Discrimination of surface alteration based on digital processing of airborne multispectral data

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ABSTRACT

This study concerns the analysis of spectra from a high-spectral resolution airborne spectroradiometer. Airborne data are severely affected by two factors, topographic effects and atmospheric effects. These effects must be removed to compare airborne data with laboratory measurements of reflectance spectra. Three techniques were applied in analyzing the Yerington and Virginia City (Nevada, U.S.A.) data; Logarithmic Residual, Flat Field Correction and Band Ratio. Interpretation based upon a combination of the Logarithmic Residual analysis and field measurements provided successful delineation of the alteration mineralogy.

1. INTRODUCTION

High spectral resolution airborne and field surveys were carried out over the Yerington and Virginia City mining areas in Nevada. The Yerington district was picked for research because it is a major, well-exposed porphyry copper deposit, that is geologically (Dilles, 1984, Carten, 1986) and spectrally (Green and Lyon, 1984) well-studied. On the other hand, the Virginia City district is a typical example of vein-type silver and gold deposits, that is also geologically (Thompson, 1956) and spectrally (Elvidge and Lyon, 1984) well-studied.

Recent studies with high spectral resolution remote sensing data have shown that the identification of individual alteration minerals is possible (Marsh and McKeon, 1983). However, researchers have been beset with many perplexing difficulties during the analysis of spectral curve-shape. Radiance spectra acquired in aircraft based spectrometers bear little resemblance to laboratory measurements of reflectance spectra. Though the cause or mechanism of these phenomena has yet to be sufficiently clarified, topographic and atmospheric effects can be considered as the main factors.

In point of mineral exploration, airborne data must be converted into a form similar to reflectance spectra. Several practical methods for extracting mineral-related features have been developed (Green and Craig, 1985). In this study the authors applied three techniques; Logarithmic Residual, Flat Field Correction and Band Ratio.

2. INSTRUMENTATION AND DATA ACQUISITION

The airborne survey was flown with the GER (Geophysical Environmental Reserch Corp.) visible and infrared spectroradiometer system. This system has 512 channels covering the visible to near-infrared (VNIR; 400nm to 1000nm) region, where the iron minerals have characteristic spectral features. The short wave infrared (SWIR; 2000nm to 2500nm) region, where the clay and other alteration minerals have distinctive absorption features, is covered with 64 channels. Each channel has an individual detector and the measurements are made simultaneously. The aircraft was flown at the barometric altitude of 8500 feet for the major part of the survey. Three traverses were flown at a higher altitude of 20000 feet in order to study the effect of the pixel-size. The flying speed was about 110 miles per hour. The 8500 feet ASL is roughly translated to 2000 feet above the average ground surface of 6500 feet elevation, so that an instantaneous field of view (IFOV) was 60 feet square. At a higher altitude, the IFOV was 60 feet along the flight path and 400 feet perpendicular to it.

The airborne survey was made between 9:00 AM and 2:00 PM fixing upon clear days; May 29 and 30, 1986.

The field survey was carried out with the GER IRIS Mk-II and Mk-III system, which cover the 350nm to 3000nm region with the spectral bandwidth of 2nm (350nm to 1000nm) to 4nm (1000nm to 3000nm). IRIS is a dual beam system that looks at a target and a reference material (barium sulfate plate) simultaneously so that reflectance spectra can be measured with immunity to variations in the source illumination. This immunity has merits in the fields because a measurement takes not less than 10 minutes, which depends on the illumination level, and variations in this period in the solar illumination cannot be disregarded.

Field spectra were converted to percent reflectance by dividing the target radiance by the reference spectra.

3. GEOLOGY

The Yerington district is composed of Cretaceous metamorphosed volcanics and marine sediments which were intruded during the Jurassic by Yerington batholith and Shamrock batholith, and of early Mesozoic pluton. Regional metamorphism converted these Mesozoic rocks into greenschist facies; chlorite, epidote, zoisite, albite, quartz and clay minerals. The Mesozoic system is unconformably overlain by Oligocene ignimbrite and Miocene andesite, basalt and sedimentary rocks. Figure 1 shows a geologic map of the Yerington disrict (Dilles, 1984).

The Virginia City district is composed mainly of post-Cretaceous volcanics. The most extensively exposed formations are the Miocene Kate Peak formation and the Miocene Alta formation composed of andesitic lava and pyroclastic rocks. The Alta formation and the lower Kate Peak formation were subjected to hydrothermal alteration; propylitization, argillization and alunitization. Major silver and gold deposits were mined from the Comstock Lode district. Figure 2 shows a geologic map of the Virginia City district (Thompson, 1956).

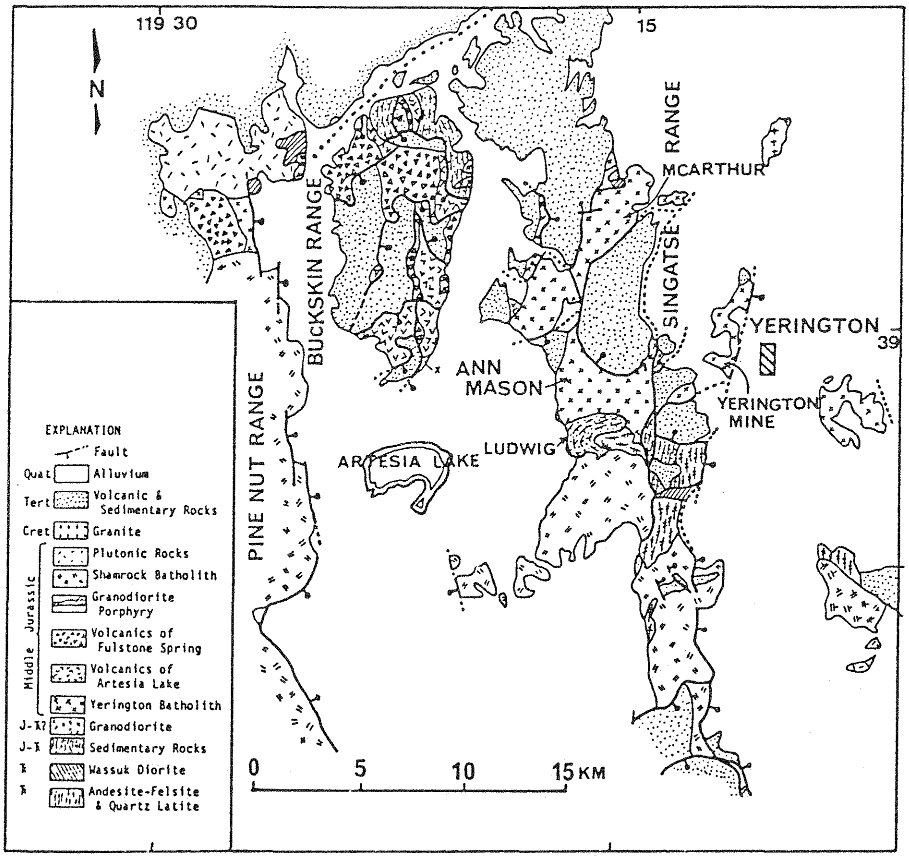


Figure 1 Geologic map of the Yerington district (after Dilles)

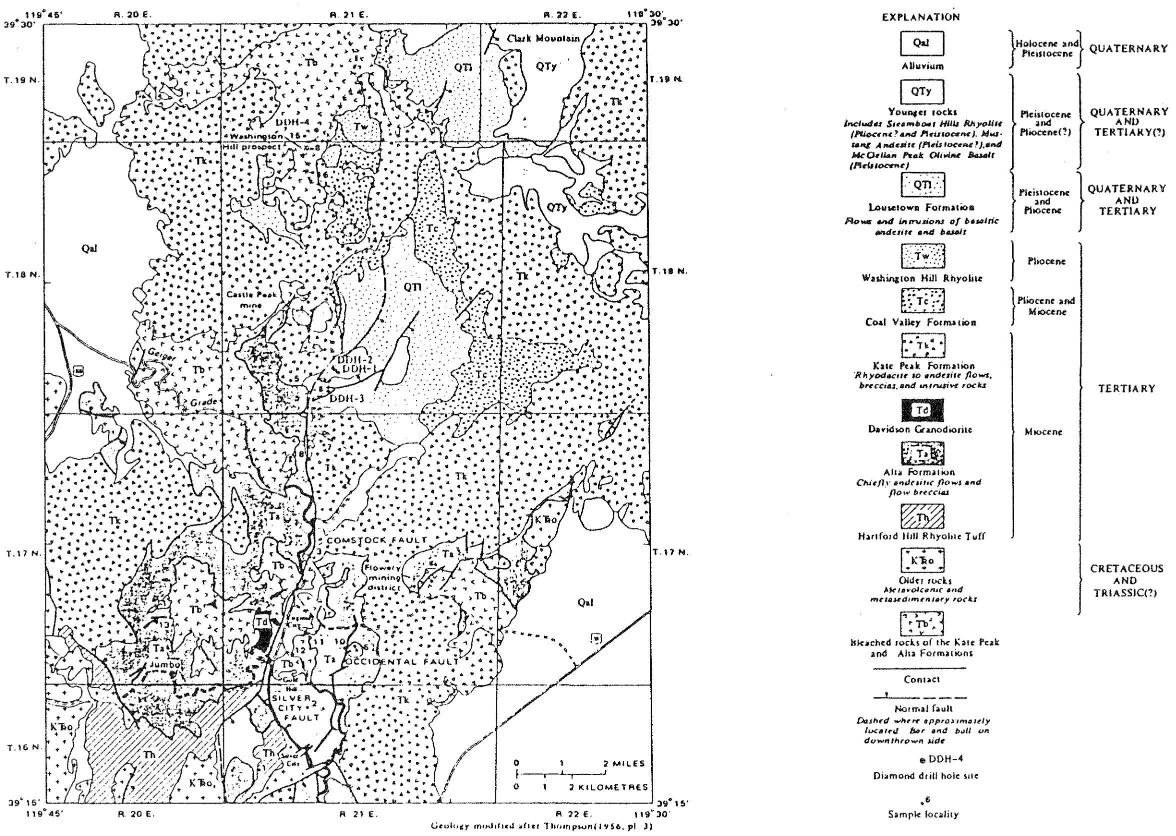


Figure 2 Geologic map of the Virginia City district (after Thompson)

4.FLAT FIELD CORRECTION

Flat field correction is a method that uses a pixel or a number of pixels which are spectrally flat as references. Every pixel is devided by the reference spectra. Basalt Hill located in the southwestern part of the Virginia City area is underlain literally by basaltic rocks. Figure 3 shows a reflectance spectrum of a basalt sample which was collected at Basalt Hill. The reflectance curve is flat in the interesting region (500 to 2500nm). Radiance spectra acquired over Basalt Hill were employed as references. Figure 4 and 5 show an unprocessed radiance spectrum (SWIR) over an altered area and the result of Flat Field Correction. The resulting spectrum has a distinctive absorption feature of 2210nm clay mineral.

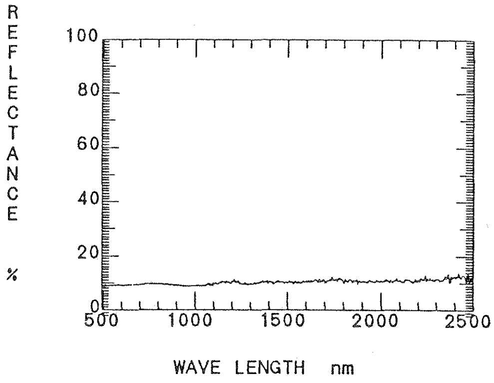


Figure 3 Reflectance spectrum
Basalt

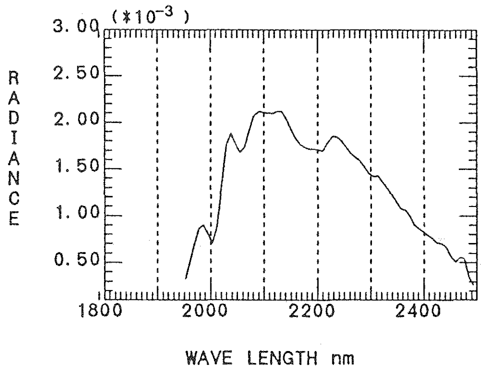


Figure 4 Unprocessed radiance spectrum

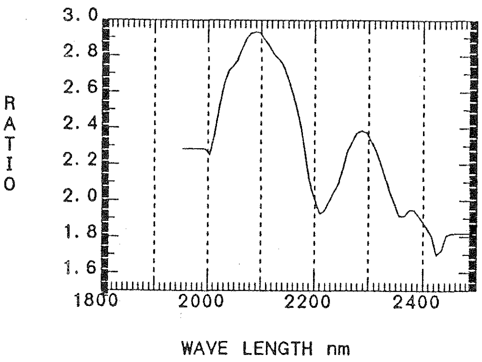


Figure 5 Flat field corrected spectrum

5.LOGARITHMIC RESIDUAL

Logarithmic Residual (Log Residual) is based upon the following relationship.

$$X_{i\lambda} = T_i \quad \rho_{i\lambda} \quad I_\lambda \qquad (1)$$

where

$X_{i\lambda}$: Radiance in channel λ at point i
T_i : Topographic factor at point i
$\rho_{i\lambda}$: Reflectance of the terain in channel λ at point i
I_λ : Solar illumination in channel λ

The Log Residual is defined by the following formula.

$$Y_{i\lambda} = \log X_{i\lambda} - X_{i\cdot} - X_{\cdot\lambda} + X_{\cdot\cdot} \qquad (2)$$

where

$$X_{\cdot\lambda} = M^{-1} \Sigma_i \log X_{i\lambda}$$

$$X_{i\cdot} = N^{-1} \Sigma_\lambda \log X_{i\lambda}$$

$$X_{\cdot\cdot} = (MN)^{-1} \Sigma_i \Sigma_\lambda \log X_{i\lambda}$$

Figure 6 shows the result of Log Residual for the same location as Figure 4 and 5. The Log Residual spectrum shows a distinctive feature of 2210nm clay. The weak absorption centered near 2350nm is characteristic of sericite.

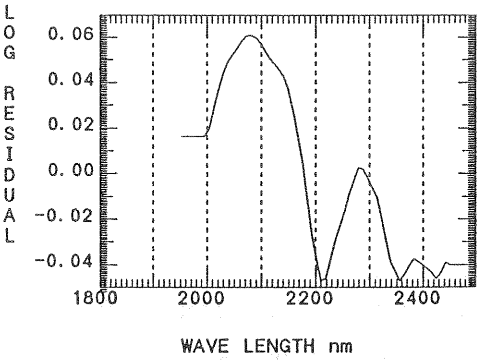


Figure 6 Log Residual spectrum

Figure 7 and 8 show another comparison of Flat Field Correction and Log Residual. Log Residual spectrum has a doublet near 2200nm which indicates the characteristic of kaolinite. This doublet can be hardly detected even in the labolatry measurement of rock samples. The Flat Field Correction could not extract the doublet.

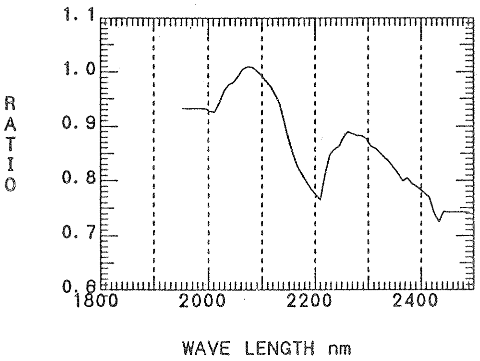


Figure 7 Flat field corrected spectrum

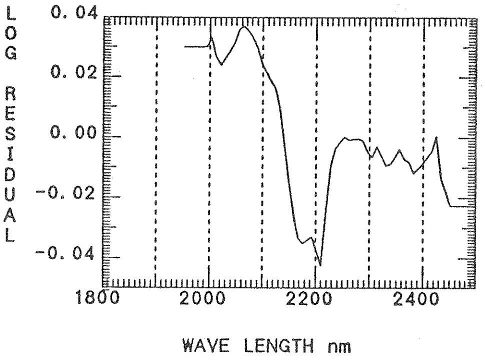


Figure 8 Log Residual spectrum

Comparing figure 7 to figure 8, so far as extracting the mineral-related feature, it is evident that Log Residual is superior to Flat Field Correction.

Flat Field Corrected spectrum is formularized as follows on referring to equation (1).

$$Z_{i\lambda} = T_i \rho_{i\lambda} / T_{ref} \rho_{ref} \qquad (3)$$

The topographic effect can be considered as a constant with the wavelength, so that the ratio of topographic factors could not have influence on the curve-shape but shifts the average level. The assumption used in equation (1) holds valid when the solar illumination can be regarded as a function of wavelength.

The fluctuations with time in the solar illumination would reduce the efficiency of Flat Field Correction. The difference of the data acquisition time between the target point and the reference is about 30 minutes. The fluctuations in this period had a fatal effect on the Flat Field Correction.

6. BAND RATIO

Band Ratio is used widely because it is very convenient to extract spectral features from a large quantity of data such as satellite data. Figure 9 shows a ratio profile of channel 365 (800nm) over channel 220 (600nm). Chlorophyll pigments cause strong absorption in the visible region so that the vegetation has a reflectance plateau in the near infrared region. The high values shown in Figure 9 represent vegetated area.

In order to identify the minerals, all the channels must be taken into consideration. However, Band Ratio is very useful as an expedient method to throw light on the remote sensing data at the first stage.

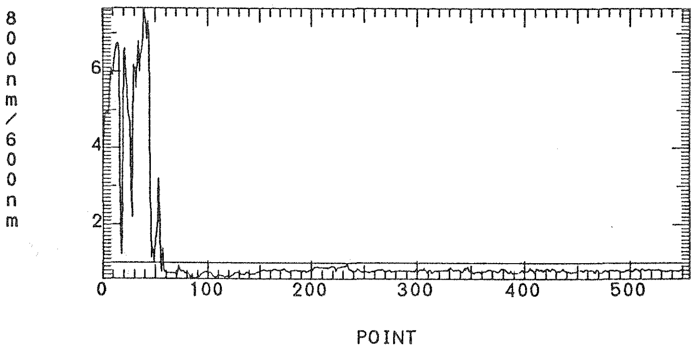


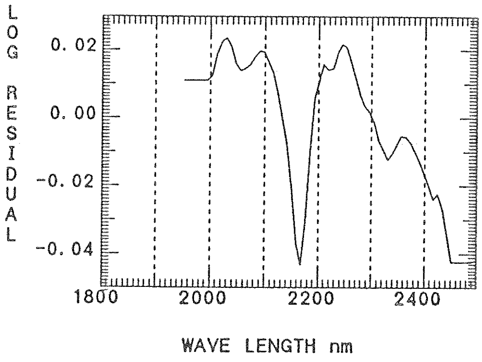
Figure 9 Ratio profile
channel 365 / channel 220

7. IDENTIFICATION OF ALTERATION MINERALS

Of the three techniques investigated, the Log Residual was the best. The resulting spectra could be directly compared with the reflectance spectra. However, visual examination of the spectral curve-shape takes much time. There were 94,928 spectra to investigate, so that the identification of individual minerals was done automatically by a computer to some degree. The algorithm was based upon the combination of the absorption detection by averaging differentiation and the correlation with the simulated standard reflectance spectra. The following are the selected typical samples of Log Residual spectra and the standard reflectance simulated from the field measurements by resampling the digital readings into the same wavelength centers as the airborne spectroradiometer in order to calculate correlation coefficients.

(a) Alunite

Alunite has absorption bands centered near 2165nm, 2210nm and 2335nm.



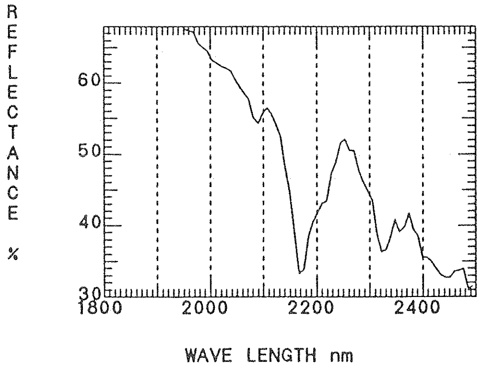
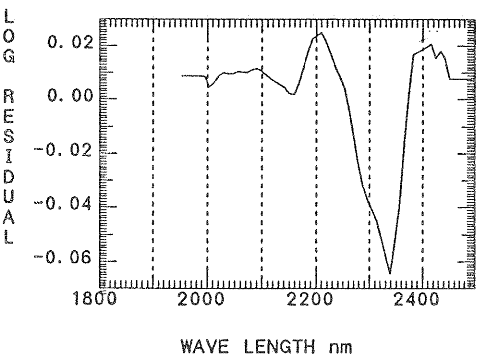


Figure 10 Log Residual spectrum, Alunite

Figure 11 Simulated standard reflectance, Alunite

(b) Calcite

Calcite has an absorption band centered near 2340nm.



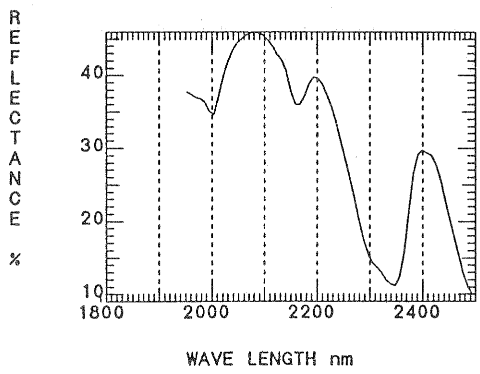
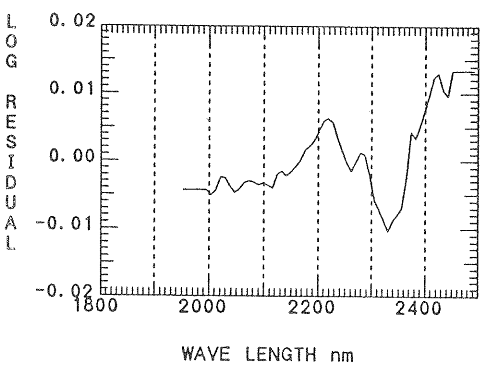


Figure 12 Log Residual spectrum, Calcite

Figure 13 Simulated standard reflectance, Calcite

(c) Chlorite

Chlorite has an absorption band centered near 2340nm.



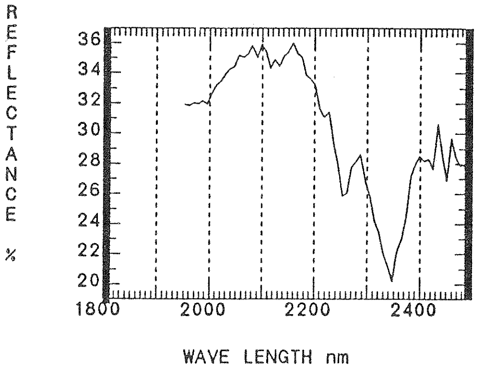


Figure 14 Log Residual spectrum, Chlorite

Figure 15 Simulated standard reflectance, Chlorite

(d) Epidote

Epidote has absorption bands centered near 2340nm. The curve-shape bears resemblance to chlorite as shown in Figure 16 and 17.

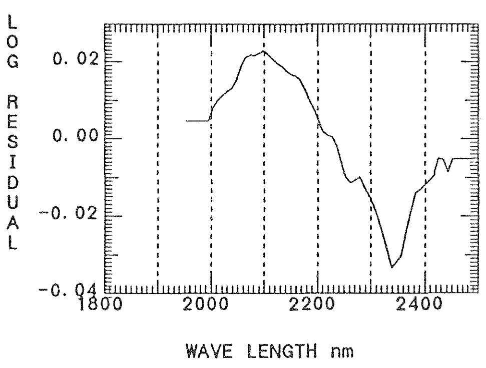


Figure 16 Log Residual spectrum, Epidote

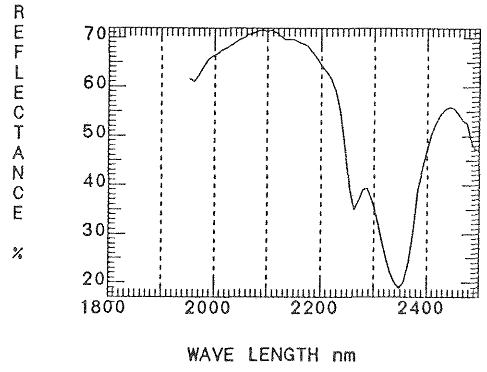


Figure 17 Simulated standard reflectance, Epidote

(e) Gypsum

Gypsum has a wide and shallow absorption band from near 2140nm to 2310nm which is formed by several absorption bands.

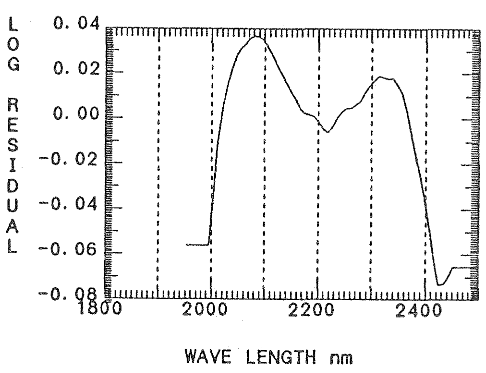


Figure 18 Log Residual spectrum, Gypsum

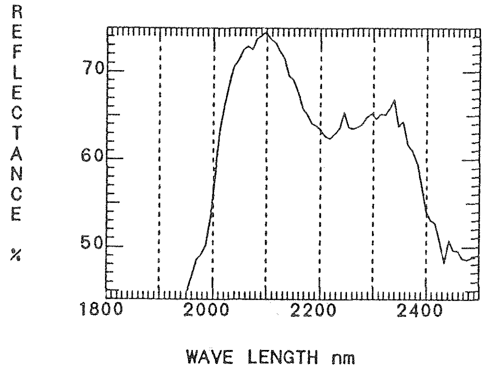


Figure 19 Simulated standard reflectance, Gypsum

(f) Montmorillonite

Montmorillonite has an absorption band centered near 2200nm. Montmorillonite can be distinguished from sericite by lack of 2350nm absorption.

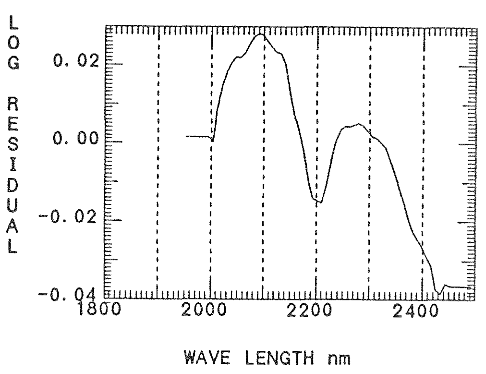


Figure 20 Log Residual spectrum Montmorillonite

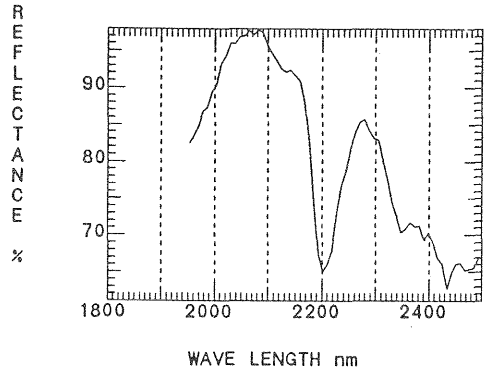


Figure 21 Simulated standard reflectance Montmorillonite

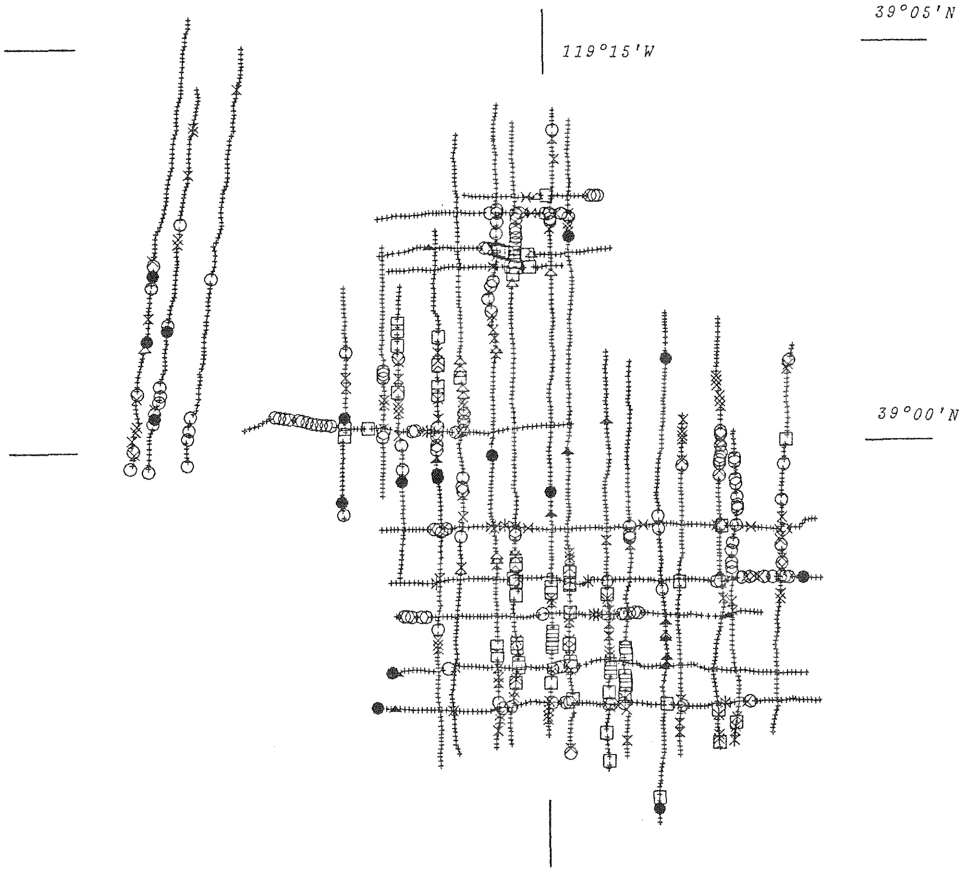


Figure 22 Alteration map of the Yerington district

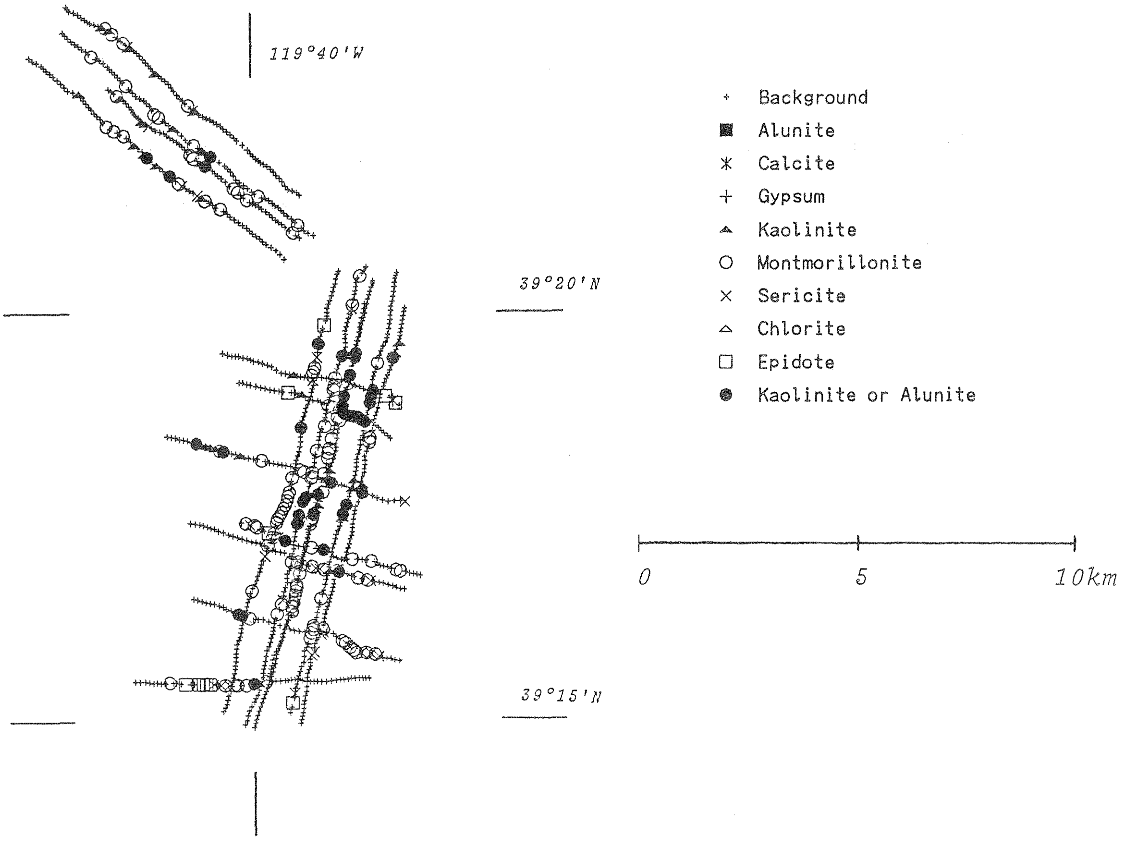


Figure 23 Alteration map of the Virginia City district

(g) Sericite and Kaolinite
The typical Log Residual spectra of sericite and kaolinite are shown in Figure 6 and 8.

Figure 22 shows the result of the automatic identification of alteration minerals in the Yerington district. The notable alteration pattern composed mainly of epidote and chlorite was detected in the Yerington batholith that has undergone intrusion and mineralization several times. In the Tertiary facies, montmorillonite is common in Mickey Pass tuff and Singatse tuff. Typical gypsum spectra were detected in the southwestern part of Singatse Range where a sedimentary gypsum deposit was once mined.

Figure 23 shows the spectral-alteration map of Virginia City district. This region is characterized by kaolinite, alunite, sericite and montmorillonite. These minerals were detected in an order that reflects the alteration intensity, e.g., transitional pattern from sericite to alunite. This result has proven that the high-resolution spectral survey is an effective means for zoning of the alteration area.

Problems of mixed layer minerals and of mixed pixel, i.e., the ambiguity introduced by the heterogeneous composition of each pixel are left pending. However, the fact that the low and high altitude surveys have detected the same mineral zones leads to the conclusion that the IFOV was not critical as the spectral resolution in the investigated areas.

8. CONCLUSIONS

The airborne high-resolution spectral surveys over the Yerington and Virginia City mining areas have proven to be an effective means of identifying alteration minerals which are important for mineral exploration. The Log Residual spectra have mapped the surface mineral pattern in fine detail along the traverses. In accord with the field spectral survey, the result provided successful delineation of the alteration mineralogy. The computerized mineral identification system that has still been under development will provide useful means for future research into remote sensing data of larger area with a large number of spectral channels.

9. REFERENCES

Carten, R.B., 1986, Sodium-Calcium Metasomatism: Chemical, Temporal, and Spatial Relationships at the Yerington, Nevada, Porphyry Copper Deposit; Economic Geology, Vol.81, pp.1495-1519

Dilles, J.H., 1983, The Petrology and Geochemistry of the Yerington batholith and the Ann-Mason Porphyry Copper Deposit, Western Nevada; Stanford Ph.D. Thesis

Elvidge, C.D., Lyon, R.J.P., 1984, Mapping Clay Alteration in the Virginia Range - Comstock Lode, Nevada with Airborne Thematic Mapper Imagery; Int. Symp. on Rem. Sen. of Env., Third Thematic Conference, Rem. Sen. for Exploration Geology, p.161-170

Green, A.A., Craig, M.D., 1985, Analysis of Aircraft Spectrometer Data with Logarithmic Residuals; Proceedings of the Airborne Imaging Spectrometer Data Analysis Workshop, pp.111-119

Green, R.O., Lyon, R.J.P., 1984, Mapping Mineral Alteration with Airborne Thematic Mapper Imagery in the Ann-Mason Region, Yerington District, Nevada; Int. Symp. on Rem. Sen. of Env., Third Thematic Conference, Rem. Sen. for Exploration Geology, pp.775-784

Marsh, S.E., McKeon, J.B., 1983, Integrated Analysis of High-Resolution Field and Airborne Spectroradiometer Data for Alteration Mapping; Economic Geology, Vol.78, pp.618-632

Thompson, G.A., 1956, Geology of the Virginia City Quadrangle, Nevada; U.S.G.S. Bulletin 1042-C