A COMBINED APPLICATION OF HIGH-RESOLUTION THERMAL INFRARED AND MAGNETIC DRONE-BASED SURVEYS OVER LARGE AREAS FOR GEOTHERMAL AND ELEMENT EXPLORATION IN WESTERN CANADA

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ABSTRACT

In Canada, geothermal and element exploration is challenging due to thick vegetation cover, steep topography, and the presence of hundreds of meters of glacial overburden masking geothermal expressions. Consequently, unique exploration techniques sometimes need to be deployed. Remote sensing thermal infrared surveys and magnetic surveys can be a useful tool for mapping geothermal anomalies and thus aid in characterizing the underlying geothermal system. However, the resolution-to-cost relationship of airborne/satellite surveys often do not match the needs for geothermal prospecting over a large area. In November 2018, Borealis GeoPower employed an unmanned aerial vehicle (UAV or drone) to conduct the first combined drone-based thermal and magnetic survey over a ~22 km^2 area to investigate their Terrace, British Columbia, geothermal project, located near the hottest hot spring in Canada. Over 47,000 georeferenced thermal images were taken; image processing techniques were consequently applied to orthorectify and mosaic the images to obtain a thermal map with sub-meter (~0.5 m) resolution. The high-resolution of the magnetic data enabled enhanced mapping of small magnetic features that would typically go undetected in surveys with lesser resolution. The combination of drone-based thermal and aeromagnetic surveys effectively identified unreported geothermal outflows and subsurface geological structures, demonstrating the usefulness of these techniques for geothermal exploration.

1. INTRODUCTION

The development of geothermal resources can be a challenging endeavour, characterized by high upfront costs and subsurface uncertainty that may translate into poor drilling outcomes, particularly in the initial drilling program. Geothermal and element (concentrated in geothermal brines) exploration within Canada is further hampered by glacial overburden that obscures surface geothermal expressions and hinders bedrock mapping using conventional field techniques. Additionally, physical and regulatory land access challenges such as thick vegetative cover and permitting also pose as obstacles for exploration. To overcome these obstacles complementary approaches must be used in combination with ground-based exploration techniques.

The mining industry has extensively used airborne geophysical surveys involving helicopters or fixed-wing aircraft to cover large, remote areas in a timely manner and at low cost. Typical techniques used in an airborne geophysical survey include gravimetric, electromagnetic, magnetic, radiometric and thermal measurements, all of which can be performed by on-board systems and specifically designed aircraft. These surveys must be conducted at elevations and speeds that allow for safe flying, thus restricting the parameter range for the survey design. Ultimately, this limits the survey's spatial resolution. In addition, conventional airborne techniques can represent a large portion of the cost of exploration campaigns and consequently restrict the survey area coverage.

In recent years, unmanned aerial vehicles (UAVs, or drones) have become a more attractive alternative to airplane or helicopter borne surveys. Not only are drone-based surveys more cost effective to deploy, but they can also overcome most of the aforementioned limitations associated with conventional airplane or helicopter borne surveys. Following recent technological improvements, UAV surveys are capable of producing Digital Surface Models (DSM) (Colomina and Molina, 2014; Harvey et al., 2014), thermal imagery (e.g., Harvey et al., 2016; van der Veeke et al., 2018), and a variety of geophysical surveys (e.g., Macharet et al., 2016). Drone-based surveys used in geoscientific applications have demonstrated a drastic increase in cost efficiency for areas <5 km^2 by reducing or eliminating expenses associated with operating conventional aircraft such as airport fees, deployment and operation, permitting, fuel, and labour costs. Aside from the economic advantages of drone-based surveys these systems are also capable of providing higher spatial resolution as UAVs are able to fly at lower elevations and speeds than traditional aircraft, thus increasing grid granularity and reducing signal attenuation as a function of elevation.

In terms of geothermal and element exploration, there is potential for drone-based surveys to compliment and/or replace ground-based techniques. Gravity, radiometric, and magnetic drone-based surveys are being increasingly implemented in mineral exploration campaigns in favour of their efficiency and cost effectiveness over other techniques (e.g., Parshin et al., 2018). However, the application of this emerging technology for geothermal exploration has been almost exclusively limited to thermal imaging and elevation modeling (Harvey et al., 2016). The use of aeromagnetic surveys, in addition to thermal and elevation surveys, can help to characterize a geothermal resource by identifying subsurface structures from their magnetic expressions. These structures can then be correlated to areas of anomalous temperatures (potential geothermal brine outflows) to better understand the subsurface structures associated with the geothermal system.

Borealis GeoPower Inc. conducted the first-of-its-kind thermal and magnetic drone-based survey in Lakelse Field near Terrace, British Columbia, Canada (Figure 1). This joint

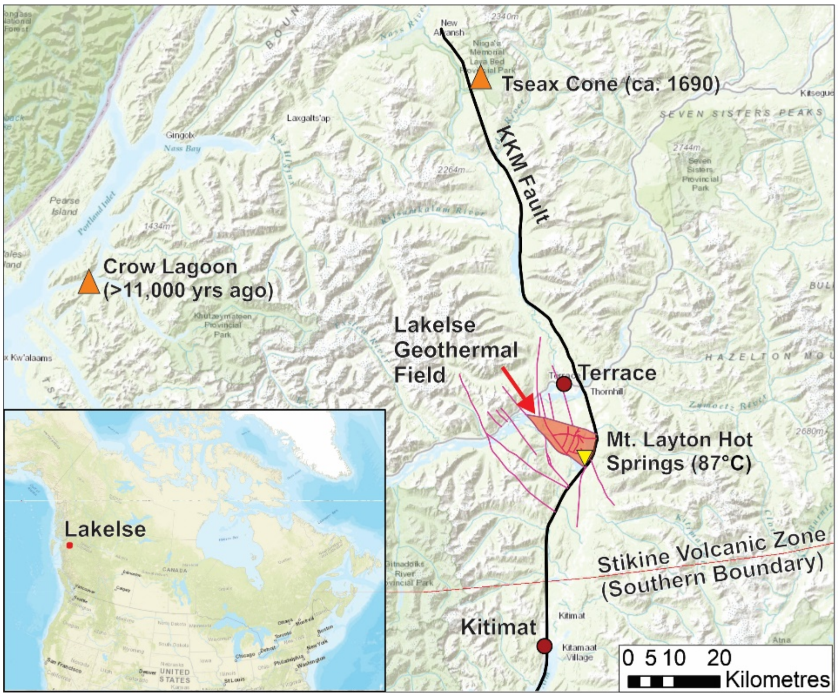

Figure 1: Map of the Lakelse Field near Terrace, British Columbia, Canada, with respect to significant geological features of interest. The inset shows the location of Lakelse in relation to North America.

survey, in combination with in-house reprocessing of thermal data, identified previously unknown geothermal brine outflows, and provided valuable input for the refinement of the conceptual model of the play. This paper serves to highlight the effective application and cost-efficiency of joint geophysical drone-based surveys for the purpose of geothermal and element exploration. An overview of the methodologies and results used for these surveys are thus detailed herein.

2. STUDY AREA

The Lakelse Geothermal Field south of Terrace, BC, lies in a mountainous region of British Columbia, Canada, and presents a unique combination of geological attributes that are favourable for geothermal development. The Lakelse Field is located within the Stikine Volcanic Zone, a region of abnormally hot crust. Canada's two most recent volcanic eruptions occurred within this zone, with the Tseax Cone (ca. 1690 AD) located just 60 km north of the Lakelse Field (Figure 1). Geothermal fluids within the Lakelse Field circulate to the subsurface and back through active fractures in a zone of crustal extension, discharging in the form of Canada's hottest hot spring, Mount Layton Hot Springs, with surface temperatures of up to 87°C (Souther and Halsted, 1973). The peculiarity of combining both near-magmatic and extensional activity make the Lakelse Field unique within Canada.

3. METHODS

A drone-based magnetic and thermal infrared survey was conducted over a 22 km^2 area of the Lakelse Field. The data acquisition, instrument descriptions and data processing associated with each survey are outlined below.

3.1 Magnetic Survey

The aircraft used in the survey was DJI's Matrice 600 UAV (Figure 2), equipped with a laser altimeter, GPS system, Inertial Measurement Unit, and GEM's UAV-MAG™ potassium magnetometer, which provided a sensitivity of 0.0002 nT and ±0.1 nT absolute accuracy. The survey used 100 m spacing between lines running N-S and was conducted at a nominal altitude of 60 m above ground level. A total line length of 337.35 km was acquired over an area of 22 km^2. Data was collected at an airspeed of 10 m/s during ideal flying conditions. This was modified when necessary to accommodate the effects of wind and steep topographic gradients within the survey area.

Figure 2: Image of the Matrice 600 drone used for the magnetic survey (Photo Credit: Global UAV: Pioneer Aerial Surveys Ltd).

The magnetic data was quality checked in the field and any excessively noisy data points or those lacking sufficient georeferenced data were removed. The resulting data was processed as mosaics throughout the survey area as data was collected daily.

A GEM GSM-19 Overhauser Magnetometer was used as the base station. The base station was placed in a location of low magnetic gradient, away from electrical transmission lines and moving metallic objects, such as motor vehicles and aircraft. The base station readings were processed and filtered to remove sudden spikes. The filtered base station dataset was then used to perform a diurnal correction on the magnetic survey data. The diurnally corrected profile data were interpolated into a grid using the minimum curvature technique with a grid size of approximately 1/3 of flight line spacing.

After leveling the data using the tie lines the data was micro-leveled. This task was done by applying a high-pass butterworth filter with a threshold of 400 metres (line spacing x 4) followed by a directional cosine filter perpendicular to the line direction.

The filtered magnetic data was interpolated based on the flight lines of the the drone to obtain the total magnetic intensity map. The First Order Vertical Derivative, Reduction to Pole and 3D Analytical Signal were also calculated to better delineate the edges of magnetic bodies.

3.2 Thermal Infrared Survey

The thermal infrared survey was conducted during the same week as the magnetic survey. The drone used for this survey was DJI's Matrice 200 UAV equipped with FLIR's radiometric Zenmuse XT infrared camera. Flights were conducted after dusk to reduce the impact of remnant solar heat and forestry activities on collected data. Due to the dense vegetation cover in the surveyed area, an 80% forward overlap and 30% side overlap of all images was ensured while acquiring the data. In total, 47,888 infrared raster images were captured in a .tiff format. All of the images were pre-geotagged and organised by flight path using the built-in Flight Data Manager function of the DJI Matrice 200. Temperature calibration of the images was not performed as part of the survey.

3.3 Reprocessing Thermal Data

Initial processing of the thermal data by the vendor identified several broad thermal anomalies and provided a coarse overview of the study area. However, the low resolution of the thermal map was insufficient for further interpretation of the potential geothermal features (Figure 3a). To improve the resolution, further in-house processing was conducted.

As the images were geotagged and organised by flight number, Borealis was able to import hundreds of images associated with the thermal anomalies into professional photogrammetry software for further processing. The large overlap in imagery allowed for adjacent images taken from different angles to be orthorectified and stitched together by comparing, matching, and measuring angles between objects within each image. Additionally, manually selected control points from the source layer were matched with target locations (e.g. road intersections) identified from satellite imagery to aid in geo-referencing the orthomosaics. This resulted in sub-meter resolution of thermal features (Figure 3b).

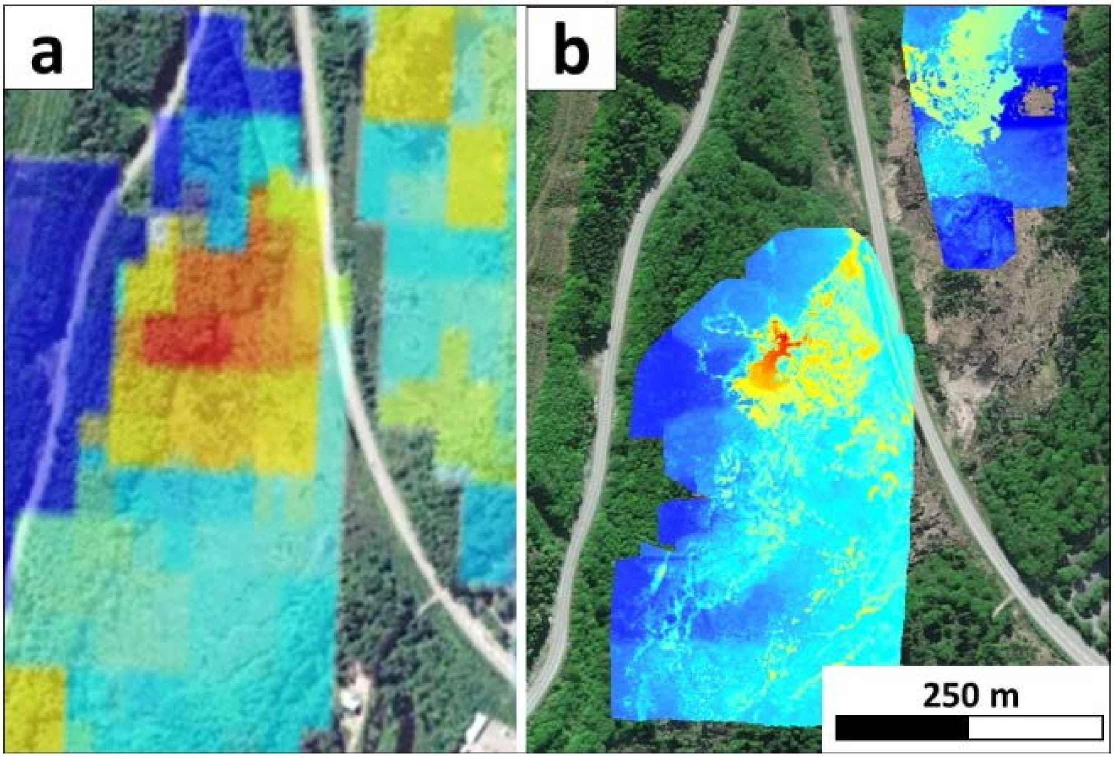

Figure 3. A comparison of thermal images identifying a previously unknown geothermal brine outflow before (a) and after (b) in-house processing.

4. RESULTS

The drone-based magnetic and thermal infrared survey of the Lakelse Field near Terrace, BC, highlighted the value of combining both systems for geothermal and element exploration. This survey also represented, to the authors' knowledge, the first application of a drone-based magnetic survey for geothermal exploration.

4.1 Thermal Infrared Results

Temperature anomalies, both natural (hot/warm springs, pools) and anthropogenic (transmission towers, vehicles, landfill, etc.) in origin, were effectively identified in the initial low-resolution thermal maps. Further in-house processing of the infrared data provided sub-meter resolution of these anomalies, making it possible to distinguish between the various sources and to pinpoint the location of water bodies of elevated temperature relative to their surroundings for future field exploration. Subsequent field visits to these water bodies confirmed the existence of previously unreported geothermal brine outflows draining into a larger water body. Various samples had been collected from the area during previous field campaigns, however these outflows were not identified due to meteoric waters mixing with and thus reducing the temperature of the geothermal brines, making this a less obvious feature to identify. Additionally, thick vegetation cover hindered access to the outflow zone, which became more accessible in winter when the vegetation had died back. The drone-based thermal survey proved to be crucial in the identification of both major and minor geothermal manifestations. Other natural thermal anomalies from the drone survey were investigated and were found to originate from non-geothermal features such as beaver ponds in sun-exposed areas.

4.2 Magnetic Results

The overlapping magnetic survey complimented the infrared thermal data by providing information about the shallow subsurface, allowing for better characterization of the lithology and structures. Although the major faults in this region had been previously mapped by the British Columbia Geological Survey using standard field mapping practices (Nelson, 2017), inherent uncertainty on their specific position remained due to the glacial overburden overlying the bedrock surface. Strong lineaments of high magnetic contrast were observed in the magnetic dataset, parallel to previously mapped faults but offset by 0.5-1 km (Figure 4). The observed magnetic lineaments were interpreted, in combination with additional geological data, to represent the accurate position of the faults. In areas where the magnetic signatures of the faults were obscured by the thick (> 300 m) overlying glacial overburden, the trace of the faults were projected to follow the orientation of the visible magnetic feature (Figure 4). The revised positions of these faults coincided with the locations of the aforementioned geothermal outflows identified with the thermal drone survey, thus further corroborating our interpretation of the magnetic data and demonstrating the effectiveness of these types of surveys to characterize the shallow subsurface of geothermal systems and other types of geological plays beneath Quaternary overburden.

4.3 Operational Advantages

The increase in efficiency associated with drone-based surveys was maximized through an operational plan that enabled a close collaboration between crews and alternating day/night surveying times. This minimized the cost per area of the survey and resulted in a 30-50% increase in efficiency when compared to equivalent ground-based or traditional airborne systems.

The thermal survey conducted by Borealis identified several previously unknown geothermal outflows. By using the magnetic data in combination with the thermal data the origin of active geothermal brine outflows was identified and correlated to subsurface structures. This provided a crucial test of the conceptual model of the system, as well as demonstrated the application of this cost-effective methodology for identifying thermal and structural features of a geothermal play.

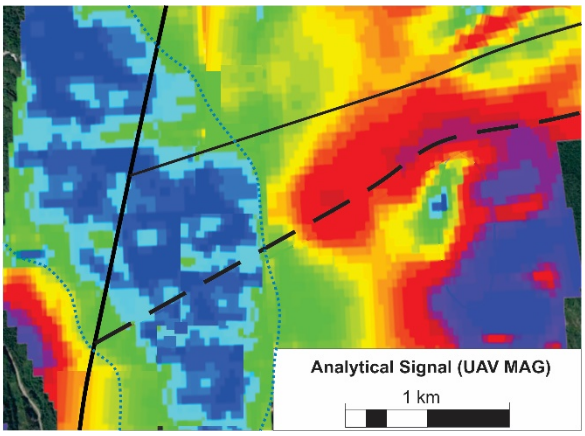

Figure 4: Map showing newly interpreted fault structures (dashed line) based on the 3D Analytical Signal of the magnetic data (high values shown as hot colours and low values shown as cold colours) relative to inferred fault structures (solid lines) obtained via geological mapping (Nelson, 2017). Blue dotted lines outline an area of very thick glacial overburden that obscures the magnetic signatures of faults that are clearly visible elsewhere in the region.

5. CONCLUSION

The first combined drone-based thermal and aeromagnetic survey was conducted by Borealis GeoPower over the Lakelse Field near Terrace, British Columbia. The use of unmanned airborne geophysical surveys, combined with efficient operational procedures, resulted in a significant decrease in the cost of the exploration campaign. Post-processing of thermal images accurately located unreported geothermal brine outflows with sub-meter resolution. Maps generated from the aeromagnetic survey were used to interpret and relate the subsurface structures to geothermal outflows, thus refining the conceptual model of the play.

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