SATELLITE STUDIES OF THE WAIMANGU AND WAIOTAPU GEOTHERMAL AREAS, TVZ

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SUMMARY - This report of joint research in progress aims to evaluate (1) the reconnaissance/exploration role and (2) the surface mapping applications of satellite data for the Waimangu and Waiotapu geothermal areas.' Combinations of SPOT XS and LANDSAT TM data were evaluated and classification of the TM data for Waiotapu conducted. Many geothermal features, including hot pools, sinter terraces, hot bare ground and areas of heat-stressed vegetation were mapped and classified from the large scale $TM1_b4_g5_r$ colour composite of southern Waiotapu. The results show the key role of the mid-infrared (MIR, 1.55-1.75 μm) TM band 5 for mapping heat-stressed vegetation, which acts as a surrogate for hot ground. TM multispectral analysis incorporating visible, near-IR and MIR bands provides a valuable geothermal reconnaissance/exploration technique. At large scales, detailed surveying is also possible.

1. INTRODUCTION

This is a report of research in progress. A joint New Zealand/France cooperative project between Auckland University Department of Geography and Geothermal Institute, Institute of Geological and Nuclear Science Ltd, Wairakei, and BRGM, Orléans, is analysing the roles of different types of satellite data for geothermal studies in the Taupo Volcanic Zone (TVZ) of the central North Island of New Zealand (Fig. 1). This paper continues the geothermal investigations initiated at Te Kopia (Cochrane, *et af.*, 1993) and Craters of the Moon (Wairakei) geothermal areas (Mongillo, et al., 1993).

Earth resource satellites such as LANDSAT, SPOT and JERS-1 regularly pass over New Zealand. Though they are capable of frequent and repetitive surveying of the country, cost and frequent cloud cover have limited satellite coverage of the TVZ. For the Waimangu-Waiotapu area (Fig. 1) five satellite images are available (LANDSAT MSS [1975], LANDSAT TM [1990], two SPOT XS [1986 and 19921, JERS-1 [1992]), However, these are all at different dates, different wavelengths monitored, different spatial resolutions (120 m - 10 m) and with different numbers of bands. Since there is no SPOT PAN coverage, previously demonstrated data merging techniques (Mongillo, *et al.*, 1993) cannot be applied for Waimangu or Waiotapu.

However, there are close links between vegetation and thermal ground. This ecological relationship, measured from satellite spectral data, enables vegetation to be used as a surrogate for mapping patterns of hot ground in geothermal areas.

The physical characteristics of Waimangu and Waiotapu geothermal areas are well documented (Simmons, *et* al., 1993; Hedenquist, 1986). In addition, vegetation information is available (Clarkson, 1982). Thus, these areas serve as excellent test sites to evaluate the relative merits of SPOT and LANDSAT multispectral scanner data for (1) reconnaissance/exploration (location) and (2) detailed investigation (survey) roles at enlarged scales for geothermal studies. Previous studies of SPOT colour infrared (CIR) composite imagery and band ratio data for Waiotapu (Mongillo and Belliss, 1989; Mongillo, 1992) showed that bare hot ground and also a broad category of heat-stressed vegetation could be detected. However, similar *spectral* patterns present outside hot areas limit the usefulness of such data.

This paper presents the results of a preliminary evaluation of the relative roles of the different spatial resolutions, scales and spectral ranges (wavelengths measured) of the SPOT XS and LANDSAT TM data for Waimangu and Waiotapu geothermal surface studies. Emphases are on evaluating how comprehensively the TM visible, NIR and MIR band combinations ($TM1_b4_g5_r$ and $TM3_b4_g5_r$) *can* detect a range of geothermal features and map thermally stressed vegetation. The role of LANDSAT TM Band 5 (MIR) is stressed.

2. STUDY AREAS

The Waimangu and Waiotapu geothermal areas are located in the central TVZ (Fig. 1). Waimangu is a geologically youthful thermal area which came into existence as a consequence of the Tarawera eruption of 1886 (Simmons, *et* al.. 1993). The thermal activity is strongly oriented along a major ENE trending rift. All vegetation in this area has developed since the 1886 eruption and is locally effected by thermal activity.

The Waiotapu geothermal field has a large variety of surface features distributed over its 18 km² surface area. These include regions of steaming ground; eruption, collapse and dissolution craters; mud pools; fumaroles; hot pools; areas of bare and altered ground and a large sinter terrace. Lakes Ngakoro, Whangioterangi and Champagne Pool occupy large hydrothermal eruption craters (Fig. **2**). The vegetation cover includes pasture, pine plantations, bush and simpler shrub communities (bracken, kanuka, manuka, broom) and swampland (Clarkson, 1982). Large areas of heat-stressed vegetation, characteristically small and dark-leaved and simple, dwarfed and prostrate in habit, closely indicate ground temperatures (Cochrane, *et at.,* 1993; Mongillo, et *at.,* 1993).

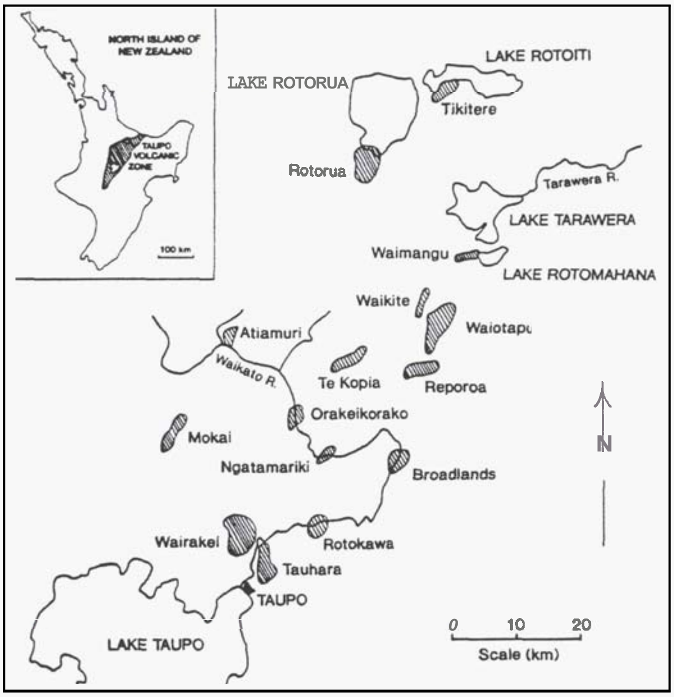

Fig. 1 Map showing the locations of the major geothermal fields in the Taupo Volcanic Zone.

3. METHODS

SPOT XS (August 1986) and LANDSAT TM (December 1990) subscenes of Waimangu and Waiotapu geothermal areas were assessed. The Waiotapu and **Waimangu** SPOT imagery were rectified to the New Zealand Metric Grid. The Waiotapu TM data were registered to the SPOT imagery to make them geometrically compatible. However, the Waimangu TM imagery was examined separately.

Various image processing techniques were investigated at both small and large scales. SPOT and TM CIR composites of both Waiotapu and Waimangu areas were prepared and compared. TM visible, **NIR** and MIR colour composites (**$TM1_b4_g5_r$** and **$TM3_b4_g5_r$**) were created and compared to the corresponding CIR images. At small scales, the TM combinations clearly identified the geothermal areas at Waiotapu and Waimangu. Consequently, the **TM** visible, NIR and **MIR** combinations were chosen for more detailed study of the southern Waiotapu area.

The large scale **$TM1_b4_g5_r$** image **of** southern Waiotapu was visually interpreted and classified on the basis of tonal patterns and digital analysis. The patterns present were compared to occurrences of known thermal ground features and mapped vegetation (Clarkson, **1982).** Subsequently, results were checked and verified using large scale aerial photographs and field surveys.

4. RESULTS

SPOT CIR composites have been very successful in many vegetation studies. Small scale **SPOT** and TM CIR imagery for **Waimangu** and Waiotapu were examined. Only the largest hot pools and bare ground **areas** could be identified. The SPOT CIR was marginally better than the TM because of its higher spatial resolution (20 m vs. **30** m), however, the spectral signatures of the stressed and unstressed vegetation were too similar for their separation. Examination of a large scale SPOT CIR image for the Waiotapu area showed that, in addition to the hot pools and bare ground, a broad category of stressed vegetation could be recognised with *a priori* knowledge of the plant cover. However, the spectral similarities between the stressed and certain non-stressed vegetation gave no confidence·r CIR classification capabilities. Some of the tonal subtleties of the original images are degraded in the reproductions presented here.

Images in Fig. 3 illustrate the role of TM **data** for location of geothermal areas from visual analysis of tonal contrasts. The relative merit of an enlarged TM scene for Surface cover mapping of a geothermal area is also shown. These images combine relatively narrow **bands** of selected visible, NIR, and **MIR** wavelength **data at** 30 m spatial resolution.

4.1 Waimangu

The small scale $TM1_b4_g5_r$ colour composite image of Waimangu (Fig. 3a) was much superior ***to*** the corresponding SPOT and TM CIR images for mapping heat-stressed vegetation. This combination covers a wider **spectral** range **(0.4-1.65 μm)** than *can* be achieved with the higher spatial resolution (20 m) SPOT **XS** data (0.5-0.89 μm). Hence, it proved very good for detecting the geothermal **areas within** their vegetated surroundings. The results showed only minor variations when the different visible bands (TM 1, 2 or 3) were used.

In Fig. 3a the stressed vegetation of numerous heat centres are shown **as** brown tones. These are clearly aligned along the rift of the Waimangu Valley. There is an extension along the steaming cliffs (red-browns) of Lake Rotomahana. The extent of hot ground extends westward considerably beyond the actual cliffs. The small pink-white areas along the western cliffs are bare geothermal ground. The **dark** green area in the NW of the image is mature pines. The mixed green/olive green tones on the SE slopes of the valley are regenerated native bush. The yellow tones are broad-leaved scrub. The pale green areas are younger broad-leaved scrub. The small pink and yellow-pink areas on the central western margin of the image are pastures. On the

CIR images the native bush area (SE) and stressed vegetation along the western cliffs showed as the Same tone, hence, could not be separated. Similarly, the stressed vegetation along the valley floor could not be distinguished from the flanking vegetation. In contrast these classes are clearly obvious on the $TM1_b4_g5_r$ image.

4.2 Waiotapu

Following the successful location of geothermal areas at Waimangu with the TM visible, NIR and MIR combination (Fig. 3a), the $TM1_b4_g5_r$, $TM2_b4_g5_r$ and $TM3_b4_g5_r$ images of the Waiotapu geothermal region were examined (Fig. 3b). These also clearly separated out thermally stressed vegetation, resulting from the spectral contribution of band 5. Comparison of the stressed vegetation distribution with a detailed (3 m spatial resolution) aerial thermal infrared survey (Mongillo, in press) shows that they are located in anomalously hot areas and that they provide an indication of the extent of hot ground around the localised hot spots. Again, there were only minor variations derived from using the different visible bands. The results were superior to the SPOT CIR combination of higher spatial resolution (20 m vs. 30 m).

The colour tones for the small scale Waiotapu image (Fig. 3b) are: dark greens for forest plantations; yellow for pastures; browns for thermally stressed vegetation; and bright pinks for logged areas. The light greens represent both younger forest plantations and also second growth bush on Rainbow Mountain (Mt Maungakakaramea) at the north. Much of the western and southern slopes of Rainbow Mountain show evidence of thermally stressed vegetation (brown tones). Further south, the scattered pattern of thermal areas of central Waiotapu is also apparent. At the southern end of Waiotapu, the hot bare thermal ground appears as pale pink-white tones. The blues are lakes and a water covered sinter terrace, the thin yellow and yellow/pink linear features are bare pumice roads and the cleared firebreak at Rainbow Mountain shows pinkish.

Both of the above examples demonstrate the use of TM imagery for reconnaissance/exploration purposes. For detailed mapping purposes, rather than for location of geothermal areas, a large Scale $TM1_b4_g5_r$ image of the southern area of Waiotapu was examined (Fig. 3c).

Comparison of the tonal patterns shown here (Fig. 3c) with a map of the major surface activity (Fig. 2) and a vegetation map of the Waiotapu thermal area (Clarkson, 1982) illustrates the great detail that is present on the TM image. Extending vertically through the centre of the image is the main southern Waiotapu thermal area. It is bounded on the west by the arcuate area of light yellowish tones of pasture. The elongated dark blue-toned Lake Whangioterangi and the large pinkish-toned area of cleared forest plantation are conspicuous at the NE. South of Lake Whangioterangi the white tones of a large geothermal area are predominant. The results of analysing tones and classifying the digital number values of the very complex pattern of spectral tones (reflectances) in this image are presented in Table 1.

Within the Waiotapu thermal area the range of white, magenta, green-browns, brown, pink, and yellow-green tones are mainly caused by heat-stressed vegetation effects. The large white area (south of tea rooms), two smaller white areas (mid-centre) and the area south of Lake Whangioterangi represent bare, hot and acid altered ground (Fig. 2). Very sparse prostrate kanuka (if present at all) contributes little to the spectral signal. The dominant response is from bare ground. The crescentic area of brown tones west of the acid alteration craters area is a characteristic response of thermally stressed dwarfed kanuka scrubland (with this TM combination). There is considerable subtle variation in tones corresponding to plant variations caused by differences in surface temperature. Smaller areas of brown tones in the north, south and east of Lake Ngakoro also denote localised thermal areas of stressed vegetation (Mongillo, in press). The dark brown tones occupying much of the western margin are predominantly old, tall manuka (scrub). The lighter brown tones within it are due to local thermal activity with lower kanuka scrub.

Lake Ngakoro (centre south), Lake Whangioterangi (east) and smaller lakes near the western border are dark blue. The large cyan (lighter blue) area (upper centre) is an extensive sinter terrace often covered with chloride water overflow from Champagne Pool, the lefimost dark blue area (see Fig. 2). The two smaller blue areas (centre) are the water filled Alum Cliffs and Frying Pan Flat hydrothermal explosion craters.

5. DISCUSSION

The indigenous vegetation of New Zealand has a combination of features that does not allow easy remote sensing analysis of spectral variations. The vegetation is evergreen. Seasonal changes are minimal. Multitemporal analyses (eg. brown wave/green wave) that have been so useful elsewhere are not suitable for New Zealand native vegetation studies. The colour of the plant foliage is mostly dark dull green tones. Leaves are predominantly small, not very mesic and with little variation in green tones between the many species. Uniformity prevails.

For remote sensing analysis these combined characteristics result in (1) very low to low spectral irradiance (reflectance) in the visible wavelengths; (2) relatively low spectral irradiance in the near infrared (NIR) reflective wavelengths, and (3) a low dynamic range in spectral or DN values (digital number) between species. Contrast enhancement of CIR products can differentiate between broadleaf and podocarp (eg. rimu, totara) forest communities and kanuka-manuka scrub. However, manuka and kanuka are euryvalent species; i.e. they are hardy and tolerant of a wide range of ecological conditions. They are widespread, especially in disturbed habitats. Much of the vegetation of the TVZ has been modified from milling, so manuka-kanuka communities occur widely. These communities serve an early successional role in the slow regeneration from scrub through secondary bush to bush. The most characteristic vegetation on hot geothermal ground in the TVZ is prostrate dwarfed kanuka (Given, 1980; Cochrane, et al., 1993).

Table 1 Classification of selected Waiotapu geothermal features (refer to Fig. 3c).

GRID SITE	TONE	FEATURE	DN VALUE RANGE		
			TM 1	TM 4	TM 5
F4; L9	white	Bare ground	137-173	100-106	98-128
F2, F3	Pinkish-white	Bare ground plus sparse prostrate kanuka	122-146	82-96	90-121
F1; F4	Pale magenta	Bare ground with more prostrate kanuka	94-104	68-77	91-98
E4	Light brown	Low, dense prostrate kanuka (100 % cover)	72-75	61-68	82-84
E3, E4	Olive green	Taller, dense, mostly prostrate kanuka	57-71	62-66	48-76
E2, E3	Brownish-green	Taller, erect scrub (kanuka and other spp.) and scattered trees	56-61	54-67	29-43
B9; D9	Greenish-brown	Erect (2 m high), dense kanuka/mingimingi	56-59	53-61	45-54
C8; D12	Dark brown	Old, tall (3.5-4 m high) manuka	53-61	45-52	45-52
G4	Magenta	Erect (2 m high), dense mingimingi/kanuka	65-68	60-63	84-91
G4, G5	Cyan	Sinter terrace	133-172	70-90	16-32
G4	Dark blue	Champagne Pool	147-147	100-100	51-51

Bare ground too hot for any plant growth may be followed by a hardy moss mat, then sparse prostrate kanuka, gradually becoming denser as the ground temperature grades towards ambient, is the most ubiquitous vegetation of hot areas. More erect kanuka, manuka and mingimingi communities also occur on warm and altered ground. These communities are also on ambient temperature ground and often flank hot and altered ground areas.

With CIR analyses the spectral variations between these communities present on hot and ambient ground cannot be confidently used for mapping purposes without *a* priori knowledge. The use of the MIR TM Band 5 (1.55-1.75 μm) does enable discrimination between heat-stressed and non-stressed vegetation (Figs. 3a and 3b). Therefore, the wider areas of hot ground, other than surface manifestations of steaming ground, hot pools, geysers, etc., *can* be mapped using the distinctive spectral values from TM band 5 of heat-stressed vegetation (*see* Table 1). Thus a TM colour composite (visible, NIR, MIR) serves a valuable initial reconnaissance/exploration role (location) by clearly differentiating heat-stressed communities from adjacent non-heat-stressed vegetation (Waimangu, Fig. 3a; Waiotapu, Fig. 3b). This cannot be achieved with the higher spatial resolution SPOT CIR composite (visible, visible, NIR) using only visible and NIR bands.

Furthermore, a more detailed second stage analysis (mapping survey) of geothermal areas can be achieved with enlargement. Fig. 3c shows a complex pattern of colour tones corresponding to vegetation and surface feature spectral differences. There is much greater detail and complexity of tonal patterns in the TM colour composite (Fig. 3c) than on a map (Clarkson, 1982) showing major vegetation types of the Waiotapu thermal area.

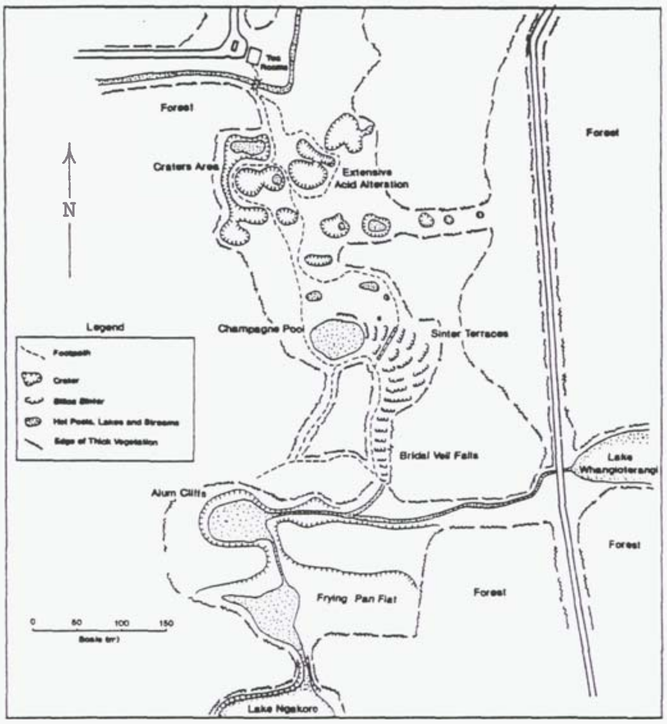

Fig. 2 Map of the major thermal features in the southern Waiotapu geothermal area (after Hedenquist, 1983).

Fig. 3a This enhanced TM$1_b4_g5_r$ colour composite image covers the **main** Waimangu geothermal area. North is to the top.

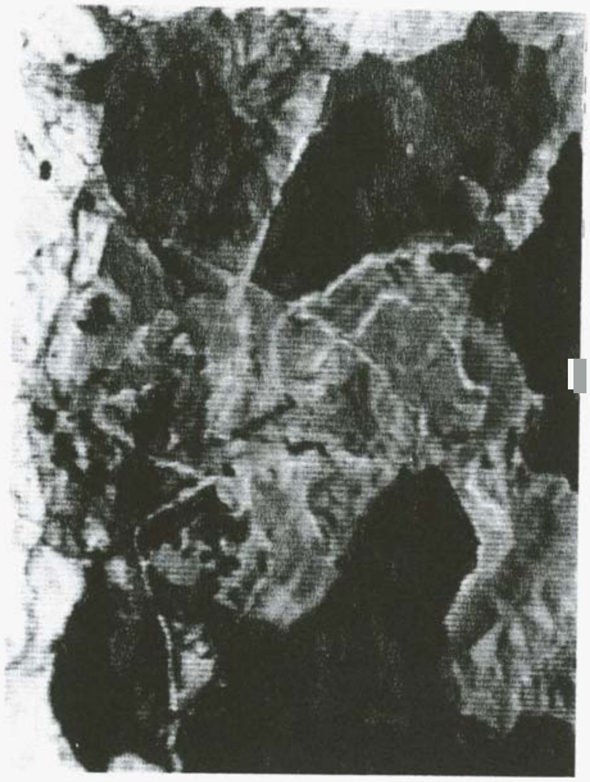

Fig. **3b** This **enhanced** TM$1_b4_g5_r$ colour composite image covers the main **Waiotapu** geothermal **area and Rainbow** Mountain. North **is to the top.**

Fig 3c. Large scale enhanced TM$1_b4_g5_r$ image covering the southern Waiotapu geothermal area. North **is** to the **top.**

6. CONCLUSIONS

The results presented here demonstrate that visual interpretation of small scale TM (visible, NIR, MIR) composite images can detect heat-stressed vegetation present in the Waimangu and Waiotapu geothermal areas and discriminate it from surrounding non-stressed vegetation. Both visual interpretation and digital analysis of large scale imagery covering the located geothennal areas can provide more detailed information on the presence and relative temperature distribution of hot ground using stressed vegetation as a surrogate temperature indicator. These may provide low cost techniques for locating and mapping active geothermal areas in other highly vegetated regions in the reconnaissance/exploration phases of geothermal investigation.

Higher spatial resolution aircraft scanner multispectral data of these areas is now being examined. Results will aid in a more confident interpretation of the satellite data.

7. ACKNOWLEDGEMENTS

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