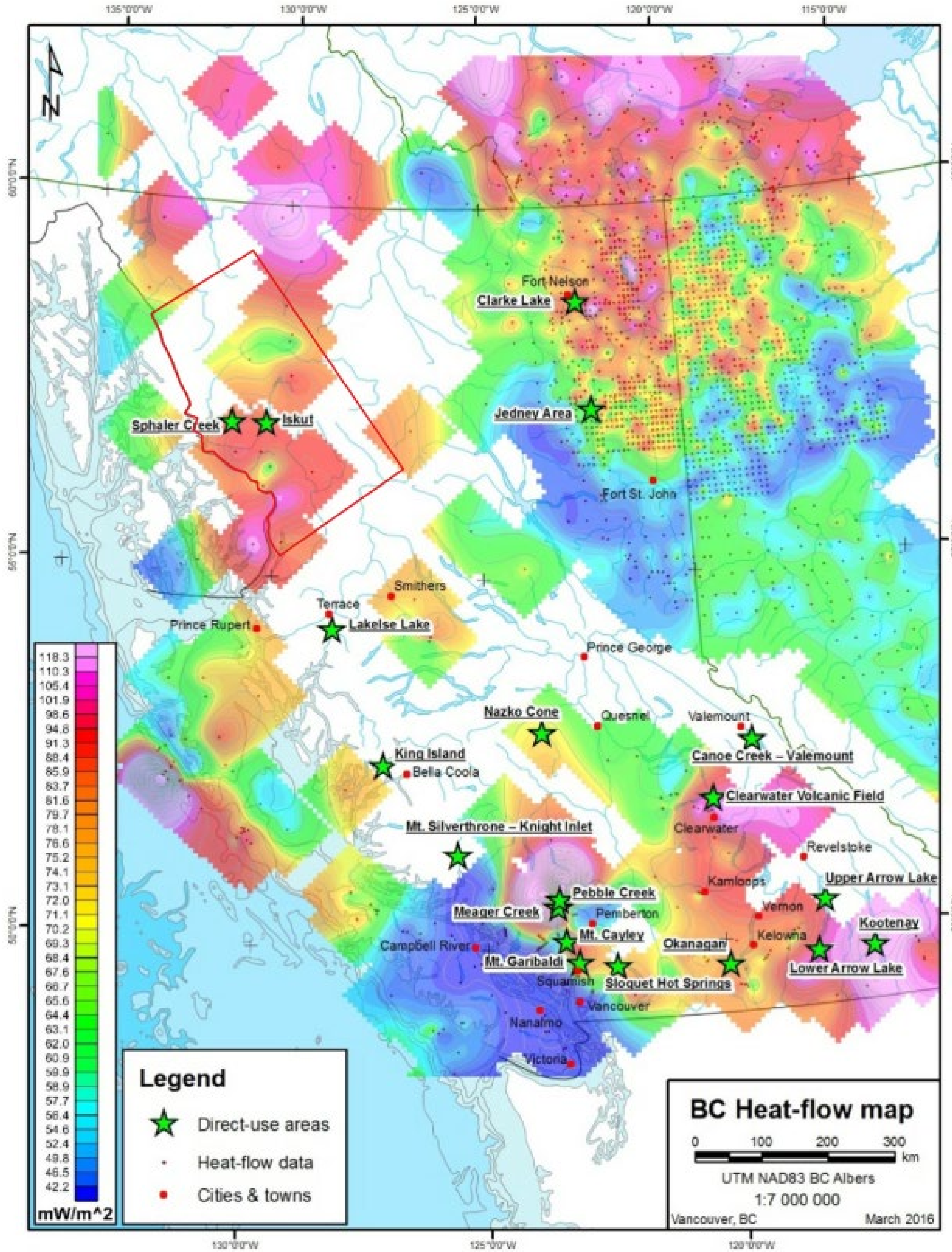
Heat Flow in the project area is elevated from other areas to the east, so provides a first level assessment of the area as to the potential for hosting geothermal systems.

Limitations of Datasets:

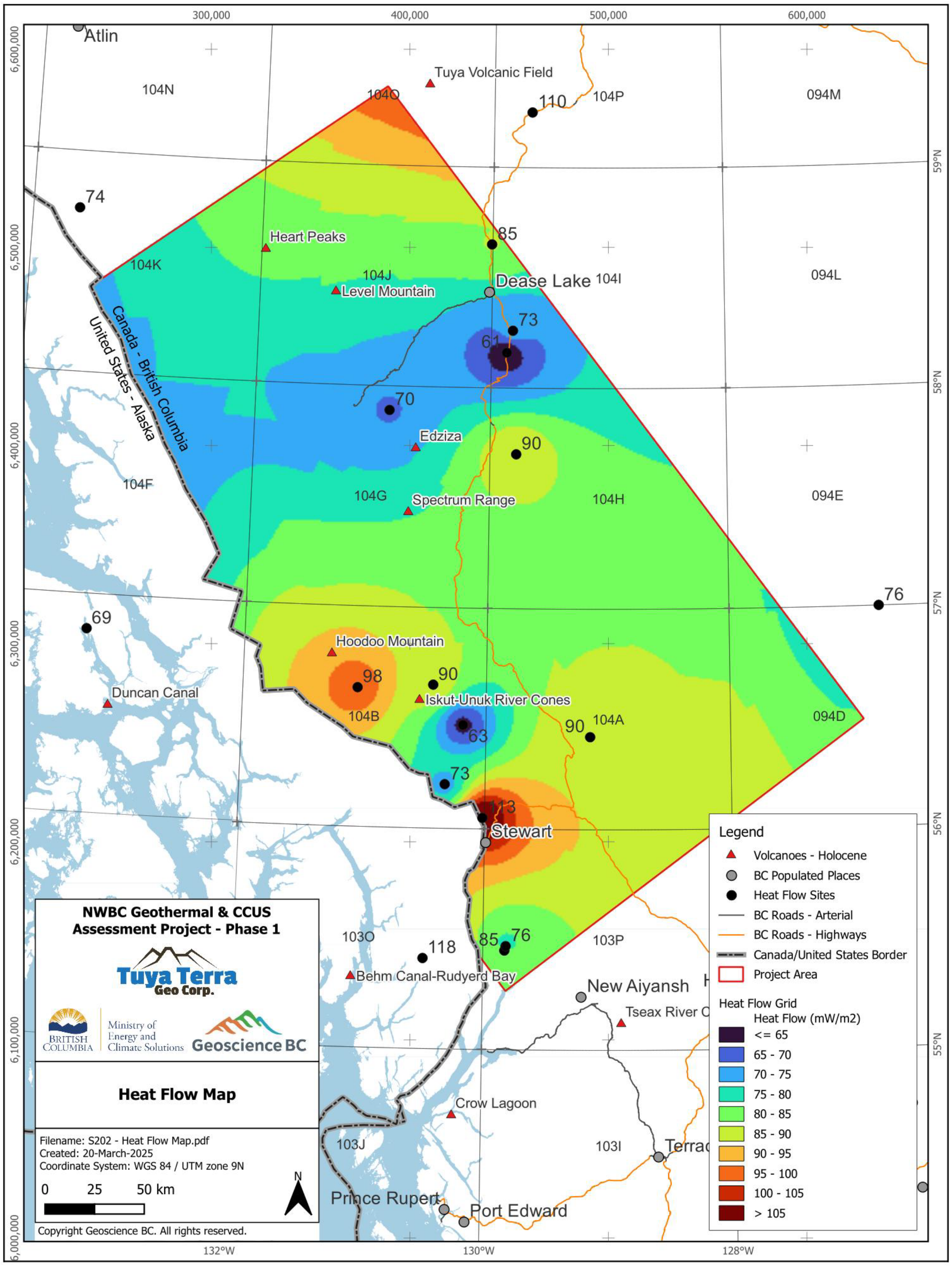
Limited temperature gradient boreholes in the study area create a map that is poorly constrained and lacks detailed information. The usefulness of this data set is only from a regional perspective, identifying the region as one that might have potential to host geothermal systems. For a detailed example of the use of temperature gradient boreholes for both local and regional exploration, the reader is referred to (Faulds et al., 2021).

Data Gaps:

The limited number of measured boreholes in the study area significantly reduces quantification of heat flow mapping over the project area as the results must be extrapolated large distances. There is no detailed heat flow information such as might be useful for well targeting in a specific area.



Section 2.2 Figure 1: This heat flow map was created by Jacek Majorwicz for inclusion in Geoscience BC Report 2016-07 (Hickson et al., 2016). The project area in red was overlain on the map



Section 2.2 Figure 2: Heat flow map gridded from heat flow sites found in GBC Report 2016-07_GIS_Geothermal.zip data files. Due to the sparse data, little inference can be made, but heat flows within the project area appear higher on a regional basis when compared to other areas of British Columbia (Figure 1).

Recommendations for Additional Work

All naturally occurring geothermal systems and technologies for heat extraction are more efficient at higher temperatures (See Section 1.1). Additional temperature gradient boreholes would be a significant contribution to increased understanding of heat flow in the region. Collaboration with mining and exploration companies working in the region may lead to opportunities to drill boreholes. Additionally, mine developments may have water wells or observation wells that could be utilized as temporary gradient boreholes. However, other data, such as the presence of Quaternary volcanoes, is a more robust indicator of regional high heat flow. In areas where there is favourability for fault hosted systems, temperature gradient boreholes may be helpful exploration tools to identify if there are thermal anomalies associated with faults or fracture systems. Providing temperature gradients (not just bottom hole temperatures) for all sites would also be a very useful addition to these data. The gradient information can be used to calculate how deep a well needs to be to reach a specific temperature. It makes a factor of two difference between holes drilled in clay and in solid crystalline rocks.

References

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2.3 Fracture/Fault Mapping

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Section 2.3 Figure 1: Fracture/Fault Map 61

Overview

Fracture and fault mapping is essential in geothermal exploration, as these structures control subsurface permeability and fluid flow. Emphasizing neotectonic features is crucial since recently active faults are more likely to remain open, enhancing heat transport and geothermal fluid circulation (c.f., Faulds et al., 2021) These structures also indicate high-temperature anomalies linked to tectonic activity and magmatic intrusions (Cembrano and Lara, 2009). Additionally, understanding fault activity helps mitigate seismic risks (Horne et al., 2025; Huenges, 2025), especially in enhanced geothermal systems (EGS).

Geological faults are part of the British Columbia Digital Geology dataset, which provides seamless, up-to-date, and detailed bedrock geology across the province. This dataset integrates compilations at scales from 1:50,000 to 1:250,000. However, large areas are covered by Holocene volcanism, forests and glacial cover, in addition to the challenging terrain. This data set is biased by these factors and this bias must be integrated into the favourability analysis. Additional mapping and understanding of the types and timing of the faults would significantly improve these data.

Dataset created by:

Félix-Antoine Comeau

Dataset Source:

British Columbia Geological Survey's MapPlace 2

Geological Survey of British Columbia https://www2.gov.bc.ca/gov/content/industry/mineral-exploration-mining/british-columbia-geological-survey/geology/bcdigitalgeology (Cui et al., 2017)

Built from the compilation of maps of: (Heung et al., 2022)

Data Format:

Line GeoPackages

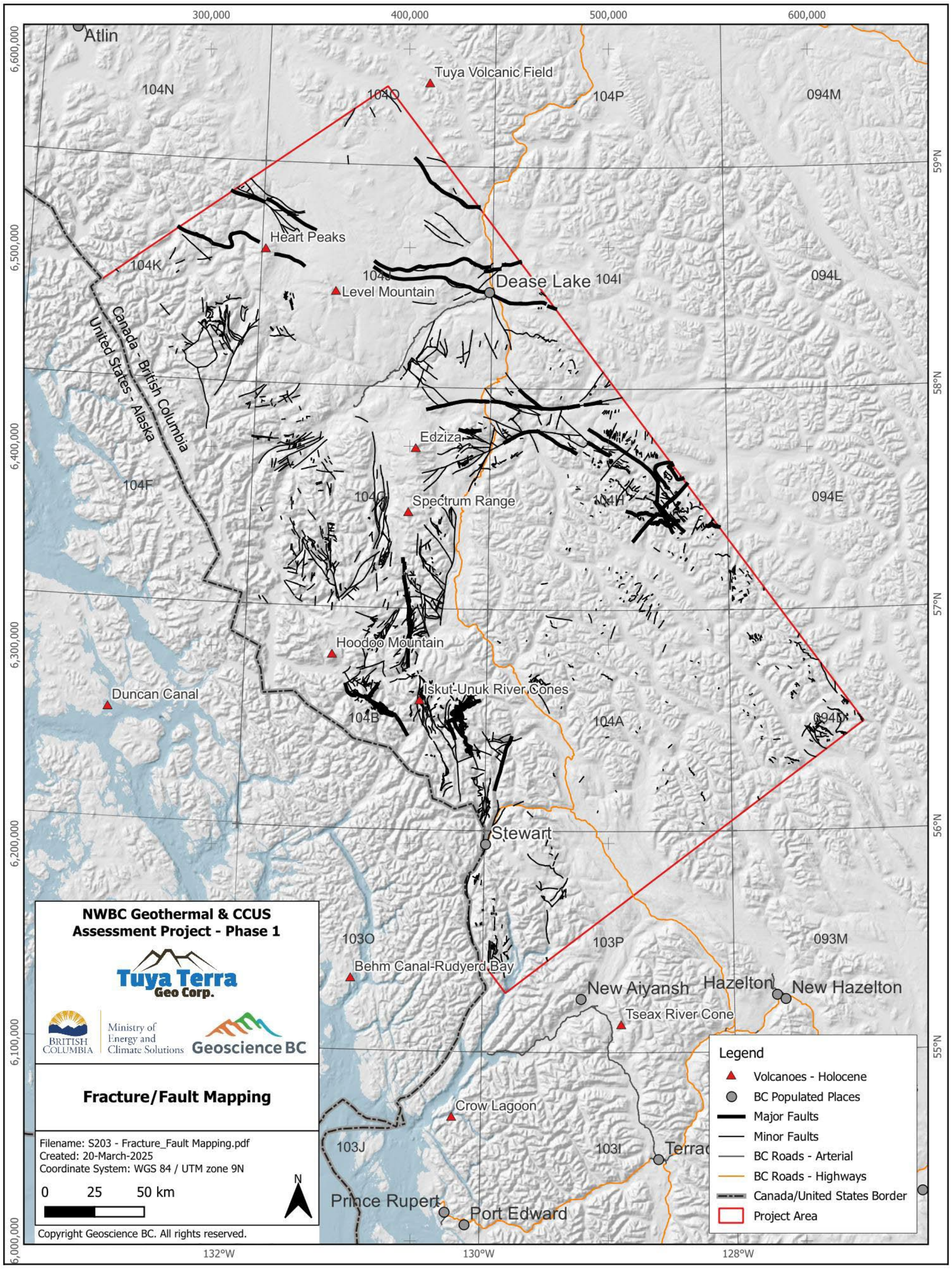
Project use case:

Fault orientation plays a crucial role in identifying the most permeable zones within a geothermal system. Fault dilatancy is often associated with geothermal systems and some fault styles have been shown to be more favourable for hosting geothermal systems (Faulds et al., 2021) than others. Step-over faults, fault transfer zones, and other types of faulting, that lead to dilatancy depending on their orientation have potential to host geothermal systems. Faults with maximum dilatancy are typically oriented parallel to the regional stress field and are more likely to remain open and facilitate fluid flow with dilatancy perpendicular to the stress field. Additionally, areas with a high fault density, regardless of fault orientation, often correspond to zones of enhanced fracture connectivity, which can significantly increase bulk permeability. These favourably faulted regions are also prime targets for deep geothermal exploration, as they may promote the upwelling of hot fluids from depth, creating localized geothermal anomalies with higher energy extraction potential.

Data distribution:

The study area faults are categorized into two distinct groups: major and minor. Major faults are defined as those that have been assigned a specific name in the dataset table downloaded with the data. The dataset table indicates the faults significance and recognition within the geological framework. These faults often play a crucial role in regional tectonics and may influence geological processes such as fluid movement and seismic activity. In contrast, minor faults are those that do not have an assigned name, suggesting they are less prominent or have a limited impact on the surrounding geology. This classification is the only information available for making such interpretations and analyses.

The following map displays the identified major and minor faults, highlighting their location within the geological landscape.



Section 2.3 Figure 1: Fracture/Fault Map

Limitations of Datasets:

Data set compilation was completed at a regional scale; however, no age attributes could be assigned to the faults. This lack of temporal information limits our understanding of the faults' geological history and their potential implications for geothermal exploration, as knowing the age of faults is crucial for assessing their activity, stability, and influence on fluid movement within geothermal systems.

Data Gaps:

There is no information on the age of the faults and their last movement. Significant areas appear to have no faults. This is not likely to be true but is due to scale of mapping, post faulting geological cover, topography and recent glacio-volcanic cover.

Recommendations for Additional Work

Age and orientation of fractures and faulting is an important attribute for favourability mapping (see Section 3.1 for how this data set was used and weighted). Based on the lack of age attributes for the identified faults in the data set compilation, several recommendations for additional work include conducting age dating studies using radiometric or relative dating techniques to enhance understanding of fault activity and stability. Detailed structural mapping and analysis should be performed to assess fault geometries, orientations, and their relationships with surrounding geological features, providing insights into potential influences on geothermal fluid pathways. Implementing geophysical surveys, such as seismic reflection or resistivity methods, could further investigate the subsurface characteristics of the faults. Additionally, hydrothermal alteration studies should be conducted to identify areas of increased permeability that may indicate favourable geothermal reservoirs. Integrating existing geological data with new findings will help create a comprehensive geological model, while establishing a long-term seismicity monitoring program can assess fault activity over time, aiding in understanding seismic risks and the stability of geothermal reservoirs.

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2.4 Regional Stress Direction

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Section 2.4 Figure 1: Regional Stress Direction Map 65

Overview

Regional-scale tectonic forces (called "stresses") acting on the Earth's crust are an important control on the permeability of fractures. For example, fractures oriented perpendicular to the direction of compressive stress would tend to be pressed shut by the tectonic forces. Importantly, fractures oriented parallel to the maximum compressive stress are in the most likely orientation to be dilatant and permeable (see discussion under Section 2.3). Thus, determining the direction of maximum horizontal stress in the project area is important for understanding the orientation of rock fractures that are most likely permeable.

Dataset created by:

Jeff Witter

Dataset Source:

Leonard et al. (2007) and Mazzotti et al. (2013)

Data Format:

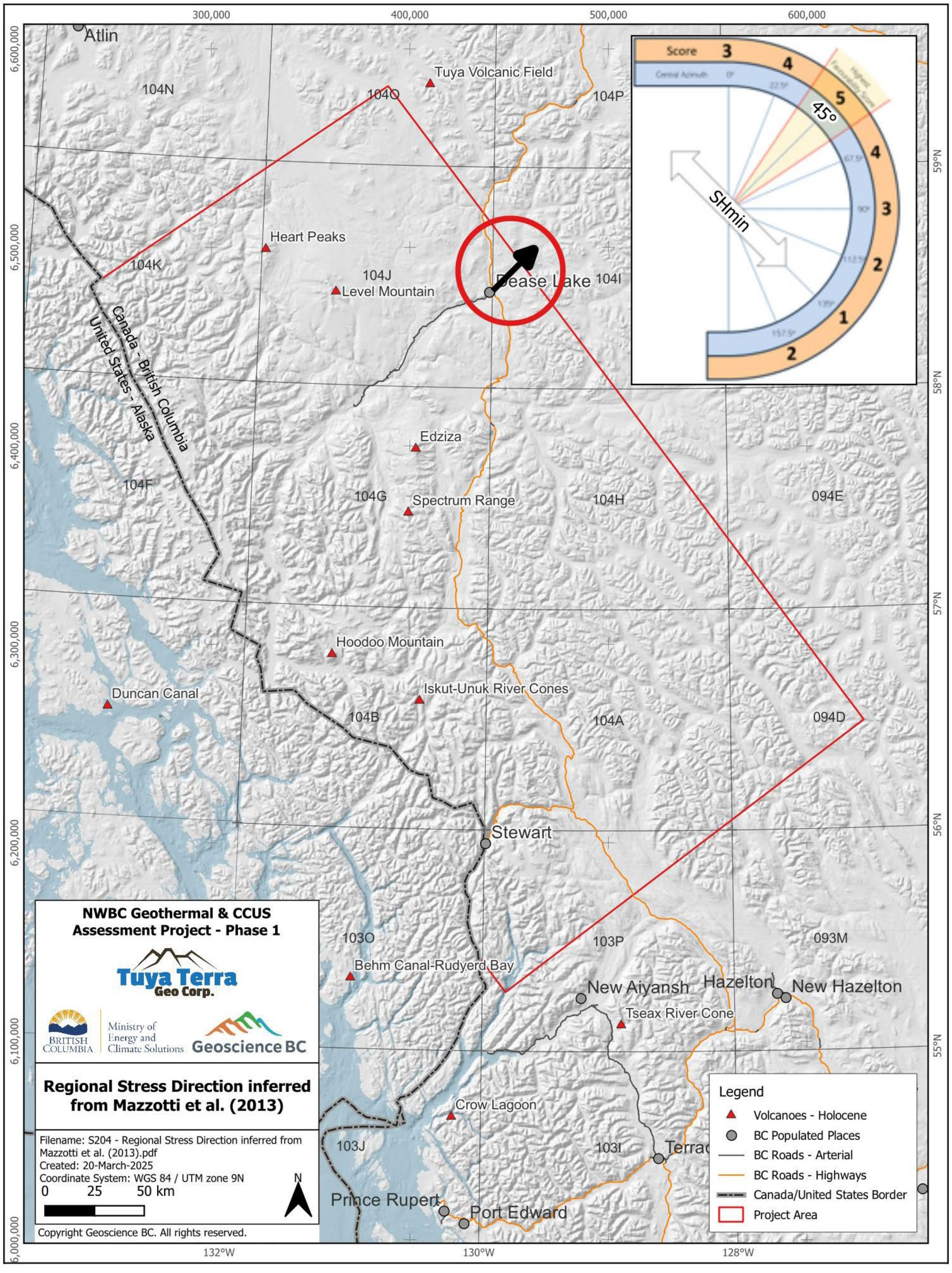
Point data

Project use case:

Regional stress direction helps to identify the orientation of fractures in rocks that are the most favourable for permeability and fluid flow.

Data distribution:

Regional stress direction in the project area is inferred in a single GPS data point from a monitoring station at Dease Lake (Mazzotti et al, 2013) This is shown in the figure below as an arrow representing relative plate motion towards the NE at ~2±1 mm/year. From this stress direction a direction of minimum horizontal stress was inferred (see inset diagram). This minimum horizontal stress direction was used as a weighting factor in the PF Analysis (see Section 3.1).



Section 2.4 Figure 1: Regional Stress Direction Map

Data from Adjacent Areas:

The nearest GPS measurements from Leonard et al. (2007) and Mazzotti et al. (2008) that estimate plate motion are located > 200 km away from Dease Lake in Atlin, British Columbia and in the Alaska panhandle. Additional GPS measurements across northwestern British Columbia would be a game-changer to help better define the larger scale tectonic forces that influence rock fracture and permeability in the crust.

Limitations of Datasets:

Unfortunately, there are no regional stress measurements from the World Stress Map (Heidbach et al., 2018) for all of northwestern British Columbia. The closest measurements are along the Queen Charlotte Transform fault or in the Western Canadian Sedimentary Basin of northeastern British Columbia and are not relevant to the question of regional stress direction in the project area.

Leonard et al. (2007) and Mazzotti et al. (2013) use GPS measurements to show plate motion for the portion of continental crust within the project area. Their results show plate motion to be compressional and towards the NE (relative to stable North America) at a rate of ~2±1 mm/year. This would suggest that the regional Maximum Principal Stress direction is NE-SW and the Least Principal Stress is perpendicular to that at NW-SE. This suggests that faults that strike NE-SW would be more likely to be dilatant (and more permeable) compared to faults in other orientations. Mazzotti et al. (2013) also make an argument for tensile gravitational forces in the Northern Canadian Cordillera within the project area, that is balanced by NE-SW boundary compressional forces. If true, these balanced tensile and compressional forces would limit actual crustal extension and permeability development.

Data Gaps:

Data coverage is severely limited because there is only one data point (located in Dease Lake).

Recommendations for Additional Work

Regions with many geothermal systems that are not directly associated with Holocene volcanism, are known to occur in extensional (least stress) environments (Faulds et al., 2016) so understanding the regional stress field can be an important indicator for favourability mapping. See Chapter 3 for how this data set was used and weighted. Campaign-style GPS surveys at a dozen or more locations in northwestern British Columbia would dramatically improve our understanding of plate motion and regional stress direction in this portion of the Canadian cordillera. For example, plate motions in the Alaska panhandle are estimated at ~2-5 mm/year towards the N and NW. This contrasts with an estimate of ~2±1 mm/year towards the NE at Dease Lake within the project area. Plate motions between these two areas have not been measured. Additional GPS measurements would help constrain the changes in magnitude and direction of plate motion across northwestern British Columbia and shed light on regional stress directions. Other datasets that could be used to invert stress fields are earthquake focal mechanisms and borehole caliper or image logs. Given the wealth of mining activity in the region and the lack of requirements to seal non-artesian holes, there may be a large number of boreholes available for re-entry to collect borehole orientation data required to resolve local and regional stress fields, as well as additional industry-held data.

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2.5 Seismicity Scan

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Section 2.5 Figure 1: Seismicity Scan Map. This data set is not filtered for seismic activity that may be related to mines, abandoned mines, glaciers or other factors that might result in seismic activity. Due to the low magnitude of the events Geological Survey of Canada analysists were not able to provide a manual review of the dataset within the time frame of the project. ... 72

Overview

Northwest British Columbia (specifically this project area) has many mapped surface faults (small and large) but is a region of low seismicity, with no recorded significant (M>4) earthquakes within the project area boundaries (Section 2.5 Figure 1) . Large magnitude (e.g., M8+) earthquakes have occurred along the major plate boundary faults (such as the Queen Charlotte Fault and the Chatham Strait Fault) located 150-250 km to the west.

Although there are numerous surface faults throughout this region, at a variety of scales, seismicity cannot be directly linked to these structures, due to seismic monitoring limitations.

The first seismograph station in the vicinity of the northern Cordillera began operating at Sitka, Alaska (SIT), in 1904. It wasn't until the late-1950s to mid-1960s when short-period, high-gain seismographs in Alaska and Canada were deployed that smaller (to about local magnitude ML ≈ 5) earthquakes could be located in the northern Cordillera. There was still a very sparse seismic network in northwestern British Columbia area as recently as 2003, when Whitehorse, YK, Haines Junction, YK, Dease Lake, British Columbia and Fort Nelson, British Columbia were the only Canadian National Seismograph Network Stations operating in the area. The best seismic coverage in southeast Alaska and parts of northwestern British Columbia occurred with the temporary deployment of the Earthscope Transportable Array from 2014-2020 (Busby and Aderhold, 2020). This included 6 seismic stations within this project area (Schaeffer et al., 2025). Many studies detail the history of seismic monitoring in this region (Busby and Aderhold, 2020; Cassidy et al., 2005; Cassidy and Mulder, 2024; Schaeffer et al., 2025), highlighting the evolution of techniques and findings that contribute to our understanding of seismic activity and its implications for geological and geothermal assessments.

Over the past six decades, there have been a number of temporary seismic deployments and some detailed (targeted) geophysical studies in this region. A few are briefly summarised here. Note that this is not a complete list.

One of the first detailed studies was to look for seismicity in the vicinity of the volcanic belt in northwest British Columbia (Rogers, 1976). For short periods in 1968, 1969 and 1971-1972, seismographs were operated within and around the Quaternary volcanic zone in northern British Columbia (Milne et al., 1970; Rogers, 1976). A key finding of these studies was that there was no significant earthquake activity associated with the volcanic sector (including Mt. Edziza).

The most common type of seismic event observed during these studies was small, low-frequency events that had a pronounced seasonal cycle, with high rates of activity in the summer and fall and almost no activity in the winter and early spring. Their locations were concentrated in a few areas in the vicinity of large glaciers in southeast Alaska, and they were interpreted as having a glacial origin (Rogers, 1976). More recent studies (Wolf et al., 1997) have also shown seasonal variations in seismicity suggesting a hydrologically-related causal mechanism.

In the 1990's, a variety of geophysical data were collected along the LITHOPROBE Corridor (in particular Line 22 that extended from just north of Prince Rupert, north to Dease Lake and then into the Yukon (see Section 2.9 Figure 1). This study included both seismic refraction and reflection data for detailed structural imaging. Key results included mapping crustal velocities and a thin (~25 km depth) Moho at the south end of Line 22 and a more typical Moho depth (~35 km) along most of the corridor (Clowes et al., 2005).

Other relevant studies in this area include the computation of regional moment tensor solutions in the region (Cassidy et al., 2018; Kao et al., 2012). These solutions are generally possible for M>4 earthquakes and it is noted that no moment tensor solutions exist within the boundaries of this project area.

Details of the US Array deployment in Alaska (including parts of the Yukon and six stations in this project area) are provided in the literature (Busby and Aderhold, 2020; Ruppert and West, 2020). These seismic data are available via IRIS/Earthscope Consortium for detailed studies of seismicity and tectonics Some examples of using dense seismic station coverage (such as the US Array) to better understand seismicity, focal mechanisms, and crustal stress are illustrated in previous studies (Gosselin et al., 2024). This research covers a portion of the area of interest in this study.

It is also noted that numerous *Environmental Impact Assessments* have been undertaken for major projects in this project area, including mines, LNG and other energy-related facilities, etc. If some or any of these reviews are publicly available, they may contribute to a better assessment of baseline seismic hazard. The current (2020) national seismic hazard values are available via the NRCan website https://www.earthquakescanada.nrcan.gc.ca/hazard-alea/interpolat/nbc2020-cnb2020-en.php, with details provided in previous research (Kolaj et al., 2023).

Dataset created by:

John F. Cassidy (Geological Survey of Canada);

Félix-Antoine Comeau;

Dataset Source:

British Columbia Geological Survey's MapPlace 2

Geological Survey of British Columbia https://www2.gov.bc.ca/gov/content/industry/mineral-exploration-mining/british-columbia-geological-survey/geology/bcdigitalgeology (Cui et al., 2017)

Built from the compilation of maps of: (Heung et al., 2022)

Additional datasets utilized in this section is a collection of publicly available data sets:

NRCan Earthquake Database

NOAA Alaska Region - Glaciers (AK_2020_debris_free_area.shp)

GeoBC Branch - Freshwater Atlas Glaciers

Natural Resources Canada - Principal Mineral Areas, Producing Mines, and Oil and Gas Fields (900A)

The Canadian Minerals and Metals Plan - National Inventory of Orphaned and Abandoned Mines

Data Format:

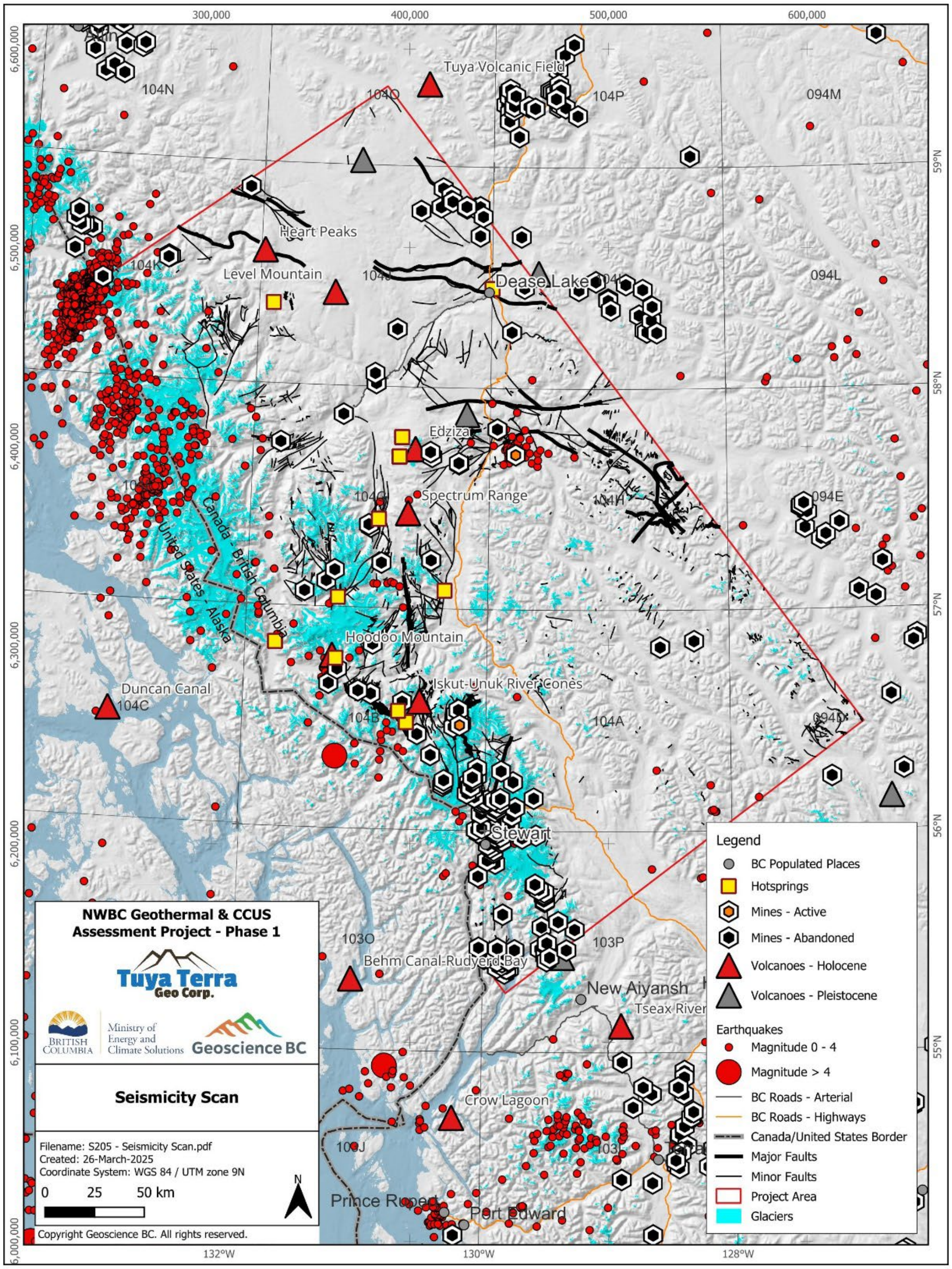
Polygon, Line and Point GeoPackages

Project use case:

A high concentration of earthquakes can signal recent neotectonic activity, which may indicate the presence of permeable faults that allow for the upwelling of deep, hot fluids. In geothermal exploration, these seismic patterns are crucial, as they can highlight areas with enhanced permeability that are favourable for geothermal energy extraction (Cembrano and Lara, 2009; Sibson, 1996). Identifying and studying these regions can lead to more effective targeting of drilling efforts and improved understanding of geothermal resource potential.

Data distribution:

The following map displays earthquakes since 1985. Also shown are the locations of volcanoes and hot springs. The earthquakes are categorized into two groups: those greater than magnitude 4 and those below. Additionally, the extent of glaciers and the presence of active and closed mines provide context for evaluating the significance of earthquake clusters.



Section 2.5 Figure 1: Seismicity Scan Map. This data set is not filtered for seismic activity that may be related to mines, abandoned mines, glaciers or other factors that might result in seismic activity. Due to the low magnitude of the events Geological Survey of Canada analysists were not able to provide a manual review of the dataset within the time frame of the project.

Limitations of Datasets:

The absence of M>4 earthquakes in the area limits the availability of focal mechanisms and hampers crustal stress mapping. With few nearby seismic stations, the locations and depths of smaller earthquakes are uncertain. Additionally, no detailed studies have been conducted, leaving the causes of seismic activity—potentially linked to glacier meltwater or hydrological factors—unclear. There is no evident connection between seismicity and volcanic cones, nor have studies explored potential mining-related (blasting, for example) or induced seismic events. Consequently, the seismic data in the region remains largely uninformative and of limited utility for geothermal exploration.

Data Gaps:

There are many key knowledge gaps in this project area related to seismic hazards and tectonics. Given the lack of M>4 earthquakes in this region, there are no earthquake focal mechanisms (moment tensor) available. This hampers the ability to map crustal stresses. With a lack of nearby seismic stations, the locations (and especially focal depths) of the small earthquakes are poorly constrained, and therefore, possible connections with surface faults cannot be made at this time. Although there are numerous mapped surface faults through this region, there have been no detailed studies or paleo-seismological studies in the study region. One of the most significant knowledge gaps is simply the cause of earthquakes in this region, and the potential for future, larger earthquakes. A few studies looking at seasonal variations in seismicity suggest possible linkages with glacier meltwater/hydrological factors (Rogers, 1976; Wolf et al., 1997) for some of the clustering of microseismic events. There is no clear correlation between seismicity and volcanic cones in the region, and no studies have identified possible mining-related or induced seismic events in this area.

Recommendations for Additional Work

Recording, collecting and analysis of seismic data is a federally run program through the Geological Survey of Canada. Recent seismicity is an important dataset to investigate for geothermal exploration. Seismic activity can indicate permeability along fault lines and can also provide information on the regional stress field. Additionally, seismic activity related to volcanic centers may indicate movement of magma or cooling of magma bodies. The seismic data from the project area is limited because sensors and recordings are limited and not optimized for this region in terms of density and sensitivity. If better data could be collected, a number of studies (some that would utilise existing data and others that would require data collection) could be undertaken to address key knowledge gaps and better assess earthquake hazards in the region.

For example, existing seismic data (especially the US array data and other temporary deployments through the region) could be used to better locate select earthquakes (location and focal depths). The modern seismic data could be used to obtain focal mechanisms and the crustal stress field for select earthquakes (Gosselin et al., 2024). A search for existing Lidar data could be undertaken (e.g., Lidar BC https://lidar.gov.bc.ca/) to help assess fault movements. Based on these studies, and more detailed seismicity studies, additional targeted airborne or drone LiDAR data (Finley et al., 2022) could be undertaken.

Other data that could be collected to better assess earthquake hazards and their correlation with subsurface geology include:

- temporary deployment of seismic stations for targeted areas;

- deployments of Distributed Acoustical Sensor (DAS) technology to record and locate seismicity in areas of interest;
- electrical resistivity tomography,
- paleo-seismology studies.

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2.6 Fluid Geochemistry

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Overview

Hot springs are a key indicator of geothermal systems. In fact, the presence of a thermal spring indicates that some kind of geothermal system is present at depth. Water, hotter than natural ground water, is flowing to the surface. Where the heat originates, or the size and pathways to the surface, are not known without additional research.

The word, "hot springs" is also poorly defined. In Europe, where hot springs have been commercially developed for millennia, only those with a temperature above 20°C are classified as "hot springs". In Japan, anything above 25°C is considered a hot spring. The Geothermal Resources of Washington Map, 1981 and the USGS Thermal Springs in the U.S data set 20°C as the dividing line, with 21°C set as the lower limit of hot springs. Woodsworth and Woodsworth, 2014 state there is 'No uniformly accepted temperature cut off for hot springs', but in the book they use these temperatures: hot spring > 32 °C; warm spring 20-32 °C; cool spring 5-20 °C. In this study, "hot springs" refer to locations in the data base, regardless of measured temperatures. Within this chapter, a more conservative approach is used, referring to the locations as "thermal springs", as several do not meet the Woodworth and Woodworth (2014) criteria of "hot spring".

There are 12 reported thermal springs in the project area (Hickson et al., 2016):

1. Dease Lake
2. Elwyn Creek
3. Tawen/Taweh/Tawah Creek (Sezill)
4. Mess Lake
5. Mess Creek
6. Sphaler Creek
7. Hoodoo Mountain
8. Len King (King Creek)
9. Iskut River
10. Choquette (Stikine River Fowler)
11. Snippaker Creek (Julian Lake)
12. Shelsay

Reports of geochemical sampling of the fluids have been found for most of these thermal springs, with the exception of Dease Lake (temperature and pH only), Hoodoo Mountain, Snippaker Creek (Julian Lake), and Shelsay. The geochemistry data have been compiled by Hickson, Proenza, et al. (2016) and are found in Appendix A.

Analyses (including geochemistry, classification, and others) have been conducted on samples from Mess Creek, Mess Lake, Len King, Elwyn Creek, and Tawah Creek springs by Piteau, D. R. and Associates Ltd. (1988). Souther (1976) provides a written summary analysis of the Mess Lake, Mess Creek, Elwyn Creek, and Tawah Creek springs. Souther and Halstead (1973) report gaseous constituents and associated rocks for Elwyn Creek, Tawah Creek, and Mess Lake springs, and chemical constituents and associated rocks for Choquette. A summary of these analyses and reports that have been conducted are provided in Table 3.

Climate:

Air temperatures at the thermal spring locations were calculated for springs with geothermometry calculations: Mess Creek, Mess Lake, Elwyn Creek, Sezill (Tawah Creek), which are within the Mount Edziza area, and Len King (King Creek) which is closer to the town of Stewart, British Columbia.

There are several weather stations near Mount Edziza. The Telegraph Creek station (elevation about 180 m asl) is approximately 40 km northwest and the Dease Lake station (about 206 m asl) is approximately 85 km northeast. The Stewart station (about 0 m asl) is approximately 73 km southeast of the Len King hot spring. Each of these stations have historical climate data from 1981-2010, including daily average temperatures for each month, which were used to calculate mean annual temperature (Government of Canada, 2025). The historical data for Telegraph Creek have many missing values and gaps, therefore, data from the Dease Lake station were used to calculate temperature for the springs around Mount Edziza. The mean annual temperature from 1981-2010 is -0.5 ° C. The Stewart station was used for the Len King hot springs and has a mean annual temperature from 1981-2010 of 6.2 °C.

In this geographic region, air temperature drops around 1.5 °C per 1000 m rise in altitude (Piteau, D. R. and Associates Ltd., 1988). The Mess Creek and Mess Lake springs sit at an elevation of around 762 m asl, and Elwyn and Taweh springs are around 1400 m and 1370 m asl, respectively (Piteau, D. R. and Associates Ltd., 1988). Based off topographic maps, the elevation of the Len King hot springs are estimated to be 540 m asl. Using the spring and station elevation, the temperature gradient of 1.5 °C/1000m, and the historical data for the weather stations, the estimated mean annual air temperature is 0.4 °C for Mess Creek and Mess Lake, 1.3 °C for Elwyn and Taweh, and 7.0 °C for Len King (Table 1).

The following is a summary of work completed by Piteau, D. R. and Associates Ltd. (1988):

Scope:

1. Characterize major ion and trace metal geochemistry
2. Evaluate isotopic nature of geothermal waters to establish their recharge area
3. Geothermometry
4. Relative age using natural tritium and carbon-14

Thermal Springs Analyzed:

1. Elwyn Hot Spring and Spring (sampled from vents)
2. Taweh (sampled from hot spring vent, mushroom, and hot spring)
3. Mess Creek Hot Spring
4. Mess Lake Spring
5. King Creek (Len King) Hot Spring

Sample Analysis:

1. Major and trace element geochemistry
2. Stable and radioactive environmental isotopes in water (^{18}O, ^{2}H, ^{3}H)
3. Isotopes of dissolved carbonate (^{13}C, ^{14}C), calcite tufa (^{13}C, ^{18}O), sulphate (^{18}O)

Major Element Geochemistry:

- Piper Diagram

Geothermometry Conducted:

- Na-K-Ca-Mg
- Mg-K
- Na-Li
- Sulphate-water (^{18}O)

- Silica

Geothermometry results are reported in Table 1.

Section 2.6 Table 1: Geothermometry results from Piteau, D. R. and Associates Ltd. (1988)

Name	**Sample Location**	**Est. Mean Annual Air Temperature (°C)**	**Geothermometer (°C)**								
			Na-K-Ca (Uncorrected for Mg)	**Na-K-Ca (Corrected for Mg)**	**Na-Li**	**Mg-K**	**Sulphate-Water**	**Quartz**	**Chalcedony**	**SO_4-H_2O**	**Mean[3]**
Mess Creek	Hot Spring	0.4			105	56	57				73
Mess Lake	Lake Spring	0.4									77
Elwyn Creek	Vent #1	1.3	169	<50	77	60	23[1]	114	81[2]		68
Sezill (Tawah Creek)	Main vent	1.3	151	<50	80	64	47[1]	113	80[2]		73
Len King (King Creek)		7.0								67	75

[1]Affected by low sulphate concentrations in water. Also less reliable at lower temperatures.

[2]Chalcedony likely more accurate than quartz because silica source is likely from leaching of glassy volcanic rocks.

[3]Mean is presented by Piteau, D. R. and Associates Ltd. (1988). The exact method for its calculation is unknown.

The following is a summary of the written analysis by Souther (1976):

Thermal Springs Analyzed:

1. Elwyn Hot Spring
2. Taweh Hot Spring
3. Mess Creek Hot Spring
4. Mess Lake Hot Spring

- All these thermal springs are classified as 'Class III Hot Springs' which are described as 'spatially related to belts of Quaternary igneous activity. Most yield alkaline waters of either bicarbonate or sulphate type with dissolved SiO_2 between 80 and 250ppm'.
- They summarize that the hot springs concentrated around the Mt. Edziza volcanic complex are within the 'north-south Stikine belt of Quaternary volcanoes'
- The waters are classified as sodium bicarbonate containing 190 ppm silica, which is relatively high
- They also state: 'Of all the volcanic centers in the Stikine belt, Mt. Edziza and adjacent Spectrum Range have produced the only significant volume of siliceous lava that might be associated with subvolcanic intrusions.'
- Note that in other reports, Mess Lake is classified as a cool spring (Woodsworth and Woodsworth, 2014) with reported low temperatures (Piteau, D. R. and Associates Ltd., 1988; Souther and

Halstead, 1973). In this report, however, Mess Lake has reported high temperatures, so there may have been a difference in naming convention.

The following is a summary of the work completed by Souther and Halstead (1973):

Thermal Springs Analyzed:

1. Elwyn Creek (gaseous constituents, associated rocks)
2. Tawah Creek (gaseous constituents, associated rocks)
3. Mess Lake (gaseous constituents, associated rocks)
4. Stikine River Springs (Choquette) (chemical constituents, associated rocks)

A summary of the analyses is provided in Table 2.

As well, the report provides a written summary only of the Stikine River Springs (Choquette):

- Eighteen flows which come from joints in granitic rocks
- Spring water combines and flows at approximately 700 gallons/min
- Water is clean, odorless, and 800 ppm dissolved solids
- Water composition is mainly sodium-chloride and calcium-sulphate
- The temperature of the hottest spring is 150 °F and forms bubbles of carbon dioxide

Further, Kerr (1948), suggest that Stikine River Springs (Choquette) is likely magmatic in origin and related to recent igneous activity.

Section 2.6 Table 2: Data of hot springs reported in Souther and Halstead (1973)

Name and Location	**Temp (°C)[1]**	**Flow (1 gpm)**	**TDS (ppm)**	**Chemical Constituents (ppm)**	**Gaseous Constituents**	**Associated Rocks**
Eastside of Stikine R. opposite Great Glacier	49-66	700	880	NaCl(423), $CaSO_4$ (202), Na_2SO_4 (154)		Fractured schist
Elwyn Creek	49	Large			CO_2	Tertiary Granite
Tawah Creek	77	Large			CO_2	Jurassic Shale
Mess Lake	10	Small			CO_2	Triassic Andesite

[1]Converted from °F. Note that the original values in °F were even values of 10, suggesting that they may have either been rounded or approximated.

Table 3 provides a summary of all reported springs, their sources, which data is available, analyses that are available, outlines data gaps, and suggests further analyses for each spring.

Section 2.6 Table 3: Summary of available geochemical data, gaps, and suggestions for further analysis

Name	Source	Data	Analysis	Data Gaps	Suggested Further Analysis
Sphaler Creek	Ron Yehia/Glen Woodsworth	Major ion analysis	None Found	Isotopes	Geothermometry, characterization, double check data
Choquette (Stikine River Fowler)	Hickson, Proenza, et al. (2016)	Major ion analysis	None Found	Isotopes	Geothermometry, characterization, double check data
Choquette (Stikine River Fowler)	Souther and Halstead (1973)	Chemical Constituents, Associated Rocks	Written Summary		
Mess Creek	Souther (1976)	Major ion analysis	Written Summary		Geothermometry, characterization
Mess Creek	Piteau, D. R. and Associates Ltd. (1988)	Major and trace ion analysis, isotopes	Geothermometry, isotope analysis, characterization, relative age		None
Mess Creek	Hickson, Proenza, et al. (2016)	Major ion analysis	None Found		Geothermometry, characterization, double check data
Mess Lake	Souther and Halstead (1973)	Gaseous Constituents, Associated Rocks	None Found		
Mess Lake	Souther (1976)	Major ion analysis	Written Summary		Geothermometry, characterization

Mess Lake	Piteau, D. R. and Associates Ltd. (1988)	Major and trace ion analysis, isotopes	Geothermometry, isotope analysis, characterization, relative age		None
Len King (King Creek)	Piteau, D. R. and Associates Ltd. (1988)	Major and trace ion analysis, isotopes	Geothermometry, isotope analysis, characterization, relative age		Resample
Len King (King Creek)	Hickson, Proenza, et al. (2016)	Major ion analysis	None Found		Geothermometry, characterization, double check data
Elwyn Creek	Souther (1976)	Major ion analysis	Written Summary		Geothermometry, characterization
Elwyn Creek (3 samples)	Piteau, D. R. and Associates Ltd. (1988)	Major and trace ion analysis, isotopes	Geothermometry, isotope analysis, characterization, relative age		None
Elwyn Creek	Hickson, Proenza, et al. (2016)	Major ion analysis	None Found		Geothermometry, characterization, double check data
Elwyn Creek Hot Springs	Souther and Halstead (1973)	Gaseous Constituents, Associated Rocks	None Found		
Snippaker Creek (Julian Lake)	Woodsworth and Woodsworth (2014)	Location only		Major and trace ion analysis, isotopes, temperature, pH, flow rate	
Sezill (Tawah Creek)	Souther (1976)	Major ion analysis	Written Summary		Geothermometry, characterization

Sezill (Tawah Creek) (3 samples)	Piteau, D. R. and Associates Ltd. (1988)	Major and trace ion analysis, isotopes	Geothermometry, isotope analysis, characterization, relative age		None
Sezill (Tawah Creek)	Hickson, Proenza, et al. (2016)	Major ion analysis	None Found		Geothermometry, characterization, double check data
Tawah Creek Hot Springs	Souther and Halstead (1973)	Gaseous Constituents, Associated Rocks	None Found		
Iskut River	Hickson, Proenza, et al. (2016)	Major ion analysis	None Found	Isotopes	Geothermometry, characterization, double check data
Dease Lake	Hickson, Proenza, et al. (2016)	Temperature and pH only	None Found	Major and trace ion analysis, isotopes	
Hoodoo Mt	Hickson, Proenza, et al. (2016)	Location only	None Found	Major and trace ion analysis, isotopes, temperature, pH, flow rate	
Shelsay	Hickson, Proenza, et al. (2016)	Location only	None Found	Major and trace ion analysis, isotopes, temperature, pH, flow rate	
Unreported spring	(Holbek, 2025)	Estimated location only	None Found	Major and trace ion analysis, isotopes, temperature, pH, flow rate	

Dataset created by:

Katherine Huang

Dataset Source:

Hickson et al., 2016; Kerr, 1948; Piteau, D. R. and Associates Ltd., 1988; Souther, 1976; Souther and Halstead, 1973; Waring, 1965; Woodsworth and Woodsworth, 2014.

Data Format:

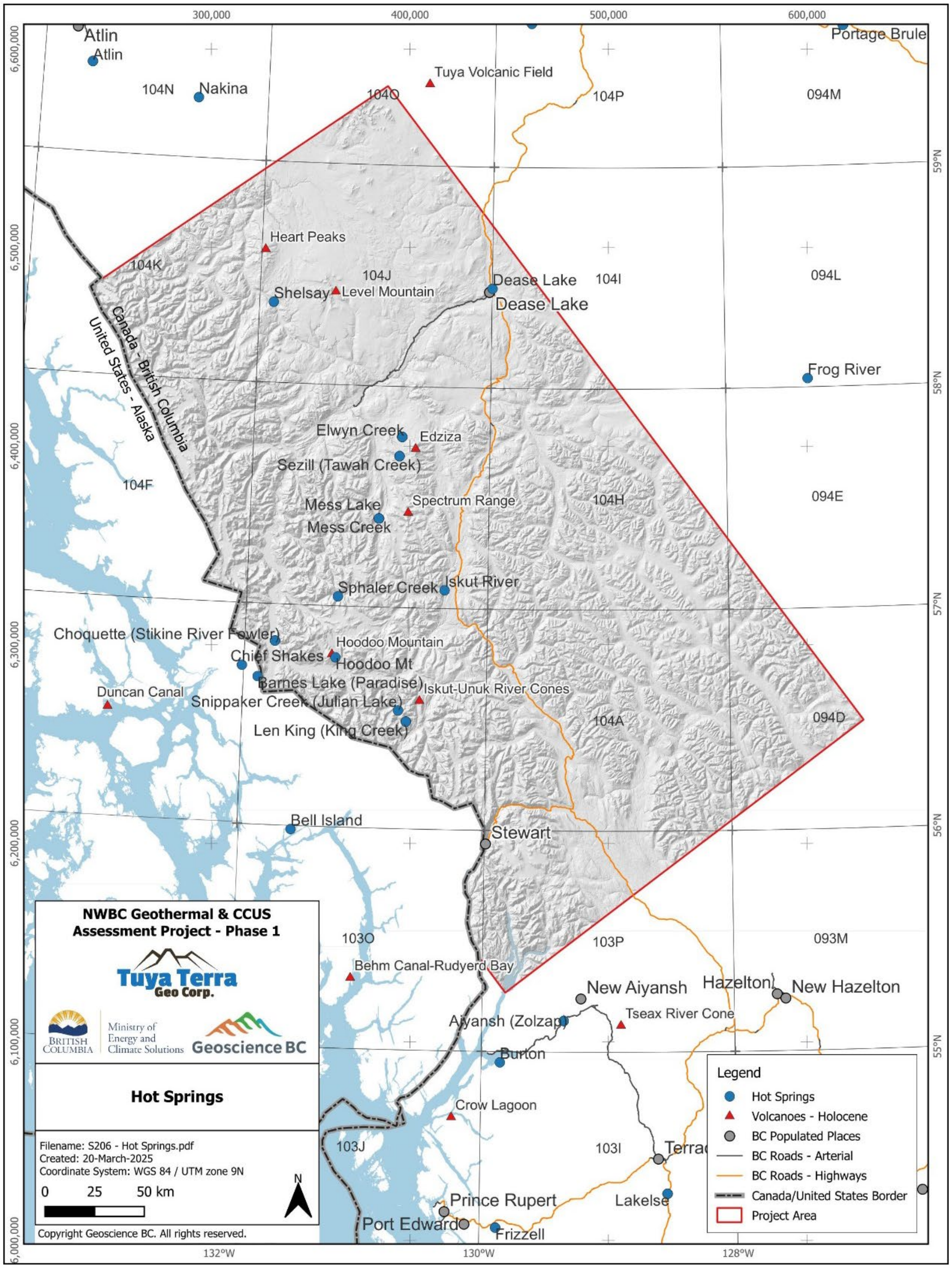
Excel tables and Appendix

Project use case:

Fluid geochemistry is a critical parameter for understanding naturally occurring geothermal systems. These data were considered significant for the identification of heat in the subsurface and thus were weighted heavily in the GRI-Heat module (See Chapter 3 Table 3), despite limited verification of the source of heat and depth of circulation

Data distribution:

The 12 reported thermal springs in the project area are mapped in Figure 1. They are distributed throughout the project area but several cluster around Mount Edziza and the surrounding area.



Section 2.6 Figure 1: Map of hot springs in project area, as well as hot springs outside of the project boundary

Data from Adjacent Areas:

Barnes Lake (Paradise) and Chief Shakes hot springs lay just outside of the project boundary across the US border and may be related to geothermal/hydrothermal system within the project area.

Limitations of Datasets:

The number of thermal springs is small in relation to the project area size, therefore there is limited understanding of the area as a whole from using only fluid chemistry. However, in certain areas such as Mount Edziza, where there are clusters of thermal springs, the hydrothermal systems are better understood.

The nature of the chemistry and enthalpy of the samples analyzed by Piteau, D. R. and Associates Ltd. (1988) made it difficult to calculate consistent and reliable geothermometry temperatures. It is unknown if this is the case with the other samples. Therefore, temperatures of the origin fluids may be limited.

Data Gaps:

Fluid samples for major ion analyses, temperature, and pH were not collected for Snippaker Creek (Julian Lake), Hoodoo Mountain, and Shelsay. Fluid samples for major ion analysis were not collected for Dease Lake (only temperature and pH are reported).

Isotopes data as well as tritium and carbon-14 were collected for samples to understand their recharge area and relative age, respectively (Piteau, D. R. and Associates Ltd., 1988). These data could be also collected for Sphaler Creek, Choquette (Stikine River Fowler), Snippaker Creek (Julian Lake), Dease Lake, and Iskut River. See Table 3.

Recommendations for Additional Work

In addition to Holocene volcanic activity, thermal features (hot springs and fumaroles) are direct evidence of thermal energy in the subsurface. These features may form due to deep circulation on faults or near recently active volcanic centers. Their presence is an important indicator of subsurface heat and as such was given a high weighting factor in the PF analysis (see Section 3.1). The work done by Piteau, D. R. and Associates Ltd. (1988) is quite comprehensive and further geothermometry and classification are likely not necessary. However, gases were sampled using a beer bottle, therefore re-sampling is suggested if possible as there may be sampling inaccuracies. As well, they report that lack of field filtering or preservation of the samples may have affected the cationic geothermometry for Len King (King Creek) hot spring, so resampling is suggested.

Many of the major ion analyses reported in (Hickson et al., 2016) are from unpublished data, therefore is it recommended to either re-check the sources or re-sample for Sphaler Creek and Iskut River, as these thermal springs do not have any published data.

Geothermometry and classification using a Piper Diagram is recommended for all samples except from those already published by Piteau, D. R. and Associates Ltd. (1988). These recommendations are all listed in Table 3. But all samples would benefit from modern tertiary diagram plot analysis.

Additionally, steam was spotted at a location near Galore Creek, by the headwaters of Scud River (Holbek, 2025). However, the steam may have been due to sulphide decomposition in the till and outwash sediments. Regardless, it is still recommended that this location be explored further. The two estimated locations are 57°03'58.3, 130°25'25.3 and 57°20'37.0, 130°41'15.0. Additionally the reports of “heat” in the underground workings of the Eskay Creek mine deserve further investigation.

As previously stated, Barnes Lake (Paradise) and Chief Shakes hot springs lay just outside of the project boundary across the US border and should be reviewed.

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Appendix A

Appendix A: Fluid Geochemistry

Name	Lat	Long	Temp (°C)	pH	Conductivity (uS/cm)	Eh (mV)	TDS	SiO_2	Na	K	Ca	Mg	Cl	Li	SO_4	HCO_3	CO_3	F	B	Al	As	Ba	Co	Cr	Cu	Fe	Hg
Choquette (Stikine River Fowler)	56.83246	-131.75272	59.9	7.65			973	61.9	220	9.13	55.59	0.294	240	0.109	184	31.89		1.559	0.207								
Mess Creek	57.40067	-130.92362	41.2	6.81				71.5	1186	38.2	564	77.1	393	1.28	1960	2074		0.29			0.004						
Mess Creek	57.40067	-130.92362	41.5	6.96				60.5	290	14.8	127	18.7	166	0.275	405	469.4		2.2			0.026						
Mess Creek	57.40067	-130.92362	42.5	6.2	2400	-026	1216	44.5	190	18	138	20.4	209	0.31	150	441		1.7	13.8	0.34	0.024	0.073					
Mess Creek	57.40067	-130.92362	13	6.69	4800	+367	4858	51.8	950	44	361	94.7	526	1.11	560	2243		0.38	0.92	0.25	0.0006	0.016	0.01	0.005	0.011	7.1	0.001
Mess Creek	57.40067	-130.92362	42.5	6.55			16100	51.8	352	15.5	145	19.3	191	0.354	386	581		1.61	0.902		0.035						
Len King (King Creek)	56.48499	-130.65689	40	7.48	3850			145	437	14.5	413	207	200	0.07	1900	1110				0.17		0.013				0.5	
Len King (King Creek)	56.48499	-130.65689	33.6	6.85			3420	137	526	16.1	437	201	205	0.239	1310	1540		0.048	3.26		0.0044						
Elwyn Creek	57.77206	-130.74563	25	7.26				167	662	45	74.3	101	38.9	0.86	0.5	2449		0.35			0.002						
Elwyn Creek	57.77206	-130.74563	19.5	6.19	1805	238	2005	83.4	345	29	71.8	60.6	36.6	0.35	1.02	1374		0.31	0.96	0.14	0.0027	0.116		0.004		1.06	
Elwyn Creek	57.77206	-130.74563	29	6.06	2300	166	3083	118	501	41	122	102	68.3	0.53	1.93	2126		0.19	1.34	0.16	0.0038	0.197		0.004		1.01	0.0001
Elwyn Creek	57.77206	-130.74563	36	6.01	2780	137	3639	134	659	49	126	104	51	0.66	0.62	2512		0.25	1.73	0.17	0.0081	0.295				2.5	0.00005
Elwyn Creek	57.77206	-130.74563	35.8	6.44			2370	135	665	45.5	128	111	38.9	0.837	1.55	2670		0.129	1.92		0.006						
Snippaker Creek (Julian Lake)	56.53472	-130.723																									
Hoodoo Mt	56.766667	-131.25																									
Sezill (Tawah Creek)	57.684660	-130.76424	43.0	9.18				191.0	476.0	55.6	3.7	132.0	50.2	0.68	0.50	1466		0.084			0.006						
Sezill (Tawah Creek)	57.68466	-130.76424	45.9	6.71	3005	82	3489.0	144.0	529.0	62.0	171.0	136.0	61.2	0.56	1.78	2455		0.16	1.34	0.160	0.019	0.405		0.004		4.510	0.00006
Sezill (Tawah Creek)	57.68466	-130.76424	43.0	6.77	3000	103	3516.0	144.0	529.0	63.0	170.0	138.0	63.2	0.58	1.83	2401		0.11	2.16	0.160	0.018	0.389		0.004	0.007	2.500	0.00005
Sezill (Tawah Creek)	57.68466	-130.76424	46.0	6.72	2900	129	3033.0	122.0	444.0	54.0	143.0	116.0	58.2	0.48	1.59	2088		0.09	1.82	0.170	0.015	0.342		0.004	0.005	5.070	
Sezill (Tawah Creek)	57.68466	-130.76424	45.9	6.42			5230.0	152.0	515.0	54.6	167.0	141.0	52.7	0.732	5.01	2440		0.023	2.31		0.014						
Sphaler Creek	57.04258	-131.24553	48.5	6.59			1360.0	69.9	396.0	16.3	64.8	12.3	63.4	0.372	145.00	963		3.890	1.79								
Iskut River	57.0825	-130.36139	74.5	6.95			1760	78.09	511	26.8	39.4	2.529	153	0.594	364	711	8.41	8.41	4.01		0.018						
Dease Lake	58.45	-130	16.0	8.00																							
Shelsay	58.363	-131.880830																									

Appendix A: Fluid Geochemistry

Name	Mn	Mo	Pb	Sb	Se	Sr	Ti	Zn	Discharge (L/s)	Reference	Comments
Choquette (Stikine River Fowler)									0.01	Hickson, Proenza, et al. (2016)	(2007 sample) Polaris Infrastructure kind permission
Mess Lake	0.01					5.64			3.2	Souther (1976)	
Mess Lake	0.42		0.002		0.0002	9.74			0.01	Piteau, D. R. and Associates Ltd. (1988)	Lake Spring
Mess Creek	0.12					1.32			1.3	Souther (1976)	
Mess Creek	0.17				0.0007	2.85		0.007	0.5	Piteau, D. R. and Associates Ltd. (1988)	HS
Mess Creek									0.2	Hickson, Proenza, et al. (2016)	(2007 sample) Polaris Infrastructure kind permission
Len King (King Creek)	0.005					9.48				Piteau, D. R. and Associates Ltd. (1988)	
Len King (King Creek)									2	Hickson, Proenza, et al. (2016)	(2007 sample) Polaris Infrastructure kind permission
Elwyn Creek	0.002					0.28			2.5	Souther (1976)	
Elwyn Creek	0.032	0.02			0.0008	0.384	0.002		0.3	Piteau, D. R. and Associates Ltd. (1988)	Vent #1
Elwyn Creek	0.14				0.002	0.634			0.3	Piteau, D. R. and Associates Ltd. (1988)	Vent #2
Elwyn Creek	0.068	0.02		0.07	0.0007	0.684			0.1	Piteau, D. R. and Associates Ltd. (1988)	Vent #5
Elwyn Creek									0.3	Hickson, Proenza, et al. (2016)	(2007 sample) Polaris Infrastructure kind permission
Snippaker Creek (Julian Lake)										Woodsworth and Woodsworth (2014)	
Hoodoo Mt									5	Hickson, Proenza, et al. (2016)	(2008 sample) Polaris Infrastructure kind permission. Coordinates from Woodsworth
Sezill (Tawah Creek)						0.01			1.9	Souther (1976)	
Sezill (Tawah Creek)	0.0370				0.0020	1.30			0.3	Piteau, D. R. and Associates Ltd. (1988)	Main vent
Sezill (Tawah Creek)	0.0370					1.24			0.3	Piteau, D. R. and Associates Ltd. (1988)	Mushroom
Sezill (Tawah Creek)	0.2100				0.0001	1.06			0.3	Piteau, D. R. and Associates Ltd. (1988)	South hotspring
Sezill (Tawah Creek)									2.0	Hickson, Proenza, et al. (2016)	(2007 sample) Polaris Infrastructure kind permission
Sphaler Creek									0.2		
Iskut River								2		Hickson, Proenza, et al. (2016)	(2007 sample) Polaris Infrastructure kind permission
Dease Lake											
Shelsay											

2.7 Quaternary Volcanism

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Section 2.7 Figure 1: Northern Cordillera Volcanic Province (NCVP), Anahim Volcanic Belt (AVB), Wells Gray Clearwater Volcanic Field (WGC), Garibaldi Volcanic Belt (GVB). The project area is outlined in red. Figure from Edwards and Russell (2000; modified from Hickson, 1991); **used with permission** 92
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Overview

The Quaternary Period in northwestern British Columbia was a period of substantial and prolonged volcanism at several volcanic centers in the study region, these being Hoodoo Mountain, Mount Edziza and Level Mountain. In addition, some of Canada's youngest volcanic centers form a cluster in the southeastern margin of the project area (Iskut-Unuk River Cones). The volcanism recorded in the project area incorporates the southern end of the Northern Cordillera Volcanic Province (NCVP) within which volcanism ranges from 20 Ma to 200 y.b.p. Much of this volcanism encompass the Quaternary Period, broken into the Pleistocene (2.58Ma -0.0117) and Holocene (0.0117 – present) Epochs (Cohen et al., 2013; Walker, 2012).

Quaternary volcanic rocks in the project area are dominated by Alkali Olivine Basalt (AOB) and Hawaiite (mafic magmas). Recognition of and mapping the spatial distribution of Quaternary volcanism is an important element of a favourability map for demonstration of "heat". Recent volcanism is a clear signal of magmatic heat, high heat flow and locally high geothermal gradients. This is because Quaternary volcanism is geologically young enough that hydrothermal systems formed during magma emplacement and/or the outpouring of lava may still retain heat to support a hydrothermal system. Whether volcanic hosted geothermal systems (hydrothermal systems) form is dependent on the magma composition and volume of magma emplacement among other factors. The presence of hot springs and/or fumaroles is a key indicator to the presence of a geothermal system. Depending on geological context, hot springs may be related to a cooling magma body.

Although mafic volcanic rocks are not generally thought to originate from large magma chambers there is evidence that some of the larger volcanic centres in the region may have formed from magma chambers. Magma chambers may take a million or more years to cool and crystallize, hence the review of Quaternary magmatism was undertaken for the project area. During magma chamber cooling, water is expelled from the crystallizing magma that under certain geological conditions may evolve into a hydrothermal system. In addition, in areas where significant ground water recharge is occurring, meteoric water may play a roll in creating and sustaining the geothermal-hydrothermal system using the cooling magma body as the heat source. This is a similar mechanism to geothermal systems associated with high heat producing radiogenic plutons. The presence of hot springs and/or fumaroles is a key indicator to the presence of a geothermal system.

Dataset Created by:

C.J. Hickson

Dataset Source:

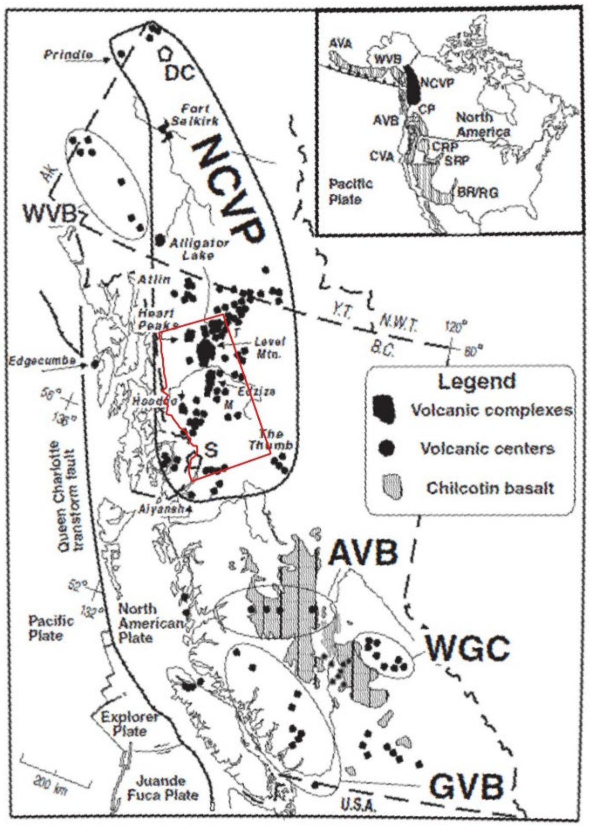
Edwards and Russell, 2000; Hickson, 1991; Russell et al., 2023

Data Format:

Excel spreadsheet (Edwards and Russell, 2000) and MapPlace shape files

Project use case:

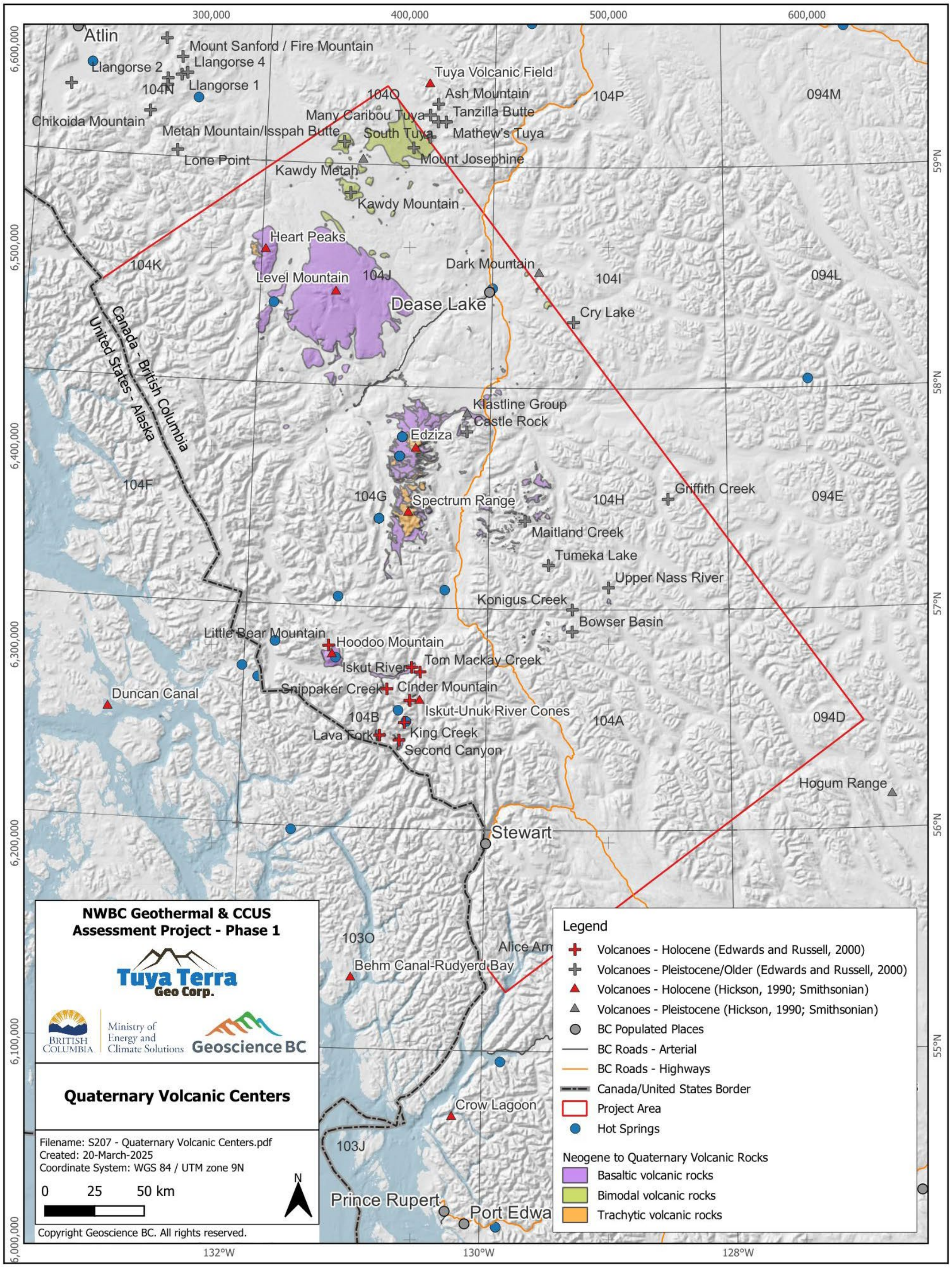
The project area is at the southern end of the Northern Cordilleran Volcanic Province (NCVP) (Figure 1). This volcanic province contains over 100 volcanic centers ranging in age from 20 Ma to 200 y.b.p. The volcanism is dominated by alkali olivine basalt and hawaiite (Edwards and Russell, 2000; Russell et al., 2023). A variety of more strongly alkaline rock types not commonly found in the North American Cordillera are locally abundant in NCVP. These include nephelinite, basanite, and per-alkaline phonolite, trachyte, and comendite. This chemistry is consistent with an asthenospheric source region similar to that for average oceanic island basalt (OIB) and for post-5 Ma alkaline basalts from the Basin and Range of the USA, including Nevada (Edwards and Russell, 2000). As much information as possible was reviewed in order to understand the timing, frequency and chemistry of these geologically young volcanic centers. As the favourability mapping is heavily weighted to the presence of Holocene volcanic rocks, understanding the data gaps and shortcomings of these data is important in the final results.



Section 2.7 Figure 1: Northern Cordillera Volcanic Province (NCVP), Anahim Volcanic Belt (AVB), Wells Gray Clearwater Volcanic Field (WGC), Garibaldi Volcanic Belt (GVB). The project area is outlined in red. Figure from Edwards and Russell (2000; modified from Hickson, 1991); ***used with permission***

Data distribution:

Volcanological studies cover the project area where Pleistocene volcanic rocks are founds.



Section 2.7 Figure 2: Quaternary volcanic centers and outcrops, also shown with known hot springs.

Data from adjacent areas:

The project area is an integral part of the NCVP, as defined by Edwards and Russell (1999, 2000). It includes more than 100 mapped occurrences of Pleistocene and younger volcanic rocks distributed across northwestern British Columbia, the Yukon Territory, and adjacent eastern-most Alaska (Figure 1). The NCVP encompasses a broad range of volcanic styles, including large volcanic plateaus with mafic and felsic eruption products, isolated volcanic cones, lavas, and glaciovolcanic eruption products. Volcanism across the NCVP has been studied by many more research groups relative to other volcanic domains in the Canadian Cordillera. Much of this research was driven by the ancillary studies done in support of Lithoprobe (Cook et al., 2004; Edwards and Russell, 2000) as well as the Geological Survey of Canada's regional process specific studies such as young volcanism in the Canadian Cordillera. Virtually no new studies have been carried out since the early 2000's (Russell et al., 2023) within the project area although this early work provides a satisfactory foundation for the current study (Figure 2).

Over the decades, research themes have varied but included studies of edifice stratigraphy and petrology (Edwards et al., 2002, 2011; Eiche et al., 1987; Hamilton and Evans, 1983), focused studies on glaciovolcanism (e.g., (Allen et al., 1982; Edwards and Russell, 2002; Mathews, 1947; Moore et al., 1995; Russell et al., 2021), analysis of primitive lava chemistries to characterize mantle source regions (Abraham et al., 2005; Canil and Hyndman, 2023; Cousens and Bevier, 1995; Edwards and Russell, 2000; Francis and Ludden, 1995, 1990; Hyndman and Canil, 2021; Nicholls et al., 1982), and studies of peridotite xenoliths to characterize the underlying Cordilleran lithosphere (Brearley et al., 1984; Canil and Russell, 2022; Canil and Scarfe, 1989; Francis et al., 2010; Ghent et al., 2019; Harder and Russell, 2006; Peslier, 2002; Ross, 1983). All of these studies have built an understanding of the source and triggers for volcanism in the NCVP pertinent to this study.

The Northern Cordilleran Volcanic Province was previously referred to as the Stikine Volcanic Belt (e.g., (Wood and Kienle (ed), 1992) Souther 1992). Recent geophysical work by (Miller et al., 2018) and (Gama et al., 2022) has shown that the Denali Fault System demarcates a fundamental lithospheric boundary, with colder and thicker lithosphere to the north of the boundary. Consequently, NCVP volcanism is spread across four major tectonostratigraphic terranes: Stikinia, Cache Creek, Yukon-Tanana, and Cassiar. The project area is largely underlain by rocks of the Stikine Terrane. This underpinning appears to have a fundamental bearing on the type and chemistry of volcanism within the project area.

Edwards and Russell (2000) used phase equilibria calculations based on lava compositions and geothermometry of mantle-derived xenoliths to construct a north–south cross-section of the NCVP lithosphere. The model cross-section predicted that the lithosphere beneath the NCVP thickens from the north to the south and that it is thicker beneath Stikinia (southern NCVP) than beneath the Cache Creek and Yukon-Tanana terranes (northern NCVP). This lithospheric thickening may be important, influencing the formation of magma chambers in the upper lithosphere.

The southern limit of the NCVP is nearly coincident with the southern limit of the project area with the exception of Tseax volcano (Figure 2). This southern limit is defined by isolated volcanic vents and eroded lava remnants to the south of which starts of a gap in magmatism between the NCVP and the three Neogene magmatic provinces to the south, the Anahim Volcanic Belt (AVB), the Chilcotin Group basalts, and the Wells Gray-Clearwater Volcanic Field (WGCF) (Figure 1).

Eruption ages for NCVP volcanism span more than 10 Ma, with older magmatism focused at large complexes (Level Mountain and Edziza (Figure 2) within the project area. Many individual centers show evidence of interactions with ice and are assumed to be Pleistocene; this has been confirmed recently for more than 20 centers in the Tuya-Kawdy area (Edwards et al. 2020), where tuya volcanoes range in age from 2.8 to 0.06 Ma. This volcanic field is just outside the project area to the northeast (Figure 2). The NCVP also hosts the largest number of Holocene vents and the youngest eruption in Canada just south of the Iskut River at Lava Fork (within the project area), which may have erupted in the 1800s (Russell and Hauksdóttir, 2001).

Edwards and Russel (1999) proposed that magmatism in the northern Cordillera is linked to changes in far field forces between the Pacific and North American Plate. They showed that timing and volumetric rates of volcanism in the NCVP correlate with changes in the relative plate motions. During the Pleistocene, the plate motions changed from dominantly compressional to dominantly transtensional (Edwards and Russell, 2000). This volcanological evidence is corroborated by present day monitoring of the station at Dease Lake (See Section 2.4) within the project area. As indicated by the monitoring, the modern stress field may have resolved.

The importance of these findings is related to Neogene faulting in the project area. In the Basin and Range, USA, geothermal systems are strongly correlated with extensional "step over faults" (Faulds et al., 2016). Extensional faulting provides space for geothermal systems to establish when associated with areas of elevated heat flow. Where the elevated heat flow is associated with volcanism there is strong potential to develop robust geothermal systems. This is especially true if the volcanism is felsic and related to long lived magmatism (>2Ma) where there is potential for upper crustal magma chambers and intrusions. Edwards and Russell (1999) liked the NCVP to the Basin and Range geologic province in the United States.

The Pleistocene volcanic rocks in the project area dominated volumetrically by Alkali Olivine Basalt (AOB) and Hawaiite. However, more strongly alkaline rock types, including nephelinite, basanite, and peralkaline phonolite, trachyte, and Na-rich rhyolite (i.e., comendite), are locally abundant. These more evolved rock types (e.g., phonolite to Na-rich rhyolite) are found at the three longer-lived volcanic systems within the project area: Level Mountain (Hamilton and Evans 1983), Edziza (Souther 1992), and Hoodoo (Edwards et al. 2002) (Figure 2). For mapping purposes these rocks have been grouped into the "trachyte" rocks but represent a wider compositional range than just trachyte as noted above. The work of Souther and Hickson (1984), based on geochemistry from Mount Edziza, demonstrated that these highly alkaline end members likely resulted from crystal fractionation of the AOB parent originating in the asthenosphere (Souther and Hickson, 1984). Trace element abundances and isotopic compositions from Edziza and other centers are consistent with an asthenospheric source region similar to average oceanic island basalt (e.g., Edwards and Russell 2000, and references therein).

The magmatic evolution of the AOB and Hawaiite has important geothermal ramifications for two reasons. Firstly, low viscosity magmas such as AOB tend to transit the crust quickly, in hours or days and in many cases carry upper mantle and crustal xenoliths. The mantle xenoliths provide a measure of the speed at which they were carried from depth to the surface. The mineralogy indicates their depth of origin and from their size and mineralogy, density of the entraining magma can be determined to keep the material in suspension. Additionally, crustal xenoliths are also present. These may imply something about the force of brecciation of the ascending magma column, but also the speed, as the crustal material has a much lower melting point than the enveloping magma. In many cases, crustal xenoliths show little evidence of melting. As most of the basaltic eruptive rocks and dykes in the project area contain entrained xenoliths of both types it suggests that the magmas are of low viscosity and transiting the crust rapidly allowing little time for heating of the surrounding crustal material (conductive heat transfer).

Despite the limited favourability of basaltic magmas to form geothermal systems, they may be influencing the development of hydrothermal systems in several ways. Where there are numerous cones spatially and temporally associated (southern project area), their eruption represents high heat flux. In the Basin and Range geological province of the USA, monogenic mafic volcanism may represent the heat source for several of the geothermal systems. Notably, the Soda Lake geothermal system, Nevada, USA, is associated with Holocene aged phreatomagmatic mafic volcanism. Mafic dykes have also been noted in well bores in the field. It has been suggested that the presence of the basaltic dykes are the main reason for the development of the geothermal system at this specific site. A major factor was likely the water saturated sedimentary basin, into which the mafic lavas were intruded. The basin promoted convective heat transfer away from the intrusive bodies. Whether any similar geological environments exist in the project area can not be determined from the present data set.

Where high volume mafic volcanism has taken place over millennia, the upper crust is likely to be hotter and may show favourability for development of geothermal systems. An example is Level Mountain, the largest volcano in the NCVP covering over 1,800 km_2 where volcanism began 6.5 Ma and continued to very recent times (Hamilton and Evans, 1983). The volumes and length of time suggest that conductive heat transfer may have taken place. One hot spring is found is the area, Selsey (See Section 2.6), suggesting there is residual heat but additional data is required in order to full evaluate the spring and its geological context.

The presence of the highly evolved Na rich magma series (phonolytic rhyolites for example) suggests that magma chambers have formed beneath the large volcanic centers in the project area. Work in the early 1980's concluded that the magmatic suite present at Mount Edziza formed from crystal faction in large crustal reservoirs from an OIB parent (Souther and Hickson, 1984). These reservoirs were likely made possible by the extensional stress regime and thickened lithosphere of Stikine Terrane below the volcanic centers. These long-lived magma chambers would also be at higher temperatures than felsic magma chambers due to the chemical nature of the magmas. These factors support the establishment of geothermal systems around the large volcanic centers. Thus, hydrothermal systems may be more likely than might have previously been thought based on magma chemical considerations alone.

Limitations of Datasets:

Limited modern geochemical studies of the main volcanic centers have been carried out. The interpretations of the 1990's (when most of the work was completed), deserves reinvestigation. Additional dating of Level Mountain is required, as the current understanding limits its usefulness in the favourability analysis.

Data Gaps:

Magma emplacement and extrusion timing is poorly constrained, especially at Level Mountain, Canada's largest shield volcano. Significant glaciations during the Pleistocene have likely removed evidence of volcanism, leading to an under representation of volume and frequency. In the western and southern parts of the project area glacial streams transferring the Cordilleran Icesheet from areas of accumulation in the east to the west, likely removed any evidence of valley bottom flows and/or vents, leaving the record of Pleistocene volcanism incomplete. These data gaps will reduce the sensitivity of the favourability outcome,

Recommendations for Additional Work

As heat is the primary driver of the favourability analysis, understanding the volcanic history of the region is a key element of favourability mapping. The foundational volcanic history of the area is reasonably well established from the perspective of an input data set for a high level regional geothermal favourability study. Much more detailed work will be required to inform the decisions as to targeting for a volcanic hosted geothermal system. This work will required detailed mapping including dating of the deposits.

Geochemical studies to determine crystallization history and potential for magma chambers as well as crystallization timelines. Detailed gravity and aeromagnetic studies to ascertain if there are any remnants of volcanic deposits below glacial fluvial deposits, or through heavily forested areas. In areas where dykes are present, dating and structural studies on the dykes would be beneficial.

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Overview

Regional gravity and aeromagnetic (G&M) data were accessed from publicly available data sources. Numerous datasets were accessed from the NRCan Geoscience Data Repository for Geophysical Data database. Though the project scope did not allow for detailed G&M analysis, inversion and quality control, some insights can be derived. For example, gravity and magnetic derived lineament datasets were interpreted by the authors utilising first vertical derivative and horizontal gradient attributes downloaded from the NRCan site (Natural Resources Canada 2024b). It should be noted that this analysis was not automated and thus may be subject to user bias.

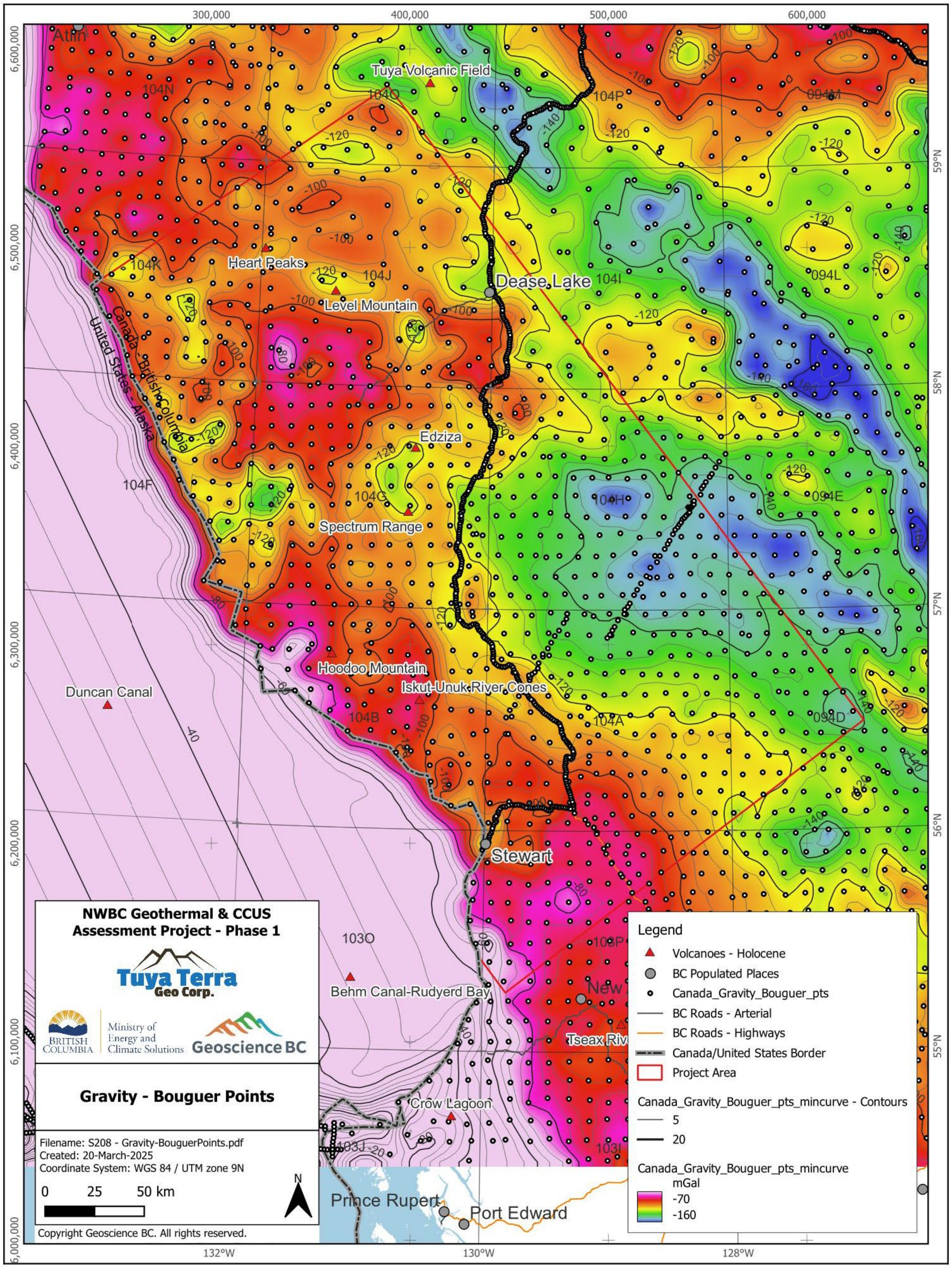
Although no detailed G&M analysis was completed for this study, an analysis of the Bowser basin using the same data has been completed by (Lowe 2006). Conclusions and observations from Lowe are relied on in the preparation on this study.

Gravity

Gravity data show variations in the earth's gravity field caused by lateral variations in the density of the earth's crust. Density variations may be caused by changes in thickness and composition of rock units. Local gravity anomalies result from near surface changes in geological composition resulting from different geological compositions and structures. Longer wavelength variations in the gravity anomaly are in response to deeper seated density variations and crustal thickness.

The gravity data stations for the entire country have been acquired between 1944 and 2003. All data are reduced to the International Gravity Standardization Network 1971 (IGSN71) datum. Theoretical gravity values are calculated the Geodetic Reference System 1980 (GRS80) gravity formula. Coordinates for each observation are reported in NAD83 (Natural Resources Canada 2024b).

The dataset utilized for the study is the Bouguer gravity anomaly shown in Figure 1. Bouguer gravity anomaly represents the difference between the observed gravity at a specific location and the theoretical gravity expected at that point. Bouguer gravity anomaly is utilized to isolate surface features and crustal variations from the background gravitational field.



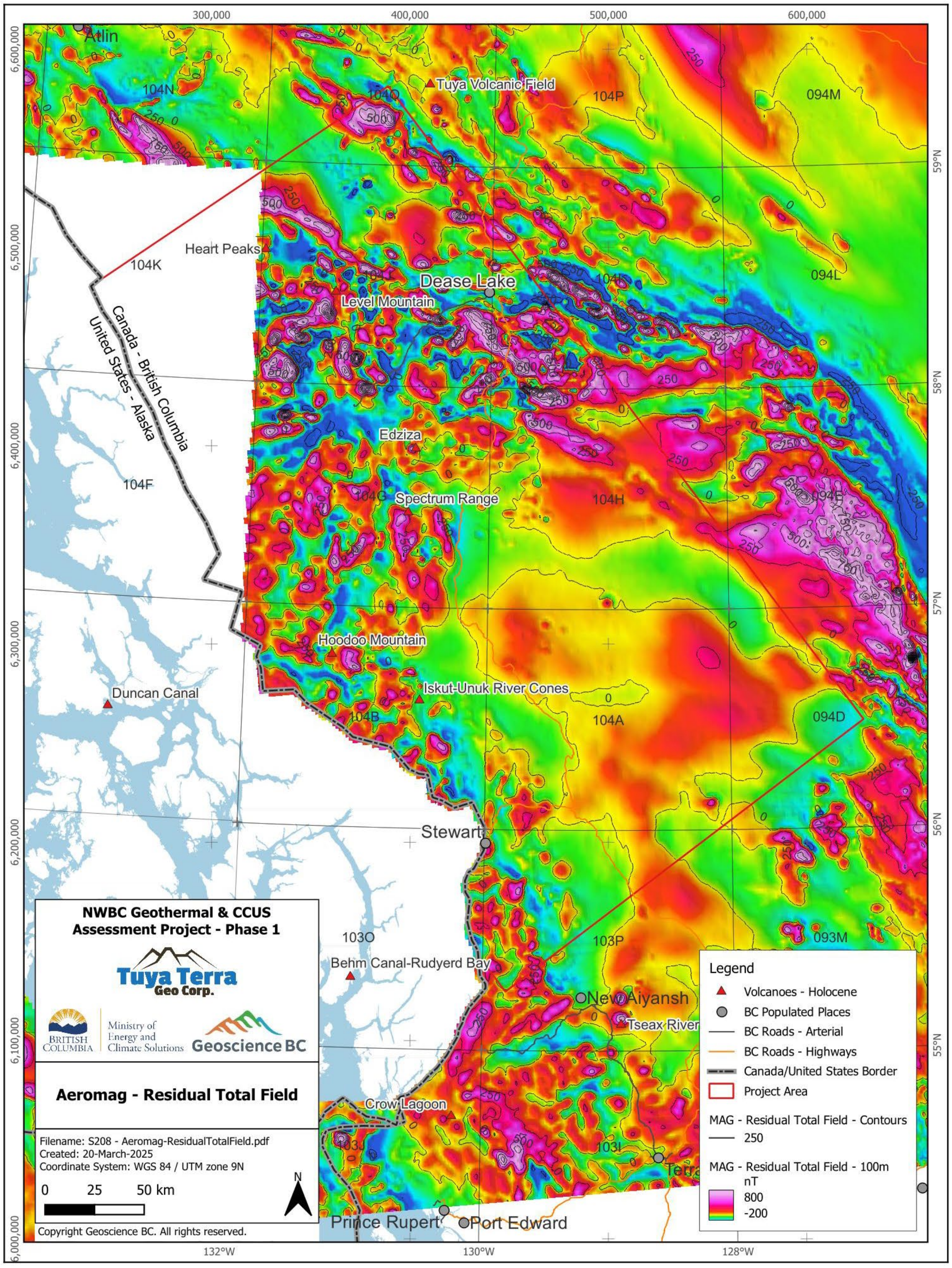
Section 2.8 Figure 1: Bouguer Gravity anomaly over the project area with observation points locations. Note the collection of Bouguer points overlays the highway

Magnetics

Total magnetic intensity data shows variations in the concentrations of magnetically susceptible minerals in rocks. Sedimentary rocks generally have lower concentrations of magnetic minerals whereas volcanic and metamorphic rocks generally have higher concentrations of ferromagnetic minerals such as magnetite and, therefore, a higher magnetic susceptibility. Within volcanics rocks, mafic rocks are generally much richer in ferromagnetic minerals compared to felsic deposits, as such insights into the composition and extents of different rock types can be inferred.

The magnetic data utilized in this study is the Geoscience BC data compilation (Oneschuk et al. 2024). Contributing datasets in the project area were from regional aeromagnetic surveys and high-resolution aeromagnetic surveys acquired between 2006 and 2021. These high-resolution surveys have been merged with the Geological Survey of Canada high-resolution survey data and regional 200 m Magnetic Grid (Natural Resources Canada 2024a). The regional 200 m grid was re-gridded to 100 m, and the survey data from the high-resolution aeromagnetic surveys were gridded to 100 m and statistically levelled into the regional grid. Apparent mismatches between survey blocks are a result of differing line spacing, flight altitudes and equipment platforms; helicopter surveys were flown at a constant elevation and fixed wing aircraft surveys were flown at a nominal terrain clearance (Oneschuk et al. 2024).

The main magnetic dataset utilized for the study is the Residual Magnetic Field (Figure 2).



Section 2.8 Figure 2: Residual Total Magnetic Field over the project area.

Dataset created by:

Phil Harms

Dataset Source:

All gravity and magnetic data utilized are in the public domain and were accessed from the Natural Resources Canada geophysical data repository: https://geophysical-data.canada.ca/

Section 2.8 Figure 3: Data download query area for G&M data showing search area longitude -134 to -126 West, latitude 55 to 60 North - NRCan Geoscience Data Repository for Geophysical Data: https://geophysical-data.canada.ca/

Access to the data on the NRCan Geoscience Data Repository for Geophysical Data is provided based on your acceptance of the following terms and conditions.

1. Copyright:
   The data provided through this web site are copyright of His Majesty the King in Right of Canada, 2024.
2. Disclaimer:
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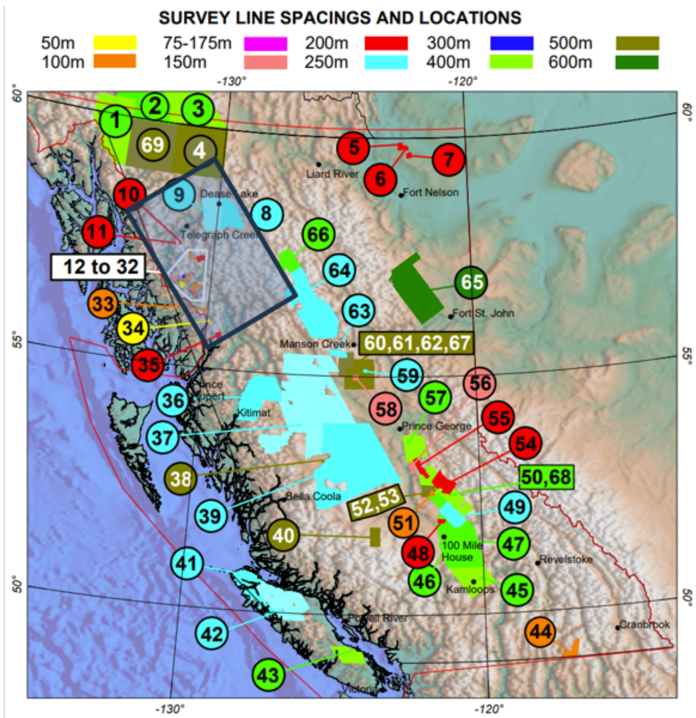
   - These terms and conditions remain with the data at all times.
   - The citation appropriate to the data type appears on any publication of the data.

- Notification of any publication of the data is provided to the appropriate contact.

See the Open Government Licence - Canada for more information.

The magnetic dataset is a compilation of higher resolution datasets prepared by (Oneschuk et al. 2024). Figure 4 shows the aeromagnetic datasets which have been merged into the compilation over the project area.



Index Map Reference	Survey Name	Survey Area	Contractor	Client	Year	Line Spacing (m)	Mag sensor height (m)
8	QUEST-NW East Block	Northwest BC	Aeroquest Airborne Ltd.	Geoscience BC	2011	250	80
9	QUEST-NW West Block	Northwest BC	Aeroquest Airborne Ltd.	Geoscience BC	2011	250	80
10,11	Yeti & Dokx	Northwest BC - Golden Triangle	Precision Geosurveys Inc.	Ram Explorations Ltd. - Purchased by Geoscience BC	2018	100	50
12,13	Mess Creek & North More	Northwest BC - Golden Triangle	Fugro Airborne Surveys Corp.	Paget Resources Corp. - Purchased by Geoscience BC	2006	100	54
14	Ball Creek	Northwest BC - Golden Triangle	Geo Data Solutions	Blue Gold Miing Inc. - Purchased by Geoscience BC	2012	200-100	50
15	Ball Creek	Northwest BC - Golden Triangle	Precision Geosurveys Inc.	Evrim Exploration Canada Corp. - Purchased by Geoscience BC	2018	200	43
16,17,18,19,20	Hoodoo West & North, Hurricane, Black Dog, and Hammer Blocks	Northwest BC - Golden Triangle	Geotech Ltd.	Etruscus Resources Corp - Purchased by Geoscience BC	2020	100-150	99
21	Bronson Slope Areas	Northwest BC - Golden Triangle	Fugro Airborne Surveys Corp.	Skyline Gold Corp - Purchased by Geoscience BC	2011	100	35
22	Iskut Property	Northwest BC - Golden Triangle	Aeroquest Airborne Ltd.	Spirit Bear Minerals Ltd. - Purchased by Geoscience BC	2006	100	47
23	Cannonball	Northwest BC - Golden Triangle	Precision Geosurveys Inc.	Ram Explorations Ltd. - Purchased by Geoscience BC	2018	100	50
24	Area C3 Newmont Lake Block	Northwest BC - Golden Triangle	Geotech Ltd.	Romios Gold Resources Inc.	2013	300	218
25	Area C1	Northwest BC - Golden Triangle	Digem	Enduro_Metals - Purchased by Geoscience BC	2007	100	
26	Area C2	Northwest BC - Golden Triangle	Digem	Enduro_Metals - Purchased by Geoscience BC	2008	150	
27	E&L and PSP Projects	Northwest BC - Golden Triangle	Geotech Ltd.	Garibaldi Resources Corp. - Purchased by Geoscience BC	2018	100	83
28	E&L Project	Northwest BC - Golden Triangle	Geotech Ltd.	Garibaldi Resources Corp. - Purchased by Geoscience BC	2017	100	100
29	Kirkham Property Infill G4	Northwest BC - Golden Triangle	Geotech Ltd.	Metallis Resources Inc. - Purchased by Geoscience BC	2018	75-175	77
30	Kirkham Property G2	Northwest BC - Golden Triangle	Geotech Ltd.	Metallis Resources Inc. - Purchased by Geoscience BC	2016	100	117?
31	Kirkham Property G1	Northwest BC - Golden Triangle	Aeroquest Airborne Ltd.	Metallis Resources Inc. - Purchased by Geoscience BC	2013	250	97
32	Kirkham Property G3	Northwest BC - Golden Triangle		Metallis Resources Inc. - Purchased by Geoscience BC	2018	100	99
33	Summit Lake Block	Northwest BC - Golden Triangle	Precision Geosurveys Inc.	Scottie Resources Corp - Purchased by Geoscience BC	2021	100	113
34	Unspecified Project	Northwest BC - Golden Triangle	Axiom Exploration Group Ltd	Genesis Aviation - Purchased by Geoscience BC	2020	50	109
35	Dolly Varden Property	Northwest BC - Golden Triangle	Geotech Ltd.	Dolly Varden Silver Corp. - Purchased by Geoscience BC	2012	200	157

Section 2.8 Figure 4: After (Oneschuk et al. 2024) showing high resolution aeromagnetic survey locations, approximate project area outline and list of datasets utilized in the project area.

Data Format:

Data was accessed in three formats:

- **Geotiff** – geotiff data as prepared by NRCan (indicated as RGB files) is useful for making displays and qualitative analysis. Colour bars, shading and display parameters are presented as the original author intended. Geotiff values are RGB values, actual attribute units are not captured in this format and the data cannot be used for further analysis. As such, geotiff files can be used, unmodified for unitless attributes such as first vertical derivative and horizontal gradient.
- **Point Data** – regional gravity data was downloaded as a csv. Data were gridded in surfer using a simple minimum curvature gridding algorithm.
- **Geosoft files** – grids were also available in Geosoft format. Geosoft formats were converted to grid files using the Seequent Connector in ArcMap.

Datasets, formats, and processing is summarized below.

Section 2.8 Table 1: Listing of gravity and magnetic datasets utilized for this study

Dataset	Format	Processing	Comment
Canada_Gravity_2018_Bouguer2_pts.csv	csv	Bouguer anomaly point data as downloaded. Bouguer separated and converted to NAD83 projection.	Generally, 10km data point spacing except for high density (~1200m sample spacing) along transects and Stuart-Cassian Highway.
Canada_Gravity_2018_Bouguer2_pts_proj_table-NAD83xy_mincurve.grd	Surfer Grid	Simple minimum curvature gridding performed in Surfer by the author	Bouguer gravity grid with blues representing low gravity values and reds/ pinks representing higher gravity values.
GRAV_AGG- 1st Vertical Derivative_AC- 2km.TIF Sidecar files: (TIF.aux.xml, tfw)	Raster	Downloaded file	1VD of the Bouguer anomaly. Display parameters set by original author. No units.
GRAV – 1st Vertical Derivative 2km.GRD	Geosoft Grid	Downloaded file	1VD of the Bouguer anomaly. Despite 2km name in the description, sample spacing is ~8000m
GRAV – 1st Vertical Derivative 2km.tif Sidecar files: (tif.aux.xml, tfw, tif.ovr)	Geotif	Converted Geosoft grid	1VD of the Bouguer anomaly. Geotif with units. Despite 2km name in the description, sample spacing is ~8000m Display parameters can be configured in QGIS
GRAV_AGG – Horizontal Gradient_AC- 2km.TIF Sidecar files: (TIF.aux.xml, tfw)	Raster	Downloaded file	HG of the Bouguer anomaly. Display parameters set by original author. No units.

GRAV – Horizontal Gradient_AC- 2km.GRD	Geosoft Grid	Downloaded file	HG of the Bouguer anomaly. Despite 2km name in the description, sample spacing is ~8000m
GRAV – Horizontal Gradient_AC- 2km.tif Sidecar files: (tif.aux.xml, tfw, tif.ovr)	Geotif	Converted Geosoft grid	HG of the Bouguer anomaly. Geotif with units. Display parameters can be configured in QGIS
MAG- Residual Total Field- 50.TIF Sidecar files: (TIF.aux.xml, tfw)	Raster	Downloaded file	Residual Total Magnetic field. Display parameters set by original author. No units.
MAG- Residual Total Field- 100m.GRD	Geosoft Grid	Downloaded file	Residual Total Magnetic field. Despite 2km name in the description, sample spacing is ~8000m
MAG- Residual Total Field- 100m1.tif Sidecar files: (tif.aux.xml, tfw, tif.ovr)	Geotif	Converted Geosoft grid	Residual Total Magnetic field. Geotif with units. Display parameters can be configured in QGIS
MAG- 1st Vertical Derivative- 50m.TIF Sidecar files: (TIF.aux.xml, tfw)	Raster	Downloaded file	1VD of Residual Total Magnetic field. Display parameters set by original author. No units.
MAG- 1st Vertical Derivative- 100m.GRD	Geosoft Grid	Downloaded file	Residual Total Magnetic field. Despite 100m name in the description, sample spacing is ~1600m
MAG- 1st Vertical Derivative- 100m.tif Sidecar files: (tif.aux.xml, tfw, tif.ovr)	Geotif	Converted Geosoft grid	Residual Total Magnetic field. Geotif with units. Display parameters can be configured in QGIS

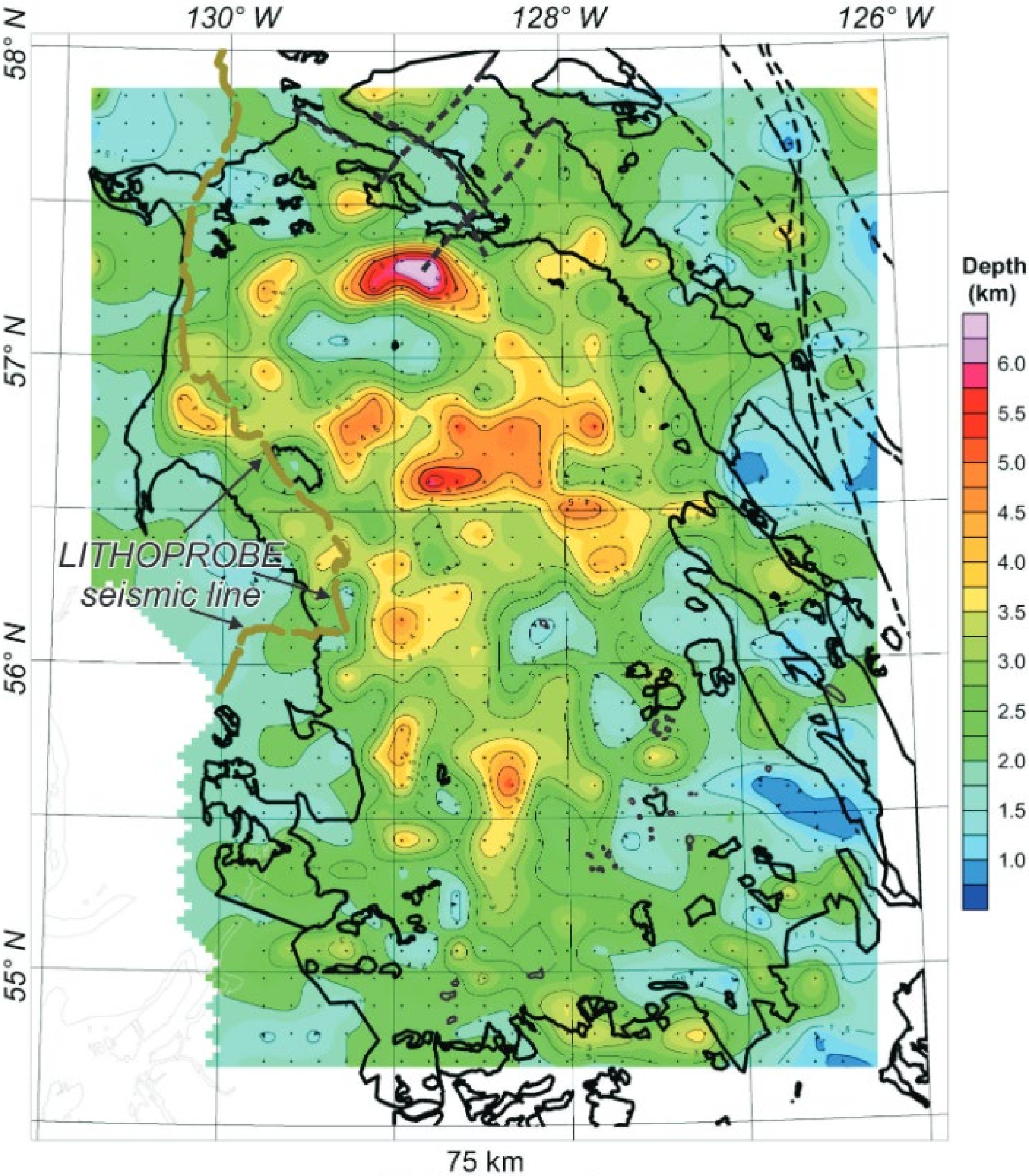
Project use case:

G&M datasets are particularly important for PF analysis workflows because of the regional nature of the data which can cover the entire analysis area consistently with the same data eliminating the data bias of point data or in studies for which the data only cover a portion of the analysis area. Furthermore, G&M datasets are the only regionally extensive coverage which provide insight into the subsurface across the entire project area.

Basin Thickness and Extents

Visual inspection of the gravity data shows a gravity low corresponding with the western portion of the known Bowser Basin extents (Figure 1). This may be somewhat indicative of basin depth and extent, however, according to (Lowe 2006), the gravity contact between the sedimentary rock (Bowser Formation) and the underlying crystalline basement (Hazelton Group, Stikinia Assemblage) is in-sufficient to invert for the depth of the sedimentary basin. However, there is a significant contrast of the magnetic susceptibility between to the sedimentary rock and underlying crystalline rock. A depth inversion was completed using the magnetic only which represents our best estimate of the depth of the sedimentary rock in the Bowser basin (Figure 5).

Depth of the sedimentary basin is a significant driver for the favourability and existence of sedimentary geothermal systems. The depth map produced by (Lowe 2006) is used exactly as received and should be noted that large uncertainty is associated with the depth map.

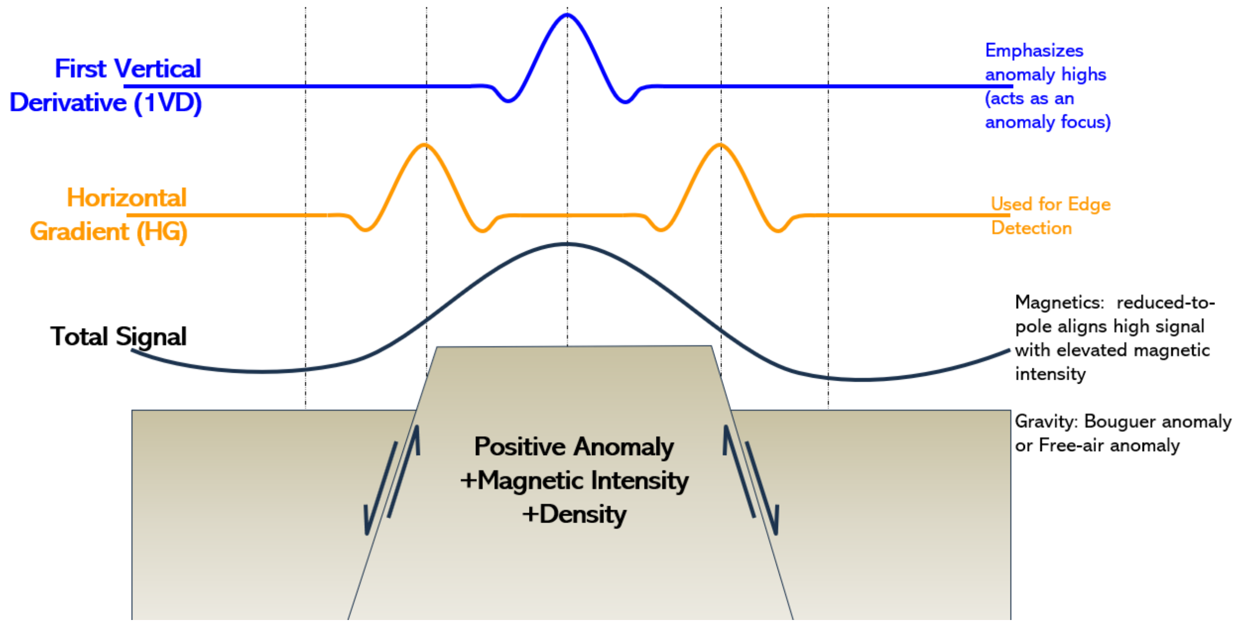


Section 2.8 Figure 5: After (Lowe et al., 2006) ***Figure reprinted by permission of CEGA whose permission is required for further use****. Estimated maximum magnetic source depths computed for 25km x 25km data windows using spectral analysis. The locations of the Bowser and Sustut basins are outlined (solid black). Dashed black lines denote the surface traces of selected faults. Thick, green line denotes the location of the SNORCLE seismic reflection-refraction transect. The depth values are used in the study as a proxy for thickness of the Bowser sedimentary basin.*

Lineament Analysis

High level lineament analysis was completed by this report's authors to support PF analysis. Lineaments are assumed to indicate subsurface structures possibly as a proxy for faulting and fracturing – a permeability and fluid Geothermal Resource Indicator (GRI).

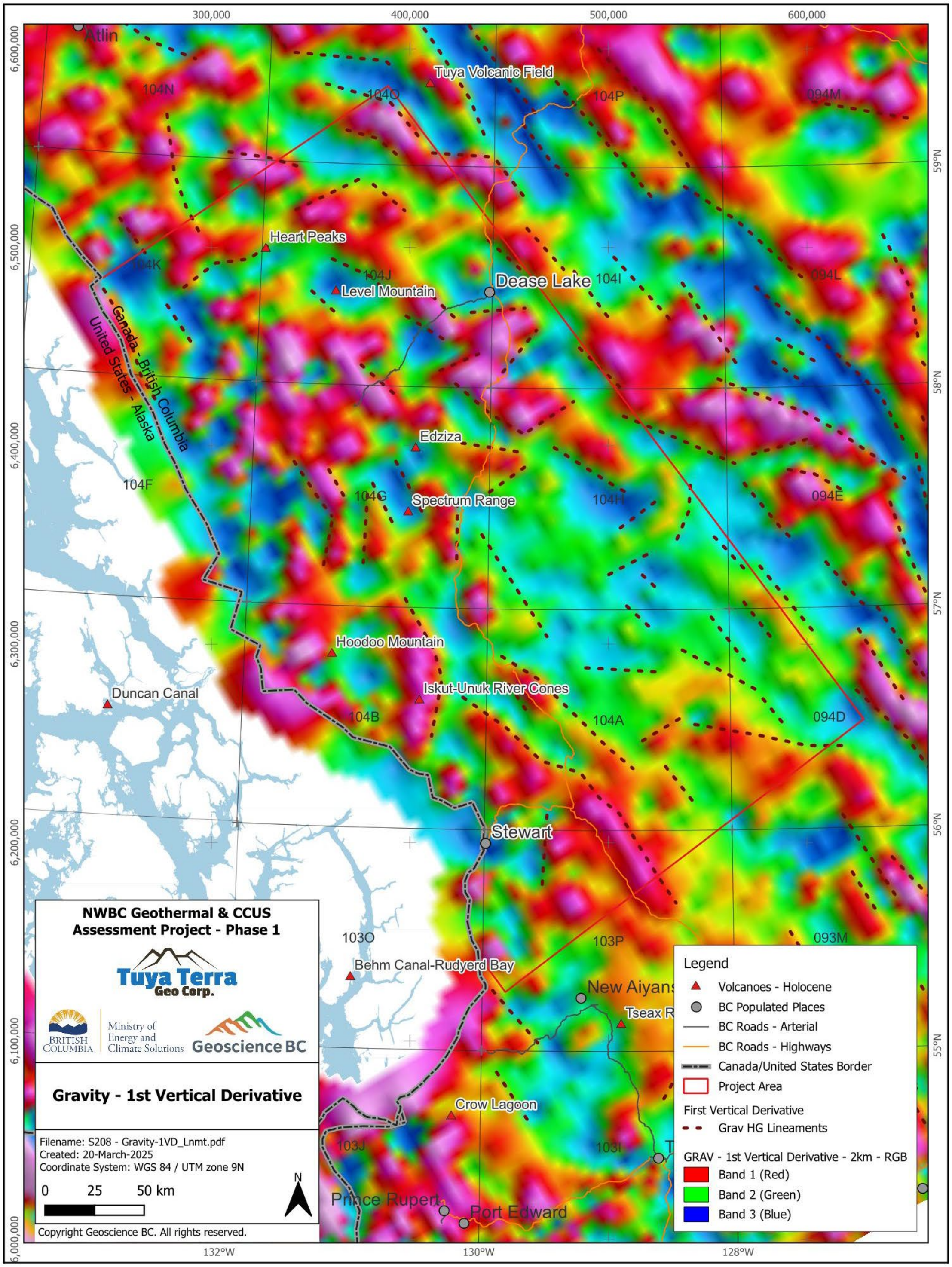
Lineaments were interpreted from both magnetic and gravity attribute maps. Two attributes were utilized to support the interpretation of the gravity data: first vertical derivative (1VD) and horizontal gradient (HG). Both attributes are highlight edges from the input field data. Figure 6 shows schematic responses of potential fields to a positive anomaly in the subsurface and the associated attribute responses. Lineaments were interpreted by tracking high amplitude trends in the HG attribute while edges of the linear features are tracked in the 1VD domain.



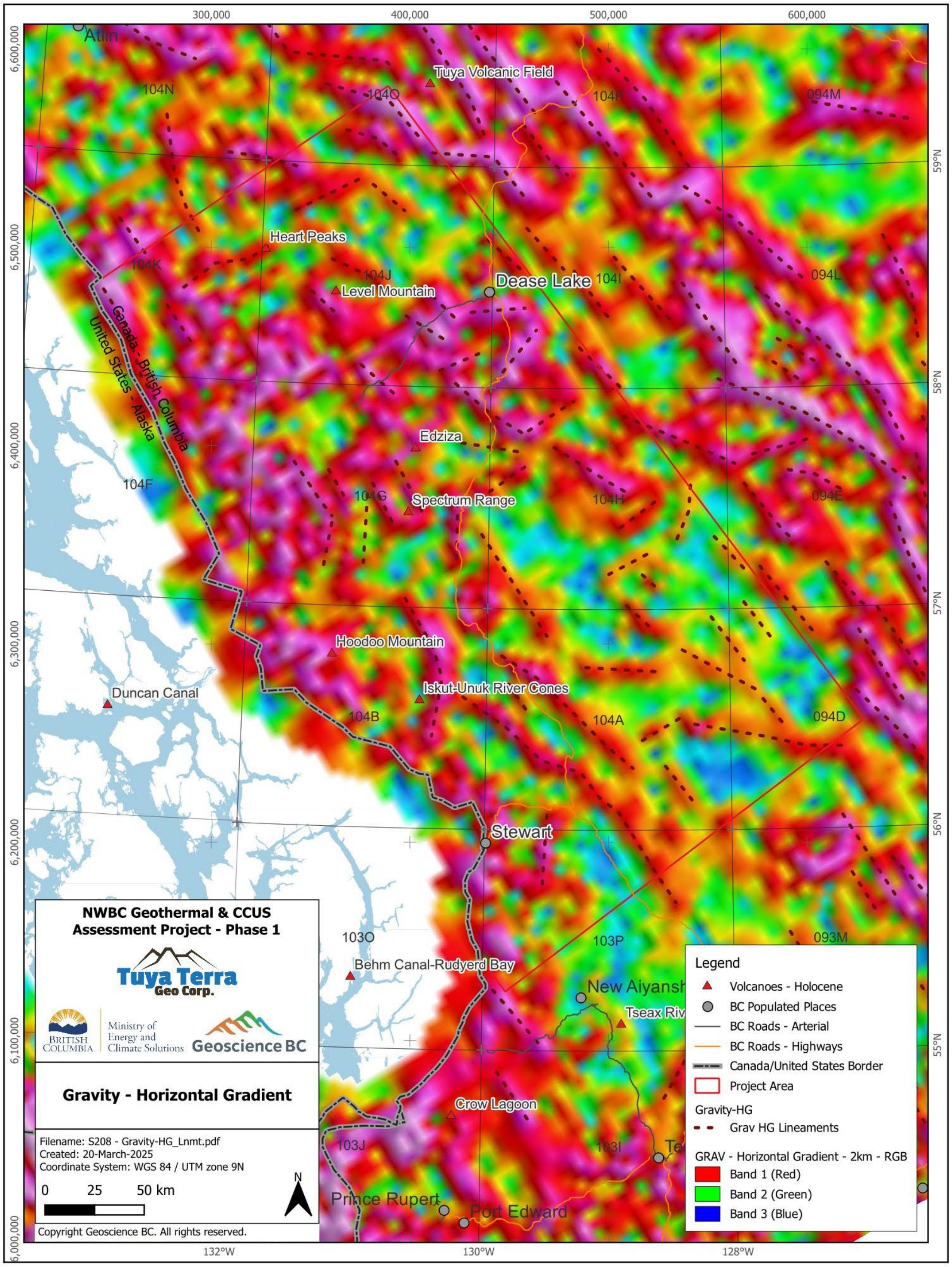
Section 2.8 Figure 6: Schematic attribute response diagram for potential field data

First Vertical Derivative and Horizonal Gradient of the Bouguer Gravity were utilized to delineate linemeant features observed in the gravity data (Figure 7 and Figure 8).

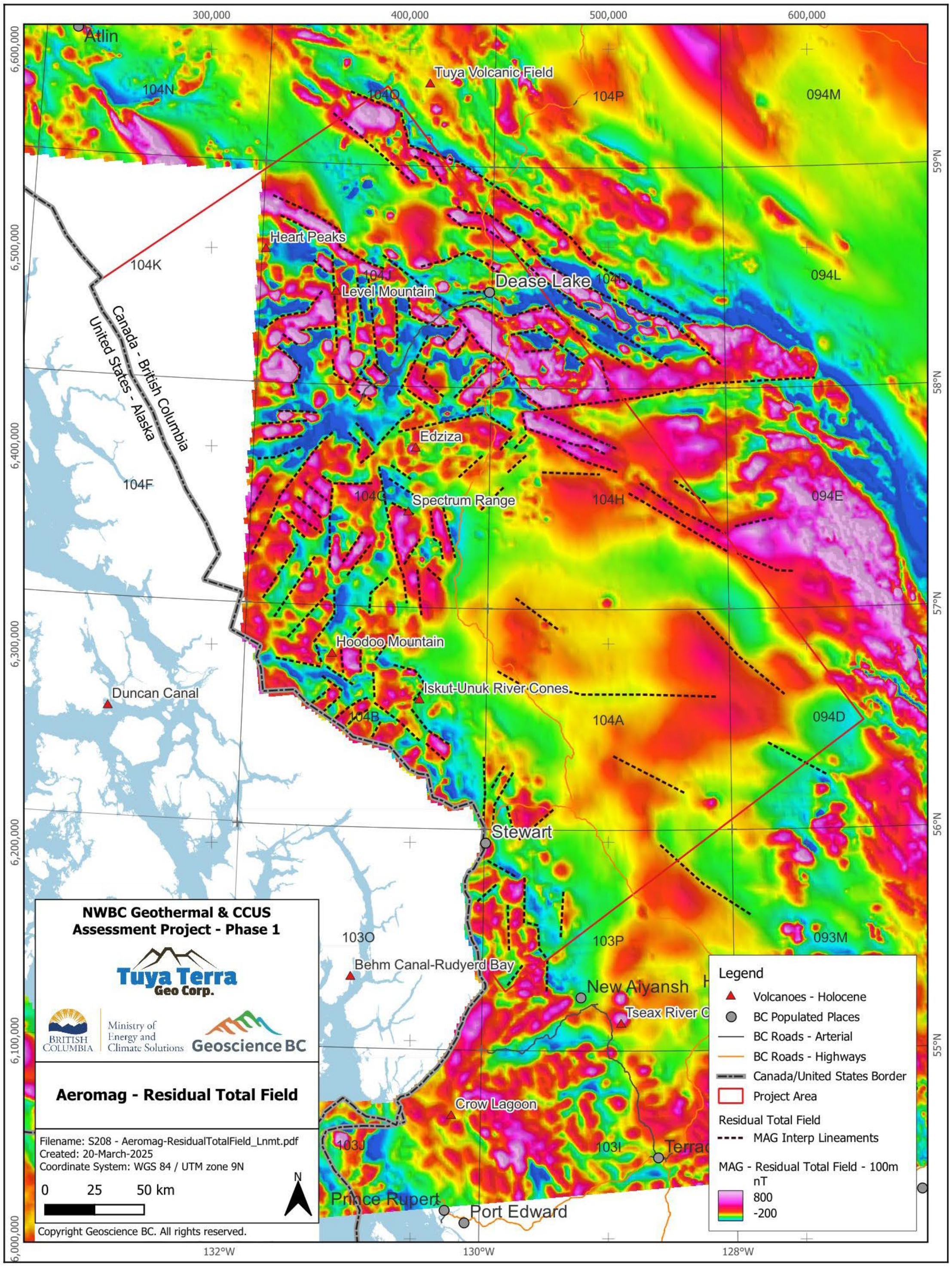
Residual Total Magnetic (RTM) Field and First Vertical Derivative of the RTM were utilized to delineate linemeant features observed in the magnetic data (Figure 9 and Figure 10).



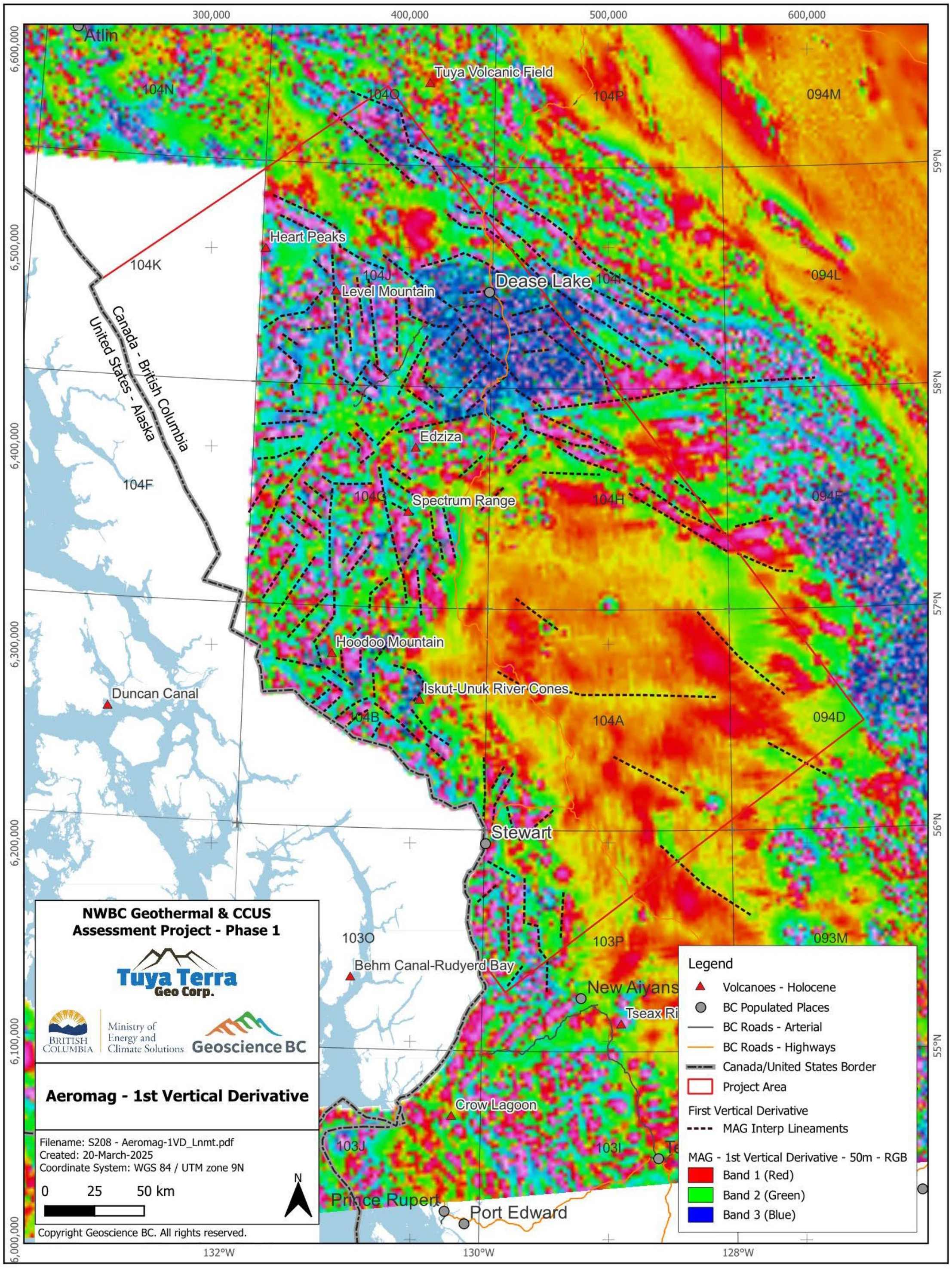
Section 2.8 Figure 7: First Vertical derivative of Bouguer Gravity Anomaly. Dashed lines are lineaments interpreted in this study. RGB image NRCan Download



Section 2.8 Figure 8: Horizontal Gradient of Bouguer Gravity Anomaly. Dashed lines are lineaments interpreted in this study. RGB image NRCan Download.



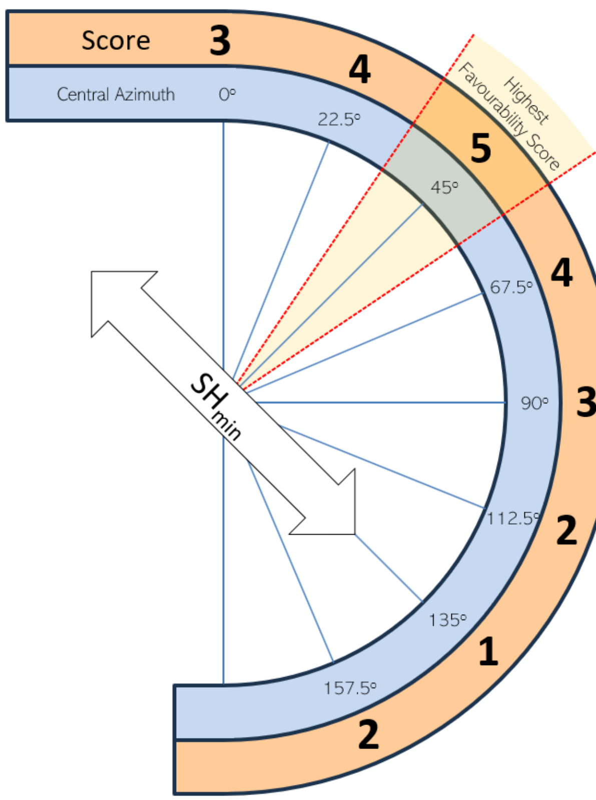
Section 2.8 Figure 9: Residual Magnetic Field Grid. Dashed lines are lineaments interpreted in this study. Converted grid NRCan Download



Section 2.8 Figure 10: First Vertical Derivative of Residual Magnetic Field Grid. Dashed lines are lineaments interpreted in this study. RGB image NRCan Download.

At the regional scale of this study, linking gravity and magnetic derived lineaments to fractures has limited confidence. This limited confidence is reflected in the linkage between lineaments and fracture to permeability. As such, G&M lineaments were used as a low weighted background indicator. When coincident with faults and fractures on the surface, the attribute will stack together for a stronger favourability indicator. When lineaments exist without a secondary surface indicator (i.e. in the Bowser basin where limited surface faulting is mapped), the lineaments can provide valuable insight into the possibility of faulting and fractures that may exist in the subsurface.

Faults and fracture systems are more prone to permeability if they are under extensional stress. The regional stress field was analysed (See section 2.4), and a minimum horizontal stress (SH_{min}) oriented NW-SE was identified. Lineaments were categorized based on azimuth and lineaments oriented perpendicular to SH_{min} were given the maximum scoring whereas lineaments oriented parallel to SH_{min} were given the minimum score. A gradational scoring scheme was then applied for azimuths between these two end members and input into the PF analysis (Figure 11). It should be noted that there is likely a significant error in this analysis as it is based on the single GPS monitoring site at Dease Lake (See Section 2.4).



Section 2.8 Figure 11: Lineament azimuth scores relative to minimum horizon stress. Lineaments are binned in 22.5° increments around the central azimuth.

Data distribution:

Gravity

Gravity point data spacing is variable. In the project area, observations are generally spaced in a 10 km grid. Higher density observations exist along the Stewart-Cassiar highway, which transects the project area, with variable data spacing averaging around 1200 m (Figure 1). Gravity data is cropped at the Canada-USA border along the west edge of the project area.

Magnetic

Magnetic data provided continuous coverage over the entire project area except for the map sheets 104K and 104F (Figure 2).

Data from Adjacent Areas:

No data was used from USA database along the west edge of the project area (Figure 1).

A large buffer surrounding the project area was used to understand the bigger picture and context of the project area (Figure 1 and Figure 2).

Limitations of Datasets:

Detailed data processing and analysis were not in the project scope; therefore, limited conclusions can be drawn for this study.

Additional targeted and purpose design studies may be designed to better characterize and invert geothermal features, (faults, volcanic rock, structures (faults and fractures) utilizing existing or newly acquired G&M data.

Data Gaps:

Gravity and magnetic data provide continuous coverage over the project area except for block 104K and 104F in the magnetic datasets (Figure 2).

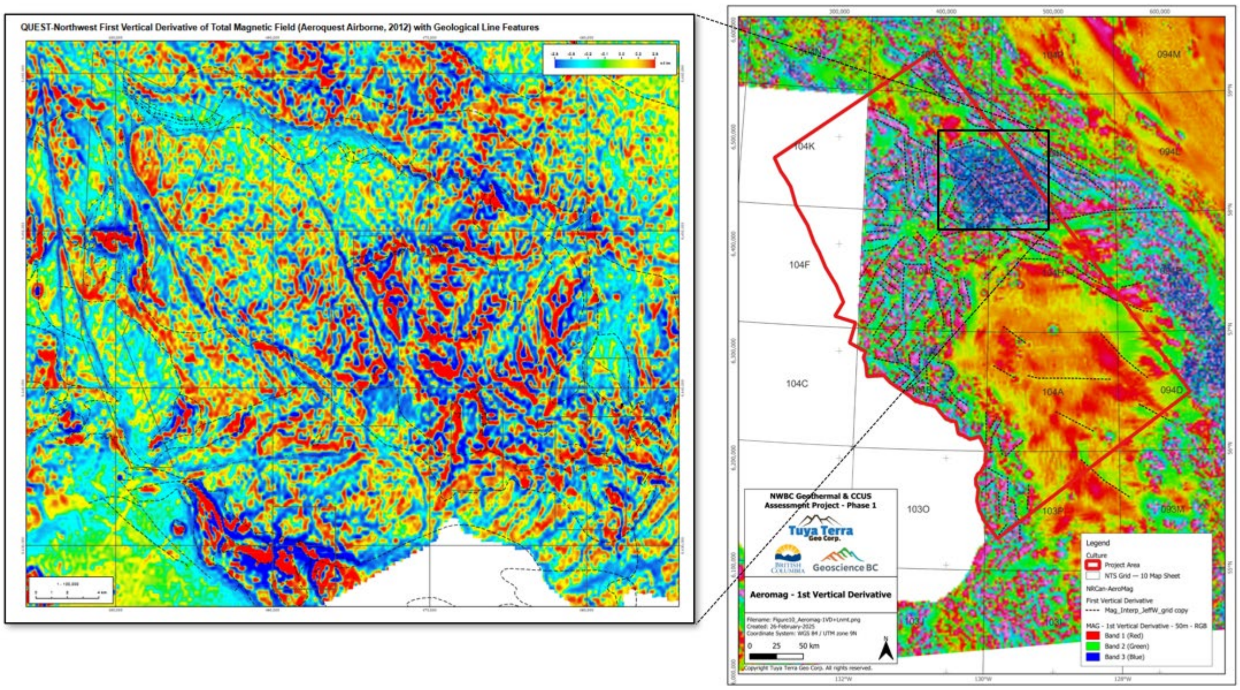
Recommendations for Additional Work

Regional Gravity Data

Regional gravity data is a useful tool for understanding foundational geology and is another data set supported financially by both federal and provincial governments. These data provide a non-invasive (i.e. no drilling) window into the structure of the deep subsurface. As geothermal systems are strongly controlled pre-existing geological architectures, gravity studies are key. It is fortunate that these data have been collected for the map area. Without the gravity data and magnetic data, understanding of the Bowser Basin depth would be significantly limited. These data were adequate for this regional study, but if high resolution data exists over favourable geothermal areas, additional analysis would be warranted. It is possible that access to high resolution gravity data through partnership with private sector exploration and mining companies currently working in the area, or have worked in the area in the past, may be possible. See Section 2.17 for additional information on mineral exploration taking place in the project area.

Regional Magnetic Data

As with gravity data, government supported acquisition of these data is a tremendous asset to studies such as this one. The foundational architecture of the cordillera is key for exploration for mineral resources, including geothermal energy. It is possible that access to high resolution gravity data through partnership with private sector exploration and mining companies currently working in the area, or have worked in the area in the past, may be possible. See Section 2.17 for additional information on mineral exploration taking place in the project area. Additionally, high-resolution aeromagnetic data exists and is much higher resolution without the down sampling completed during the compilation processing (Figure 12). It was beyond the time constraints of this study to review and integrate the information into the favourability analysis, but if there is coincidence of favourable area with high resolution magnetic data, it should be analyzed.



Section 2.8 Figure 12: Example of high-resolution data (left hand figure) (van Straaten et al., 2012) compared to regional data compilation(right hand figure) (Oneschuk et al., 2024)

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van Straaten, B.I., Logan, J.M., Diakow, L.J., 2012. Mesozoic magmatism and metallogeny of the Hotailuh batholith, northwestern British Columbia. BC Geological Survey - Open File 2012-6.

2.9 Lithoprobe Magnetotelluric Profile

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Overview

The Canadian national Lithoprobe project involved a geophysics-focused investigation of the Canadian Cordillera (Cook et al., 2012). The northern half of the Lithoprobe project, called SNORCLE (Slave-Northern Cordillera Lithospheric Evolution) included a magnetotelluric (MT) profile along the Stewart-Cassiar highway (SNORCLE Line 2a; Dehkordi et al., 2019) that passes through the project area. The magnetotelluric method is a commonly used technique to image the electrical resistivity variations in the subsurface to better understand faults and geologic structure, the geometries of subsurface rock units, magma, hydrothermal alteration, and the location of geothermal brines.

Magnetotelluric data (MT) is one of the key datasets gathered for exploration of high temperature geothermal systems. The methodology is based on the varying electromagnetic properties of rocks and penetrates from one to five-kilometer depth where geothermal resources are accessible for resource extraction. Although the results are ambiguous (as are most geophysical methodologies), when combined with surface geology, gravity and magnetic field studies robust interpretations of the subsurface can be made. These interpretations can provide greater clarity as to the geo-structural setting of the subsurface. Resolution of faults and fracture zones as well as subsurface structure related to varying resistivity of rock units (for example “clay caps” often associated with high temperature geothermal systems) can be resolved to help target boreholes and build more robust conceptual models.

The only publicly available MT data available in the project area was collected as part of the Lithoprobe project, called SNORCLE (Slave-Northern Cordillera Lithospheric Evolution). Lithoprobe was focused on the deep crustal structure (greater than 40 km depth) using high resolution seismic but also included collection of magnetotelluric (MT) data. An MT profile was collected along the Stewart-Cassiar highway (SNORCLE Line 2a; Dehkordi et al., 2019) that passes through the project area. Although these results are not appropriate for geothermal evaluation due to their depth, they provide interesting corroboration with data from Holocene volcanism in the region (See Section 2.7). One possible interpretation of the Lithoprobe results suggest that a magmatic heat source is currently present beneath the Mount Edziza and Spectrum Range volcanoes. The SNORCLE Line 2a magnetotelluric transect along the Stewart-Cassiar highway provides intriguing evidence that magma and associated geologic processes (e.g. hydrothermal alteration and geothermal aquifers) might be present. Further magnetotelluric studies in the area to answer these questions are merited.

Data set created by:

Jeff Witter

Dataset Source:

Dehkordi et al. (2019)

Data Format:

2D electrical resistivity cross-section

Project use case:

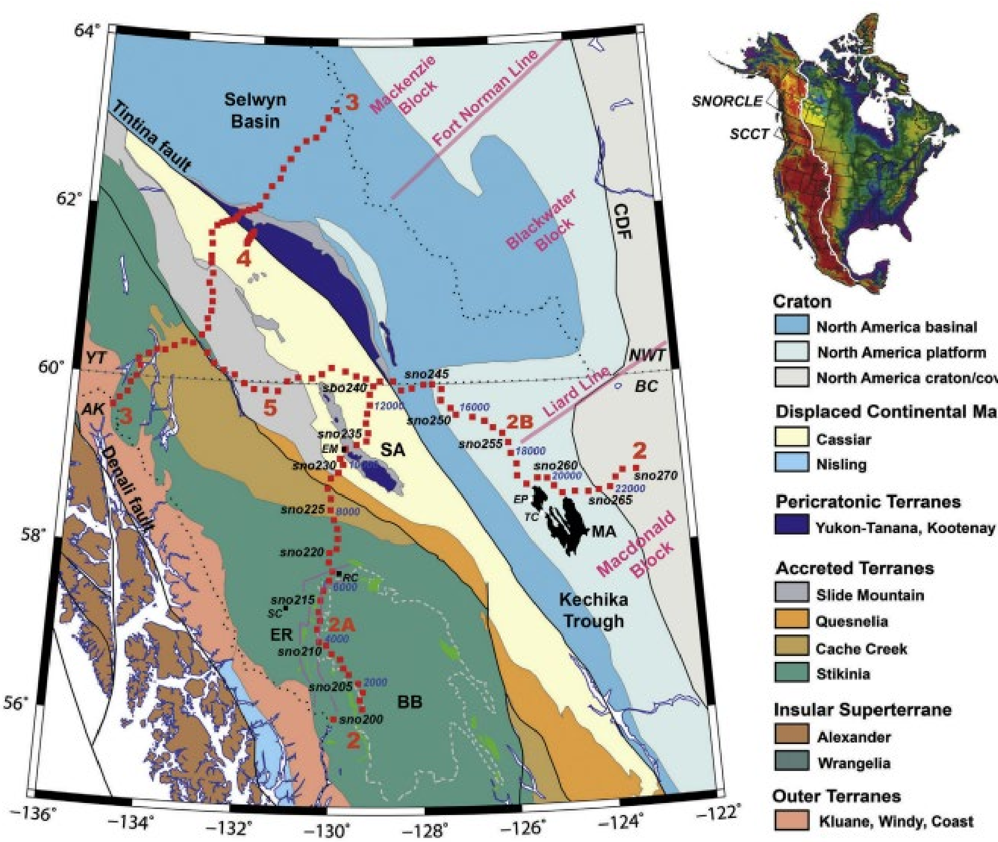
Magnetotelluric measurements are commonly used in geothermal exploration to help better understand and identify faults and geologic structure, the geometries of subsurface rock units, magma, hydrothermal alteration, and geothermal brines in the subsurface. The Canadian national Lithoprobe project involved a geophysics-focused investigation of the Canadian Cordillera (Cook et al., 2012). The northern half of the Lithoprobe project, called SNORCLE (Slave-Northern Cordillera Lithospheric Evolution) included a magnetotelluric (MT) profile along the Stewart-Cassiar highway (SNORCLE Line 2a; Dehkordi et al., 2019) that passes through the project area. The magnetotelluric method is a commonly used technique to image the electrical resistivity variations in the subsurface to better understand faults and geologic structure, the geometries of subsurface rock units, magma, hydrothermal alteration, and the location of geothermal brines.

The MT resistivity profile along SNORCLE Line 2a shows a clear low-resistivity anomaly of ~5-10 ohm.m at a depth of ~10 km below the surface situated under the highway just east of the Mount Edziza volcanic complex (SNORCLE MT station 216; see figure below). This anomaly appears on virtually all of the different inversion model results and, therefore, it is likely a robust representation of the subsurface. This anomaly could represent magma and/or partial melt beneath Mount Edziza; however, a more likely explanation is that it represents hydrothermally altered material caused by current or past magmatism in the area and/or geothermal brine.

In addition, a low-resistivity anomaly of ~5 ohm.m extends from ~25-31 km below the surface, located immediately SE of the Spectrum Range (SNORCLE MT stations 214-215; see figure below). One geologic interpretation is that this low-resistivity body represents deep-seated magma originating near the Moho that feeds the shallower ~10 km deep magma body mentioned above.

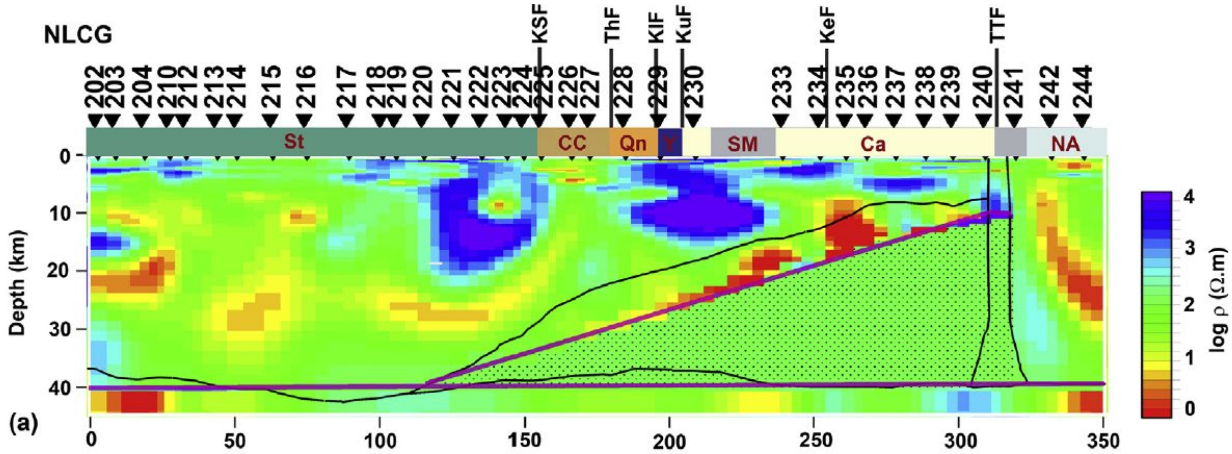
Data distribution:

The SNORCLE Line 2a magnetotelluric profile runs along the Stewart-Cassiar highway.



Section 2.9 Figure 1: SNORCLE Line 2A is shown along with the other lines where MT data was collected as part of the SNORCLE project. (Dehkordi et al., 2019, their Figure 1)

The project area extends from SNORCLE MT station 202-230 (MT station numbers are shown in bold along the top of the resistivity profile below).



Section 2.9 Figure 2: SNORCLE Line 2A Resistivity Profile. The purple lines show the approximate position of breaks in the smoothing in the inversion. In the NLCG inversion the resistivity of the seismic wedge has been fixed at 100 Ω·m. The black lines superimposed on the model show the seismically-defined location of the Moho, the Tintina Fault Zone, and the westward tapering wedge of reflective rocks. The stippled region is the portion of the NLCG inversion that has been fixed at 100 ohm.m (i.e. the seismic wedge). Key: KSF = King Salmon Fault; ThF = Thibert Fault; KlF = Klinkit Fault; KuF = Kutcho Fault; KeF = Kechika Fault; TTF = Tintina Fault; FF = Forcier Fault; St = Stikinia; CC = Cache Creek; Qn = Quesnellia; Y = Yukon-Tanana; SM = Slide Mountain; Ca = Cassiar; NA = North America; M = Muskwa Anticlinorium. (Dehkordi et al., 2019, their Figure 11(a)

Data from Adjacent Areas:

Other than SNORCLE Line 2a, public domain magnetotelluric data has not been collected in the project area. However, MT data may have been collected by mining companies as part of their mineral exploration programs. Additional MT surveys in the vicinity of Holocene volcanoes in the project area is critical to help identify possible locations of magma, hydrothermal alteration, and/or geothermal brines as part of a regional geothermal exploration effort.

Limitations of Datasets:

The MT data quality and 2D resistivity modelling of SNORCLE Line 2a is excellent; however, the wide spacing of the MT stations (~12 km) significantly limits the spatial resolution and detail in the resistivity profile shown above.

Data Gaps:

The magnetotelluric data (and associated 2D resistivity profile) exist only along the Stewart-Cassiar highway. There is no other public domain MT data in the project area.

Recommendations for Additional Work

Magnetotelluric data collected to target upper crustal geothermal systems (1 to 5 km) is a key data set for geothermal exploration. No such data exists in the area. It is possible that some EM surveys have been carried out as part of mineral exploration, but none have been identified. New MT surveys' purpose designed for geothermal exploration would have much more closely spaced MT stations in order to image the upper 1 to 5 kilometers where most geothermal resources are extracted from. These surveys are relatively cost effective for the surface area covered and when combined with surface mapping, gravity and magnetics provide a robust image of the subsurface suitable for geothermal assessment.

References

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2.10 Physical Rock Properties

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Overview

Physical rock properties, such as transmissivity and thermal conductivity, are critical for assessing heat flow and fluid movement in geothermal exploration. Understanding these properties in specific geological units helps evaluate reservoir potential and optimize well placement (Clauser, 2021). Collecting physical rock properties like transmissivity and thermal conductivity involves a combination of field measurements, laboratory analysis, and geophysical surveys. In the field, borehole logging (thermal, acoustic, and nuclear logs) helps estimate temperature gradients, porosity, and permeability, while pumping and injection tests assess subsurface water flow to determine transmissivity. Thermal response testing (TRT) in boreholes provides direct conductivity measurements. In the lab, steady-state (divided bar, guarded hot plate) and transient methods (laser flash, hot disk) measure thermal conductivity, while permeability and porosity tests (gas permeametry, mercury intrusion) estimate fluid flow potential. Additionally, seismic, electrical, and electromagnetic surveys offer large-scale indirect assessments that, when calibrated with direct measurements, enhance subsurface characterization for geothermal exploration.

Furthermore, rock physical properties serve as a crucial link between geophysical surveys and geological interpretation. The British Columbia rock physical properties database, compiled by the Geological Survey of Canada, contains thousands of values for density, electrical resistivity, and magnetic susceptibility, providing essential data for geothermal exploration and resource assessment (Enkin, 2014).

Dataset created by:

Félix-Antoine Comeau

Dataset Source:

British Columbia Geological Survey's MapPlace 2

Data Format:

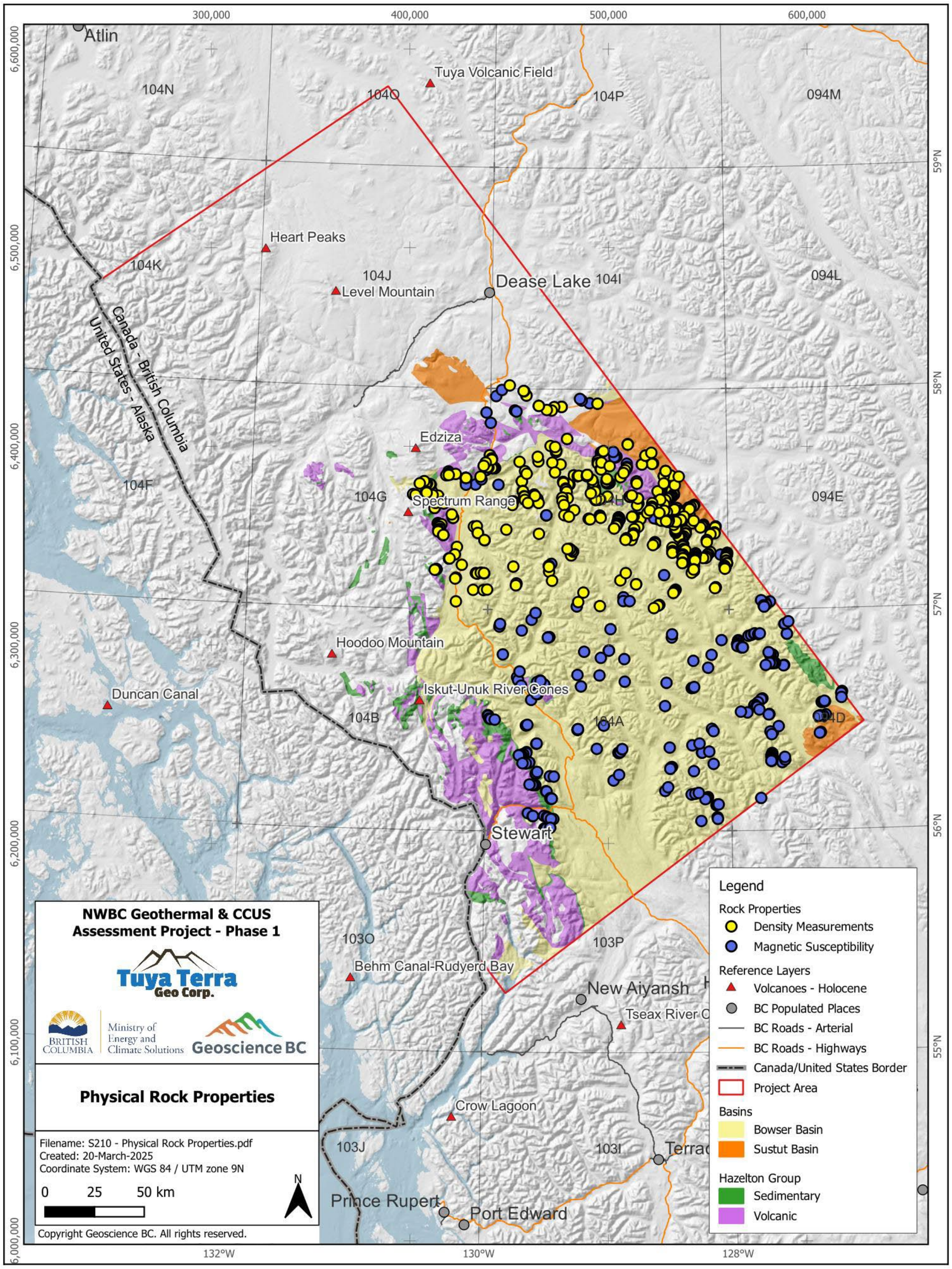
Points GeoPackage

Project use case:

Magnetic density and susceptibility data are crucial for refining geophysical interpretations, particularly in assessing subsurface structures. In geothermal exploration, these data help estimate the depth of sedimentary basins like the Bowser Basin (Lowe et al., 2006).

Data distribution:

The following map presents the location of points where data on the physical properties of rocks is available. These dates are limited to density measurements and magnetic susceptibility. It highlights the Bowser Basin, where most of the data were collected, along with its foreland basin, the Sustut Basin. The map also displays the sedimentary and volcanic units of the Hazelton Group, at or near the base of the Bowser Basin.



Section 2.10 Figure 1: Physical Rock Properties Map

Limitations of Datasets:

Currently, the only available data pertain to the geological units associated with the Bowser sedimentary basin.

Data Gaps:

Information on thermal properties, such as conductivity and heat capacity, is highly limited, and no consistent dataset is available.

Recommendations for Additional Work

At an advanced exploration stage, physical rock properties are an important parameter to have information on for specific rock units. Typically, these properties are tested in rock cuttings and core from exploration boreholes. Prior to drilling, field sampling of exposed sedimentary units may provide some valuable clues as to the characteristics of the same units in the subsurface. Understanding the transmissivity of the units is best carried out using flow testing in drilled boreholes. Currently a knowledge gap for both geothermal and carbon (CO_2) storage favourability mapping is information on physical rock properties of potential target units. A comprehensive dataset could be created that would serve multiple purposes, including geothermal and mineral exploration.

References

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2.11 Radiogenic Heat Flow

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Overview

Plutonic rocks have varying compositions similar to their extrusive volcanic counterparts. In addition to major chemical compositional variations (felsic to mafic), some plutons have higher radiogenic compositions that create elevated heat halos around the plutonic body. The "hot" plutons have been the target of both low temperature geothermal energy systems (Chena Hot springs, Alaska, USA) and higher temperature systems (Cooper Basin, Australia). Understanding if any plutonic bodies with elevated radiogenic composition exist in the project area is an important first step to see if there are any suitable exploration targets.

Dataset created by:

Bastien Poux

Dataset Source:

Radiogenic Heat data were gathered from two sources:

- Global whole-rock geochemical database compilation https://zenodo.org/records/3359791 (Gard et al., 2019)
- Measurements by (Jessop et al., 1984)

Global whole-rock geochemical database compilation

Data Format

CSV table holding rock geochemical analyses including 65 samples in the project area. One of the values in the table indicate the heat production in µW/m^3.

Project use case:

Radiogenic heat is the energy produced by rocks due to the radioactive decay of elements in their chemical composition. Igneous rocks, and in particular those of felsic composition can have important radiogenic heat production and thus can constitute a heat source that, in the presence of hydrothermal fluids, can develop into a geothermal system.

Data distribution:

A total of 65 data points have been analyzed within the project area. The majority of samples consist of mafic igneous rocks, such as basaltic rocks and gabbro. Only seven samples correspond to intermediate to felsic intrusive rocks, including monzonite, monzodiorite, granite, and granodiorite lithologies, and they can be separated into two categories

- Low Radiogenic Heat Production: Four samples located west of the Spectrum Range volcanic field exhibit very low radiogenic heat production (<2.5 µW/m^3). Two samples, one approximately 30 km west of Hoodoo Mountain and another in the southern project area, show even lower values of 1.71 µW/m^3 and 0.77 µW/m^3, respectively.
- High Radiogenic Heat Production: One sample, located in the northern project area southwest of the Tuya Volcanic Field, corresponds to a monzogranite intrusion and indicates a notably high radiogenic heat production value of 4.59 µW/m^3.

Two additional samples indicate average to slightly elevated radiogenic heat production (2.5-4 µW/m³), however, these are associated with veins rather than intrusive bodies and are unlikely to serve as sufficient heat sources for a geothermal system.

Data from Adjacent Areas:

Data from just outside the project area, particularly in Alaska, USA which borders the western margin of the project area, show numerous felsic intrusive rock samples, including granodiorite, monzogranite, and quartz monzodiorite. These rocks belong to the same Cenozoic Sloko-Hyder Plutonic Suite found along the project area's western border. Although no samples are available from this section in the project area, the Alaskan samples indicate low radiogenic heat production (<2.5 µW/m³).

A few samples with slightly elevated to high radiogenic heat production values are located north of the project area, near the mapped boundary of the Sloko-Hyder Plutonic Suite and transitioning into the Cenozoic volcanics of the Sloko Group. However, interpretation from these data is limited due to the absence of detailed rock type information in the database.

Limitations of Datasets

Data in the project area are very limited and thus a clear understanding of the potential for the area to have plutons with elevated radiogenic values is unknown and will bias the results. For this reason, no favourability analysis for radiogenic geothermal systems was carried out.

Measurements by Jessop et al.,1984

Dataset source:

https://cdnsciencepub.com/doi/abs/10.1139/e84-064?journalCode=cjes

Data format:

Scientific research paper in digital PDF format, Table 1 shows the heat flow and heat generation data for a total of seven (7) locations in British Columbia and Yukon Territory. The table was digitized into a CSV file before being plotted as points in QGIS.

Project use case:

Radiogenic heat is the energy produced within rocks due to the radioactive decay of elements in their chemical composition. Igneous rocks, particularly those of felsic composition can generate important radiogenic heat and thus can constitute a heat source, where in the presence of water, a hydrothermal system can form. It is important to note that some of the rock samples used to determine heat generation originate from deeper sections of the boreholes that were drilled for this study. Generally, these samples were taken at less than 500 meters depth.

Data distribution:

Data in the project area are very limited and thus it is unclear if there are any major intrusive body with high radiogenic heat production. Adjoining areas of the USA do suggest that plutons with elevated radiogenic values may be present.

Five (5) of the sites references by Jessop et al. 1984, are located within the project area but one does not have a heat generation estimate. Three of the sites show very low radiogenic heat production (<1.5 µW/m³), the last sample taken just south of Dease Lake, a Buckley Lake, shows an average heat production value of 2.50 µW/m³.

Limitations of Datasets:

Similarly to the whole-rock database, the few samples available provide limited information on the potential for the development of hydrothermal systems related to hot plutons within the project area and more sampling should be conducted.

Data Gaps

Many plutons within the project area have not been sampled, and the concentrations of uranium (U), thorium (Th), and potassium (K) have not been measured. As a result, the radiogenic heat potential of these plutons remains incomplete, limiting our understanding of their contribution to the region's heat flow.

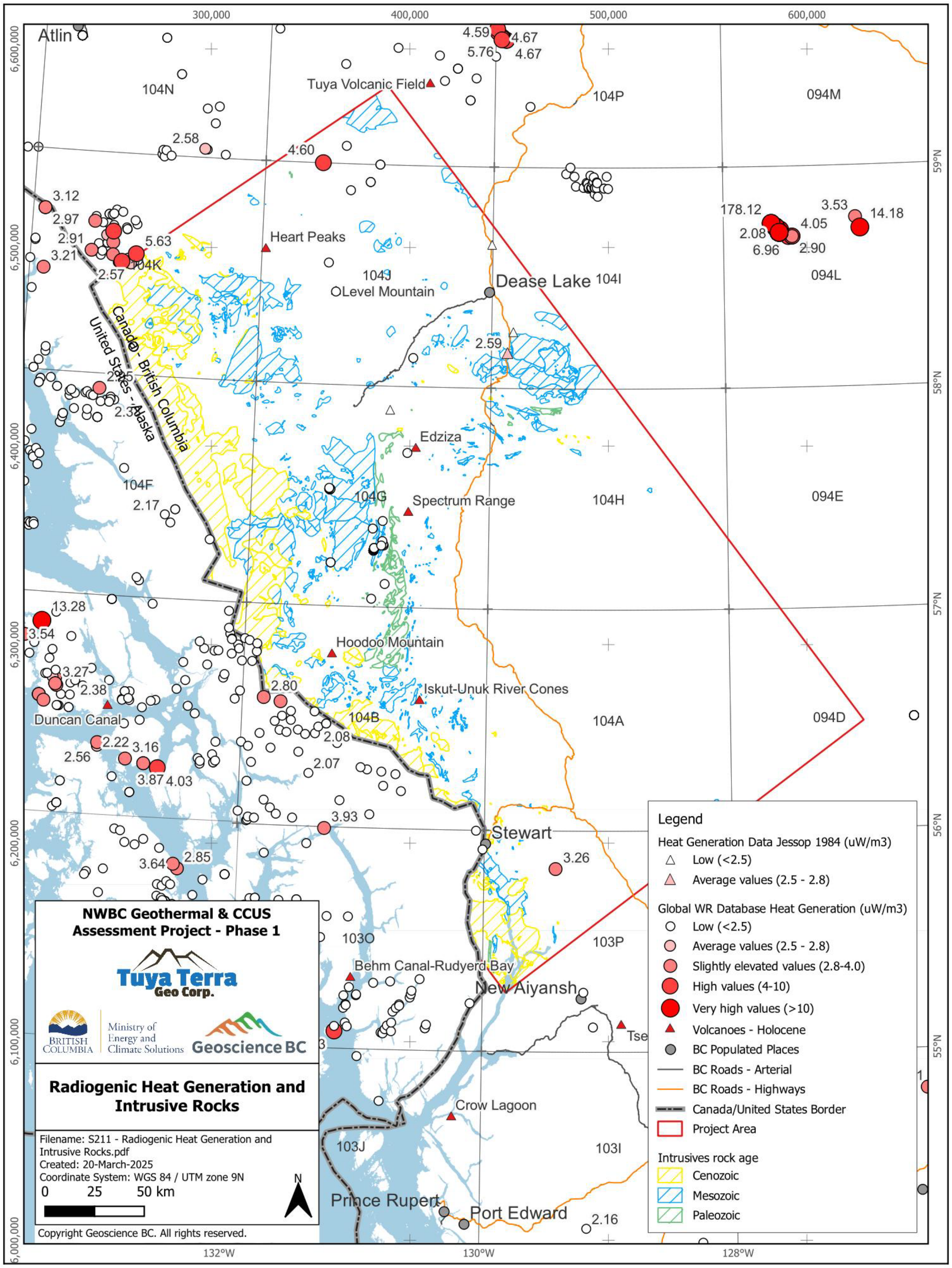
Recommendations for Additional Work

Data in the project area are very limited and do not highlight any major intrusive body with a high enough radiogenic heat production value for development of a hydrothermal system. This may be a data gap that should be filled with additional analysis, especially where plutons are disrupted by recent faulting as these may be sites where a naturally occurring geothermal system might form as in the case of Chena Hot Springs, Alaska. It is possible that access to additional analyses may be available through partnership with private sector exploration and mining companies currently working in the area or have worked in the area in the past. See Section 2.17 for additional information on mineral exploration taking place in the project area.

Case study: Chena Hot springs: (from Kolker, 2008; Kolker et al., 2007).

The Chena Hot Springs geothermal system in Alaska's Central Hot Springs Belt is a moderate temperature convective system fueled by radiogenic heat from a Cretaceous granitic pluton, reheated in early Paleogene. Unlike magmatic systems, Chena's geothermal activity relies on the elevated radiogenic heat flux from U/Th-rich pluton, combined with structural permeability resulting from fractures and faults within or near the pluton that act as pathways for meteoric water to circulate, convectively transferring heat to the surface. The heat production value for the plutons associated with the Chena hot springs is in the order of 6 +/-1 mW/m^3, comparable to other plutons associated with hot springs in Alaska, with the highest heat production values reaching up to 8-9 mW/m^3 at the Circle and Manley hot springs. Other plutons in Alaska, not associated with hot springs, typically have heat production values in the range of 2 to 3 mW/m^3

This example shows that plutons can constitute a sufficient heat source to favour the development of a geothermal reservoir.



Section 2.11 Figure 1: Map of the Radiogenic Heat Generation data in the project area vicinity and intrusive rocks of the project area.

References:

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Kolker, A., Newberry, R., Layer, P., Larsen, J., Stepp, P., 2007. Geologic Setting of the Chena Hot Springs Geothermal System, Alaska, in: Proceedings of the Thirty-Second Workshop on Geothermal Reservoir Engineering. Stanford, California.

2.12 Regional Geochemistry

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Section 2.12 Table 1: R Value boundaries for elements related to geothermal evaluation 147

Overview

Regional Geochemistry surveys (RGS) provide a valuable tool for mineral exploration but has limitations for geothermal exploration. The value of these surveys is not just for mineral exploration but also can be used as a proxy for identifying faults and fracture zones along which mobile elements such as Arsenic, Mercury and Selenium (after Sulphur) may have been mobilized. The mobilization of these elements may be due to circulation of groundwater. A cautionary note is that these elements may also be associated with mineral deposits, and do not represent "modern" deposition. The applicability of RGS data to geothermal exploration has not been validated but is included as it provides some insight into regional geological controls, such as bedrock exposure and sedimentary cover. It is also one of the few regional data bases available for analysis.

The British Columbia Ministry of Mining and Critical Minerals maintains a regional geochemical database the covers British Columbia. In the project area (Figure 1) regional geochemical analysis of stream silt samples were available and are used in the evaluation. The elements that selected from the database, which are thought to be particularly relevant to geothermal evaluation are:

1. Arsenic: a mobile element, commonly anomalous around hot springs.
2. Mercury: commonly deposited as mercury minerals, such as cinnabar, in geothermal areas.
3. Acidity (pH): sulphurous activity is commonly associated with hot springs and is often acidic; since acid conditions are low pH and pH is a logarithmic function Inverse pH (InvPh = 10 – pH) is used so that large numbers will reflect acidic conditions.
4. Selenium: selenium, chemically closely associated with sulphur, will identify areas of sulphurous activity that often is associated with geothermal activity.

Of note, is that the four elements selected exhibit a wide range of concentrations in known and developed geothermal fields, as their presence in the fluids is strongly controlled by spatially variable host rock chemistry and is quickly diluted upon mixing with surface waters. Adding to this ambiguity, a geochemical signal may have an origin in a Paleozoic, Mesozoic, or Cenozoic hydrothermal deposit. Hence, the use of element geochemistry as a prospecting tool for geothermal resources is not as applicable as it is for minerals. However, field experience has shown that on a regional scale, these elements might provide additional insight into areas that have the potential to host geothermal systems, thus they have been included in the data analysis with attendant cautionary notes.

Dataset Created by:

Colin Godwin

Dataset Source:

Colin Godwin, downloaded from the internet of the British Columbia Ministry of Mining and Critical Minerals the data used for this project area. All data came from their 2017 compilation of regional silt geochemical data (Han and Rukhlov, 2017).

Where multiple analyses were available on some samples they were amalgamated to a single value, generally by taking the maximum value of all analyses. An example for arsenic is: arsenic by atomic emission spectroscopy = 382 ppm and arsenic analyzed by instrumental delayed neutron activation analysis = 401 ppm; thus, the value selected for this project would be the highest one, 401 ppm.

Many sites are not analyzed for all elements.

Data Format:

GIS mapping was done in MapInfo/Discover. Datum used was NAD83, following the British Columbia Ministry. Latitude North and Longitude East were used to facilitate province-wide evaluations by avoiding different UTM Zone complications.

Project use case:

Mercury and Arsenic were used to evaluate if there were any correlations of these elements with other geothermal favourability features such as faults, hot springs or young volcanic centers. These results are reported in Section 3.1.

The geochemical evaluation was expanded by "**RDVM"** analysis (Relative Value (**R**-Value), Discrimination Factor (**D**-Factor), and Relative Value of Discrimination Factor (RD Values) **RDVM**) analysis to incorporate values of selenium and inverse pH in water at sample sites.

Data distribution:

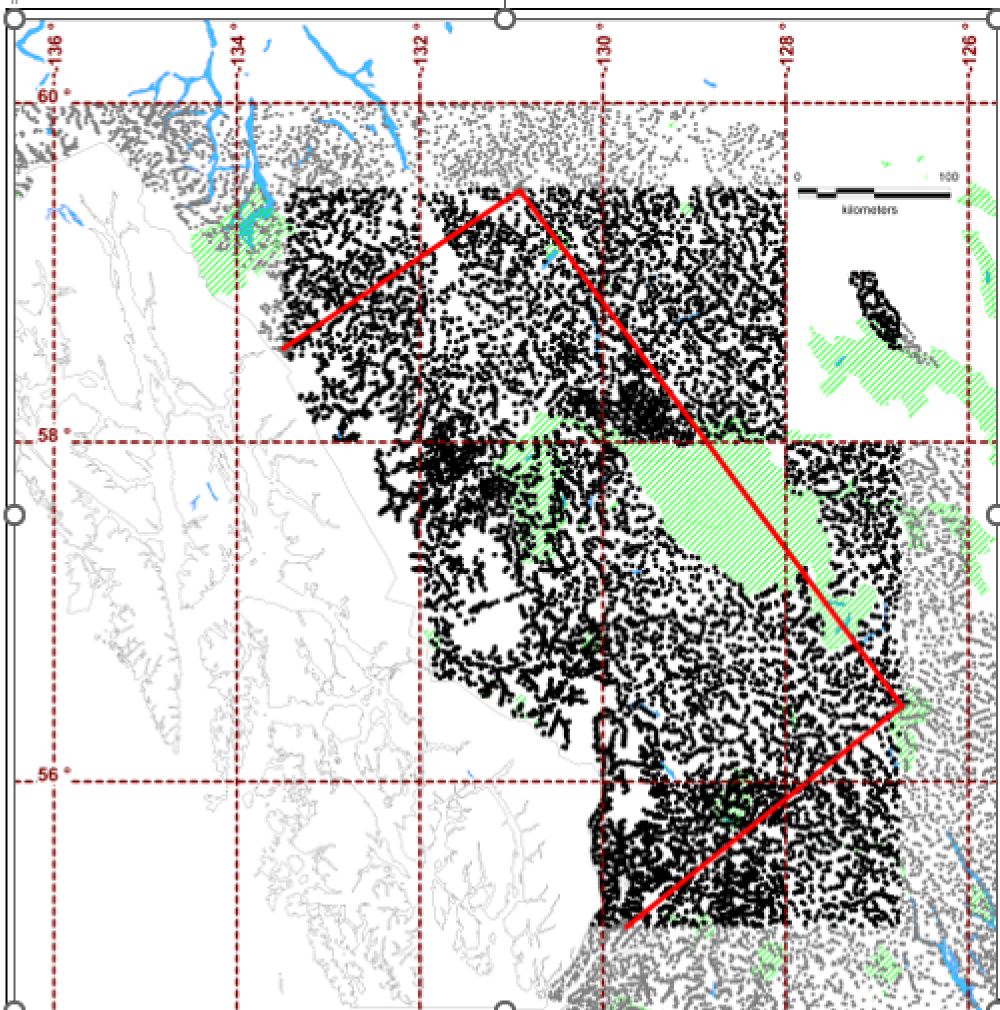


Figure 1. Target area for geothermal evaluation is outlined in red.
Grey dots represent regional geochemical sample sites. Black dots are those regional sites used for evaluation of the target area.

Section 2.12 Figure 1: Project area for Geothermal Evaluation

Figure 1 shows the project area bordered in red. The grey dots mark regional sample sites. The black dots are those from the regional set that were used in evaluation of the project area. The Excel file for sample sites (11,707 sample sites) for the project area and their interpretation is ***BcGeotR_D-RD.xlsx***, (Godwin, 2025). Areas where no data has been collected are typically British Columbia Provincial parks such as the Spatsizi Plateau Wilderness Park along the eastern margin of the project area (Figure 1). Other areas along the western margin are typically areas of extreme terrain and glaciers.

Data from Adjacent Areas:

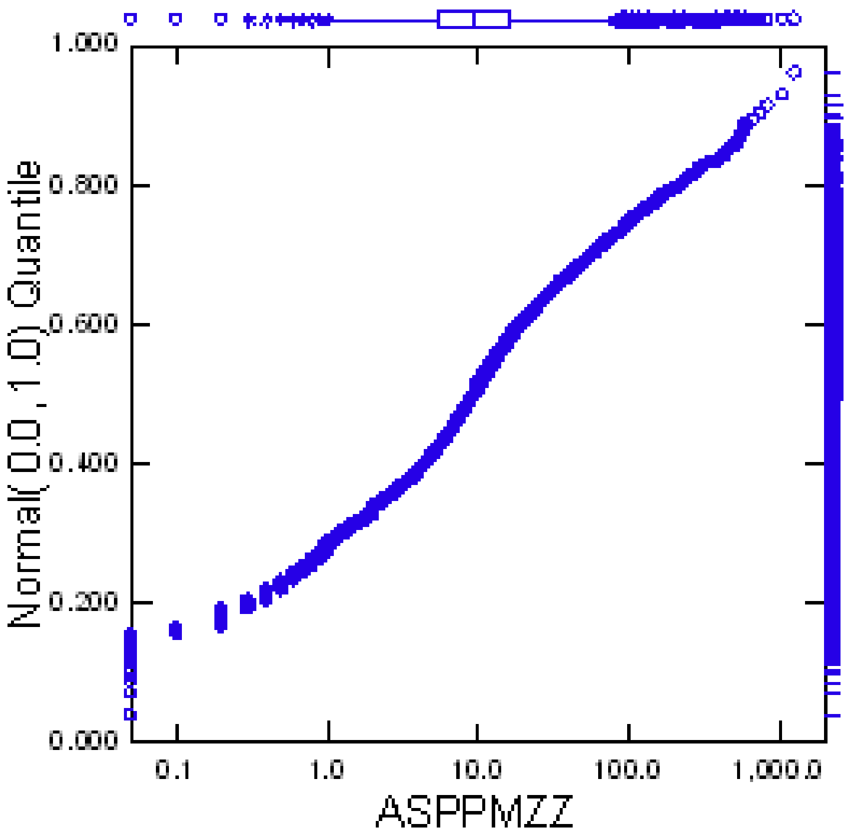
Data for the project area was excised from the total data set from north, south and east of the project area. Triangular areas outside the project area are included in the following study. This was not only convenient but provided a larger data set for statistical evaluations.

Statistical Evaluations

Arsenic Silt Geochemistry

Statistical evaluation of the silt arsenic geochemistry is shown in Figure 2 and TABLE 1.

	ASPPMZZ
N of Cases	11,682
Minimum	0.050
Maximum	1,270.000
Range	1,269.950
Interquartile Range	10.600
Median	9.500
Arithmetic Mean	17.253
Standard Deviation	37.427



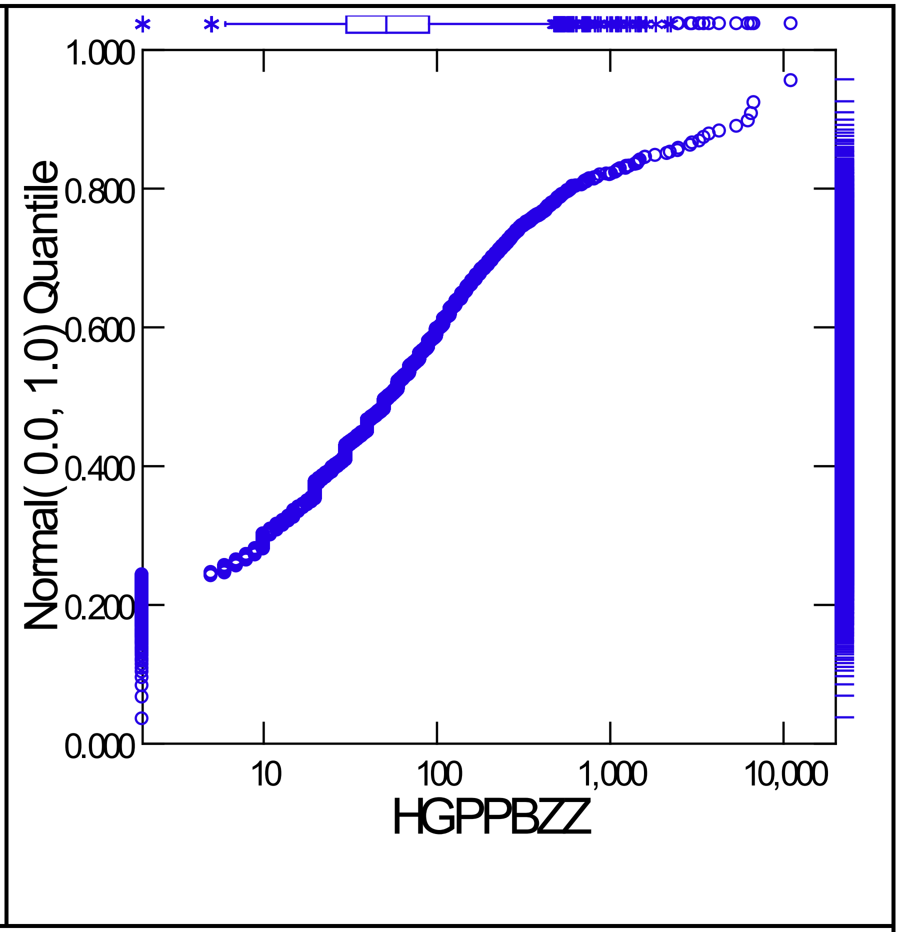
Section 2.12 Figure 2: Basic statistics and probability plot for arsenic

RDVM assessment of R Values for the probability plot are in TABLE 1.

Mercury Silt Geochemistry

Statistical evaluation of the silt mercury geochemistry is shown in Figure 3 and TABLE 1.

	HGPPBZZ
N of Cases	11,689
Minimum	2.000
Maximum	11,131.000
Range	11,129.000
Interquartile Range	60.000
Median	51.000
Arithmetic Mean	78.654
Standard Deviation	197.321



Section 2.12 Figure 3: Basic statistics and probability plot for mercury.

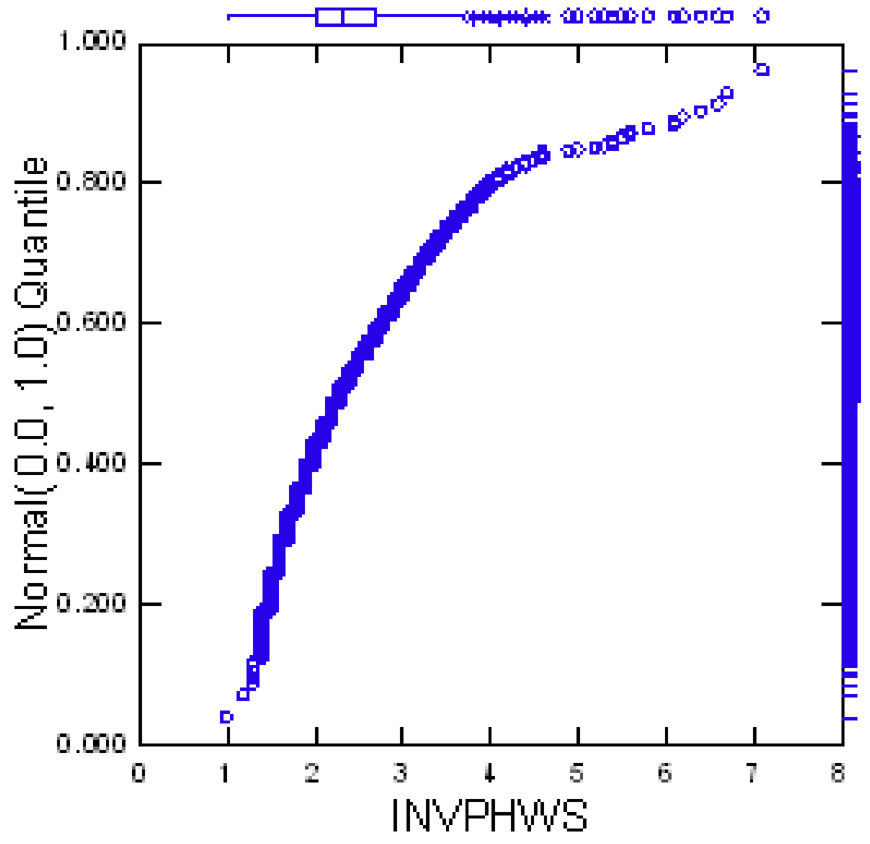
RDVM assessment of R Values for the probability plot are in TABLE 1.

Inverse of pH in Water Geochemistry (InvPh)

Statistical evaluation of the inverse-pH in water geochemistry is shown in Figure 4 and TABLE 1.

The inverse of pH (InvPh) was used so that acidic sites could be emphasized and added in **RDVM** calculations. The formula used was ***InvPh = 10-pHwWs***.

	INVPHWS
N of Cases	11,579
Minimum	1.000
Maximum	7.100
Range	6.100
Interquartile Range	0.700
Median	2.300
Arithmetic Mean	2.373
Standard Deviation	0.506



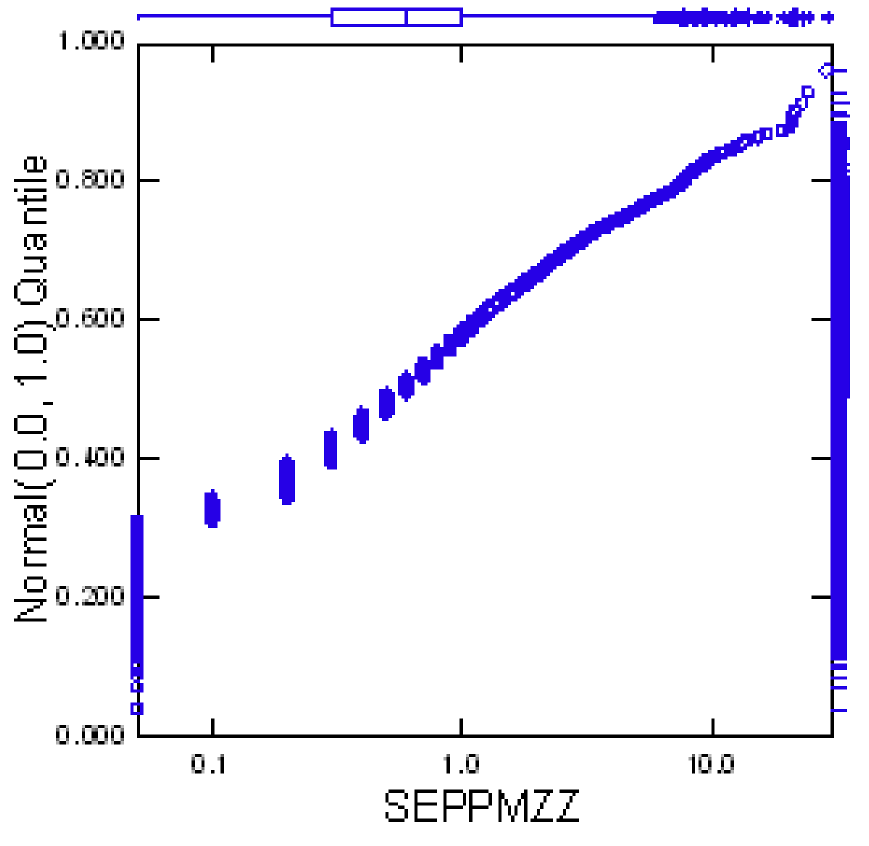
Section 2.12 Figure 4: Basic statistics and probability plot for the inverse of pH (InvPh).

RDVM assessment of R Values for the probability plot are in TABLE 1.

Selenium Silt Geochemistry

Statistical evaluation of the silt selenium geochemistry is shown in Figure 5 and TABLE 1. Selenium was selected because of its close chemical association with sulphur that is associated with hydrothermal vents, and consequently, might be related to areas with elevated geothermal favourability.

	SEPPMZZ
N of Cases	11,384
Minimum	0.050
Maximum	29.000
Range	28.950
Interquartile Range	0.700
Median	0.600
Arithmetic Mean	0.875
Standard Deviation	1.228



Section 2.12 Figure 5: Basic statistics and probability plot for selenium.

RDVM assessment of R Values for the probability plot are in TABLE 1.

RDVM Calculation of R Values, DGeot and RDGeot

Relative Value (R-Value), Discrimination Factor (D-Factor), and Relative Value of Discrimination Factor (RD Values) are part of a methodology (RDVM) where significant thresholds are established, and the data is reduced to the odd numbers 1 to 11. The technique is detailed in (Godwin, 2016)and (Godwin, 2024). This processing allows elements to be combined based on geological criteria creating a fit-for purpose strategy that assumes one is looking for specific targets which can be modeled from mineral systems of interest. This pragmatic approach enhances discovery opportunities in geochemical analysis. It facilitates rapid analysis of massive datasets and identification of key anomalous sites for specific types of deposits. It also defines those sample sites that are anomalous for specific types of deposits thus enabling data to be separated into relevant anomalous sets.

RDVM generally uses log transformed data to normalize the data distributions, and log-probability plots (Sinclair, 1982, 1976; Stanley, 1987; Stanley and Sinclair, 1987)to partition the data into anomalous and background values. Relevant statistical numbers can be generated quickly with most statistical programs. RDVM is based on the statistical distinction between background and anomalous populations. Specifically, the technique uses:

1. All elements are analyzed geochemically.
2. Statistical identification and separation of anomalous and background populations using log-probability plots.
3. Simple renumbering of anomalous and background populations to obtain Relative Values (**R** Values) that are additive.
4. Addition of **R** Values to form geologically meaningful Discrimination Factors (**D**-Factors) to identify underlying rock types and anomalous signatures for different types of mineral deposits.
5. Relative Values of **D** Factors (**RD** Values) standardize anomaly interpretation—to enhance and facilitate map interpretations (i.e., changes **D** Factors to the anomalous levels **11**, **9**, **7** and **5** to standardize plotting and to make visual interpretations of maps easier).
6. Direct application of **R** Values, and **RD** Values to the interpretation of extensive, multi-element datasets.

RDVM is a 'geologists' factor analysis. It enhances geological interpretation of data in a way that has geologically genetic significance because it is based on commonly known pathfinder elements for situations in question. Importantly, where anomalous values exist for two or more elements, **D**-Factors or **RD**-Values derived from the addition of **R**-Values enhance the reliability of the anomaly. The great practical advantage is the **RDVM** geological and genetic synthesis of features related to discovery.

Defining **R**-Values, **D**-Factors, and **RD**-Values apply and unify probability statistics, and geological knowledge and experience. **RDVM** complements traditional approaches and aids in discovery from geochemical datasets from regional surveys.

R Value boundaries in TABLE 1 were estimated from the probability graphs of Figures 2 to 6.

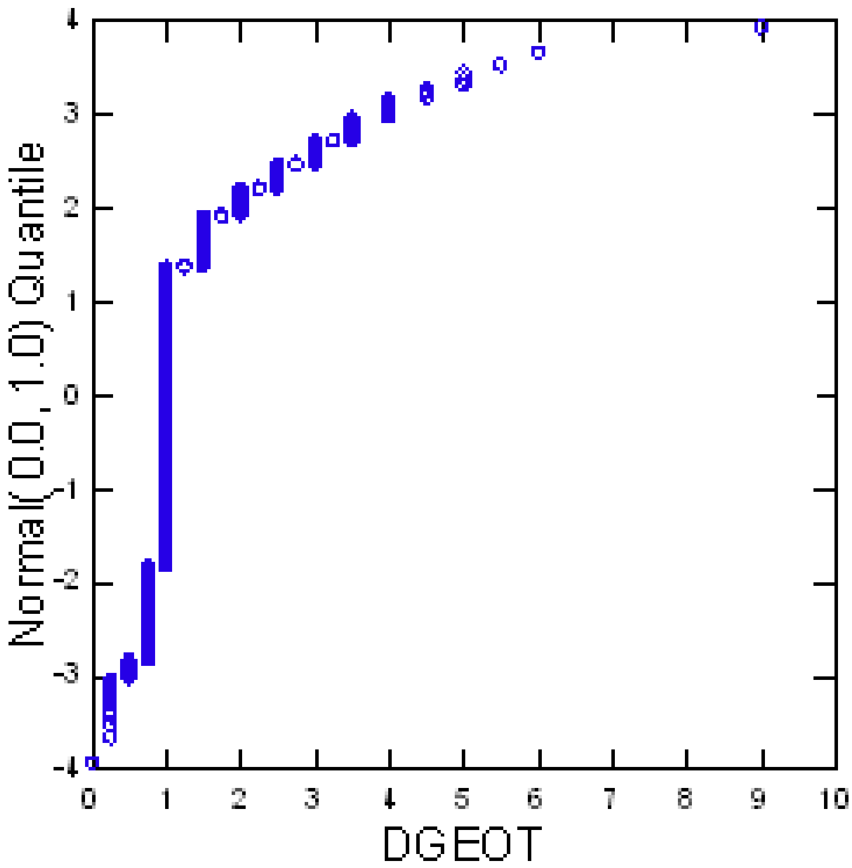
Relative-values (**R** Values) are determined visually from log-probability plots. A bimodal, log-normal population generally is assumed (pH is naturally logarithmic and not log transformed but it is inverted (RInvPh = [10-pH]) so that acidic sites have high values. **R** Values are assigned as follows:

- **R** = **11** = **outlier anomalous** data with exceptional concentrations (traditionally this is commonly assigned as equal to, or greater than, the 99.6 percentile).

- **R** = **9** = **highly anomalous** data (generally sparser in density than the clearly anomalous data = **7**).
- **R** = **7** = **clearly anomalous** data (immediately above the mixed population = **5**).
- **R** = **5** = **mixed population** of background and anomalous data (data will have characteristics of both the background population and the anomalous population and commonly will be marked by an inflexion point).
- **R** = **3** = **high background** data that generally is above the third quartile (75^{th} percentile) and extends up to the mixed population = **5**.
- **R** = **1** = **low background** data that commonly is equal to or below the third quartile or upper hinge (equal to or less than the 75^{th} percentile) and generally can be disregarded.

The **D**iscrimination Factor (**D**) is calculated as the average of summed **R** Values. The **R** Values tested here for geothermal targets (Geot) are **D**Geot= (**R**As+**R**Hg+**R**InvPh+**R**Se)/4. The resulting probability plot of **D**Geot is in Figure 6 and the **RD**Geot Value boundaries (**RD** Values convert **D**-Factors to the standard **RD** Values of 11, 9, 7, 5, 3 and 1) are in Table 1. **D**Geot and **RD**Geot might reflect geothermal sites anomalous in arsenic, mercury, acid pH, and selenium reflecting sulphateric action. However, they might also represent precious metal sites, that also are commonly related to pre-Holocene (or older) geothermal history. Note that the addition of gold, silver, antimony, etc., to the **D** Factor calculation for geothermal targeting (**D**Geot) would target precious metal deposits (**D**Prec). Additional **D** Factors and **RD** Values might be worth exploring. For example, arsenic and mercury together could be evaluated by **D**AsHg = (**R**As+**R**Hg)/2, followed by estimation of **RD**AsHg evaluation.

	DGEOT
N of Cases	11,707
Minimum	0.000
Maximum	9.000
Range	9.000
Interquartile Range	0.000
Median	1.000
Arithmetic Mean	1.061
Standard Deviation	0.303



Section 2.12 Figure 6: Basic statistics and probability plot for selenium.

RDVM assessment of RD Values for the probability plot are in TABLE 1.

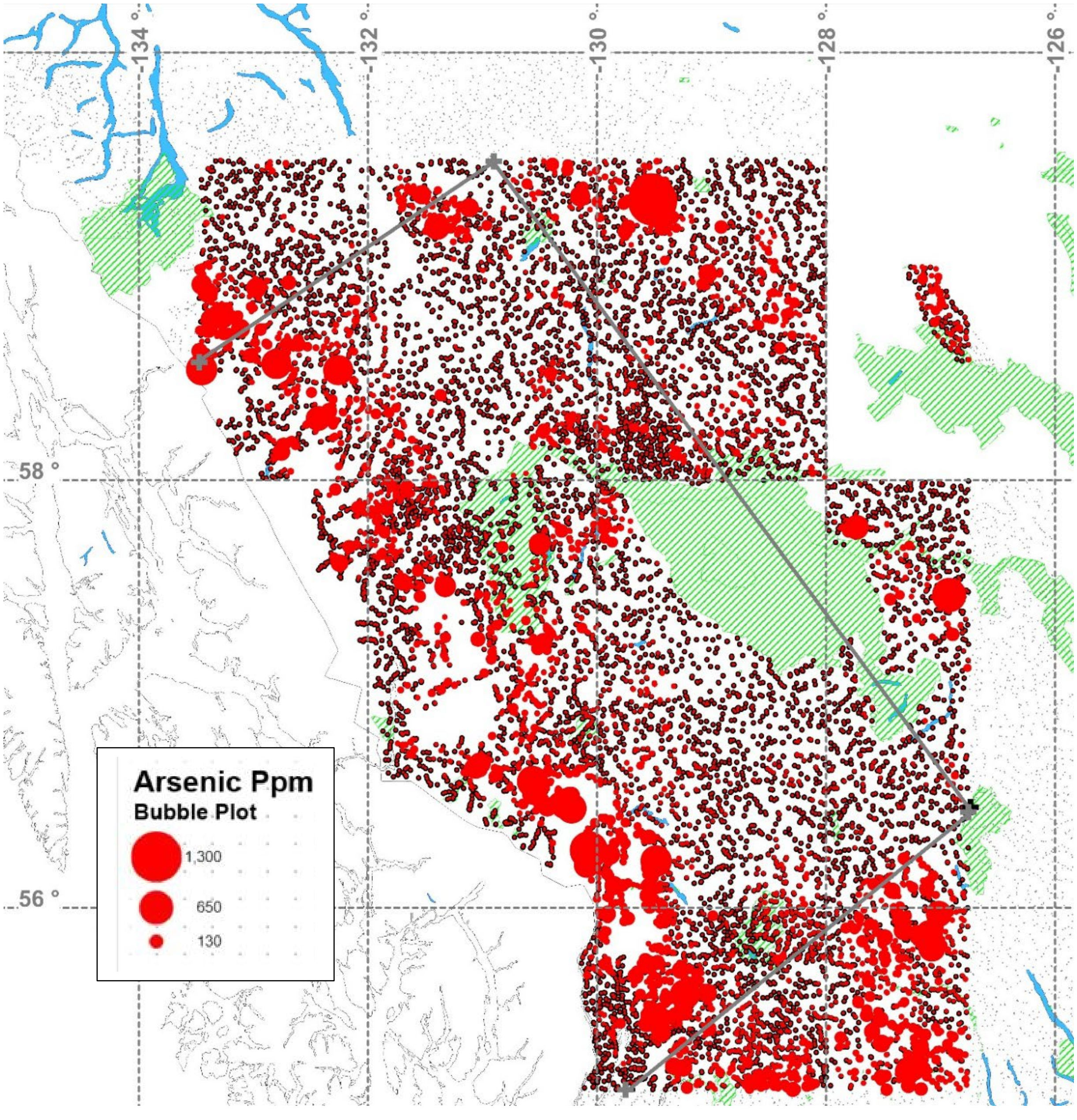
Section 2.12 Table 1: R Value boundaries for elements related to geothermal evaluation

Probability plots are of data related to black dots in Figure 1. As an example, **R**As11 = values ≥ 680 ppm, and **R**As9 = values 421 ppm to 680 ppm.

ELEMENT	**R**=11 ≥	**R**=9 ≥	**R**=7 ≥	**R**=5 ≥	**R**=3 ≥	**R**=1 <
AsPpm	680	421	226	153	61	61
HgPpb	6,578	2,500	1,100	570	350	350
InvPh	6.6	5.4	4.6	4.0	3.5	3.5
SePpm	21.2	13.3	9.7	7.3	4.9	4.9
RDGeot	6.5	4.5	3.0	2.0	1.5	1.5

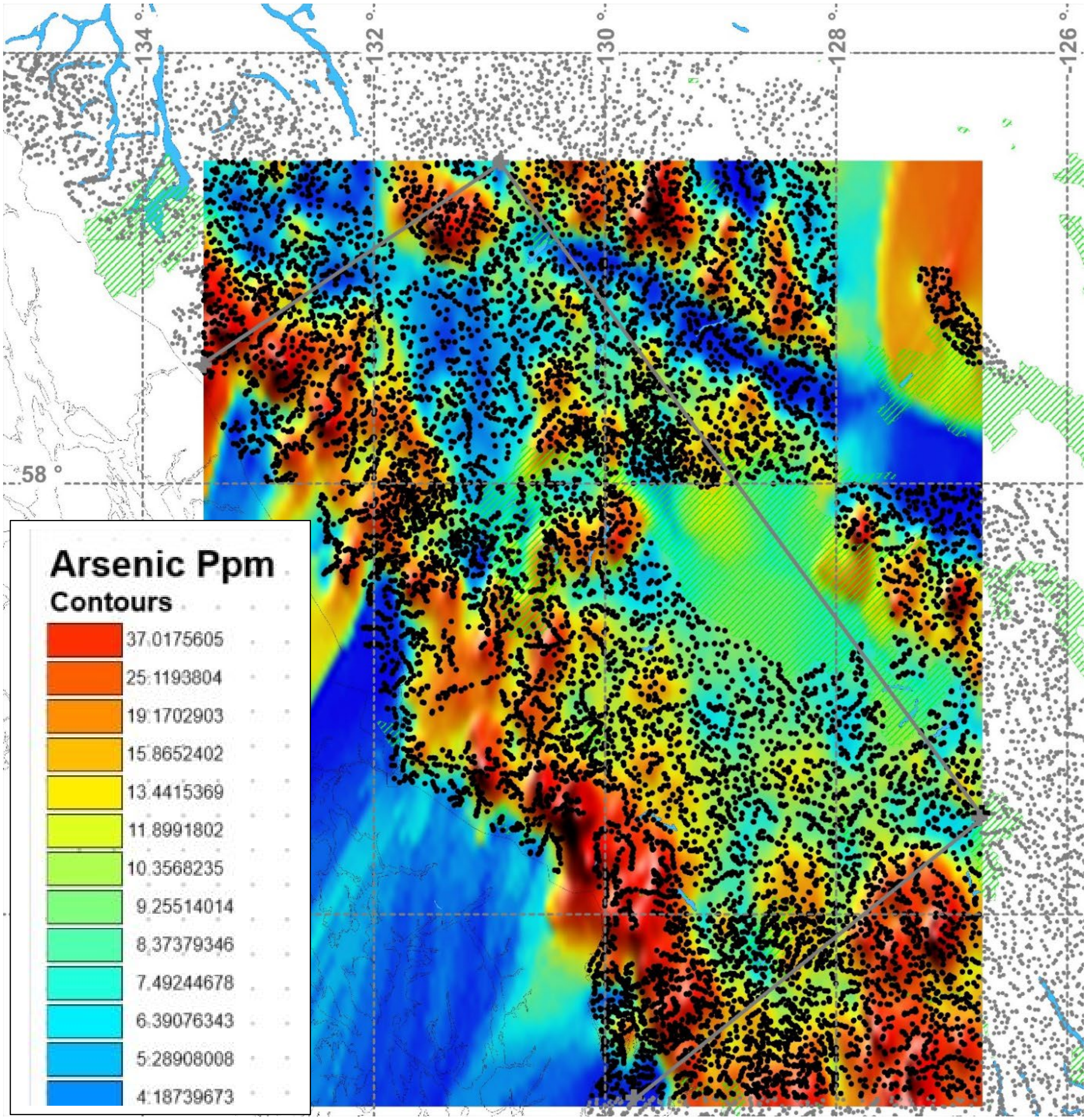
ARSENIC MAPS

Arsenic anomalies are identifiable on the bubble and contour plots of Figures 7 and 8.



Section 2.12 Figure 7: Arsenic bubble plot for project area.

Project area outlined by grey line. Green areas identify parks and regional geochemical silt data is sparse or absent.

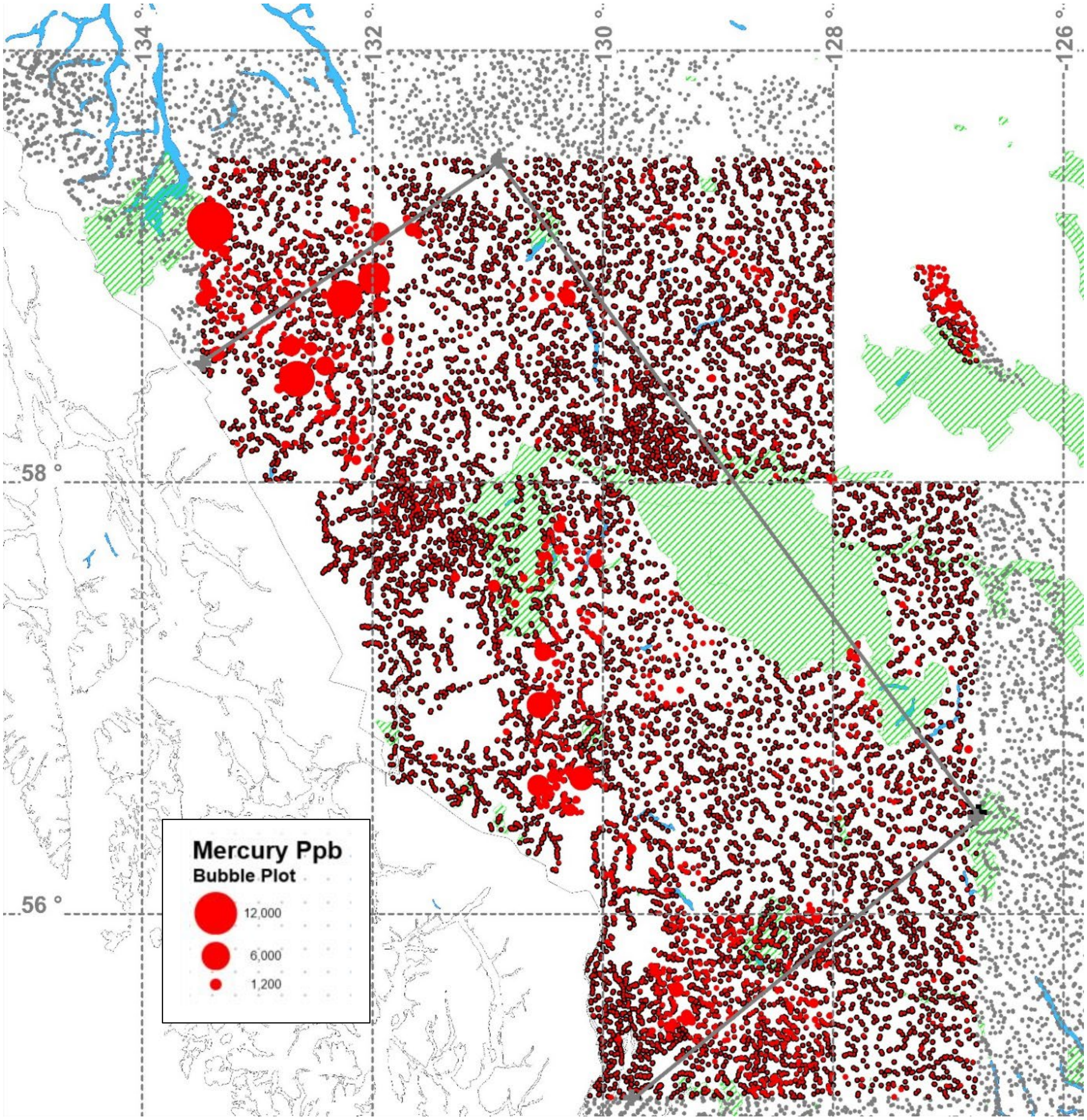


Section 2.12 Figure 8: Arsenic contours for project area

Areas distant from black dot sites are invalid. Project area outlined by grey line. Green areas identify parks and regional geochemical silt data is sparse or absent.

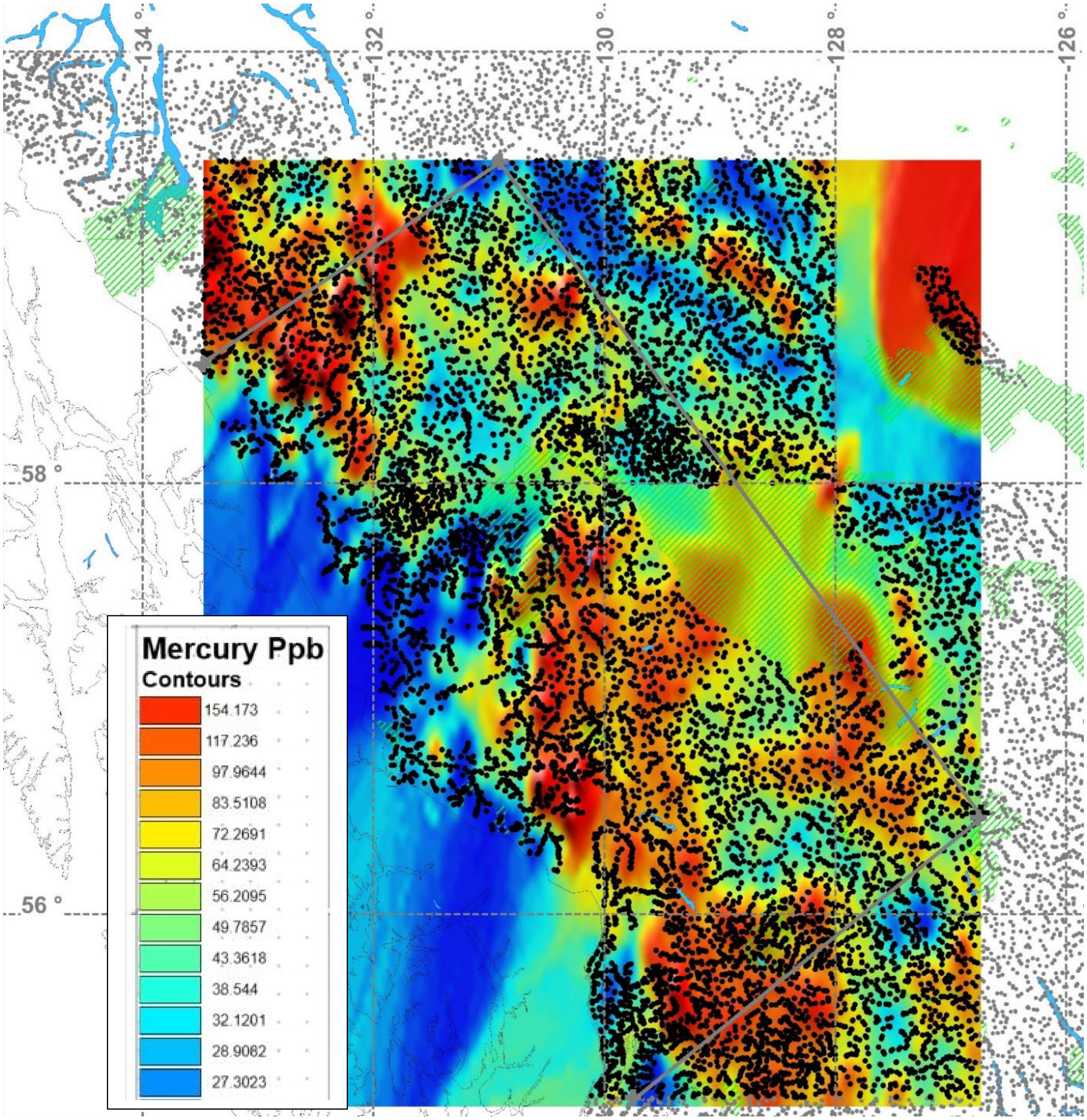
MERCURY MAPS

Mercury anomalies for are identifiable on the bubble and contour plots of Figures 9 and 10.



Section 2.12 Figure 9: Mercury bubble plot for project area

Project area outlined by grey line. Green areas identify parks and regional geochemical silt data is sparse or absent.

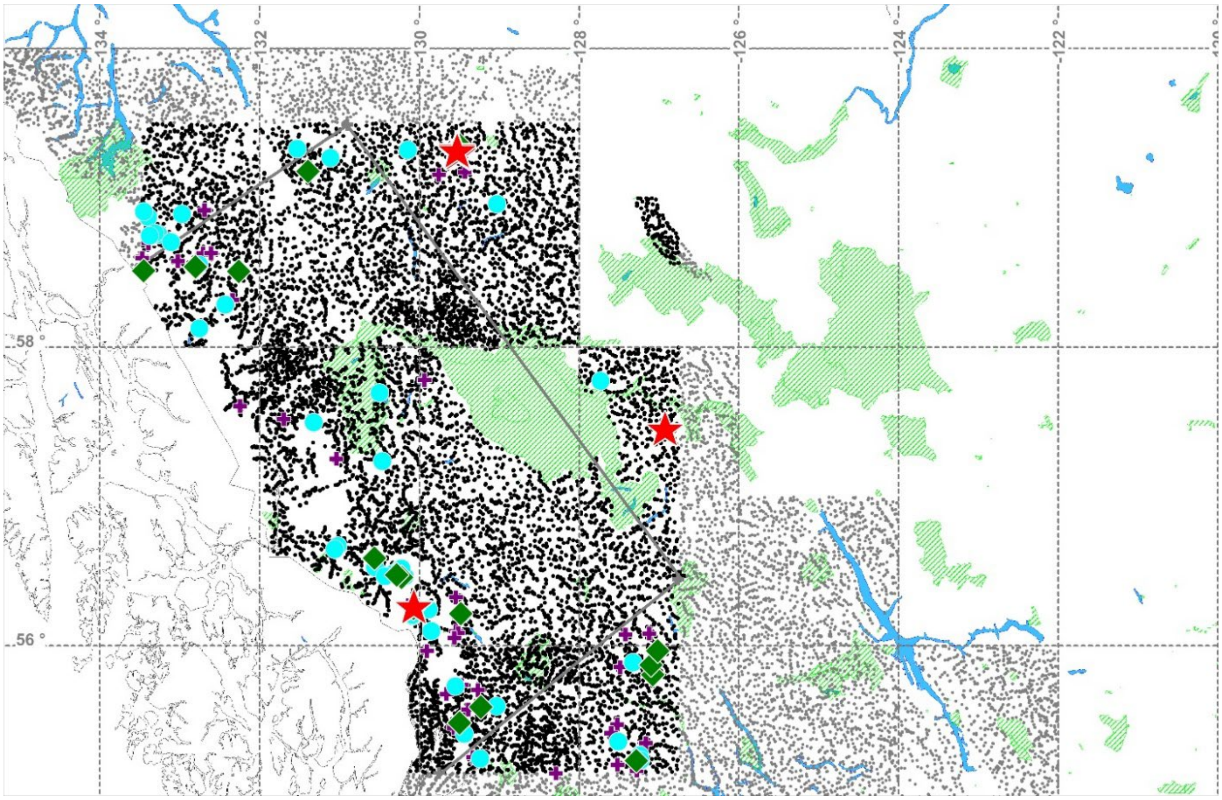


Section 2.12 Figure 10: Mercury contours for project area

Areas distant from black dot sites are invalid. Project area outlined by grey line. Green areas identify parks and regional geochemical silt data is sparse or absent.

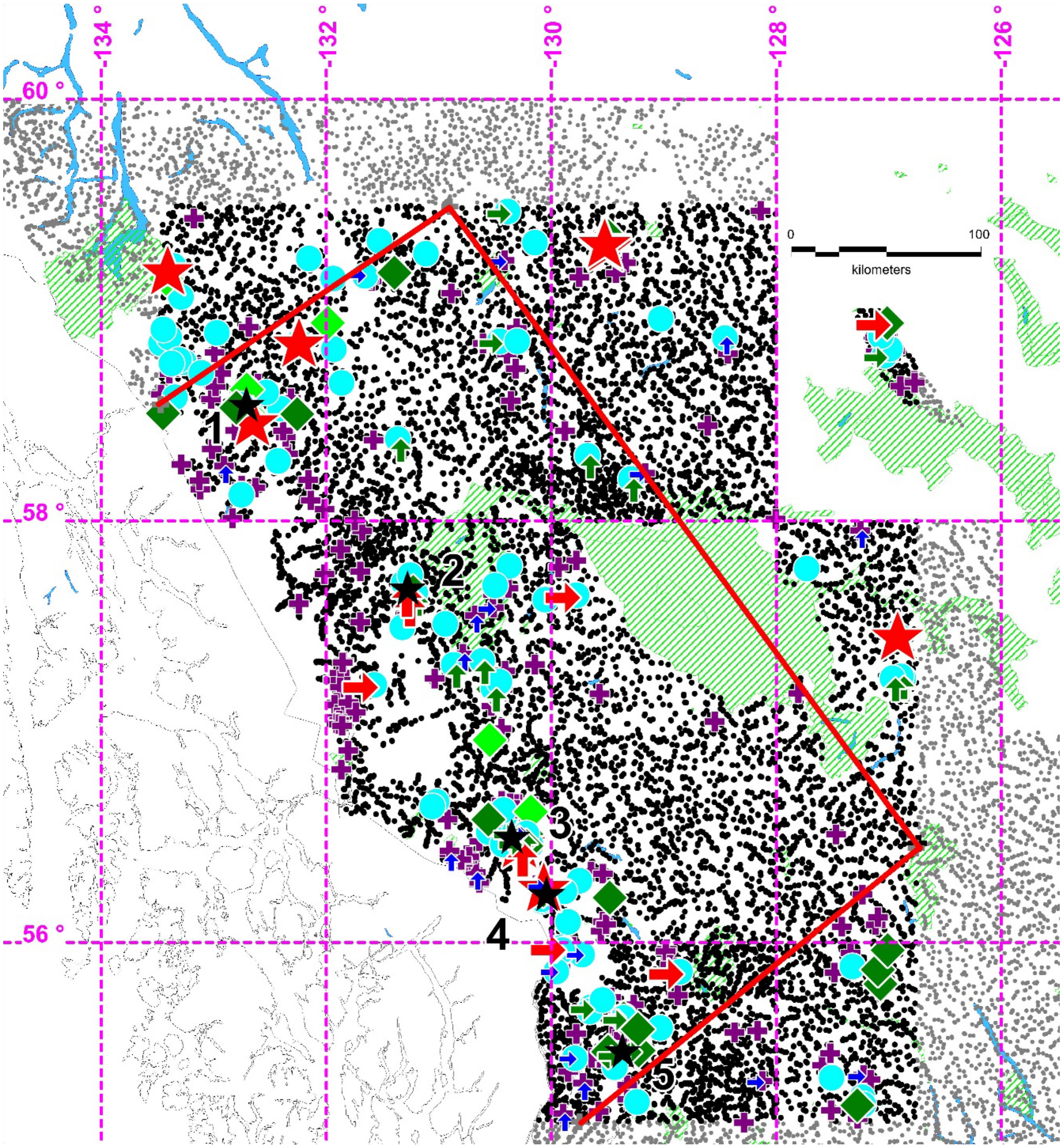
RDVM MAPS

RDVM maps follow in Figures 11 to 15. They provide focal points by identifying clusters of geochemical features commonly anomalous to geothermal sites.



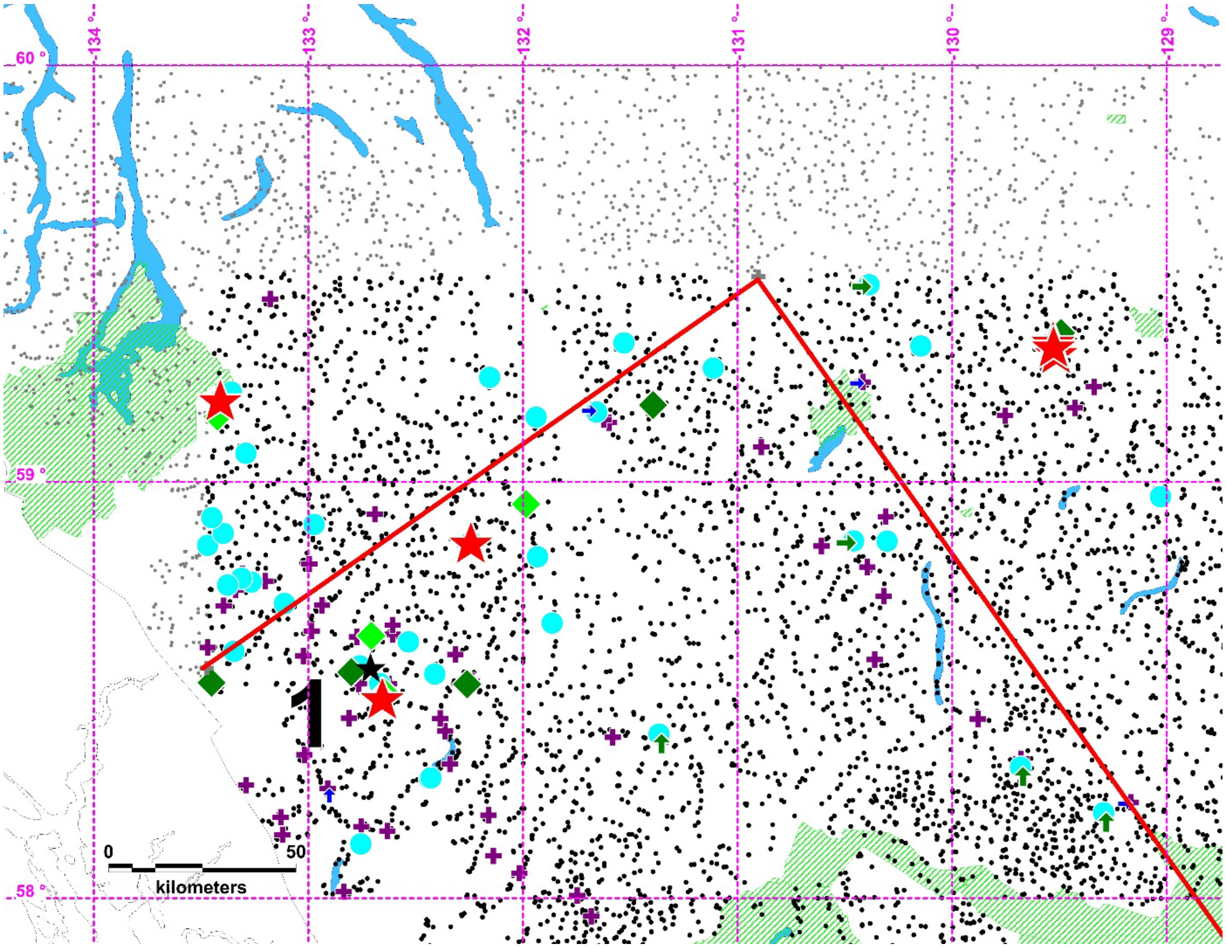
*Section 2.12 Figure 11: **RDVM** plot of **RD**Geot Values in project area.*

Black dots mark sample sites in project area. Values for **RD** of 5, 7, 9 and 11 are progressively bigger, where purple pluses = **RD**5, blue dots = **RD**7, green diamonds = **RD**9, and red stars = **RD**11. Project area outlined by grey lines. Green areas identify parks and regional geochemical silt data is sparse or absent.



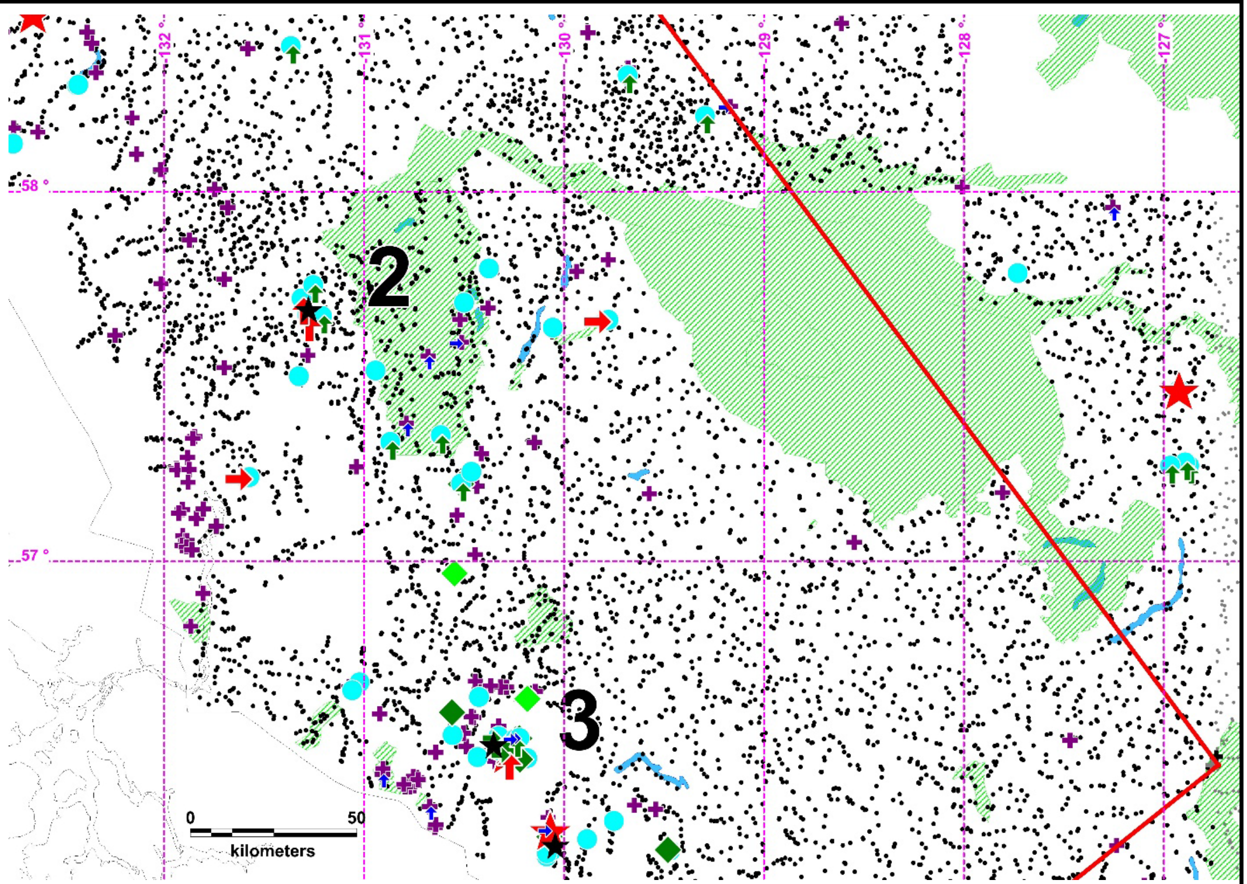
*Section 2.12 Figure 12: **RDVM** plot of **RD**Geot Values in project area with **R** Values added as arrows.*

Black dots mark sample sites in project area. Values for RD of 5, 7, 9 and 11 are progressively bigger, where purple pluses = RD5, blue dots = RD7, green diamonds = RD9, and red stars = RD11. Arrows are small = R7 and blue, medium = R9 and green, and large = R11 and red. Vertical down arrows = mercury = RHg. Horizontal-left pointing arrows = arsenic = RAs. Vertical up arrows = inverse pH = RInvPh. Horizontal right pointing arrows = selenium = RSe. Green areas identify parks and regional geochemical silt data is sparse or absent. Project area outlined by red lines. Notably anomalous areas are marked as black stars numbered 1 to 5 located at 1 = 58.5545,-132.7106, 2 = 57.6825,-131.2780, 3 = 56.5050,-130.3524, 4 = 56.2329,-130.0439, 5 = 55.4895,-129.3701.



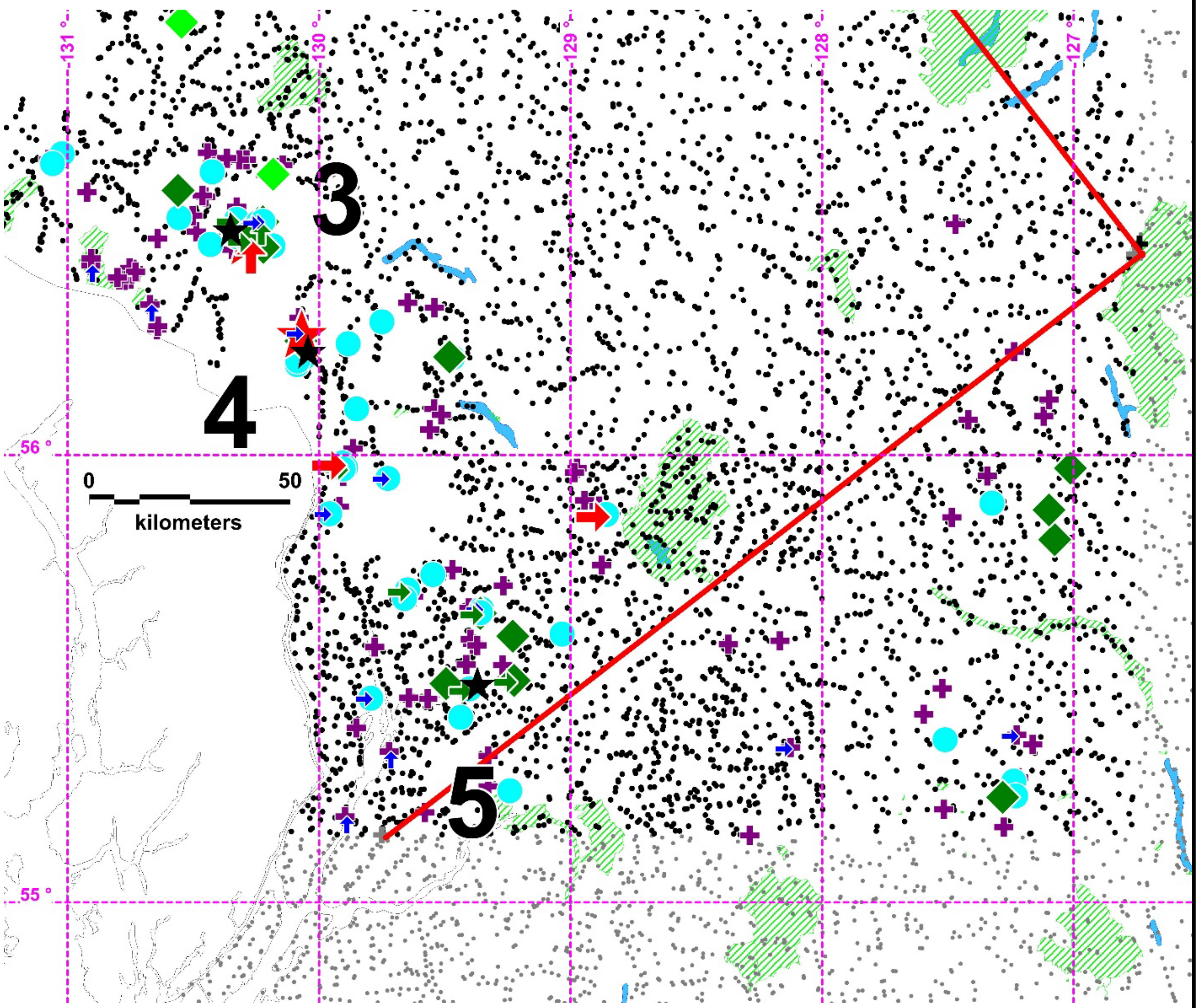
*Section 2.12 Figure 13: **RDVM** detail of northern part of project area*

Black dots mark sample sites in project area. Values for RD of 5, 7, 9 and 11 are progressively bigger, where purple pluses = RD5, blue dots = RD7, green diamonds = RD9, and red stars = RD11. Arrows are small = R7 and blue, medium = R9 and green, and large = R11 and red. Vertical down arrows = mercury = RHg. Horizontal-left pointing arrows = arsenic = RAs. Vertical up arrows = inverse pH = RInvPh. Horizontal right pointing arrows = selenium = RSe. Green areas identify parks and regional geochemical silt data is sparse or absent. Project area is outlined by red lines. A notably anomalous area is a black star numbered 1 at 58.5545,-132.7106.



*Section 2.12 Figure 14: **RDVM** detail of central part of project area.*

Black dots mark sample sites in project area. Values for RD of 5, 7, 9 and 11 are progressively bigger, where purple pluses = RD5, blue dots = RD7, green diamonds = RD9, and red stars = RD11. Arrows are small = R7 and blue, medium = R9 and green, and large = R11 and red. Vertical down arrows = mercury = RHg. Horizontal-left pointing arrows = arsenic = RAs. Vertical up arrows = inverse pH = RInvPh. Horizontal right pointing arrows = selenium = RSe. Green areas identify parks and regional geochemical silt data is sparse or absent. Project area is outlined by red lines. Notably anomalous areas are marked as black stars numbered 2 and 3 located at 2 = 57.6825,-131.2780, and 3 = 56.5050,-130.3524.



*Section 2.12 Figure 15: **RDVM** detail of southern part of project area.*

Black dots mark sample sites in project area. Values for RD of 5, 7, 9 and 11 are progressively bigger, where purple pluses = RD5, blue dots = RD7, green diamonds = RD9, and red stars = RD11. Arrows are small = R7 and blue, medium = R9 and green, and large = R11 and red. Vertical down arrows = mercury = RHg. Horizontal-left pointing arrows = arsenic = RAs. Vertical up arrows = inverse pH = RInvPh. Horizontal right pointing arrows = selenium = RSe. Green areas identify parks and regional geochemical silt data is sparse or absent. Project area is outlined by red lines. Additional notably anomalous areas are marked as black stars numbered 4 to 5 located at, 4 = 56.2329,-130.0439, 5 = 55.4895,-129.3701.

Conclusions:

Arsenic and mercury anomalies in the bubble and contoured plots of Figures 7 to 10 are concentrated on the southwestern boundary of the project area and are generally coincident. However, the mercury is somewhat divided into three clusters: northern, central and southern.

RDVM analysis in Figures 11 to 15 focuses more sharply on the significance of individual points. The figures map not only identify anomalies of R**D**Geot, but also anomalous **R** Values for mercury, arsenic, inverse pH, and selenium. Notably clusters of anomalous sites are marked as black stars in Figures 12 to 15. The stars are numbered 1 to 5 and located at 1 = 58.5545,-132.7106, 2 = 57.6825,-131.2780, 3 = 56.5050,-130.3524, 4 = 56.2329,-130.0439, 5 = 55.4895,-129.3701. A lot of individual sites are anomalous and might be significant, especially if the correlate with other geothermal related features such as rock type or faults.

Limitations of Datasets:

Be aware that the anomalous arsenic, mercury, selenium, inverse pH and **RD**Geot Values can also reflect mineral deposits. Anomalous areas can be additionally assessed with finding associations with known mineral deposit occurrences available from Minfile (https://minfile.gov.bc.ca/) from the British Columbia Ministry of Mining and Critical Minerals.

Data Gaps:

- Regional geochemical silt data is sparse or absent in parks that are mapped as green areas in Figures 1 to 15.
- The geochemical data set is a regional one. Consequently, denser sample sites would enhance evaluation.

Recommendations for Additional Work

Data in the project area are limited and do not provide sufficient information to base any conclusions as to the presence of present day (i.e. active) hydrothermal systems. It is possible that access to additional analyses may be available through partnership with private sector exploration and mining companies currently working in the area or have worked in the area in the past. See Section 2.17 for additional information on mineral exploration taking place in the project area.

Regional geochemical surveys are another government supported data set that provides significant information for exploration for a variety of different resources. As used here, Mercury and Arsenic were evaluated as potential indicators of present day (i.e. active) hydrothermal activity. In the project area, analyses combined with other relevant data related to potentially important geothermal anomalies, additional data might be important. Some questions remain in order to better understand the significance of the RGS finding:

- Does additional geochemical data exist in detailed government or mineral deposit reports (e.g., Minfile and assessment reports by mining companies) that might provide greater insight into the relevance and/or significance of the findings relative to geothermal systems?
- Should specific geological units be identified as significant, should they be evaluated statistically separately? (This work suggests that given adequate sample density, for geochemical significant features—**RDVM** can help.)
- Does this preliminary analysis provide enough evidence to justify the need for additional field geochemical sampling and/or geological mapping?

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2.13 Curie Point Depth

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Section 2.13 Figure 1: Curie Point Depth Map 162

Overview

Curie Point Depth (CPD) mapping is a method, originally developed in the 1970s, which uses regional-scale magnetic survey data to map the depth to the Curie point temperature (~580 °C) where magnetization in rocks disappears (i.e. the depth to the inferred Curie point transition of magnetite) (Okubo et al., 1985). Regions found to have shallow CPD values are expected to have higher heat flow, higher average thermal gradient, and therefore, a higher likelihood of geothermal energy resources that are accessible via drilling. CPD has not been used in geothermal exploration, as the dataset is too coarse grained and lacks the spatial resolution necessary for prospect scale level analysis. However, it has shown value in helping define the underlying geological framework of regions. Three different CPD studies have been undertaken in the project area and they are reviewed here (see Figure 1). The results show that the Bowser Basin can be differentiated from the rest of the project area based on CPD analysis, consistent with the magnetitic and gravity data.

Dataset created by:

Jeff Witter

Dataset Source:

(Li et al., 2017)

Data Format:

Gridded data

Project use case:

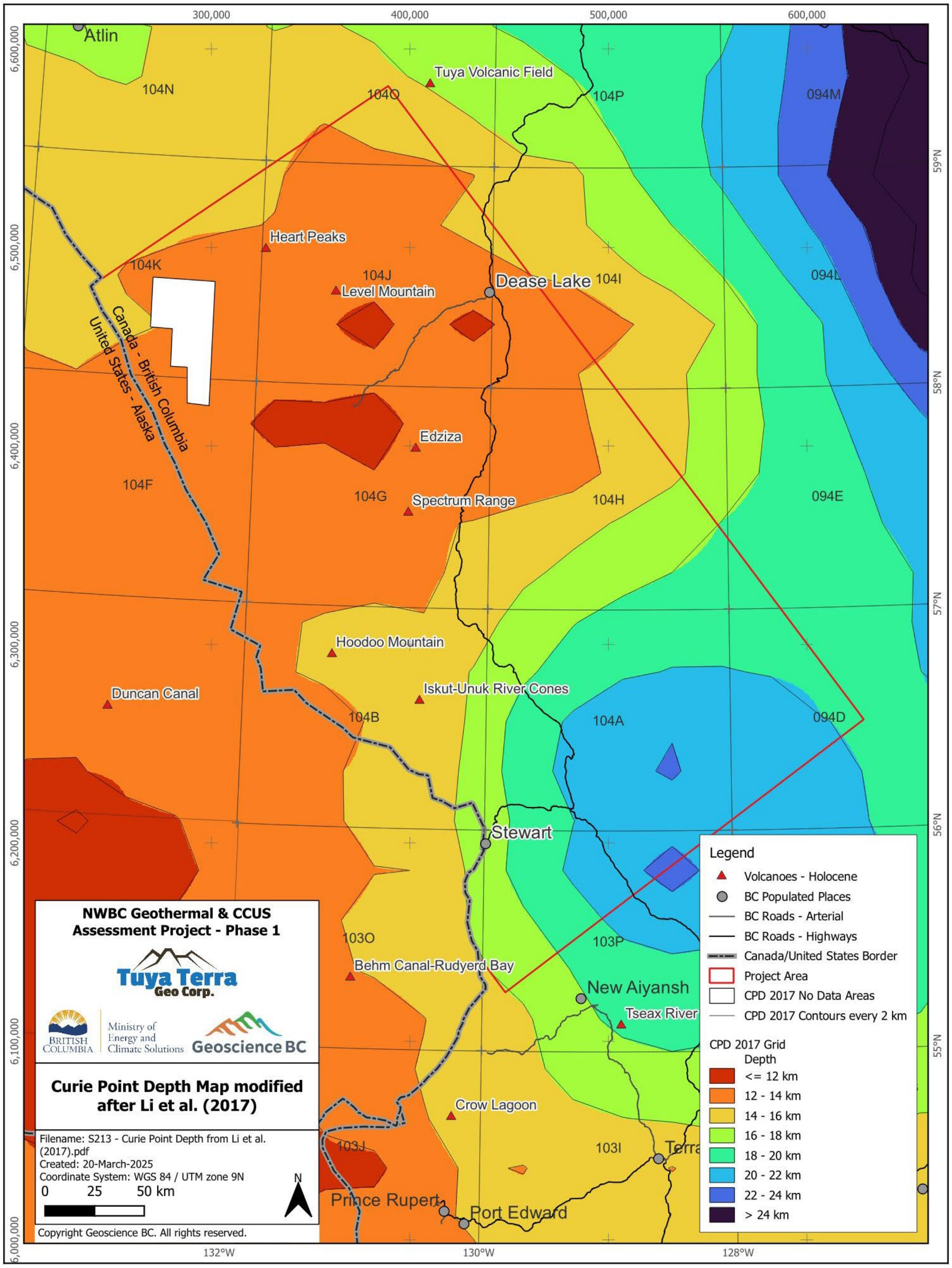
(Witter and Miller, 2016) used the simpler CPD calculation methodology of Tanaka et al. (1999) in a CPD pilot study covering 300 km x 300 km in northwestern British Columbia along the Yukon border. The method of Tanaka et al. (1999) requires the use of large windows of magnetic data (e.g. 100 km x 100 km) which severely limits the spatial resolution of the results. The outcome of the (Witter and Miller, 2016) study gave qualitatively accurate, relative CPD estimates. However, the absolute CPD estimates given (Witter and Miller, 2016) are likely too deep based upon comparison with other datasets. Specifically, (Witter and Miller, 2016) found a CPD of 23-24 km under the Holocene volcanoes within the project area, which translates into an average crustal temperature gradient of 24 – 25 °C per km depth, likely an underestimation of the true geothermal gradient of the area (See Section 2.2).

Gaudreau et al. (2019) used a more advanced wavelet based CPD calculation methodology to avoid the issue of large window sizes in a study that covered most of the Canadian cordillera. Unfortunately, the CPD results of Gaudreau et al. (2019) are clearly erroneous in the eastern half of the project area considered here where they return CPD estimates of ~0 km depth. In contrast, in the western half of the project area, the CPD results from Gaudreau appear more reasonable. For example, near the Holocene volcanoes (Gaudreau et al., 2019) calculated CPD values of 9-18 km, which translates into an average crustal temperature gradient of 32-64 °C per km.

(Li et al., 2017) used the CPD calculation methodology of (Bouligand et al., 2009) to map CPD for the entire planet using a global magnetic dataset. Of the three methods, it is likely that the results of (Li et al., 2017) give the most reliable CPD estimates for the project area. The results of (Li et al., 2017) clearly show shallower CPD under the Holocene volcanoes with in the project area and deeper CPD under Bowser Basin as expected. Beneath the Holocene volcanoes the estimated CPD values are 12-14 km based upon (Li et al., 2017), gives an average crustal temperature gradient of 41-48 deg °C per km.

Data distribution:

The Curie Point Depth map generated from the data of (Li et al., 2017) covers the vast majority of the project area.



Section 2.13 Figure 1: Curie Point Depth Map

Limitations of Datasets:

Curie Point Depth mapping yields a very rough estimate of regional variations in the Earth's crust at a very coarse spatial resolution (i.e. 25-50 km). Limitations of the technique include variable quality input data (i.e. aeromagnetic survey data) and key calculation parameters that remain inadequately defined (e.g. the fractal magnetization of the crust).

Data Gaps:

A 60 km x 30 km area in the NW corner of the project area is lacking Curie Point Depth estimates due to a lack of input data (i.e. aeromagnetic survey data) in that area.

Recommendations for Additional Work

Curie Point depth mapping was considered a fast way to assess large regions of the globe for areas that are hotter than surrounding regions. Although it has been useful to augment other data, the information is too coarse to be of much value, but it did differentiate the Bower Basin as having a lower Curie point than the rest of the region. No additional work is recommended.

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2.14 Satellite Imagery

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Section 2.14 Figure 1: Landsat Topography Map 166

Overview

Though not included in the favourability assessment for this project, a base level of understanding of the surface topography was developed to inform future work recommendations related to prospect-level analysis.

Dataset Created by:

Marc Colombina

Dataset Source:

NASA Landsat satellite imagery accessed through USGS Earth Explorer (https://earthexplorer.usgs.gov/)

Data Format:

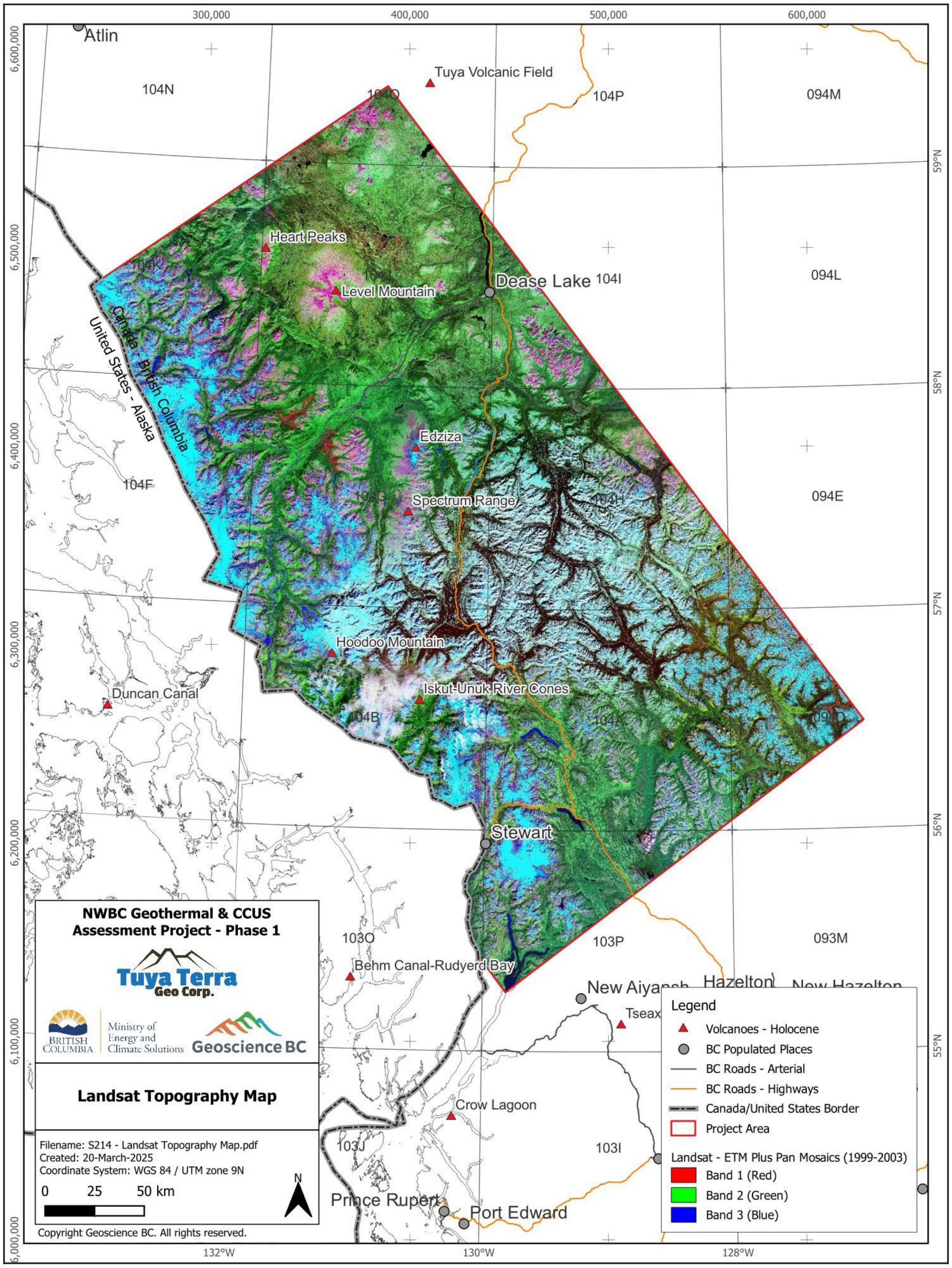
Satellite imagery

Project use case:

The use of high-resolution satellite imagery offers the potential for cost-effective site mapping of areas of interest for targeted geothermal exploration. These images can also complement geophysical/geochemical techniques applied for more detailed and focused geothermal exploration.

Data distribution:

Satellite images were generated for the entirety of the project area.



Section 2.14 Figure 1: Landsat Topography Map

Limitations of Datasets:

This data set utilized regional scale, lower resolution data from publicly available datasets. High-resolution data was not purchased. As well, the images were not taken during a targeted exploration/imaging project and therefore, a composite was made over a longer time-frame than would be useful to assess the status of a specific site at one time.

Recommendations for Additional Work

The only satellite imagery used was Landsat, and these data did not factor into the weighting analysis. This data set is free for downloading, and although Landsat data is not optimal for geothermal exploration or resource confirmation, it did provide some quality imagery. High resolution imagery can be purchased from various services such as Apollo Mapping's Pléiades Neo satellite for $22.50/sq km or $1,876,815 for the total project area of 83,414 sq km. Purchase of imagery was outside the budget of the project and would not have been an effective tool over so large an area. If a smaller focused area is chosen for future investigation, purchase of imagery may assist exploration planning.

2.15 Bowser Basin Sedimentary Stratigraphy

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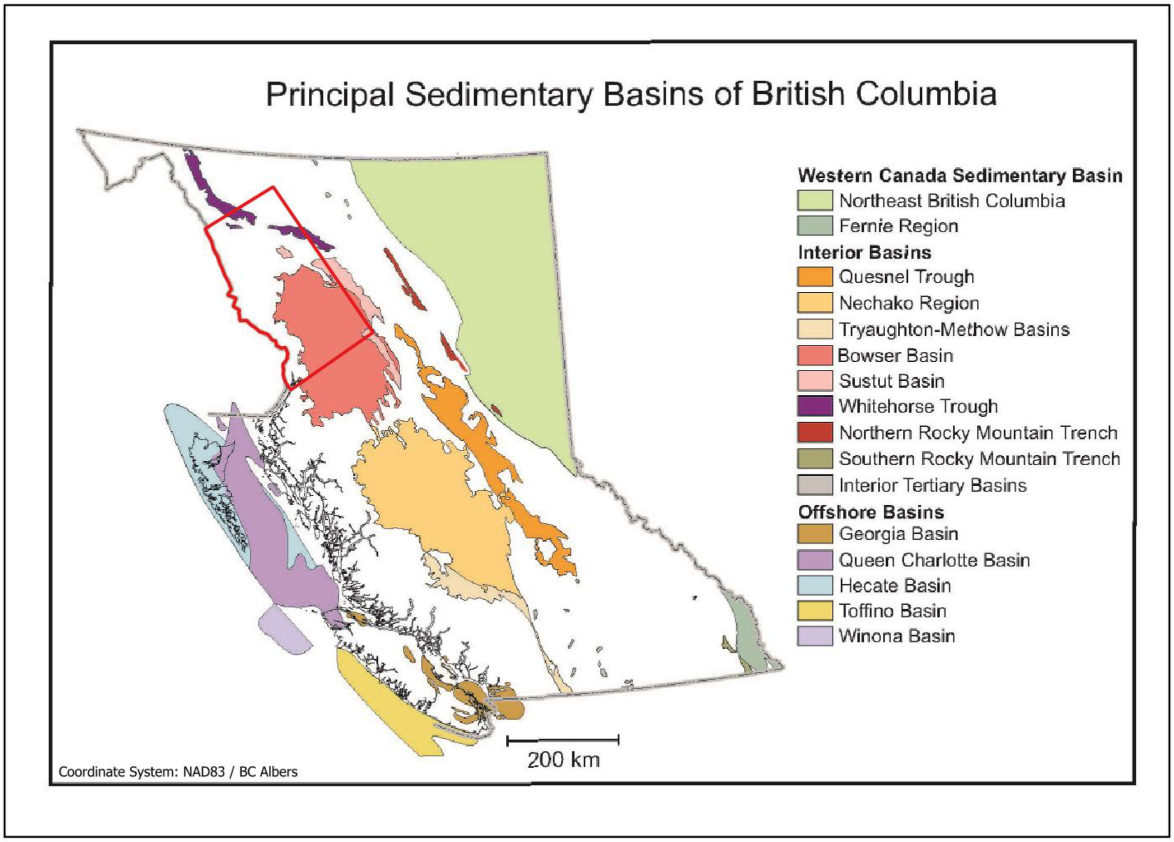
Section 2.15 Figure 1: Project area overlain on the principal sedimentary basins of British Columbia map. https://www2.gov.bc.ca/assets/gov/farming-natural-resources-and-industry/natural-gas-oil/petroleum-geoscience/princ_sedimentary_basins_map.pdf (accessed March 20, 2025) 170
Section 2.15 Figure 2: Bowser sedimentary basin stratigraphy map 172

Overview

The Bowser Basin and its near neighbour, the Sustut Basin (Figure 1) covers an area of over 65,000 square kilometers. The bedrock foundations of the basin consist of the Triassic-Jurassic Hazelton volcanic assemblage (Ricketts, 2008). The basin is uplifted in the north by the Stikine Arch and in the south by the Skeena Arch and is mostly a package of middle Jurassic to Early Cretaceous clastic rocks that may have had an original paleo-thickness in excess of 5,000 metres. The Bowser Lake Group is by far the most widespread succession in the basin. It ranges in age from late Middle Jurassic to mid-Cretaceous and includes strata deposited in environments ranging from distal submarine fan, to deltaic, to fluvial, and lacustrine (Evenchick et al., 2002). It was deposited directly on volcanic arc strata of Stikinia, and clasts were derived primarily from the oceanic Cache Creek terrane to the east, as a result of closure of the Cache Creek ocean and accretion of Stikinia to North America in the Middle Jurassic. Identification of Stikinia sources and recognition of possible reservoirs in the Hazelton Group indicates that strata below the Bowser Lake Group might also be prospective for petroleum accumulation (Evenchick et al., 2003).

The northern and eastern margins of the basin are overlain unconformably by the Cretaceous Sustut Basin. These clastics sediments of the Late Cretaceous represent of foreland basin at least 2,000 metres thick and were deposited along the eastern margins of the Bowser Basin (Evenchick and Thorkelson, 2005).

Only two deep oil and gas exploration boreholes have been drilled into the Bowser Basin, reaching depths of 2 to 3 km, and both were located near each other in the southeastern part of the project area (Ritchie wells). In 2004, three additional boreholes were drilled to less than 1 km depth. While no hydrocarbons were encountered, these five boreholes penetrated several thousand meters of Bowser Lake Group sediments, which included multiple sections of coarse clastics.



Section 2.15 Figure 1: Project area overlain on the principal sedimentary basins of British Columbia map. https://www2.gov.bc.ca/assets/gov/farming-natural-resources-and-industry/natural-gas-oil/petroleum-geoscience/princ_sedimentary_basins_map.pdf (accessed March 20, 2025)

Dataset created by:

Félix-Antoine Comeau

Dataset Source:

British Columbia Geological Survey's MapPlace 2;

Geological Survey of British Columbia https://www2.gov.bc.ca/gov/content/industry/mineral-exploration-mining/british-columbia-geological-survey/geology/bcdigitalgeology (Cui et al., 2017)

Built from the compilation of maps of: (Heung et al., 2022)

British Columbia Energy Regulator (BCER) – GIS Open Data Portal

Data Format:

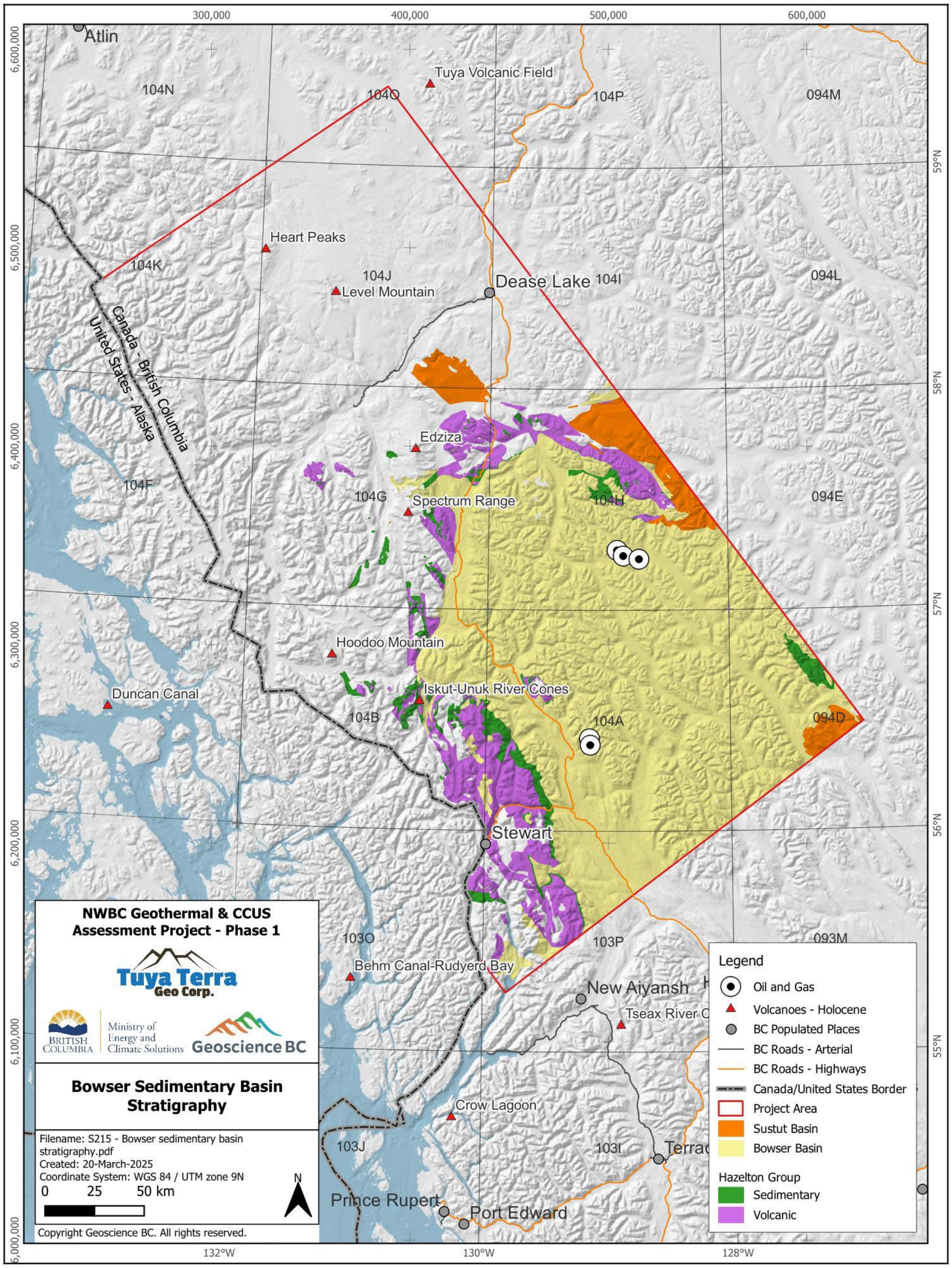
Polygon and point GeoPackages

Project use case:

Surface units help delineate sedimentary rock formations, highlighting areas where permeable reservoirs are likely to be present at depth.

Data distribution:

The project area contains only the northern half of the Bowser Basin. The following map illustrates the Bowser Basin and its foreland basin, the Sustut Basin, displaying the sedimentary and volcanic units of the underlying Hazelton Group, upon which the Bowser Basin was deposited. The map also indicates the locations of the five oil and gas exploration boreholes drilled in the region. The base map is derived from GEBCO's global terrain model.



Section 2.15 Figure 2: Bowser sedimentary basin stratigraphy map

Limitations of Datasets:

Enables identification of the basin's surface extent but does not provide insights into its subsurface structure or depth variations.

Data Gaps:

There is very little deep drilling into the sedimentary basin, and the gravity and magnetitic studies are useful, but not conclusive. Understanding the extension and thickness of the stratigraphic units at depth, would significantly improve the identification of favourable sectors for both geothermal energy and carbon (CO_2) storage in subsurface storage in saline aquifers.

Recommendations for Additional Work

Limited information exists for the deep subsurface of the Bower Basin. Drilling exploratory stratigraphic boreholes would provide valuable insight into the vertical distribution and lateral continuity of geological units at depth, allowing for a more precise characterization of subsurface layers. This would not only improve our understanding of the stratigraphic framework but also enable more accurate assessments of key parameters such as porosity, lithology, and mineral composition. However, being a relatively fragmented and deformed basin filled with marine to terrestrial sediments, the lateral continuity of units is likely to be low even across closely-spaced boreholes. This could be tested by examining the correlatability of petrophysically-defined sequences across boreholes. This deeper understanding is critical for optimizing the placement and efficiency of deep geothermal systems within sedimentary basins, where the permeability and thermal conductivity of rocks are key factors influencing heat extraction efficiency and long-term sustainability.

References

Evenchick, C.A., Ferri, F., Mustard, P.S., McMechan, M., Osadetz, K.G., Stasiuk, L., Wilson, N.S.F., Enkin, R.J., Hadlari, T., McNicoll, V.J., 2003. Recent results and activities of the Integrated Petroleum Resource Potential and Geoscience Studies of the Bowser and Sustut Basins Project, British Columbia (No. Current research 20032003-A13). Natural Resources Canada, Ontario - Canada.

Evenchick, C.A., Hayes, M.C., Buddell, K.A., Osadetz, K.G., 2002. Vitrinite and bitumen reflectance data and preliminary organic maturity model for the northern two thirds of the Bowser and Sustut basins, north-central British Columbia (No. 4343). https://doi.org/10.4095/213538

Evenchick, C.A., Thorkelson, D.J., 2005. Geology of the Spatsizi River map area, north-central British Columbia (No. Bulletin 577). Geological Survey of Canada.

Ricketts, B.D., 2008. Chapter 10 Cordilleran Sedimentary Basins of Western Canada Record 180 Million Years of Terrane Accretion, in: Sedimentary Basins of the World. Elsevier, pp. 363–394. https://doi.org/10.1016/S1874-5997(08)00010-5

2.16 Existing Borehole Data

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Section 2.16 Figure 1: Existing Borehole Location Map superimposed on the Hazelton Group Geology. Other geological units have been excluded for clarity. 177

Overview

Existing boreholes, along with associated geological, geophysical, and thermal data, provide critical insights for geothermal exploration. "Boreholes" are holes drilled in the ground for the purpose of exploration, sampling, or to access underground resources. Data from boreholes help assess subsurface conditions, including rock permeability, temperature gradients, and fluid flow potential, guiding site selection and resource evaluation.

Only two deep oil and gas exploration boreholes ("Ritchie wells") have been drilled into the Bowser Basin, reaching depths of 2 to 3 km, and both were located near each other in the southeast part of the project area. In 2004, three additional boreholes were drilled in the northwestern part of the basin, but to less than 1 km depth.

	Year	Depth (m)
Ritchie A	1969	2 113
Ritchie C	1972	2 957
Summit D	2004	311
Ridge A	2004	901
Hobbit C	2004	850

Additionally, 13 boreholes in the project area are listed in the International Heat Flow Commission database, containing sufficient data on temperature, thermal conductivity and heat production of geological units. It should be noted that the Ritchie A well is included in this list and is therefore both an oil and gas and heat flow borehole.

Although some water well data is available for the area, analysis of these data was beyond the scope of this study. Most of the water well data are from mineral exploration and mining development activities and provide an opportunity for future follow-up.

Dataset created by:

Félix-Antoine Comeau

Dataset Source:

British Columbia Geological Survey's MapPlace 2;

Geological Survey of British Columbia https://www2.gov.bc.ca/gov/content/industry/mineral-exploration-mining/british-columbia-geological-survey/geology/bcdigitalgeology (Cui et al., 2017)

Built from the compilation of maps of: (Heung et al., 2022)

British Columbia Energy Regulator (BCER) – GIS Open Data Portal

The International Heat Flow Commission Database

Data Format:

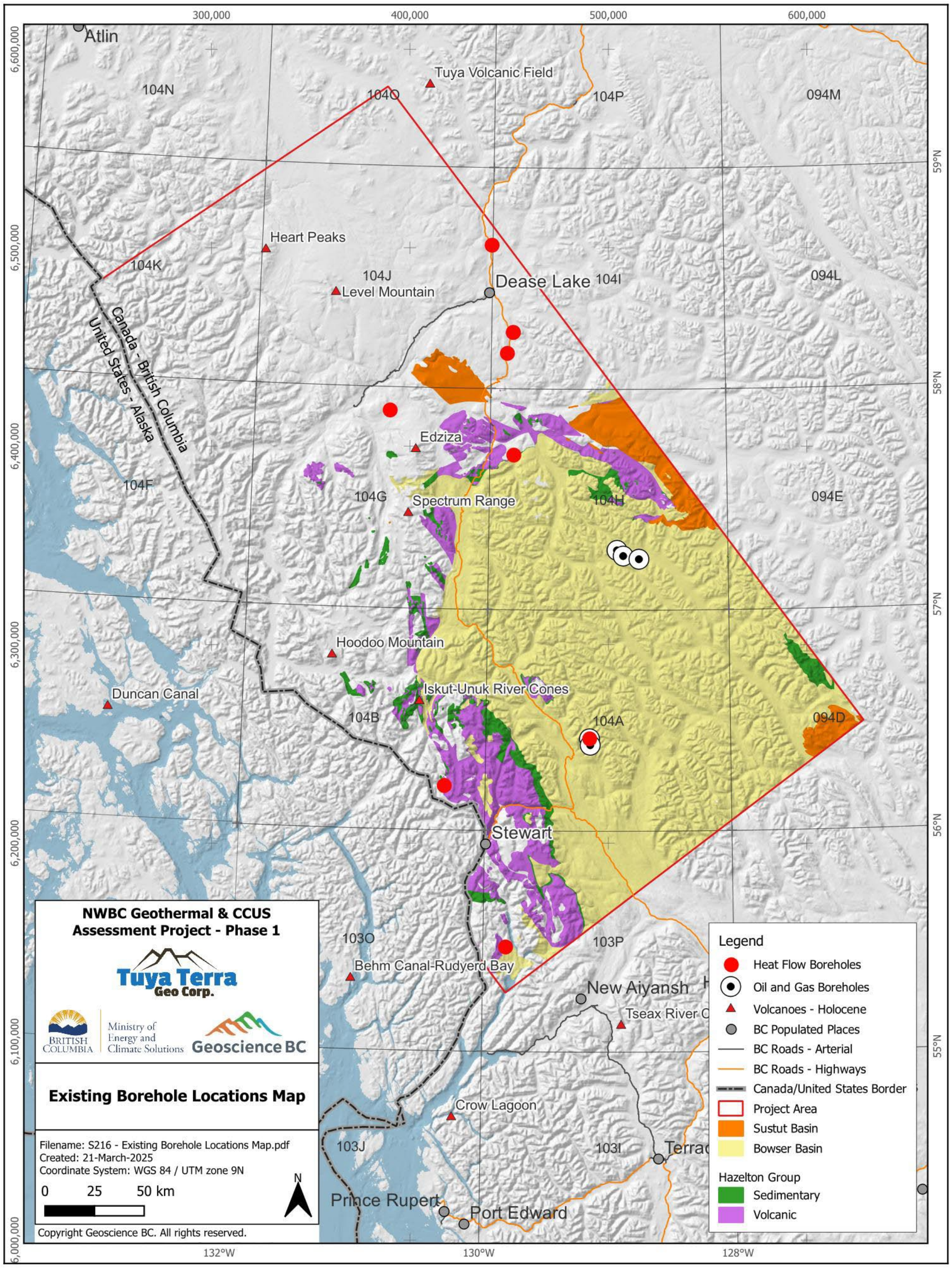
Point GeoPackages

Project use case:

The thirteen boreholes used for collection of heat flow data, provide a sparse regional assessment of heat flow (See Section 2.2). These boreholes were not logged for physical rock properties.

Data distribution:

The following map illustrates the locations of the five oil and gas boreholes and thirteen boreholes used to estimate heat flow. It highlights the Bowser Basin and its foreland, the Sustut Basin, while also displaying the sedimentary and volcanic units of the surrounding and potentially underlying Hazelton Group, which likely served as the foundation for the Bowser Basin's deposition.



Section 2.16 Figure 1: Existing Borehole Location Map superimposed on the Hazelton Group Geology. Other geological units have been excluded for clarity.

Limitations of Datasets:

Only five oil and gas boreholes have been drilled in the area, including two Ritchie wells in the west central area of the basin that exceed 2 km in depth. These boreholes were drilled in close proximity to each other. The three other wells in the north area of the basin are less than 1 km deep. These boreholes are the primary source of information necessary for identifying permeable reservoirs suitable for conventional geothermal systems and deep saline aquifers for carbon capture, utilization, and storage (CCUS).

Data Gaps:

There was insufficient time to incorporate all the information included in the reports from the drilled boreholes. These boreholes do provide information on rock mechanics and physical rock properties, however, their distribution, depth and number provided only limited regional information on the subsurface conditions.

Recommendations for Additional Work

Subsurface information relevant to geothermal and carbon (CO_2) storage is lacking in the area due to the paucity of boreholes and the original purpose for drilling the boreholes that do exist. As a first step to advancing understanding of the region for geothermal exploration, additional temperature gradient boreholes should be drilled. A low-cost option may be to partner with mineral exploration companies that could have boreholes of opportunity that could be used for gradient measurements. However, mineral exploration in the Bowser Basin is limited (see Section 2.17). Following the gathering of additional information from these boreholes, targeted geophysics could be carried out in order to further reduce the area of interest for additional studies. Larger diameter boreholes should target areas with promising geological and geothermal characteristics, as identified through existing data, new temperature gradient boreholes and additional geophysics (see Section 1.2). A comprehensive exploration program will not only improve resource characterization but also facilitate the on-going assessment of sustainable geothermal energy solutions.

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Section 2.17 Figure 1: Mineral exploration in project area by year. The report year is indicated by colour and the source of the data is indicated by shape. Holocene volcanoes are labelled as geographic reference points 186

Section 2.17 Figure 2: Mineral exploration in project area. Prospect status indicated by colour, and data source indicated by shape. MINFILE producers and past producers represented by stars to highlight their significance. Current producers labelled with produced commodities 187

Section 2.17 Figure 3: Mineral exploration in project area by amount spent on the project. The source of the data is indicated by colour. The size of the point indicates the reported cost of the project (ranges in legend; equal interval distribution). 188

Overview

The general scope of work for this Section was to provide mineral exploration geological data compilation and cursory geological data evaluation to support the project analysis. The intention of this work was to determine if there were any easily accessible datasets that could augment the publicly available ones and to establish contact with field operations that might provide collaborative support for Phase II and III activities.

The work specifically included:

1) a review of British Columbia Geological Survey ("BCGS") mineral (and possibly, coal) technical Assessment Reports, specifically reviewing the usability of the following datasets for assessing geothermal favourability:
    a. MINFILE dataset
    b. ARIS dataset
    c. COALFILE dataset
2) connecting with individuals that are working with currently active mining and mineral exploration companies that are at an advanced project development on their mining projects. The purpose of this industry engagement is to evaluate if there is opportunity of knowledge sharing between the mineral and geothermal exploration industries.
    a. a total of 15[1] companies were identified at the time in late 2024 and early 2025, based on:
        i. actively producing operators with published reserves and/or measured mineral resource estimates
        ii. the most advanced mineral exploration and development project with a minimum of indicated mineral resource estimates
        iii. other companies that did not necessarily have indicated or measured mineral resource estimates, but were actively exploring in the region during 2024 – 2025
3) providing input on the usefulness of the above datasets for geothermal favourability assessment(s) and recommendations for future phases.
4) supporting the development of a draft and final Chapter 18 (this Chapter) for the Project.

The BCGS is a department within the British Columbia Ministry of Mining and Critical Minerals ("MoM", or some other name variation as governments change). The purpose of the BCGS is to provide *"accessible geoscience expertise, evolving knowledge, new technology and comprehensive public geoscience data to benefit land use planning and governance, societal development, low carbon innovation, economic opportunity, education services and Indigenous reconciliation in British Columbia".* To provide these

[1] During January 2025, projects actively being explored and developed are identified as follows: American Creen Resources Ltd. (Treaty Creek project), Ascot Resources Ltd. (Premier and Red Mountain proposed mine projects), Centerra Gold Corp., Coast Copper Corp., Dolly Varden Silver Corp. (Kitsault project), Galore Creek Mining Corp. (subsidiary of Teck Resources Inc.; Galore Creek proposed mine project), Goliath Resources Ltd., Imperial Metals Corp., Kingfisher Metals Inc., Newmont Mining Ltd., Seabridge Gold Inc. (KSM proposed mine project), Scottie Resources Corp. (Scottie Gold Mine project), Skeena Resources Inc. (SNIP and Eskay Creek projects), Tudor Gold Corp. (Treaty Creek project), Teuton Resources Corp. (Treaty Creek project), Eskay Mining Corp. (Eskay Creek and Corey projects)

services, the BCGS generates and publishes geoscience studies to support effective mineral exploration, responsible land use management, reliable governance, revenue generation and diverse investment opportunities for the province.

As part of the mandate by the BCGS, it regularly reviews, maintains and updates, on a minimum monthly basis, collections of reports to keep claims (mineral and coal tenure) in good standing. These include mineral technical Assessment Reports ("ARIS" and "MINFILE") and coal ("COALFILE") technical Assessment Reports ("ARs") which are submitted under the terms of the Mineral Tenure Act, the Coal Act, and the Regulations under these Acts.

The Mineral Title Branch administers the legislation governing the acquisition, exploration and development of mineral, coal (and placer) rights in British Columbia. The Branch maintains the coal and mineral titles registries under the Mineral Tenure Act, Coal Act, and regulations under these Acts.

The list of currently active mining and mineral exploration companies changes as claims are picked up and dropped by various individuals, private, or public companies.

After the recent provincial election in fall 2024, on January 22, 2025, the British Columbia Ministry of Mining, announced that the Mineral Tenure Act Modernization Office ("MTAMO") will be implementing a new Mineral Claims Consultation Framework ("MCCF"). These changes are occurring at the time of this project and may or may not result in changes in how the following datasets are organized and published.

Dataset Created by:

Yuliana Proenza, Senior Geologist, APEX Geoscience Ltd.

Rachel Webb, Junior Geologist, APEX Geoscience Ltd.

Dataset Sources:

The BCGS datasets (primarily, MINFILE, COALFILE and ARIS) and various resources (such as digital data downloads, reports, publications) mentioned in this chapter are publicly updated on a continuous (at minimum, monthly) basis.

Online data download links, and source locations of these datasets may also move and not work during future attempts. The datasets and resources are maintained by the BCGS. The public availability of the referenced source data in this Chapter is administered by the BCGS. The project team that is releasing this Report is not responsible for the validity and the accuracy of the BCGS datasets that are referenced and summarized in this report.

As changes occur, the datasets may be re-located to another working location, as administered by BCGS. The responsibility for updating and using the most recent BCGS datasets and resources is wholly placed on the future data user(s).

Below, a summary is provided for the data source, data format, context and project use case, and comments of the overall data distribution and usability of the ARIS, MINFILE and COALFILE datasets. The discussion of these datasets is presented in the context of evaluating geothermal favourability in the project area.

All COALFILE, MINFILE, and ARIS data were sourced from various British Columbia Geological Survey databases or spatial file download links, through the Government of British Columbia website:

British Columbia Geological Survey website link:

https://www2.gov.bc.ca/gov/content/industry/mineral-exploration-mining/british-columbia-geological-survey (last updated August 19, 2024) [accessed February 2025]

ARIS: “**A**”ssessment “**R**”eport “**I**”ndexing “**S**”ystem

British Columbia Geological Survey Assessment Reports Summary website link:

https://www2.gov.bc.ca/gov/content/industry/mineral-exploration-mining/british-columbia-geological-survey/assessmentreports (last updated March 18, 2024)

British Columbia Geological Survey Assessment Report **ARIS** Database website link:

https://apps.nrs.gov.bc.ca/pub/aris

As of February 26, 2025, ARIS contains 40,771 approved reports.

Of these, a total of 3,598 approved Assessment Reports are within the project area and presented below in Figures 1 to 3.

Of the 3,598 approved Assessment Reports within the project area, the types of geological work name are recorded and tabulated as follows (under the column “gwrk nm”):

Drilling	76 (Drilling only) 610 (Drilling and other)
Drilling, Geochemical	220
Prospecting	

The way the type of work is categorized is currently within one column. It may be useful to decategorize this column and have 5 separate work columns for each work type that are either listed as “YES” or “NO” if completed that year. That way it is easier to present each type of work in a map figure. At this point, these figures were not completed. This would further allow to refine which reports would be most valuable to focus on.

British Columbia Data Catalogue download link location:

https://catalogue.data.gov.bc.ca/dataset/af68d1d1-b85e-4ea9-b5f3-e09fc83f3f4f

British Columbia Geological Survey download link location:

https://www2.gov.bc.ca/assets/gov/farming-natural-resources-and-industry/mineral-exploration-mining/bc-geological-survey/assessment-reports/aris/aris_db_shp_export.zip

The Assessment Report Indexing System, or ARIS, is the collection of technical assessment reports and data from mineral exploration and development properties across British Columbia. Filed by the British Columbia mining and mineral exploration industries since 1947, assessment reports are filed by the operator, and document geological, geophysical, geochemical, drilling, and other exploration-related activities. Assessment reports are submitted by the claim tenure holders or operators and once approved, reports are kept confidential for one-year from the date that the exploration and development work was registered. Assessment reports are made publicly available as part of the ARIS on a monthly basis, once they go “off-confidential”.

MINFILE: MINFILE is a shorthand abbreviation for a dataset that represents 3 different types of databases:

1) Mineral Occurrence database
2) Mineral Inventory database
3) Mineral Production database

The MINFILE databases are used by government, industry and academia for resource management, land-use planning, exploration and research. MINFILE contains metallic, industrial and coal occurrences for British Columbia.

These databases may be useful when categorizing the Assessment Reports from ARIS, as it allows the data user to review reports specifically associated with a particular deposit or prospect type (that is identified by a unique MINFILE ID number).

It is also possible to tabulate how much mineral inventory has been estimated for a particular deposit style (ie. Epithermal, or porphyry). These estimates may be historic in nature or may be in more recent NI 43-101 format resource estimation reporting format.

MINFILE contains geological, location and economic information on metallic, industrial mineral and coal occurrences in British Columbia. The MINFILE mineral occurrence database depicts bodies of rock containing, or thought to contain, ore minerals or potential ore minerals. The point location of the spatial GPS coordinates in the database depicts the most significant physical reference point to mineralization. MINFILE is updated regularly (daily) and can be downloaded as a .csv or .xlsx file from the BCGS website.

MINFILE download link location:

https://minfile.gov.bc.ca/publish/minfilepc.zip

COALFILE: COALFILE is shorthand abbreviation for a dataset that provides additional work type information, such as borehole, bulk sample and trench locations associated with specific assessment reports. Some reports are missing and are not captured digitally, represent a data gap uncertainty.

COALFILE is the collection of assessment reports and data from coal exploration and development properties across British Columbia. The information contained in COALFILE is stored as a relational database (Microsoft Access) and includes spatial information for boreholes, bulk samples, and trenches. COALFILE is available for download from the BCGS database in shapefile (.shp and associated files) or database (.mdb) format.

COALFILE download link location:

https://www2.gov.bc.ca/assets/gov/farming-natural-resources-and-industry/mineral-exploration-mining/bc-geological-survey/assessment-reports/coalfile/coalfile_db_shp_export.zip

Data Format:

The ARIS, MINFILE and COALFILE datasets are available in CSV, MDB, and SHP data formats.

If there is digital data submitted along with the technical assessment reports, examples of the associated geological digital data associated with the technical assessment reports are:

General Digital Data Types

Data Type	Work or Survey Type	Data File Examples
Airborne Geophysics	Magnetic, Electromagnetic, Versatile Time Domain Electromagnetic, Radiometric Surveys	.dat .grd .gi .map .gdb .kml .kmz .xyz .jpg .pdf .png .dxf .msh .sus .ers .bdx .bin (some files quite large in size)
Ground Geophysics	Induced Polarization, Magnetic, 3-Dimensional Induced Polarization, Very Low Frequency Electromagnetic Surveys	.txt .gdb .csv .arw .srf .xyz .tif .tfw .vtx .pvs .con .res .chg .pre .out .inp .inv .egh .ehf .gdd .gi .png .xml .shapefiles
Geochemistry	Assay certificates, geochemical compilations, metallurgical results	.xls .xlsx .csv .accdb
Drilling	Core logs, geotechnical/RQD logs, selected analytical results, collar locations, drill hole parameters, downhole surveys	.xls .xlsx .accdb
Imagery	Orthophotos, LiDAR, Digital Elevation Models, ASTER	.tif .tfw .jpg .ecw .dwg .dbf .pdf .shapefiles (some files quite large in size)
Geological Mapping	Structural measurements, GIS files of ground mapping	.xls .xlsx MapInfo Files (.dat .id .map .tab .ind), Shapefiles (.shp .shx .prj .sbn .sbx .dbf)
GIS	Base mapping collections, map files, sample/drillhole locations and parameters	MapInfo Files (.dat .id .map .tab .ind), Shapefiles (.shp .shx .prj .sbn .sbx .dbf)

Project use case:

Projection of point data for assessment reports and mineral occurrences to WGS84 / UTM zone 9N (EPSG:32609) coordinate system, clipping to the project area (or other area of interest).

Various symbology was utilized to highlight different attributes associated with the ARIS, MINFILE, and COALFILE datasets in Figures 1 to 3 below.

Other data representations are possible such as: who the assessment work was completed by (typically the operator or claimholder), types of deposit styles being explored, type of work completed (drilling, geophysical, geochemical, imagery, geological, spatial compilation or analysis) or other attributes of interest.

Data distribution:

The data is moderately clustered and unevenly distributed across the project area.

MINFILE and ARIS data points concentrated around the southern, western and northeastern portions of the project area.

COALFILE data points are less numerous and were focused within and around the Bowser Basin in the southeastern portion of the project area.

Three figures were made summarizing in different attributes or formats the overall distribution of mineral exploration that has been conducted within the project area, for the purpose of administering and maintaining mineral and coal tenure claims.

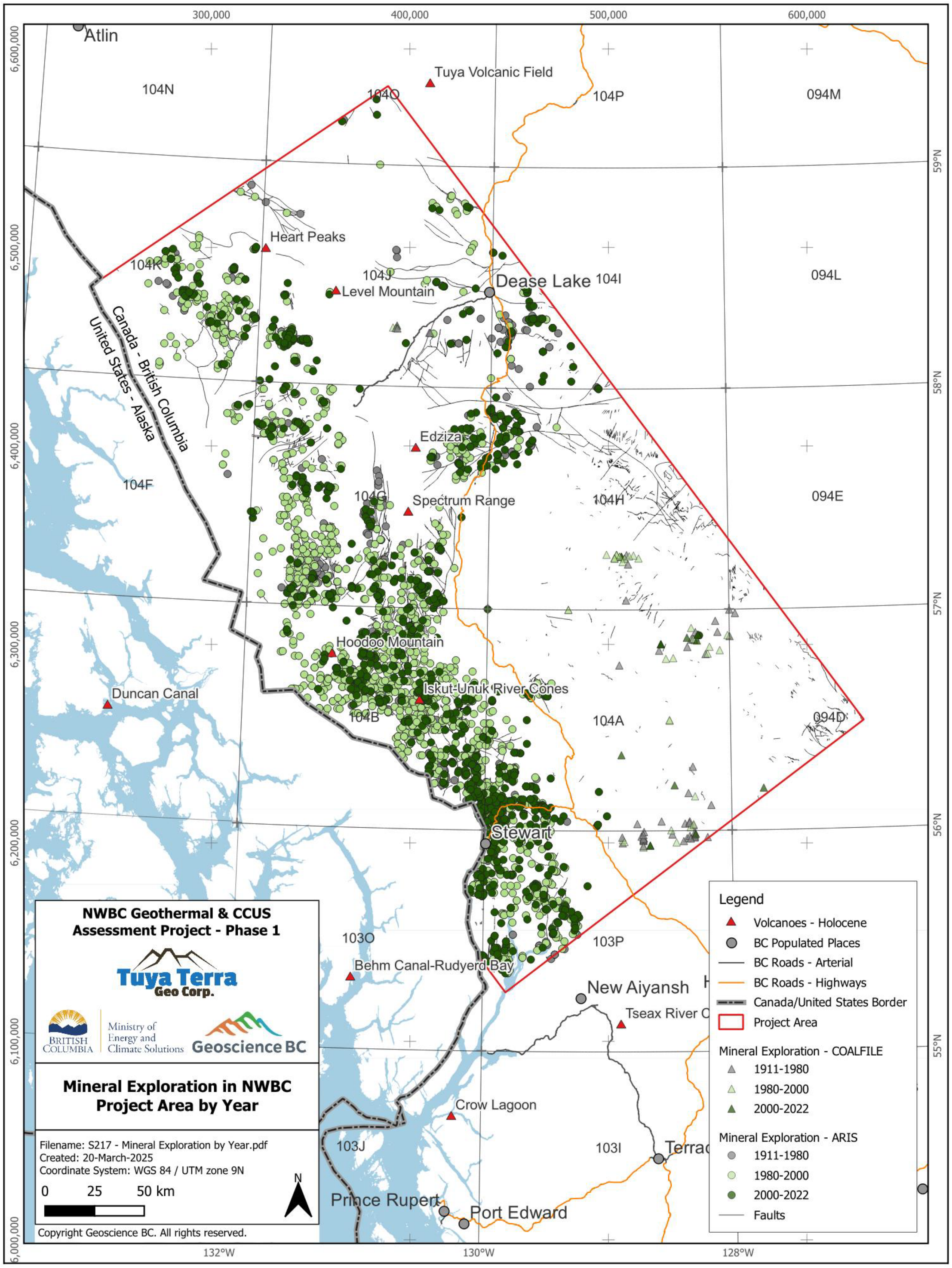
COALFILE, MINFILE, and ARIS datasets were accessed from the provincial BCGS website. As mentioned above, it is prudent for future dataset users to download the most up to date datasets directly from the BCGS website.

Figures below were created using QGIS with select base reference data layers (highways, volcanoes, faults, project area outline, NTS gridlines).

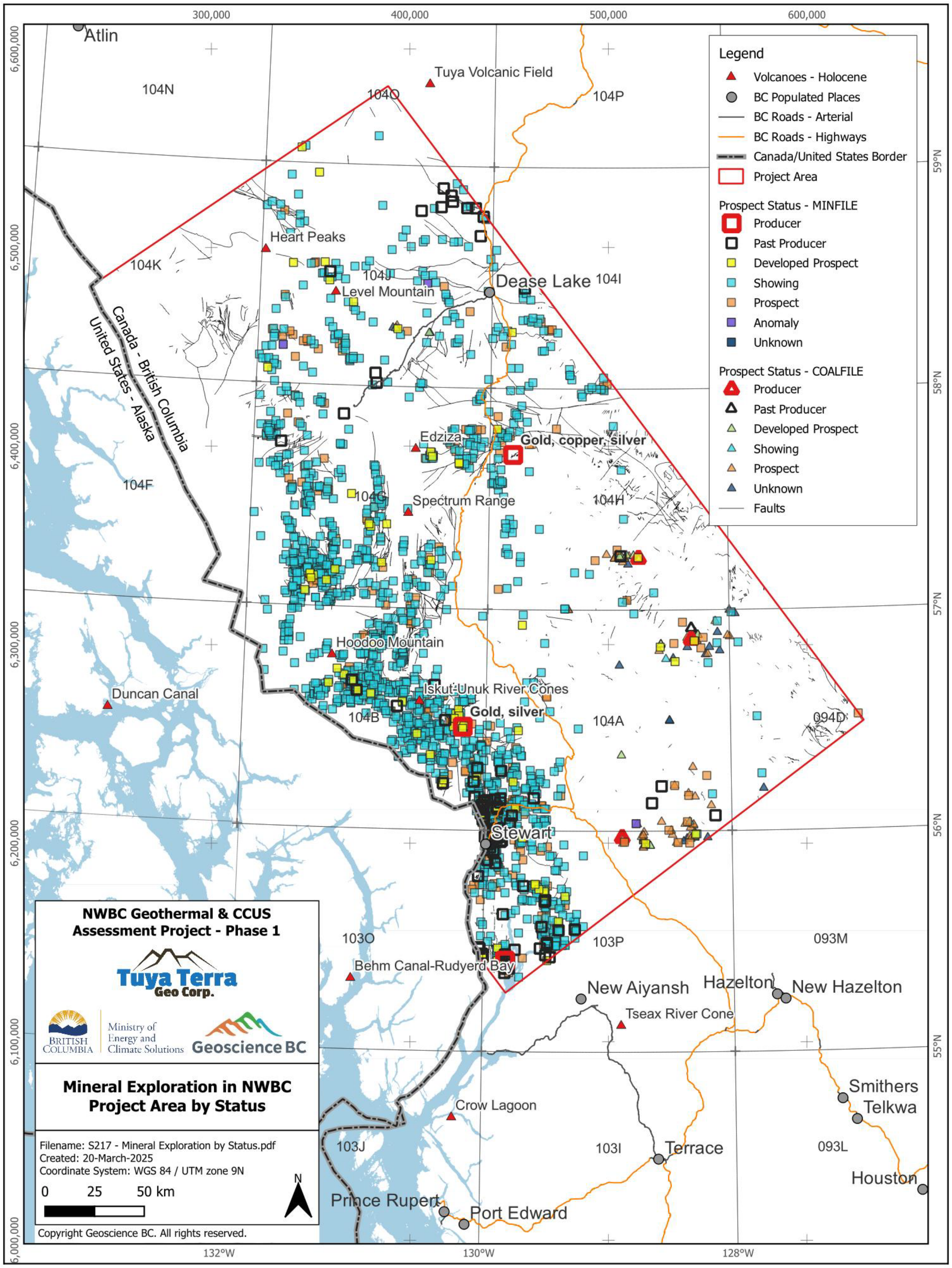
Figure 1 ARIS by Year: shows the ARIS dataset within the project area presented by the year the assessment work was completed.

Figure 2 ARIS and MINFILE status: shows the distribution of the prospect status of the MINFILE mineral occurrence (producer, past producer, developed prospect, prospect, showing, anomaly, and unknown if not categorized).

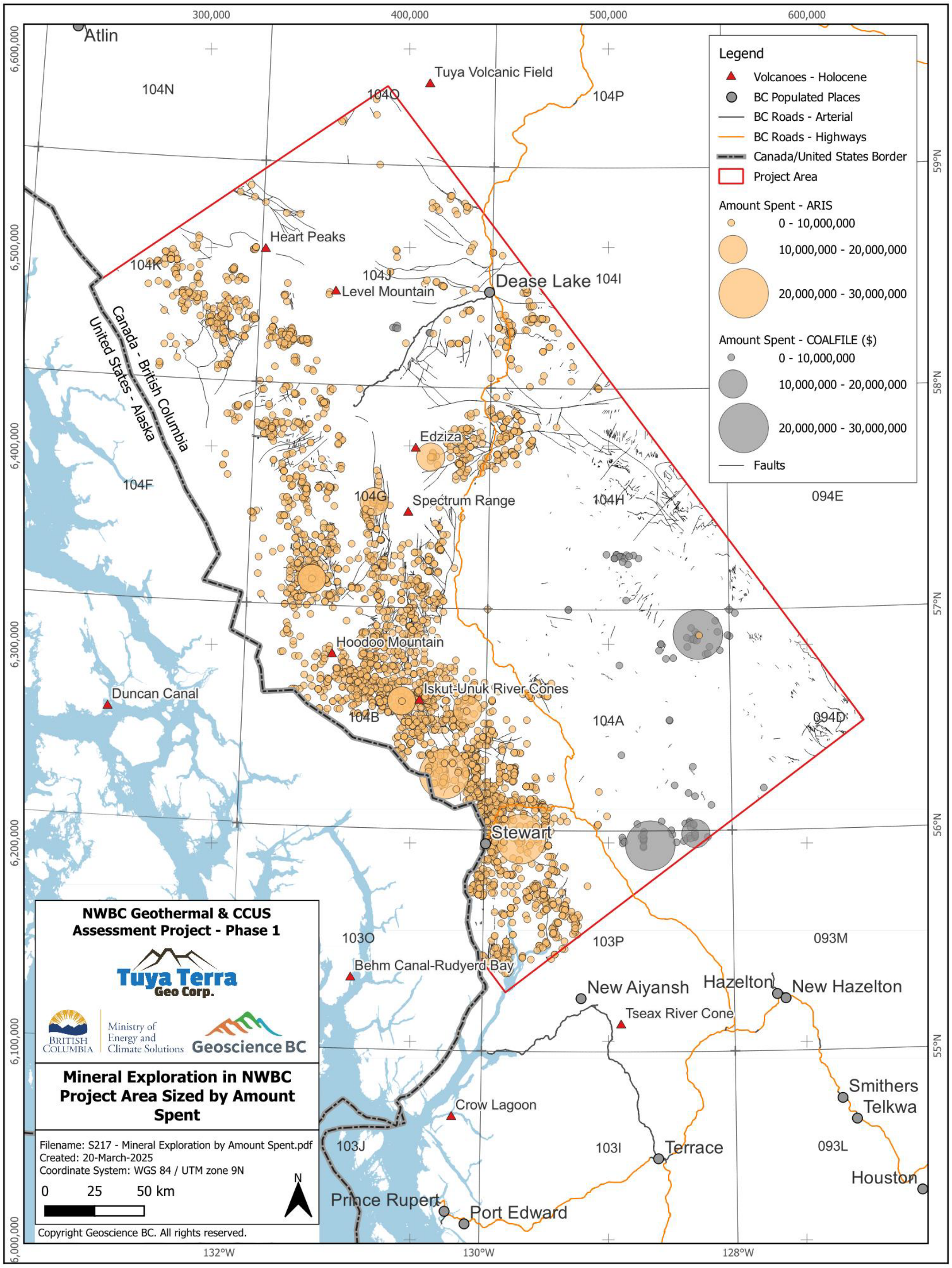
Figure 3 ARIS by $CAD spent: shows ARIS cost of assessment work completed (keeping in mind it is tied to the value of the Year the work was completed).



Section 2.17 Figure 1: Mineral exploration in project area by year. The report year is indicated by colour and the source of the data is indicated by shape. Holocene volcanoes are labelled as geographic reference points



Section 2.17 Figure 2: Mineral exploration in project area. Prospect status indicated by colour, and data source indicated by shape. MINFILE producers and past producers represented by stars to highlight their significance. Current producers labelled with produced commodities



Section 2.17 Figure 3: Mineral exploration in project area by amount spent on the project. The source of the data is indicated by colour. The size of the point indicates the reported cost of the project (ranges in legend; equal interval distribution).

Data from Adjacent Areas:

Holocene volcanoes, as well as British Columbia Highways and arterials, are displayed outside the project area as geographic reference points. The inclusion of connected highways adjacent to the areas of interest helps to show the level of access to and around the project area.

Limitations of Datasets:

The datasets are not evenly distributed across the project area, and data points tend to be highly clustered. Additionally, there are many data points with missing information, such as ARIS and COALFILE reports that do not include the amount spent on the project (and are thus represented as $0 on the map), and MINFILE and COALFILE reports that do not report the status of the prospect (and are thus represented as Unknown on the map). It was beyond the scope of this Phase I study to isolate data that might provide additional information for specific areas, without biasing the regional data.

Data Gaps:

Data from past mineral, coal exploration and mining, coal development in the province has typically centred around the most accessible and historically prospective areas. These prospective areas include regions around the population centers: Kitsault, Stewart, Stikine, Fowler, Bob Quinn, Iskut, and Dease Lake. None of the data collected was for the purposes of geothermal exploration. Any data collected, must be evaluated for its relevance to geothermal exploration.

Data gaps exist where exploration has been limited, either due to sparsity of outcrop, unfavourable mineral exploration targets, or the presence provincial parks.

Recommendations for Additional Work

The following summary points of recommendations is included for future follow-up phases.

1) Identify a list of priority areas to focus the effort of integrating mineral exploration datasets as part of a desktop compilation for geothermal assessment prior to beginning geothermal exploration fieldwork.
2) Reviewing historical technical assessment reports (using ARIS, MINFILE and/or COALFILE) for usability of data, whether digitization will be required, an estimate of time and personnel required. Preferably this review would be completed in the order of the priority areas identified in step 1) above.
3) Continue to monitor the government developments surrounding the modernization of the Mineral Tenure Act.

   Changes to the Mineral Tenure Act aim to support collaboration with First Nations, and engagement with the mining and mineral exploration industry.

   The purpose of understanding the developments to modernize the Mineral Tenure Act is to advance understanding on how to explore and develop geothermal resources under the current provincial framework given the different approaches taken by the Mineral Tenure Act vs. the Geothermal Resource Act vs. the role of the British Columbia Energy Regulator, which regulates power-generating geothermal facilities under the Oil and Gas Activities Act.
4) Follow up with industry contacts initiated during this Phase of the project.

Personnel for mining projects change, so it is important to stay informed as organizational structure of companies, partnerships, joint ventures, or other types of organizational re-arrangements emerge and develop.

The mining industry landscape continues to change with advancements in technologies, as well as changes in how government engages and consults with land rightsholders, communities and other stakeholders.

Understanding who the most appropriate contact(s) is/are for follow up can be a time-consuming endeavor.

Possible contacts to follow up with include:

1) Geoscience BC, BCGS, or other Ministry of Mining staff or personnel,
2) Mining company personnel in charge of environmental permitting and land use considerations,
3) Data geoscientists (VP Exploration, Chief Geologist),
4) Staff, or other personnel at the appropriate First Nation offices,
5) Past workers,
6) Community members,
7) Municipal representatives, and
8) Private and public Industry contacts.

5) Review and integrate other BCGS mineral exploration (or other geological research) focused datasets that may be relevant for geothermal assessment of favourable areas based on priority targets (for example, priority areas identified in step 1) above).

   Examples of other types of datasets that may provide additional data or data sharing opportunities for evaluation of geothermal favourability in the province, include:

   a. NI 43-101 dataset
      i. Example NI 43-101 technical report:
         Premier and Red Mountain Gold Project Feasibility Study NI 43-101 Technical Report, prepared by Sacre-Davey Engineering Inc. for Ascot Resources Ltd. (Bird et al., 2020).
   b. BCGS Publication Catalogue
      i. Example BCGS Publication:
         Geological Fieldwork 2005, Paper 2006-1: Bowser Basin Geochemical Survey, North-Central British Columbia: Anomaly Follow-up (Lett and Friske, 2006).
   c. GeoFiles: GeoFiles enable rapid release of extensive data from ongoing geochemical, geochronological, and geophysical work. As such, they serve the same function as data repositories by many journals, providing immediate access to raw data from specific projects. GeoFiles are a type of BCGS Publication, and can also be searched through the BCGS Publication Catalogue (mentioned above).
      i. Example GeoFile 2020-08:
         Update of the provincial Regional Geochemical Survey (RGS) database at the British Columbia Geological Survey (Han and Rukhlov, 2020).
         This GeoFile is available as two MS Excel files, 'RGS2020_data.xlsx' and 'RGS2020_metadata.xlsx'.
         This GeoFile is an update to the 2017 RGS Release by BCGS (Han and Rukhlov, 2017).

ii. Example GeoFile 2025-11:
Assessment report drillhole database: Development and initial data release (Fortin and Silva, 2025)

d. Download digital data associated with assessment reports that have been identified through above stops, if available. According to the British Columbia MoM website, the BCGS encourages and welcomes the submission of assessment report digital data, such as spreadsheets, databases, maps, grids, etc., that were used or created for work described in the submitted technical assessment report.

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2.18 Infrastructure

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Overview

Though not included in the favourability assessment for this project, a base level of understanding of the current infrastructure in the project area was developed in order to inform future phases of geothermal investigation. The infrastructure in the project area was grouped into three specific areas: population centers and protected areas, transportation infrastructure, and power systems infrastructure.

Localities and Parks/Protected Areas

Population Centers and Localities

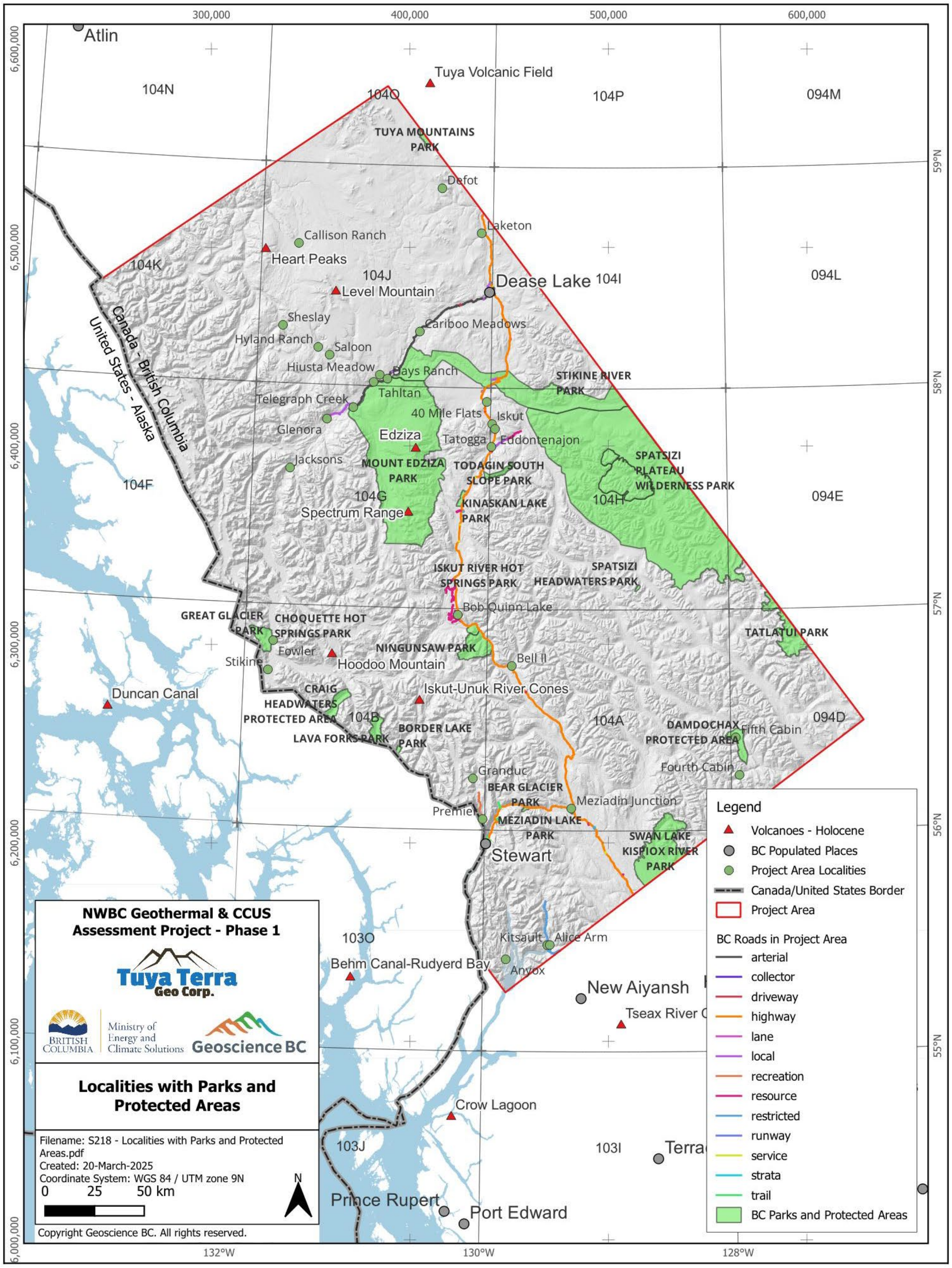
The project area encompasses portions of both the Kitimat-Stikine Regional District and the unincorporated Stikine Region. It is a sparsely populate area with the entire Stikine Region being home to 740 people (with 547 living in Atlin, outside of the project area) and the Regional District pf Kitimat-Stikine being home to 37,790 people (with the majority of the population living outside of the project area in Terrace, Kitimat, and Thornhill). Within the project area, the major centers of population are Stewart (population of 517) and Dease Lake (population of 229). There are a number of other smaller communities, mostly unincorporated, such as Telegraph Creek, Iskut, Tatogga, and Eddontenajon. As well, the project area contains a number of fully, or mostly abandoned towns, such as Premier, Glenora, and Kitsault.

Parks and Protected Areas

There are 21 British Columbia administered Parks and Protected Areas located within the project area. Though many of the parks are limited in their extent, the eastern portion of the project area is dominated by 3 parks and a single ecological reserve: Mount Edziza Park, Stikine River Park, Spatsizi Plateau Wilderness Park, and the Gladys Lake Ecological Reserve.

Section 2.18 Table 1: Parks and protected areas in the project area

Parks and Protected Areas in the Project Area	
Bear Glacier Park (542 ha)	Mount Edziza Park (226,180 ha)
Border Lake Park (814 ha)	Ningunsaw Park (15,705 ha)
Choquette Hot Springs Park (52 ha)	Ningunsaw River Ecological Reserve (2,372 ha)
Craig Headwaters Protected Area (7,101 ha)	Spatsizi Headwaters Park (427 ha)
Damdochax Protected Area (8,129 ha)	Spatsizi Plateau Wilderness Park (698,659 ha)
Gladys Lake Ecological Reserve (44,098 ha)	Stikine River Park (257,177 ha)
Great Glacier Park (9,313 ha)	Swan Lake Kispiox River Park (62,255 ha)
Iskut River Hot Springs Park (6 ha)	Tatlatui Park (105,829 ha)
Kinaskan Lake Park (1,800 ha)	Todagin South Slope Park (3,557 ha)
Lava Forks Park (7,463 ha)	Tuya Mountains Park (18,001 ha)
Meziadin Lake Park (335 ha)	



Section 2.18 Figure 1: Localities with parks and protected areas. Names and sizes of the parks can be found in Table 1

Transportation Infrastructure

Ports

There is a single port located in the project area. The Port of Stewart, opened in 2015, is located within the project area at the head of the Portland Canal. This salt-water port is the most northerly ice-free port in Canada and supports a barge terminal and bulk community loading. The major industries serviced by the port are the mineral industry, both for export of items such as bulk mineral concentrates and coal, and for the import of mine resupply, pipe, and equipment. The port has 200 acres of laydown area and can also store logs for water log loading in a stored runoff inlet.

Highways and Roadways

The project area is bisected by Highway 37, alternatively called the Stewart-Cassiar Highway. The highway begins in Kitimat, British Columbia and terminates at a junction with Highway 1 near Upper Liard, Yukon. Highway 37 is mostly paved and provides access for tourist travel and connection points for trucking and connections to smaller resource roads.

Highway 37 also has a significant paved spur at Meziadin Junction that connects Stewart and its Port to the remainder of British Columbia. This spur is designated Highway 37A and extends for 65 km where it continues through Hyder, Alaska as Salmon River Road. Highway 37A then re-enters British Columbia at the site of Premier, where it continues as Granduc Road to its ultimate terminus at the Granduc Mine.

There are a number of additional roads that access more remote locations in the project area. The Telegraph Creek Road runs from Dease Lake to the community of Telegraph Creek along the Stikine River. The road is 110km with only 4.7km of paved surface and is mostly a single lane with pullouts for passing purposes. At Telegraph Creek, the road continues as the Glenora Road to the formerly populated location of Glenora.

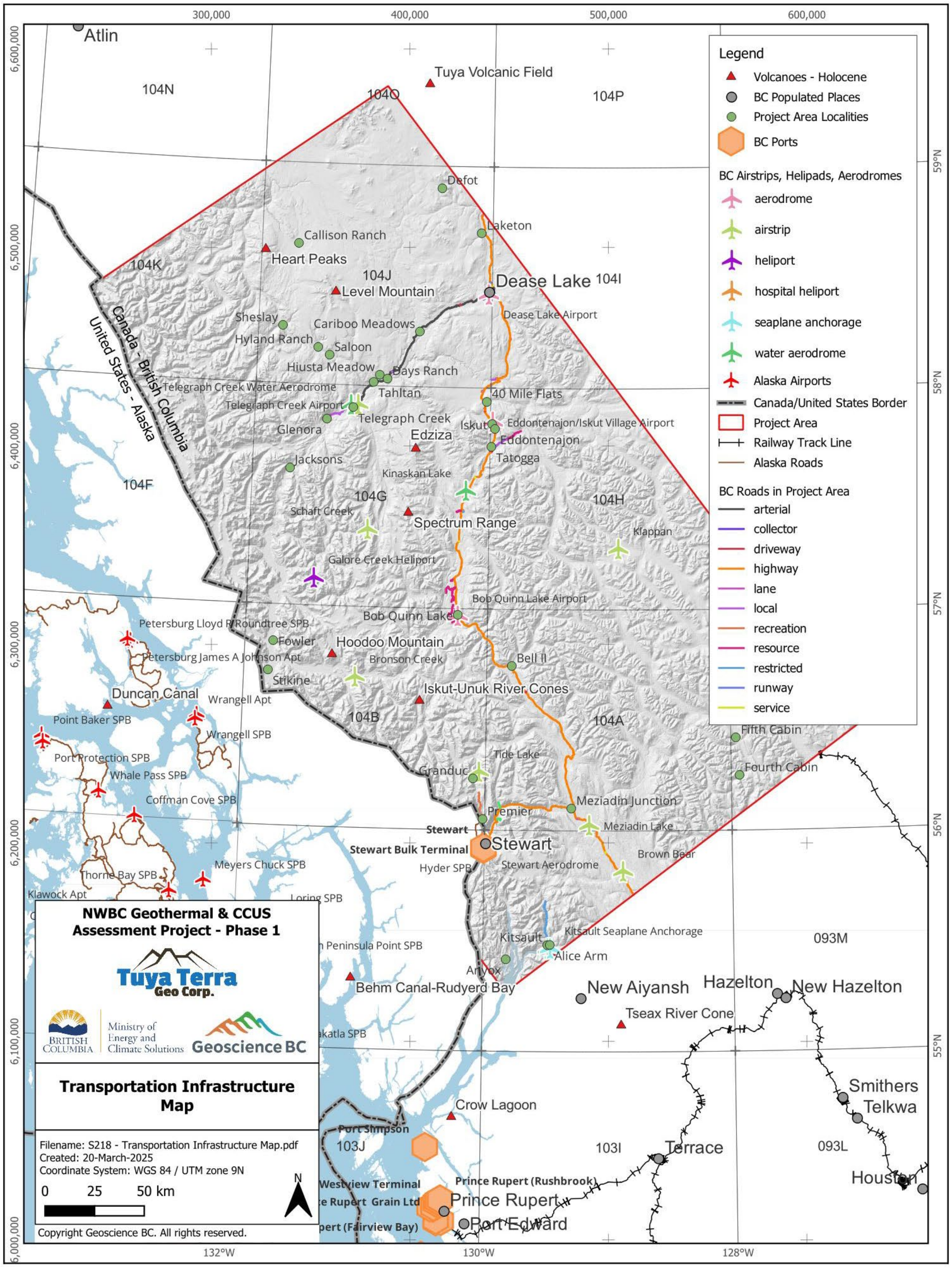
Most other roads are dirt and gravel roads that lead to former sites of mining interest, such as the Alice Arm Road in the southern portion of the project area, or forestry activities such as the Bob Quinn Lake forest service roads which provide access to a logging camp and operations. The Eaule Lake Road, exiting Highway 37, just south of Tatogga, is a 22km gravel road that extends to the BC Rail Grade/Klappan Rail Grade for access to the Spatsizi River and the Spatsizi Plateau Wilderness Park

Airports, Helipads, Aerodromes

There are 18 airports, helipads, airstrips, and aerodromes in the project area. There are 2 existing Heliports (Galore Creek and Stewart Health Centre) and a number of active aerodromes that service industrial traffic. Also a number of airstrips, both active and inactive, in the project area exist to service both communities and current and former industrial activity. Directly outside the project area, at Hyder, Alaska, is an additional seaplane berth.

Rail Lines

There are no existing rail lines in the project area. The current CN Rail tracks terminate at the edge of the project area. In the 1970’s there was the clearing and development of a rail grade to Dease Lake and included a bridge over the Stikine River at the confluence of the Klappan and Stikine. However, this rail grade was abandoned and currently exists as a periodically maintained trail. The British Columbia Government releases information on washouts and impassable sections of the rail grade when available to inform park access.



Section 2.18 Figure 2: Transportation Infrastructure Map

Power System Infrastructure

Transmission Infrastructure

There are two transmission lines that run through the project area. The first line, 230 kV, follows the general path of Highway 37 and terminates near Tatogga. It also connects the Coast Mountain Hydro Run of River Hydroelectric projects to the British Columbia Power Grid. A second line, 138 kV, connects the Long Lake Run of River Hydro Electric project to both the mining sector and to the larger British Columbia Power Grid.

Power Generation

In the project area, there are a number of existing power plants but split into 3 categories: Diesel Generating Stations, Run-of-River Hydroelectric Facilities, and Thermal Generating Stations.

Run of River Hydro

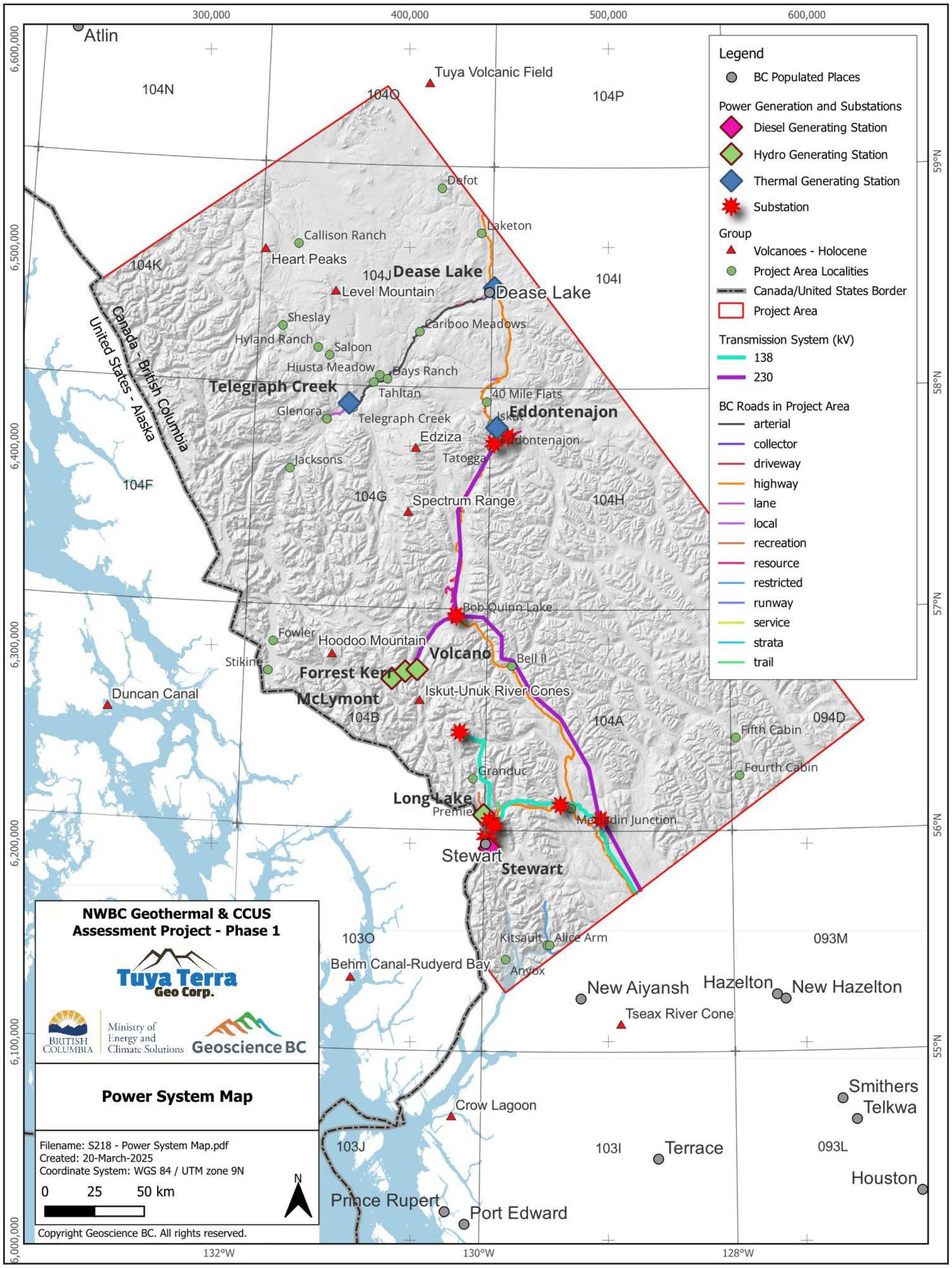
Coast Mountain Hydro, a project company owned by Axium Infrastructure, Manulife, TriSummit Utilities and the Tahltan Nation, operate 277 MW of run of river hydro projects (Forrest Kerr, McLymont, and Volcano) in the western portion of the project area. Near Stewart, there is the 31 MW Long Lake Hydro-Electric Project which is partially owned by Connor, Clark, and Lunn Infrastructure.

Unconnected Power Stations

The project area also contains a number of plants that are not connected to the British Columbia Power Grid and instead provide local power. These power stations are all diesel generators: Dease Lake, Eddontenajon, and Telegraph Creek.

Diesel Generating Station

There is one diesel generating station listed as existing at Stewart. This is likely the former diesel power generator that has been replaced by other sources of electrical generation.



Section 2.18 Figure 3: Power System Map (transmission lines and power stations digitized from BC Hydro Transmission-System-2023-2024)

Dataset created by:

Marc Colombina

Dataset Sources:

The dataset utilized in this section is a collection of publicly available datasets:

Alaska Government dataset
Alaska Department of Transportation and Public Facilities – Roads_AKDOT
Alaska Department of Transportation and Public Facilities - Airports
British Columbia Government datasets:
Ministry of Environment and Climate Change Strategy BC Parks - BC Parks, Ecological Reserves, and Protected Areas
Ministry of Tourism, Arts, Culture and Sport Heritage Branch – BC Geographical Names
Ministry of Water, Land, and Resource Stewardship GeoBC Branch – Digital Road Atlas
Ministry of Water, Land, and Resource Stewardship GeoBC Branch – BC Airports
Ministry of Water, Land, and Resource Stewardship GeoBC Branch – BC Ports and Terminals
Ministry of Water, Land, and Resource Stewardship GeoBC Branch – Railway Track Line
BC Hydro (digitized):
BC Hydro, 2024. BC Hydro Transmission-System-2023-2024.
https://www.bchydro.com/content/dam/BCHydro/customer-portal/documents/transmission/maps/Transmission-System-2023-2024.pdf

Data Format:

Point data and spatial boundaries

Project use case:

For the current favourability mapping of the resource, this dataset has not been utilized. However, in order to develop a geothermal resource in the project area, it is vital that an exploration of the utilization of existing infrastructure be undertaken.

Data distribution:

The data utilized in this dataset encompasses the entirety of the project area.

Data from Adjacent Areas:

In the creation of this dataset, information from both Alaska and portions of British Columbia outside of the project area were included.

Limitations of Datasets:

The data available was derived from government sources and may not be an accurate reflection of the current condition of much of the transportation infrastructure. Anecdotal evidence can be gathered from various travelogues and blogs but those may be mis-referenced or only accurate for a limited period of time.

Data Gaps:

The existing British Columbia Rail Grade has not been mapped in a manner that can be integrated into the current data visualization. The status of all existing airstrips has not been updated and the status of building infrastructure in formerly populated locations has not been confirmed

Recommendations for Additional Work

The majority of infrastructure currently maintained by the Provincial Government has been mapped. In order to assess the viability of prospect level sites, additional work to survey former mine sites, abandoned rail grade and bridges, and airstrips as to their suitability to be repurposed for geothermal exploration or development would be beneficial. As well, incorporating infrastructure maps from current mining activities would be beneficial in areas of exploration or development interest.

An early-stage next step to filter exploration targets would be the overlay of the existing infrastructure layers, particularly the Parks and Protected Areas, onto the favourability maps in order to provide guidance as to potential conflicts.

Additionally, no attempt has been made in the current project to assess geothermal development in relation to existing power infrastructure. Critical to project development would be the technical and economic assessment of connection to existing transmission infrastructure or the ability to provide electrical power to currently unconnected localities.

3.1 Play Fairway Analysis, Discussion, and Conclusions

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Overview

The Play Fairway (PF) analysis for the project area focused on naturally occurring geothermal systems:

1. Volcanic hosted systems (VH)
2. Structurally (fault/fracture) hosted systems (FF)
3. Sedimentary basin hosted systems (SB)
4. Radiogenic pluton (RP)
5. Ultra deep/ultra hot rock (UD)

Favourability maps were created for volcanic, structural (fault/fracture) and sedimentary basin hosted systems. Insufficient data existed to produce a favourability map for radiogenic plutons and by inference, also ultra deep/ultra hot rock. This section of the report presents the methodology, data analytics and outcomes. The 20 sets of data were the "evidence layers" grouped into "heat" and "permeability" values. Only geological data was considered in the analysis. Although infrastructure was collected as a data set (Section 2.18), it was excluded from the data analytics. The outcome of the analyses are presented as favourability maps that represent areas more or less favourable, relative to other areas within the project area, to host naturally occurring geothermal systems.

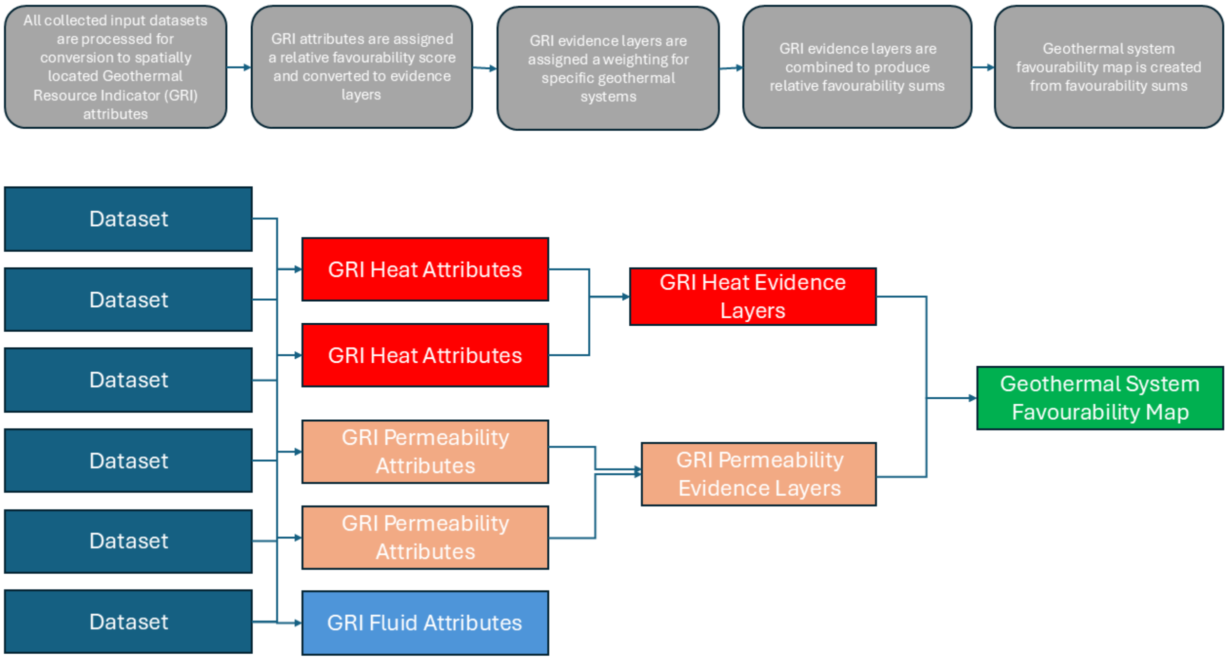
The PF analysis is implemented using the Interactive Analytics approach (Harms et al., 2020). PF analysis evidence layers are processed as grid cells in the Interactive Analytics approach. Instead of a static PF analysis result, the PF analysis outputs can be viewed and interrogated in an interactive manner. Static output maps from the interactive analysis and workflows show the PF analysis results.

Play Fairway Analysis Methodology

The PF analysis concept is discussed in Section 1.3, but for clarity on the underlying approach, Figure 1 is repeated but modified to reflect the reality of the specific PF analysis completed in this study – the lack of data concerning fluid parameters meant that this was excluded from the analysis. The PF analysis is implemented using a geospatial, interactive methodology developed by the authors (Harms et al., 2020).

The PF analysis implementation uses the Interactive Analytics approach (Harms et al., 2020). The project area is divided into grid points every 1 km resulting in 83,415 grid points to represent the project area of 83,415 km^2.

Geothermal Resource Indicators (GRI) are represented by input datasets (Figure 1) and assigned to the defined grid. The datasets were processed in such a way that spatial information is enhanced for this PF analysis. A scoring scheme for the project was developed by the authors and applied to each dataset converting the input dataset to geothermal evidence layers. A Python script is used to automate the geoprocessing tasks allowing for rapid iteration, parameter testing, optimization, and idea generation.



Chapter 3 Figure 1: Schematic representation of the PF analysis. Due to insufficient attribute data on fluids, no GRI fluid evidence layers were calculated.

Datasets

The datasets can be raw or derived. Raw datasets are assigned to the grid with minimal processing applied and intended to honour the source datasets as best possible. Derived datasets are enhanced from the source datasets through a sequence of geoprocessing steps. Examples of derived datasets include distance to volcanic centers or gridding heat flow data.

The datasets are classified as GRI-Heat or GRI-Permeability. Table 1 presents a list of the GRI-Heat datasets and Table 2 presents a list of the GRI-Permeability used in this PF analysis. GRI-Fluid indicators are commonly used in geothermal PF analyses, but there were insufficient datasets available at the time of publication to provide meaningful input over and above the location of the hot springs.

A master table with one row per grid point and one column per dataset is loaded into Spotfire (analytics software), which has been configured to score and weight the datasets, as well as visualize and interact with the data and explore relationships.

Chapter 3 Table 1: GRI-Heat Attributes

No.	Dataset	Data Type	Description	Data Chapter
1	Geothermal Gradient (CDP) (km)	Raw	Curie Depth Point (CDP) for the entire planet using a global magnetic dataset (Li et al., 2017)	Section 2.13 – Curie Point Depth
2	Heat Flow Grid (mW/m^2)	Derived	Heat flow values from each site gridded using an inverse distance weighted technique.	Section 2.16 – Existing Borehole Data Section 2.2 – Heat Flow Map
3	Heat Flow Site Closest (m)	Derived	Each grid point is assigned a distance to the closest heat flow site.	Section 2.16 – Existing Borehole Data Section 2.2 – Heat Flow Map
4	Hot Springs Closest (m)	Derived	Each grid point is assigned a distance to the closest hot spring.	Section 2.6 – Fluid Geochemistry
5	Hot Springs Measured Surface Temperature (°C)	Derived	Each grid point is assigned the highest surface temperature of a hot spring within a 5 km buffer.	Section 2.6 – Fluid Geochemistry
6	Volcanic Center Closest (Holocene) (m)	Derived	Each grid point is assigned a distance to the closest volcanic center (Holocene)	Section 2.7 – Quaternary Volcanism
7	Volcanic Center Closest (Pleistocene and Older) (m)	Derived	Each grid point is assigned a distance to the closest volcanic center (Holocene)	Section 2.7 – Quaternary Volcanism
8	Volcanic Extrusive Rocks (Neogene to Quaternary)	Raw	Each grid point is assigned a volcanic extrusive rock attribute (e.g. Basaltic) if it is within an extrusive rock polygon.	Section 2.1 – Geological Data – Rock Types and Ages
9	Volcanic Extrusive Rocks (Paleogene)	Raw	Each grid point is assigned a volcanic extrusive rock attribute (e.g. Basaltic) if it is within an extrusive rock polygon.	Section 2.1 – Geological Data – Rock Types and Ages
10	Volcanic Extrusive Rocks (Older Volcanics)	Raw	Each grid point is assigned a volcanic extrusive rock attribute (e.g. Basaltic) if it is within an extrusive rock polygon.	Section 2.1 – Geological Data – Rock Types and Ages
11	Volcanic Intrusive Rocks (Cenozoic)	Raw	Each grid point is assigned a volcanic extrusive rock attribute (e.g. Felsic) if it is within an intrusive rock polygon.	Section 2.1 – Geological Data – Rock Types and Ages

Chapter 3 Table 2: GRI-Permeability Attributes

Counter	Dataset	Data Type	Description	Data Chapter
1	Fault Azimuth (Surface Faulting) (orientation range)	Derived	An azimuth was attributed to each fault based on a start-to-end bearing of each fault line. Each grid point is assigned an azimuth of the fault it intersects. If a grid point has >1 faults, the fault assigned is prioritized based on the scoring in Attributes. Table 2	Section 2.3 – Fracture/Fault Mapping
2	Fault Density (Surface Faulting)	Derived	Each grid point is assigned a count of faults to generate a density attribute.	Section 2.3 – Fracture/Fault Mapping
3	Lineament Azimuth (Gravity)	Derived	The lineament azimuth was buffered using a 5 km buffer An azimuth was attributed to each fault based on a start-to-end bearing of each fault line. Each grid point is assigned an azimuth of the fault it intersects. If a grid point has >1 faults, the fault assigned is prioritized based on the scoring in Table 2	Section 2.8 – Existing Gravity and Magnetic Data
4	Lineament Azimuth (Magnetics)	Derived	An azimuth was attributed to each fault based on a start-to-end bearing of each fault line. Each grid point is assigned an azimuth of the fault it intersects. If a grid point has >1 faults, the fault assigned is prioritized based on the scoring in Table 2	Section 2.8 – Existing Gravity and Magnetic Data
5	RGS Arsenic Anomalies	Derived	RGS samples were filtered to anomalous R-Values (Relative-Values) 7, 9, and 11. The R-Values are explained in the Regional Geochemistry Data Chapter. Each grid point is assigned a distance to the anomaly location.	Section 2.12 – Regional Geochemistry
6	RGS Mercury Anomalies			
7	RGS pH Acidic Anomalies			
8	Sedimentary Basin Present	Raw	Each grid point is assigned a sedimentary basin depth based on its location within a magnetic depth map. Contours 4500, 3500, 2500, and 1500 polygons were digitized.	Section 2.15 – Bowser Basin Sedimentary Stratigraphy
9	Seismicity	Derived	Seismic events were filtered to only those events deeper than 1 km and greater than 1 Magnitude. The events were then buffered using a 5km radius. Each grid point with the 5km buffer gets assigned a seismic event attribute.	Section 2.5 – Seismicity Scan

Evidence Layers and Weightings

The scoring of each dataset was implemented in Spotfire using calculated columns to convert dataset values such as distance, temperature, etc. to a score of 0-5 (Table 3). Once a dataset has a scoring scheme applied, it shall be referred to as an "Evidence Layer".

Chapter 3 Table 3: Dataset Scoring

5	High relative favourability
4	High to Medium relative favourability
3	Medium relative favourability
2	Medium to low relative favourability
1	Low relative Favourability
0	Unknown/ insufficient data/ not relevant

Evidence Layers were then assigned weightings deemed appropriate for the different geothermal systems. In the weighting's framework, the sum of all weighted scores must equal one (1) for GRI-Heat and must equal one (1) for GRI-Permeability, i.e. a 50/50 split between these indicator classifications. This means the highest weighted score of any grid point is two (2).

The scoring and weightings logic for each Evidence Layer is presented in Table 4 for GRI-Heat and Table 5 for GRI-Permeability.

Each evidence layer is presented as a map in Appendix A.

Chapter 3 Table 4: GRI-Heat Scoring of Evidence Layers

No.	Evidence Layer	Scoring	Scoring Explanation	Weighting[1]			Weighting Explanation
				VH	FF	SB	
1	Geothermal Gradient (CDP)	5 = 4 = 3 = <19 km CDP 2 = 1 = 0 = >19 km CDP	Curie Depth Point (CDP) <19 km represents a geothermal gradient above a typical average of >30°C/km. Shallow CDP values are indicative of elevated geothermal gradients.	0.05	0.05	0.30	VH/FF: low weighting as CDP has low confidence and other layers were deemed more impactful. SB: higher weighting due to limited regional data for sedimentary basin heat
2	Heat Flow Grid (mW/m2)	5 = >100 mW/m^2 4 = >80 mW/m^2 3 = >60 mW/m^2 2 = >40 mW/m^2 1 = <40 mW/m^2 0 = no value	Assessing thermal heat flow is essential for identifying the best geothermal zones.	0.05	0.05	0.40	VH/FF: low weighting due to large areas of interpolated data using the inverse distance weighting technique and other layers deemed more impactful. SB: higher weighting due to limited regional data for sedimentary basin heat
3	Heat Flow Site Closest	5 = <10 km 4 = <20 km 3 = <30 km 2 = <40 km 1 = <50 km 0 = > 60 km	This attribute combined with the Heat Flow Grid attribute puts a higher score for points closer to a heat flow site	0.05	0.05	0.10	VH/FF: low weighting since other layers were deemed more impactful SB: very few heat flow sites within the significant Bowser basin; weighting developed experimentally to visualize a reasonable sedimentary basin map
4	Hot Springs Closest	5 = <1,000 m 4 = <2,500 m 3 = <5,000 m 2 = <7,500 m 1 = <10,000 m	Flowing hot springs are highly indicative of a geothermal system. At a regional map scale, larger spheres of	0.15	0.20	0	VH: high weighting hot springs are indicative of a working hydrothermal system. FF: high weighting hot springs are

No.	Evidence Layer	Scoring	Scoring Explanation	Weighting[1]			Weighting Explanation
				VH	FF	SB	
		0 = >10,000 m	influence are attributed to hot spring locations because of their significance even though hot spring point locations is not a radial attribute.				indicative of a working hydrothermal system. May be direct indication of fluid movement along a permeable fault. SB: not ranked – sedimentary basins systems tend to be blind systems; geothermal fluids are not expected to emit at the surface.
5	Hot Springs Surface Temperature	5 = <5 km of >80°C 4 = <5 km of >70°C 3 = <5 km of >60°C 2 = <5 km of >50°C 1 = <5 km of <50°C 0 = >5 km of any spring	Flowing hot springs are highly indicative of a geothermal system, however, are complicated by topography and unknown underground flow pathways. A relatively small radius is utilized to high grade based on temperature.	0.10	0.20	0	VH: high weighting higher temperatures may be indicative of a shallower heat resource. FF: high weighting higher temperatures may be indicative of an efficient fluid pathway to the surface. SB: n/a
6	Volcanic Center Closest (Holocene)	5 = <5 km 4 = <10 km 3 = <15 km 2 = <20 km 1 = <25 km 0 = >25 km	Proximity to Holocene volcanoes highlights the main areas with recent volcanic activity	0.30	0.15	0.05	VH: weighted high as recent volcanism is a key indicator for heat in a volcanic hosted system. FF: moderate weighting since nearby volcanism may contribute to background heat SB: moderate weighting since nearby volcanism may contribute to background heat
7	Volcanic Center Closest (Pleistocene and Older)	5 = <5 km 4 = <10 km 3 = <15 km 2 = <20 km	Increases score based on the proximity to Pleistocene & older volcanoes	0.05	0.05	0.05	Weighted low for all 3 systems. Typically, systems which predate the Holocene are

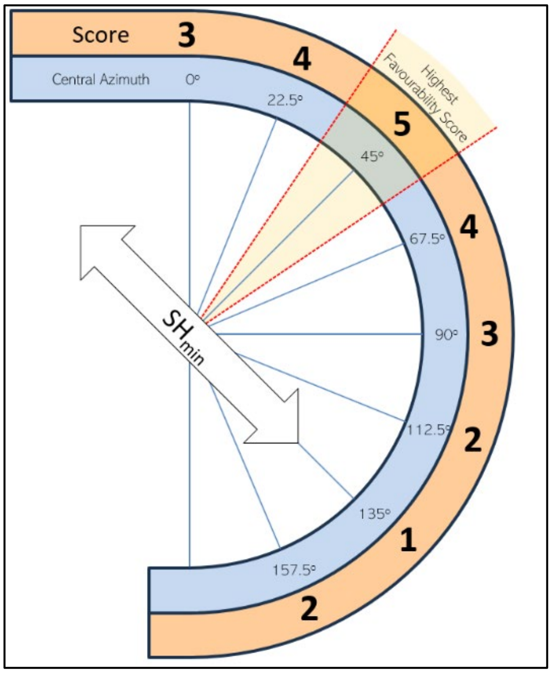
No.	Evidence Layer	Scoring	Scoring Explanation	Weighting[1]			Weighting Explanation
				VH	FF	SB	
		1 = <25 km 0 = >25 km					unlikely to have residual heat.
8	Volcanic Extrusive Rocks (Neogene to Quaternary)	5 = trachytic 4= 3 = bimodal 2 = basaltic 1 = 0 = no extrusive	Highlights the main areas with recent volcanic activity. Rock types scored differently based on indications of a shallower heat source.	0.15	0.10	0	VH / FF: weighted high as evolved compositions are a key indicator of a crustal magma chamber. SB: n/a
9	Volcanic Extrusive Rocks (Paleogene)	5 = rhyolitic 4 = andesitic 3 = 2 = basaltic 1 = undivided 0 = no extrusive	Paleogene to older volcanic rocks can indicate areas of crustal weakness and presence of cooling magmas at depth.	0.07	0.03	0	VH / FF: evolved compositions are a key indicator of a crustal magma chamber. Weighted low due to older age. SB: n/a
10	Volcanic Extrusive Rocks (Older Volcanics)	5 = rhyolitic 4 = andesitic 3 = 2 = basaltic 1 = mixed volcanic rock/ volcano-sedimentary 0 = no extrusive		0.03	0.02	0	VH / FF: evolved compositions are a key indicator of a crustal magma chamber. Weighted lower due to older age. SB: n/a
11	Volcanic Intrusive Rocks (Cenozoic)	5 = felsic 4 = intermediate 3 = mafic 2 = ultramafic 1 = undivided intrusive rocks 0 = no intrusive	Indicator of radiogenic heat.	0	0.10	0.10	VH: old intrusive outcrops are not expected to have associated residual heat. FF/ SB: old intrusive outcrops are not expected to have associated residual heat, however, there is potential for radiogenic heat generation.
			Total:	**1**	**1**	**1**	
Notes: [1] VH = Volcanic Hosted System, FF = Fault/Fracture Hosted System, SB = Sedimentary Basin Hosted Systems							

Chapter 3 Table 5: GRI-Permeability Scoring of Evidence Layers

No.	Evidence Layer	Scoring	Scoring Explanation	Weighting[1]			Weighting Explanation
				VH	FF	SB	
1	Fault Density (Surface Faulting)	5 = top quintile 4 = second quintile 3 = third quintile 2 = fourth quintile 1 = bottom quintile 0 = no faults	High fault density, regardless of orientation, indicates regions likely to exhibit higher permeability and the potential upwelling of deep hot fluid.	0.15	0.30	0.10	VH: recent volcanism in the NCVP has been noted to be associated with faulting. FF: High fault density of is a key component for fault hosted systems SB: faulting may enhance connectivity and permeability of sedimentary reservoirs.
2	Fault Azimuth (Surface Faulting)	All azimuths below are +/-11.25° See Figure 2 5 = 45° (NE-SW) 4 = 22.5° (NNE-SSW) or 67.5° (ENE-WSW) 3 = 0° (N-S) or 90° (E-W) 2 = 112.5° (ESE-WNW) or 157.5° (SSE-NNW) 1 = 135° (SE-NW) 0 = no lineament	The orientation of the faults helps in determining the most permeable areas. Faults oriented perpendicular to the assumed minimum horizontal stress (SH_{min}) are more prone to being permeable, while faults oriented parallel to SH_{min} are likely to be under closing stresses.	0.15	0.30	0.10	Higher weighting than lineaments due to higher reliability.
3	Lineament Azimuth (Gravity)			0.05	0.05	0.10	Lineaments from gravity & magnetics benefit from continuous coverage and subsurface imaging but are assigned a lower weighting compared to surface faulting due to lower reliability.
4	Lineament Azimuth (Magnetics)			0.10	0.10	0.10	
5	RGS Arsenic Anomalies	Scoring based on distance to an anomalous sample based on the R-Values (Relative-Values). 5 = < 1,000 m of anomaly 4 = <2,500 m 3 = <5,000 m 2 = <7,500 m 1 = <10,000 m	Useful for corroborating fracture/faulting data and potentially hot spring/thermal data. Arsenic is mobilized at low temperatures and can be deposited along fractures. Mercury is mobilized in fractures and at high temperatures. High temp hydrothermal systems create pH <7 (so do mineral deposits	0.15	0.05	0	VH: high arsenic and mercury concentrations are often associated with faulting and high temperature anomalies. FF: same as VH but correlation is not as strong SB: n/a
6	RGS Mercury Anomalies			0.15	0.05	0	

No.	Evidence Layer	Scoring	Scoring Explanation	Weighting[1]			Weighting Explanation
				VH	FF	SB	
		0 = >10,000 m from an anomaly	resulting in ambiguity as an indicator).				
7	RGS pH Acidic Anomalies	5 = < 1,000 m of anomaly 4 = <2,500 m 3 = <5,000 m 2 = <7,500 m 1 = <10,000 m 0 = >10,000 m from an anomaly	High temp hydrothermal systems create pH <7 (so do mineral deposits resulting in ambiguity as an indicator)	0.15	0.05	0	VH / FF: High temperature volcanic hosted systems have a low pH. Low pH may be indicative of degassing a thus potentially a permeability indicator SB: n/a
8	Sedimentary Basin Present	5 = MAG depths >4,500 m within Bowser Basin 4 = MAG depths >3,500 m within Bowser Basin 3 = MAG depths >2,500 m within Bowser Basin 2 = MAG depths >1,500 m & within Bowser Basin 1 = within Bowser Basin 0 = outside the Bowser Basin	For sedimentary hosted systems, thick deep sedimentary basin increases the possibility for porous / permeable sedimentary rocks in a heated condition. The Bowser Basin is the only significant sed basin in the project area. Magnetic density and susceptibility data are essential for calibrating geophysical interpretation. This was useful in determining the depth of the Bowser basin.	0	0	0.50	VH/FF: unrelated to these systems SB: significant weighting based on depth/ thickness of sedimentary rock
9	Seismicity	5 = <5 km of ML>5 4 = <5 km of ML>4 3 = <5 km of ML>3 2 = <5 km of ML>2 1 = <5 km of ML>1 0 = no seismic event	A high concentration of earthquakes may indicate recent neo tectonic movement, suggesting the presence of permeable faults that facilitate the upwelling of deep hot fluids.	0.10	0.10	0.10	Lower weightings in general because seismic events may be attributed to mining activities and glacier quakes, some natural seismicity may be present but cannot differentiate at this time. No focal mechanism information (lack on monitoring network/ lack of large EQ's).
			Total	**1**	**1**	**1**	
Notes							

No.	Evidence Layer	Scoring	Scoring Explanation	Weighting[1]			Weighting Explanation
				VH	FF	SB	
1. VH = Volcanic Hosted System, FF = Fault/Fracture Hosted System, SB = Sedimentary Basin Hosted Systems							



Chapter 3 Figure 2: Example of fault and lineament scoring relative to assumed minimum horizontal stress. See discussion in Section 2.4.

Results and Discussion

Three final favourability maps were created for volcanic, structural (fault/fracture) and sedimentary basin hosted systems. The maps are colored by percentiles to show statistically higher favourability target areas for each geothermal system. Within each PF analysis map, relative favourability colour coding was assigned using probability as shown in Table 6:

Chapter 3 Table 6: Statistical relative favourability cutoffs used on the favourability maps

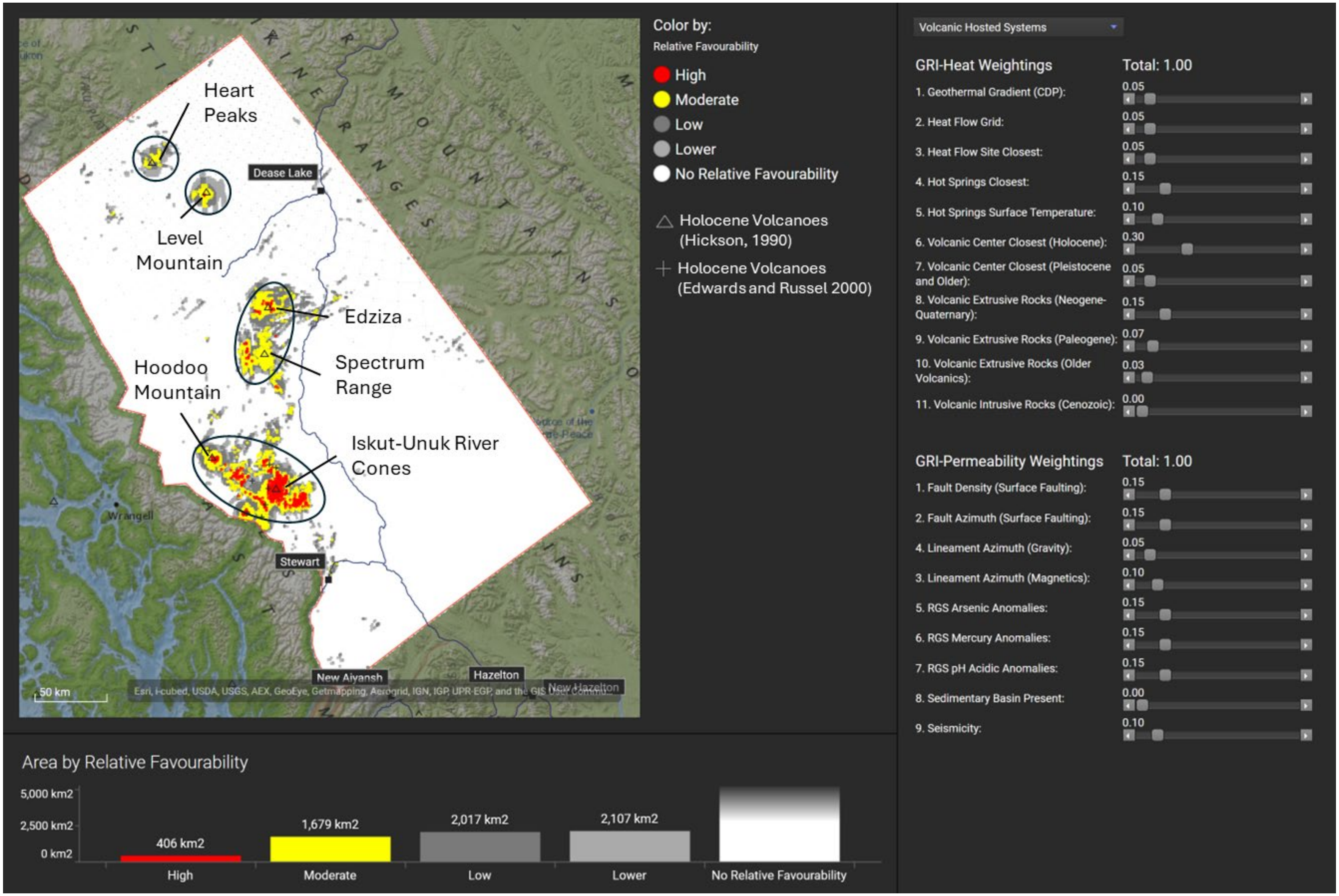
>P99.5	High Relative Favourability	(red)
P97.5 to P99.5	Moderate Relative Favourability	(yellow)
P95.0 to P97.5	Low Relative Favourability	(dark grey)
P92.5 to P95.0	Lower Relative Favourability	(light grey)
<P95.0	No Relative Favourability	(white)

Volcanic Hosted Systems

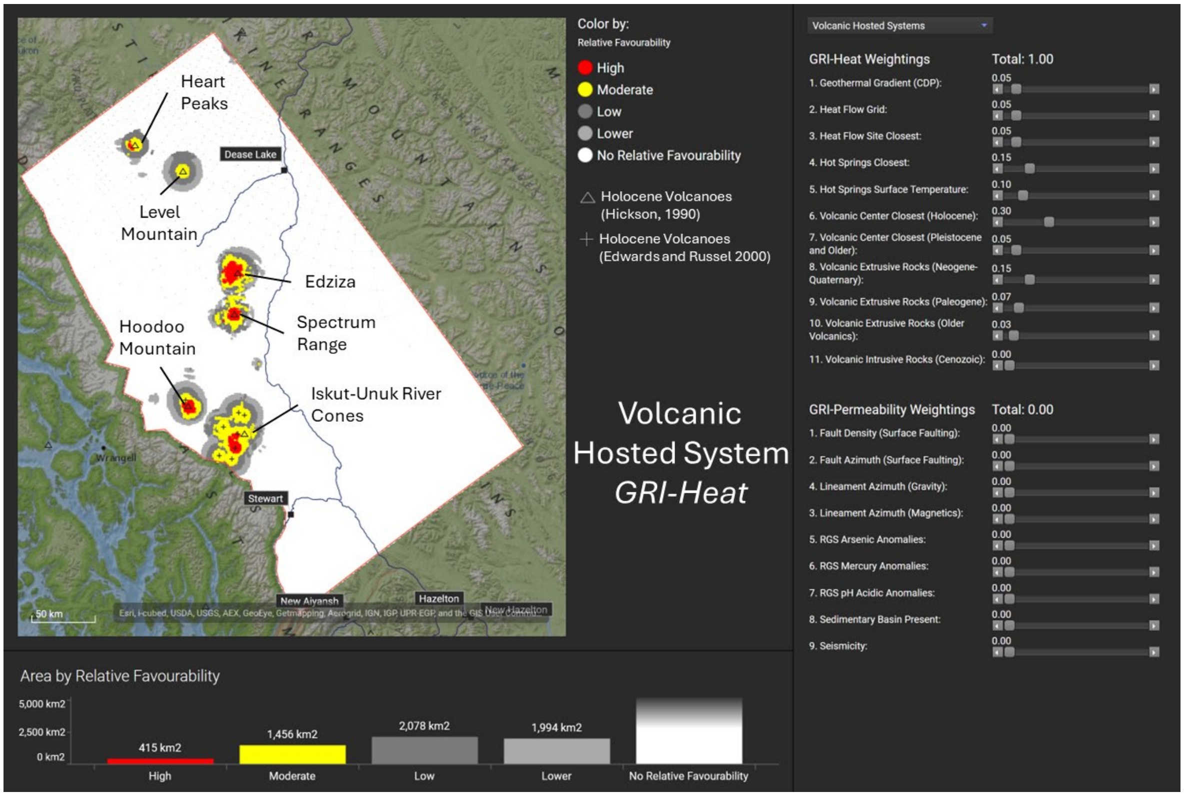
Figure 3 presents the final Volcanic Hosted System PF analysis favourability map. Favourability in this PF analysis map is strongly controlled by the presence of Holocene volcanic centers. As discussed in Section 2.7, there is evidence that despite the low viscosities of the high Sodium rhyolites (phonolites for example) there is evidence that upper crustal magma chambers may be present under the long-lived volcanic centers shown on the map. In addition, the calculations are strongly influenced by the presence of hot springs, faults oriented perpendicular to the principal direction of stress and fault density.

The Hoodoo Mountain/Iskut-Unuk River Cones region shows up strongly because the volcanism in this area is Holocene and there are a number of closely associated cinder cones in the Iskut-Unuk River area (Section 2.7). Despite their basaltic composition, the clusters of the volcanic centers along with a significant fault density perpendicular to the principal direction of stress, results in high scoring grid points. By comparing only the GRI-Heat map Figure 4) and the GRI-Perm map (Figure 5) it becomes apparent Hoodoo Mountain/Iskut-Unuk River Cones region is visually higher scoring (more red grid points) compared to Edziza and other Holocene volcanoes, because of higher GRI-Permeability scoring, the result of the faults.

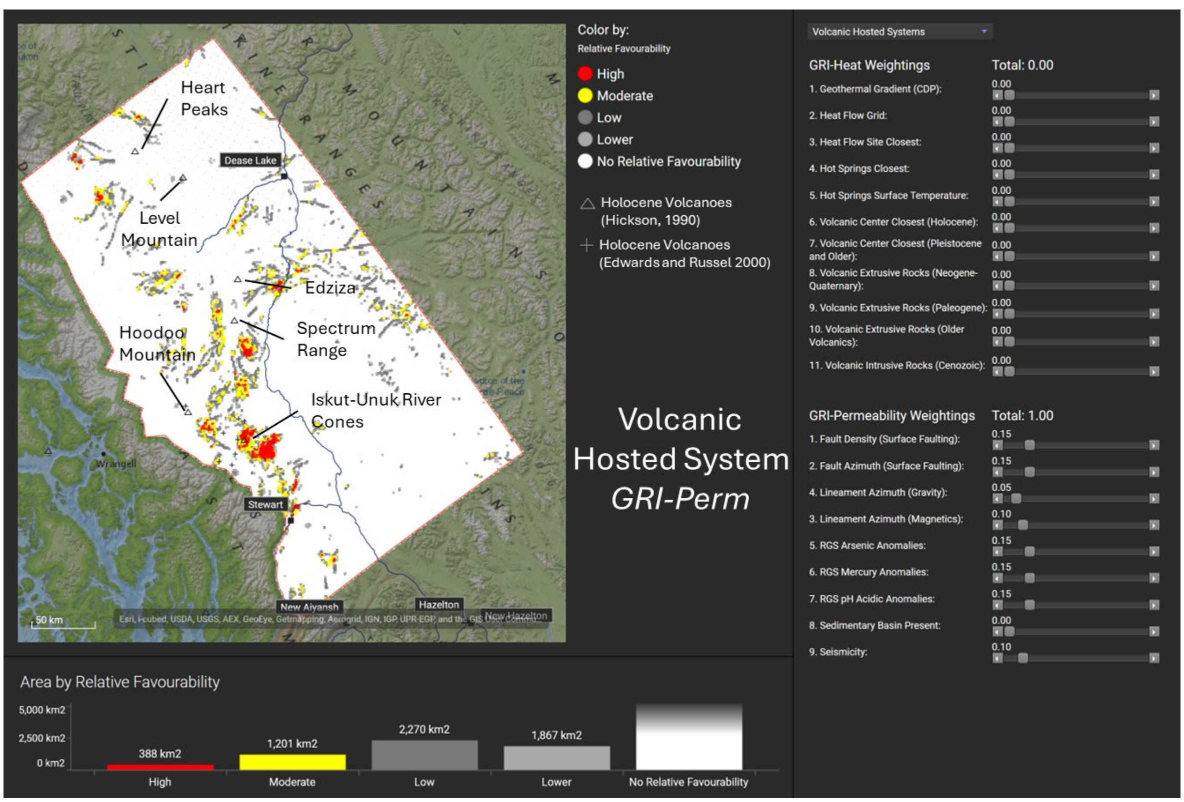
Another feature of this area is the presence of several hot springs (Section 2.6). All of these factors indicate that the area has anomalous heat flow. Without the PF analysis, this area would likely have been discounted due to the basaltic nature of the Holocene volcanism and the presence of mantle xenoliths, indicating rapid transit through the crust (Section 2.7). Additionally, the Eskay mine is located within this area and miners reported the underground workings being anomalously hot and weeping Mercury. These reports have not been substantiated but deserve further investigation.



Chapter 3 Figure 3: Volcanic Hosted System PF analysis Favourability Map



Chapter 3 Figure 4: Volcanic Hosted Systems. GRI-Heat Only

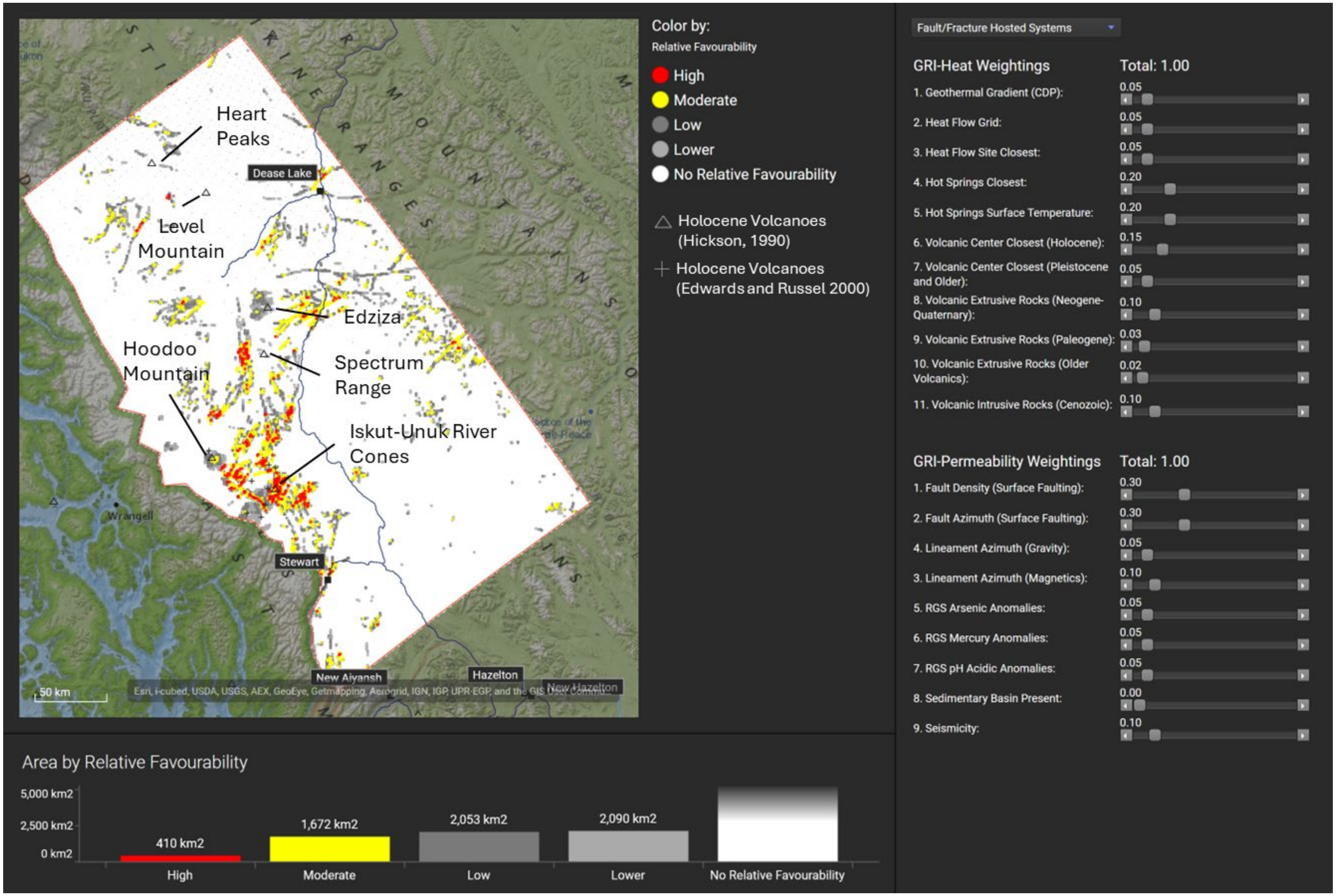


Chapter 3 Figure 5: Volcano Hosted System. GRI-Perm Only

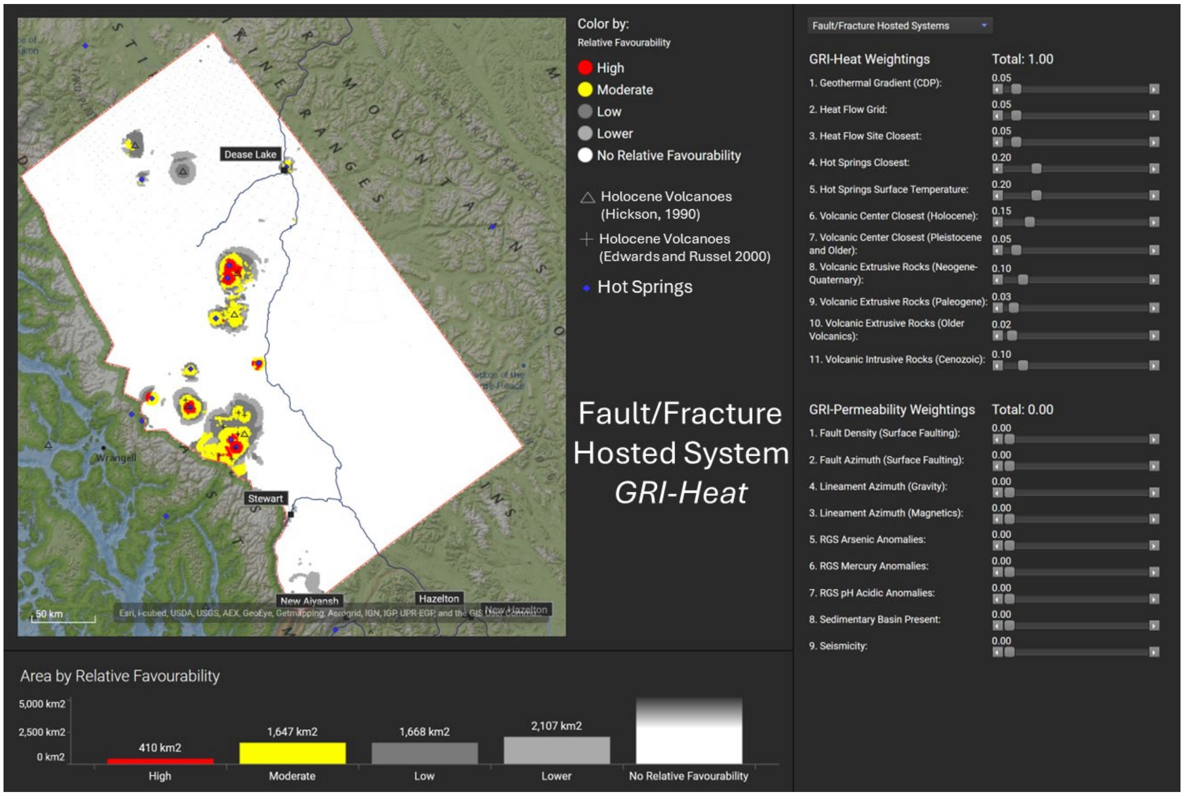
Fault Hosted Systems

Figure 6 presents the final Fault Hosted System PF analysis favourability map. There are higher scoring patches likely following significant fault systems or closely spaced faults. Figure 7 shows the GRI-Perm map. These closely spaced faults favour increased potential for permeability due to brecciation. Faults that are aligned parallel to the principal stress direction (Section 2.4) may be extensional and thus there is potential for deep circulation of meteoric waters. Main drivers for favourability analysis were Fault "size" as mapped (Section 2.3), Fault orientation and Fault Density.

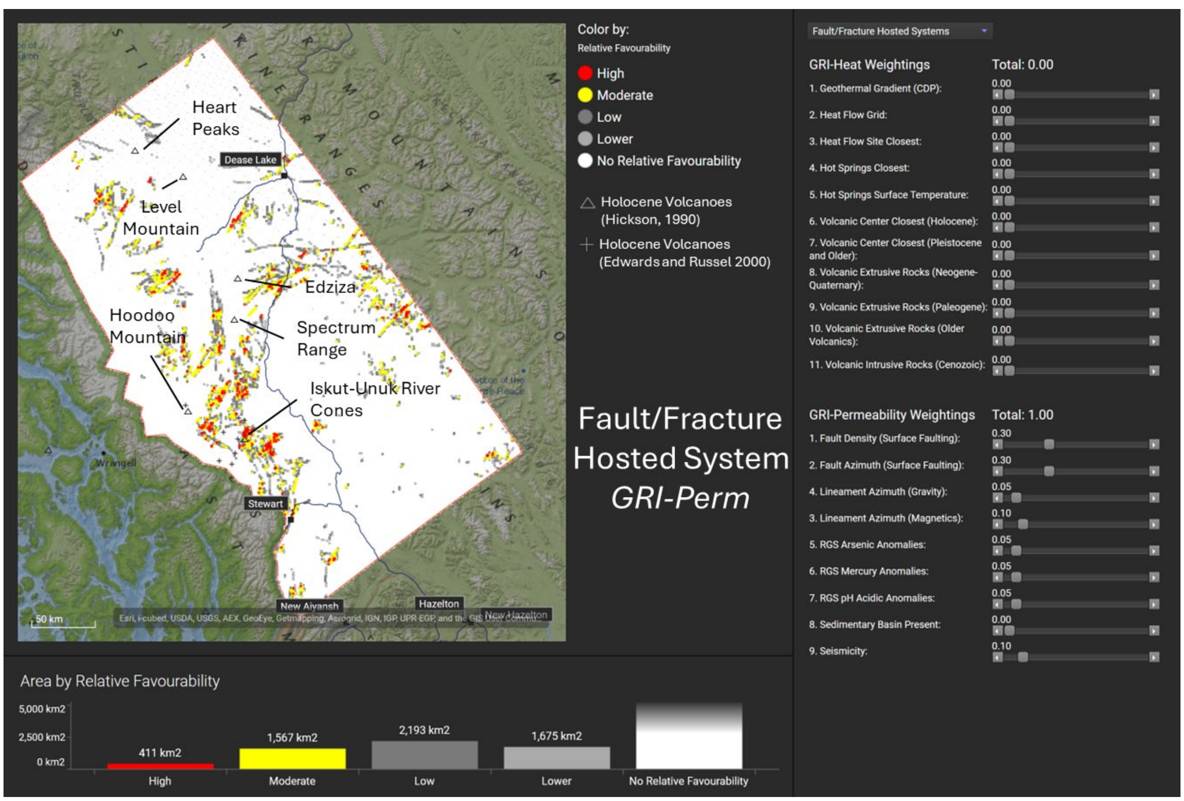
The Iskut-Unuk River cones area shows up strongly on this map, indicating positive favourability for both fault and volcanic hosted systems. Figure 8 shows the GIR-Heat map. The two are likely linked, particularly with the association of hot springs (Section 2.6). This map is strongly dependent on the age, quality and scale of the mapping used to compile the fault information. If the fault density has been underrepresented in some areas due to age, quality or scale of mapping, these areas will have a lower favourability. Benchmarking the mapping with fault density throughout the map area would be one way of assessing this potential bias.



Chapter 3 Figure 6: Fault Hosted System PF analysis favourability map



Chapter 3 Figure 7: Structural (Fault/Fracture) Systems. GRI-Heat Only.



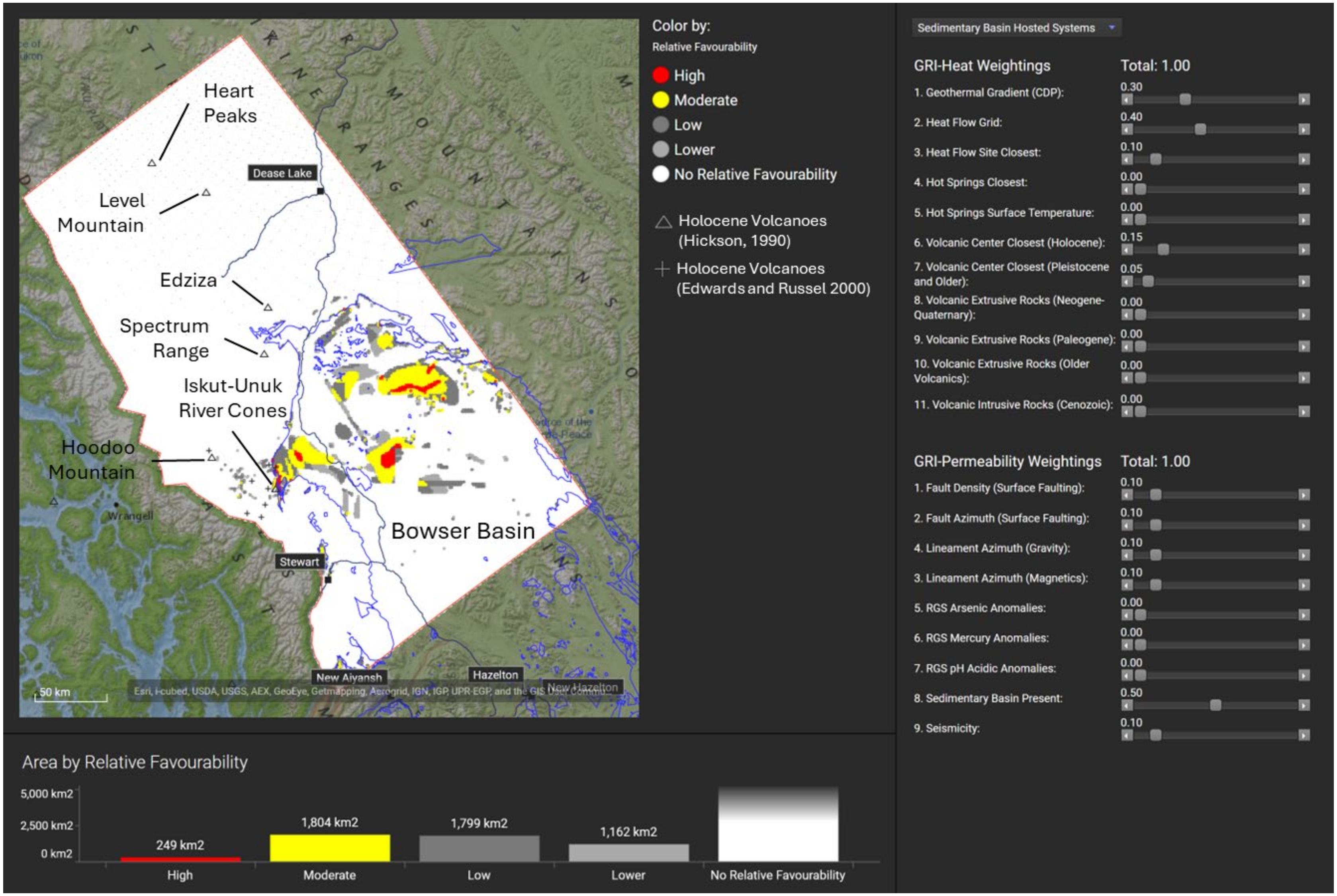
Chapter 3 Figure 8: Structural (Fault/Fracture) Hosted Systems. GRI-Perm Only

Sedimentary Basin Hosted System

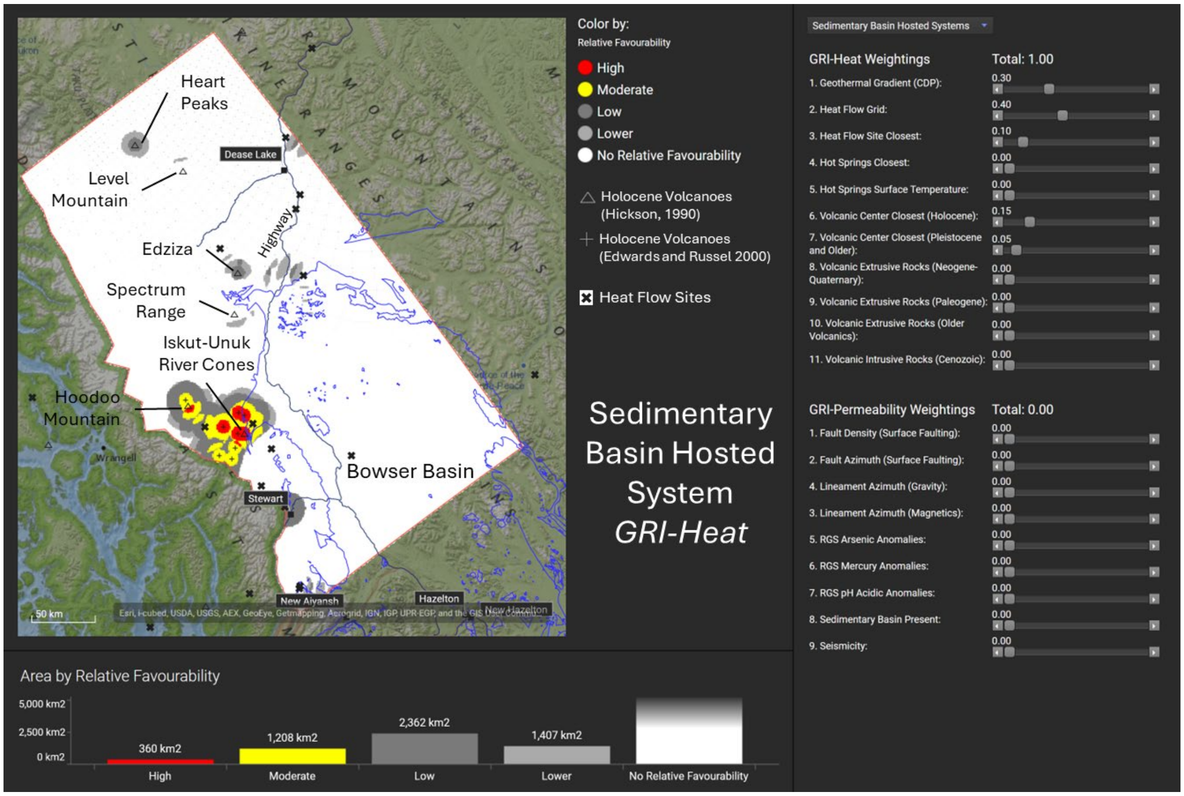
Figure 9 presents the final Sedimentary Basin Hosted System PF analysis favourability map. The favourability result is strongly driven by the presence (or absence) of the Bower Basin, as it is the only sequence of thick sedimentary strata in the project area that has not been dismembered by faulting. It is also the only sedimentary package that has been drilled for hydrocarbons (See Section 2.15). Within the basin, the favourability analysis is strongly weighted to thickness of the basin fill.

GRI-Heat is shown in Figure 10, and it can be seen as only relevant in the region of the Iskut-Unuk River cones at the west margin of the Bowser Basin. The thickness of the Bowser Basin is the main driver for favourability. Depth in a sedimentary basin is a critical factor for the formation of a sediment hosted geothermal system. Gravity and magnetic lineaments interpreted within thicker section of the basin would enhance fracture permeability as shown as red linear features in Figure 11. Hence, deeper sections of the basin generally scored high. A western portion of the basin in the region of the Iskut-Unuk River Cones also had higher scoring grid points due to the presence of high heat flow grid values (and close proximity to heat flow sites) as well as the Holocene volcanism (Figure 10). As the basin sediments are shallow in this area, any geothermal system is more likely to be fault or volcanic hosted.

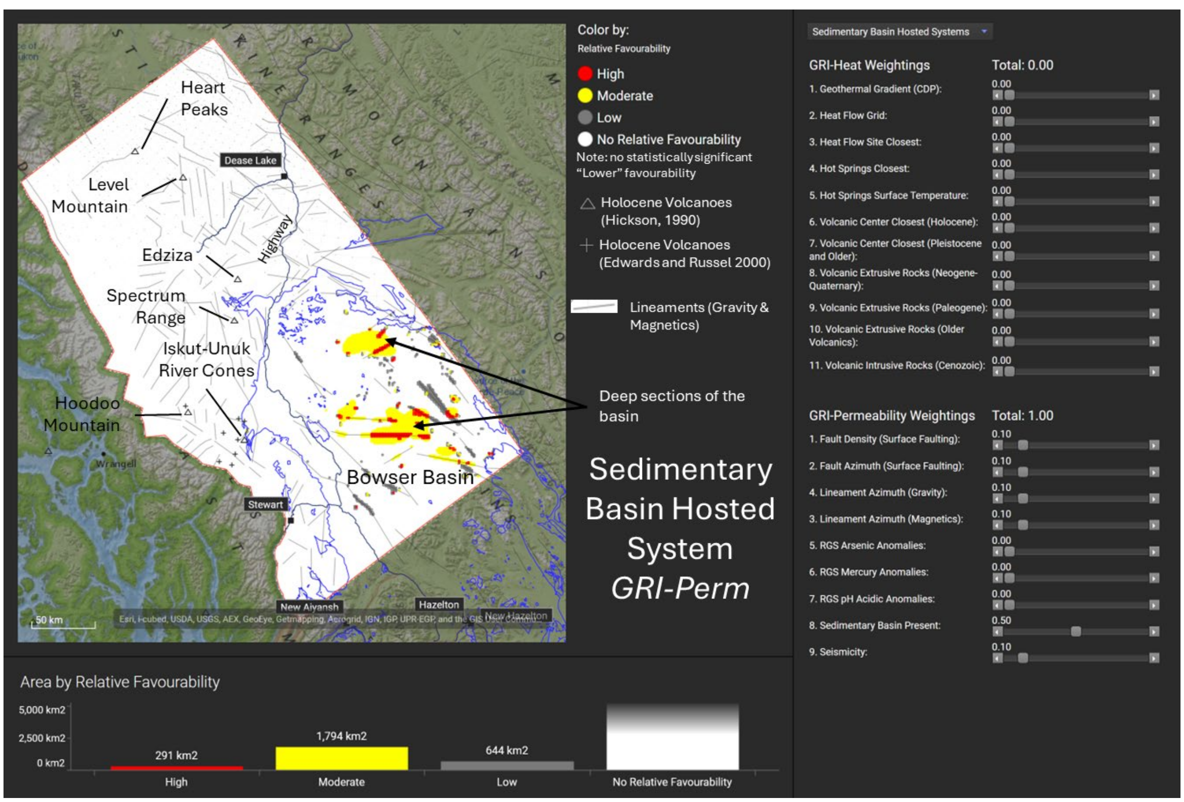
If should be further emphasized that if the target is a sedimentary basin play, the Bowser Basin is the only play in the project area. It must be stressed that minimal information is known about the subsurface. Before investment of exploration funds, the likelihood of finding a geothermal system within the Bowser Basin, relative to finding volcanic or fault hosted systems within the project area would need to be carefully evaluated. The depth data for the basin is tenuous and no evidence of permeable, brine filled aquifers exist.



Chapter 3 Figure 9: Sedimentary Basin Hosted PF analysis favourability Map



Chapter 3 Figure 10: Sedimentary Basin Hosted System. GRI-Heat Only



Chapter 3 Figure 11: Sedimentary Basin Hosted Systems. GRI-Perm Only

Conclusions

Insufficient data exists to produce a favourability map for radiogenic plutons and by inference ultradeep/ultra hot. Data was barely adequate for the analysis of volcanic, fault hosted, and sedimentary basin plays (limited to the Bower Basin). It must be stressed that this analysis provides an estimate of relative favourability only. The hot springs are the only surface manifestation of geothermal systems in the project area and none of these are known to be associated with radiogenic plutons. Additional work could be done to see if analogous areas could be used for comparison and additional analysis of the hot spring data carried out. The hot springs provide the only direct evidence for a geothermal system existing in the subsurface, but certainly these are not the only areas where systems might exist, nor is the presence of a hot spring proof of an extractable resource. Only additional exploration will determine the location, size and temperature of naturally occurring geothermal systems that might exist in the region.

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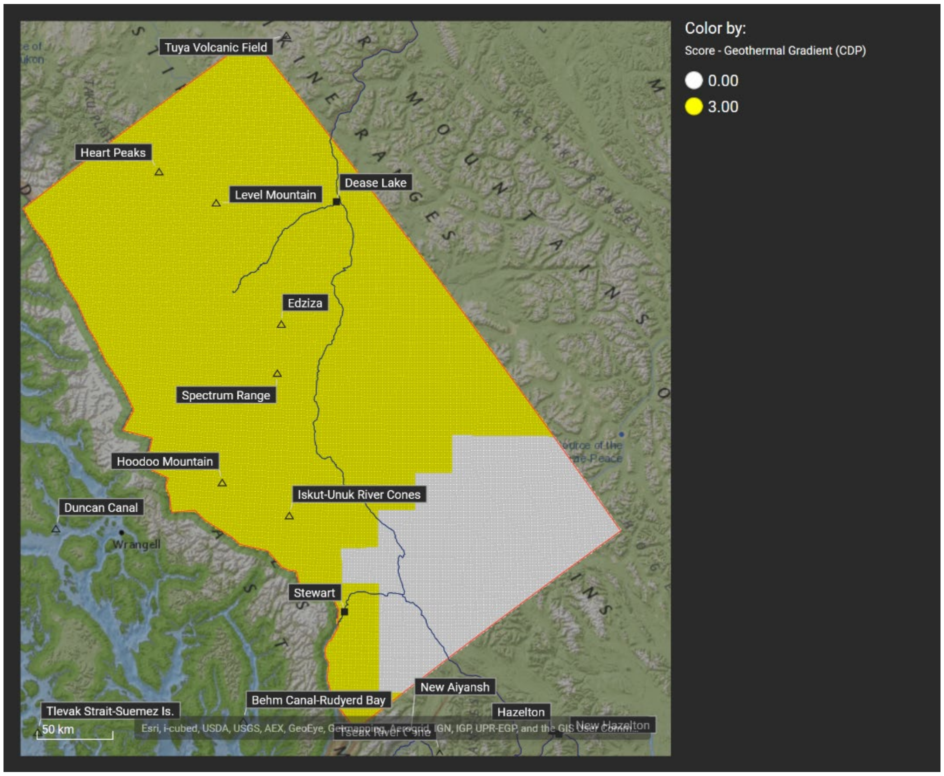
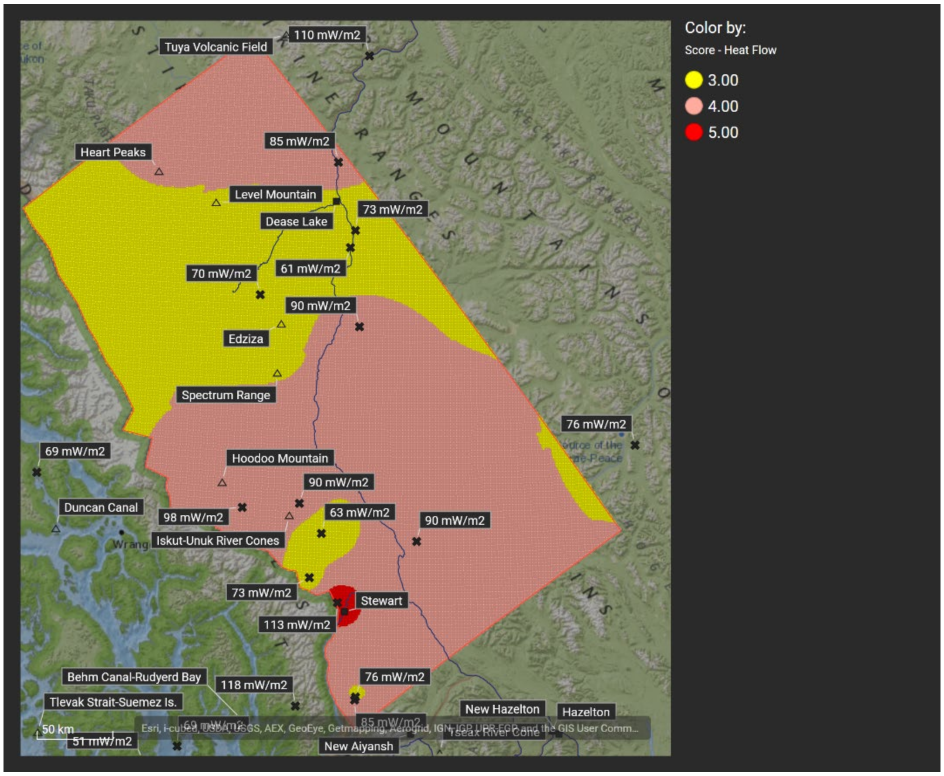
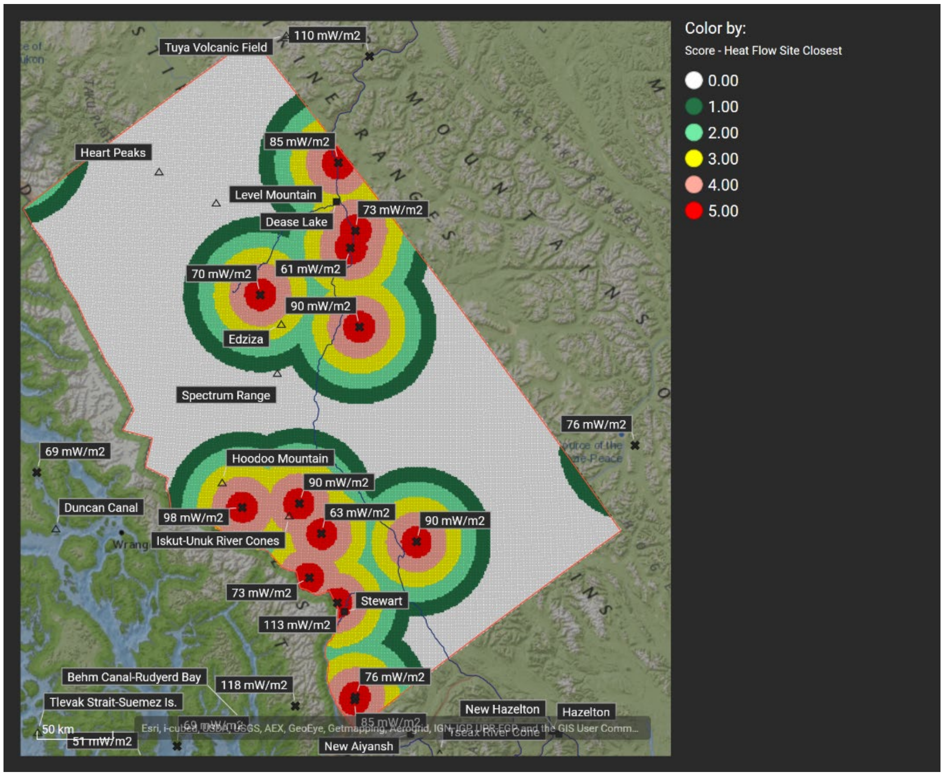
Appendix A: Evidence Layers



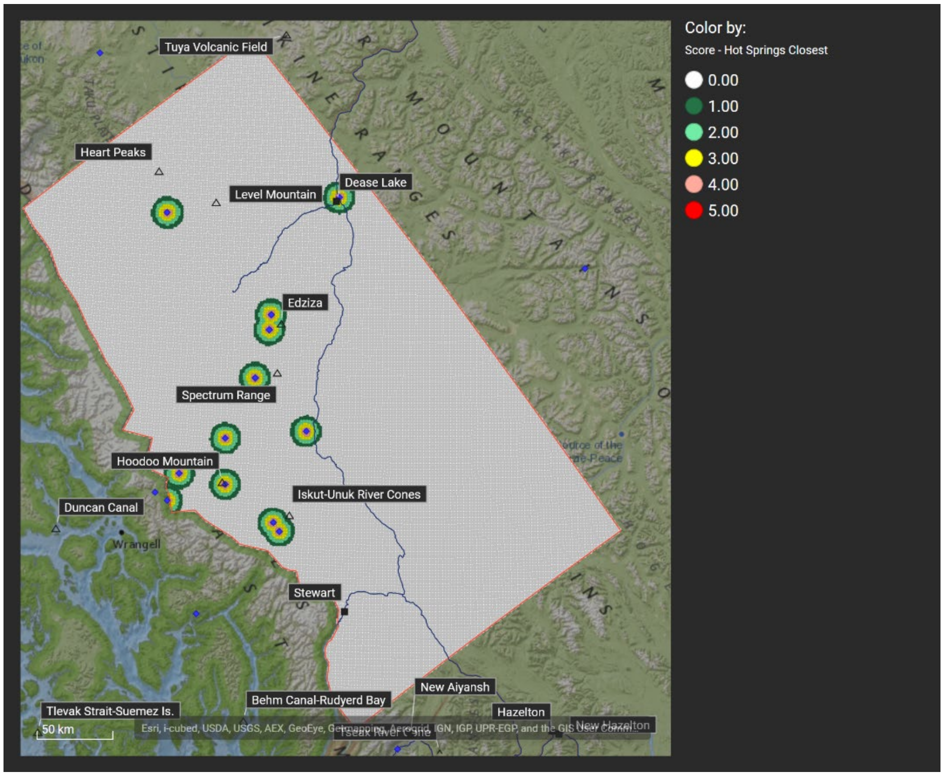
Chapter 3 Figure 12: Geothermal Gradient (CDP)



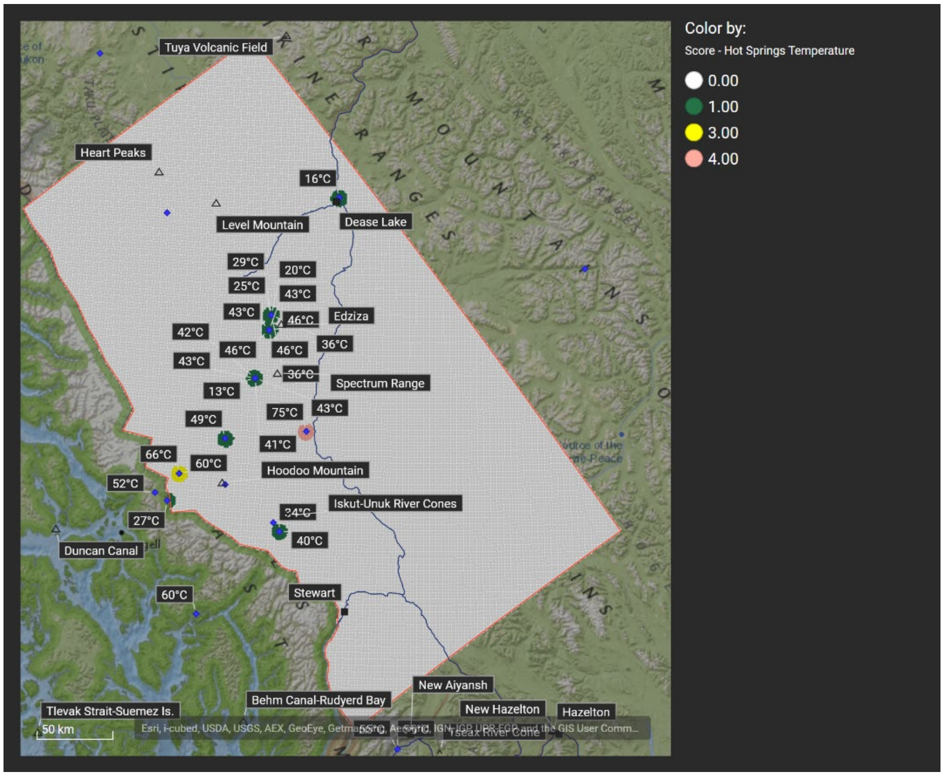
Chapter 3 Figure 13: Heat Flow Grid.



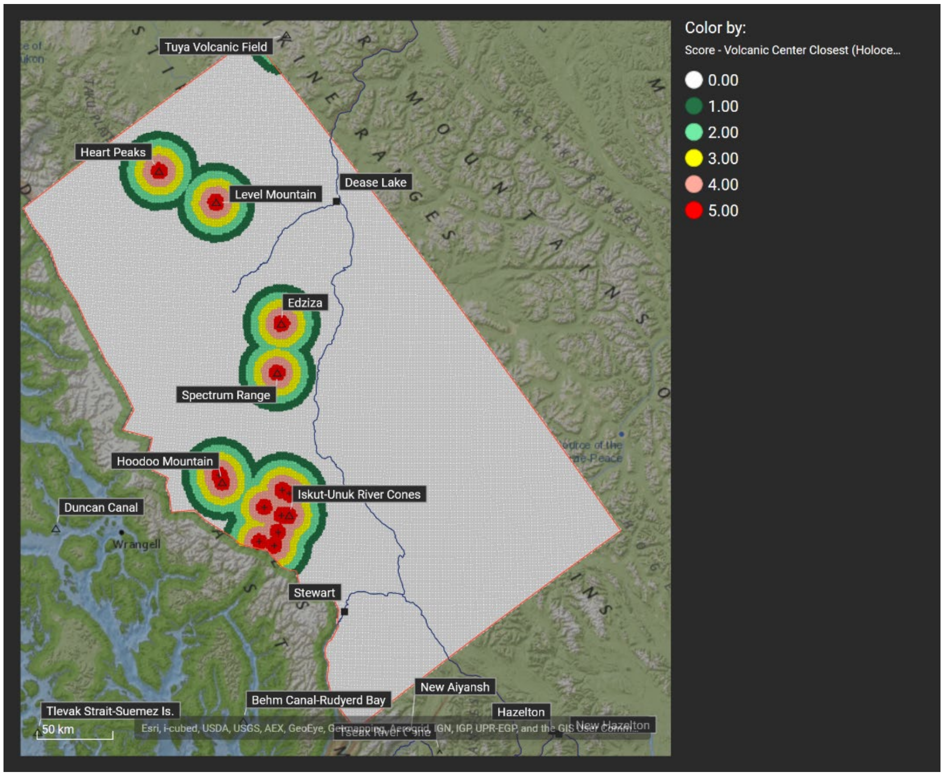
Chapter 3 Figure 14: Heat Flow Site Closest



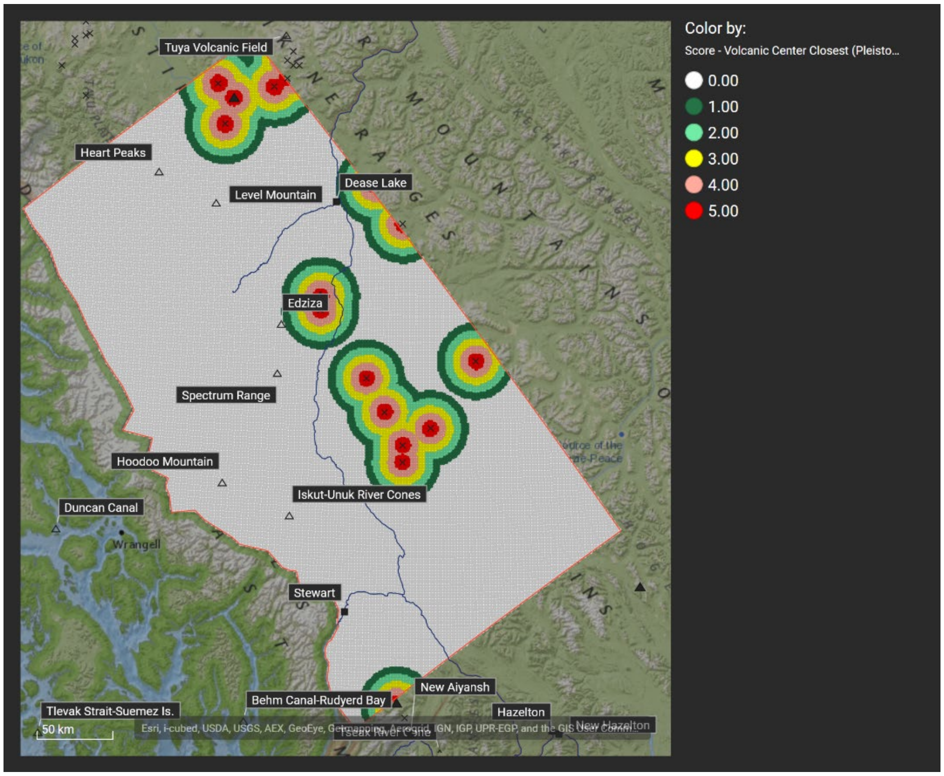
Chapter 3 Figure 15: Hot Springs Closest



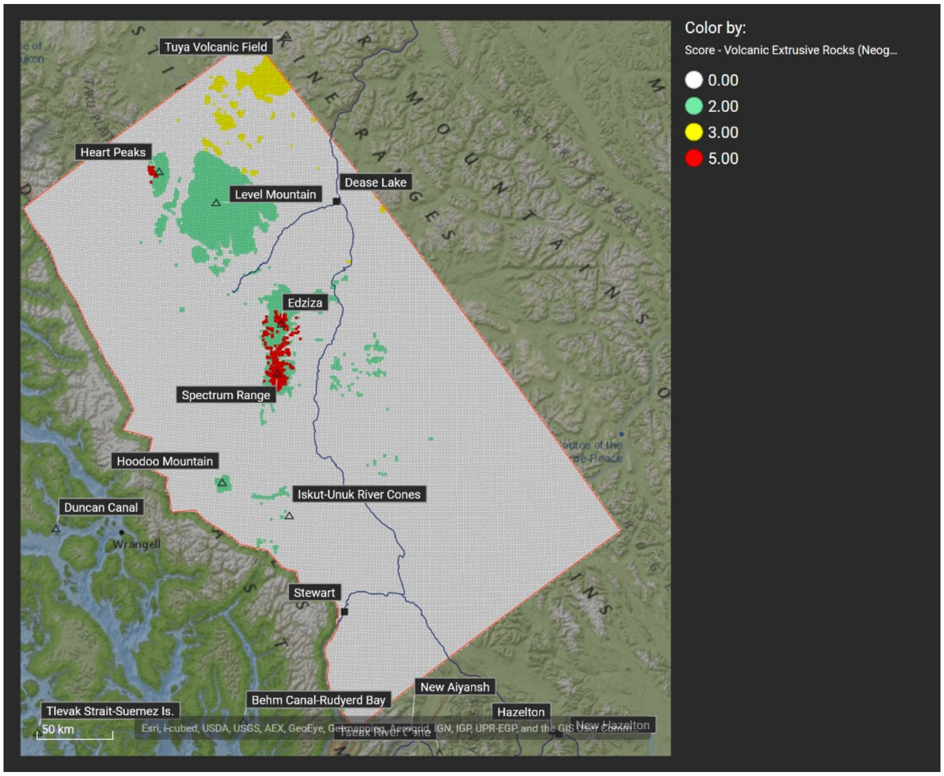
Chapter 3 Figure 16: Hot spring (fluid) measured temperature at the surface.



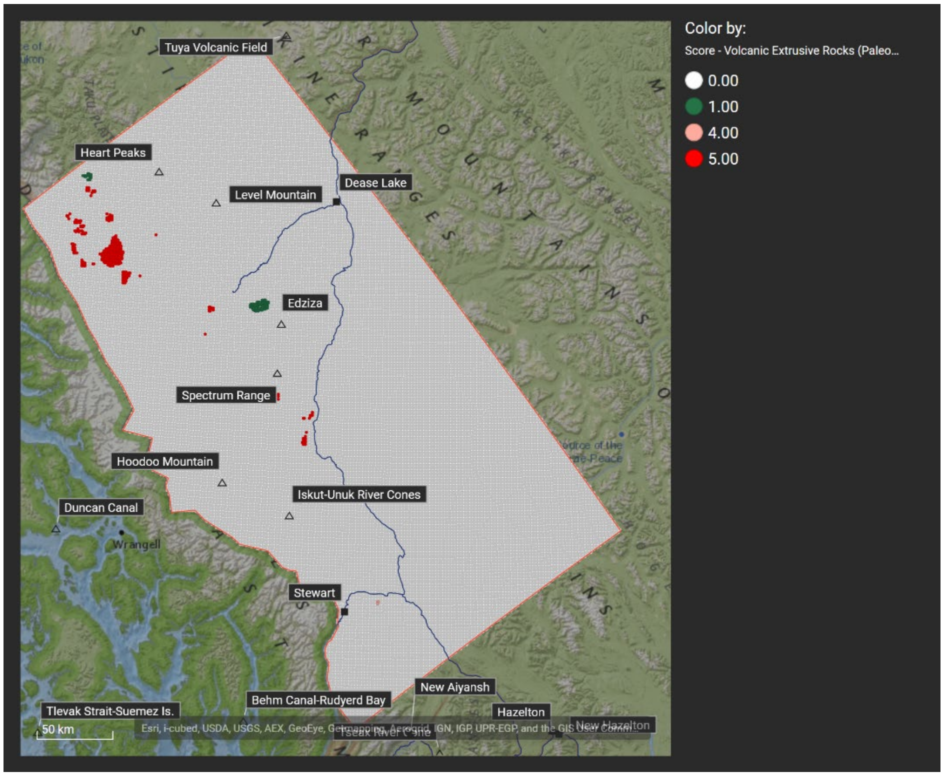
Chapter 3 Figure 17: Volcanic Center Closest (Holocene)



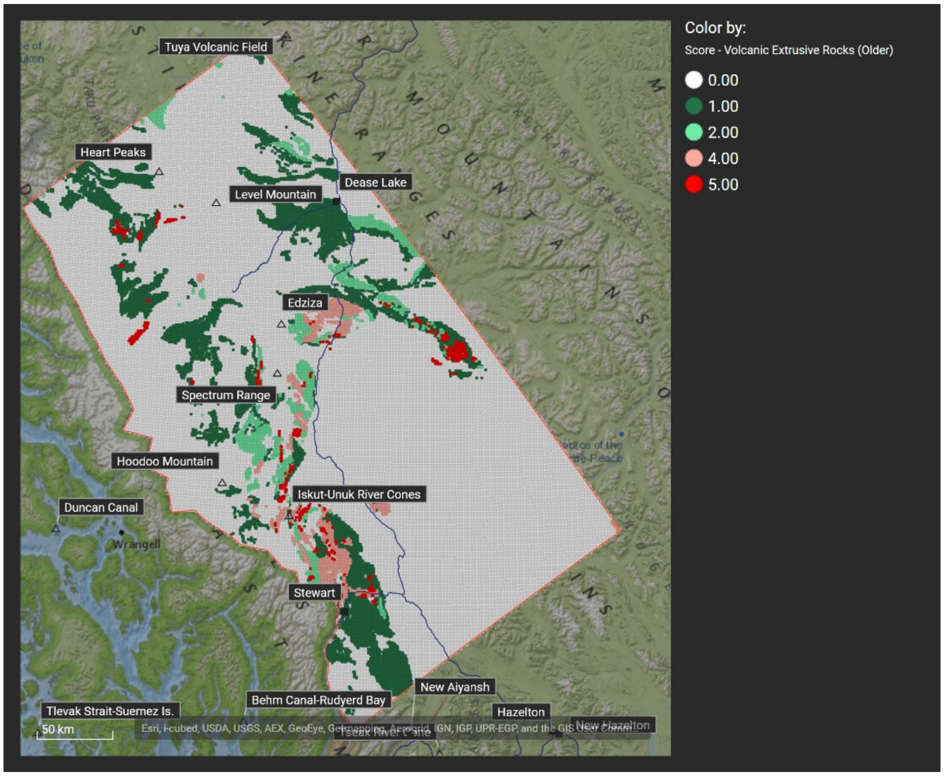
Chapter 3 Figure 18: Volcanic Center Closest (Pleistocene and Older)



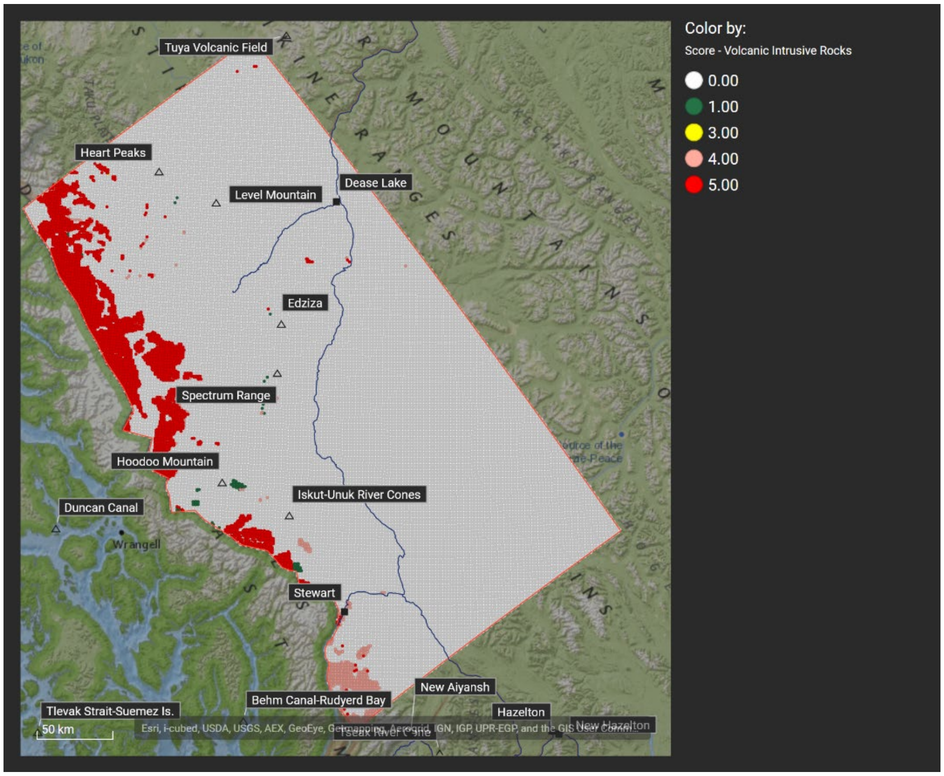
Chapter 3 Figure 19: Volcanic Extrusive Rocks (Neogene-Quaternary).



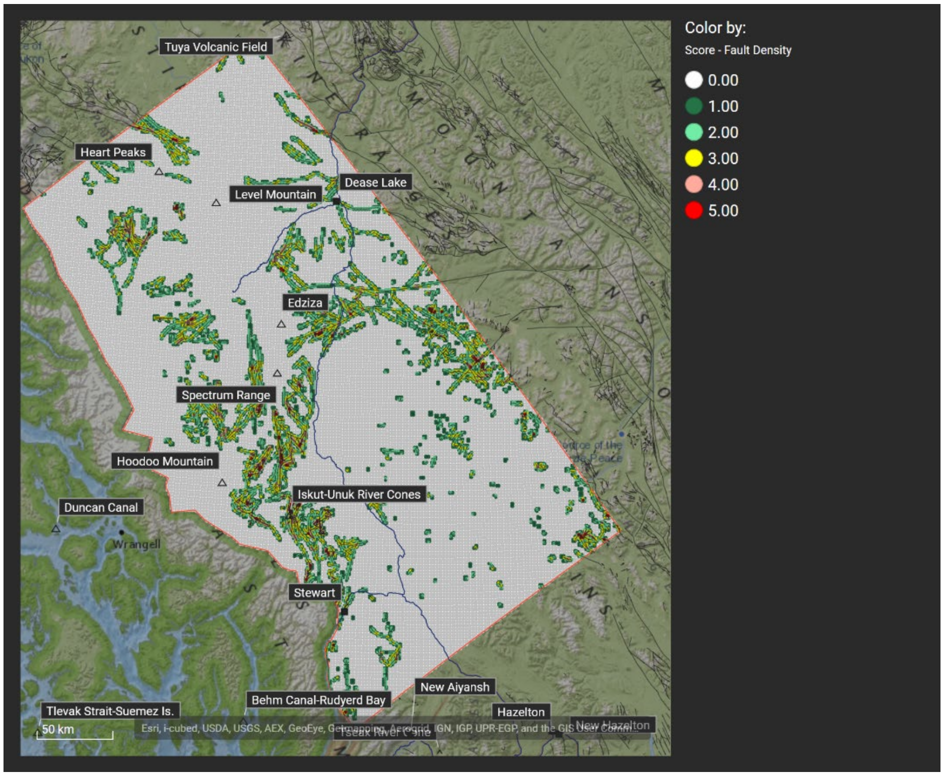
Chapter 3 Figure 20: Volcanic Extrusive Rocks (Paleogene)



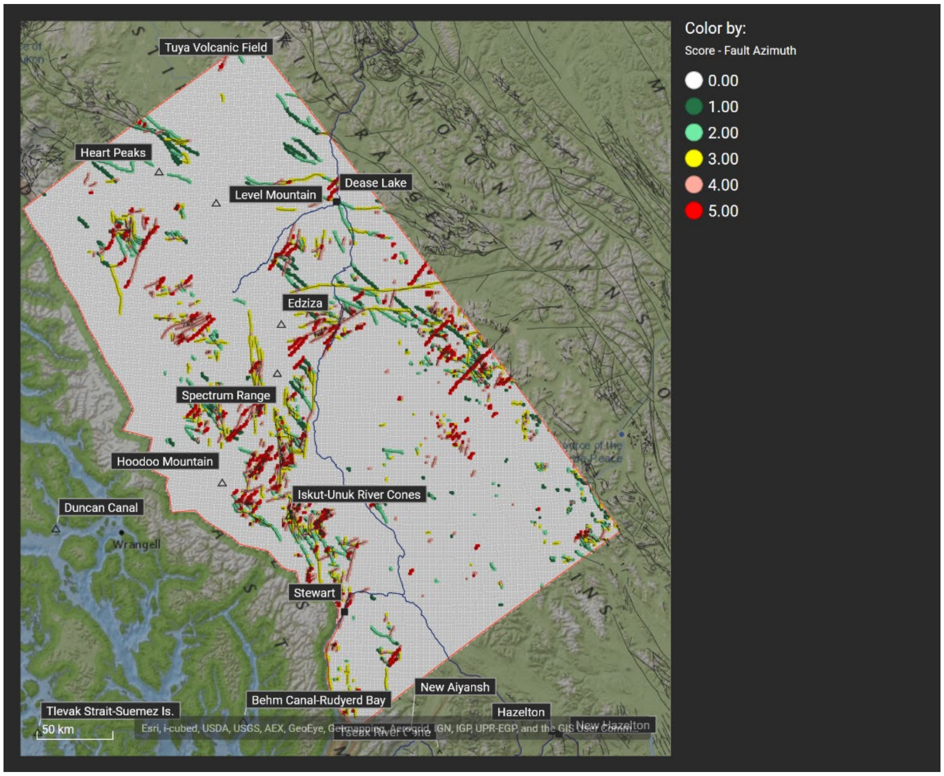
Chapter 3 Figure 21: Volcanic Extrusive Rocks (Older Volcanics)



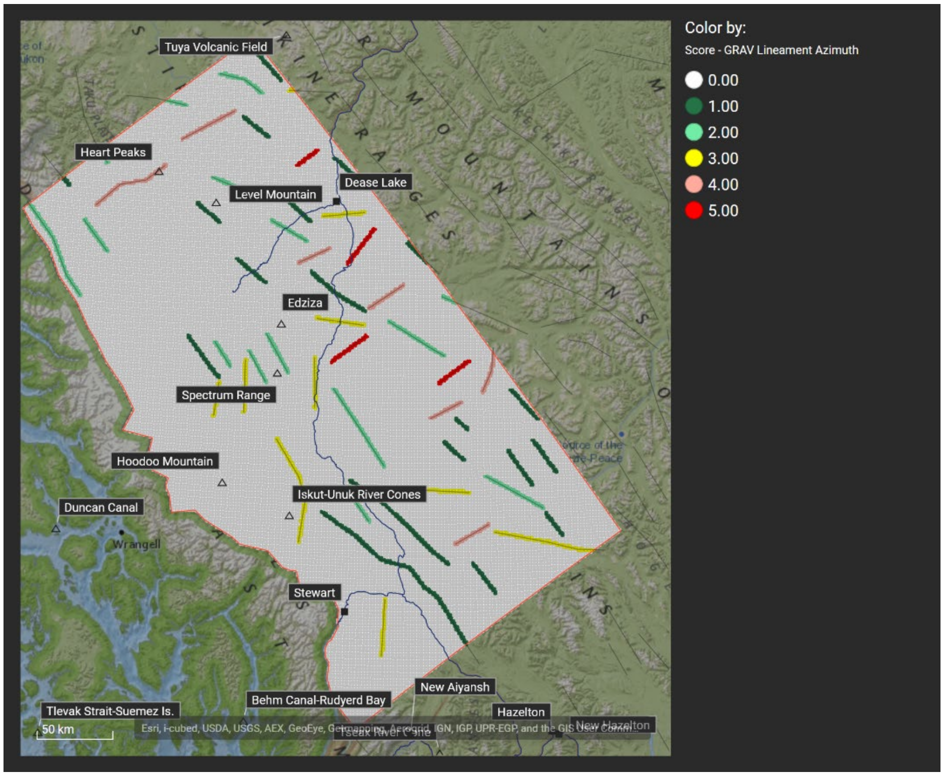
Chapter 3 Figure 22: Volcanic Intrusive Rocks (Cenozoic).



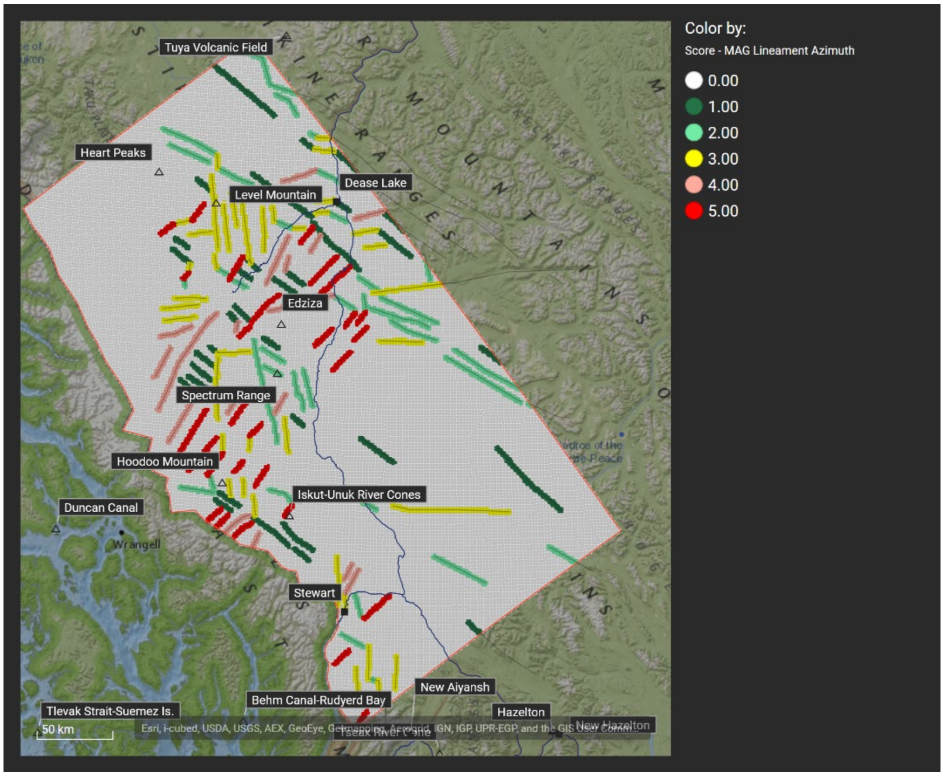
Chapter 3 Figure 23: Fault Density (Surface Faulting)



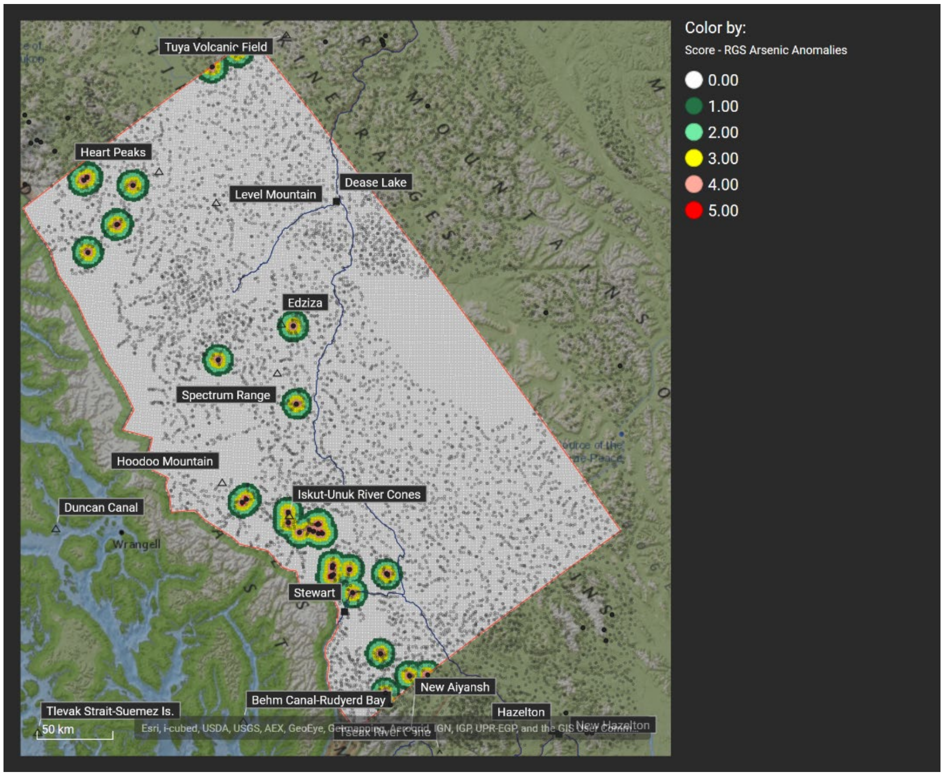
Chapter 3 Figure 24: Fault Azimuth (Surface Faulting)



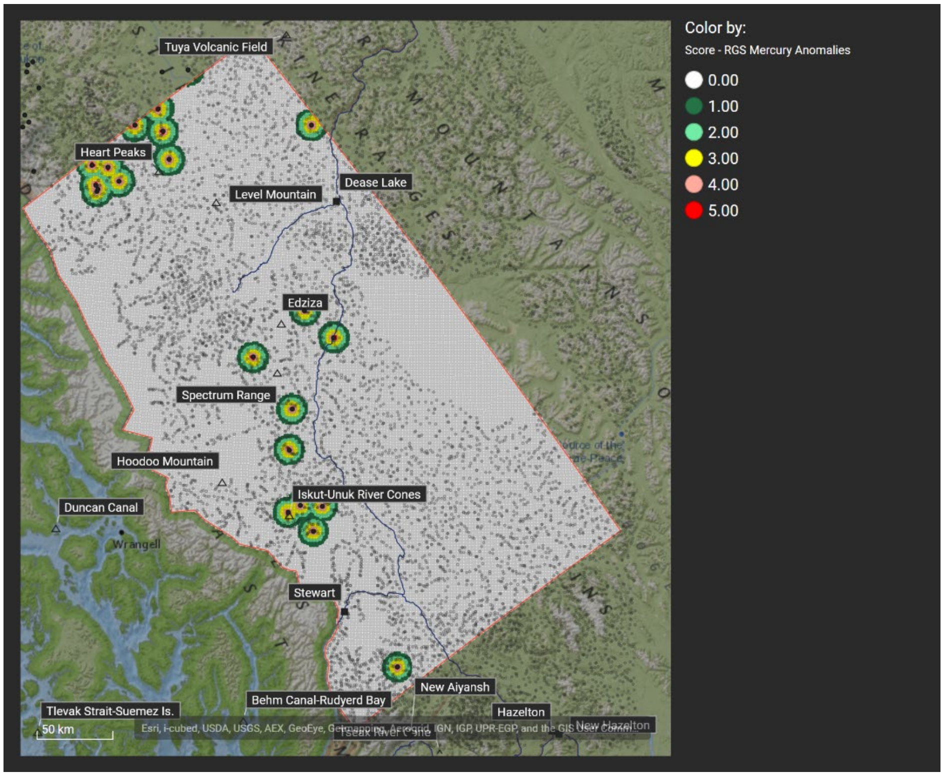
Chapter 3 Figure 25: Lineament Azimuth (Gravity).



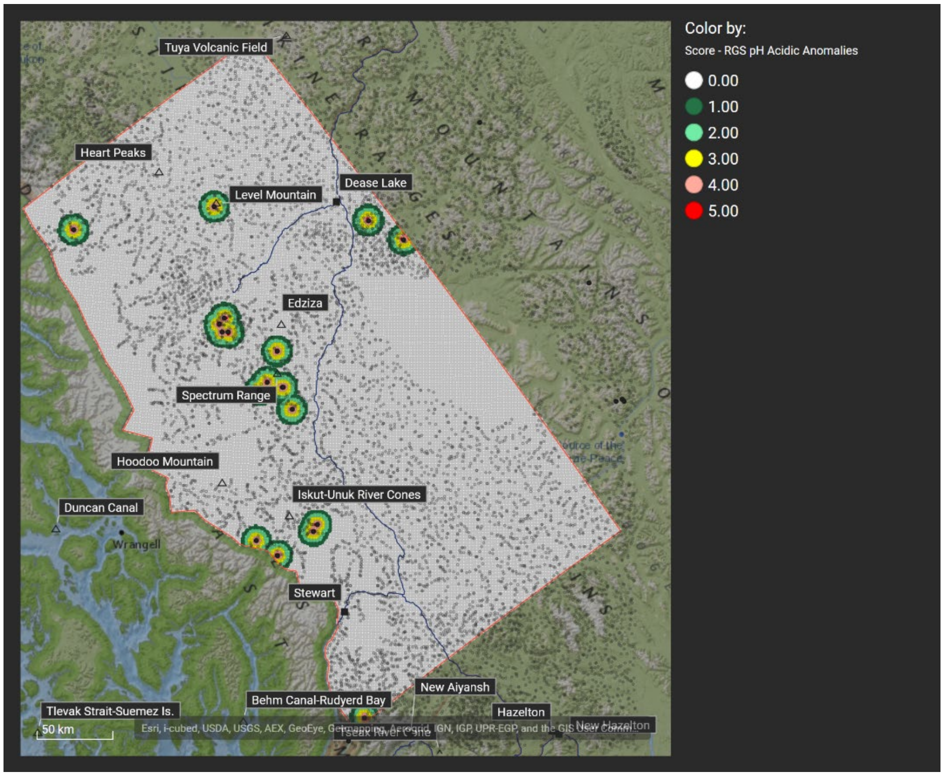
Chapter 3 Figure 26: Lineament Azimuth (Magnetics).



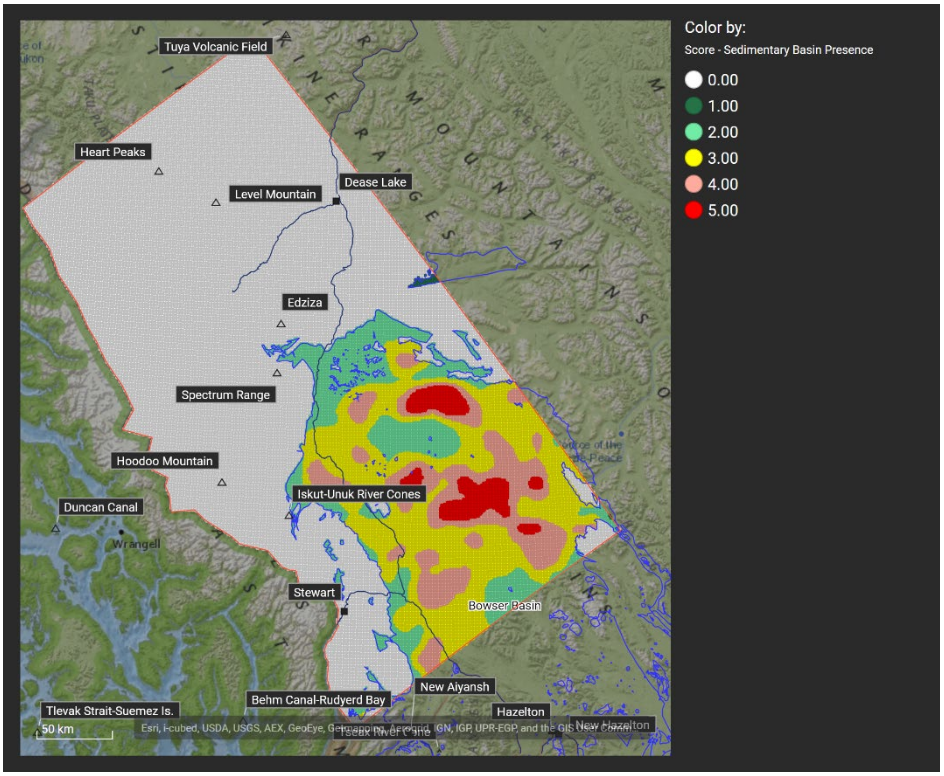
Chapter 3 Figure 27: RGS Arsenic Anomalies



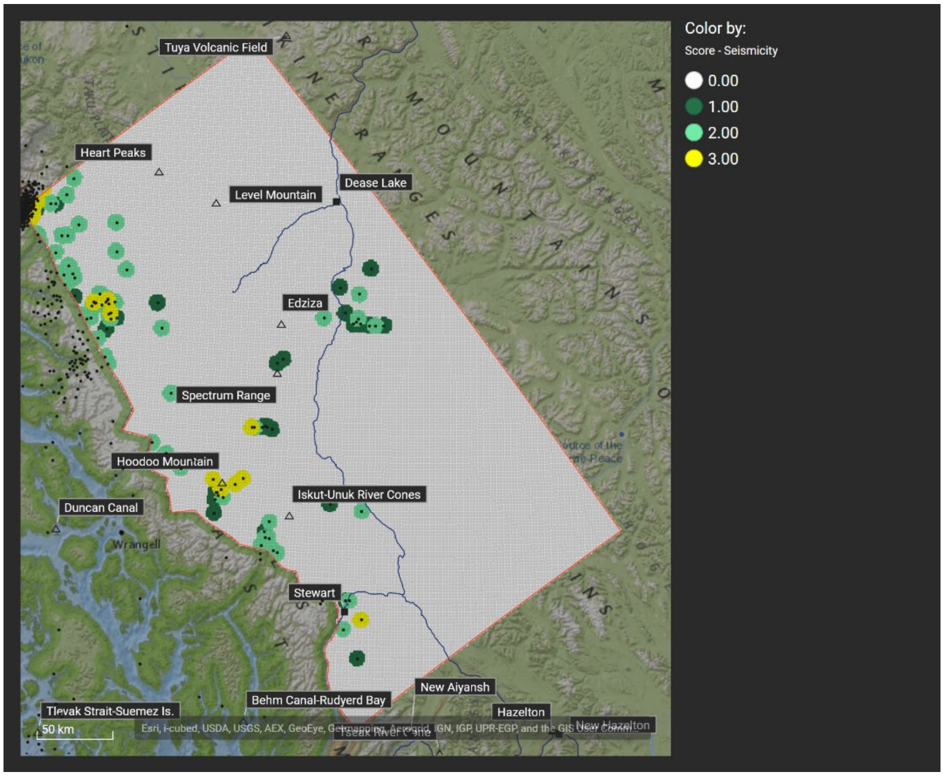
Chapter 3 Figure 28: RGS Mercury Anomalies



Chapter 3 Figure 29: RGS pH Acidic Anomalies



Chapter 3 Figure 30: Sedimentary Basin Present. Blue outline is the Bowser basin



Chapter 3 Figure 31: Seismicity.

Chapter 4: Recommendations for Future Phases

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Overview

This research provides a valuable review of the potential of the project area to host naturally occurring geothermal systems but is greatly impeded by both geological and geographical constraints. The applicability of the PF analysis methodology has not been validated in regions that are data-poor and geologically diverse. However, the study demonstrates that there are areas within the region that are likely to have a higher potential (are more favourable) to host systems than other areas within the region and should receive additional investigation. Phase II studies outline what could be done without field work, but in most cases gathering of additional field data will be required in order to validate the outcomes of this study. Expert opinion, reviewing the data suggests that there are areas that could have high potential for high temperature systems, but considerable additional work will be necessary to identify these systems as to location, temperature and potential size.

This additional work starts with a more detailed review of those areas deemed "favourable" in the analysis. Which data are leading to the conclusion that a geothermal reservoir might be present? What additional information is required to confirm the presence (or absence) of a reservoir? A set of general recommendations is provided for additional work that could be carried out as desk top studies (Phase II) and what requires additional field-based studies (Phase III). It must be stressed, that although the area of interest has been reduced significantly, it is still very large and poorly constrained.

Exploration Recommendations

Neogene and Quaternary volcanic outcrop map.

Foundational geoscience work carried out by the Geological Survey of British Columbia and the Geological Survey of Canada, along with their academic and private sectors partners and contractors, has provided British Columbia with an enviable set of data rich geoscience maps. Further, the availability of these maps and their databases in a publicly available digital format provides researchers and explorationist and significant advantage to other jurisdictions. It is because of this foundational geoscience research that a study such as this one, can provide such a high-level assessment of the area under investigation. The geological map provides complete and reliable coverage of the area of interest at a regional scale, suitable for the favourability analysis. However, it is important to stay updated on any improvements or refinements to the map to ensure that the most current information is available, supporting future geothermal exploration and development. Additionally, as additional investigations proceed, more detailed mapping will be required. It is possible that some of this detailed mapping may be available through partnership with private sector exploration and mining companies currently working in the area or having worked in the area in the past. See Section 2.17 for additional information on mineral exploration taking place in the project area.

Spatial distribution of Cretaceous and older mafic rocks.

Foundational geoscience work carried out by the Geological Survey of British Columbia and the Geological Survey of Canada, along with their academic and private sectors partners and contractors, has provided British Columbia with an enviable set of data rich geoscience maps. Further, the availability of these maps and their databases in a publicly available digital format provides researchers and explorationist and significant advantage to other jurisdictions. It is because of this foundational geoscience research that a study such as this one, can provide an assessment of the area under investigation.

The geological mapping publicly available, provides comprehensive, but regional (small scale) coverage of the entire area of interest, ensuring that no data gaps exist. All relevant geological features, including lithology and faults are well-documented at a resolution available. These data are suitable for the high-level assessment carried out for this report, but are not suitable for detailed, focused or site-specific work. Large scale mapping may be available through mineral exploration companies and when focused areas are found, additional relevant mapping may be available that could be evaluated.

Heat flow mapping

All naturally occurring geothermal systems and technologies for heat extraction are more efficient at higher temperatures (See Section 1.1). Additional temperature gradient boreholes would be a significant contribution to increased understanding of heat flow in the region. Collaboration with mining and exploration companies working in the region may lead to opportunities to drill boreholes. Additionally, mine developments may have water wells or observation wells that could be turned into temporary gradient boreholes. However, other data, such as the presence of Quaternary volcanoes, is a more robust indicator of regional high heat flow. In areas where there is favourability for fault hosted systems, temperature gradient boreholes may be helpful exploration tools to identify if there are thermal anomalies associated with faults or fracture systems. Providing temperature gradients (not just bottom hole temperatures) for all sites would also be a very useful addition to these data. The gradient information can be used to calculate how deep a well needs to be to reach a specific temperature. It makes a factor of two difference between holes drilled in clay and in solid crystalline rocks.

Fracture/fault mapping

Age and orientation of fractures and faulting is an important dataset for favourability mapping (See Section 3.1 for how this data set was used and weighted). Based on the lack of age attributes for the identified faults in the data set compilation, several recommendations for additional work include conducting age dating studies using radiometric or relative dating techniques to enhance understanding of the faulting history. Detailed structural mapping and analysis should be performed to assess fault geometries, orientations, and their relationships with surrounding geological features, providing insights into potential influences on geothermal fluid pathways. Implementing geophysical surveys, such as seismic reflection or resistivity methods, could further investigate the subsurface characteristics of the faults. Additionally, hydrothermal alteration studies should be conducted to identify areas that may indicate favourable geothermal reservoirs through the identification of electrical resistivity clay caps and/or subsurface permeability. Integrating existing geological data with new findings will help create a comprehensive geological model, while establishing a long-term monitoring program can assess fault activity over time, aiding in understanding seismic risks in the region as more infrastructure is established in the area.

Regional stress field information

Regions with many geothermal systems that are not directly associated with Holocene volcanism, are known to occur in extensional (least stress) environments (Faulds et al., 2016) so understanding the regional stress field can be an important indicator for favourability mapping (See Section 3.1 for how this data set was used and weighted). Campaign-style GPS surveys at a dozen or more locations in northwestern British Columbia would dramatically improve our understanding of plate motion and regional stress direction in this portion of the Canadian cordillera. For example, plate motions in the Alaska panhandle are estimated at ~2-5 mm/year towards the N and NW. This contrasts with an estimate of ~2±1 mm/year towards the NE at Dease Lake within the project area. Plate motions between these two areas have not been measured. Additional GPS measurements would help constrain the changes in magnitude and direction of plate motion across northwestern British Columbia and shed light on regional stress directions. Other datasets that could be used to invert stress fields are earthquake focal mechanisms and borehole caliper or image logs. Given the wealth of mining activity in the region and the lack of requirements to seal non-artesian holes, there may be a large number of boreholes available for re-entry to collect data required to resolve local and regional stress fields, as well as additional industry-held data.

Seismicity data

Recording, collecting and analysis of seismic data is a federally run program through the Geological Survey of Canada. Recent seismicity is an important dataset to investigate for geothermal exploration. Seismic activity can indicate permeability along fault lines and can also provide information on the regional stress field. Additionally, seismic activity related to volcanic centers may indicate movement of magma or cooling of magma bodies. The seismic data from the project area is limited because sensors and recordings are not optimized for this region in terms of density and sensitivity. If better data could be collected, a number of studies (some that would utilise existing data and others that would require data collection) that could be undertaken to address key knowledge gaps and better assess earthquake hazards in the region.

For example, existing seismic data (especially the US array data and other temporary deployments through the region) could be used to better locate select earthquakes (location and focal depths). The modern seismic data could be used to obtain focal mechanisms and the crustal stress field for select earthquakes (Gosselin et al., 2024). A search for existing Lidar data could be undertaken (e.g., Lidar BC https://lidar.gov.bc.ca/) to help assess fault movements. Based on these studies, and more detailed seismicity studies, additional targeted airborne or drone LiDAR data (Finley et al., 2022) could be undertaken.

Other data that could be collected to better assess earthquake hazards include:

- temporary deployment of seismic stations for targeted areas;
- deployments of DAS technology to record and locate seismicity in areas of interest;
- electrical resistivity tomography, geological and paleo-seismology studies, as required.

Fluid Geochemistry

In addition to Holocene volcanic activity, hot springs and thermal features are direct evidence of thermal energy in the subsurface. These features may form due to deep circulation on faults or near recently active volcanic centers. Their presence is an important indicator of subsurface heat and as such was given a high weighting factor in the PF analysis (see Section 3.1). The work done by Piteau, D. R. and Associates Ltd. (1988) is considered adequate for application of the PF analysis methodology, as the locations were used as the main weighing factor. However, as already noted, modern sampling and analysis would likely contribute significantly to increased understanding of the source of the thermal waters and their evolution. Many of the major ion analyses reported in Hickson et al., 2016 are from unpublished data, therefore is it recommended to either re-check the sources or re-sample for Sphaler Creek and Iskut River, as these hot springs do not have any published data. Additionally, more modern triangular graphically representations may provide helpful insight into the evolution of the fluids.

Additionally, steam was spotted at a location near Galore Creek, by the headwaters of Scud River (Holbek, 2025) and unconfirmed reports of heat in the underground working of the (now abandoned) Eskay Creek mine should be investigated.

Quaternary Volcanism

As heat is the primary driver of the favourability analysis, understanding the volcanic history of the region is a key element of favourability mapping. The foundational volcanic history of the area is reasonably well established from the perspective of an input data set for a high level regional geothermal favourability study. Much more detailed work will be required to inform the decisions as to targeting for a volcanic hosted geothermal system. This work will required detailed mapping including dating of the deposits. Geochemical studies to determine crystallization history and potential for magma chambers as well as crystallization timelines. Detailed gravity and aeromagnetic studies to ascertain if there are any remnants of volcanic deposits below glacial fluvial deposits, or through heavily forested areas. In areas where dykes are present, dating and structural studies on the dykes would be beneficial.

Regional gravity data

Regional gravity data is a useful tool for understanding foundational geology and is another data set supported financially by both federal and provincial governments. These data provide a non-invasive (i.e. no drilling) window into the structure of the deep subsurface. As geothermal systems are strongly controlled pre-existing geological architectures, gravity studies are key. It is fortunate that these data have been collected for the map area. Without the gravity data and magnetic data, understanding of the Bowser Basin depth would be significantly limited. These data were adequate for this regional study, but if high resolution data exists over favourable geothermal areas, additional analysis would be warranted. It is possible that access to high resolution gravity data through partnership with private sector exploration and mining companies currently working in the area, or have worked in the area in the past, may be possible. See Section 2.17 for additional information on mineral exploration taking place in the project area.

Regional magnetic data

As with gravity data, government supported acquisition of these data is a tremendous asset to studies such as this one. The foundational architecture of the cordillera is key for exploration for mineral resources, including geothermal energy. It is possible that access to high resolution gravity data through partnership with private sector exploration and mining companies currently working in the area, or have worked in the area in the past, may be possible. See Section 2.17 for additional information on mineral exploration taking place in the project area. Additionally, it is known that some high-resolution magnetic data does exist. It was beyond the time constraints of this study to review and integrate the information into the favourability analysis, but if there is coincidence of favourable area with high resolution magnetic data, it should be analyzed.

Magnetotelluric data

Magnetotelluric data collected to target upper crustal geothermal systems (1 to 5 km) is a key data set for geothermal exploration. No such data exists in the area. It is possible that some EM surveys have been carried out as part of mineral exploration, but none have been identified. New MT surveys, purpose designed for geothermal exploration would have much more closely spaced MT stations in order to image the upper 1 to 5 kilometers where most geothermal resources are extracted from. These surveys are relatively cost effective for the surface area covered and when combined with surface mapping, gravity and magnetics provide a robust image of the subsurface suitable for geothermal assessment.

Physical rock properties of specific geological units (transmissivity and conductivity).

At an advanced exploration stage, physical rock properties are an important parameter to have information on for specific rock units. Typically, these properties are tested in rock cuttings and core from exploration boreholes. Prior to drilling, field sampling of exposed sedimentary units may provide some valuable clues as to the characteristics of the same units in the subsurface. Understanding the transmissivity of the units is best carried out using flow testing in drilled boreholes. Currently a knowledge gap for both geothermal and CCUS (carbon (CO_2) storage) favourability mapping is information on physical rock properties of potential target units. A comprehensive dataset could be created that would serve multiple purposes, including geothermal and mineral exploration.

Geochemical analysis that includes (U, Th and K) for radiogenic plutons and spatial distribution

Data in the project area are very limited and do not highlight any major intrusive body with a high enough radiogenic heat production value for development of a hydrothermal system. This may be a data gap that should be filled with additional analysis, especially where plutons are disrupted by recent faulting as these may be sites where a naturally occurring geothermal system might form as in the case of Chena Hot Springs, Alaska. It is possible that access to additional analyses may be available through partnership with private sector exploration and mining companies currently working in the area or have worked in the area in the past. See Section 2.17 for additional information on mineral exploration taking place in the project area.

Petrological/geochemical whole rock XRF analysis

Data in the project area are limited and do not provide sufficient information to base any conclusions as to the presence of present day (i.e. active) hydrothermal systems. It is possible that access to additional analyses may be available through partnership with private sector exploration and mining companies currently working in the area or have worked in the area in the past. See Section 2.17 for additional information on mineral exploration taking place in the project area.

Regional geochemical surveys are another government supported data set that provides significant information for exploration for a variety of different resources. As used here, Mercury and Arsenic were used as indicators of present day (i.e. active). In the project area, analyses combined with other relevant data related to potentially important geothermal anomalies, additional data might be important. Some possibilities about areas of significance include:

- Does additional geochemical data exist in detailed government or mineral deposit reports (e.g., Minfile and assessment reports by mining companies).

- Should specific geological units be identified as significant, they can separately be evaluated statistically, given adequate sample density, for geochemical significant features—**RDVM** can help.
- Is there a justifiable need for additional field geochemical sampling and/or geological mapping

Curie Point Depth mapping.

Curie Point depth mapping was considered a fast way to assess large regions of the globe for areas that are hotter than surrounding regions. Although it has been useful to augment other data, the information is too coarse to be of much value, but it did differentiate the Bower Basin as having a lower Curie point than the rest of the region. No additional work is required.

Hyperspectral/ASTER satellite images, Landsat or other image sets

The only satellite imagery used was Landsat, and these data did not factor into the weighting analysis. This data set is free for downloading, and although Landsat data is not optimal for geothermal exploration or resource confirmation, it did provide some quality imagery. High resolution imagery can be purchased from various services such as Apollo Mapping's Pléiades Neo satellite for $22.50/sq km or $1,876,815 for the total project area of 83,414 sq km. Purchase of imagery was outside the budget of the project and would not have been an effective tool over so large an area. If a smaller focused area is chosen for future investigation, purchase of imagery may assist exploration planning.

Bowser Basin sedimentary stratigraphy

Limited information exists for the deep subsurface of the Bower Basin. Drilling exploratory stratigraphic boreholes would provide valuable insight into the vertical distribution and lateral continuity of geological units at depth, allowing for a more precise characterization of subsurface layers. This would not only improve our understanding of the stratigraphic framework but also enable more accurate assessments of key parameters such as porosity, lithology, and mineral composition. However, being a relatively fragmented and deformed basin filled with marine to terrestrial sediments, the lateral continuity of units is likely to be low even across closely-spaced boreholes. This could be tested by examining the correlatability of petrophysically-defined sequences across boreholes. This deeper understanding is critical for optimizing the placement and efficiency of deep geothermal systems within sedimentary basins, where the permeability and thermal conductivity of rocks are key factors influencing heat extraction efficiency and long-term sustainability.

Existing borehole locations and relevant data.

Subsurface information relevant to geothermal and CCUS (carbon (CO_2) storage) is lacking in the area due to the paucity of boreholes and the original purpose for drilling the boreholes that do exist. As a first step to advancing understanding of the region for geothermal exploration, additional temperature gradient boreholes should be drilled. A low-cost option may be to partner with mineral exploration companies that could have boreholes of opportunity that could be used for gradient measurements. Following the gathering of additional information from these boreholes, targeted geophysics could be carried out in order to further reduce the area of interest for additional studies. Larger diameter boreholes should target areas with promising geological and geothermal characteristics, as identified through existing data, new temperature gradient boreholes and additional geophysics (see Section 1.2). A comprehensive exploration program will not only improve resource characterization but also facilitate the development of sustainable geothermal energy solutions.

Future work

Phase II Recommendations

This Phase I study investigated what regional datasets were available and manipulatable within the time frame of the study (roughly 12 weeks). These data were then integrated, and a data analytics methodology (Play Fairway) was applied. The favourability maps provide focus areas to continue investigations as to the existence (or not) of naturally occurring geothermal systems. The PF analysis provided proof that the region is best separated into two sectors – the Bowser Basin geological area, and the rest of the map, dominated by Quaternary volcanism and ruggedly uplifted mountains. Further, the analysis demonstrates the limitation of the application of the PF analysis methodology in a data-poor region, biased by topography and geography. The results must be carefully considered as they may be misleading.

The favourability maps produced for this report should not be used to guide investment in exploration and large-scale regional planning, without the involvement of qualified geoscientists and further analysis. The maps are merely tools to demonstrate what is known and what remains unknown, informing the next Phase of analysis. This next phase is defining focus areas for detailed assessment, and identifying the geoscientific studies required to fully understand the geothermal development potential within a specified region of interest.

Creating a comprehensive geothermal strategy for the region is recommended. This strategy would evaluate the geologically-driven, rather than the geospatially driven prospect assessment integrating it with infrastructure considerations. By working through an analysis that focuses on those areas for which there is more geothermally relevant information (i.e. around hot springs and Holocene volcanic centers) a better perspective of the region might be gained.

Part of the study was to reach out to mining companies and explorers working in the area (See Section 2.17). Although several responded and indicated they may have relevant data and/or were willing to work with investigators, it was not possible to integrate this information in the time frame of the project. An important next set is to capitalize on these contacts by following up with the connections. As a next step, now that the data has been effectively filtered by the PF analysis is to identify a list of priority (focus) areas to integrate mineral exploration datasets as part of an ongoing desktop data review.

The proposed Phase II work would encompass reviewing historical technical assessment reports for usability of data, whether digitization will be required, an estimate of time, and categorized by the priority areas identified in the current study favourability mapping. Following up relatively quickly is important as personnel for mining projects change, so it is important to stay informed of changes in organizational structure of companies. The mining industry landscape continues to change with advancements in technologies, as well as possible mergers or acquisitions, changing the ownership or governance structure of a project.

As discovered in the current study, understanding who the most appropriate contact(s) is/are for follow up can be a time-consuming endeavor. Possible contacts include personnel at the appropriate First Nation offices, mining personnel in charge of environmental permitting and land use considerations, data geoscientists (VP Exploration, Chief Geologist), past workers, community members, industry contacts, etc.

Infrastructure is also a consideration in undertaking additional studies. An updated infrastructure map was compiled as part of this study (Section 2.18). The infrastructure mapping identified several gaps, an important one being an existing British Columbia Rail Grade that has not been mapped in a manner that can be integrated into the current data visualization. The status of all existing airstrips has also not been updated and the status of building infrastructure in formerly populated locations has not been confirmed.

The presence of communities and their perceptions of land use and economic development will also influence future exploration. Understanding their desires and expectations will be an important next step before field investigations are initiated.

Phase II desk top compilation work would focus on those areas deemed to have potential from a technical and socio-economic perspective, evaluating their potential to host geothermal systems. With additional Phase II work, there may be enough data to develop a detailed and focused Phase III exploration plan, of which field sampling of hot springs, dating Holocene eruptive material and geologically young plutonic rocks, and drilling temperature gradient wells would be the priority.

Phase III Recommendations

Phase III exploration would be field based and focus on collecting new information for the focus areas, wherever they are chosen to be. From these new data, a conceptual model would be built and an inferred resource estimation calculated. The table outlines some of the potential field-based studies and exploration methods that could be deployed dependent on existing data, target geothermal system, and a plethora of other considerations (see Section 1.2). Of the suggestions below, the most important field studies would be (1) updating the analysis of hot springs by collecting new samples and flow information; (2) drilling or using “boreholes of opportunity” to gather additional temperature gradient data; and (3) dating of geologically young volcanic and plutonic rocks. These three datasets would provide additional information and confidence before undertaking more detailed exploration work as outlined below.

Description	**Purpose**
Infill gravity data acquisition	Better delineate fault and basin structure
Infill magnetic data acquisition	Better delineate fault and basin structure
Acquisition of MT data	Necessary for identification of high temperature geothermal systems.
Acquisition of high-resolution seismic data	Better delineate fault and basin structure
Temperature gradient boreholes	Location of boreholes would be dependent on the location of the focus areas, but additional data throughout the project area would be of value to ensure that the geospatial analysis did not undervalue some areas unnecessarily.
Update/upgrade fluid geochemistry	If a hot spring or other thermal feature exists in the focus exploration area.
Dating and geochemistry of volcanic and/or plutonic rocks	If volcanic and/or plutonic features exist in the focus exploration area, dating and geochemistry to provide better understanding of magma evolution and/or radiogenic content.
Mapping and dating of faults	Detailed mapping of faults and fractures to determine their time of movement, seeking evidence of Holocene displacement.
Conceptual Model	A conceptual model of the geothermal system is built using new and existing information. This model is then used for targeting exploration drilling as to location and depth.

Conclusions

This Phase I study did a thorough investigation and integration of publicly available geoscience information. The favourability maps provide a first step to understanding the regional geology of the project area as applicable to the assessment of naturally occurring geothermal systems. The favourability maps are heavily biased towards the presence of "heat" as manifested by Holocene volcanism and hot springs. The methodology may be misleading as there are significant data gaps and no bench marking data. Additionally, these maps do not address the potential for technological solutions such as ultra deep/ultra hot geothermal, nor do they adequately address the presence of low temperature resources such as useful for space heating or other direct use applications.

Despite the limitations, these maps provide a starting point for further geothermal assessment. By providing a more limited geographic focus on areas of promising geology they provide a more manageable framework to proceed with Phase II studies. Due to the lack of geothermal specific data and site-specific data, no resource estimates could be calculated. However, despite the limitation of the data and the methodology, there is sufficient information to suggest that robust geothermal systems exist within the project area. The exact location, size and resource potential of these systems (and whether they may be developable by either conventional or unconventional technologies) await further data and investigation.

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Carbon Capture, Utilisation, and Storage

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Chapter 5 Figure 1: Geological Carbon Sequestration Map 250

Overview

Geological carbon sequestration has mostly focused on storage into saline aquifers.

Deep storage into these saline aquifers relies on injecting CO_2 into porous rock formations, where it is trapped through physical and chemical mechanisms. Another approach is carbon mineralization, which involves the reaction of CO_2 with silicate-rich rocks, such as basalts and ultramafic formations, to form stable carbonate minerals, permanently locking carbon in solid form.

In the project area, the only area with potential for deep saline aquifer storage is the Bowser Basin, while surface-exposed basaltic and ultramafic rocks offer opportunities for carbon mineralization. Our studies have found limited potential for deep saline aquifer storage within the Bowser Basin and no favourability assessment was completed due to the absence of data. To address this absence of data, field mapping, rock sampling, and geophysical surveys are needed to refine subsurface models and assess storage feasibility.

Types of Geological Carbon Sequestration

Deep Saline Aquifer Storage

Deep saline aquifer storage of CO_2 geological storage involves injection and sequestration into porous and permeable rock formations deep underground, where it is trapped through different various mechanisms. The main types of storage are classified into Enhanced Oil/Gas Recovery (EOR/EGR), depleted reservoirs, un-mineable coal seams, and saline aquifers, with these the latter being the most widely used (Ali et al., 2022). Geological storage is a proven technology that has been used for decades in the oil and gas industry as an associated feature of CO2 use for enhanced oil recovery, and is increasingly being used in carbon capture and storage applications (Zhao et al., 2023)

Carbon Mineralization

Carbon mineralization involves a rapid chemical reaction between CO_2 and certain rocks, particularly those containing magnesium, forming stable carbonate minerals that will sequester CO2 over geologic time spans. It occurs naturally during rock weathering but can be accelerated for carbon sequestration. The two main targets are basaltic and ultramafic rock masses, both of which have been targeted undergoing pilot projects for sequestration to assess their effectiveness as a permanent CO2 storage mechanism (Nisbet et al., 2024). These rocks contain highly reactive silicate minerals abundant in metal cations. When acidic CO_2-charged water reacts with these rock types, dissolution of the silicate minerals is promoted, releasing the cations into the pore fluid, where they can react with dissolved carbonate ions to precipitate carbonate minerals, “locking” the carbon in the subsurface. Successful pilot-scale mineral carbon storage projects in mafic rock, including CarbFix in Iceland (Clark et al., 2020) and the Wallula basalt sequestration site in Washington in the USA (White et al., 2020), have demonstrated rapid storage via mineralization on 2-3 year time scales.

Targets in the Project Area

The following map highlights the Bowser Basin, identified as a candidate for deep geological storage assessment, alongside the surface distribution of basaltic and ultramafic rocks (A to H) targeted for carbon mineralization. It also displays faults and well locations, providing key geological context for subsurface evaluation.

Deep geological storage appears potentially feasible only within the Bowser Basin, where five oil and gas boreholes have been drilled, two (Ritchie wells) exceeding 2 km depth at the same location and three others less than 1 km deep.

Recent volcanic activity has resulted in both young and older basalt formations (shown in green on the map), while scattered ultramafic rock outcrops in the northern part (in orange), primarily peridotites (McGoldrick et al., 2017), present potential opportunities for carbon mineralization.

Discussion on Ultramafic Rocks

Eight areas of interest containing ultramafic rocks have been identified (Zagorevski, 2025, personal communication) and are highlighted on the following map (A to H).

Area A, located outside the project area, likely has the highest potential due to its abundance of ultramafic rocks. It has been mined for jade, explored sporadically for gold, including the largest gold nugget found in British Columbia, and investigated for awaruite (Ni-Cr-Fe alloy), with the nearby Kutcho VMS deposit. Though outside the mapped area, it remains a noteworthy consideration.

Areas B and D contain sparse occurrences of ultramafic rocks, primarily serpentinite. Observations from roadside exposures north of Dease Lake and aerial views over Area D suggest a significant volume of ultramafic material. However, major knowledge gaps remain, including:

1) **The actual distribution of ultramafic versus other lithologies**
   The volume of ultramafic rocks, particularly in the north, appears to be underestimated due to mapping methods. Poorly exposed areas were often assumed to be underlain by recessive chert, leading to patches of other lithologies being depicted as isolated bodies within the 'Kedahda Formation.
2) **The structural context and the impact of Jurassic faulting on these lenses**
   The geology is complex, comprising ophiolites, underthrust footwall limestone, volcanics, and Late Triassic to Jurassic overlap sequences.
3) **The ultramafic rock composition (cumulate vs. mantle-derived)**
   Dease Lake (Area A) appears to be a classic 'Penrose-style' ophiolite, characterized by cumulates and sheeted dikes. In contrast, the ophiolites to the northwest, such as those near Level Mountain, are oceanic core complexes. While this distinction may seem academic, it has significant implications for ultramafic rock composition, cumulates tend to be more iron-rich and contain a higher proportion of pyroxene-rich lithologies, whereas mantle-derived rocks are more magnesium-rich and pyroxene-poor.
4) **the extent of serpentinization or listwaenitization (silica or carbonate alteration)**
   There is significant variability in the degree of serpentinization in ophiolites, ranging from less than a few percent to fully serpentenized rock.

Area C contains known high-pressure rocks (blueschist) and holds strong potential for further discoveries. It likely represented the footwall beneath the now largely eroded ophiolite. Notably, this is where a jadeite jade block was found, unlike the nephrite jade found elsewhere, including at Cassiar. The northwest portion of Area C is highly inaccessible, with some ophiolite massifs showing minimal serpentinization amid extensive basaltic volcanic fields.

Several studies explore the relationships between ophiolites and ultramafic rocks (Bogatu et al., 2023; Zagorevski et al., 2021), along with an ongoing geochemical compilation that includes sites from this area (Zagorevski, 2020).

Area E contains a small volume of pyroxenite and hornblendite linked to the Cake Hill Pluton (~220 Ma). These rocks are fresh and likely non-reactive for carbon mineralization.

Areas F (Yehiniko), G (near Galore), and H (near Schaft Creek) contain ultramafic rocks, some intrusive and others volcanic. Their carbon mineralization potential is likely similar to ophiolitic rocks to the north. However, their low volume and limited regional constraints significantly reduce their viability.

Data Gaps

Rock properties represent a major knowledge gap due to the lack of a consistent dataset. Such data would be highly valuable for both carbon storage assessment and mineral exploration.

The absence of data and a comprehensive subsurface stratigraphic model severely hampers precise target identification and assessment of potential identification leads for deep geological saline aquifer storage.

Similarly, the uncertain extent and depth of ultramafic rocks constrain their viability for carbon mineralization. Additionally, key aspects of the structural framework, composition, and degree of serpentinization in these ultramafic formations remain unknown, requiring further investigation.

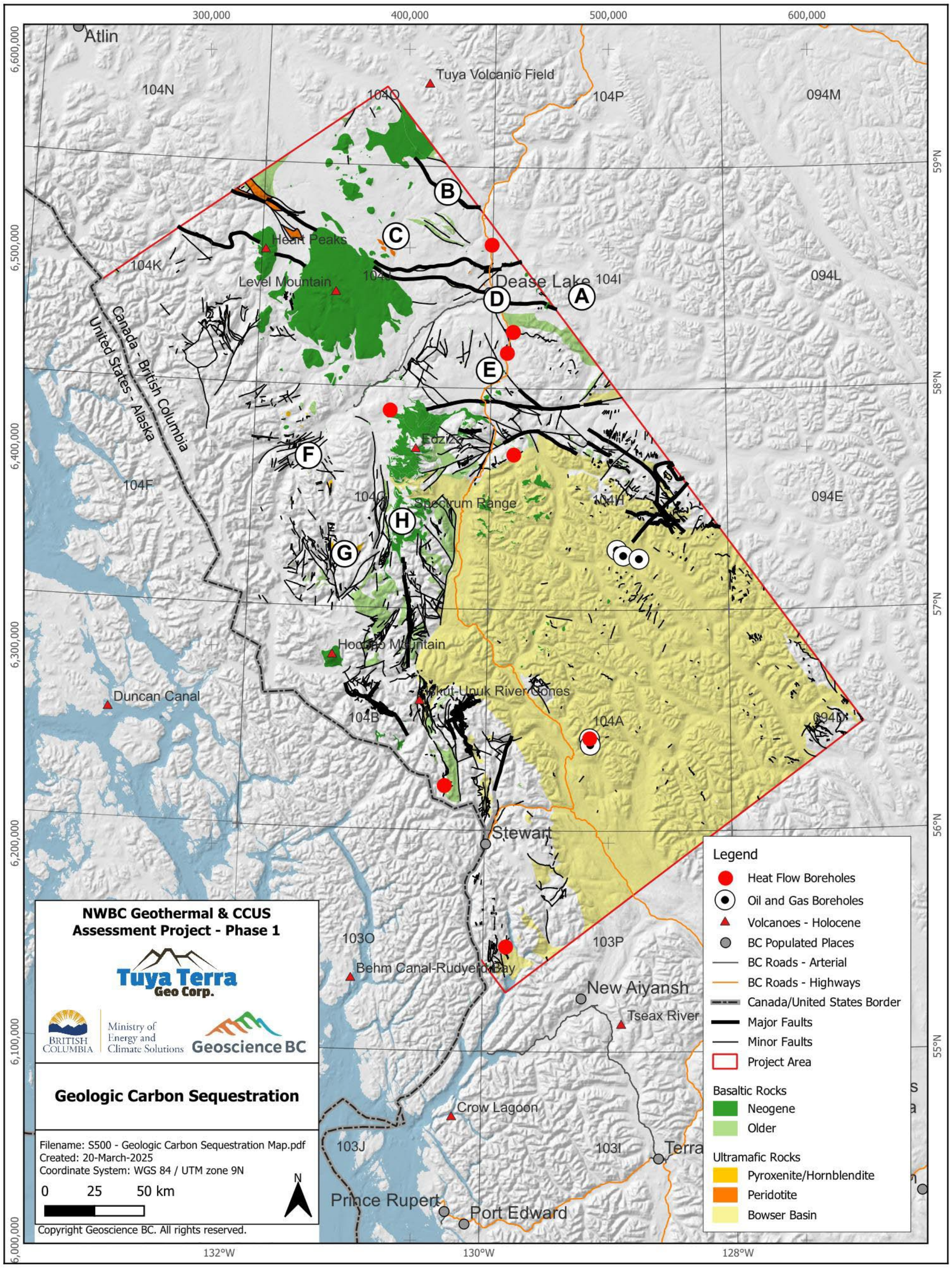
Finally, it is unclear whether the extensive basalts, including the Stuhini and Hazelton groups or the Level Mountain basalt fields and fissures, have carbon mineralization potential.

Recommendations for Additional Work

A significant amount of new drilling and a more detailed characterization of the Bowser Basin's subsurface would be required to develop a 3D geological model, which is essential for accurately identifying high-quality targets for deep geological saline aquifer storage. Although the Bowser Basin is an unlikely candidate for deep saline sequestration, further assessment of basin structure, stratigraphy and other attributes would help assess sequestration potential.

For carbon mineralization, field mapping and rock sampling for geochemical analysis and physical property measurements are essential next steps. If mapping indicates substantial continuity and depth of basaltic and ultramafic formations, an airborne geophysical survey would provide valuable data to better define their subsurface extent and potential for carbon mineralization.

Also, serpentinization and carbonation of ultramafic rocks results in changes in their physical properties such that they should be detectable using geophysical surveys; this could provide constraint on the reactivity of rocks without extensive sample characterization (Cutts et al., 2021).



Chapter 5 Figure 1: Geological Carbon Sequestration Map

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RESEARCH AND ANALYTICAL TEAM MEMBERS

Overview

Tuya Terra Geo Corp. (TTGEO), a geological, geothermal and management consulting company was engaged by Geoscience BC to carry out the Northwest BC Geothermal and CCUS Assessment Project – Phase 1. TTGEO was founded in 2014 and in 2024 expanded its services to include other forms of energy (e.g. waste heat capture and geoexchange systems) to assist its clients in evaluating green energy options. To complete the Geoscience BC, project, TTGEO engaged a number of experts to complete various aspects of the work. The sections show the principal person who carried out the compilation of the specific data set.

Catherine Hickson, PhD, PGeo

President, Tuya Terra Geo Corp.

Dr. Hickson is a globally recognized geothermal expert, with over 40 years of experience in geothermal exploration, development, operations, and maintenance. She spent 25 years with the Geological Survey of Canada (GSC), where she played a pivotal role in the evolution of geothermal energy in Canada. Internationally, Dr. Hickson has conducted greenfield exploration in eight countries and has overseen the development, operation, and maintenance of geothermal projects in Chile, Iceland, Italy, Peru, and the U.S., including key roles as VP Exploration and Chief Geoscientist. Her impressive track record includes direct responsibility for the operations and resource management of 190 MW of geothermal energy, with significant projects like Soda Lake in Nevada and the Svartsengi and Reykjanes facilities in Iceland. As CEO of the Alberta No. 1 project, she leads the development of geothermal energy projects in Canada, securing over $25 million in funding. Dr. Hickson is also the Past President of Geothermal Canada. A recognized thought leader, she has authored over 100 scientific publications and continues to advance geothermal energy development worldwide. Early in her career as a Research Scientist with the Geological Survey of Canada, she mapped and researched the young volcanic fields in northwestern British Columbia. Hickson's experience also includes investigations of CO_2 sequestration in Saskatchewan and Alberta as well as a research collaboration with CANMet and the University of Alberta on combining carbon sequestration with geothermal operations.

Marc Colombina

An operations focused leader, Marc has led operations, project management, logistics, and procurement for geothermal and waste heat projects in Canada and the United States. His extensive experience runs through managing the technical, commercial, and regulatory aspects of large energy projects research studies. This includes permitting the first geothermal energy project in Alberta's history; contract negotiation with utilities in both Canada and the United States for the implementation of first-of-kind thermal energy conversion projects; on-site contractor management for a thermal energy conversion project at an operating nickel-cobalt refinery; and leading procurement activities for thermal energy network projects for municipal governments. With his multidisciplinary skill set, Marc has led teams to secure and manage over $30MM CDN in grant funding from Provincial and Federal government agencies for technology development, project feasibility, and project implementation.

Felix-Antoine Comeau, PGeo

Félix-Antoine Comeau is a research associate and professional geologist with 20 years of diversified experience in Earth Sciences and energy issues, both in terms of understanding fundamental phenomena and applied problems, by being involved in scientific research, university teaching and private industry. He obtained his master's degree in Earth Sciences at Université Laval in 2004 and he is now specialized in stratigraphy and structural geology of sedimentary basins. During his work year in Mali (West Africa) for gold exploration, his team discovered a world-class gold deposit in 2005-2006 that led to the opening of the Nampala mine. From 2006-2010, he developed oil and gas exploration strategies in Québec for the Gaspé and the Anticosti sedimentary basins with the company Pétrolia, which brought the Haldimand oil field into production and resulted in the promising definition of the Macasty Shale Oil play. In 2011, he joined the research community of INRS to evaluate the potential of CO_2 underground storage in the Province of Québec. Over the past 10 years, his research has focused on the evaluation of the geothermal resource potential in sedimentary basins and for remote northern communities in Canada, but recently its work has expanded to include hydrogen storage, natural hydrogen exploration and CO 2 storage. At the INRS, he also manages the Open Geothermal Lab, a facility created to measure the thermal and hydraulic properties of geological materials. He's a professional member of the Ordre des géologues du Québec.

Phil Harms, PGeo

Phil completed his BSc from the University of Calgary in 2006 with a double major in Geology and Geophysics. Phil is a registered Professional Geoscientist with the Association of Professional Geoscientists of Alberta (APEGA) and a member of the CSEG. He has over 15 years of international exploration, development, and gas storage experience. His roles have included project leadership, geological and geophysical interpretation, seismic data acquisition and processing, resource quantification and risk assessment, data analytics and GIS analysis. Phil has a keen interest in leveraging exploration technology and workflows from the oil and gas industry into the geothermal space and integrating emerging energy trends and technologies into environmentally balanced energy solutions both in Canadian and international markets.

Katherine Huang, PGeo

Katherine is a geothermal geologists based in Alberta with over 5 years of experience in Alberta, British Columbia, Saskatchewan, and on global consulting projects. She is a P.Geo registered with APEGS and completed her BSc. Hon. Geology at the University of British Columbia and MSc. Geology at the University of Iceland. Her MSc. thesis focused on a geochemical assessment of thermal fluids from Mount Meager, British Columbia. Throughout her career, she has conducted geochemical analyses and overviews for several projects throughout Canada and globally.

Dan Kalmanovitch, PEng

Dan is a senior GIS and data analytics expert and a Geomatics Engineer with over 18 years of experience in the energy industry providing geomatics, mapping, and data analytics expertise. His specialty is creating sophisticated interactive visualizations built on a foundation of geospatial integration. Dan's analytical problem solving, GIS and programming skillsets has propelled companies he has worked for to undertake a wide variety of energy challenges. Dan has a global focus, providing his expertise for oil and gas clients operating in countries such as Canada, Colombia, Guyana, Madagascar, Kenya, and Tanzania.

Bastien Poux, PGeo

Bastien is a Senior Geothermal Geologist, registered as a Professional Geoscientist (P.Geo.) in British Columbia, with 15 years of experience in geothermal resource exploration and evaluation, wellsite geology and 3-D modelling. With his experience across various geological contexts, Bastien has made substantial contributions to the exploration and evaluation of numerous geothermal fields worldwide and has been a wellsite geologist on more than 25 deep geothermal boreholes across the United States, Montserrat, India, Djibouti and Iceland, including the Iceland Deep Drilling Project IDDP-2. Bastien is an expert in the use of Leapfrog 3-D modelling software to compile extensive exploration and drilling datasets and to build complex geological models.

Yuliana Proenza, PGeo

Yuliana is a registered geoscientist with Engineers and Geoscientists BC and has been actively working in the mineral and geothermal exploration since 2006. Yuliana's geothermal technical experience includes working on geothermal projects in British Columbia that included data gathering, data analysis, project coordination, community engagement, and reporting. Yuliana has a unique perspective: her career has been a blend of mineral and geothermal exploration, and she works with clients that are active in the prolific Golden Triangle and was involved with the team that developed the 2016 BC Geothermal Roadmap funded by Geoscience BC.

Jeff Witter, PhD, PGeo

Since 2016, Dr. Jeff Witter has run his own consulting company, called Innovate Geothermal Ltd., working full-time to provide cutting-edge exploration and resource assessment services to the North American geothermal industry. Jeff has provided expert geoscience advice to U.S. and Canadian geothermal developers, served as a geothermal advisor to government, participated in government-funded geothermal research programs, and provided geothermal due diligence services to investor groups. Jeff is a professional geoscientist (PGeo) with Engineers and Geoscientists British Columbia (EGBC) and an adjunct professor in the Department of Earth Sciences at Simon Fraser University. He has served on the boards of the geothermal industry groups Geothermal Rising and Geothermal Canada. He holds an Advanced Bachelor's degree (magna cum laude) in geophysics from Occidental College (California) as well as a Master's degree from the University of Hawaii and a Ph.D. from the University of Washington, both in volcanic geology. Prior to 2016, Jeff worked as Senior Geologist for 3 years at Sierra Geothermal Power Corp. where he managed the geological and geophysical aspects of the exploration program at the company's top four geothermal prospects in Nevada (USA).

Other Contributors

Colin Godwin PhD, PEng, PGeo

Colin is a Professor Emeritus of UBC, where he taught economic geology for 22 years with a specialty in galena lead isotopes and its application to ore-search. During his time at the university he published more than 100 professional papers and was awarded the Duncan Derry Medal--the highest award to mineral deposit geologists bestowed by the Geological Association of Canada. Exploration with mining companies has involved him mainly in the Yukon, Mexico, Argentina and Chile. In the past he has been President of Rome Resources Ltd., a Director of Argentex Mining Corporation and a consultant to IMPACT Silver Corp.

John Cassidy PhD

Dr. John Cassidy is a senior Research Scientist with Natural Resources Canada, (Head of the Earthquake Seismology Section and Project Leader of Assessing Earthquake Geohazards). His research involves all aspects of earthquake hazard studies to help mitigate the impact of future earthquakes in Canada. John served as a member of the Canadian Association of Earthquake Engineers Chile Earthquake Reconnaissance Team that travelled to Chile after the devastating magnitude 8.8 earthquake in 2010. He continues to work with scientists and engineers in Chile to strengthen research partnerships and better understand the hazards associated with subduction earthquakes in Chile, Canada, and elsewhere.

John serves on a number of local, national, and international steering committees and editorial committees, and is a regular reviewer of research proposals and journal articles. John is an Adjunct Professor at the University of Victoria where he teaches courses and supervises graduate students in earthquake research.

Alex Zagorevski, PhD

Alex is a Research Scientist with Natural Resources Canada and an adjunct research professor at Carleton University.