SOCIETIAL ACCEPTANCE OF REMOTE SENSING INNOVATIONS : EXAMPLE FROM WHAKAREWAREWA-ARIKIKAPAKAPA, ROTORUA GEOTHERMAL FIELD

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ABSTRACT

Vision Mātauranga (VM) – unlocking the Māori innovation potential – is a key goal of the government to include in the New Zealand science landscape. Mātauranga Māori is dynamic and locally specific, based on longstanding interactions – through time and space – of post-modern technology between people and their surrounding environment. We have used the latest remote sensing technology, on both satellite and aircraft platforms, to map the vegetation coverage, areas of thermal activity and the dominant geothermal mineral associated with larger areas (>56 m^2).

The WorldView-3 (WV3) commercial satellite, launched in August 2014, has multi-sensor bands capable of capturing short wavelength infrared (SWIR) imagery at high spatial and spectral resolutions (i.e., 7.5 m pixel size; 8 wavelength bands, 1195 – 2365 nm). Using these wavelengths, images from this satellite can be used to map surface mineral occurrences at superior spectral and spatial resolutions than historical ASTER satellite instrumentation.

A mineral map of the Whakarewarewa-Arikikapakapa geothermal area is produced showing the occurrences of silica sinter and kaolinite at the larger areas. The method demonstrates the utility of the WV3 imagery to map geothermal features in areas of relatively high vegetative cover.

Māori believe that each rock and mineral type emerges from the earth with its own story, its own whakapapa (genealogy) relating to its origin – hei koha tū, hei kura huna a Papa. This knowledge has been developed through hundreds of years of interaction and adaptation to the environment. This paper combines the indigenous and western science perspectives of the Whakarewarewa geothermal area. This approach aims to show what a given technology can contribute to its growth and development to foster the development of indigenous capability in remote-sensing technology in a culturally respectful and appropriate manner.

1. INTRODUCTION

Whakarewarewa is the legacy and home of the Tuhourangi – Ngati Wahiao people, who have been sharing their unique way of life with visitors from all around the world for over two hundred years. Since the early 1800s residents have hosted and welcomed guests into their homes and backyards, demonstrating the utilization of the natural geothermal wonders for cooking, bathing and heating. The people of Tuhourangi/Ngati Wahiao have been the trail blazers of the tourism industry in Rotorua and NZ. It is their goal to continue the legacy and to follow in the footsteps of their ancestors.

Geothermal energy is a taonga, with intrinsic value in the traditional Māori world, and economic and sociological value to contemporary Māori. Utilisation of geothermal energy has potential to provide a range of commercial and non-commercial benefits at local, regional and national levels. Māori retain customs and tikanga concerning surficial thermal features, and provide kaitiakitanga of the geothermal systems. In the past, development has adversely affected some thermal areas and resulted in irreparable damage to surface features, buildings etc. Even small-scale activities over long periods can be damaging (e.g. past balneological treatments at Queen Elizabeth Hospital, Rotorua, and their effect on Tianakore—a mud pool—at Arikikapakapa). Regional Councils are responsible for monitoring geothermal resource development through the Resource Management Act (1991), so Māori must balance their commercial aspirations with a realistic assessment of the capacity of the geothermal resource to support sustainable development.

In Māori society, understanding the nature of environments and environmental indicators represents one of the earliest forms of hazard mitigation used in New Zealand. Insights can be gained from the settlement patterns of Māori communities impacted by natural hazards and their oral histories of early warning signs, impacts and adaptation that can complement scientific knowledge. Recorded observations relevant to earth science inherent in Māori oral tradition can be compared and contrast with those recorded in conventional western geological science.

Remote sensing mapping techniques, which use satellite, aircraft, and/or UAV (unmanned aerial vehicle) platforms, for identifying, documenting and categorising geothermal areas as part of monitoring and exploration programmes are being increasingly utilised as improving technologies have lowered costs, promoted availability and enhanced both spatial and spectral resolutions. There are significant advantages for their use in geothermal environments as they greatly minimise impacts on the ground, in and around geothermal surface features that are commonly culturally and scientifically sensitive. Geothermal areas in steep and/or heavily vegetated areas are easily covered, and there are lower health and safety risks. These methods and techniques are fully consistent with kaitiakitanga, in that they allow for geothermal monitoring and characterisation in a low-impact and safe way.

GNS Science implements thermal infrared (TIR) imaging and aerial photography for monitoring of geothermal areas with fixed-wing aircraft and UAV platforms, respectively. Thermal infrared survey over Rotorua Geothermal Field compared data between 1992 and 2014 to identify any temporal changes in surface thermal activity across the surveyed area (Reeves and Rae, 2016). Processing and mosaicking of ~2700 TIR images produced a 16-bit image with a ground pixel size of ~2 m x 2 m. The survey successfully identified two areas where geothermal activity had decreased over the twelve years, and established that there were no significant changes in other areas.

Satellite mapping of vegetation types and their seasonal and temporal variations is a well-established technique. Recently, more advanced satellites (Sentinel-1 and -2) have created the opportunity for more detailed vegetation mapping in hydrological and groundwater studies (Westerhoff, 2017). Application of these satellite data to geothermal areas can help to better assess variations caused by geothermal-induced thermal and chemical anomalies (Burns and Leathwick, 1995).

GNS Science is presently building capability for remotely sensed mineral mapping using the WorldView-3 (WV3) satellite platform (Durance et al. 2017). This has multi-sensor bands capable of capturing short wavelength infrared (SWIR) imagery at relatively high spatial and spectral resolutions (i.e., 7.5 m pixel size; eight bands between 1195 and 2365 nm wavelengths). Using these bands at this spatial resolution, advances this technique for mapping geothermal mineral occurrences at relatively large (i.e., 56 m^2 is the resolving resolution) geothermal surface features.

For this study we test the use of WV3 SWIR images for mineral mapping by focusing only on the distributions of amorphous silica and kaolinite, which are direct products of geothermal fluid deposition and host-rock alteration. Amorphous silica deposits directly from neutral chloride water and can be found as sinter aprons and terraces around neutral chloride pools, springs and geysers. Kaolinite is a hydrothermal alteration product from the interaction of steam-heated acid fluids and host rocks. It is typically found in and around mud pools.

We demonstrate how WV3 data can be used to basically categorise surface features across a given geothermal area. This is advantageous in areas with difficult land access such as steep terrain and/or heavily vegetated. Used in conjunction with TIR imaging it will be possible to distinguish what type of features are present, and whether they are presently active. Clearly this has advantages during geothermal exploration, when planning field surveys and the need to prioritise features for chemical sampling.

This preliminary study focuses on a well-known and studied geothermal area, Whakarewarewa-Arikikapakapa (Lloyd, 1975), in the Rotorua Geothermal Field (Figure 1A). We test the use of WV3 satellite data for mapping the distribution of silica sinter and kaolinite at known features across the area. This could be an important tool for geothermal exploration in greenfields geothermal prospects, where little is known about the types of geothermal activity in the district. Used in combination TIR, we will develop a capability for determining both the type of geothermal feature and whether or not it is active. Furthermore, mapping vegetation types as we have done for our area of interest is the first step for diagnosing vegetated areas that might be thermally and/or chemically stressed. Thus identifying a tool for identifying "blind" geothermal activity, hidden beneath vegetative cover.

2. WHAKAREWAREWA-ARIKIKAPAKAPA GEOTHERMAL AREA

Whakarewarewa is the legacy and home of the Tuhourangi/Ngati Wahiao people, who have been sharing their unique way of life with visitors from all around the world for over two hundred years. Since the early 1800s residents have hosted and welcomed guests into their homes and backyards, demonstrating the utilisation of the natural geothermal wonders for cooking, bathing and heating. Their geothermal existence continues to fascinate tourists visiting Whakarewarewa today. The people of Tuhourangi/Ngati Wahiao have been the trail blazers of the tourism industry in Rotorua and NZ. It is our goal to continue the legacy and to follow in the footsteps of the ancestors.

2.1 Geothermal Features

The Rotorua Geothermal Field is located near the southern margin of the Rotorua caldera, formed from the eruption of the Mamaku Ignimbrite (Wood, 1992). The field covers ~12 km^2 and extends beneath Rotorua City northwards beneath Lake Rotorua. Deep geothermal fluids arise in the eastern part of the field, discharging at Whakarewarewa and Ngapuna. Chemical geothermometry of these fluids indicate they have originated from a reservoir with a temperature up to 250°C (Giggenbach and Glover, 1992).

Arikikapakapa and Whakarewarewa are the two main areas of geothermal activity in the southern part of the Rotorua Geothermal Field, which is transected by NE-trending faults (e.g. Pohaturoa and Whakarewarewa Faults) that are subparallel to the caldera margin. These faults provide permeable pathways for geothermal fluids to ascend and discharge at the surface in the Whakarewarewa Valley.

A wide range of features types occur in the Whakarewarewa Valley. More than five hundred geothermal features (Figure 1B). ranging from geysers, steam vents, boiling mud pools, effervescent and boiling springs and turbid pools. Fluid derived from the deep primary geothermal reservoir, which has ascended directly to the surface, with minimal mixing and dilution with local groundwater, steam and gases, forms springs of clear, hot (70-100°C), neutral to alkaline (pH 6.5-8) chloride water. This water is saturated with respect to silica, and as such typically have aprons or terraces of pale grey silica sinter. The largest of these terraces occur around the Pohutu Geyser (~3100 m^2), and also at Waikite Geyser (~2700 m^2; Figure 1A). Acidic features such as mud pools and ponds of turbid water typically occur at slightly higher elevations or on impermeable ground. Hydrogen sulphide (H_2S) gas, derived from the boiling of geothermal fluids (between 10–100 m below ground surface), mixes with oxidised meteoric ground water to produce acid sulphate waters that dissolve the surrounding rock and alters rock forming minerals to kaolinite and sulphates. These processes result in the degradation of ground, forming the mud pools and collapse holes that are common at Whakarewarewa. The largest of these is the roughly circular feature, Frog Pond (Ngamokaiakoko) (~560 m^2; Figure 1A).

At Arikikapakapa geothermal features are mostly located within the confines of the Rotorua Golf Course and are all of acid sulphate type, consisting of boiling mud pools, turbid acid pools, steam venting and barren ground. Significant features are the large warm pools or small lakes (Lakes

Tangatarua, Tunoe and Arikikapakapa) of turbid water (Figure 1A). The largest, Lake Arikikapakapa, measures 330 m x 175 m across. The feature with the largest area of exposed mud is labelled as Golf Course mud pool (~7600 m^2) in Figure 1A.

3. REMOTE SENSING METHODS

3.1 Thermal Infrared Imaging

Reeves et al. (2014) summarise data collection, processing and image mosaicking of aerial thermal infrared (TIR) survey over the Rotorua geothermal Field on 6-7 March 2014. Data were collected with a Flir A615 thermal infrared camera (recording in the 7.5-13 μm wavelength band) connected to a digital recording (recording 16 bit images) and navigation system, mounted to a light fixed-wing plane. Collection times were from 21:15 through to 00:20 and had an approximate pixel size of 0.7 m. Data have been resampled to 2 m x 2 m pixels as described by Reeves et al. (2014).

A sub-dataset from this survey is presented in this paper. It has small "holes" in the southern part of the area where the aircraft was either off course or had a high pitch/yaw which resulted in no data getting collected. These small areas are located in vegetated area, away from areas of geothermal activity (Figure 1C)

3.2 Vegetation Mapping of a Geothermal Area

The Sentinel-1 satellite mission provides synthetic aperture radar data of land and ocean from a constellation of two satellites (Sentinel-1A was launched in April 2014, Sentinel-1B was launched in April 2016). The satellites provide data with a 10 m x 10 m resolution, typically every three to four days. The radar data is hardly affected by clouds (i.e., it provides data in all weather, day and night).

The Sentinel-2 satellite mission provides multi-spectral data from a constellation of two satellites (Sentinel-2A was launched in June 2015; Sentinel-2B was launched in March 2017). The resolution of these data is 10 m x 10 m for most bands (e.g., red, green, blue, near-infrared—NIR) with other bands with a larger footprint (e.g., short-wave infrared 20 m x 20 m; European Space Agency, 2017a, b).

All available Sentinel-1 and -2 data covering the Whakarewarewa – Arikikapakapa region of interest in the research period January to August 2017 were used:

- 58 Sentinel-1 images, available in both VV and VH polarisations;
- 25 Sentinel-2 images.

All processing was performed in the Google Earth Engine processing facility (Gorelick, 2017). Sentinel-1 images were averaged to one image for the research period. All clouds in the Sentinel-2 data were filtered and then averaged to one image. Vegetation indices were calculated from the Sentinel-2 data. These were: Normalised Difference Vegetation Index (NDVI) from the NIR and red bands (e.g., Rouse et al., 1974); and Normalised Difference Water Index from the SWIR and NIR bands (Joint Research Centre, 2011).

The radar (VV, VH) bands and some multi-spectral bands (red, green, blue, NIR), including the derived indices (NDVI, NDWI) were used in a K-means clustering machine learning algorithm (Likas, 2003; Hall, 2009). This algorithm classifies all data into clusters with similar properties. It is an unsupervised algorithm, which means that no training data is needed beforehand. Interpretation of vegetation cluster types was based on expert knowledge and Google Earth.

3.3 Mineral Mapping of Geothermal Areas

The WorldView3 satellite captures images in eight bands of visible to near infrared spectral range at 1.2 m x 1.2 m spatial resolution. In addition to these bands, eight bands are captured in SWIR range at 3.6 m x 3.6 m ground resolution. Due to US government restriction, WV3 SWIR data is down-sampled to 7.5 m resolution. This is high resolution comparing to ASTER sensor which captures data in similar spectral range at 30 m resolution. Data from all sixteen bands were combined in one image for further processing to detect alteration minerals in Whakarewarewa area.

The NDVI and NDWI were computed to identify pure vegetation and water pixels which were then removed from the image. The remaining pixels were classified based on the ISODATA (Iterative Self-Organising Data Analysis Technique) unsupervised classifier method (Tou and Gonzalez 1974).

4. REMOTE SENSING RESULTS

4.1 Thermal Infrared Red Mapping

The resulting TIR image for our area of interest (Figure 1C) shows thermal anomalies associated with surface thermal activity in Whakarewarewa-Arikikapakapa. Highlighted features include the small lakes and ponds in Arikikapakapa, as well as Lake Roto-a-Tamaheke in eastern Whakarewarewa. Hot springs, pools, mud pots and hot ground comprise many of the smaller thermal anomalies in Whakarewarewa.

Surface thermal gradients are recognised across some of the larger features, with hotter areas occurring in the western part of Lake Roto-a-Tamaheke, and the western parts of Lake Arikikapakapa being somewhat cooler (Figure 1C).

4.2 Vegetation Mapping

Vegetative cover over the Whakarewarewa-Arikikapakapa area of interest has been broadly classified into five types (Figure 1D): grass, mix grass/shrubs, low lying shrub/trees, mixed trees including natives, and mixed trees including pines.

Heaviest vegetation occurs in the southern parts of Whakarewarewa on the upper and lower northeast-facing slopes that are densely covered with mixtures of native forest and mixed exotic trees and scrub (Landcare Research). These include stands of conifers close to the ridge top. In and around the Whakarewarewa thermal features vegetation has been largely classified as low lying shrubs and trees, such as stunted scrub of mixed manuka and kanuka. Small grassy/shrubby areas are also identified.

At Arikikapakapa, satellite imaging has identified the grassed golf course, with pockets of low lying shrubs and trees (mixed manuka and kanuka) that occur marginal to the geothermal lakes and mud pools.

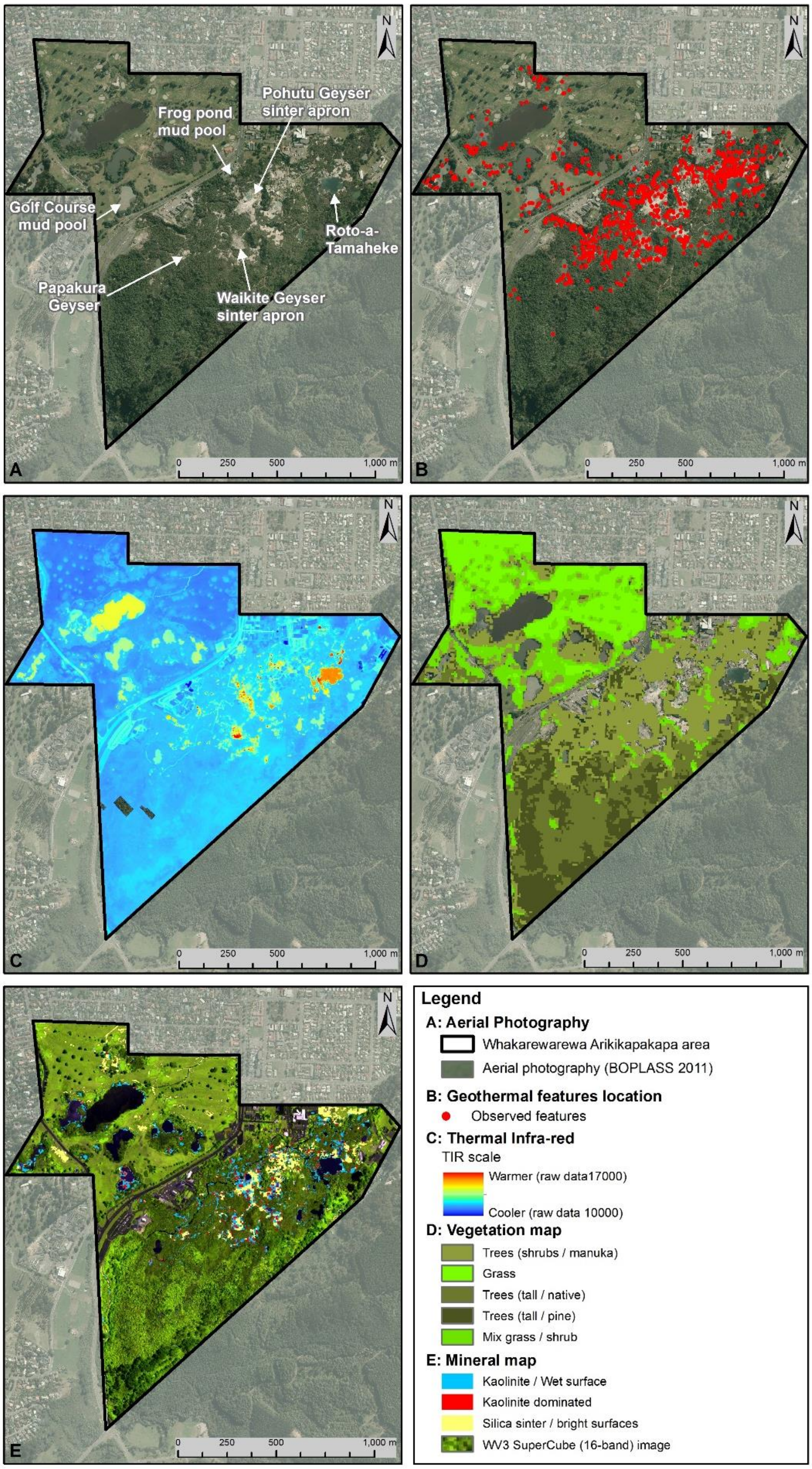

Figure 1. A. Aerial photograph of the Whakarewarewa-Arikikapakapa geothermal area, with significant features mentioned in the text labeled. B. Aerial photograph showing the distribution of geothermal features at Whakarewarewa-Arikikapakapa occurring in the GNS Science Geothermal and Groundwater Database. C. False colour TIR image of the raw TIR data for Whakarewarewa-Arikikapakapa. D. Vegetation map of Whakarewarewa-Arikikapakapa. E. Mineral map of Whakarewarewa-Arikikapakapa.

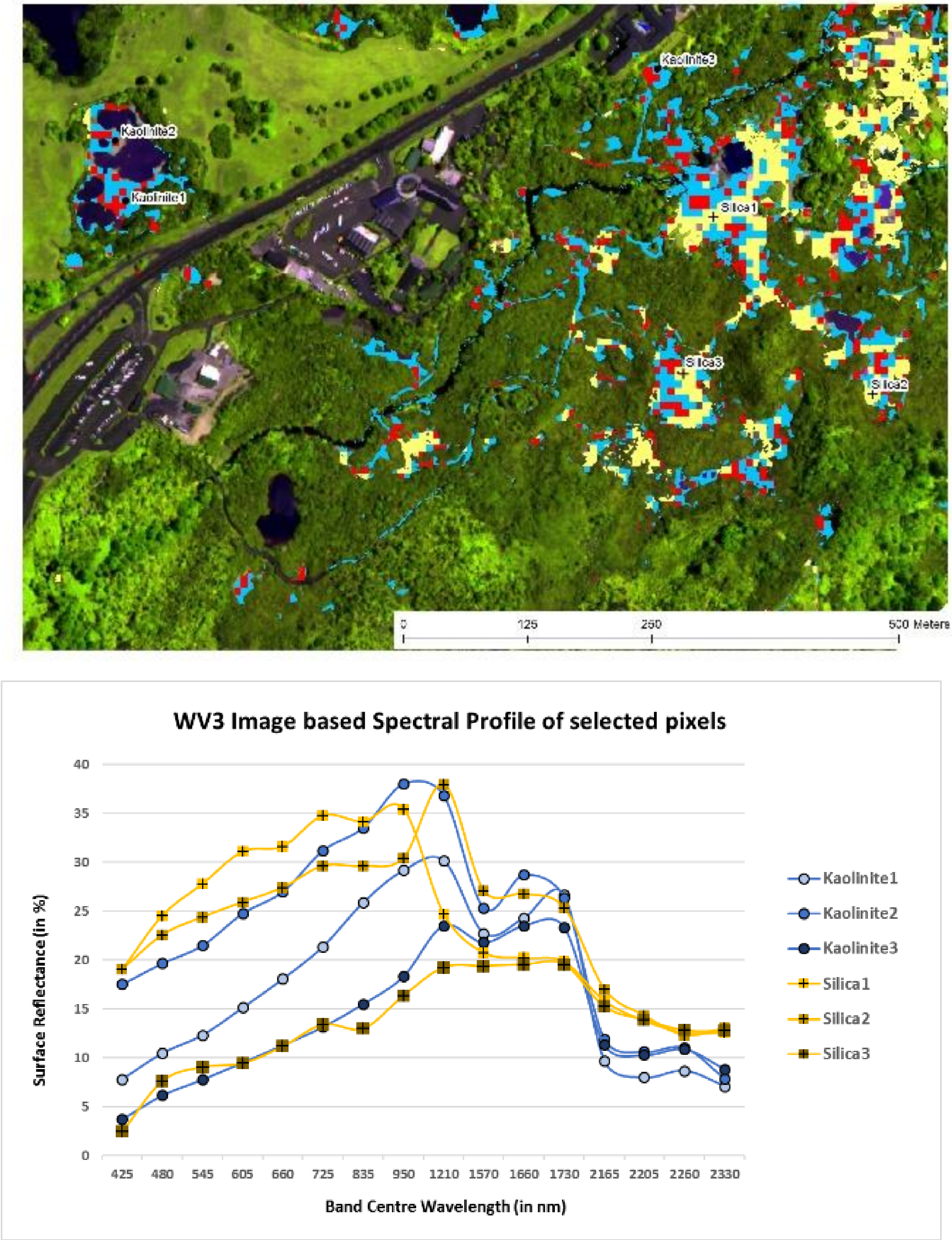

Figure 2. Top. Details of Figure 1E showing mineralogical classification of part of Whakarewarewa-Arikikapakapa. Silica (pale yellow), kaolinite dominant (red), and kaolinite – wet (blue). Six specific pixels are highlighted and their spectral response shown in the chart. Bottom. The spectral response of the six spots highlighted in the above aerial photo. Despite the large spectral variation in the VNIR (425-950 nm) and lower SWIR bands (≤1730 nm), it is the spectral response of the higher three SWIR bands (i.e., SWIR-6, -7, -8 at 2205-2330 nm) that distinguish kaolinite from silica.

4.3 Mineral Mapping of Whakarewarewa-Arikikapakapa

For the resulting mineral map of the Whakarewarewa-Arikikapakapa geothermal area we focus on four of the largest features: two sinter terraces associated with the Pohutu and Waikite Geysers, Frog Pond mud pool, and the Golf Course mud pool (Figure 1A). Each of these features are significantly larger than the WV3 SWIR resolving resolution of 56 m^2.

Initial results of the unsupervised classification were not able to distinguish between kaolinite and silica due to high spectral variance in visible to near infrared (VNIR). The last three SWIR bands (SWIR-6, -7 and -8) show a peculiar spectral response for both kaolinite and silica. It is therefore only the data from four bands (SWIR-5 to SWIR-8) that has been used to classify kaolinite and silica sinter dominated pixels. The close up WV3 image of Whakarewarewa-Arikikapakapa area (Figure 2) shows six locations and the spectral response of both minerals that clearly identifies their peculiar spectral response in the last three bands, despite significant variations in the VNIR and lower SWIR bands.

We have categorised features into three categories: silica sinter dominated, kaolinite dominated, and kaolinite + water dominated (Figure 1E). The WV3 SWIR imaging distinguishes silica sinter from kaolinite at the four large features, and some of the smaller features. The Pohutu and Waikite sinter terraces are mapped as sinter, with kaolinite (and kaolinite + water) occurring marginally (Figures 1E and 2). Smaller satellite areas around the Waikite sinter apron contain mixtures of sinter and kaolinite. At the two mud pools, kaolinite and kaolinite + water are discerned at both the Frog Pond and the Golf Course mud pool (Figures 1E and 2).

Smaller features are also distinguished, such as the sinter associated with the Papakura geyser near Puarenga Stream. In the eastern parts of Whakarewarewa, areas of mixed sinter and kaolinite occur at Roto-a-Tamaheke, a lake of mixed chloride-sulphate waters (Figure 1E). In Arikikapakapa, kaolinite and kaolinite + water categories rim the small lakes and some of the smaller mud pools are recognized.

5. DISCUSSION AND CONCLUSION

Rangatira for Tuhourangi – Ngāti Wahiao leaders honour a guiding legacy of the generations of a tourism industry in Rotorua New Zealand. It is their goal to continue this legacy through honouring the traditions of the people, which include the following principles:

- Kaitiakitanga - Protector & Guardian of resources;
- Manaakitanga – Hospitality, kindness-of-heart, generosity, warmth and caring;
- Mātauranga Māori - Preservation and sharing of our history and knowledge;
- Taonga Tuku Iho - Custodians of our treasured heritage;
- Whenua – the land, placenta and its significance.

Kaitiakitanga and Taonga Tuku Iho aim to preserve resources and cultural heritage for future generations, ensuring all interactions in and around the resources are done so sustainably. Documenting, categorising and monitoring the geothermal features at Whakarewarewa-Arikikapakapa establishes the baseline database to manage the resource. Mapping the geothermal area using remote sensing is a low-impact and safe method of establishing this database in a culturally respectful and appropriate manner.

This study uses the latest technological remote sensing techniques, from both satellite and aircraft platforms to broadly classify and map the vegetation types across the area, map the thermally active areas of Whakarewarewa-Arikikapakapa and the dominant alteration mineral associated with the largest of these (>56 m^2). Both TIR and SWIR datasets establish the type of feature present at that geothermally active site (neutral chloride vs acid sulphate). A mineral occurrence at a location that lacks a geothermal signature demonstrates that the features is extinct.

Historically, mineral mapping of geothermal areas using remotely sensed satellite SWIR imagery has been done with the ASTER instrument. This is usually done in tandem with airborne mounted SWIR scanners that have higher spatial resolution and greater spectral coverage. ASTER has been useful at a regional reconnaissance level, in sparsely vegetated desert terrain, such as has been achieved across geothermal areas in the western USA (Hellman and Ramsey, 2004), particularly in the Basin and Range Province, Nevada (Calvin et al., 2015; Kratt et al., 2010). The minerals mapped include kaolinite, alunite, gypsum, muscovite, calcite and amorphous silica (sinter) (Calvin et al., 2015). However, with spatial resolutions of 30 m it is considered restrictive in regions with highly dense vegetative coverage, such as in temperate and tropical climates. Additionally, the low spectral range limits the detectable reflectance responses, in particular the distinction between clay-rich and silica-rich areas (Calvin et al., 2015). Additionally, the ASTER SWIR sensors have issues with elevated sensor temperatures that result in stripes and saturation of the Digital Number data. Therefore, since April 2008 SWIR data from ASTER has not been available for research and exploration.

In geothermal areas hydrothermal mineralogy and mineral associations can be relatively simple, and commonly trending towards mono-mineralic associations (e.g., amorphous silica or kaolinite). For this study our interest primarily lies in testing whether it is possible to identify mono-mineralic products of geothermal alteration, which in the case of Whakarewarewa-Arikikapakapa is kaolinite and amorphous silica. Recognising the dominant alteration product is important for identifying the type of geothermal fluid discharging at a particular feature. For example, kaolinite implies a steam-heated acid sulphate feature; amorphous silica implies silica sinter and a neutral chloride feature. This distinction can be important during a geothermal exploration programme, where the location of feature types has implications for establishing a conceptual model for the shallow geothermal geohydrology, and for planning a sampling survey of the district.

Vegetation mapping of geothermal areas is part of an ongoing research project at GNS Science, recognising spectral indicators of different types of vegetation but also those that are environmentally stressed from geothermal processes (i.e., thermal and chemical stress). This could prove valuable for determining the areal extent of surface activity that is otherwise hidden from view by vegetative cover.

Further analysis using Sun et al, using indices rather than classification may improve our distinctions. Continue our mapping of other Rotorua geothermal areas.

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