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Preliminary Results of SPOT Satellite Multispectral Observations of the Waiotapu Geothermal Field, New Zealand

M.A. Mongillo* and S.E. Belliss**

*Geothermal Coordination Group, Head Office, D.S.I.R., Wairakei
**Remote Sensing Consultancy Group, D.I.T., D.S.I.R., Gracefield

ABSTRACT

Preliminary analysis of SPOT-1 HRV multispectral imagery of the Waiotapu geothermal field illustrates the usefulness of high resolution (20 m) satellite remote sensing techniques to geothermal investigations. Differences in vegetation type, vegetation at various stages of maturity, acid altered ground, sinter terraces, thermal pools and lakes and unpaved forestry roads are clearly distinguished. For the ~1.7 km x 1.3 km region of study, two of the three HRV bands are strongly correlated, making the imagery statistically two-dimensional in nature.

INTRODUCTION

The SPOT-1 satellite was launched on 22 February 1986 as the first in a series of four instruments planned to provide a continous source of relatively high resolution (20 m) imagery during the next 10 years.

The SPOT satellite programme was initiated by the French Government in 1978, with Sweden and Belgium joining in 1978 and 1979 respectively. SPOT system development and operation is managed by the French space agency, CNES, at Toulouse space centre in southwest France. SPOT imagery information is marketed on a commerical non-discriminatory worldwide basis by the SPOT IMAGE Corporation (Bracket, 1984). By agreement with SPOT IMAGE, the Division of Information Technology (DIT), Department of Scientific and Industrial Research (DSIR), is the New Zealand and Pacific Islands distributor for SPOT satellite data.

The SPOT satellite is in an approximately circular polar orbit (see Table 1 for details). Its equipment package consists of two identical High Resolution Visible (HRV) instruments, each capable of operating in a panchromatic (i.e. a single broad spectral band) or multispectral (i.e. three spectral bands) mode. The principal characteristics of the HRV instrumentation (and that of LANDSAT's -1, -2, -3, for comparison) are provided in Table 1. The HRV is the first satellite instrument to obtain data via a "push-broom" technique, which allows collection of a complete line of data (60 km wide on the ground) utilizing a wide-angle optical system for imaging onto a linear array of 6000 charged-coupled devices (CCD's). This technique eliminates the necessity of mechanical scanning, providing a much more reliable system. These instruments are also pointable in the cross-track direction, allowing acquisition of stereoscopic image pairs and rapid access to any point on earth. Data can either be stored by two on board recorders (each able to hold up to 22 minutes worth of data) for later transmission to receiving stations at either Toulouse or Kiruna (Sweden) or directly telemetered to ground (Courtois, 1984).

Numerical data for each scene (60 km x 60 km) can be supplied on computer compatible tapes (CCT's). This allows "local" image processing to be performed. Images can also be obtained as film products.

DIT has obtained CCT's of two complete (60 km x 60 km) multispectral scenes centred at approximately Tokoroa and Rerewhakaaitu. As illustrated in Figure 1, the scenes together cover a major portion of the Taupo Volcanic Zone (TVZ), hence include most of the known major geothermal areas.

Because it is a relatively new instrument, very few studies utilising SPOT-1 have been published, none dealing with geothermal investigations that I am aware of. This preliminary report is the first description of SPOT satellite investigations of a geothermal area in New Zealand. The criteria and techniques developed in the Waiotapu study are to be applied to other SPOT imagery in an attempt to derive generalised methods for geothermal exploration and reconnaissance.

The SPOT HRV multispectral data discussed here cover that portion of the Waiotapu geothermal field which exhibits the major surface thermal manifestations. The data consists of an 85 x 65 pixel subscene (~1.7 km x 1.3 km), extracted from the complete Lake Tarawera scene which is approximately centred on Rerewhakaaitu (see Table 2).

DESCRIPTION OF WAIOTAPU AREA

The Waiotapu geothermal area has been described in detail recently (Hedenquist, 1983a; 1983b; 1986). It is located approximately 40 km northeast of Wairakei (Figure 1), is the largest known geothermal field in the TVZ (18 km^2), and has the greatest measured surface heat flow, ~540 MW (Benseman, et al., 1963). From 1956 to 1958, seven exploration wells were drilled to depths ranging from 450 m to 900 m. The maximum deep temperature measured was 295°C (Dench, 1963). The extensive and varied surface thermal activity, consisting of mud pools, large steaming hydrothermal eruption craters, sinter terraces, hot pools and colourful hydrothermally altered ground make Waiotapu a very popular tourist area.

The Waiotapu geothermal field (Figure 2) extends southward from two dacite domes, Mt Maungaongaonga (~825 m) and Mt Maungakakaramea or Rainbow Mountain (~743 m), which last erupted ~160,000 years ago (Nairn, 1973). A rhyolite dome (Trig. 8566, ~590 m), >200,000 years old is located at the western margin of the field (Healy, 1974). The surface material in the northern part of the field consists of predominantly dacite domes and flows and moderately welded, quartzose ignimbrite; while the western margin has a rhyolite dome and flows (Nairn, 1973). Surficial material in the central and southern extent of the field mainly consists of pumiceous pyroclastics that have been reworked to silts and sandstones (Hedenquist, 1986) and rhyolitic pyroclastic flows and airfall ash and pumice that have been redeposited as alluvium. Two small areas of pisolitic grey ash and redeposited aeolian material occur near the southwestern and southern boundaries (Nairn, 1973).

The northeast trending Ngapouri Fault extends across the northwest corner of the Waiotapu field (Figure 2). North northeast trends in the occurrence of thermal activity in central Waiotapu suggest the presence of several minor faults there. Further south, Champagne Pool, Alum Cliffs and Lakes Ngakoro and Whangioterangi, occupy hydrothermal eruption craters that were formed within the past 900 years (Lloyd, 1959). These sites also appear to occur at

TABLE 1: Characteristics of SPOT HRV instrument and Landsats -1, -2, -3 for comparison.

	INSTRUMENT	
	SPOT' BRV	LANDSATS[2,3] -1, -2, -3
Spectral Bands (μm)	B1 (green) 0.50-0.59 B2 (red) 0.61-0.68 B3 (near IR) 0.79-0.89 PA 0.51-0.73	B4 0.5-0.6 B5 0.6-0.7 B6 0.7-0.8 B7 0.8-1.1 B8[4] 10.4-12.
Spatial Resolution (m)	~20[5]	-79
Ground Swath Width (km)	60	185
Satellite Altitude (km)	-832	~917
Orbital Period (min)	~102	-103
Period of Nadir Area Revisit (days)	26[6,7]	18
Orbital Inclination (degrees)	98.7[7]	~99

1 SPOT data from Courtois (1984).
2 These Landsats chosen because they are the only ones from which N.Z. obtained data.
3 Landsat data from Freden and Gordon, 1983.
4 Never operational.
5 10 m in PA mode.
6 The of€-nadir viewing allows an area at N.Z. latitude to be observed every 1-4 days, w/average of 2.4 days.
7 Data from Brachet (1984) and S. McNiel (1987, pers. comm.).

TABLE 2: Details of the Lake Tarawera SPOT scenes.

Scene Centre:	-38°19'39" 176°31'57"
Scene Size:	-60 km x 60 km
Cloud Cover:	0%
Instrument Height:	839.61 km
Acquisition Date/Time:	5 August 1986/10:17 am (local)
World Reference Path/Row:	444 /427
Look Angle from Vertical:	2.3° West

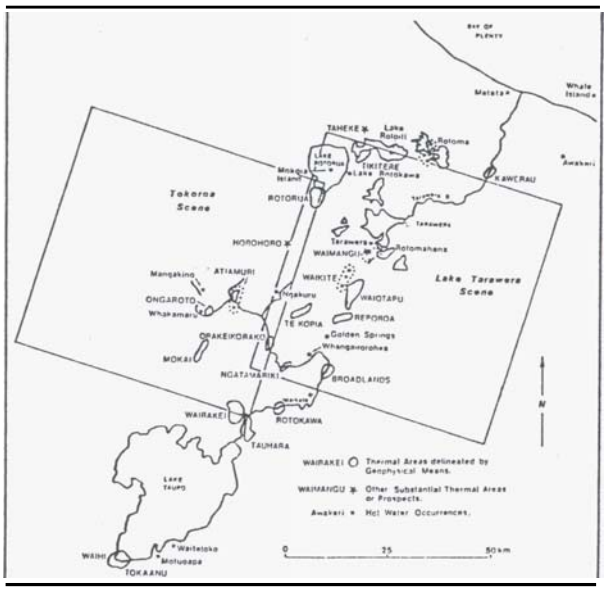
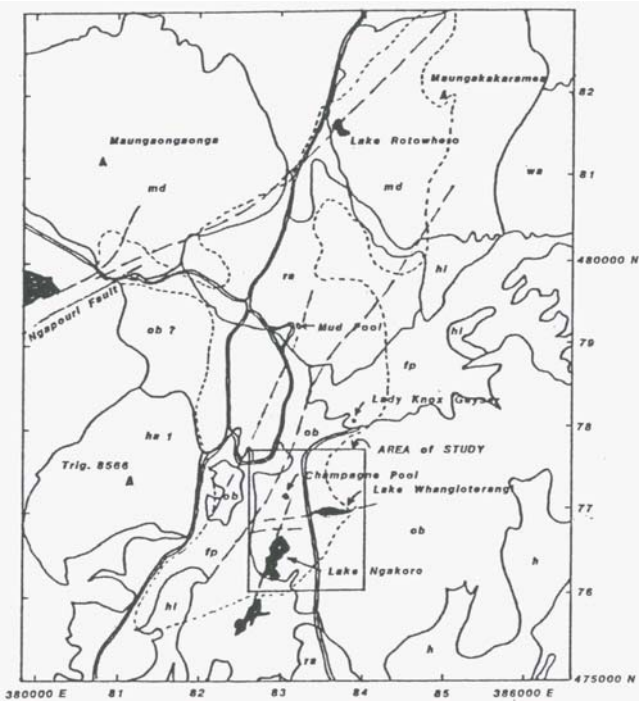


Figure 1: Approximate coverage of the Taupo Volcanic Zone by the 60 km x 60 km Tokoroa and Lake Tarawera SPOT HRV scenes (Figure modified from Mongillo and Clelland (1984), D.S.I.R. Geothermal Report No. 9).



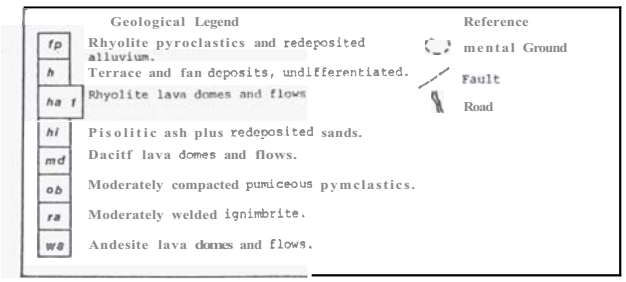


Figure 2: Geologic map of the Waiotapu area (from Nairn, 1973) illustrating the faults, approximate extent of thermal ground (from Healy, 1974) and area of this study.

the intersections of the previously mentioned north northeast trends and east-west lineations (Figure 2) (Hedenquist, 1986).

The natural surface activity of Waiotapu has been described by Lloyd (1959, 1963) and reviewed by Hedenquist (1983a, 1983b, 1986). The thermal features exhibit a progressive change in chemical nature from north to south, with acid sulphate features dominating the northern half of the field, acid sulphate-chloride features and the appearance of neutral pH chloride springs occurring south of the large mud pool area and the predominance of chloride springs south of Lady Knox Geyser.

Large expanses of exposed altered ground occur in the south central area centred on Champagne Pool (Figure 3). Extinct sinter and geyser mounds are present in the north of this area. Regions of surface alteration consisting of alunite, kaolinite and montmorillonite clays occur about 150 m north of Champagne Pool, where several collapse craters containing acid mud pools (having kaolinite and fine pyrite) and native sulphur lined walls are also found. Champagne Pool, having a temperature of ~75°C, is the largest chloride discharge feature in the field. A large sinter terrace extends east and south from it, terminating in the south by the narrow Bridal Veil Falls, which flows into an east-west orientated valley. Mounds of pisolitic sulphur occur in the eastern part of the valley, while to the west, several acid pools drain into Alum Cliffs crater. Frying Pan Flat, an area of mixed acid sulphate-chloride springs, occurs to the south and drains into Lake Ngakoro. Lake Whangioterangi, a cool acid lake, is located about 200 m east of Bridal Veil Falls.

DATA ANALYSIS

Analysis of the digital SPOT data was performed using the DIT MICORVAX2 computer system, and the EPIC image procesing software (McDonnell, 1986). Though DIT's dedicated colour monitors were used for some of the investigation, most of the analysis was performed on computer printouts obtainable at the Wairakei Geothermal Research Centre via DSIR's VAX network.

Initial. image analysis was performed using Rands 1 and 3 because of problems arising with the reading of the Band 2 CCT. Because interhand ratioing of multispectral images both removes first order brightness variations due to topographic efEects and enhances subtle spectral reflectance (colour) differences that are often difficult to detect on standard individual band images, emphasis was placed on examining the B3/B1 ratio image.

A computer printout of the Waiotapu B3/B1 ratio image is shown in Figure 4. Each number represents the relative brightness in Band 3 (an 8-bit digital number, or DN, between 0 (white) and 255 (black)) divided by that in Band 1 for the corresponding spatial location. The resulting ratios have been linearly scaled to preserve the original ratio relationships and enhance the contrast. The final redistributed DN values shown in Figure 3 range from 0 to 255.

By examining the 83/81 image for tone gradients, i.e. differences in DNs with spatial location, feature "boundaries" are determined as illustrated in Figure 3.

RESULTS

Comparison of the B3/B1 ratio image features shown in Figure 4 with Figure 3, aerial photographs (SN5945 N/36 and SN5945 N/37, flown 3 March 1983) and Orthophoto plans (No. 1396/14 and 1396/17, flown 16 January 1982) shows excellent agreement. Table 3 provides a list of preliminary land cover categories identified in Figure 4 along with their associated DN values. Note the clear difference among the various categories listed. At the scale being investigated, this image includes relatively complex land cover.

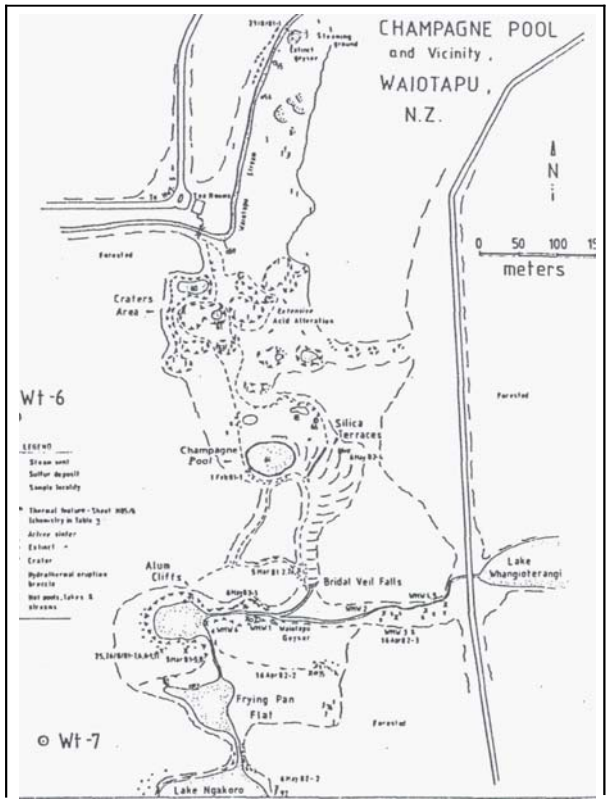


Figure 3: Sketch map of the Champagne Pool area showing the major thermal features (from Hedenquist, 1983a).

TAELE 4: Statistical details of the three HRV multispectral bands for the Wafotapu scene (5525 pixels).

BAND	DIGITAL NUMBER (DN)*				
	MINIMUM	MAXIMUM	RANGE	MEAN	σ
1	13	64	52	18.9	6.9
2	7	65	59	12.1	5.9
3	5	60	56	25.7	8.6

* DN refers to the digital number within the range 0-255, where the complete tonal range is from white (0) to black (255).

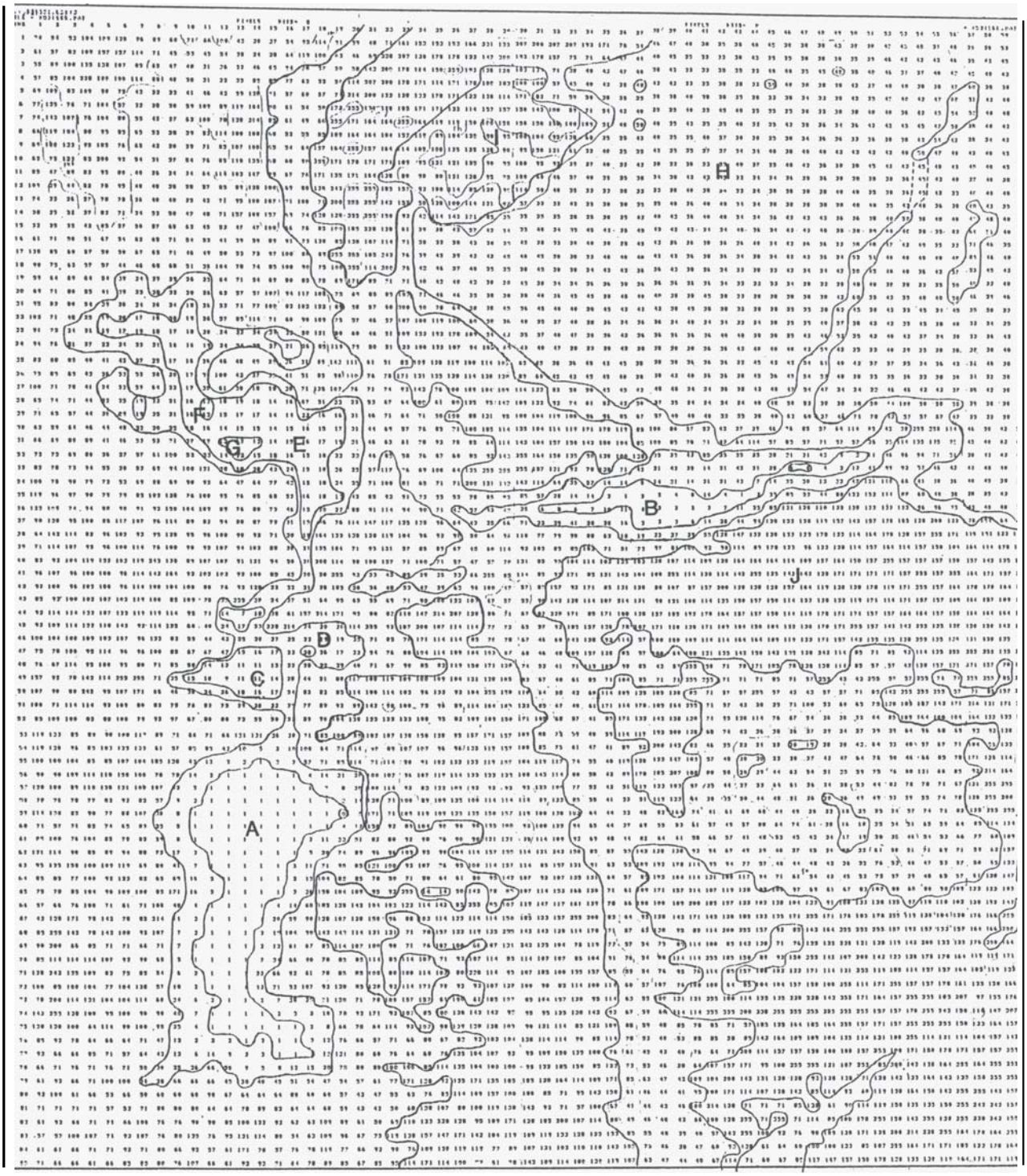


Figure 4: Computer printout of the SPOT HRV B3/B1 ratio for the area of study. Preliminary feature boundaries are illustrated. Note the vertical and horizontal scales are different: yscale/xscale ≈ 0.83 (Copyright SPOT IMAGE).

TABLE 3: Major land cover categories and their associated digital number (DN) ranges.

CATEGORY	DIGITAL NUMBERS (DN)					
	B3/B1			BAND 1	BAND 2	BAND3
	Range	Average	σ	Range[1]		
A. Lake Ngakoro	0-1	1.0	-	48-51	27-29	8-9
B. Lake Whangioterangi, Frying Pan Flat	0-10	4.1	2.8	25-31	11-15	7-10
C. Western Sector[2]	9-18	13.6	2.7	37-47	20-42	26-40
D. Eastern Sector[3]	17-34	25.2	5.2	22-39	14-33	34-40
E. Sinter Terraces[4]				44-61	28-65	31-57
Including Champagne Pool	12-19	16.1	1.8			
Excluding Champagne Pool	14-19	16.2	1.6			
F. Altered Ground						
Including Pools[5]	13-19	16.7	1.9			
Excluding Pools[6]	14-19	17.1	1.5			
G. Champagne Pool	12-13	12.8	0.5	60-64	51-64	38-50
H. Large Pine Forest in Northeast[7]	30-42	36.7	3.1	18-20	10-15	17-28
I. Rectangle of Pine West of H.	80-171	115.1	22.4	15-19	8-10	13-34
J. Pine Forest South of Lake Whangioterangi[8]	109-255	147.5	29.7	-	-	-

1 Approximate only.
2 West of pixel 16.
3 East of pixel 15.
4 East of pixel 12.
5 West of pixel 13 and including part of Champagne Pool and other NW pool.
6 West of pixel 13 and excluding part of Champagne Pool and other NW pool.
7 Values determined from within box: pixel = 36-47r line = 8-13.
8 Values determined from within box: pixel = 46-51; line = 40-44.

Examination of the three individual SPOT band images has only just begun. Statistics for the data of these bands are given in Table 4 and histograms illustrating the frequency of occurrence (as a percent of the total number of pixels in the image) of each DN in the image scene are presented in Figure 5. Note that there is a very similar range in DN values, -56, for all three bands. The larger standard deviation exhibited by the Rand 3 data reflects the less "peaked" nature in DN values, perhaps a consequence of a greater sensitivity to variations in vegetation condition or type. Results of preliminary assessment of these individual bands are provided in Table 3. The twin peaks occurring at the lower DN values in Bands 1 and 2 and the main broad peak in Band 3 occur at DN values associated with the pine forest located in the northern and eastern parts of the study area. The Lake Ngakoro DN values are located in the small peak at the high DN end of Rand 1 while those for both Lakes Ngakoro and Whangioterangi cluster in the low DN peak of Band 3.

Correlation between the three HRV bands for the Waiotapu scene was examined, and as the correlation matrix (Table 5) illustrates, there is a strong correlation between Bands 1 and 2,

TABLB 5: Correlation matrix for Waiotapu scene.

BAND	1	2	3
1	1.00	0.83	0.11
2	0.83	1.00	0.28
3	0.11	0.28	1.00

while Band 3 differs significantly from both the others. As expected, these results contrast with those obtained for the arid region of Chottel Djerid, south Tunisia (Quarmby and Townshend, 1986). The relative complexity in land cover at Waiotapu, especially the large tracts of vegetation cover, decrease the inter-band correlations (Chavez and Berlin, 1984; Price, 1984). The eigenvalues obtained for the Waiotapu scene (Table 6),

TABLE 6: Eigenvalues for the Waiotapu scene.

Eigenvalue Number	Variance	Cumulative 0
1	0.571	57.1
2	0.390	96.1
3	0.040	100.1

also indicate a two-dimensional structure, with more than 960 of the total variation in the scene accounted for by the first two eigenvalues, a result of the strong correlation between Bands 1 and 2. These results are in good agreement with those obtained for an irrigated palm oasis: E1 = 0.566; E2 = 0.422; E3 = 0.012 (ibid).

CONCLUSION

The preliminary results obtained to date indicate that SPOT HRV high resolution imagery is very useful in mapping a complex land cover area such as that of the Waiotapu geothermal field. Geothermal features as small as Champagne Pool and the Bridal Veil Falls end of the sinter terraces are easily distinguished. Thermal ground, both exposed and partially covered in Vegetation, can be discerned.

ACKNOWLEDGEMENTS

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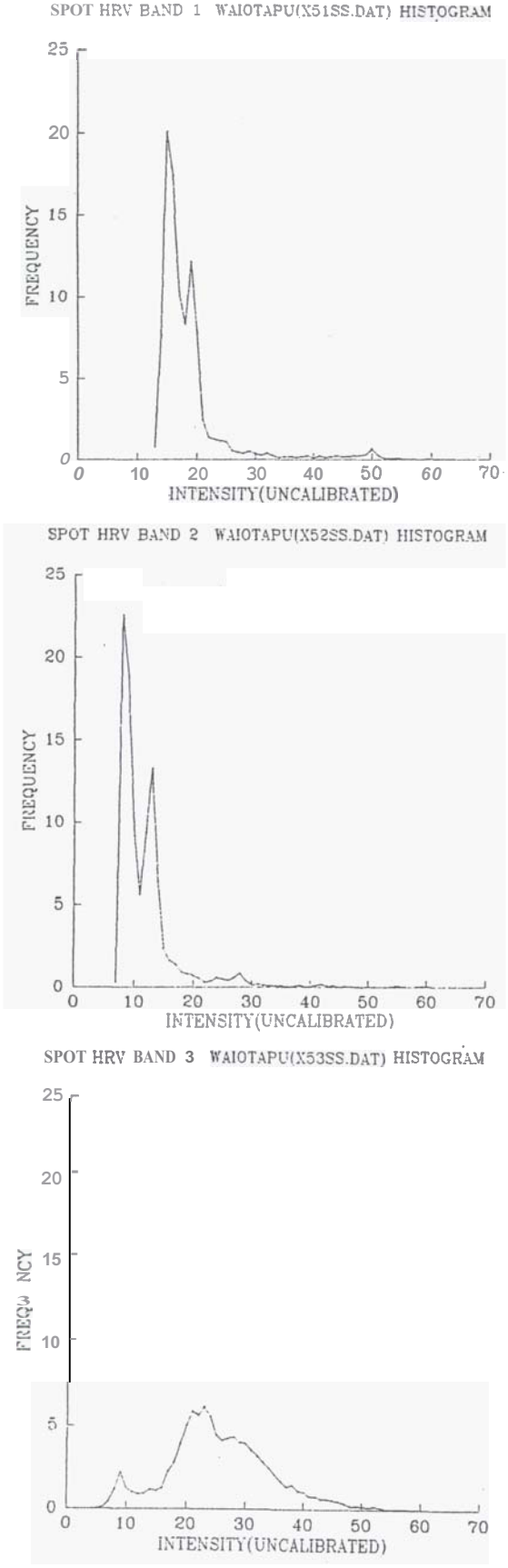

Figure 5: Histograms of the three SPOT HRV bands for the Waiotapu scene. The frequency units are given in percent of the total number of scene pixels (5525).

REFERENCES

Benseman, R.F., Fisher, R.G. and Dickinson, D.J. (1963). Survey of Surface Heat Output at Waiotapu, Chap. VI In: Waiotapu Geothermal Field, N.Z. D.S.I.R. Bull. 155, pp. 50-58

Brachet, G. (1984). The Spot program: organization and data distribution policy, In: SPOT Simulation Applications Handbook, Proc. 1984 SPOT Symp. 20-23 May 1984, Scottsdale, Arizona, pp 3-7.

Chavez, P.S. Jr, and Berlin, G.L. (1984). Digital processing of SPOT simulator and LANDSAT TM data for the SP Mountain Region, Arizona; In: SPOT IMAGE Corp. (1984), SPOT Simulation Applications Handbook, Proc. 1984 SPOT Symp., pp. 56-66.

Courtois, M. (1984). SPOT system conception and project status, In: SPOT Simulation Application Handbook, Proc. 1984 SPOT Symp., Scottsdale, Arizona, pp 8-18.

Dench, N.D. (1963). Drilling and testing, Chapter X, In: Waiotapu Geothermal Field, N.Z. D.S.I.R. Bull. 155, pp 119-126.

Freden, S.C. and Gordon, F. Jr, (1983). Landsat 'Satellites, Chapter 12, In: Colwell, R.N. (ed. Chief), Manual of Remote Sensing (2nd ed.), vol. I, pp 517-570.

Healy, J. (1974). Waiotapu geothermal field, In: N.Z.G.S. Minerals of New Zealand, N.Z.G.S. Report No. 38D (Geothermal Resources), 8 pp.

Hedenquist, J.W. (1983a). Waiotapu, New Zealand: The Geochemical evolution and mineraliation of an active hydrothermal system. Ph.D. Dissertation, Auckland University.

Hedenquist, J.W. (1983b). An Assessment of the Waiotapu geothermal system: geology and geocheistry, Chem. Div. Tech. Note No. 83/10, D.S.I.R., August 1983, 130 pp.

Hedenquist, J.W. (1986). Waiotapu Geothermal Field, Chap. 6, In: Monograph Ser. on Mineral Deposits 26, pp 65-79.

Lloyd, E.F. (1959). The Hot springs and hydrothermal eruptions of Waiotapu, N.Z. J. Geol. and Geophys., vol. 2, pp 141-176.

Lloyd, E.F. (1963). Thermal activity at Waiotapu, Chapter V, In: Waiotapu Geothermal Field, N.Z. D.S.I.R. Bull. 155, pp 42-49.

McDonnell, M.J. (1986). The Epic image processing system, a status report, Proc. First N.Z. Image Processing Workshop, D.I.T., D.S.I.R. Report No. 30, July 1986, pp. 13-24.

Nairn, I.A. (1973). Geology of the Waimangu geothermal mapping project area, Central Volcanic Region, N.Z. Unpublished Report, N.Z.G.S. Rotorua.

Price, J.C. (1984). Statistical analysis of SPOT simulation data and comparison with LANDSAT 4 Thermatic Mapper data, In: SPOT IMAGE Corp. (1984), SPOT Simulation Applications Handbook, Proc. 1984 SPOT Symp., pp 157-164.

Quarmby, NA and Townshend, J.R.G. (1986). Preliminary analysis of SPOT HRV multispectral products of an arid environment, Int. J. Remote Sensing, vol. 7, No. 12, pp 1869-1877.