SATELLITE STUDIES OF CRATERS OF THE MOON GEOTHERMAL AREA

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SUMMARY - A close ecological pattern exists between plant communities and geothermal ground in the Taupo Volcanic Zone (TVZ). LANDSAT TM (30 m spatial resolution) and SPOT **XS** (20 m) imagery acquired over the TVZ have been examined for identifying geothermal areas. Many non-geothermal studies have shown that, for the three similar wavelength bands, the SPOT XS imagery is superior because of its higher spatial resolution. However, one combination of TM bands, employing a near infrared (NIR) wavelength band not available on SPOT imagery, clearly identified thermally stressed vegetation. The spectral contribution of the NIR TM band is more important for this detection than the higher spatial resolution provided by the SPOT XS data. Merging the spectral power of this TM combination with the very high spatial resolution (10 m) of the SPOT PAN data optimises both the spectral and spatial contributions of the two satellite systems. This provides even better results.

1. INTRODUCTION

The Taupo Volcanic Zone (TVZ) is a tectonically youthful, complex structural area in the central North Island of New Zealand. It covers an area of approximately 12,500 km^2 and trends NE/SW for a distance of about 250 km from the active volcanoes, Mts Ruapehu, Ngauruhoe and Tongariro, in the south to active White Island Volcano, located about 50 km offshore from the Bay of Plenty coast, in the north. This volcanic belt varies around 50 km in width.

A wide diversity of cultural and indigenous vegetation adds further complexity to the structural and landform variety present in the TVZ (Cochrane, Edwards and Patera, 1993). Cultural vegetation includes very extensive managed plantations of exotic timber trees (Edwards, *et al.,* 1993). Land cleared from forest and scrubland during the past 100 years and planted into exotic pasture species supports a range of pastoral farming. Complex layered indigenous forest (bush) often occupies steep mountainous terrain. Other indigenous vegetation includes structurally and floristically simpler communities of bracken fern *(Pteridium esculentum*), kanuka (*Kunzea ericoides)* and manuka *(Leptospermum scoparium*) scrubland and swampland. Intermediate in community complexity between bush and scrubland is second growth bush which is regenerating in many areas of milled former native forest.

Within the TVZ, there are some 20 known major geothermal areas (Simmons, *et al.,* 1992). There is a close ecological response between the vegetation and the thermal ground. Consequently, a distinctive pattern characterises the vegetation communities of these geothermal areas (Dawson and Dickinson, 1970; Given, 1980; Merton, 1992; Cochrane, *et al.,* 1993). A monospecific low moss community, *Campylodus clavatus*, can occur on the hottest vegetated ground. Although green in winter, for much of the remainder of the year it dries out to a dun colour that differs very little from the surrounding bare earth tones. Harsh wiry *Dicranopteris linearis* fern communities can also be present. Often, the occurrence of these vegetation types is locally influenced by the presence of steam vents. However, the characteristic vegetation of much of the thermal ground is sclerophyllous, microphyllous, prostrate dwarf shrubs. These dark coloured plants all have low spectral reflectance, hence, produce low digital number (DN) values on the imagery. It is difficult to distinguish among them using conventional methods of satellite image analysis. It is also difficult to distinguish between these thermal ground prostrate plants and flanking areas of erect kanuka and manuka shrubs that are common on non-heated ground.

We have selected several geothermal areas within the TVZ between Rotorua and Taupo for satellite remote sensing investigation (Fig. 1). Areas chosen for specific study using LANDSAT Thematic Mapper (TM) 7-band multispectral scanner data (30 m spatial resolution) for vegetation mapping include Rotorua, Rainbow Mountain, Te Kopia, Orakeikorako, Waiotapu, Broadlands, Rotokawa, Wairakei and Tauhara. SPOT HRV multispectral scanner **(XS)** data (20 m) and SPOT PAN data (10 m) are also being analyzed for Wairakei and Tauhara geothermal fields.

This paper presents the results from an analysis of satellite imagery of the Craters of the Moon thermal area (Wairakei geothermal field). Specifically, the relative and combined information contributions of the higher **spatial resolution** SPOT HRV data and the lower spatial resolution, but **extended NIR spectral range,** TM data for **mapping** thermal ground and vegetation are evaluated and compared. Refer to Grindley (1965) and Allis (1981) for geological and other details regarding this area.

2. METHODS

2.1 Satellite Scanner Systems

Unmanned *earth* orbiting resource satellite investigations began in 1972 with the launch of NASA's ERTS, later renamed LANDSAT-1. This satellite and the subsequent USA LANDSAT and NOAA series, the French SPOT and Japanese JERS-1 operate multispectral scanners, i.e. they record the amount of radiation reflected (and in some cases emitted) from objects in different wavelength regions, or spectral bands (Table 1). The detail, or spatial resolution, which these scanners provide, is chosen as a practical compromise between the mechanics of scanner data acquisition, data processing and operator/user requirements. All these scanners provide excellent synoptic views of large areas of the earth's surface. Such instruments can view specific areas at regular intervals and" thus provide information about temporal change.

The LANDSAT series of satellites collect data in from four to seven spectral bands. The LANDSAT multispectral scanner (MSS) simulated colour infrared (CIR) composites generated using the two visible and one of the NIR bands revolutionized earth resources investigations (NASA, 1976). However, the MSS spatial resolution of 80 m was limiting for the analysis of small areas.

LANDSAT TM represents an important technological advance: the spatial resolution was improved to 30 m for the six reflective bands (bands 1-5,7); the MSS visible and NIR bands were refined to four narrower ones, providing better information with less spectral noise; and the spectral range was extended to include three new IR bands 5-7 (Table 1). Band 5 monitors plant moisture content and band 7 monitors clays and other minerals. Band 6 monitors the emissive (heat) wavelengths and has a resolution of 120 m.

The SPOT satellite HRV scanner provides a further technological advance, primarily in its method of data acquisition. It uses a **pushbroom** scanner, rather than the mechanical oscillating mirror of the LANDSAT MSS and TM. This allows improved spatial resolution to 20 m for the SPOT **XS** scanner and 10 m for the SPOT PAN scanner. The radiometric quality of each pixel (picture element) of the recorded data is also substantially improved.

More recent airborne multispectral scanners (GEOSCAN, AVIRIS, GERIS) have increased the number of spectral bands monitored to 24-224 and substantially improved the resolution of the data to 2-6 m (Table 1). Relative to satellite scanners, these aerial scanners cover much smaller areas, but provide much more detailed information.

This paper evaluates SPOT and TM data for vegetation analysis, with particular emphasis on the role of TM band-5

Table 1- Chart of satellite and aircraft scanner spatial resolutions and spectral band configurations. Typical vegetation, soil, water and alteration mineral spectra and atmospheric absorption are included for comparison.

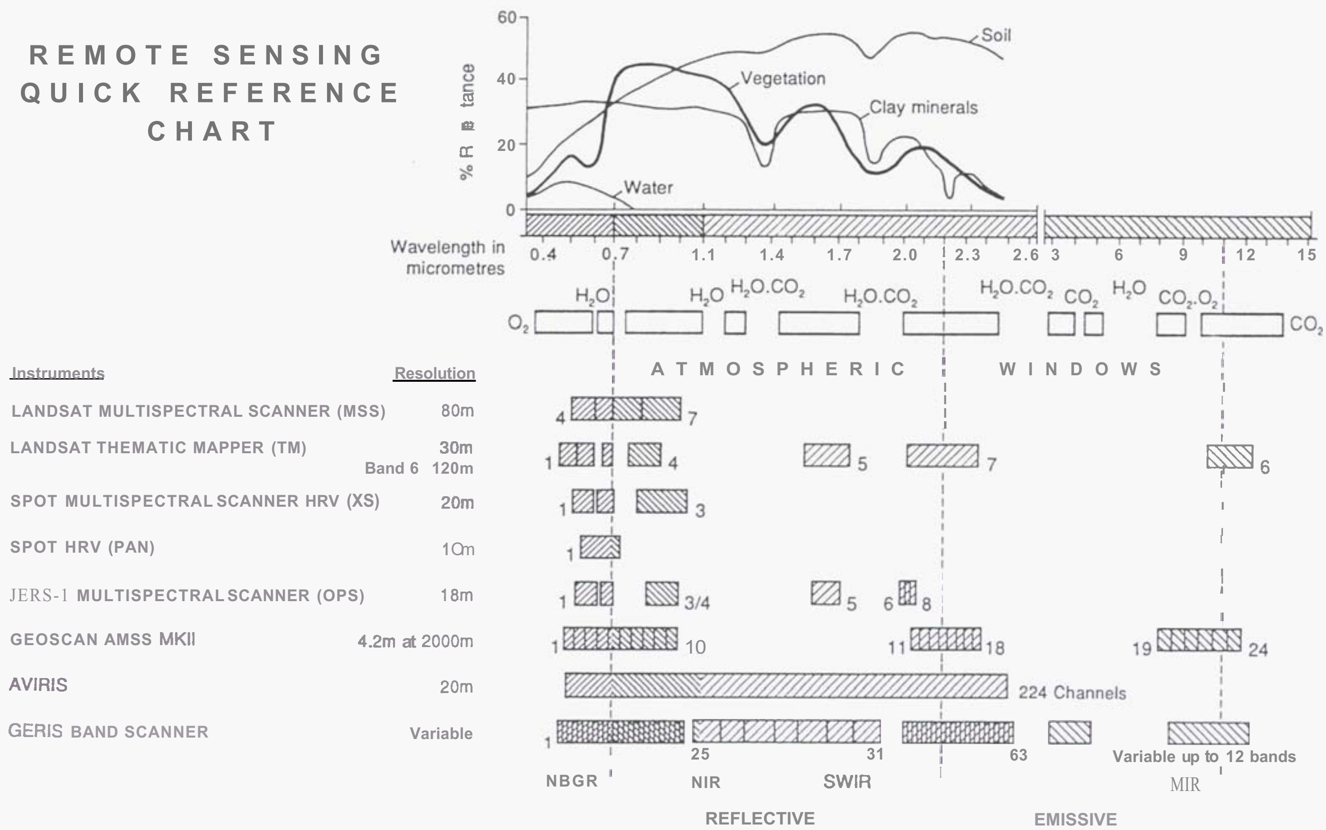

Figure 1- Main thermal areas and hot water locations in the Rotorua-Taupo geothermal region of the TVZ.

as an acute detector of thermally stressed vegetation.

2.2 Data Processing

We have satellite data for most of the TVZ, some are photographic and some are digital. Comprehensive coverage has been acquired only over a period of several years. Frequent temporal repeat coverage is not available for SPOT or TM. Less SPOT PAN data are available than SPOT XS.

A range of image processing procedures has been employed to evaluate (1) best identification and definition of vegetation differences in geothermal areas and (2) consistency of the enhanced products. For selected subscenes, single-band analysis and multi-band methods including simulated natural colour, CIR, filtering, ratioing, Vegetation Index, pseudo-colouring, intensity reversal and a range of contrast enhancements, have been examined. For Craters of the Moon thermal area, the additional techniques of rectification and merging of SPOT PAN and TM data were carried out. The Intensity-Hue-Saturation (IHS) decorrelation enhancement was employed for the merging, thus optimising the spectral range contributions of the TM multi-band data and the high spatial resolution of the SPOT PAN.

3. RESULTS AND DISCUSSION

3.1 LANDSAT TM Satellite CIR Imagery

A simulated CIR colour composite image created from bands 2,3 and 4 of a one-quarter TM scene (Ref. 72/87, 25/12/90 GMT) was analyzed. At an approximate scale of 1:500,000, there was no evidence of geothermal features. At a 2X enlargement, only the largest thermal lakes and areas of bare ground were discernable. Other CIR TM band combinations provided no improvement. The spatial resolution of 30 m seems a major limit on interpretation.

Simulated CIR (bands 2,3,4) images of several individual geothermal fields (listed in Section 1) were analyzed next. At these larger scales, subtle differences in the thermally stressed vegetation were barely discernable. They were not easily recognizable nor distinguishable from adjacent vegetation and could have been overlooked without local knowledge of vegetation differences. Of the range of enhancements tested, the Vegetation Index, using bands 3 and 4, improved separation (Cochrane, *et al.*, 1993).

3.2 SPOT Satellite Imagery

Earlier investigations of the TVZ using SPOT XS bands 1,2 and 3 as simulated CIR colour composites proved useful for landform studies (Cochrane, Edwards and Patera, 1993) and for forestry mapping (Edwards, *et al.*, 1993). At comparable scales, the present study showed all geothermal areas in the TVZ were more readily recognized on the SPOT XS photographic image than on the equivalent TM imagery. Large geothermal lakes and areas of bare ground could be identified.

Digital SPOT data (Ref. 443/428, 1/9/89>available for the present study were limited to the Wairakei and Tauhara geothermal areas. Processing of enlarged imagery of these areas allowed a broad grouping of thermally affected vegetation to be distinguished. Although subtle, vegetation differences were more apparent than on the TM imagery. Vegetation associated with heated ground at Craters of the Moon is discernable (Fig. 4a), but not easily mappable. Compare Fig. 4a with Figs. 2 and 3.

Comparison of similar wavelength SPOT XS (bands 1,2,3) and TM (bands 1,3,4; 2,3,4; and 2,3,5) data as colour composites showed that the higher spatial resolution (20 m) SPOT imagery provided more information. Thermally stressed vegetation, characterized by its morphological adaptations (prostrate habit and dwarf form) and its sclerophyllous, microphyllous foliage, exhibits low irradiance, hence appears as a very dark magenta to near black tone on the imagery, while the other (normal) vegetation shows as a range of red tones (Fig. 4a).

3.3 LANDSAT TM Band 5 Imagery

TM baud 5, centred at 1.65 μm, provides information on plant moisture content (Table 1). It should facilitate detection of thermally stressed vegetation. Using this band, a pseudo natural colour image of Craters of the Moon was generated by allocating TM bands 3, 4 and 5 to the blue, green and red colour guns, respectively (Fig. 4b). This spectral combination clearly separated the stressed vegetation

Figure 2- Black and white aerial photograph of the Craters of the Moon thermal area, Wairakei geothermal field. Patterns of the low, prostrate, even canopied, thermally stressed vegetation (grey tones) within the basin differ from the dark tones of the flanking erect vegetation on non-heated ground. The range in tones (spectral irradiance) is small and predominantly of low DN value for all the shrub and tree vegetation, thus differentiation is difficult.

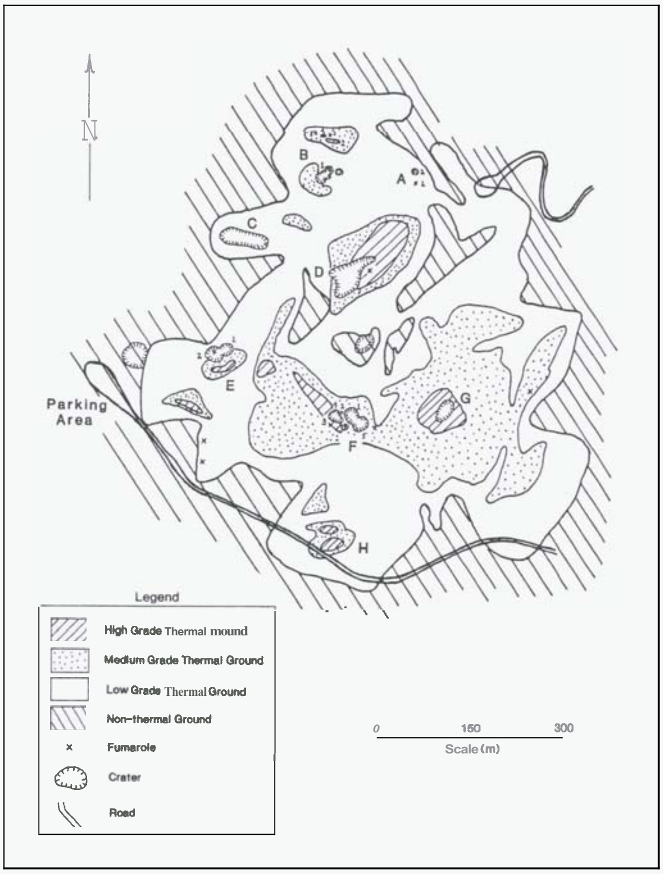

Figure 3- Map of thermal ground at Craters of the Moon, Wairakei geothermal field.

on thermal ground (1) into categories and **(2)** from adjacent vegetation growing on non-thermal ground. Despite the lower spatial resolution **(30** m) of the TM data, the additional band **5** spectral information makes this TM composite superior to the SPOT **XS** (20 m) one. Compare Figs. 4a and 4b.

This image processing method provided consistent results when tested on the imagery of several other geothermal areas in the TVZ. The vegetation moisture content information contributed by band **5** in the pseudo natural colour TM composite makes the combination a consistent classifier. The TM band 3,4,5 (bgr) colour composite provides a dramatic and very useful analytical procedure for mapping thermally stressed vegetation, clearly separating it from unstressed vegetation.

3.4 TM Vegetation Index

The Vegetation Index transformation provides information on vegetation health (Cochrane and Lasselin, 1989). Its application (using TM bands **3** and **4)** produced an image (Fig. 4c) in which a range of soil and vegetation patterns can be recognized, grading from fumaroles, steaming craters

Figure 4 (facing page): Figure 4a- A simulated CIR SPOT **XS** (bands 1,2,3) image. Patterns are present, but separation **of** the pink, red and brown tones of stressed vegetation from flanking unstressed plants is not possible. **Figure 4b-** This TM (bands **3,4,5)** pseudo natural colour composite image clearly separates thermally stressed vegetation areas. The steaming craters, bare ground and prostrate **kanuka** communities (shown **as** tones of white, blue and brownish-pink) contrast sharply with the various green tones of unstressed vegetation. **Figure 4c- A** TM Vegetation Index image. The TM **4/3** band ratioing process further enhances (1) the thermally stressed vegetation patterns and (2) separates out the unstressed vegetation. **Figure 4d-** Merged SPOT **PAN** plus TM pseudo natural colour image. This data combination method gives **very detailed** patterns of steaming ground, bare ground and stressed vegetation (shown in distinctive white, yellow, orange and red-brown tones, respectively). Some individual board walks (1.5 m wide) show as thin yellow lines, roads as cyan, unstressed scrub and tree vegetation as greens and pasture as blues. The central dark area of erect kanuka with some regenerating broadleaf shrubs is also repeated along the **rim** of the basin where similar vegetation is present.

Figure 4a

Figure 4b

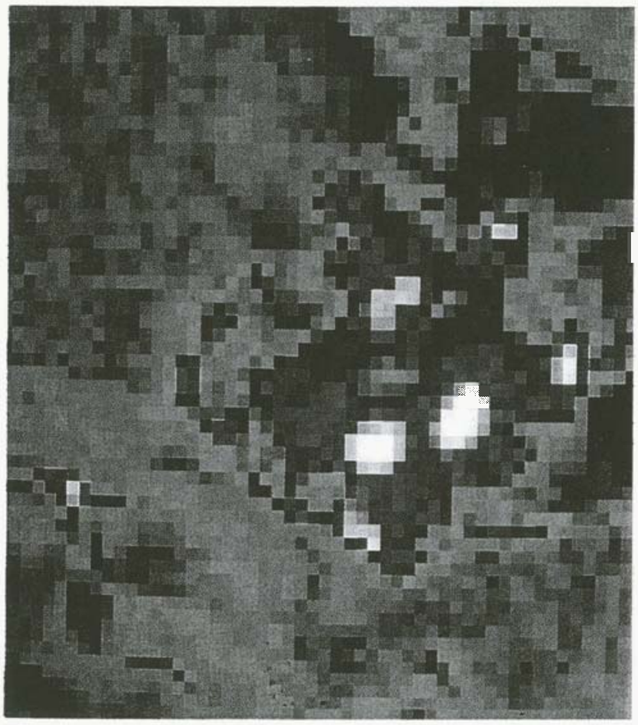

Figure 4c

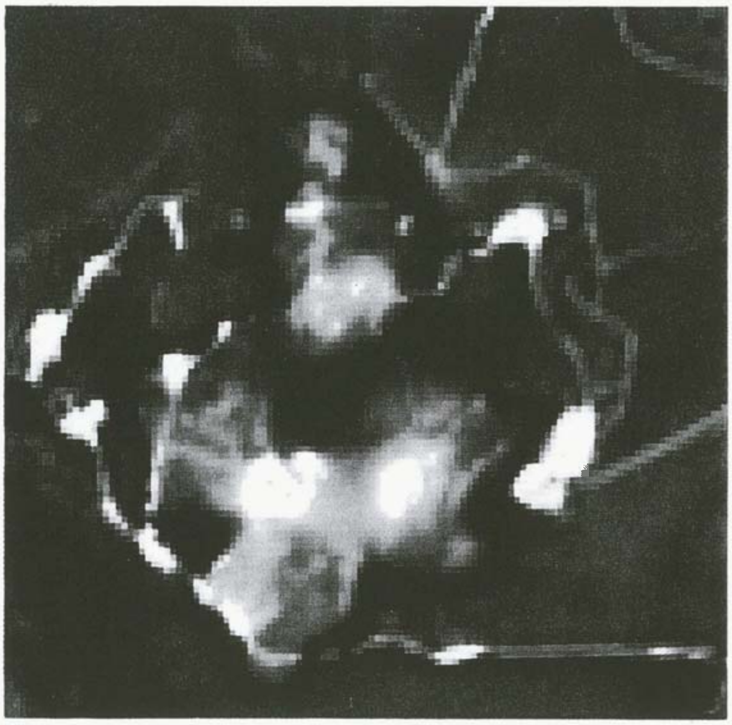

Figure 4d

Figure 4- Four different image enhancements of the vegetation at Craters of the Moon. Comparison of each of these with Figs. 2 and 3 shows the relationships between vegetation on thermal and non-thermal ground. Consecutive comparison (a,b,c,d) demonstrates the increasing sophistication of enhancement for mapping vegetation (detailed captions on facing page).

and hot bare ground (too hot for plants to grow in) through a stressed plant sequence to ambient ground. The plant progression (from hot to ambient ground) is: moss areas; prostrate, sparse coverage kanuka; low prostrate, denser kanuka; prostrate kanuka/*Lycopodium*; taller prostrate kanuka/*Dicranopteris linearis* to taller kanuka. Beyond this, erect knauka and kanuka/manuka and mixed broadleaf shrubs and low trees (notably *Pseudopanax spp.*, *Coprosma australis* and *Hebe*) mark the areas of non-thermal ground. Inplaces, planted conifers are adjacent to the thermal areas.

3.5 Merged SPOT PAN and TM Imagery

The high resolution (10 m) SPOT PAN image was merged with the pseudo natural colour TM band 3,4,5 image in order to create one having both good spatial detail and spectral separation (Fig. 4d). This gives a very powerful, accurate and visually striking technique for mapping both thermally stressed and unstressed vegetation. Compare this product (Fig. 4d) with the information on the black and white aerial photograph of Craters of the Moon (Fig. 2).

4. FUTURE INVESTIGATIONS

Further investigations of TVZ geothermal areas using the above methods are being pursued. Use of TM Band 6 TIR data is being addressed by Deroin, *et al.* (1994). GEOSCAN daytime MSS and nighttime TIR data of the Waiotapu geothermal area are also being examined.

5. ACKNOWLEDGEMENTS

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6. REFERENCES

Allis, R.G. (1981) Changes in heat flow associated with exploitation of Wairakei geothermal field. *NZ Jour. Geology and Geophysics*, 24, 1-19.

Cochrane, G.R., Edwards, M. and A. Patera (1993) Landform mapping of forested volcanic terrain from SPOT XS data. *PIX-ILES 90 N.13.*, 149-158.

Cochrane, G.R., Merton, R., Mongillo, M.A., Deroin, J-P. and P.R.L. Browne (1993) Remote sensing and vegetation patterns in the Te Kopia geothermal area, Taupo Volcanic Zone (TVZ). Geography Conference, Wellington, 12 p.

Cochrane, G.R. and D. Lasselin (1989) Vegetation Index and resource analysis: measurement of relative greeness from SPOT multispectral data. *Proceedings 15th NZ Geography Conference*, 225-229.

Dawson, G.B. and D.J. Dickinson (1970) Heat flow studies in thermal areas of the North Island of New Zealand. *Geothermics (Special Issue)*, Vol. 2, Part 1, 466-473.

Deroin, J-P., Browne, P.R.L., Cochrane, G.R., Coudert, J-M. and M.A. Mongillo (1994) Structural control of geothermal fields in the North Island (New Zealand): from the synthesis of satellite, geophysical and terrain measurements. *6ëme Symposium International Mesures Physiques et Signatures en télédétection*, Val d' Isère, January 1994.

Edwards, M., Patera, A. and G.R. Cochrane (1993) The inventory and monitoring roles of SPOT XS data for plantation forestry mapping. *PIX-ÎLES 90 N10*, 133-142.

Given, D.R. (1980) Vegetation on heated soils at Karapiti, Central North Island, NZ and its relationship to ground temperature. *NZ Journal of Botany*, 18:1-13.

Grindley, G.W. (1965) The geology, structure and exploitation of the Wairakei geothermal field, Taupo, New Zealand. *NZ Geological Survey Bull.* n.s. 75, 131 p.

Merton, R. (1992) Thermal and biogeochemical stress analysis of vegetation within the Waiotapu geothermal field. *Unpublished Report*, Geography Department, University of Auckland, 116 p.

NASA (1976) Mission to earth: LANDSAT views the world. *NASA S-P 360*, 459 p.

Simmons, S.F., Browne, P.R.L. and R.L. Brathwaite (1992) Active and extinct hydrothermal systems of the North Island, New Zealand. *Society of Economic Geology Guide Book*, Vol 15, 121 p.