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Evaluation of SPOT Simulator Data for the Detection of Alteration in Goldfield/Cuprite, Nevada*

Abstract: *The Goldfield mining district, in south central Nevada, is a classic remote sensing site. Gold and silver were mined in the earlier part of this century from epithermal deposits in Tertiary volcanic rocks. Alteration and ore deposition typically took place along fault controlled zones in andesitic and rhyolitic units. The altered zones include silicified, argillized, and propylitized rocks.*

SPOT simulator data of the Goldfield mining district and, to the south, the Cuprite mining district, were obtained on 22 June 1983. Bands 1 and 2 are positioned in the vicinity of significant iron oxide absorption features, and ratios of these bands can be used to discriminate coatings of iron oxide minerals. A false color composite of SPOT simulator data is very useful for delineation of alteration and lithologic discrimination because of the high spatial resolution (10 m or 20 m) and sensitivity to iron oxides. Enhancements such as intensity, hue, saturation transformation, and especially color ratio composites also have geologic utility.

SPOT simulator imagery, Landsat 1 MSS, Bendix 24-channel scanner, and Thematic Mapper simulator were all compared to alteration mapping and each found to have advantages and disadvantages. An effective data set for this application is SPOT simulator color ratio composite, mainly because of excellent ground resolution, and Thematic Mapper simulator, because of superior spectral range and spectral resolution.

Introduction

The SPOT simulator test site is located in southern Nevada, about 30 km south of Tonopah (Figure 1), and includes the Goldfield and Cuprite mining districts. The test site was designated as an "S" site, i.e., it is 10 km by 30 km with 20 m ground resolution. The Goldfield mining district is a classic remote sensing area; the vegetation consists mostly of grasses and sage with usually less than 20 to 30 percent cover and there is abundant hydrothermal alteration. The Goldfield mining district produced more than 4 million ounces of gold and is in the northern part of the test site while the Cuprite mining district is in the southern part.

Geology of the Goldfield Mining District

Volcanic rocks of Oligocene age, including rhyolite flows and ash-flow tuffs, are overlain by quartz-latite flows and then by rhyolite air-fall tuffs and flows (Ashley, 1975). The quartz-latitic flows and tuffs and rhyolitic rocks appear to be from vents within the Goldfield district (Ashley, 1979). The locations of inferred vents for these volcanic units suggest that a ring structure existed prior to arrival of the magmas that formed these units (Ashley, 1976). Ashley (1979) suggests that extrusion of ash flows emptied a local magma chamber, and the resulting collapse formed a small caldera with an associated ring fracture system. The ring fracture system provided important structural control for subsequent mineralization (Figure 2). Geologic and geophysical data suggest a shallow pluton is responsible for driving the hydrothermal system.

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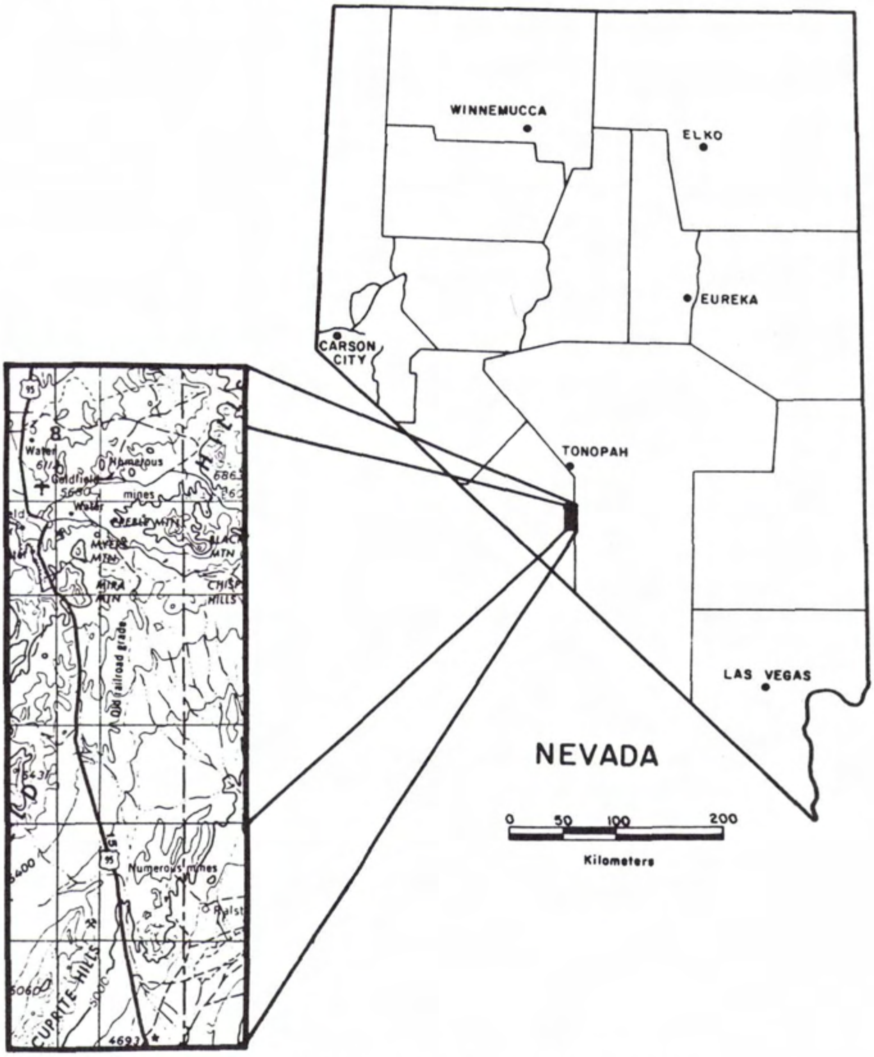

Fig. 1. Location map for SPOT simulator test site.

Ashley (1976) has described two types of mineralization in the Goldfield mining district. There is an older, variable, propylitic alteration where each variation characterizes a volcanic unit, and a younger, intense hydrothermal alteration which has a similar character in all rock units. Typically, there is a silicic zone, the ore zone, which is very resistant to erosion and weathers to form a prominent ridge. In a direction of decreasing alteration, there is an argillic zone, a propylitic zone, and unaltered dacite. The argillic zone has subzones which are characterized by different clays, including alunite, kaolinite, illite, and montmorillonite, and various iron oxides.

The altered areas, when observed in the field, are of pastel hues owing to the iron oxide staining. The iron oxide is generally a result of the oxidation of iron sulfides which gives the soil a low pH. Because of this low pH, the vegetation can be particularly sparse. Close examination of north-facing slopes of unaltered dacite shows considerable development of lichens, which can contribute to the spectral response of the dacite.

Description of Spot Data

The SPOT simulator data were collected by a Daedalus 9 channel scanner in a Learjet 25-c flying at approximately 12,700 m (41,700 ft) AGL. A pixel at nadir had a dimension of 15.9 m (52 ft) on the ground and a pixel at ±21.5 deg from nadir had a dimension of 18.4 m (60 ft) on the ground. This provided a data set suitable for resampling to 20 m IFOV. Simultaneous color infrared (CIR) photographic coverage was obtained with a 6-inch focal length camera and approximately 60 percent for-

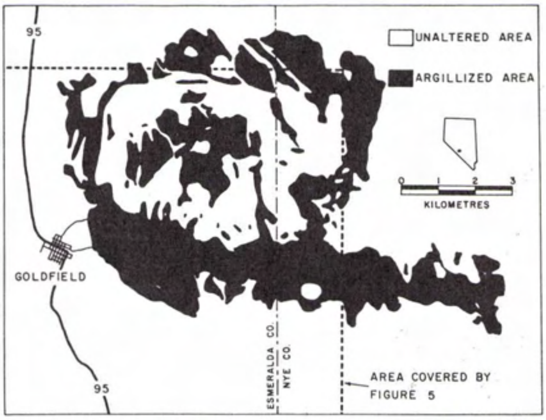

FIG. 2. Alteration map of the Goldfield mining district with the area covered by Plate 1 outlined (modified from Ashley (1976)).

ward overlap. The test site was imaged on 22 June 1983 at 12:00 PM local time.

The SPOT simulator data were processed to simulate the following SPOT-1 bands (Figure 3):

(1) A green band (500 to 590 nm) centered around the 550 nm maximum in the chlorophyll reflectance curve.
(2) A red band (610 to 680 nm) which is similar to band 5 on the Landsat MSS. This SPOT band corresponds to a high chlorophyll absorption.
(3) A near infrared band (790 to 890 nm) which is best for penetrating the atmosphere and light haze.

Figure 4 shows spectral reflectance curves for five iron oxides, with the SPOT bands superimposed. In general, the reflectance values increase rapidly across the interval included by SPOT band 1 and band 2. By ratioing band 1 and band 2, the signature of iron oxide will be enhanced on SPOT simulator imagery. Spectral reflectance curves for clays and silica are generally featureless in the portion of the visible and near infrared that is detected by SPOT.

GEOLOGY OF THE CUPRITE MINING DISTRICT

Plate 1 is a false color composite (FCC) of the SPOT simulator data; bands 1, 2, and 3 are blue, green, and red, respectively. In the southern part of the image is the Cuprite mining district which includes exposures of hydrothermally altered rocks totaling about 12 km^2. The altered rocks occur in two areas of approximately equal size and separated by U.S. Highway 95. In the eastern part of the Cuprite mining district, with which our analysis is concerned, the alteration affects volcanic and sedimentary rocks of Tertiary age. The altered rocks are divided into three groups that form mappable zones (Abrams *et al.*, 1977): silicified rocks, opalized rocks, and argillized rocks. Silicified rocks are the most intensely altered rocks and argillized rocks are the least intensely altered.

Silicified rocks occur as scattered patches in the opalite. Of five samples examined petrographically by Abrams *et al.* (1977), all contain abundant hydrothermal quartz and some calcite. In the field, they report, contacts between silicified and surrounding opalized rocks appear to be gradational. The gradation may result from a decrease in quartz accompanied by the appearance of opal, alunite, and kaolinite.

Opalized rocks form the most widespread alteration zone. All samples examined petrographically by Abrams *et al.* (1977) contain abundant opal. They also found variable amounts of alunite and kaolinite, as much as 30 to 40 percent total, in this alteration zone.

At many localities on the edge of the altered area,

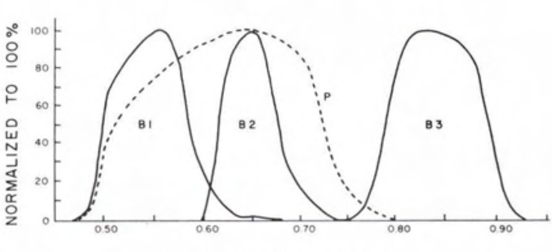

FIG. 3. Band passes for SPOT data. Dashed line indicates the panchromatic band also available.

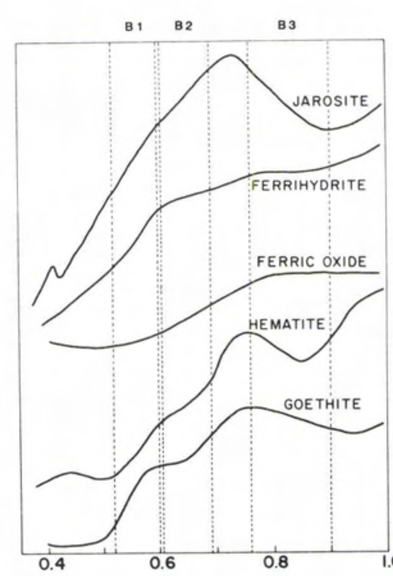

FIG. 4. Spectral reflectance curves for five iron oxides with SPOT bands superimposed (modified from Lee and Raines (1984), in publication).

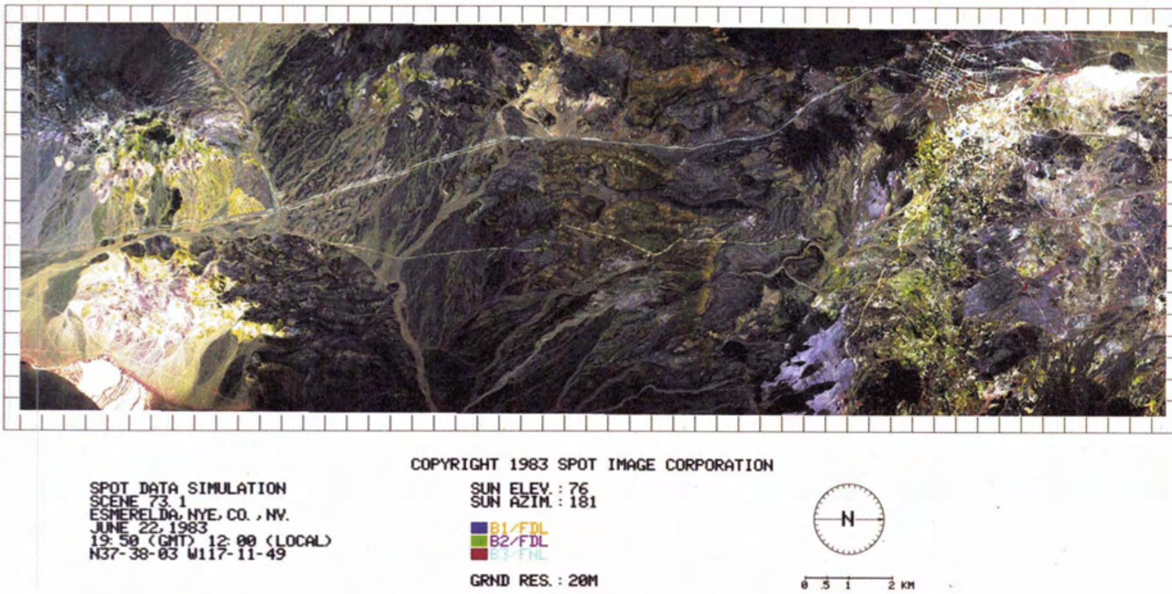

PLATE 1. SPOT simulator false color composite of Goldfield and Cuprite, Nevada.

the opalite zone grades abruptly into unaltered rock, but locally an interval of poorly exposed material mapped as argillized rock separates fresh rock from opalite (Abrams *et al.*, 1977). Abrams *et al.* (1977) report that the argillized rocks contain either kaolinite or montmorillonite or both.

Limonite content of most of the altered rocks is less than 5 percent, and large volumes of altered rock are nearly free of limonite (Abrams *et al.*, 1977). Limonite is relatively abundant in argillized rocks and some areas of opalite, while silicified rocks commonly have at most only a few percent limonite (Abrams *et al.*, 1977).

Analysis of SPOT Simulator Imagery

In Plate 1, the opalized rocks have a bright, white signature owing to the high silica content. The pink areas correspond to the volcanic rocks that have been silicified, the pink signature resulting form iron oxide staining. The argillized rocks are clearly displayed by a yellow signature, probably resulting from the presence of both iron oxide and clays.

Much of the test site, immediately north of the Cuprite mining district, is dominated by the Tertiary Thirsty Canyon Tuff and Quaternary alluvium. Examining this area on the color infrared photograph, included in the SPOT simulator data set, the intricate drainage patterns are clearly visible. The SPOT simulator FCC, in comparison, displays these drainage patterns just as clearly as the CIR photograph.

The northern part of Plate 1 includes the Goldfield mining district and the town of Goldfield. The ring-shape of alteration, east of the town of Goldfield (Figure 2), is clearly visible and is displayed as greenish-yellow. Inside the ring-shaped alteration zone is a concentric zone of unaltered volcanic rocks with a central zone of alteration (Figure 2). The SPOT simulator FCC (Plate 1) delineates the inner concentric zone of unaltered volcanic rocks although the central zone is faintly displayed.

An intensity, hue, saturation transformation (IHS), with 50 DN added to saturation, was produced in order to enhance the display of the hydrothermal alteration. The main success with the IHS image is in the area south of the Goldfield mining district. This area is dominated by outcrops of Tertiary Thirsty Canyon Tuff, a rock unit composed of several individual volcanic units. The IHS image seems to facilitate the delineation of some of these individual volcanic units, probably because of relative iron oxide content. In some areas of Nevada there are unaltered volcanic rocks with abundant iron oxide and there are some altered volcanic rocks with no iron oxide.

The SPOT simulator FCC (Plate 1) also has utility in lithologic discrimination. In comparison with Ashley's (1976) generalized geologic map, there are many volcanic units, such as the Chispa Andesite and the Chispa Hills Tuff, that can be delineated on the SPOT simulator FCC. The outcrop pattern of the Milltown Andesite, the major host rock for hydrothermal alteration, cannot be discerned for the most part, possibly because of non-selective hydrothermal alteration of the Milltown Andesite and adjacent volcanic rocks. In one area, however, the unaltered Kendall Tuff can readily be separated from the Milltown Andesite.

A ratio image of SPOT simulator band 1 divided by band 2 was produced in order to enhance the display of iron oxides. The ratio image is moderately successful for this purpose. In comparison with Ashley's (1976) alteration map (Figure 2), the ring-shaped alteration zone is clearly depicted. More importantly, the inner, concentric zone of unaltered volcanic rocks is much more apparent than on the SPOT simulator FCC. The ability to delineate the central alteration zone is unchanged.

The next enhancement product, to facilitate the detection of hydrothermal alteration, was a color ratio composite. Band 1 divided by band 2 was assigned red, band 1 divided by band 3 was assigned green, and band 2 divided by band 3 was assigned blue. This was the best enhancement product of SPOT simulation data for alteration mapping of the Goldfield mining district. The ring-shaped alteration pattern and the central alteration zone, as mapped by Ashley (1976), are easily delineated. The concentric zone of unaltered rocks separating the alteration is displayed as a contrasting deep green. The lithologic discriminating ability is not diminished with this color ratio composite. The Chispa Andesite, Chispa Hills Tuff, and many other volcanic units are displayed in mappable shades of blue and green.

Comparison with Other Imagery Types

In order to fully evaluate the usefulness of SPOT data for detection of alteration, other types of remote sensing imagery were compared to Ashley's (1976) alteration map of the Goldfield mining district (Figure 2). These other types of imagery are Landsat MSS, color ratio composite; Bendix 24-channel scanner, color ratio composite; and Thematic Mapper simulator, two false color composites.

For the Landsat MSS, color ratio composite, band 4 divided by band 5 was assigned blue, band 5 divided by band 6 was assigned green, and band 6 divided by band 7 was assigned red. With these particular ratios, iron oxides will be red and unaltered volcanic rocks will be blue.

The ring-shape of alteration is very evident and is depicted mainly as red because of the abundant iron oxide. Some areas northeast of the town of Goldfield are displayed as yellow and represent areas of mine dumps and areas of intense mining activity. Comparison with Ashley's (1976) alteration map shows that the inner, concentric zone of unaltered volcanic rocks is evident and the central zone of alteration is also perceptible. The striking disadvantage of this Landsat 1 MSS image is the 79-m ground resolution compared to the 20-m ground resolution of the SPOT simulator data.

The Bendix 24-channel data, acquired in 1974, is also a color ratio composite and has a ground resolution of 30 m. The ratio 1.6/2.2 μm was assigned green, the ratio 1.6/0.48 μm was assigned red, and the ratio of 0.6/1.0 μm was assigned blue. With these ratios, iron oxides will be red, clays will be green, areas where both iron oxides and clays are present will be yellow, and unaltered volcanic rocks will be blue.

Although the Bendix image only covers the southern part of the Goldfield mining district, when compared with Ashley's (1976) alteration map there is nearly a one-to-one correspondence in most areas. The detail of the alteration pattern is so precise that Ashley's (1976) alteration map could be reproduced from the image, or possibly improved. The Bendix 24-channel scanner has been disassembled and no longer exists.

For evaluation of equivalent types of imagery of the Goldfield mining district, a comparison was made between the SPOT simulator FCC and a Thematic Mapper simulator FCC (bands 2, 3, and 4) image.

As previously discussed, the alteration pattern on the SPOT simulator FCC is displayed in greenish-yellow hues. With the Thematic Mapper simulator FCC, the alteration pattern is equally distinquishable. One exception is that the yellowish-brown hues that depict the alteration do not contrast with the unaltered volcanic rocks to the same degree as the SPOT simulator FCC image. Also, the 20-m ground resolution is advantageous over the 30-m ground resolution of the Thematic Mapper simulator.

When the optimum spectal bands of the Thematic Mapper simulator are selected, the ability to delineate areas of hydrothermal alteration is significantly improved. A false color composite image of bands 1, 5, and 6 (0.45-0.52 μm, 1.55-1.75 μm, and 10.40-12.50 μm) was available for the Goldfield mining district. Although the ground resolution was degraded by band 6, the image provided a very accurate rendition of Ashley's (1976) alteration map. The ring-shaped alteration zone was displayed in green and yellow hues, in marked contrast to the purple hue of the unaltered volcanic rocks. The central zone of alteration was easily distinquished by the same greenish-yellow hues. A very similar version of Ashley's (1976) alteration map could be produced with this Thematic Mapper simulator image.

Conclusion

In conclusion, a very effective data set for alteration detection would be specific bands of Thematic Mapper data used in conjunction with enhanced SPOT data. Thematic Mapper data offers greater spectral range and spectral resolution and the proper selection of TM bands, such as bands 1, 5, and 7 or even bands 1, 5, and 6 will provide information on clays that could be associated with hydrothermal alteration. The superior 20-m ground resolution of SPOT, as well as the capability to also discriminate iron oxides, make it a valuable ancillary data set for delineation of hydrothermal alteration. SPOT enhancement products, such as the color ratio composite, can be especially useful for this application.

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