Proceedings World Geothermal Congress 2020+1
Reykjavik, Iceland, April - October 2021

Large-Scale, High-Resolution Drone-Based Thermal Infrared and Magnetic Surveys for Geothermal and Element Exploration in Western Canada

Jiacheng Zheng, Megan Eyre, Daniel Alonso-Torres, Fred Heikkinen, Romain Metge, Alison Thompson, and Tim Thompson,

Borealis GeoPower Inc., P.O. Box 668, 639 5th Ave SW, Calgary, AB, Canada, T2P 2J3

megan@borealisgeopower.com

Keywords: Drone, UAV, Unmanned aerial vehicle, airborne geophysics, airborne magnetism, airborne infrared, data processing, geothermal, western Canada

ABSTRACT

Geothermal and element exploration in Canada can be challenging due to the presence of hundreds of meters of glacial overburden masking geothermal expressions, therefore 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 of airborne/satellite surveys often does not match the needs for geothermal prospecting over a large area. In November 2018, Borealis GeoPower employed an unmanned aerial vehicle (UAV or drone) thermal infrared survey 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. In this paper we demonstrate the usefulness of obtaining large-scale, high-resolution, drone-based surveys to assess geothermal prospects in a fast, efficient and relatively low-cost manner.

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 Lakelese Field near Terrace, British Columbia, Canada, covering a total area of over a 22 km^2 (Figure 1). This joint 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. An overview of the methodologies and results of this combined survey are described in the following sections.

2. METHODS

2.1 Magnetic Survey

An airborne magnetic survey was conducted over the course of one week in a mountainous region of British Columbia, Canada, just south of the City of Terrace (Figure 1). This area is home to Canada's hottest hot spring with outflow temperatures of 85 °C (Souther, 1976). The aircraft used in the survey was DJI's Matrice 600 UAV, equipped with a laser altimeter, GPS system, Inertial Measurement Unit, and GEM's UAV-MAG^{TM} 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 1. Map of the Lakelse Field (red square) near Terrace, British Columbia, Canada. The inset shows the location of Lakelse in relation to North America.

2.2 Thermal Survey

The thermal 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 collected. Temperature calibration of the images was not performed as part of the survey.

2.3 Reprocessing of Thermal Data

Initial processing of the thermal data identified several broad thermal anomalies and provided a coarse overview of the project area. However, the low resolution of the thermal map was insufficient for further interpretation of the potential geothermal features (Figure 2a). To improve the resolution, further in-house processing was conducted. This resulted in sub-meter resolution of thermal features.

Sub-meter resolution was obtained by employing the built-in Flight Data Manager function of the DJI Matrice 200 to pre-geotag and organize all images by flight path. This allowed Borealis to import the images into professional photogrammetry software for further processing. Hundreds of images associated with areas of thermal anomalies were selected to be further orthorectified, stitched, and geo-referenced. 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 (CPs) from the source layer were matched with target locations (e.g. road intersections) identified from satellite imagery to aid in geo-referencing the orthomosaics (Figure 2b).

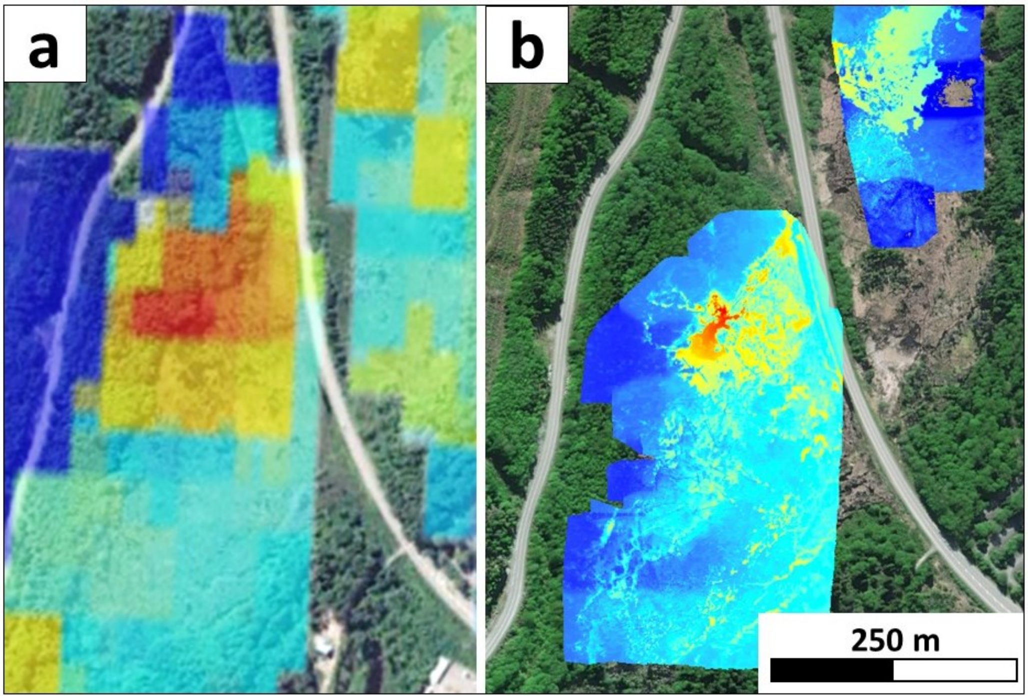

Figure 2. A comparison of thermal images generated with pre-in-house processing (a) and post-in-house processing (b), identifying a previously unknown geothermal brine outflow.

To visually reflect the relative temperature within each orthomosaic, a Stretch tool (based on standard deviation) was applied to the infrared band, and a sequence of colors ranging from blue to red (low to high) were then assigned to represent semi-quantitative temperature information. Further analysis on potential thermal features was carried out using these thermal orthomosaics.

3. RESULTS AND INTERPRETATION

The first-of-its-kind combined aeromagnetic and thermal 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. The thermal survey conducted by Borealis identified several previously unknown geothermal outflows. By using the aeromagnetic 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.

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.

After processing the raw magnetic data from the aeromagnetic survey, Total Magnetic Field (TMI), First Vertical Derivative, and Analytical Signal maps were generated. Interpretations made from these maps were used to accurately refine the estimated location of inferred subsurface features beneath the thick Quaternary cover of glacial overburden.

Temperature anomalies, both natural (hot springs, pools, and beaver ponds) 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 temperate relative to their surroundings for field exploration. Subsequent 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 thick vegetation cover hindering access to the outflow zone and meteoric waters mixing with, and thus masking, the geothermal brines. The drone-based thermal survey proved to be crucial in the identification of 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. CONCLUSIONS

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.

ACKNOWLEDGEMENTS

The authors are grateful to the Kitselas First Nation and Kitselas Geothermal Inc. for supporting this project. We also thank the Airport Society staff at the Terrace-Kitimat Northwest Regional Airport for providing logistical support in the deployment of the UAVs.

REFERENCES

Colomina, I., and Molina, P.: Unmanned aerial systems for photogrammetry and remote sensing: A review, *ISPRS Journal of Photogrammetry and Remote Sensing*, **92**, (2014), 79-97.

Harvey, M.C., Pearson, S., Alexander, K.B., Rowland, J. and White, P.: Unmanned aerial vehicles (UAV) for cost effective aerial orthophotos and digital surface models (DSMs), *New Zealand Geothermal Workshop 2014 Proceedings*, New Zealand (2014).

Harvey, M.C., Rowland, J.V., and Luketina, K.M.: Drone with thermal infrared camera provides high resolution georeferenced imagery of the Waikite geothermal area, New Zealand, *Journal of Volcanology and Geothermal Research*, **325**, (2016), 61-69.

Macharet, D., Perez-Imaz, H., Rezeck, P., Potje, G., Benyosef, L., Wiermann, A., Freitas, G., Garcia, L. and Campos, M.: Autonomous aeromagnetic surveys using a fluxgate magnetometer, *Sensors*, **16(12)**, (2016), 2169.

Parshin, A.V., Morozov, V.A., Blinov, A.V., Kosterev, A.N. and Budyak, A.E.: Low-altitude geophysical magnetic prospecting based on multirotor UAV as a promising replacement for traditional ground survey, *Geo-spatial Information Science*, **21.1**, (2018), 67-74.

Souther, J.G.: Geothermal Power, The Canadian Potential, *Geoscience Canada*, **3(1)**, (1976), 14-20.

Van Der Veeke, S., Koomans, R.L., Van Egmond, F.M. and Limburg, J.: A Drone as Platform for Airborne Gamma-Ray Surveys to Characterize Soil and Monitor Contaminations, *24th European Meeting of Environmental and Engineering Geophysics,* Portugal (2018).