AI-enabled remote sensing data interpretation for geothermal resource evaluation as applied to the Mount Meager geothermal prospective area

Zhuoheng Chen, Stephen Grasby, Christine Deblonde and Xiaojun Liu
Geological Survey of Canada, Natural resources Canada

Summary

Western Canada has significant geothermal resources (Grasby, et al., 2013). However, despite the existence of high temperature anomalies at shallow depths in active volcanic belts, economically feasible geothermal resources are found only where certain conditions intersect. The objective of this study is to search for features and indicators from the identified geothermal resource sweet spot in the south Mount Meager area that are applicable to other volcanic complexes in the Garibaldi Volcanic Belt. Ten Landsat 8 multi-spectral images, for a total of fifty one bands ranging from near infrared to thermal infrared frequency channels and covering different years and seasons, were selected. Specific features that are indicative of high temperature, permeable zones, and groundwater circulation, the three key elements in exploring for geothermal resource, were extracted. The thermal infrared images from different seasons show occurrence of high temperature anomalies and their association with volcanic and intrusive bodies, and reveal the variation in location and intensity of the anomalies with time over four seasons, allowing inference of specific heat transform mechanisms. Automatically extracted linear features using algorithms developed for computer vision from various frequency bands show various linear segment groups that are likely surface expression associated with local volcanic activities and plate tectonics induced deformation. In conjunction with regional structural models and field observations, the anomalies and features from remotely sensed images provide new insights for improving our understanding of the Mount Meager geothermal system and its characteristics. After validation, the methods developed and indicators identified in this study can be applied to other volcanic complexes in the Garibaldi, or other volcanic belts for geothermal resource reconnaissance.

Method

Landsat 8 images were employed to extract features relevant for detecting high temperature anomalies at shallow depth, permeable zones in intrusive/metamorphic and volcanic rocks associated with fracture/fault zones, and surface indication of groundwater. The images were pre-processed for suppressing noise and converting to standardized format and size. Traditional image processing techniques and advanced algorithms developed from computer vision were used to extract features associated with the work objectives, reduce subjectivity, and improve efficiency. We loaded part (801x951 pixels) of the original Landsat 8 image (8041x7941) that covers the study area with a center around the Mount Meager. Different thresholds were applied to images to map temperature anomalies, while gradient based Hough transform algorithm was applied to extract linear features. Post-processing was carried out to analyze the anomalies and combine various intermediate products for visualizing the location and intensity of temperature anomalies and identifying various linear segment groups in relation to regional tectonic and local volcanic events. A large number of Landsat 8 image tiles from the same area were employed to generate statistically meaningful outputs.

Geological interpretations of the extracted features are carried out in the context of existing regional geological and tectonic models and must be in alignment with field observations and geothermal production test data. Laboratory physical experiment and numerical deformation modeling results were used to guide field data interpretation (Guo, et al., 2017). Findings, such as: 1) physical discontinuities (fractures/faults) in the rock mass strongly influence bedrock weathering and erosion (Scott, et al., 2018), 2) drainage network patterns are highly sensitive to the mechanical weakness zones and persistent low relief associated with fault-weakened zones (Roy, et al., 2016), and 3) fracture/fault growth is sensitive to physical discontinuity crossing domain boundary (Guo, 2019), form the basis in lineament interpretation.

Results and Conclusions

The south Mount Meager area is a known prospective target of geothermal resource development at the north end of the Garibaldi volcanic belt. The thermal infrared (TIR) and near infrared (NIR) and short wave infrared (SWIR) channels, sensitive to variations in ground temperature and soil moisture content, are particularly useful for revealing shallow temperature anomalies and associated features. We selected 10 Landsat 8 images acquired over different years (seasons) for this study, primarily from the near infrared (NIR), short wave infrared (SWIR) and thermal infrared (TIR) channels, consisting of 51 single bands, in order to examine anomalies with seasons and to obtain statistically significant results related to geothermal anomalies.

The TIR images collected from different seasons show different characteristics and contain information useful for geological interpretation. TIR images from summer and fall show high temperature anomalies with sharp linear boundaries. The primary high temperature trends have a NE-SW strike and intersect often with secondary NW and EW striking anomalies. The temperature anomalies in winter TIR images are wider, but less in contrast across the volcanic complex. The high geothermal anomalies seem to retreat toward the eruption centers with less sharp boundaries. However, the south Mount Meager area remains the highest in thermal anomalies in all seasons. The changes in intensity and character may suggest shifting mechanisms of the primary heat transform. In summer, melting ice and snow provide sufficient water recharge in the mountain highs to make groundwater the primary heat transform mechanism. During winter, water recharge becomes less abundant and conductive heat transform becomes increasingly important, showing changes in the pattern and intensity of anomaly.

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Linear segments extracted from images in TIR and NIR/SWIR images are stacked together as lineament maps separately to represent surface features and their spatial variations common in specific frequency ranges. Several linear feature groups are recognized from the extracted linear segments. The NE striking lineament group forms the sharp boundaries of the high thermal anomalies and is in a good agreement with the NE-SW volcanic trend from Mount Meager (MM) massif to Bridge River (BR). The MM-BR segment of the Garibaldi volcanic belt makes a sharp turn from NW-SE to NE-SW at Mount Meager massif. This group of linear trends is orthogonal to the coastal mountain ranges of contractional deformation. Another distinct lineament group, represented by the Lillooet River valley, strikes NW-SE and is parallel to the regional mountain range and valley. Both of the lineament groups are surface expressions of plate tectonics controlled regional structural elements. Those circular and radial linear segments in the center or surrounding the volcanic complex are likely features associated with volcanic doming and eruptions. Small and chaotic linear segment group, mostly parallel to mountain ridge and slopes may represent gravitational fractures.

The active volcanic complex in the Garibaldi belt in BC is located in a rain forest climate zone, covered by forest, vegetation and glaciers with rugged topography that are difficult to access. Remotely sensed physical data contains essential information with respect to key elements in geothermal resource evaluation. Remote sensing is a proven tool of cost effective and time efficient that produces quantitative and robust data useful in geothermal resource reconnaissance. Once validated by the field observation and geological/geophysical models, the remote sensing based methods developed in this study will be applied to other volcanic complexes in mapping geothermal anomalies in the Garibaldi volcanic belt.

In conjunction with newly acquired geophysical data and analysis of field observations, the geological interpretation based on Landsat 8 images brings new insights to improve our understanding of the geothermal resource and its characteristics in the Mount Meager complex. The geothermal resource model can be used as an analogue to other volcanic complexes in Garibaldi volcanic belt for geothermal resource exploration.

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