Report
Project no.: AE 23-001

Aetna Geothermal

Preliminary Study of the Geothermal Potential at Yukon University Campus, Whitehorse, Yukon

Image: View of Haeckell Hill and Whitehorse, Source: Yukon Energy

Prepared for
Associated Engineering

By
Aetna Geothermal Limited

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Key Page

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Executive Summary

This report is a prefeasibility study performed to examine all available geoscientific data related to a geothermal direct-use project at Yukon University in Whitehorse, Yukon to develop a 3-D geological model and to establish a preliminary geothermal conceptual model of the project area. Aetna Geothermal Limited (AGL) has been hired by Associated Engineering (AE) to conduct the study using data provided by AE, the Yukon Geological Survey (YGS), and publicly available information. While no previous studies have been conducted specifically for this project, there have been nearby geothermal research projects in the past decades that will be reviewed and potentially integrated into the analysis if relevant. This report serves as a high-level prefeasibility study, ensuring that the technical aspects of the project are evaluated according to best practices.

This report is based on all available data, reports, and maps related to geology, geochemical sampling and analyses, geophysical surveys, and drilling activities conducted by the YGS and other governmental or private entities. Using the data compiled, new material was also created, including a remote sensing analysis and a 3-D geological model using the Leapfrog software.

A preliminary conceptual model was developed from the data review and the geological context of the area. Based on this conceptual model, additional exploratory work is proposed to fill the data gaps identified and provide complementary information to select a possible drilling site for an exploration well.

For the next steps of this project and to increase the probability of success of the exploration well(s), Aetna Geothermal proposes the following work:

- Geological field investigations
- Geochemical sampling and analysis
- Geophysical surveys

This work should be completed before drilling any exploratory well.

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1. Objectives

1.1. Overview

Aetna Geothermal Limited in partnership with Associated Engineering was selected by the Government of Yukon, for the provision of professional services for the geothermal project at Yukon University in Whitehorse, Yukon.

Whitehorse is the capital city of the Yukon, with a population of around 25,000 people, Whitehorse is the largest city in the Yukon and the cultural, economic, and governmental hub of the territory. It is located on the banks of the Yukon River on the traditional territory of the Ta'an Kwäch'än and Kwanlin Dün First Nations (Figure 1).

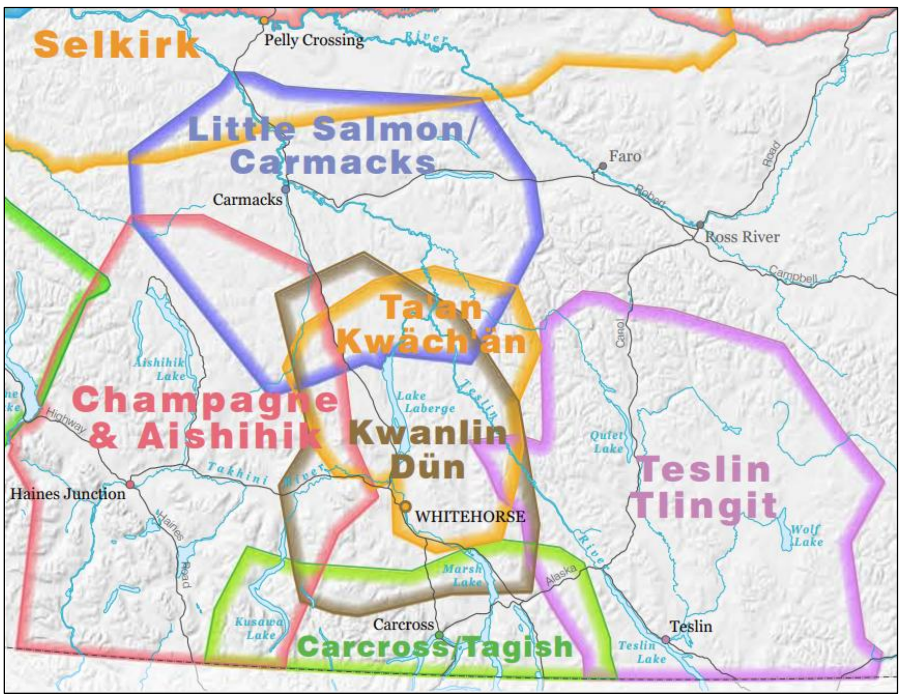

Figure 1: Map of the Traditional Territories of Yukon First Nations in Whitehorse area (modified from Yukon Government[1])

1. https://yukon.ca/sites/yukon.ca/files/env/env-traditional-territories-map-insert.pdf

1.2. Study objectives

A geothermal system has four main requirements to be considered a viable resource for geothermal energy use, whether for direct-use or electricity generation applications. The system must have:

1) A sufficient heat source capable of producing the higher temperature fluids needed for the desired application.

2) Permeability in the form of connected pathways for water to circulate, constitute a reservoir, and reach drillable depths.
3) Ample volume of water to recharge the reservoir and guarantee sustainability of the resource.
4) In the case of high temperature resources, an impermeable cap to protect the system from convective cold-water flooding and conductive heat loss. An impermeable cap is not necessary in most cases of low to moderate temperature direct-use applications.

The objective of this work is to study the geothermal potential in a project area including the Yukon University for direct use heat applications, it includes:

1) Review existing geoscientific data in the vicinity of Whitehorse.
2) Determine the likelihood for these requirements to occur within the project area.
3) Develop a conceptual geothermal model supporting the occurrence of these conditions.
4) Recommend additional work (if any) before identifying targets for exploratory drilling.

The project area used for this report is a rectangular shaped area, oriented along the cardinal axes, and elongated along the E-W direction (Figure 2). This area was selected based on the geological and geothermal features present in the Whitehorse area and the distance for Yukon University. The dimensions of the project area are 8.9x 5.2km for a total area of approximatively 46.2 km^2. The coordinate system utilized for the maps presented in this report is the NAD83 / Yukon Albers (EPSG:3578).

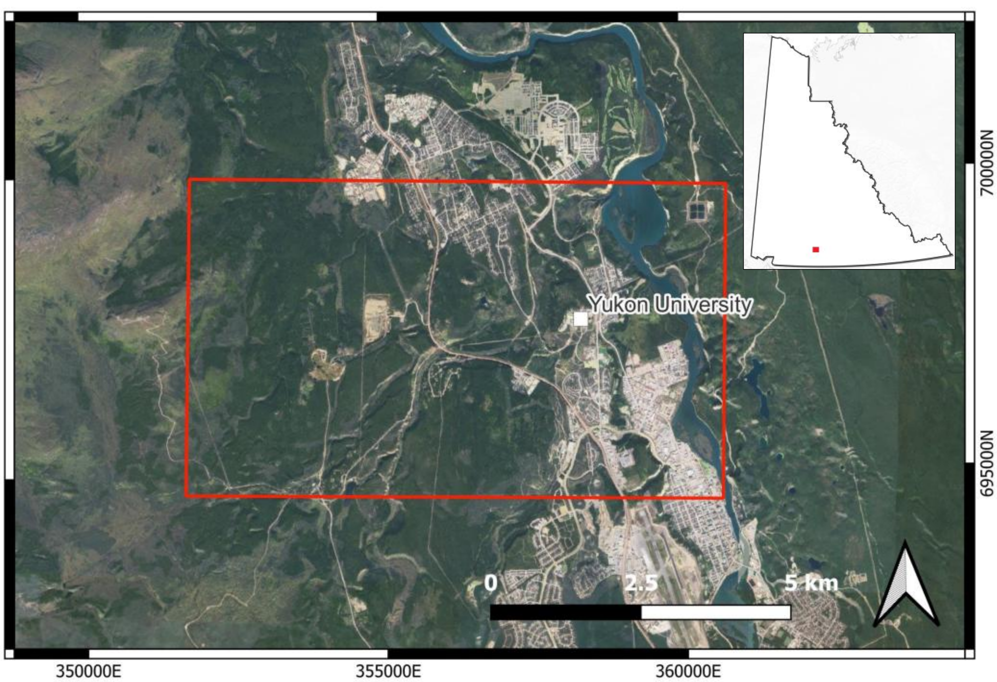

Figure 2: Satellite imagery (from Google Image) of Whitehorse and outline of the project area in red.

2. Geothermal potential in the Yukon

2.1. Brief history of geothermal studies in Yukon

The Yukon government has recognized the potential of geothermal energy and actively promotes its exploration and development. In 2016, the government released the Yukon Geothermal Opportunities and Applications Report (CanGEA, 2016), which highlights the possibilities for development of geothermal resources for electricity generation and heat applications in the territory. The report introduces a high-level delineation of geothermal exploration areas in the Yukon (Figure 3) based on key geological factors and available geothermal exploration results. Overall, there is significant potential for geothermal energy development in the Yukon. Continued exploration and development of these resources could provide a reliable and renewable source of energy for the territory.

Several geothermal studies for the Yukon have been conducted in the last decades, from the Canada's Geothermal Energy Program which started in the 1970's and resulted in several publications on the Yukon, such as the thermal and mineral spring studies by Crandall and Sadlier-Brown (1978) and subsequent analysis on temperature profiles, heat flow, thermal conductivity, geothermal gradient, and depth temperature maps from petroleum and mineral exploration wells (Geotech Ltd., 1984; Burgess et al., 1982; Majorowicz and Morrow, 1998; Jessop et al., 1984, 2005; Majorowicz and Dietrich, 1989) as highlighted by Fraser et al., 2019.

In recent years, focused exploration and drilling of temperature gradient holes have been completed at a few promising sites in the territory: Takhini Hot Springs, Ross River near the Tintina fault and Burwash Landing near the Denali fault. The Takhini Hot Springs project is the most relevant for the study being conducted and will be analyzed in more detail later in the report.

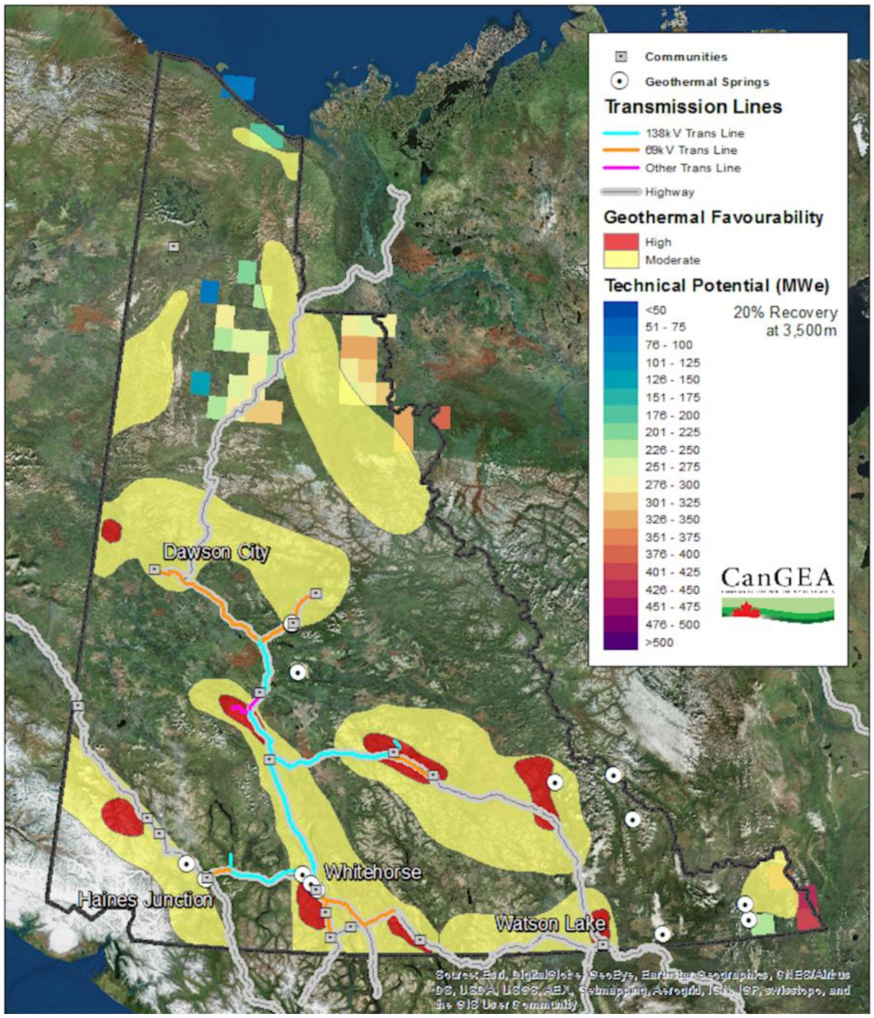

Figure 3: Primary Geothermal Exploration Areas (from CanGEA, 2016)

2.2. Heat flow and Currie Depth Point in the Yukon

Heat flow data

Data available to establish a heat flow distribution map of the Yukon are very limited, however it is still possible to highlight some areas of higher heat flow. In north and southeast Yukon, more heat flow values could be estimated due to the presence of numerous oil and gas wells in these regions (Figure 4). These areas show low values (<70 $mW.m^2$). In south-central Yukon, heat flow values have been estimated in the range of 80 to 120 $mW.m^2$ (Lewis et al., 2003, Grasby et al., 2012, Witter et al., 2018). Only one heat flow value of 60 mK/m^2 has been measured in Whitehorse, which is slightly lower than the average value of 64 $mW.m^2$ for Canada. Significant data gaps in the heat flow measurements in the Yukon must still be addressed to establish a reliable heat flow distribution map.

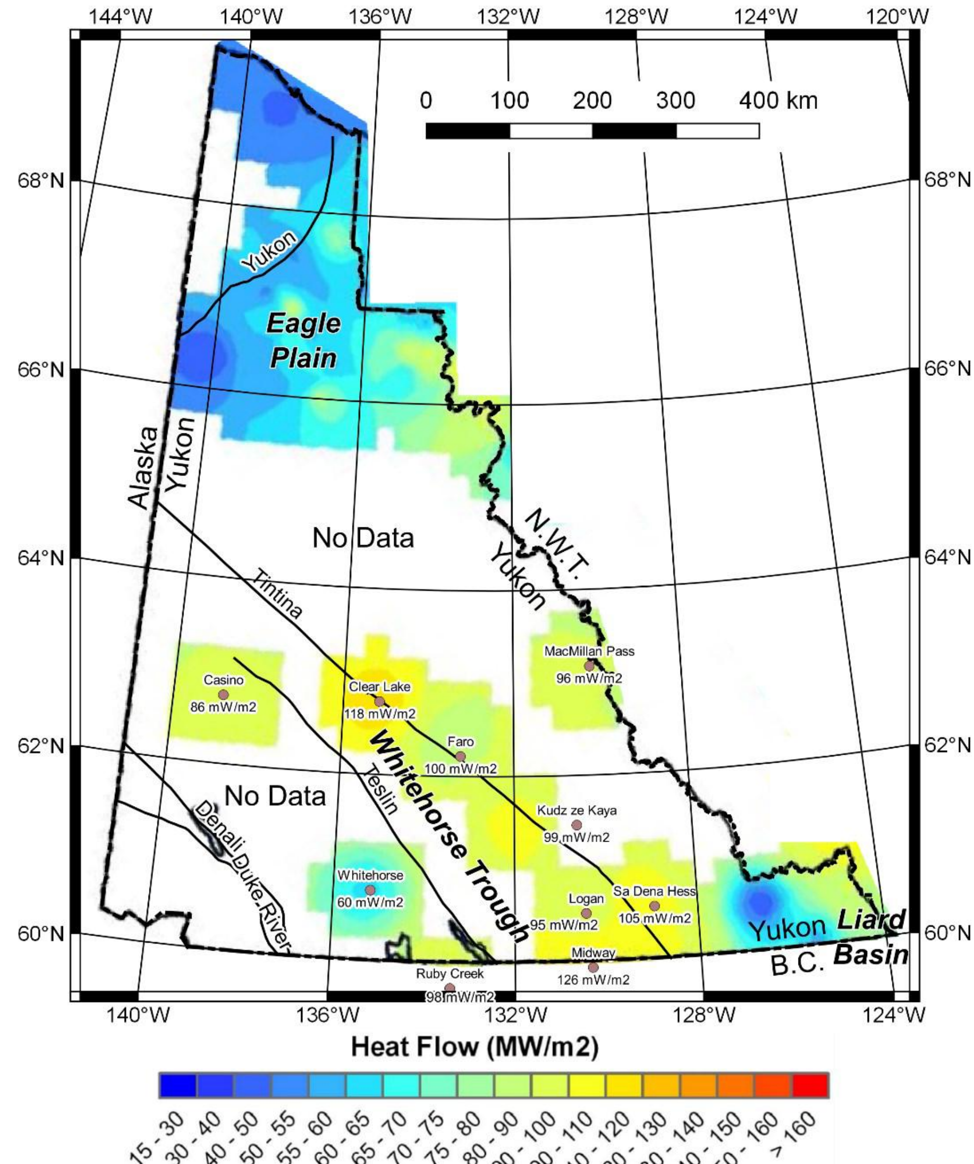

Figure 4: Heat flow map of the Yukon from Grasby et al. (2012). Warm and cool colours represent high and low heat flow, respectively.

Curie-depth Point (CDP)

The Curie Depth Point (CDP) method is a geophysical method used to determine the depth at which the Earth's magnetic field changes significantly. It is based on the concept of the Curie point, which is the temperature at which certain materials undergo a transition in their magnetic properties.

Temperature increases with depth due to the Earth's internal heat. At a certain depth, known as the Curie depth, the temperature will reach the Curie point of the local rock formation and the magnetic properties of the rock will change. This temperature is estimated to be 580 °C. This change in magnetic properties is reflected in a change in the measured magnetic field intensity.

Recent work by Witter et al. (2018) shown in Figure 5 highlighted that the regions with shallower CPD estimates in the Yukon generally corresponded to the Cordillera. Lower CDP values are found in the north and southeast portions of the Yukon, corresponding to continental platforms.

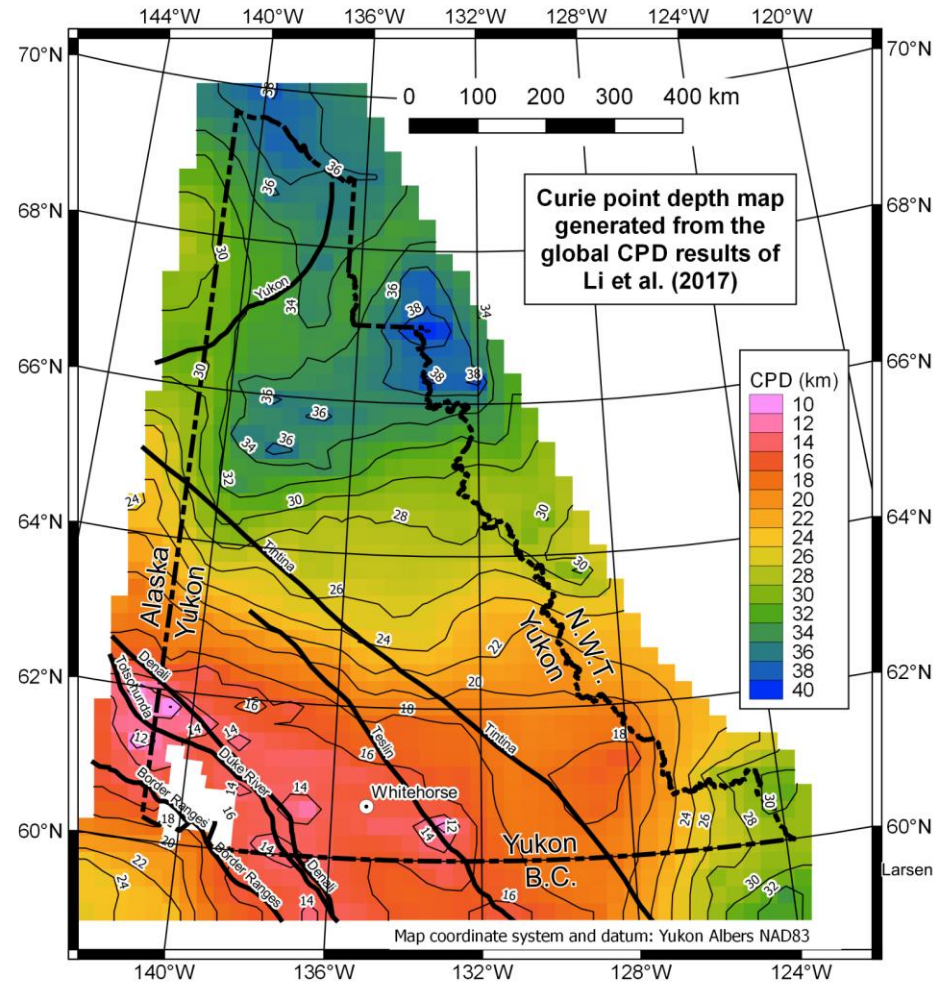

Figure 5: CPD map for the Yukon from Li et al. (2017) which assumes fractal crustal magnetization. Warm and cool colours represent shallow and deep CPD estimates, respectively. Contour lines show CPD in units of kilometers below the surface at 2 km depth intervals. Black lines depict major faults (Colpron and Nelson, 2011).

3. Past geothermal investigations

Figure 6 shows the location of springs and wells from past studies, as discussed in this section, when their location is known.

3.1. Shallow geothermal studies

In the 1970s, interest in exploring the geothermal potential of Whitehorse began to grow, resulting in some subsurface data being collected around the city. In 1976, Hydrogeological Consultants Ltd (Hydrogeological Consultants Ltd, 1976) conducted a study to compile groundwater temperature and flow data from 13 locations, including wells and springs (note that exact location of the wells and spring sampled is not shown in the report provided for this study). Of these, several were classified as warm, and one was classified as hot (the Takhini Hot Springs). We interpret the warm spring reported near “Porter Creek” as a developed spring, with temperature of 11.6°C (reported 53°F), to correspond to the spring also known as Versluce spring. The company also conducted a low-level flight to search for potential heat sources and identified two zones of thermal anomaly in and around Porter Creek and in the Selkirk Pump house area. However, caution must be used with this interpretation as topography was not removed from the analysis due to lack of data.

In 2003, a hydrogeological assessment was completed for the use of ground source heat pump on the Vanier School in the city of Whitehorse. The study site is located about 5 km to the southwest of Yukon University. For the purpose of the study, two shallow wells were drilled to depths of 56 m and 146.5 m. The deepest well reached the bedrock from a depth of 60 m encountering formation identified as the Miles canyon Basalt to 143 m and Granodiorite of the Whitehorse Batholith in the last 3 meters. two aquifers were identified in the sediments, they are composed of sand and gravels and of limited thickness (~5 m) and the Miles Canyon Aquifer, composed of fractured basalt and a thickness of about 83 m. The flow rates from the deeper reservoir could reach 10.6 L/s at temperatures between 6.9 and 7.1 °C. Maximum temperature of 8.2 °C was recorded at 143 m, which calculates a geothermal gradient of 2.93 °C/100m from surface to 143 m depth. Below 100 m depth to the bottom of the well, the geothermal gradient is more constant and calculated to be 6.98 °C/100 m.

In 2008, a comprehensive groundwater sampling and testing study was carried out by EBA Engineering Consultants Lt. (EBA, 2008) to assess the geothermal potential in the city of Whitehorse. In this study, temperature profiles were measured in 10 existing water wells and water samples were also taken for chemical analysis (see 6.2. Shallow groundwater studies).

3.2. Deep geothermal

Takhini Hot Springs

The Takhini Hot Springs are approximately 25 km northwest of the Whitehorse. According to Hart (1997), the Takhini Hot Springs have a constant temperature of 46°C, a pH of 7.4, and flow at about 250 L/min from a pit dug into glacial till. Gaseous bubbles and a weak sulfur odor are present within the vent pool and banded chalcedonic quartz veins have been observed in the sedimentary rocks north of the hot springs, suggesting hydrothermal activity. Hart's interpretation is that the fluids originate from one of the north-trending normal faults located north of the hot springs.

The YGS undertook a study to evaluate the geothermal heat potential near the Takhini Hot Springs, which are located about 25 km northwest of Whitehorse. In 2017-2018, they drilled a 500 meter deep temperature gradient hole between the Takhini Hot Springs and a Tertiary Flat Creek pluton that yielded a heat production value of 5.96 $\mu W/m^3$ (Hickson et al., 2020). Stabilized downhole temperatures in the well were measured at 50 m intervals. Results showed variable gradients along the well, with a lower gradient of about 16.5 °C/km in the upper 450 m and a higher gradient of around 250 °C/km in the lowest 50 m. The maximum recorded temperature at the bottom of the well was around 25 °C.

The formation encountered in the Takhini well corresponds to the Whitehorse trough sedimentary Richthofen formation and Nordenskiold facies of the Laberge Group. The well did not reached the Lewes River Group, as its top is interpreted to be a few hundred meters deeper (Figure 7). The geological interpretation from Langevin et al. (2020) also shows a relation, at depth, between the Flat Creek pluton to the west of the Takhini well and the Haeckel pluton to the south. However, the depths of the units are interpretive due to the lack of geophysical or deep offset well data in the area.

Finally, the conceptual model of the geothermal system in the Takhini Hot Springs area was improved with the data provided by the drilling of the temperature gradient well. It considers a conductive heat transfer with forced convective heat transfer due to rising warm fluids within steeply dipping normal faults in the area (Langevin et al., 2020). The mountainous relief and the climate of the area confers to a recharge mechanism principally through meteoric waters circulating to deeper formation thanks to the permeability of major faults. One of these faults is considered to be the path for the warm fluids to be redirected to the Takhini Hot Springs where it discharges on surface.

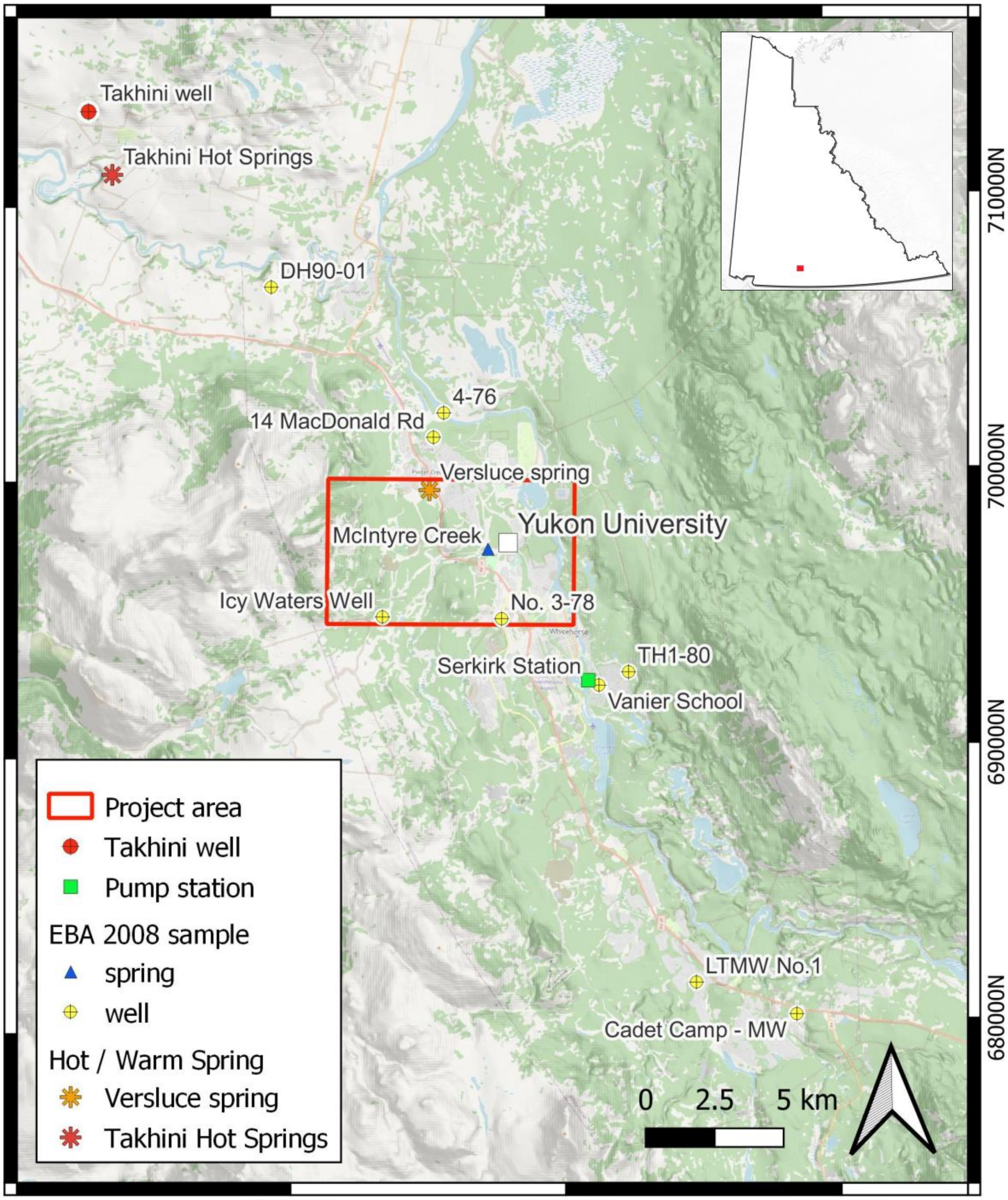

Figure 6: Map showing the location of wells and springs from past geothermal and groundwater studies and (Hydrogeological Consultants Ltd. (1978), EBA (2008), Fraser et al. (2018)).

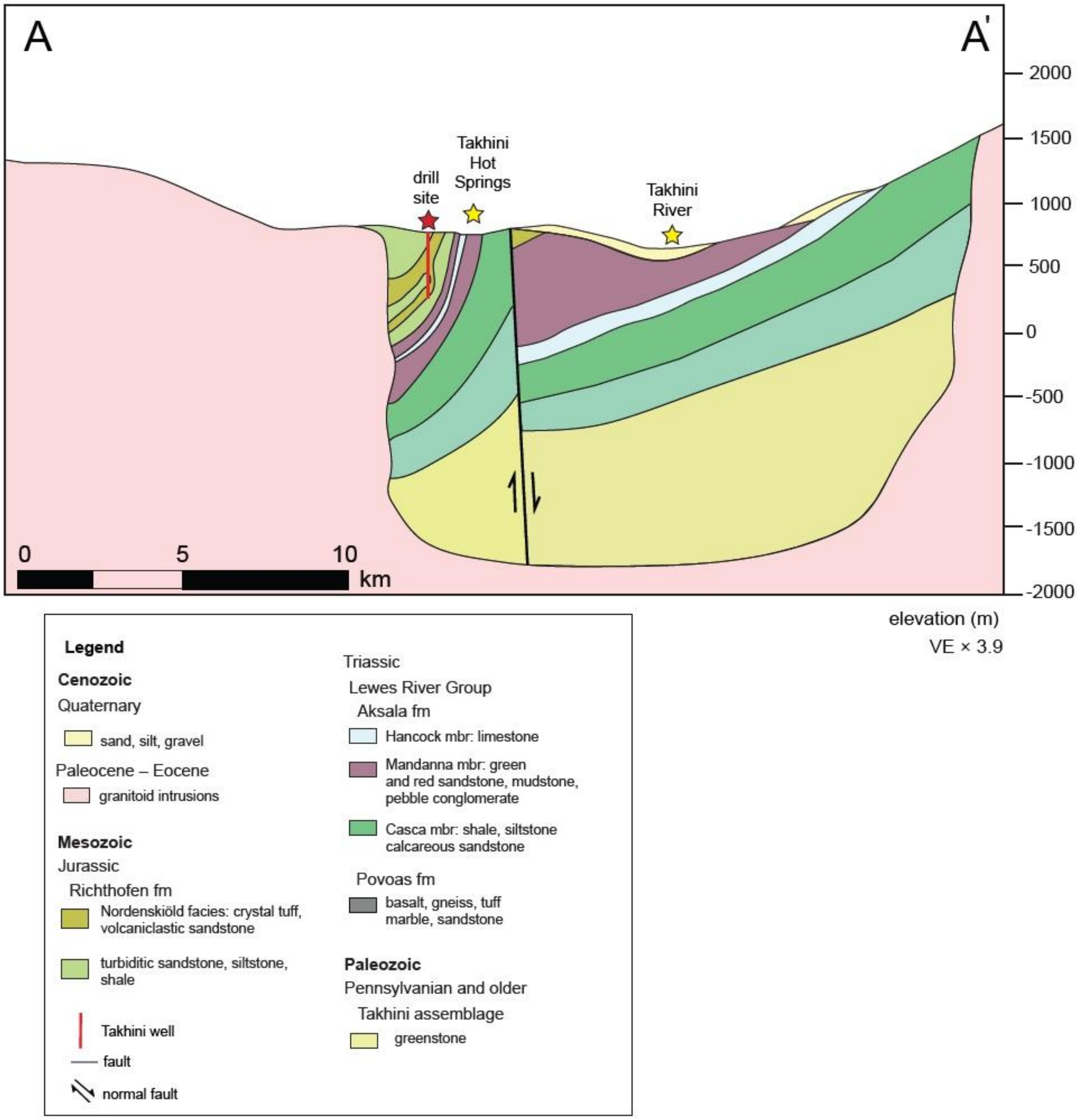

Figure 7: Schematic geological cross section through the Takhini well (interpreted from Geological map YGS-17-01 by Langevin et al. (2020)). The cross section is oriented N-S. Geology after Hart (1997), Colpron et al. (2015) and Yukon Geological Survey (2018a).

4. Geology

4.1. Regional geology setting

Whitehorse is located in the central part of the Yukon in Canada, which is part of the larger region known as the Canadian Cordillera. The Cordillera is a mountain range that stretches from Alaska down through western Canada and into the western United States, and is known for its rugged and varied landscape.

The geology of the Yukon is complex, with a mix of sedimentary, metamorphic, and igneous rock types. The region has a long geological history, with evidence of past volcanism, mountain building, and tectonic activity. Yukon is part of the northern Cordillera composed of a collage of terranes that were accreted to the North American continental margin during the Mesozoic (Zagorevski et al., 2018). The terranes are separated by faults, and each of them has its own stratigraphy, tectonic history, and mineral deposits (Coney et al., 1980). The city of Whitehorse is located within the northernmost part of the Stikinia geological terrane, part of the Intermontane terranes group, which extends to the south into British Columbia and is more than 1500 km long and 300 km wide at its widest point (Figure 8). Its deformation is attributed to collision with the Yukon-Tanana terrane, and the intermontane terranes were created post-collision. Geochronology studies on igneous rocks show a mean age between 250 and 160 Ma, reflecting the Mesozoic arc-related igneous activity (George et al., 2021 https://doi.org/10.1029/2020TC006505).

The major structures bordering the terrane were identified as the Llewellyn, King Salmon, Nahlin, and Teslin faults (Aitken, 1959; Mihalynuk et al., 2003; Mihalynuk et al., 1999; Mihalynuk et al., 2017; Monger, 1975). The Stikinia Terrane is an arc terrane composed of Triassic-Jurassic sedimentary and igneous rocks. In the Yukon Territory area, the Stikinia terrane is 80 km across and it is bordered to the west by the Yukon-Tanana terrane, to the east by the Quesnellia terrane, and to the south by the Cache Creek Terrane. It is composed of four tectonic elements: the Paleozoic Stikine assemblage, the Middle Triassic Joe Mountain volcanics, the Late Triassic Lewes River Arc, and the Upper Triassic-Middle Jurassic Laberge Group and Tantalus Formation.

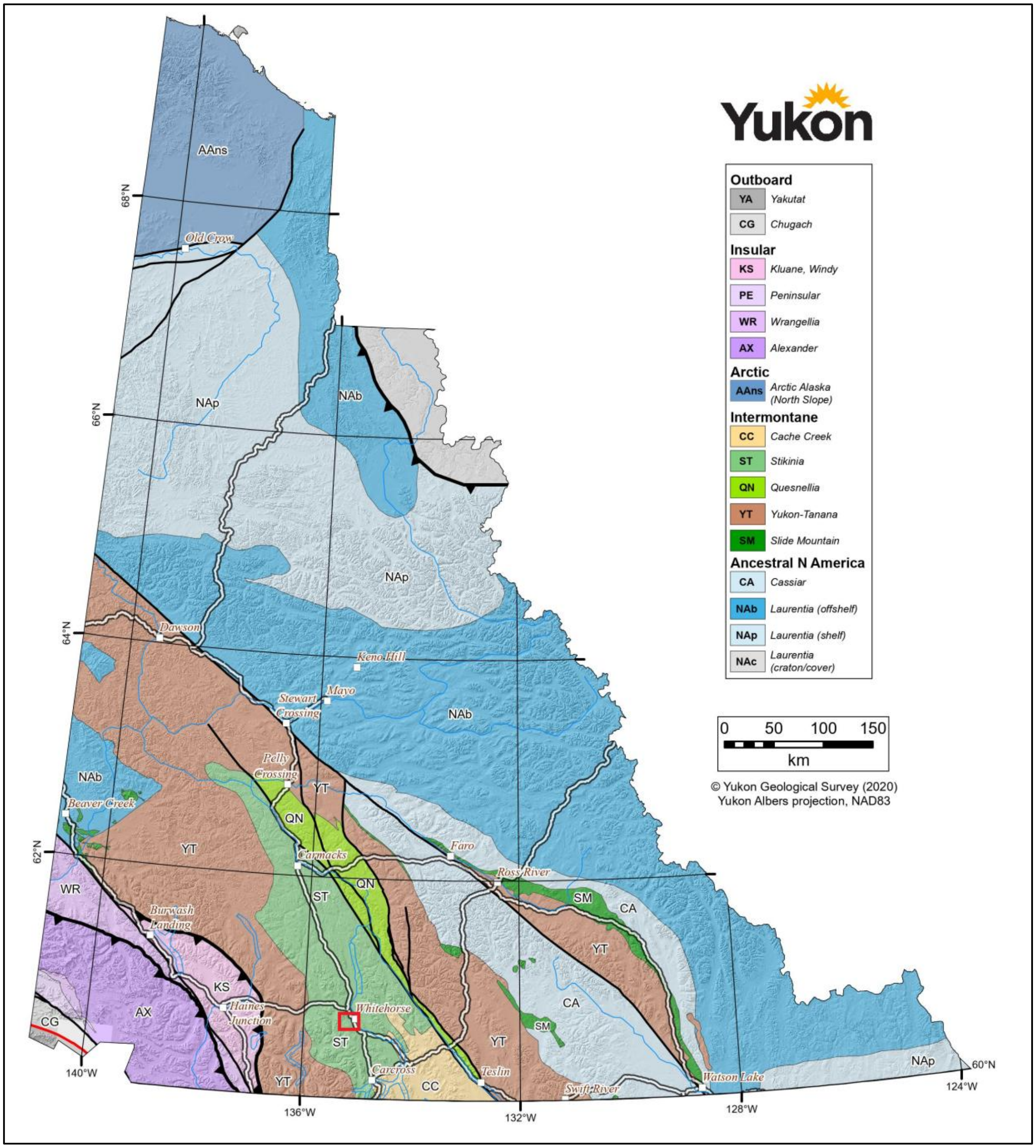

Figure 8: Geological terranes of the Yukon. The red outline represents the project area (modified from YGS)

4.2. Geology of the Whitehorse region

The topography of the area surrounding Whitehorse is moderately rugged, with elevations ranging from 600 m to about 1600 m asl. The Whitehorse valley is characterized by its elongated shape, running in a northwest-southeast direction, and is home to several lakes and forests. The Yukon River follows the general orientation of the valley and flows through the city of Whitehorse. The valley floor is composed of

Quaternary glacial and recent alluvium deposits. The Boundary Range, located to the west of Whitehorse, is closer and more easily accessible than the eastern mountain ranges. The surrounding mountain ranges are primarily made up of Precambrian metamorphic units, Paleozoic volcanics, Paleozoic and Mesozoic clastics and carbonates, and Triassic, Cretaceous, and Tertiary volcanics (Figure 10).

Structural context

Structurally, Whitehorse is situated in the Whitehorse Through (WHT), an intermontane basin formed during the Jurassic to Cretaceous time, during periods of formation and deformation of the continental margin arcs. It is a complex and intensely folded and faulted basin cut by intrusive igneous bodies. The origin of the WHT has been subject to various interpretations over the past six decades, including a geosyncline adjacent to a flaking arc (Wheeler, 1961), a back-arc origin (Tempelman-Kluit, 1978; Bultman, 1979), and a fore-arc origin shown in Figure 9 (Templman-Kluit, 1979). Eisebacher (1981) suggested that the subduction polarity may have changed over time, while Morrison (1981) and Hansen (1987, 1988) proposed that the WHT is an east-facing fore-arc basin with a west-dipping subduction.

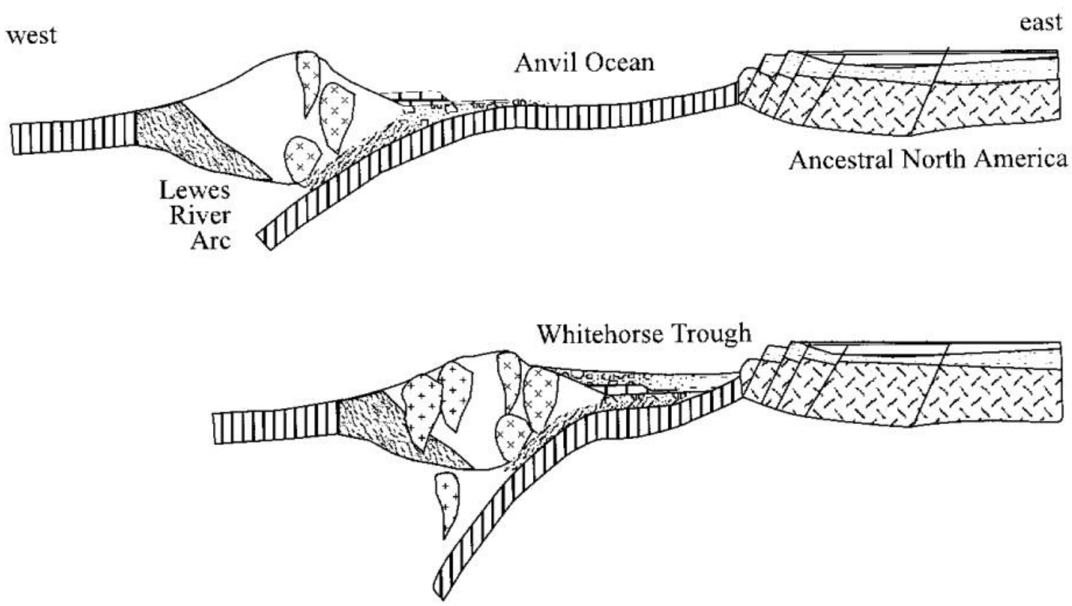

Figure 9: Schematic tectonic cross-section showing the development of the Whitehorse Through in a fore-arc basin above a west-dipping subduction zone (from Tempelman-Kluit (1979), modified by Hart (1986)).

The limits of the WHT, as indicated by the boundaries of the Laberge Group, are clearly defined to the eastern side along the Teslin fault, the northeastern Tatchun fault, and the northwestern Braeburn fault. However, in certain areas, the boundary of the basin is difficult to accurately define due to the presence of Quaternary alluvium, volcanic flows, and intrusive bodies.

Quaternary deposits

Whitehorse is situated on a low terrace of the Yukon River that has been carved out of the surrounding glacial deposits. The airport, located just south of the Yukon University campus, sits atop glaciolacustrine sediments (also known as the clay cliffs). These glacial deposits consist of fine sediments that were deposited at the bottom of Lake Laberge, which once covered the area (Bond et al, 2005). Above the lake deposits is a layer of sandy material of varying thickness, which was deposited in the Yukon River delta as it flowed into the lake.

Recent volcanism

The most recent volcanic activity in the area is represented by the Miles Canyon basalt (Wheeler, 1961; Hart and Radloff, 1990). It forms numerous disparate surface occurrences that are found to the south of the city and was dated for ~8.5 +/- 1 Ma (Hart and Villeneuve, 1999) and to 7.4 +/-1 Ma in the Wolf Creek area. The basaltic flows unconformably overlie weathered and oxidized granodioritic bedrock of the Whitehorse Batholith. The exact source of the basalt is unknown, but numerous basalt dykes and sills have been intersected within the granodiorite hot rocks (Gartner Lee Limited, 2001).

Bedrock

The geological formations in the Whitehorse area are primarily the Mesozoic sedimentary units within the WHT (Wheeler, 1961; Lowey, 2005). Up to 7 km in thickness of sediments accumulated, they are mainly composed of volcaniclastic, clastic, and coal of the Lower-Middle Jurassic Laberge Groups, and clastics and coal of the Upper Lower Cretaceous Tantalus Formation (Wheeler, 1961, Lowey, 2005). The stratigraphy of the WHT is complex, with a wide range of lithologies due to tectonic activity during sedimentation.

Sediments of the WHT lie unconformably on the Triassic Lewes River Group to the west and possibly the Joe Mountain volcanics to the east. Evidence of ancient oceanic crust has also been reported in the central and eastern parts of the trough (Hart, 1997).
The Lewes River Group formations consist of volcanic, volcaniclastic, clastic, and carbonate rocks and is subdivided in the Povoas formation and the Aksala formation (composed of the Mandanna, Hancock and Casca members). The Triassic formation lie themselves uncomfortably on the Paleozoic Takhini assemblage consisting in variably deformed and metamorphosed mafic volcanic rocks and minor felsic and sedimentary rocks (Figure 11).

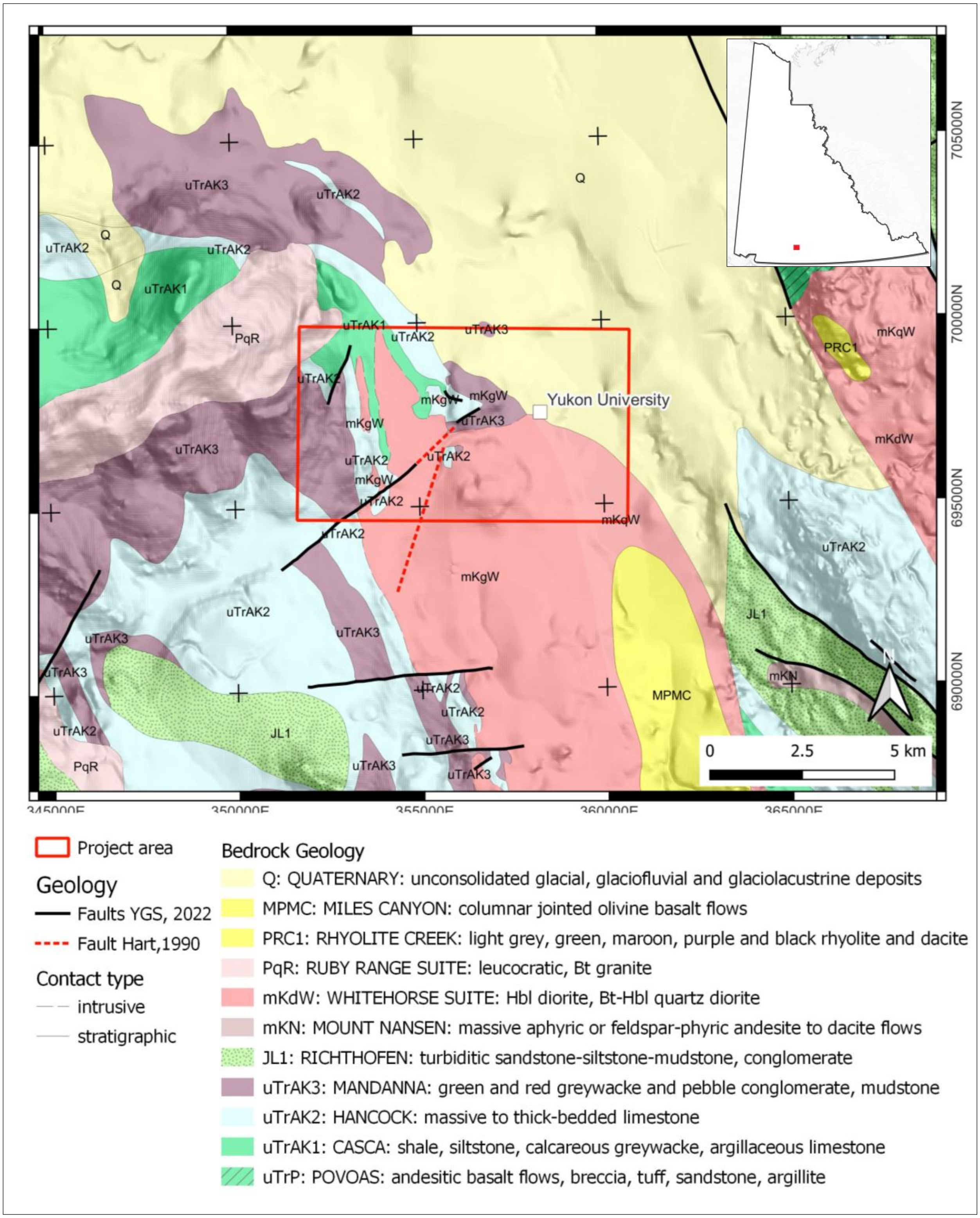

Figure 10: Bedrock geology map of Whitehorse (modified from Colpron, 2022)

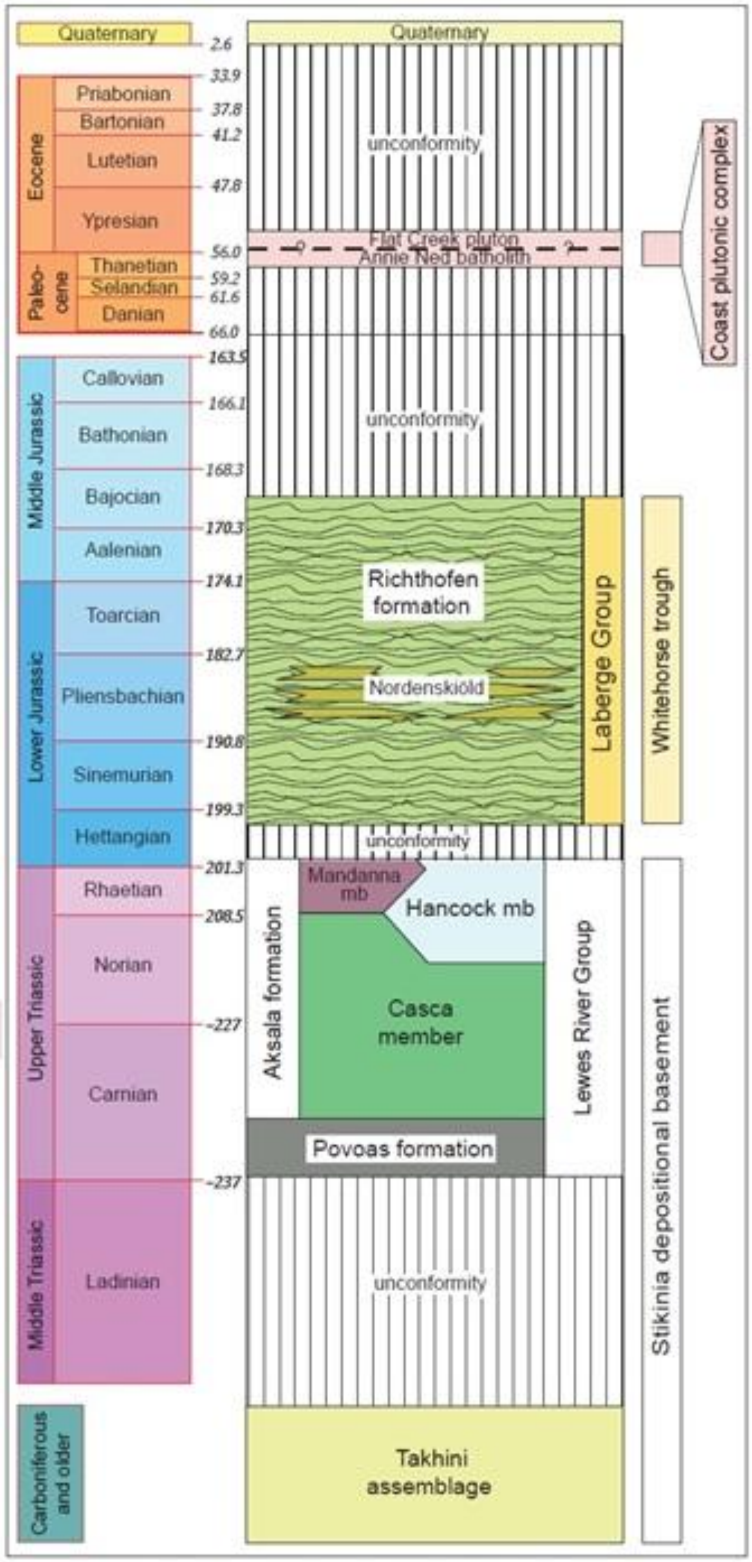

Figure 11: Geological units in the Whitehorse area (Colpron et al, 2015).

4.3. Geology of the project area

The bedrock geological map of the project area is shown on Figure 10.

Stratigraphy

The project area is underlain in part by the Upper Triassic meta-sedimentary units of the Lewes River group consisting in clastic and carbonate rocks. These sedimentary units correspond to the Aksala formation which can be up to 2000 m thick, subdivided into informal Casca (mudstone, sandstone, and limestone with minor conglomerate), Hancock (limestone, including reefal buildups), and Mandanna (sandstone, limestone, volcaniclastics, and minor conglomerate) members (Lowey et al., 2009). These units generally dip to the northeast although they are locally forded with northwest trending axes (Power, 2000). In the east part of the project area, the bedrock units are covered by quaternary sedimentary units made of unconsolidated glacial, glaciofluvial, and glaciolacustrine deposits.

These sedimentary rocks are intruded by Mesozoic to Tertiary intrusive rocks. In the southern part of Whitehorse city, the Cretaceous Whitehorse Batholith can be observed (Hart and Radloff, 1990; Hart, 1995; Morrison 1979). It is a plutonic unit described as a mix of biotite-hornblende quartz granodiorite, tonalite and diorite with a local weak foliation. The intrusive unit has a low primary permeability due to its crystalline nature, but there are fractures in which fluids can be encountered. Most fractures are steeply inclined or nearly vertical and usually trend northwesterly, with a more closely spaced series of smaller east-northeasterly trending faults and fractures (Hart and Radloff, 1990).

A more recent Cenozoic intrusive units, the Haeckel granite (also called Jackson Creek Granite), part of the Eocene/Paleocene Nisling Range Plutonic Suite of the Coast Plutonic Complex (part of the Ruby Range Suite), is present to the west of the project area in the Boundary Ranges, of which Mt Sumanik is the highest peak. It is mainly composed of medium to coarse-grained hornblende-biotite granite and granodiorite.

Structure

The main fault reported on the digital version of the geological map (Hart and Radloff, 1990) is a SW-NE trending, sub-vertical element located in the southwest corner of the area of interest. In some sections, this fault seems to show a right lateral dextral component. Additionally, in the historical documents from Hart and Radloff (1990), a second SSW-NNE structure is also reported in the same area, corresponding to the preferential orientation of the McIntyre Creek stream in this area. The two faults were shown to intersect near the intersection of Fish Lake Road and the Alaska Highway. Dip and strike measurements reported for the Lewes River formation indicate the presence of several small-scale synclines and anticlines in the mountain range to the west.

Mineralogy

In 1986, Meinert carried out a reconnaissance study in the Whitehorse Copper Belt to characterise the Cu-Au-Ag skarn deposits (Figure 12). The skarns deposits are developed in both the dolomite and calcareous carbonate units of the Upper Triassic Lewes River Group, and mainly located along the western contact of the Whitehorse Batholith. It was noted that the skarns formed from limestone contain variable amounts of retrograde alteration minerals such as actinolite, epidote, and chlorite. Although these minerals are the result of metamorphic processes and must not be mistaken for indication of hydrothermal activity, these types of mineral deposits are generally structurally controlled and located along faults and stratigraphic or intrusive contacts. Two of these occurrences, the War Eagle and the Copper King skarn deposits, are found in the project area near the SW-NE fault also identified on the geological map (Figure 10).

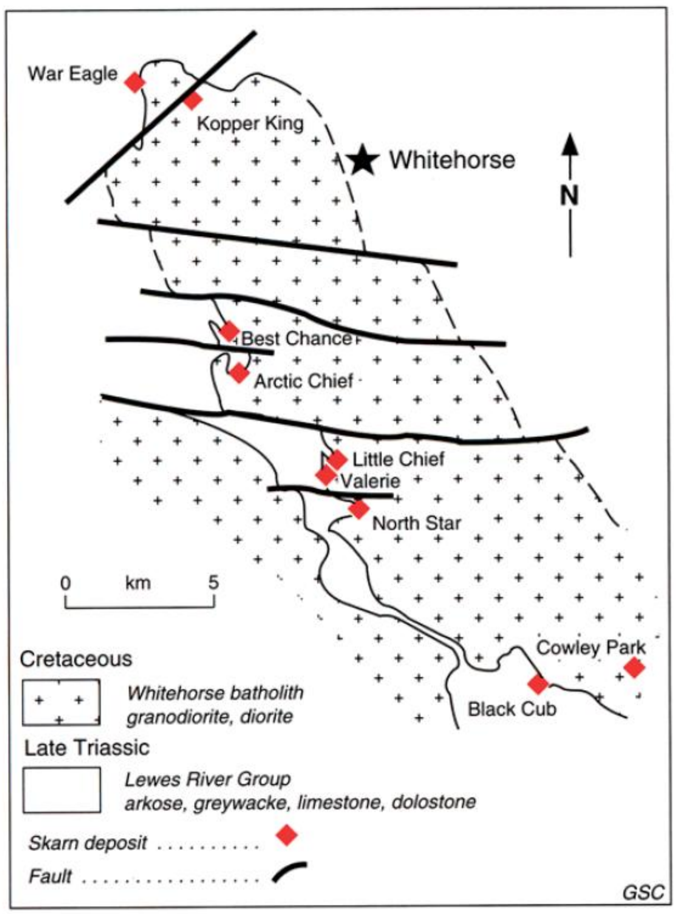

Figure 12: Simplified regional map of the Whitehorse Copper Belt showing principal Cu-Au-Ag skarn deposits (after Meinert, 1986)

Radiogenic heat production

Several rock outcrops were sampled and analyzed in the vicinity of the project area by the YGS (Colpron, 2019) (Figure 13). Results from the analysis on numerous samples on various parts of the Cretaceous Whitehorse pluton indicate a rather low to average radiogenic heat production (1.94 to 2.99 μW/m^3). Near the Takhini Hot springs, however, the Flat Creek pluton analyses shown high radiogenic heat production potential (between 3.81 and 5.84 μW/m^3) which was identified as a possible source of heat for the Takhini geothermal fluids. The Haeckell pluton, which has never been sampled and analyzed, is of a similar age and part of the same plutonic ensemble that the Flat Creek pluton, it could potentially generate radiogenic heat of the same intensity.

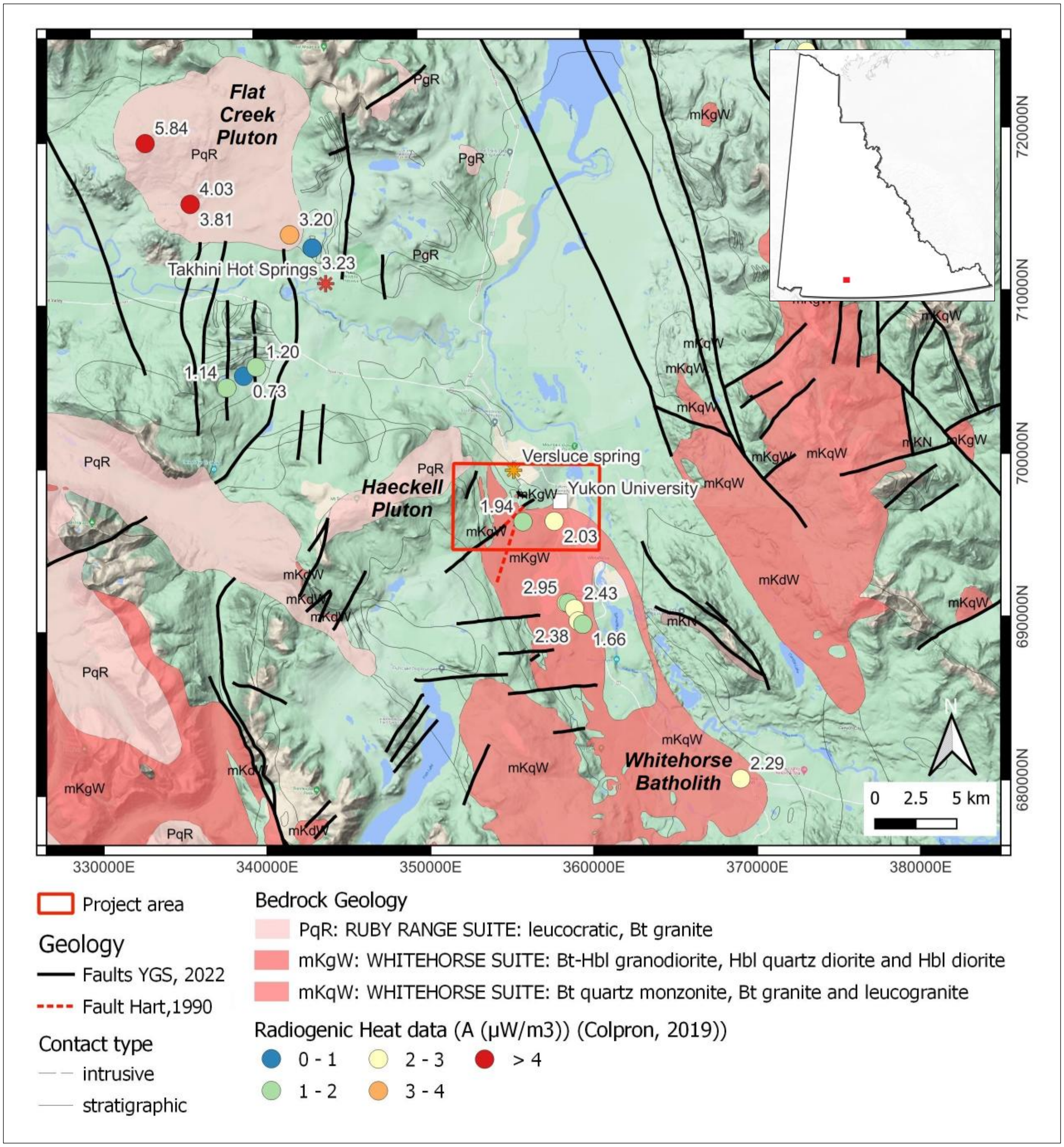

Figure 13: Potential radiogenic heat production from granitoid pluton in the Whitehorse area (Colpron, (2019 & 2022))

4.4. Remote sensing analysis

No detailed structural analysis of the area of interest could be found in the literature. Further, the geological map at the 1/250,000 scale only shows major faults in the area, which is limited to a few elements and does not show any feature in the direct vicinity of Yukon University. Analysis of high-resolution imagery can bring valuable information by helping identify small-scale elements and determining structural trends of a project area.

To complete this tectonic analysis, high resolution (1 meter) LiDAR (Light Detection and Ranging) imagery were gathered to identify these structural elements. LiDAR is a relatively new technology that uses reflected electromagnetic radiation in the visible spectrum to produce extremely detailed and accurate maps of the earth's surface. LiDAR data are typically acquired by a sensor mounted on an aircraft and can be processed to filter out vegetation and buildings to produce a high-resolution "bare-earth" digital model of the ground surface. LiDAR elevation models are particularly useful for identifying and mapping subtle tectonic-geomorphic features associated with active faults. Detailed fault maps are important for characterizing structural controls on geothermal resources in tectonically active areas (e.g., Faulds et al., 2011).

Because project area is populated and constructed with residential, industrial and transportation infrastructures, many changes of the soil has occurred in the past decade and could be mistaken for structures. To avoid misinterpreting these elements, the analysis was completed in parallel with the satellite imagery and constructed areas were generally ignored. Additionally, to help pick structures, imagery analysis processed were used, as LiDAR files usually come in raster dataset format with each cell representing the elevation of the terrain at that location. This permits us to use different remote sensing analysis tools such as Multi-directional Hillshade, Slope, and Aspect analysis generated from the LiDAR imagery.

Multi-directional Hillshade

The Multi-directional Hillshade algorithm is based on the normal Hillshade algorithm, which is a mathematical procedure that takes digital elevation data as input and generates an image that simulates the shadows cast by the terrain. The Multi-directional Hillshade, as the name suggests, allows for the simulation of light coming from multiple directions, which allows for a more realistic representation of the terrain. It is achieved by calculating the Hillshade for different azimuth and altitude values and then combining them. It greatly enhances the visualization of the terrain, particularly by improving the appearance of regions with low relief (Figure 14). This type of Hillshade can be useful for a wide range of applications, such as visualizing landforms, identifying patterns and features in the terrain.

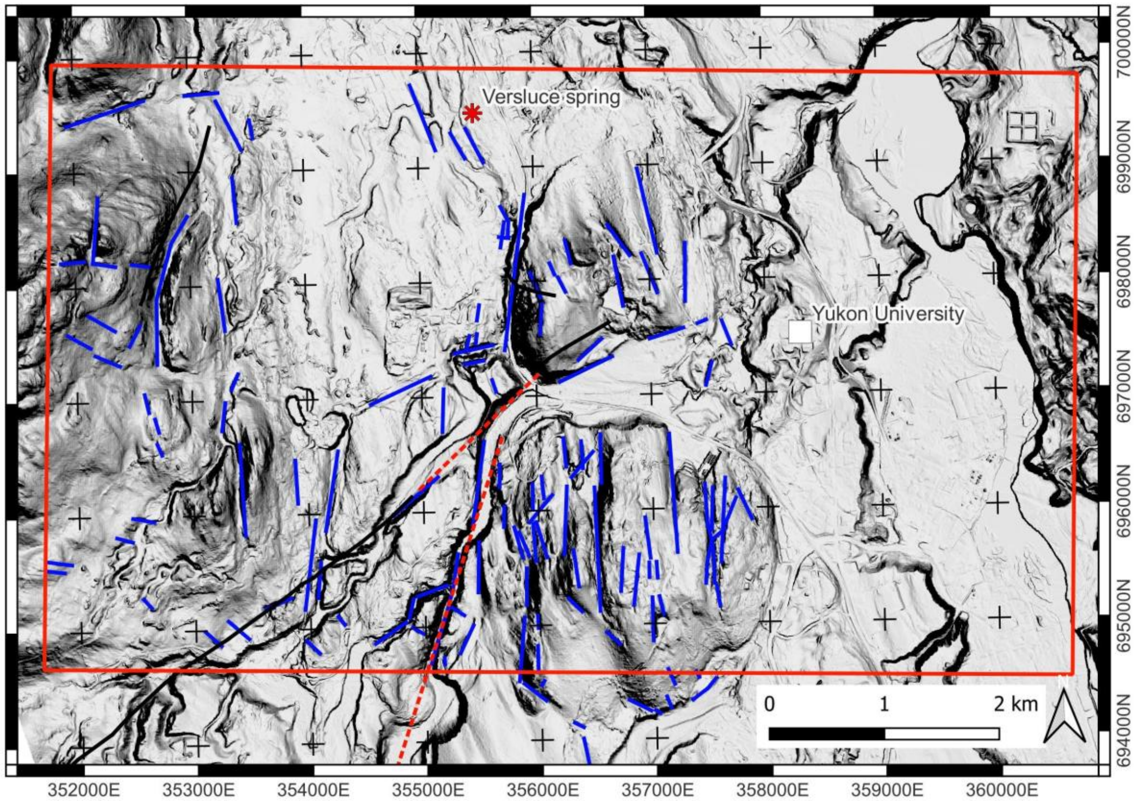

Figure 14: Multi-directional Hillshade raster of the project area. The black lines are the faults from Colpron (2022), and the red lines are interpreted faults from Hart (1990). Blue lines are identified lineaments.

Slope

The slope algorithm is used to calculate the slope of the terrain based on the elevation measured by the LiDAR survey (Figure 15). The slope is calculated in degrees and a steep slope or sudden slope change in certain areas can be the result of underlying geological structures or changes in bedrock lithology, making this algorithm particularly useful to identify geological features.

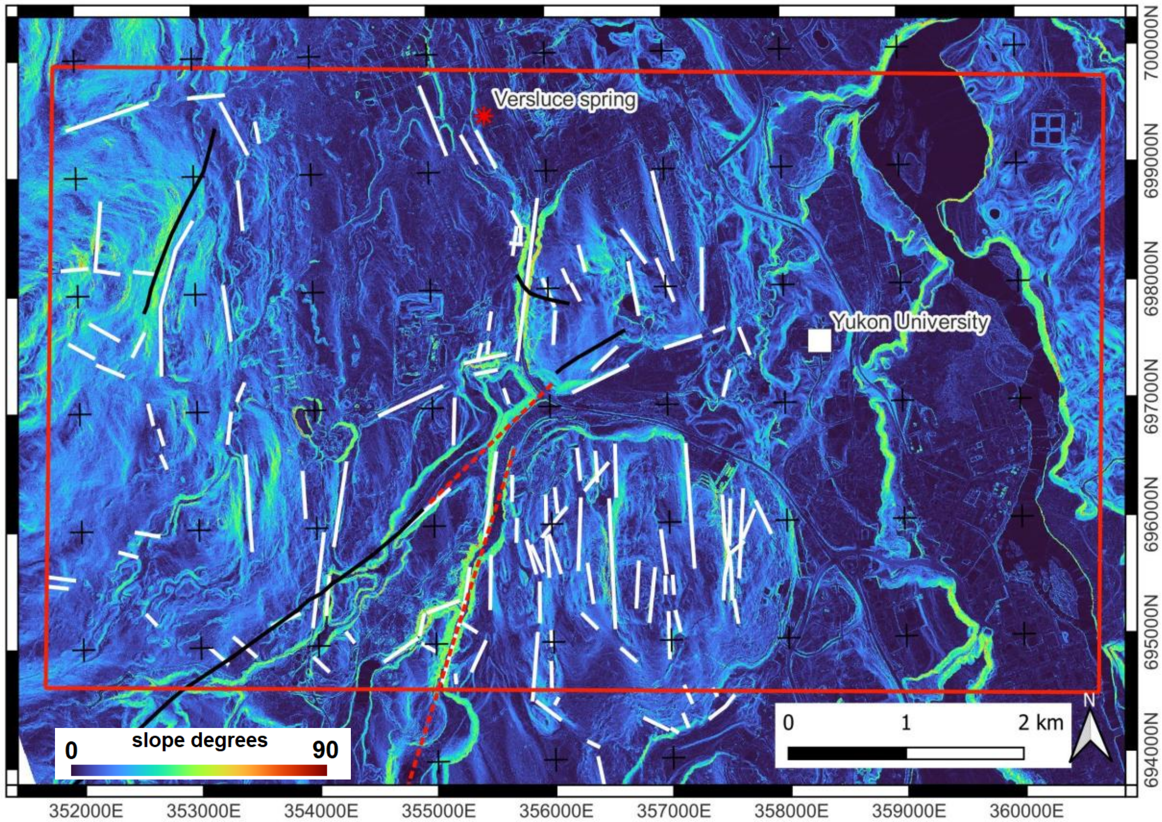

Figure 15: Calculated slope raster of the project area. The black lines are the faults from Colpron (2022), and the red lines are interpreted faults from Hart (1990). White lines are identified lineaments.

Aspect

The Aspect algorithm expresses the slope direction with values between 0 and 360. These values and colors represent the azimuth grouped by 45 degrees sections to represent the orientation using the cardinal points, while the transparency of the color decreases with the slope (Figure 16).

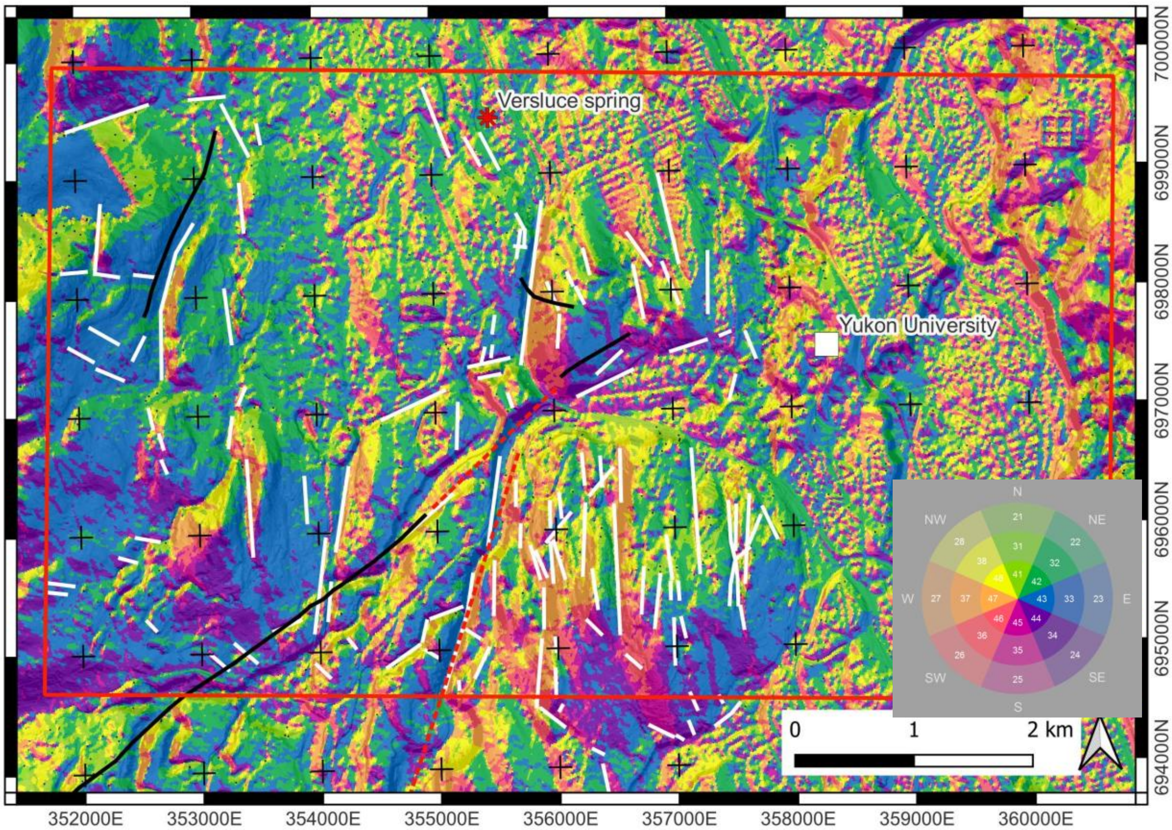

Figure 16: Aspect raster of the project area. The black lines are the faults from Colpron (2022), and the red lines are interpreted faults from Hart (1990). White lines are identified lineaments.

Results and analysis

In the project area, there are two morphologically prominent features that can bring many valuable insights on the local structural settings (Figure 17):

- Bald Hill, is situated south of the Porter Hill area, within the wide turn of the Alaska highway. Several lineaments were identified with NW-SE to N-S direction.
- Mount McIntyre, on the south side of the Alaska Highway, east of Fish Lake Road, facing Bald Hill. Numerous lineaments were identified, mostly oriented N-S and a few oriented SW-NE.

Note that, according to the geological map of the area (Colpron, 2022), these two hills are composed of different bedrock lithologies (see Figure 10): Bald hill is mainly made of the Mandanna and Hancock members of the Upper Triassic Lewes River Group, while Mount McIntyre lithology is made exclusively of the intrusive Whitehorse Batholith, which could explain the difference in the orientation and amount of lineaments identified.

The analysis of the edges of the two hills highlights several important lineaments; one is located in between the two hills and the second one on the western side of both hills. Both structures seem to correspond to previously identified faults or their continuity:

- The structure between the two hills, oriented ESE-WNW (N70-80°) aligns with the fault present in the southwest part of the project area, as represented in the most recent geological map of the area (Colpron, 2022) and with its extended continuity as reported by Hart (1990).
- The structure to the west of the hills, oriented about N5-10°, is not represented in the recent geological map of the area but was present, for its southernmost section, in the geological map by Hart (1990). This structure is thought to continue to the north.

These two structures could correspond to the two main faults crossing in the middle of the project area, which makes them important when considering zones of potentially higher permeability. It is important to note as well that the Versluce warm spring is only situated about 500m from the trace of the interpreted N5-10° fault (Figure 17).

In the westernmost part of the project area, the slopes of Mount Sumanik also show some lineaments. Some are matching the SSW-NNE fault from the geological map (Colpron, 2022) in addition to a few roughly N-S oriented lineaments.

Limited analysis could be carried in areas to the east and north of Yukon University as this area is highly developed and constructed, and any interpretation would be prone to errors.

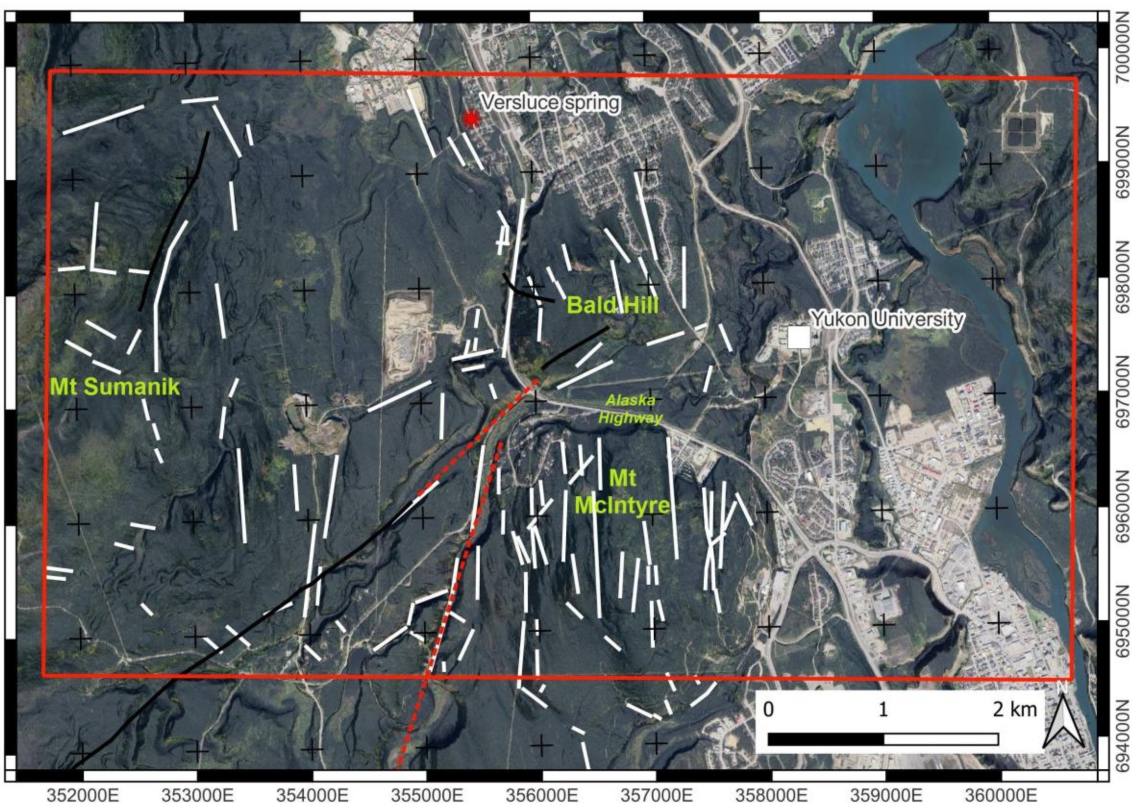

Figure 17: Satellite image (Google Image) from the project area and results of the remote sensing study. The black lines are the faults from Colpron (2022), and the red lines are interpreted faults from Hart (1990). White lines are identified lineaments.

4.5. 3-D geological model

During a geothermal field lifecycle, 3-D models are used to combine, visualize, correlate, and interpret many types of data. These data are mostly geoscientific but can also include land permit boundaries and other surface information.

The conception of a complete 3-D model project involves the generation of a series of models representing different characteristics of the sub-surface relevant to the geothermal resource. These models can be generated from geophysical surveys or be the result of surface and/or sub-surface observations. However, for most geothermal projects there are a handful of resource characteristics that are commonly represented primarily, including lithologies, structure, alteration mineralogy, and temperature distribution. Depending on the data available and the general understanding of the geology of the area, it is possible that only a geological and structural model can be generated. This is often the case in the early stages of a geothermal project, but nonetheless the model can be used as a support to plan future surveys which will then be integrated to update it. It is also common practice to develop a resource conceptual model combining the essential elements of the geothermal system and representing the best understanding of the geothermal resource at a point in time.

The data integrated in the model and the key elements that were modelled will be presented as well as the results of the modelling work.

The model presented was built in the Leapfrog software by Seequent in version 2022.1.0 which is the most recent version available at the time it was built. Besides the images and cross sections on the models presented in this report, the complete Leapfrog Project file has been made available in *.zip format as well as a selection of Leapfrog Scenes files for the Viewer.

Model boundaries

In order to add more geological context to the project area in the 3-D model, the model boundaries extended outside of the project area used in this study. The goal is to include additional elements that could play a role in the geothermal conceptual model and to better explain the general geological and structural context of the Whitehorse area. The map shown in Figure 18.

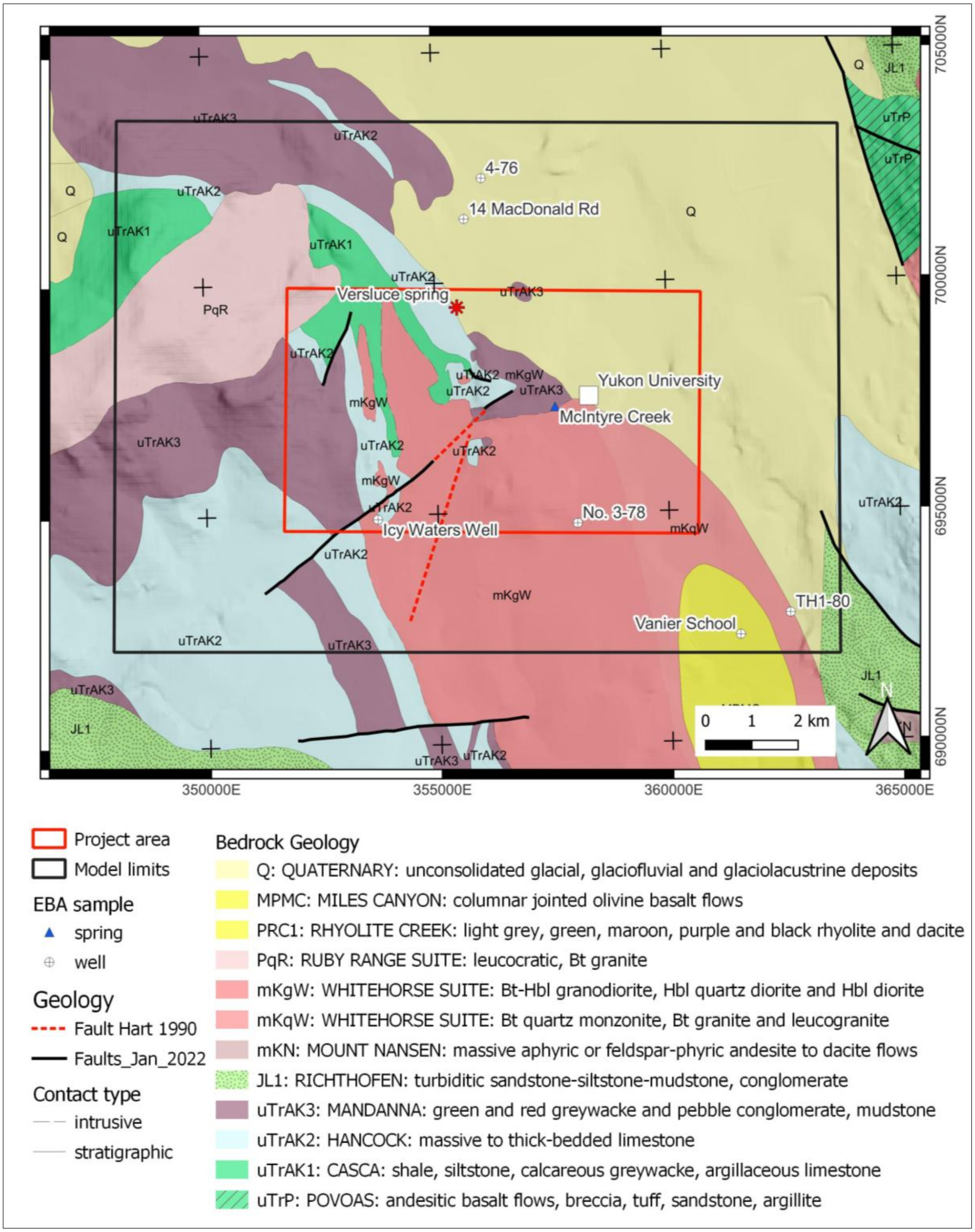

Figure 18: Geological map of the project area showing the outline of the project area and the limits of the 3-D model. Bedrock geology from Colpron (2022).

Model Inputs

Surface data

Most of the data used to build the 3-D model of the project area have been gathered from past field survey completed in the area, such as location of springs, topography, geological maps, location of samples for radiogenic analysis, and geophysical surveys. The data from the remote sensing analysis from this report was also integrated in the model. Additionally, non-resource related information was added in the model and can be projected on the topographic surface, such as the satellite image (from Google Image), and the terrain (from Google Terrain) of the area. Project specific information was also added into the model to locate the Yukon University site and outline the project area.

Sub-surface data

Information on the subsurface for the project area is limited to a handful of shallow groundwater wells. However, only the well at Vanier School had some information about the lithologies encountered, which has defined the depths of contacts between certain formations, namely between the Miles Canyon Volcanics and the intrusive Whitehorse Batholith.

The geology and information on the structures to establish the geological model of the project area are mostly based on previous interpretation illustrated by cross sections in the area, geological maps, and the results of the remote sensing analysis completed for this study. Several iterations of the Whitehorse geological map (numbered 105D) were made over the years, the most recent (Hart et al., 1990; Hart et al., 1997; Gordey, 2008; Colpron, 2011, 2022) were utilized to help build the 3-D geological model. In some areas the foliation information available were integrated to constraint the behavior of the geological units in the subsurface, and a degree a geological interpretation was sometimes necessary in poorly informed areas, particularly to the east of Whitehorse. Interpretative sections resulting from the geothermal exploration in the Takhini Hot Springs area (Figure 7) were also used to constrain the geology of the northwest area of the model.

Results

Model pictures

Three pictures of the final 3-D geological model are shown below in Figure 19 and Figure 20. The model is made available with this report in the Leapfrog Viewer format with a selection of prebuilt scenes, and the complete Leapfrog project files are provided in *.zip format.

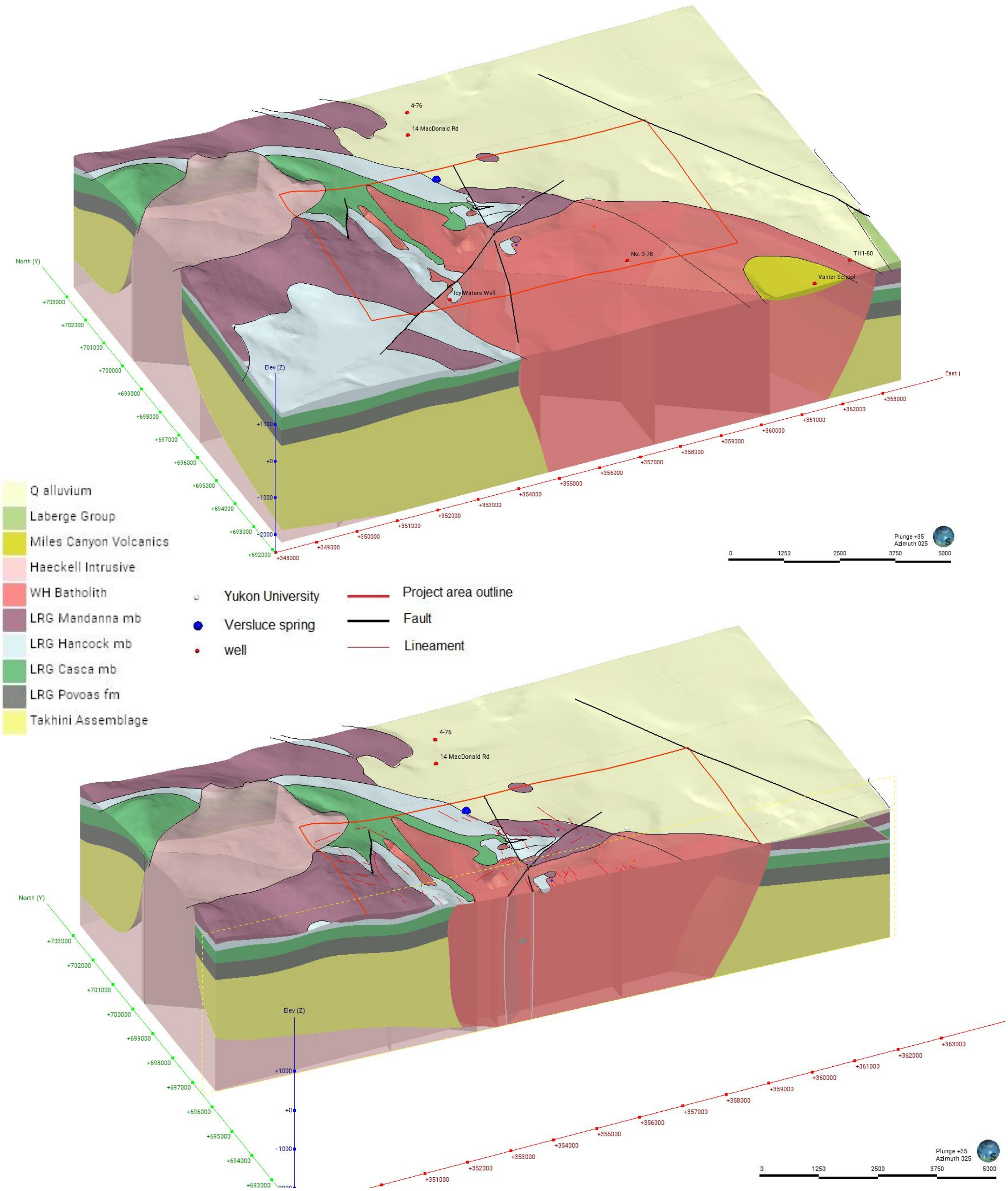

Figure 19: Image capture of the 3-D geological model of the Whitehorse area (top: full model, bottom: model sliced in the middle along E-W axis.

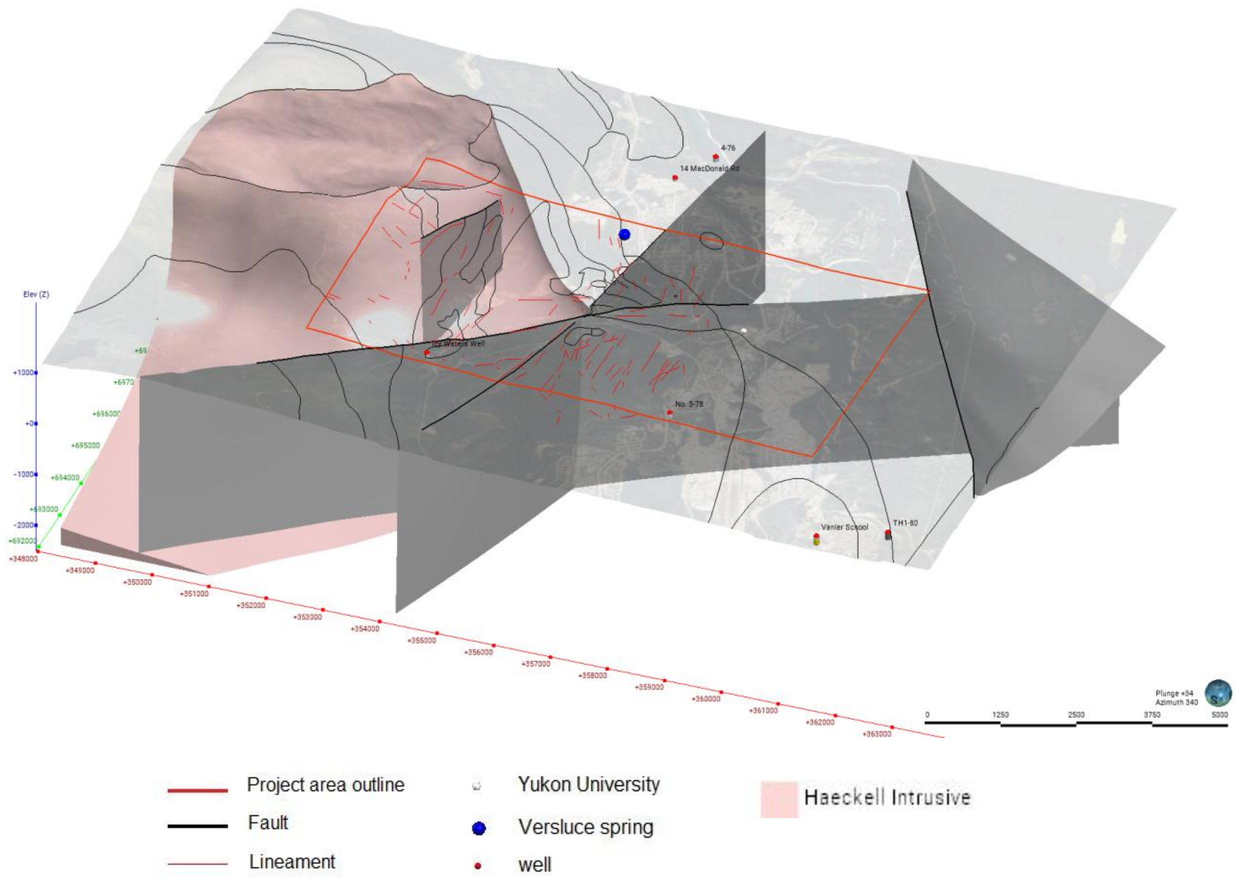

Figure 20: Image capture of the 3-D structural model of the Whitehorse area.

<u>Cross sections</u>

Several geological cross sections were created based on the 3-D geological model- their locations in the model are shown on Figure 21 and the complete cross-sections are compiled in Appendix A. Three of the cross-sections (1, 2, and 3) cut the model along the North-South axis whereas cross-sections 4 and 5 are oriented West to East. These cross-sections were positioned to cut through the main geological units and faults.

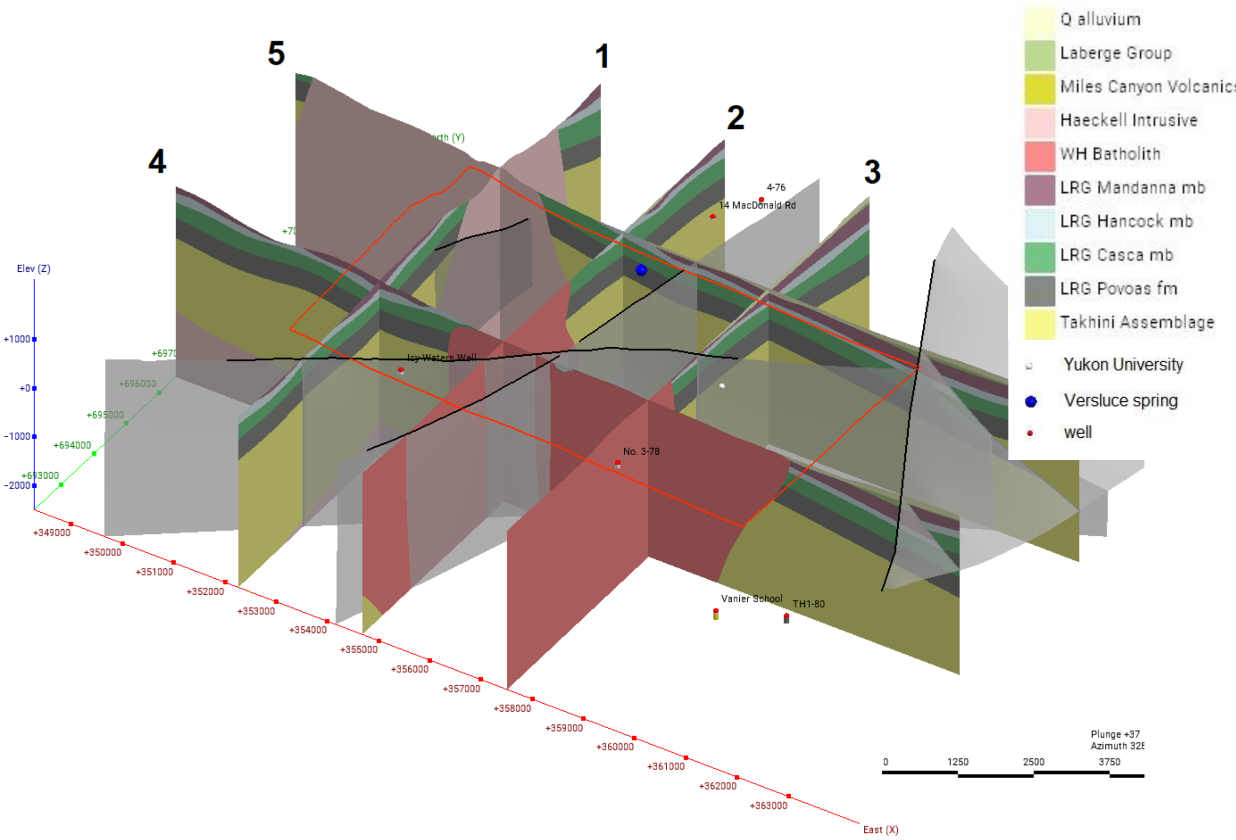

Figure 21: Cross sections extracted from the 3-D geological model (See appendix A for 2-D cross sections)

5. Geophysics

5.1. Gravity

The Bouguer gravity anomaly map (from Yukon Geological Survey, 2011; Aurora Geosciences Ltd., 2012, 2014; Figure 22) shows the variations in the Earth's gravitational field. It is created by subtracting the effects of the Earth's crust from measurements of the total gravitational field, which is used to reveal the underlying density structure of the Earth's interior. It is commonly used for geologic mapping as it can reveal information about the geologic history and structure of an area.

Low negative values indicate lower density in the subsurface, while high positive values indicate higher density. The Bouguer gravity anomaly map was extracted from the provincial scale map using station spacing of 2 km and thus is of low resolution, which inhibits us from interpreting any variation of density at the project scale.

The Bouguer anomaly map in the project area shows values ranging from around 0 to 5.8 mGal. The higher density zones coincide with the presence of the Coastal Plutonic complex to the west, as intrusive rocks have some of the highest densities, and indicates that this unit is likely massive and thick and connects several of the intrusive bodies observed on surface in the area such as the Flat Creek and Haeckell Plutons. Another element highlighted by the map is the presence of a north trending ridge south of the pluton complex which could indicate the axis continuity of the Haeckell pluton to the south at depth.

As there are no high Bouguer anomaly values observed near the location of the Whitehorse Batholith, it can be inferred that its extent at depth is limited and has little impact on the measured density. To the north of the project area, the low gravity anomaly confirms the presence of thick sedimentary deposits of the WHT.

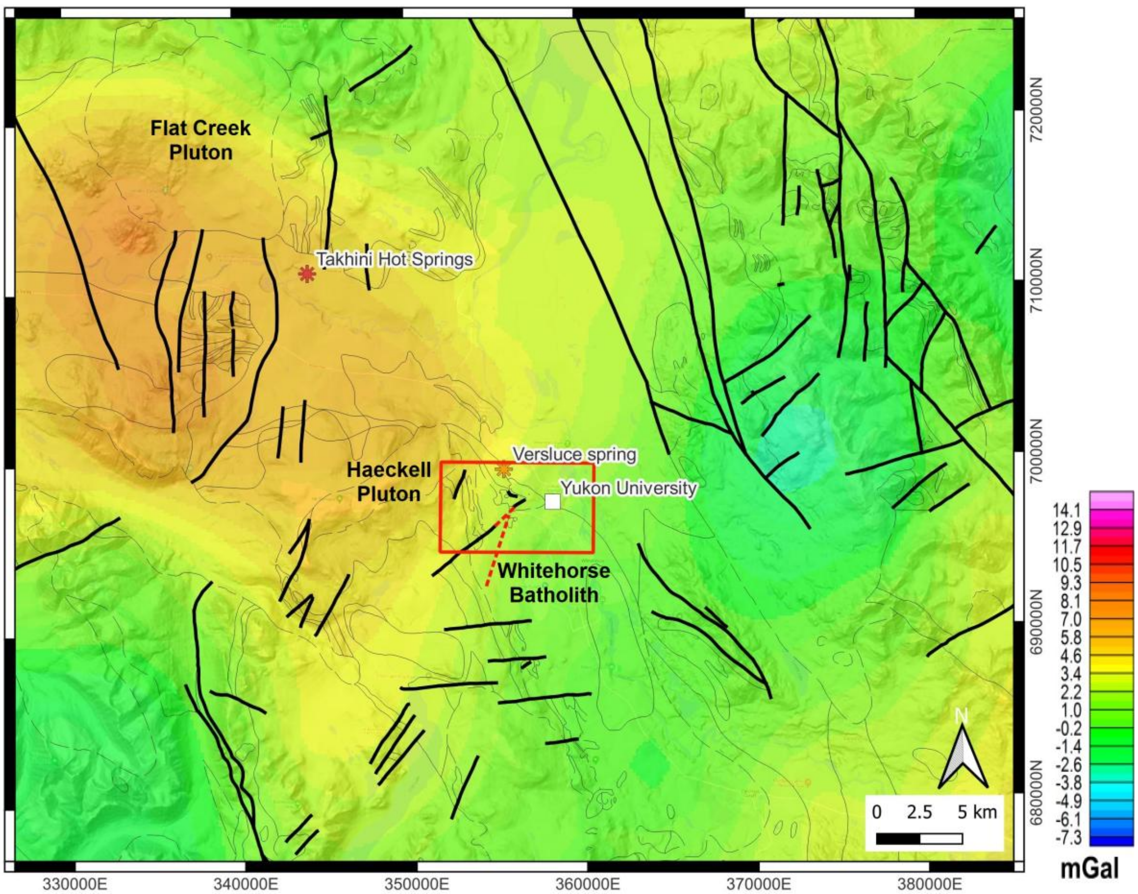

Figure 22: Gravity Bouguer Anomaly map of the project area. Data compiled from the regional Canadian Geodetic Survey ground-gravity holdings (~10 km station spacing), and high-resolution (~2 km station spacing) surveys acquired for the Yukon Geological Survey (Yukon Geological Survey, 2011; Aurora Geosciences Ltd., 2012, 2014). All surveys are reduced to a Bouguer density of 2670 kg/m3 and statically levelled to the regional data: db_project_no=10013. Black line are faults from Colpron (2022), red lines are faults from Hart (1990).

5.2. Magnetics

First vertical derivative

A first vertical derivative magnetic map shows variations in the Earth's magnetic field. It is created by taking the first derivative of the magnetic field in the vertical direction, which helps to highlight small, local variations in the field. The magnetic field can reveal information about the geologic structure and history of an area, including the presence of volcanic rocks, sedimentary rocks, or fault zones. The data shown on Figure 23 were extracted from the compilation of Oneschuk et al. (2019) and is gridded at 50 m, it clearly highlights the two plutons present in the area: The Haeckell pluton to the west and the Whitehorse Batholith in the southern half of the project area. There is a strong contrast with the lows observed in the areas where the Quaternary glacial deposits and the Lewes River Group rocks outcrop, in the southwest corner and the northeastern half of the project area.

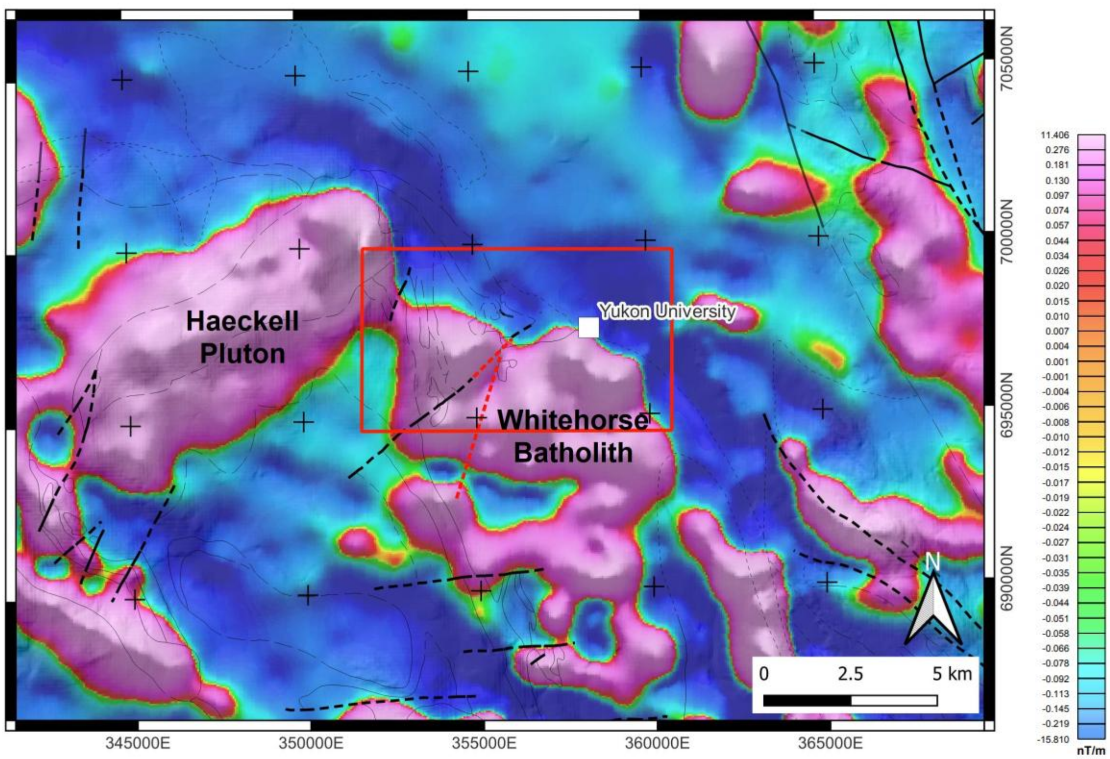

Figure 23: First Vertical Derivative magnetic map from Oneschuk et al. (2019). Fault annotations and lithological contacts are from the geological map of the Whitehorse area (Hart, 1990). The study area boundary is shown by the red polygon. Black line are faults from Colpron (2022), red lines are faults from Hart (1990).

Residual magnetic

The residual Total Field magnetic map shows the remaining variations in the Earth's magnetic field after certain effects have been removed or "reduced." These effects can include the Earth's main magnetic field, the regional magnetic field, and the effects of topographic features, such as mountains or valleys. This allows for better observation of local magnetic variations. It also provides better insights for exploration as the effects can reflect changes in lithology of the basement rocks or changes in elevation the top of the basement. The data presented in Figure 24 below were extracted from the compilation of Oneschuk et al. (2019) and is gridded at 50 m.

Similarly to the First Vertical derivative map previously shown, the magnetic high in the project area corresponds to zones mapped as the Whitehorse Batholith and the Haeckell pluton, which contains high amounts of magnetite minerals. The lowest magnetic anomalies correspond to areas mapped as the Quaternary glacial deposits overlaying the sedimentary formations of the Lewes River Group. In the intrusive units, some slightly lower magnetic anomalies are present where the main faults have been identified by Hart (1990), which could be linked to the presence of some sedimentary units or demagnetization of the rocks due to alteration in the fracture zones.

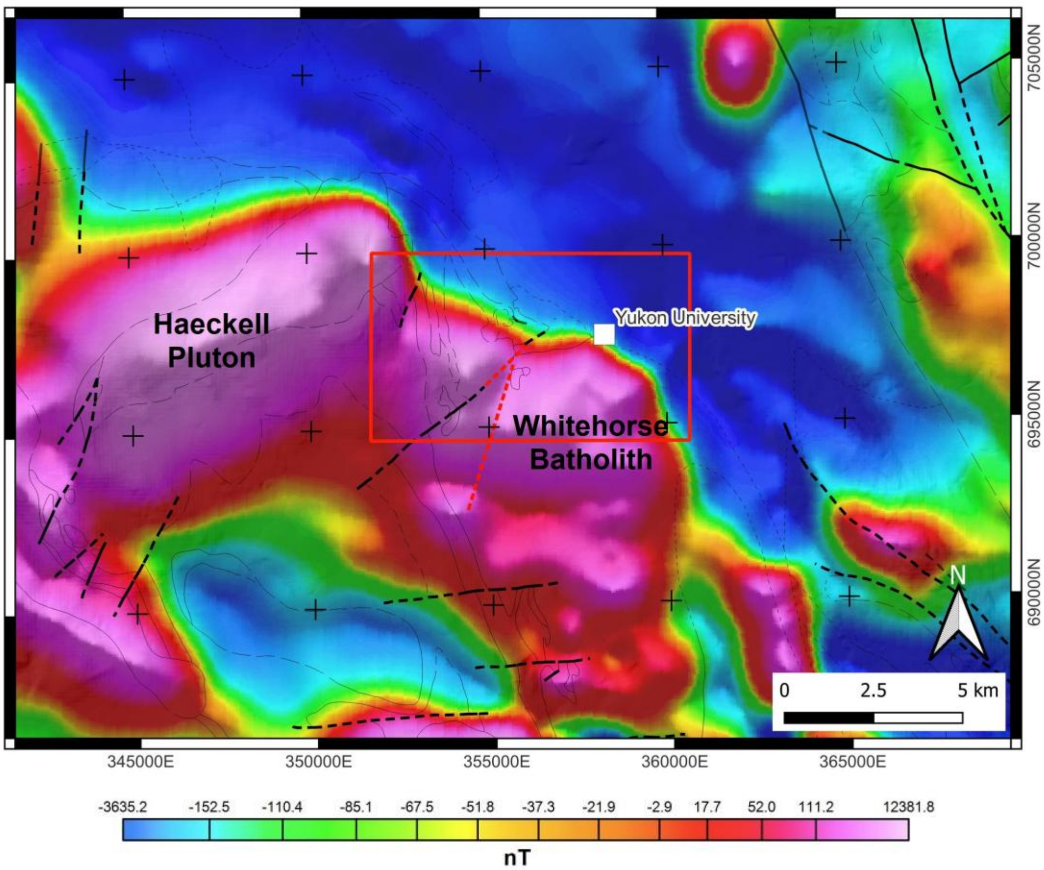

Figure 24: Residual magnetic map from Oneschuk et al. (2019). Fault annotations and lithological contacts are from the geological map of the Whitehorse area (Hart, 1990). The study area boundary is shown by the red polygon. Black line are faults from Colpron (2022), red lines are faults from Hart (1990).

6. Fluid geochemistry

6.1. Surface thermal manifestations

The Versluce Spring is located about 1-2 km NW of Yukon University and 100 m west of the north end of the Rabbitsfoot Canyon. The warm spring has a summer temperature of 12 °C, pH of 7.8, and a flow rate of less than 50 L/min. A small fault is visible near the springs. Crandall and Sadlier-Brown (1978) reported that the spring flows from glacial till overlying volcanic and sedimentary rocks of the Lewes River Group which are locally cut by granitic intrusions. The discharge chemical analysis shows a primarily bicarbonate ($Ca(HCO_3)_2$) composition and a component of magnesium (Mg) and sulfates (SO_4). It is located on privately owned land and was reportedly used as an ice-free domestic water supply. Although this spring doesn't present a very high temperature, the fact that it does not freeze in winter indicates thermal origins. The chemistry of the fluid suggests a potential mixed nature with a portion of fluids from deeper origin, possibly from higher temperature Mg-rich hosted rocks such as volcanics, diluted in shallow cold groundwater before exiting to the surface.

6.2. Shallow groundwater studies

This analysis is based on the data provided in the EBA (2008) report. Figure 6 shows the *location of springs and wells.*

Two of the water wells that were analyzed (Icy Waters Well and No.3-78) as well as the McIntyre Creek spring are located within the project area. Four more wells (4-76, 14 MacDonald Road, Vanier School, and TH1-80) are within a 3 km radius of the project area. Amongst the other water wells sampled, two (LTMW No.1 and Cadet Camp) are located 15 km or more to the southeast and one (DH90-01) is closer to the Takhini Hot Springs to the northwest; these wells will not be considered for this analysis.

Temperature profiles

The Vanier School and TH1-80 wells have the warmest groundwater temperature as reported previously. In the other wells, temperatures were between 3.8 and 4.6 °C. It is important to note that well 4-76, located within the project area, in Porter Creek, shows the highest temperature gradient of about 6.1°C/100m, reaching a temperature of 4.37 °C at a depth of 36 m. This well is located about 2.8 km to the north of the Versluce Spring. In the well named 14 MacDonald Rd, located in between the two, a similar temperature of about 4 °C was recorded at the top of the pump located at a 40 m depth.

Water chemistry

The water samples from the wells and spring in the project area all show a similar calcium (Ca) or magnesium (Mg) bicarbonate (HCO_3) chemistry with a higher chloride component for wells 4-76, Ice Waters and 14 MacDonald Rd. This fluid chemistry is likely related to circulation within the sedimentary formations (mostly sandstone) with a possible influence from mixing with fluids or deeper origins (Figure 25). The Vanier School and TH1-80 have different chemistries most likely related to their occurrences in basaltic formations.

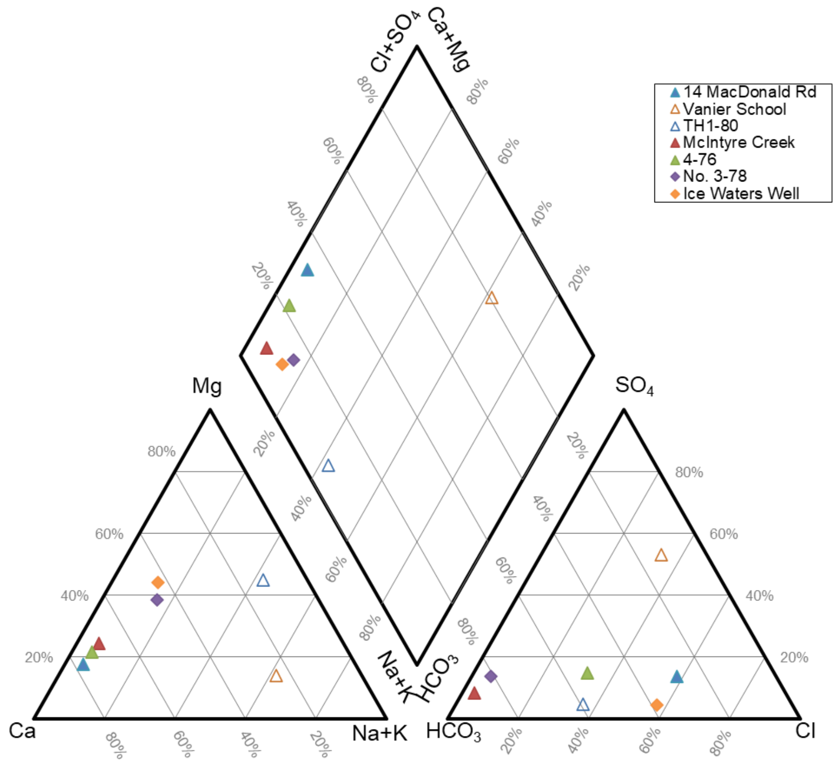

Figure 25: Piper diagram for selected samples from EBA, 2008

Geothermometer temperature estimates were re-evaluated using the water analysis results. All data could be used reliably except for well TH1-80 which shows a cations/anions charge imbalance, thus giving misleading results (Table 1).

The geothermometers indicate maximum subsurface temperature of about 40 °C, although a high degree of mixing with shallow groundwater is likely to have occurred, diluting potential geothermal waters with colder meteoric waters. Note that geothermometer calculations by EBA (2008) reported results as high as 52 °C for the Vanier School well, however no details are provided on these calculations.

Table 1: Geothermometry values for selected water samples from EBA, 2008

Well / spring	Quartz conductive (1)	Na-K-Ca Mg corr (2)	K/Mg (3)
14 MacDonald Rd	18	2	31
Vanier School	34	42	33
TH1-80	-82	17	44
McIntyre Creek	6	0	27
4-76	13	4	30
No. 3-78	33	12	20
Ice Waters Well	28	37	41

(1) Fournier and Potter, 1982,
(2) Fournier and Rowe, 1982
(3) Giggenbach, 1986

7. Geothermal conceptual model

Based on the data collected and interpreted, and on new work completed in the project area, an initial conceptual model highlighting potential elements of a geothermal resource in the Whitehorse area can be established.

The purpose of a conceptual model is to describe or illustrate the essential elements in favor of the presence of a geothermal resource in an area. It represents, at any given point in a project lifecycle, the best understanding of the sub-surface settings and the elements that control a geothermal system. Typically, it is built by geoscientists with geothermal expertise using all the subsurface information available and is updated as new data are collected and interpreted.

During the early exploration stage, the geology and in particular the geological structure of the area of interest are the most important information to consider, completed by geophysical survey results and relevant geochemistry information.

The keys elements of the preliminary conceptual models will be detailed in this section and illustrated using the 3-D geological model developed in this study.

7.1. Resource characteristics

The key elements of the conceptual model for the Whitehorse area are described below:

Heat source

Understanding the heat source is crucial for developing a geothermal resource. While temperature typically increases with depth, it is important to identify anomalies in the geothermal gradient where warmer fluids can be accessed with a shallower drilling depth. This can help to optimize the geothermal energy production process and make it more cost-effective.

In the project area, volcanism is present as shown by the Miles Canyon basalt that covers a wide area to the south. Although the location of the magmatic source is unknown, dykes and sills were found in the area which indicate a nearby magmatic source at depth. However, this volcanic activity is relatively old and most likely does represent a significant heat source in the current context.

It is possible that one of the batholiths present in the area could be a source of heat, as the radiogenic decay of such a large body could generate heat and transfer it to the fluids circulating within the fractures at depth. It is also common for geothermal systems to have deeper heat sources and fluid circulation, which can produce high-temperature reservoirs. The two main intrusive bodies around the project area are the Whitehorse Batholith to the south and the Haeckell pluton to the west; radiogenic decay measurements on the Whitehorse Batholith, a mid-Cretaceous formation, do not indicate any sufficient radiogenic heat production to heat up fluids significantly. The Haeckell pluton is a younger Cenozoic pluton; no radiogenic heat production measurements have been carried out on rock samples. However, it must be noted that it has a similar age and is located at a relatively short distance (<20 km) to the higher heat producing granite located near the Takhini Hot Springs and identified as a potential heat source for the hot geothermal fluids present in that area. The gravity survey also seems to indicate that the two plutons might be originating from the same intrusive body at depth.

Permeability

The permeability to be found at depth is most likely to be secondary permeability, related to fractures and faults. The highest permeability is likely to be found along the two main interpretated faults in the project area and in particular where they intersect in the area of where the Alaska Highway make a wide turn by the Bald and McIntyre hills. One of these faults is close to the Versluce warm spring and could indicate an upflow of deeper, warmer fluids, reaching the surface in the area. However, a more thorough study of the spring is necessary to determine this.

The Whitehorse Batholith is known to have very low primary permeability. Even if some water wells have encountered fluids at shallow depths by drilling through fractures, it is unlikely that these fractures represent a major flow pathway for fluids with deeper origins.

Recharge

Mountainous precipitation is suggested as the primary source for groundwater and potentially for a deeper reservoir. Water could be circulating down to zones of higher temperature though faults and fractures until it heats up enough to flow upward along major permeability channels. More investigations are necessary to understand the possible pathways for fluids circulating in the deeper formations.

Temperature

Fluid chemistry from shallow groundwater wells and geothermometer estimates based on groundwater fluid chemistry suggest that fluids up to temperature of about 45-50 °C could be encountered in deeper permeable zones. According to temperature gradient calculations in water wells in the project area, with values around 6°C/100m and temperatures at 4 °C around 35-40 m depths, temperatures of 40 °C could be reached from a depth of 650 to 700 m if the temperature gradient remains constant. Note that these temperature gradient values are more than twice the average geothermal gradient in the south Yukon region and are only based on shallow measurements which could be influenced by other external factors. Consequently, they must be considered with great caution. It is not uncommon in the regions of post-glacial warming to observe a thermal inversion in the first 100 m from the surface and the real gradient could be different below this inversion (Fraser et al., 2018).

7.2. 3-D conceptual model

Traditionally in the geothermal resource industry, conceptual model illustrations have been limited to 2-D cross sections (Figure 27). However, with the development of 3-D geological modelling tools in the past 10-15 years, it has become common practice to use these models to illustrate the key elements of a conceptual model (Poux et al., 2020). Figure 26 is a 3-D representation of the preliminary conceptual model of the project area.

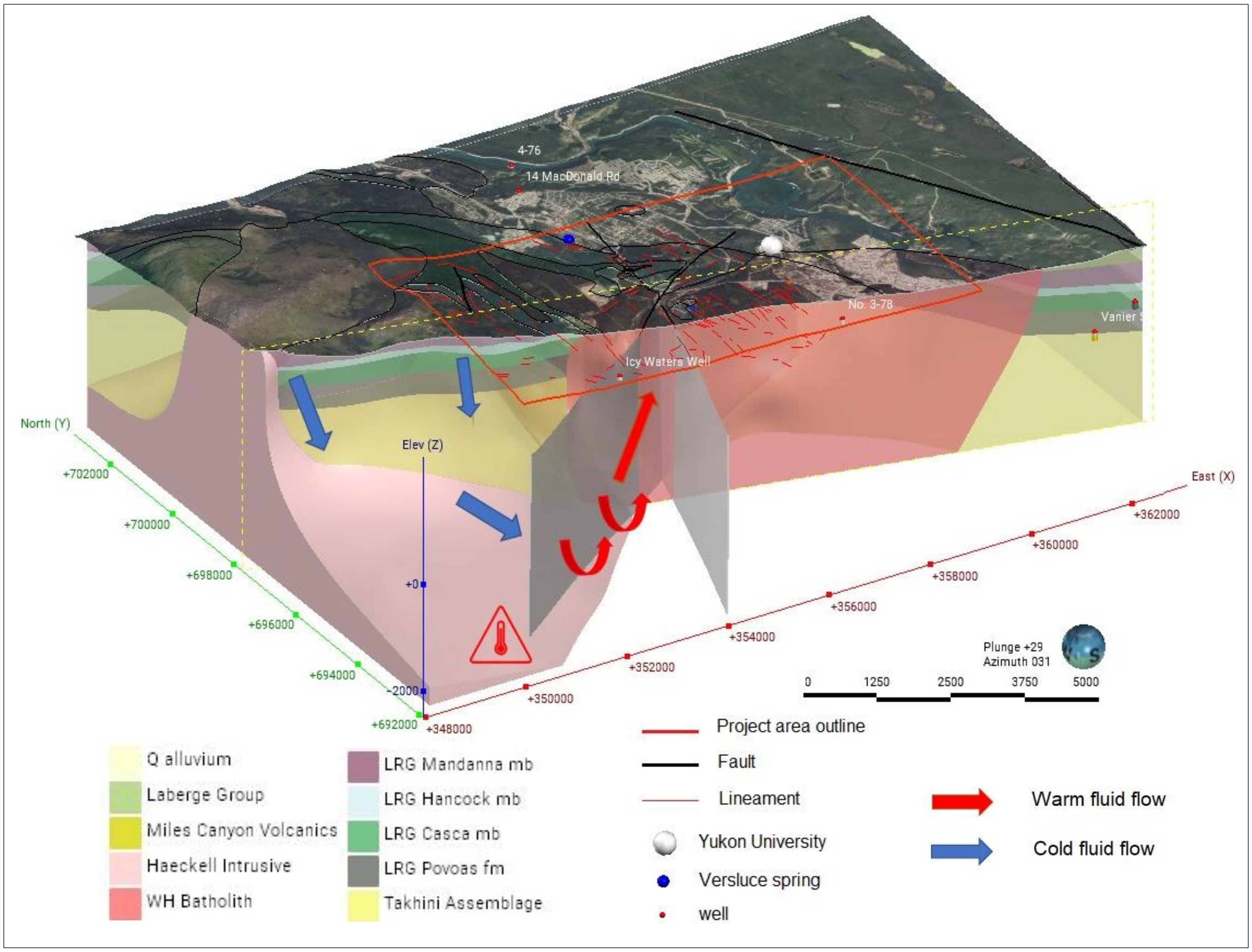

Figure 26: 3-D Conceptual model of the project area.

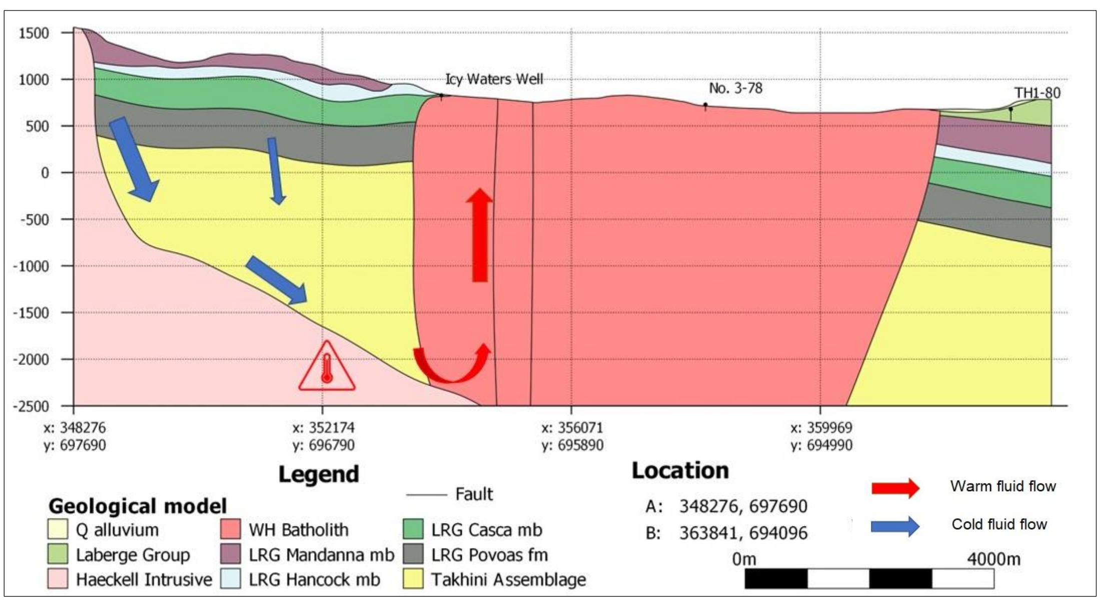

Figure 27: Cross section of the conceptual model. Section location corresponds to the slice on the Figure 26.

8. Recommendations for future work

The exploration program proposed herein comprises four different surveys, each of them designed to provide additional information to best define the geological structures controlling the project area and to narrow down the rather large region of interest to specific target locations in an area of perhaps 10 km^2. We recommend completing the totality of these surveys before drilling any wells. We also recommend that the work be performed in the specific order proposed, intentionally progressing from a larger area survey to specific tools for well targeting in a much smaller area. Our reasoning is to minimize cost by not exploring areas that do not support additional effort. Furthermore, it should be noted that this approach can be halted at any time if a survey does not produce encouraging results. The recommended exploration work includes:

Survey 1: Geological field investigations
Survey 2: Geochemical sampling and analysis
Survey 3: Ground gravity survey
Survey 4: Electromagnetic survey

Please note that it is critical to conduct the geological field investigation stage first as it will guide the extent and design of subsequent geophysical surveys and help identify the fluid and rock samples to be analyzed. Following the completion of these surveys, the conceptual model of the geothermal resource for the project area should be updated before deciding possible sites for exploratory drilling.

Geological field investigations

Field investigations are an essential part of geological surveys, as they allow geologists to gather data directly from the field and to observe and analyze geologic features in situ. The following are some field investigation techniques that may be useful:

- Create detailed maps of an area by collecting data on the location, type, and relative age of rocks, as well as on the geomorphic features of the landscape.
- Collect samples of rocks, soils, and other materials from the field for laboratory analysis. This can provide information on the composition, age, and other characteristics of the materials.
- Detailed observations of geologic features in the field, such as rock outcrops, faults, and landslides, to gain a better understanding of the geology of the area.

Geochemical sampling and analysis

Geochemical studies of fluids present in the area can provide valuable information on the potential presence of a reservoir at depth. They can provide the following information:

- Identify the location and nature of geothermal waters.
- Outline areas of potential upflow, outflow, and recharge.
- Indicate the presence of faults and aquifers.

- Other useful information for making decisions regarding the development and production of a resource.

Any thermal manifestation that has been previously identified in the area should be properly sampled and analyzed by competent professionals. Comparing the results of these analyses with geochemistry data from the Takhini Hot Springs fluids could also provide valuable insights into the geothermal fluid flow patterns in the area and on geothermal fluid characteristics. Comprehensive geochemical analyses for geothermal fluids typically involve the study of important compounds such as sodium, potassium, calcium, magnesium, lithium, boron, silicon dioxide, chlorine, sulfate, bicarbonate, ammonia, pH, and total dissolved solids.

In addition to the fluid samples to be taken for this work, it would be beneficial to sample rocks of some of the highlighted lithologies that could be source of radiogenic heat, such as the Haeckell pluton.

The location of all the samples to be taken will be determined during the geological field investigations.

Ground gravity survey

Gravity surveys can provide the interpretation of controlling faults or other subsurface structures. Gravity combined with magnetotelluric data can contribute to the understanding of fault systems.

For this survey, the area covered should be at least 5 km^2, with about 100 stations with a station spacing of 250 m. The exact design of the survey should be based on the results of the geological field investigations to cover the areas where a better understanding of the geological structure could bring valuable insights for the project.

Electromagnetic survey

A magnetotelluric (MT) survey is a type of electromagnetic survey used to determine the electrical resistivity of a subsurface geothermal system. It helps identify lithological contacts, zones of hydrothermal alteration, aquifer geometry and depth, fracture zones, fault zones, and discontinuities. The number of MT stations (e.g., sounding locations) directly impacts the final results and precision of the survey. The station grid should be dense enough to capture resistivity features for the geology of interest. The more observations taken, the more detailed the imaging. About 25-30% of the MT survey should be combined with a TEM (Transient Electromagnetic Method) measurement to correct for static shift within the MT and help provide better estimates of depth. This combination of methods is particularly useful in zones of rugged terrain.

In the case a MT survey is impossible to complete in the area of interest due to the proximity to infrastructures that could affect the accuracy and reliability of the data, it could be possible to run several parallel Electromagnetic (EM) profiles across the main structural features identified.

The design of the surveys will be based off the results of the geological and gravity surveys. Depending on the results of the work completed previously, it could also be decided that the potential for a geothermal system (or an economically exploitable resource) to be present in the area is insufficient to continue with the project and that further geophysical investigations are not necessary.

9. Closure

We trust this document meets your present requirements. If you have any questions or comments, please contact the undersigned.

Respectfully submitted.
Aetna Geothermal Limited

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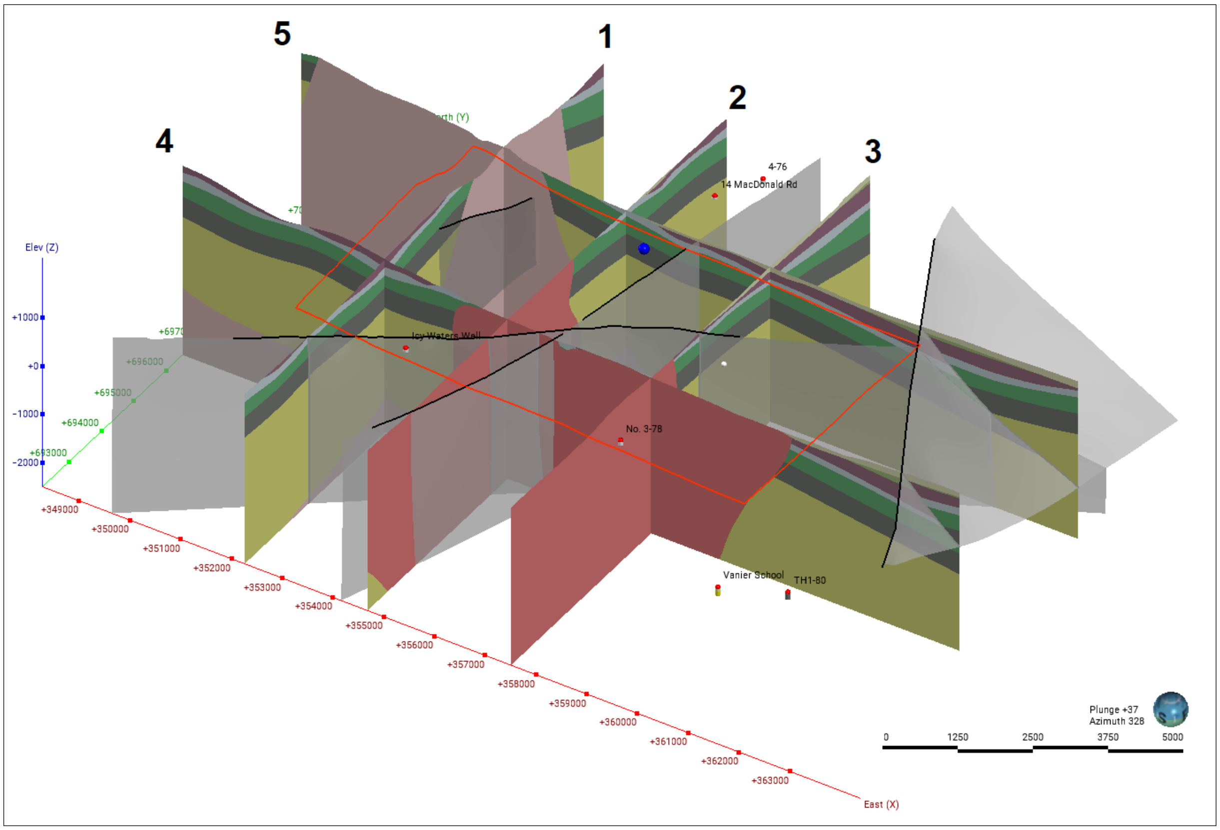
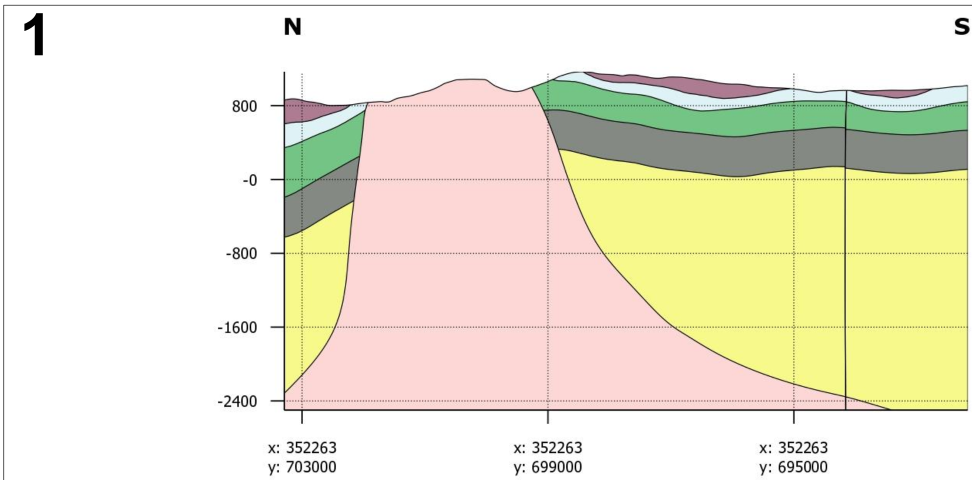
APPENDIX A:
GEOLOGICAL CROSS-SECTIONS





Legend

Geological model

- Haeckell Intrusive
- LRG Mandanna mb
- LRG Hancock mb
- LRG Casca mb
- LRG Povoas fm
- Takhini Assemblage

Geological model - Fault System

—— Fault SW-NE A (On Topography)

Location

A: 352263, 703288

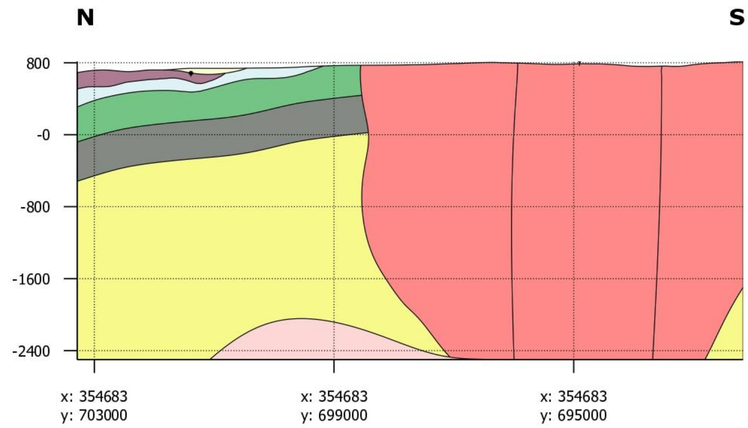
B: 352263, 692174

Scale: 1:74,000

Vertical exaggeration: 1.5x

0m 4000m

2



Legend

Geological model

- Q alluvium
- Haeckell Intrusive
- WH Batholith
- LRG Mandanna mb
- LRG Hancock mb
- LRG Casca mb
- LRG Povoas fm
- Takhini Assemblage

Geological model - Fault System

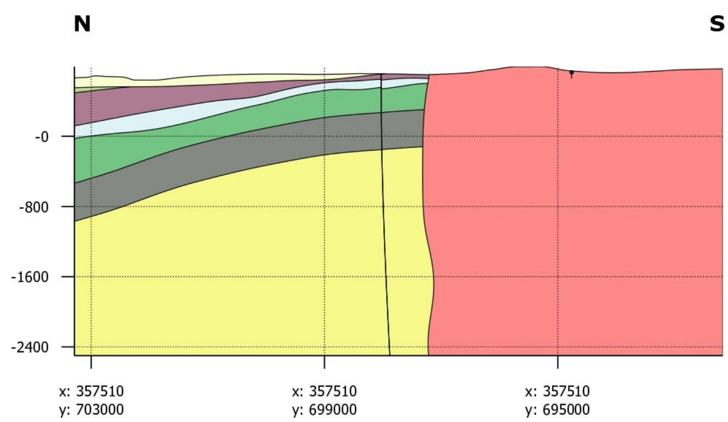
—— Fault SW-NE A (On Topography)

Location

A: 354683, 703288
B: 354683, 692174

Scale: 1:74,000
Vertical exaggeration: 1.5x
0m 4000m

3



Legend

Geological model

- Q alluvium
- Laberge Group
- WH Batholith
- LRG Mandanna mb
- LRG Hancock mb
- LRG Casca mb
- LRG Povoas fm
- Takhini Assemblage

Geological model - Fault System

—— Fault SW-NE A (On Topography)

Location

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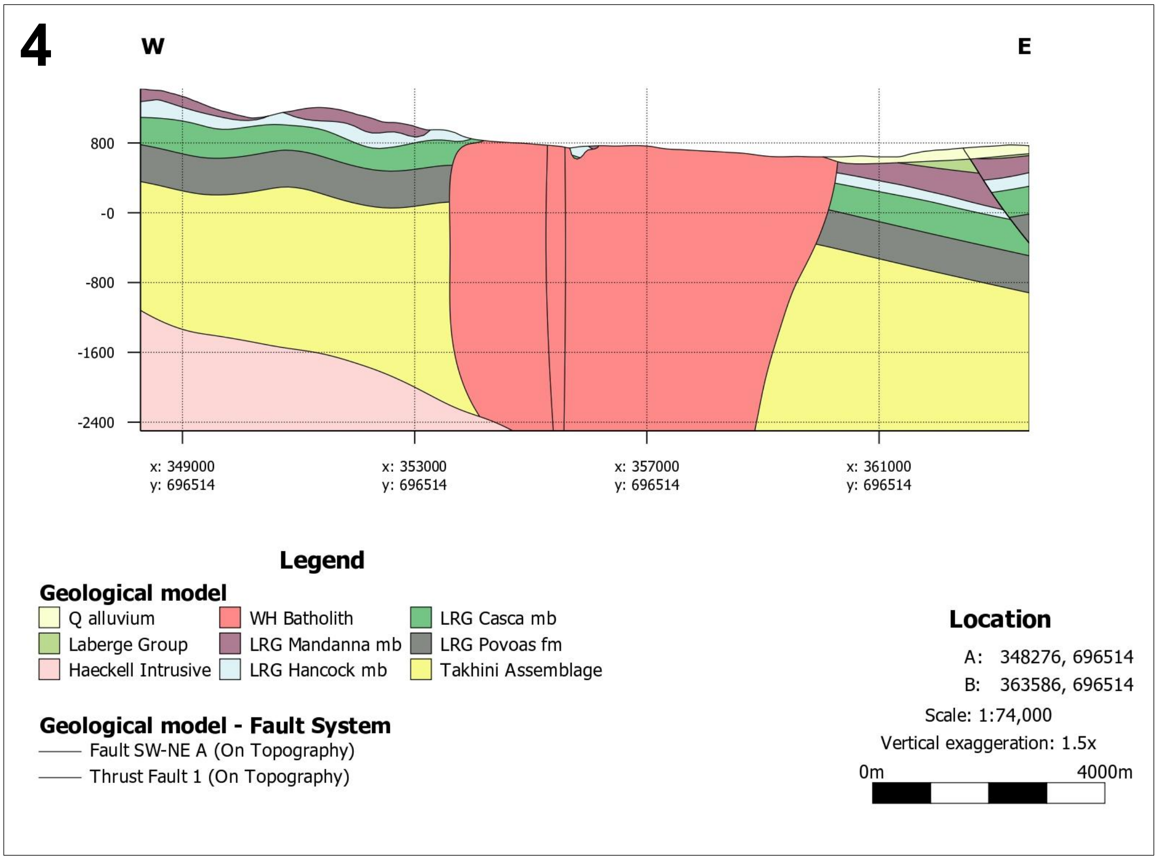
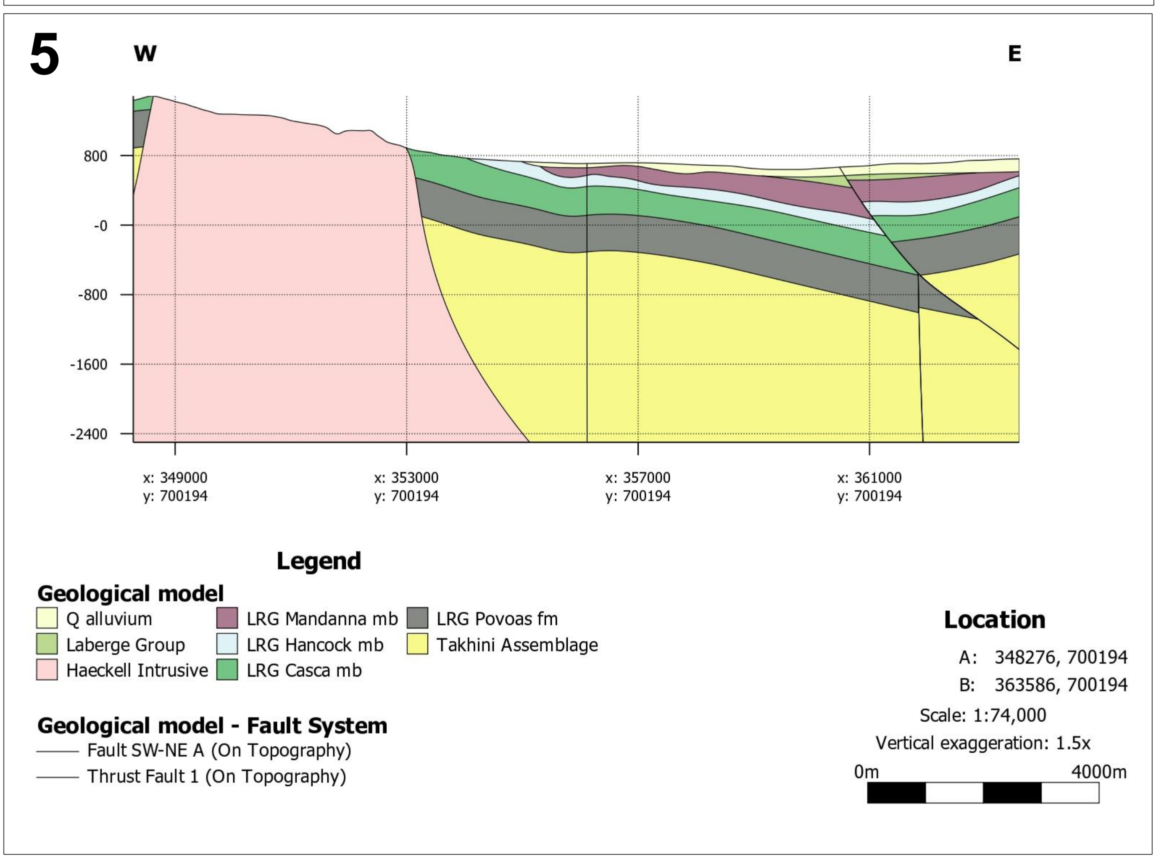
B: 357510, 692174

Scale: 1:74,000
Vertical exaggeration: 1.5x
0m 4000m


4
W
E
800
-0
-800
-1600
-2400
x: 349000
y: 696514
x: 353000
y: 696514
x: 357000
y: 696514
x: 361000
y: 696514
Legend
Geological model
Q alluvium
Laberge Group
Haeckell Intrusive
WH Batholith
LRG Mandanna mb
LRG Hancock mb
LRG Casca mb
LRG Povoas fm
Takhini Assemblage
Geological model - Fault System
Fault SW-NE A (On Topography)
Thrust Fault 1 (On Topography)
Location
A: 348276, 696514
B: 363586, 696514
Scale: 1:74,000
Vertical exaggeration: 1.5x
0m
4000m


5
W
E
800
-0
-800
-1600
-2400
x: 349000
y: 700194
x: 353000
y: 700194
x: 357000
y: 700194
x: 361000
y: 700194
Legend
Geological model
Q alluvium
Laberge Group
Haeckell Intrusive
LRG Mandanna mb
LRG Hancock mb
LRG Casca mb
LRG Povoas fm
Takhini Assemblage
Geological model - Fault System
Fault SW-NE A (On Topography)
Thrust Fault 1 (On Topography)
Location
A: 348276, 700194
B: 363586, 700194
Scale: 1:74,000
Vertical exaggeration: 1.5x
0m
4000m