Proceedings 18th NZ Geothermal Workshop 1996

AIRCRAFT SCANNER STUDIES OF SURFACE HYDROTHERMAL ALTERATION-WAIOTAPU GEOTHERMAL FIELD

G.R. COCHRANE' ,M.A. MONGILLO[2] AND G. OROZCO MEDINA'

[1] Geothermal Institute, The University of Auckland, NZ
[2] Wairakei Research Centre, IGNS, Taupo, NZ

SUMMARY - GEOSCAN MKII multispectral aircraft scanner imagery acquired over the Waiotapu geothermal field at 3 m spatial resolution is evaluated for surface mineral studies. Previous investigations showed that colour composites consisting of visible, NIR and MIR wavelength bands are valuable for mapping vegetation, water bodies and hydrothermally altered ground. This study examines the use of the GEOSCAN 18 reflective wavelength bands for the identification of minerals present in the altered ground. Spatial profiles along transects and spectral profiles for selected sites are presented. These data are interpreted using GEOSCAN colour composite images, aerial colour photographs, field survey information and laboratory analyses of samples to evaluate the role of high resolution aerial scanner data for detailed mapping of the complex patterns of minerals present in hydrothermally altered ground at Waiotapu.

1. INTRODUCTION

Work in the early 1990s by joint New Zealand/French researchers investigated the use of satellite multispectral imagery for studying geothermal areas in the Taupo Volcanic Zone (TVZ). Subsequently, Cochrane *et al.* (1994), Deroin *et al.* (1995) and Mongillo *et al.* (1995) have shown that the larger surface thermal features, such as bare altered ground, sinter terraces, fumaroles, hot pools and geothermally stressed vegetation, can be mapped using SPOT XS and LANDSAT TM multispectral data. Detailed studies were limited by the 20-30 m spatial resolution of the satellite data. Higher resolution (10 m) SPOT PAN data were examined for the few areas for which it was available (Mongillo *et al.*, 1993).

The high spatial resolution (3 m) imagery acquired over the Waiotapu area with the aerial GEOSCAN multispectral airborne scanner overcomes the limitations of the coarser satellite data. Preliminary results obtained by Mongillo (1994) and Mongillo *et al.* (1995b) using spectral bands found useful in the satellite studies showed the high potential of GEOSCAN for detailed studies of geothermal features. This paper continues these studies, focusing on detailed analyses of altered ground using high resolution aerial GEOSCAN spectral data of the northern portion of central Waiotapu.

2. STUDY AREA

The Waiotapu Geothermal Field, an active epithermal mineral depositing system, is one of the largest (18 km^2) and most complex within the TVZ of central North Island of New Zealand (Fig. 1) (see Hedenquist, 1986, for details). Complex surface activity includes large areas of surface alteration due to acid-sulphate fluids, steaming ground, fumaroles and associated collapse craters, mud pools, silica deposits, notably the large silica (sinter) terrace, hot pools, and hydrothermal eruption craters (especially Champagne Pool, the largest chloride discharge feature at Waiotapu).

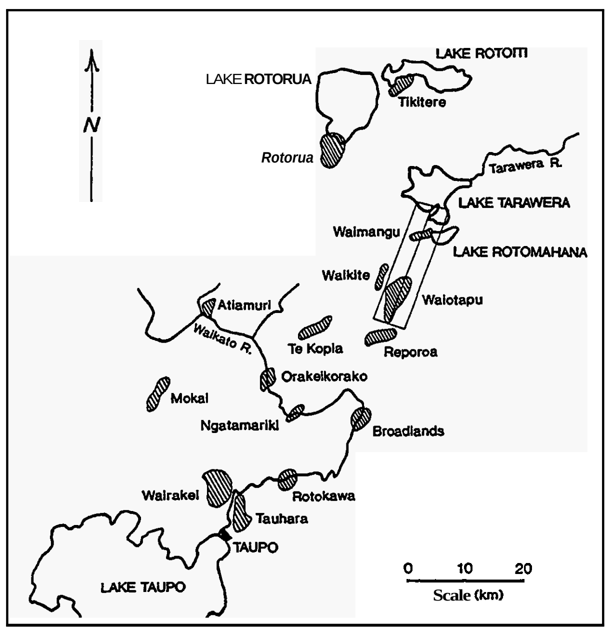


Fig. 1. Sketch map showing the major geothermal fields between Lake Rotoiti in the north and Lake Taupo in the south. The two GEOSCAN flight line image areas are indicated by the two adjacent rectangles.

3. METHODS

3.1 The GEOSCAN Instrument

The GEOSCAN MkII, an advanced airborne multi-spectral scanner, is operated from a Cessna 404 aircraft and incorporates GPS navigation. Aircraft roll, pitch and yaw variations are compensated for.

The GEOSCAN instrument can acquire imagery simultaneously in 24 geometrically registered wavelength bands which span four spectral regions (visible, near infrared, mid infrared and thermal infrared) in the 0.49- 12.0 μm range. The imagery is digitized to an 8-bit dynamic range and recorded directly onto 5.25 inch optical disks having a capacity of 325 Mbytes/side (650 Mbytes total).

3.2 The Aerial Survey

The first comprehensive, high spatial resolution remote sensing survey of the Waiotapu geothermal area was performed on 21 January 1993. Imagery was acquired during the period 01:25:10-01:38:12 New Zealand Daylight Time. The survey altitude was 1430 m above ground level, providing a swath width of 3 km and a nadir ground spatial resolution of 3 m. A 100 km^2 area, 5.5 km wide and 19 km long, extending from southern Lake Tarawera to northern Reporoa, was covered with two parallel flight lines having an overlap of about 0.5 km. Weather conditions for several days prior to, and during, the surveys were stable, warm and dry. To take advantage of the maximum dynamic range of the instrument, detector gains and offsets were set while flying over the survey areas immediately prior to imagery acquisition.

3.3 Field Survey

Ground truth investigations were conducted in January 1993, on 30 August 1994 and 21 April 1995, at which time Surface features were identified and located on field prints of GEOSCAN imagery. During 21-23 August 1996, field survey sites were accurately located along two transect lines for comparison with spatial profile data. Additionally, specific sample points were identified for spectral profile evaluation.

Oblique and near-vertical large-scale colour photographs obtained from a helicopter in November 1993 (L. Homer, pers. comm.) over the altered ground, Champagne Pool and sinter terraces areas of Waiotapu (Figs. 2 and 3), were used for detailed comparisons with GEOSCAN colour composites (Figs. 4 and 5). Field surveys conducted along transect lines oriented N/S and W/E were used to check the GEOSCAN colour composite tonal patterns. Ground temperatures were measured and physical soil characteristics (colour, texture, depth of horizons) were determined at selected sample areas in both the altered ground and sinter areas. Locations of these transect lines and sample areas are shown in Figs. 2, 3 and 5.

3.4 Image Processing and Analysis

Image processing was performed using two systems: the ERDAS/IMAGINE 8.2 system (ERDAS Inc., Atlanta, Georgia, USA) operating on a Silicon Graphics (SGI) workstation and the PC-EPIC system, operating on a standard 486/33 PC with a MATROX MVP-AT real-time processor. This dual approach provided processing flexibility since each system could perform certain operations more easily than the other.

GEOSCAN Pty., Ltd. provided the GEOSCAN imagery corrected for tangent-theta geometric distortion and atmospheric backscatter. The Waiotapu images were rectified to the New Zealand Metric Grid using 1:50 000 series maps to allow accurate location and mapping of features. A third order mapping polynomial and cubic convolution interpolation were utilized for the warping procedure. The resulting rectified images were used for the analysis and interpretation presented here.

Various wavelength (band) combinations spanning 0.4-2.5 μm (bands 1-18) were used to create colour composites that were visually assessed, with emphasis placed on combinations previously found to be of value in satellite investigations of geothermal areas (Cochrane et al., 1994; Deroin et al., 1995; Mongillo et al., 1995). The GEOSCAN imagery does not have a TM5 (1.65 pm) equivalent, consequently, the strong positive correlation known to exist between the TM5 and TM7 (2.2 pm) was used to allow substitution of the GEOSCAN 2.2 μm bands. The TM visible-NIR-MIR combination ($TM3_b4_g5_r$), found to be so useful for stressed vegetation mapping, was therefore replaced by the GEOSCAN combination: $GEO4_b8_g15_r$ where GEO 15 represents the 2.2 μm region. A supervised computer classification of the Waiotapu $GEO4_b8_g15_r$ was also assessed (Fig. 4).

Spatial profiles for all GEOSCAN reflective wavelength bands (1-18) were generated along both transects and carefully compared to the aerial photographs and the GEOSCAN colour composite (Fig. 5). Four field sample sites in the altered ground area, and four in the sinter area, were accurately located (Figs. 2 and 3, Table 1). Spectral profiles of each site were generated to facilitate detailed mapping of alteration mineral patterns. These spectral profiles (shown as Figs. 8 and 9) were compared with laboratory analyses of the field samples. Spectral profiles of vegetation (Fig. 8) and water (Fig. 9) were also included as control profiles for comparisons.

4. RESULTS AND DISCUSSION

A range of different image processing techniques were investigated to assess their utility in identifying surface features and to map the mineral patterns present in the altered ground and sinter areas of central Waiotapu geothermal area. Examples illustrating results of analyses of GEOSCAN high resolution data of Waiotapu are shown in Figs. **4,5,6,7,8** and **9.** Note that colour printer reproductions presented here for Figures **2, 3, 4** and **5** are of reduced quality.

The GEOSCAN composite **($GEO4_b8_g15_r$)** that corresponds to Landsat TM satellite combinations **$TM3_b4_g5_r$ was** found to be particularly useful for mapping the complex surface cover of the larger Waiotapu geothermal area. Figure **4** shows **this** image computer classified into **15** main classes. Two broad groups were identified: **(1)** non-geothermally affected and **(2)** geothermally modified. Group **(1)** consists primarily of two unstressed classes; the black tones representing healthy, woody vegetation (mostly pines) and the yellow tones, healthy pasture. (Note that some of the small black tone areas, e.g. in Champagne Pool and sinter terrace are anomalous signatures).

Group **(2)** includes all other categories and shows features principally modified in some way by geothermal activity. The range of blues to dark pink tones **(7) are** water features. The orange tones are bare altered ground. Dark red and white tones in the northern section indicate mineral differences within the altered ground areas. Sinter areas show **as** a distinctive dark pink tone. **This** classification clearly shows the distinctive patterns of minerals in the altered ground and sinter **areas.** Attention in **this** paper is focused on the northern altered ground (orange, dark red and white tones) and sinter areas (dark pink tones) of Fig. **4.**

The other tones: grey, green, dark red-brown are all **gradations** of heat stressed vegetation ranging from sparse moss and prostrate **kanuka,** denser prostrate **kanuka** to taller **kanuka,** manuka and mingimingi, respectively.

The colour composite, **$GEO4_b8_g15_r$,** (Fig. *5)* is a smaller sub-scene of the northern part of Waiotapu, presented in Fig. **4.** It shows a magnified view of: the altered ground-Champagne Pool-sinter terrace area. The distinctive tonal patterns of mineral variations are more readily observed **than** on Fig. **4.** In Fig. **4** sinter areas are broadly grouped **as** a single dark pink tone. Fig. **5** shows the very complex patterns of the sinter areas **as** a range of blue tones. Similarly, the three tones, orange, white and red, in Fig. **4** of the bare altered ground area are much more complexly portrayed in a wider range of tones in Fig. *5.* Comparison of these tonal pattern with the aerial photographs (Figs. **2** and **3)** confirm the subtleties of the patterns. The N/S and W E transect lines of Figs. **2** and **3** are **shown** superimposed on **this** GEOSCAN image.

The coordinates of the N/S and W/E transect ends are exactly located on Fig. *5.* The coordinates for the samples collected for spectral profiles of the altered ground (Fig. **8)** and sinters (Fig. **9)** are shown in Table **1.** Healthy woody vegetation and water are included **as** control signatures (Figs. **8** and **9,** respectively).

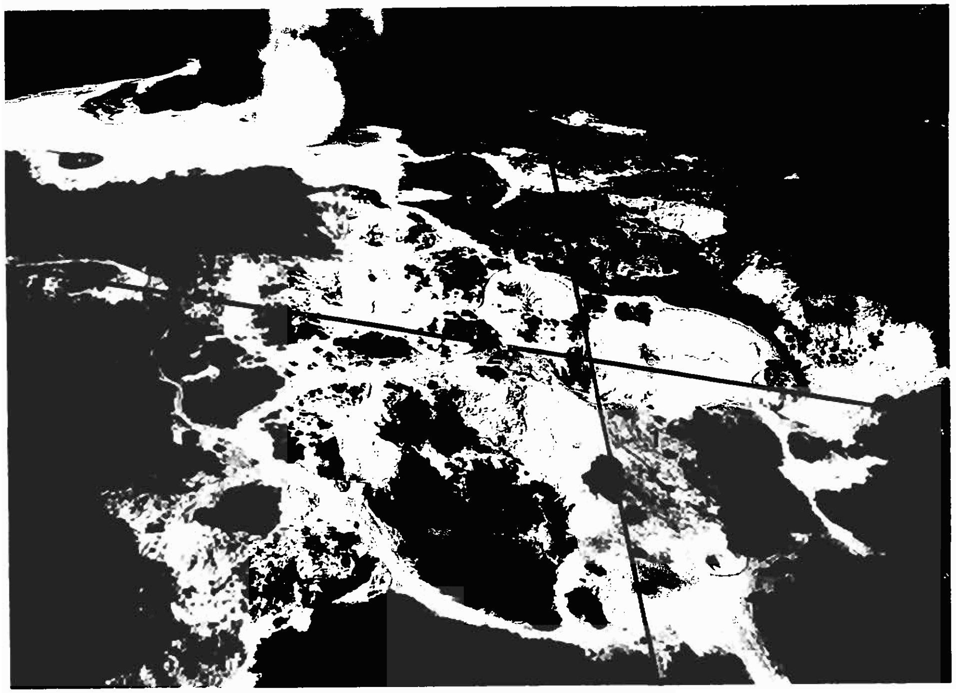
Comparison of the spatial profiles (Figs. **6** and **7)** of the **two** transects with the colour aerial photographs (Figs. **2** and **3)** clearly illustrates the detailed changes recorded with the GEOSCAN data. The profiles vary for each of the **18** bands analysed. Space limitations enable only one spatial profile example for each transect to be presented. Examples of band **2,** highly positively correlated to the field information and colour aerial photographs (Figs. **2** and **3)** are shown **as** Figs. **6** and **7.** When all **18** bands are compared enormous amounts of detail and subtle variations of mineral composition *can* be **seen.** Field surveys confirm the pattern variations shown in the GEOSCAN spatial profiles.

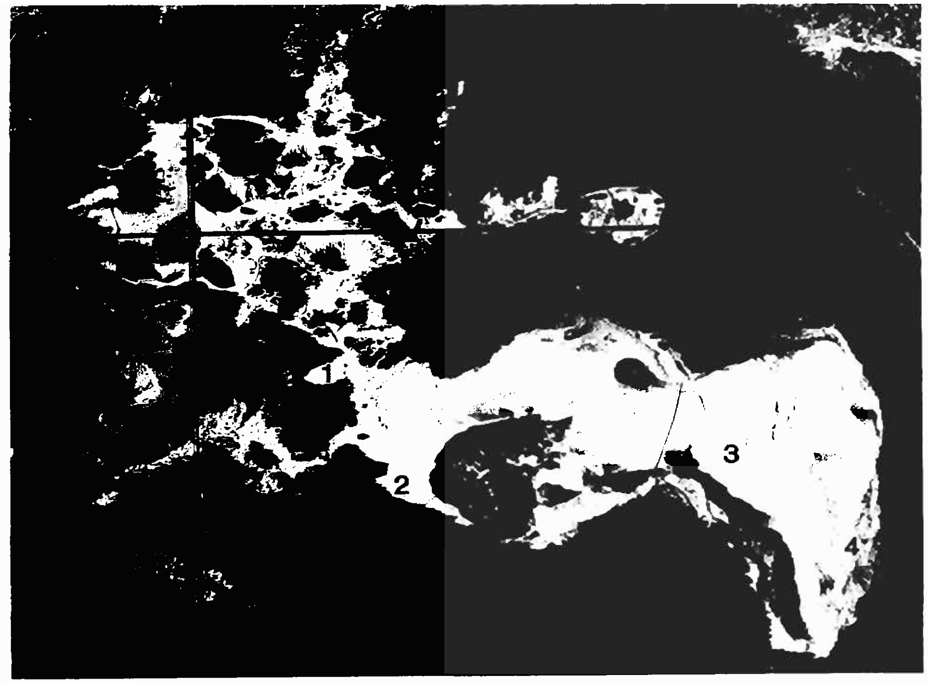
Comparison of the shapes of the spectral profiles of the altered ground samples (Fig. **8)** clearly portrays the close similarities of the four samples. These profiles also exhibit relative vertical displacements, possibly due to small variations in mineral composition and weathering. Similar correlations *can* be seen among the four sinter samples, particularly for bands **1-10 (0.4-0.91μm)** (Fig. **9).** Note the large downward displacement of the water-covered sinter (sinter-H2O) relative to the *dry* sinter (sinter-dry) sample for bands **11-18 (2.0-2.5μm).** Comparison with the water spectrum suggests the dominating influence of water at these longer wavelengths. Comparison of **spectral** profiles in Figs. **8** and **9** clearly shows major differences suggesting variations in mineral composition.

Table **1.** Locations of transect end **points** and sample sites.

N/S Transect	**(182.01, 46.49)**	**(142.96, 156.05)**
W E Transect	**(140.30, 60.88)**	**(237.74, 110.60)**
Altered Ground Sites		
Area **1**	**(170.68, 69.04)**	
Area **2**	**(178.27, 78.01)**	
Area **3**	**(189.16, 63.05)**	
Area **4**	**(202.64, 69.15)**	
Vegetation (pine)	**(229.09, 78.28)**	
Sinter Sites		
Area **1**	**(176.71, 112.09)**	
Area **2**	**(179.68, 135.79)**	
Sinter-H2O	**(221.21, 149.10)**	
Sinter-dry	**(232.98, 168.06)**	
Water (Champagne Pool)	**(193.54, 142.06)**	

Laboratory analyses (Xray diffraction) are planned for the soil samples taken from each of the field sample areas ("able **2).**





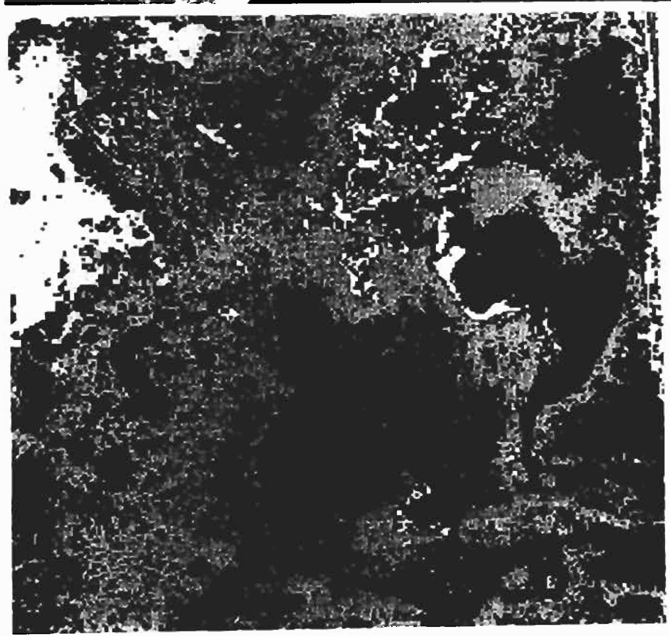
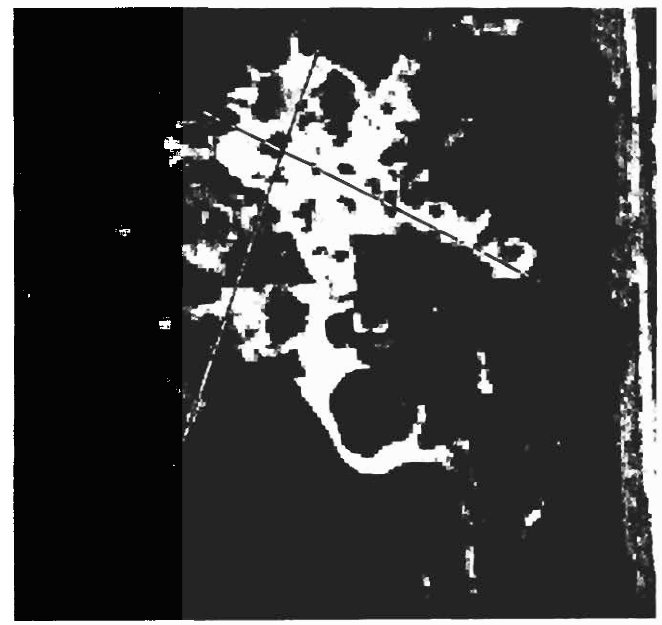


Fig. 2 (upper left). Oblique colour aerial photograph looking south over altered ground to Champagne Pool and sinter terrace, central Waiotapu. N/S transect (red) and W/E transect (green). Field sample areas labelled 1, 2, **3, 4.** (Photograph: IGNS, Lloyd Homer)

Fig. 3 (upper right). Near-vertical colour aerial photograph of central Waiotapu with N/S and W/E transect lines. Sinter field samples labelled 1, 2, **3**, 4. **3** = sinter H_2O, **4** = sinter *dry*. (Photograph IGNS, Lloyd Homer)

Fig. 4 (left). Computer classified image of $GEO4_b8_g15_r$. See text for details.

Fig. 5 (right). $GEO4_b8_g15_r$ subscene with transect lines. See text for details.



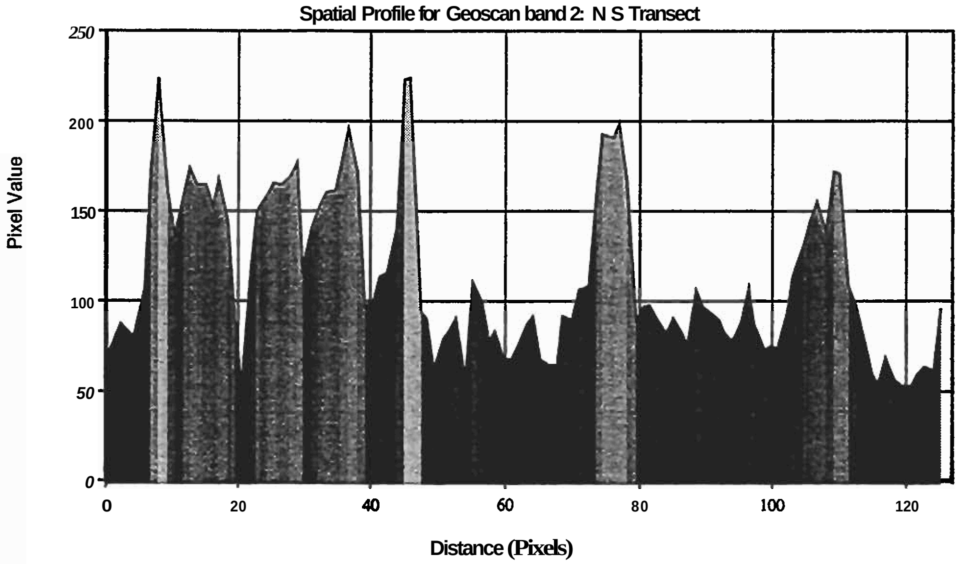


Fig. 6 (left). Spatial profile for N/S transect.

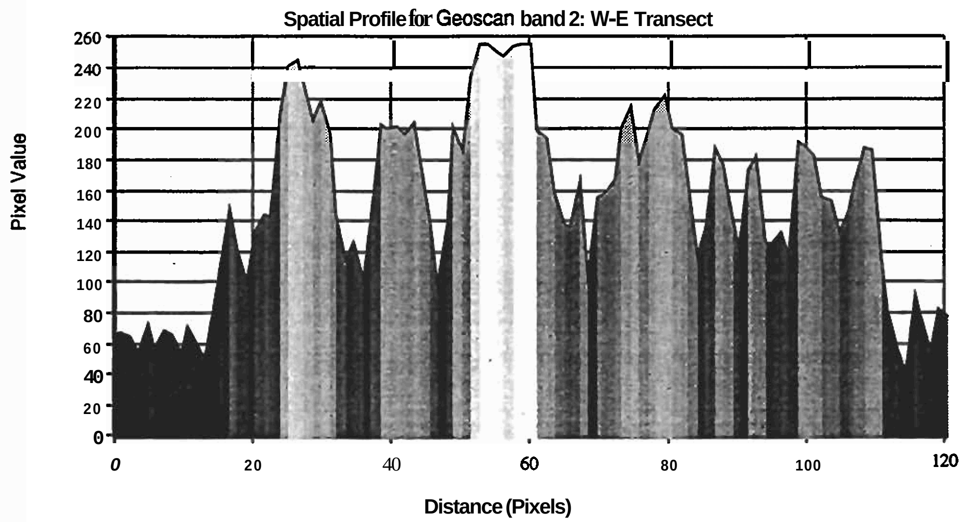


Fig. 7 (left). Spatial profile for W/E transect.

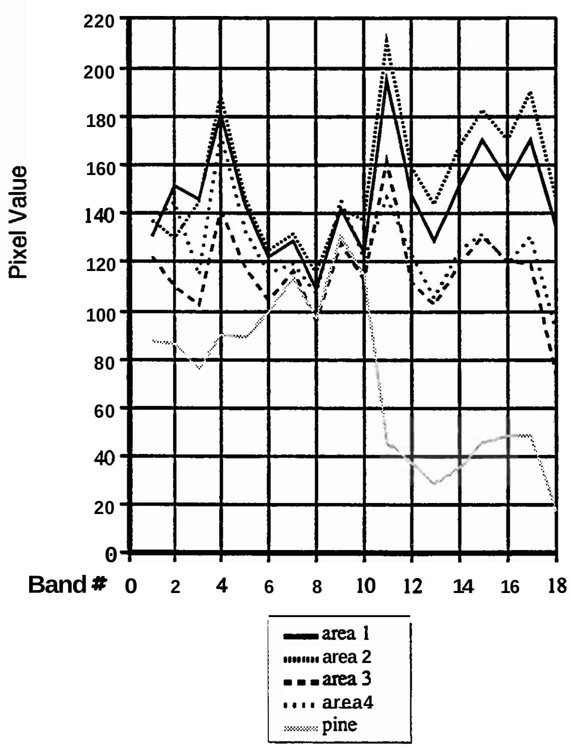


Fig. 8 (lower left). Spectral profiles for GEOSCAN **bands 1-18** for altered ground sample sites.

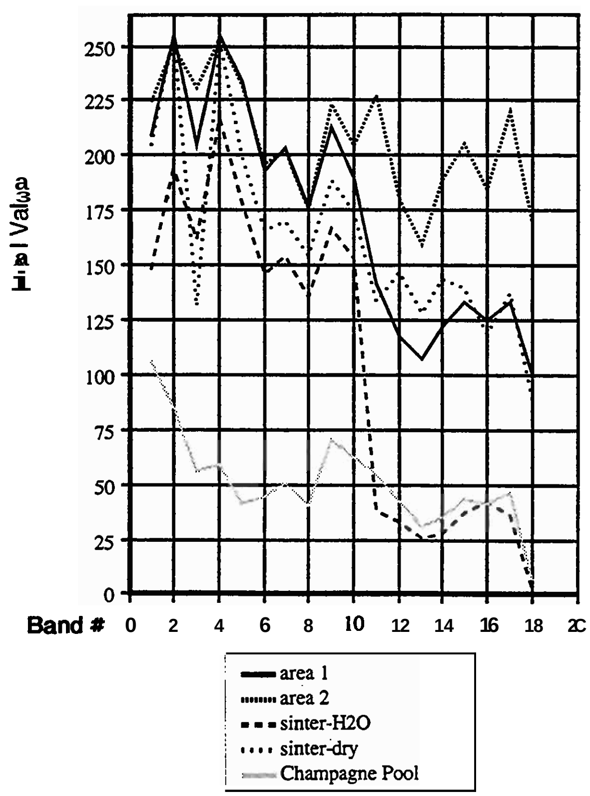


Fig. 9 (lower right). Spectral profiles for GEOSCAN **bands 1-18** for sinter sample sites.

TABLE 2: Laboratory analyses of sample sites

A:	**Altered ground sites**
1.	Amorphous silica
2.	Amorphous silica
3.	Amorphous silica
4.	Amorphous silica, Cristobalite, Jarosite
B:	**Sinter sites**
1.	Amorphous silica, Quartz, Cristobalite, Montmorillonite, Sulphur
2.	Amorphous silica, Quartz, Cristobalite, Montmorillonite, Sulphur
3.	Amorphous silica, Cristobalite
4.	Amorphous silica, Quartz, Cristobalite, Sulphur

In the altered ground area the parallels between the strong visible spectral response (orange tones) on the photographs (Figs. 2, 3), the spatial profile (Fig. 6), the spectral profile (Fig. 8) and the physical properties of the soil (colour, texture, particle size) all indicate the dominant role of iron oxides. The presence of amorphous silica throughout (Table 2) reflects the basic parent rock, ignimbrite.

In the sinter area samples 1 and 2, both close to Champagne Pool, show similar spectral profiles (Fig. 9). This is confirmed with the presence of the same five minerals (Table 2). Samples 3 (wet) and 4 *(dry)* on the large sinter terrace show different spectral profiles. Sample 4, in close proximity to clays and sulphur, reflects some leaching from the nearby sulphur.

5. CONCLUSIONS

The spectral detail recorded by the 18 GEOSCAN bands covering the visible, NIR and MIR provides great potential for analysing data. The flexibility of combinations of the 18 reflective wavelength bands used in this study, coupled with the high spatial resolution of 3 m, means geothermal areas can be mapped very exactly in great detail.

GEOSCAN scanner data is better for mapping purposes than satellite data for relatively small areas. It refines the broad patterns of satellite data, especially for individual geothermal fields as shown in this case.

Visual similarities noted from field surveys and colour aerial photographs to patterns of colour tones on GEOSCAN colour composites can be confirmed with the precise data of spatial profiles. Exact mineral patterns can be mapped using colour composite tones as a first approximation then refined using spectral profiles.

Laboratory analyses of field samples placed minerals into broad groupings confirming the information fiom spectral profile charts. Broad similarities to laboratory spectra charts indicate where additional investigations can be channelled.

The use of aircraft scanner data provides a comprehensive survey method. It is exact, rapid, objective, and quantitative. It is an efficient technique that offers a much safer approach than ground surveys. Safety is an important practical consideration. Field surveys in geothermal areas are always hazardous with potential danger a constant worry. Exactness and speed of survey is provided with GEOSCAN data. Problems with conventional surveys of difficult access areas are virtually eliminated with the precision of detail provided with GEOSCAN spatial and spectral profiling techniques.

6. REFERENCES

Cochrane, G.R., Mongillo, M. A., Browne, P.R.L. and Deroin, J-P (1994). Satellite studies of the Waimangu and Waiotapu geothermal areas, TVZ. *Proc. 16th New Zealand Geothermal Workshop* 1994: 181-187.

Deroin, J-P., Cochrane, G.R., Mongillo, M.A. and Browne, P.R.L. (1995). Methods of remote sensing in geothermal regions: the geodynamic setting of the Taupo Volcanic Zone (North Island, New zealand). *Int. J. Remote Sensing,* 11: 1664-1678.

Hedenquist, J.W. (1986). Waiotapu geothermal field. In: Henley, R.W., Hedenquist, J.W. and Roberts , P.J. (Eds.) *Guide to the Active Epithermal (Geothermal) Systems and Precious Metal Deposits of New Zealand.* Gebruder Bomtraeger, Berlin, 65-80.

Mongillo, M.A. (1994). Aerial thermal infrared mapping of the Waimangu-Waiotapu geothermal region, New Zealand. *Geothermics,* 23: 511-526.

Mongillo, M .A., Browne, P.R.L., Cochrane, G.R. and Deroin, J-P, (1993). Satellite studies of Craters of the Moon geothermal area. *Proc. 15th N Z Geothermal Workshop:* 87-92.

Mongillo, M.A., Cochrane, G.R., Browne, P.R.L. and Deroin, J-P, (1995). Application of satellite imagery to explore and monitor geothermal systems. *Proc. of the World Geothermal Congress 1995, Florence,* Italy.

Simmons, S.F., Browne, P.R.L. and Brathwaite, R.L. (1992). Active and extinct hydrothermal systems of the North Island, New Zealand. *Guidebook Series, 15,* Society of Economic Geologists.