UNITED STATES DEPARTMENT OF THE INTERIOR

GEOLOGICAL SURVEY

ALTERATION MAPPING USING MULTISPECTRAL IMAGES - CUPRITE MINING DISTRICT, ESMERALDA COUNTY, NEVADA

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ABSTRACT

In the visible and near-visible infrared (VNIR) region (0.4-2.5 μm), limonite minerals have strong absorptions below 0.55-0.6 μm and at 0.9 μm, and clays, dioctahedral micas, pyrophyllite, and alunite have a sharp absorption band between 2.15 and 2.25 μm. In addition to these absorption features, silica-rich altered rocks generally show relatively high reflectance at 1.6-1.7 μm. Aircraft scanner images were obtained for the Cuprite mining district, 17 km south of Goldfield, Nev., using the Bendix 24-channel scanner (MSDS). The MSDS scanner has nine channels that provide almost complete coverage of the range 0.46 to 1.30 μm, plus two additional channels, each about 0.25 μm wide, centered at 1.6 and 2.2 μm. Hydrothermally altered rocks of the Cuprite district include opalite, silicified rocks, and argillized rocks containing variable amounts of limonite minerals, kaolinite, and alunite. Petrographic analysis of field samples and VNIR reflectance spectra acquired at the sample sites with a portable reflectance spectrometer allow correlation of mineral composition with characteristics of the MSDS data. The results demonstrate that the ratio 1.6 μm/2.2 μm is proportional to the total amount of clays and alunite present, and a density slice of this ratio image provides a map showing relative variations in total alunite and clay content. The ratio of the band at 1.6 μm to the band centered at 0.48 μm, or any of several ratios of bands centered between 0.66 μm and 1.0 μm can be used with varying success to map relative variations in limonite content. A density slice of the ratio 0.75/0.48 μm provides the limonite map examined here. Ratios controlled by limonite content and total clay and alunite content can be combined in many different ways in color ratio composites.

INTRODUCTION

The purpose of this report is to show that selected bands within the 0.4-2.5 μm (visible-near visible infrared) spectral region can be used to map variations in total alunite and clay content and variations in iron content of hydrothermally altered rocks. The area chosen as a test site is the Cuprite mining district in western Nevada[1]. Some of the information presented here appears also in reports by Abrams and others (1977a, b).

GEOLOGY

Host rocks for alteration in the district include Tertiary ash-flow and air-fall tuff, conglomerate, and basalt, and (west of U.S. Highway 95 only) Cambrian siltstone, quartzitic siltstone, orthoquartzite sandstone, and limestone (fig. 1). The Cambrian siltstone and sandstone (Ꞓh) belong to the upper part of the Harkless Formation. The limestone (Ꞓms) belongs to the Mule Spring Limestone. The Emigrant Formation (Ꞓe) here consists mainly of thinly interlayered beds of limestone and chert. The oldest Tertiary unit (Tw) is a crystal-rich rhyolite or quartz latite ash-flow tuff containing quartz, sanidine, plagioclase, and biotite phenocrysts. It is similar to tuffs of Lower Miocene and Oligocene age extensively exposed 20-30 km to the north and

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[1] This report was presented in a poster session at the 90th Annual Meeting of the Geological Society of America, Seattle, Washington, November 7-9, 1977. The abstract was published in Geological Society of America, Abstracts with Programs (Ashley and Abrams, 1977).

Figure 1.--Geologic map of the Cuprite mining district, Nevada.

Ashley and Abrams
Figure 1

Qal	ALLUVIUM (Quaternary)--Sand and gravel, locally bearing cobbles and boulders, of alluvial fans and stream channel deposits
Qp	ALLUVIUM (Quaternary)--Sand and gravel, locally bearing cobbles and boulders, forming older alluvial fans and covering pediment surfaces
Tf	FELSITE DIKES (Tertiary?)--Porphyritic quartz latite with alkali feldspar and scarce biotite phenocrysts
Ttt	TRAIL RIDGE MEMBER OF THIRSTY CANYON TUFF (upper Miocene)--Sodic peralkaline rhyolite ash-flow tuff containing sanidine phenocrysts
Tts	SPEARHEAD MEMBER OF THIRSTY CANYON TUFF (upper Miocene)--Sodic peralkaline rhyolite ash-flow tuff containing sanidine phenocrysts
Tb	BASALT (Miocene)--Porphyritic flow with plagioclase and olivine phenocrysts
Ts	SIEBERT TUFF (Miocene)--Volcanic conglomerate and sandstone
Tst	SIEBERT TUFF (Miocene)--Air-fall tuffs, including coarse-grained tuff, and pumice lapilli tuff and tuff breccia
Tw	ASH-FLOW TUFF (Oligocene?)--Crystal-rich rhyolite or quartz latite tuff containing quartz, sanidine, plagioclase, and biotite phenocrysts
Ꞓe	EMIGRANT FORMATION (Middle and Upper Cambrian)--Thinly interbedded limestone and chert
Ꞓms	MULE SPRING LIMESTONE (Lower Cambrian)--Finely crystalline limestone
Ꞓh	HARKLESS FORMATION (Lower Cambrian)--Siltstone, quartzitic siltstone, and orthoquartzite sandstone
Ꞓhl	HARKLESS FORMATION (Lower Cambrian)--Limestone interbeds
	Contact--Dashed where approximately located
	Fault--Long dashed where approximately located, short dashed where inferred, dotted where concealed; ball on downthrown block
	Strike and dip of stratification. Bedding and eutaxitic structure
	Field spectra and rock spectra sample site

Ashley and Abrams, Figure 1

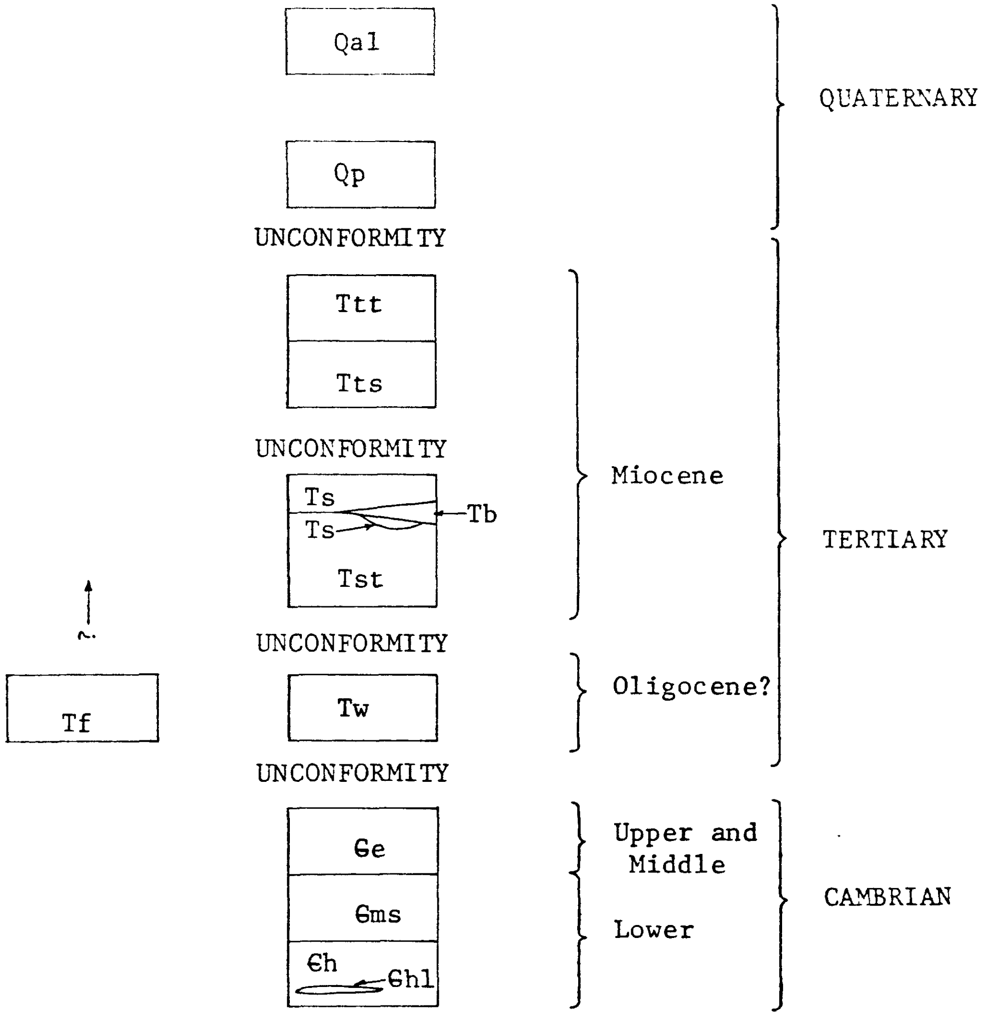

Figure 2.-- Hydrothermal alteration map of the Cuprite mining district, Nevada. Localities shown are referred to in figures 4-6.

Figure 2

s	op	a

s	SILICIFIED ROCKS
op	OPALIZED ROCKS
a	ARGILLIZED ROCKS
●	Field spectra and rock sample site

1e

northeast (Ashley, 1974). Unit Ts includes air-fall tuff, volcanic sandstone, and conglomerate. The most abundant rock type is pumice lapilli tuff. This unit has the same general lithology and stratigraphic relations as the Siebert Tuff of Middle to Upper Miocene age at Goldfield and Tonopah. Tb, a porphyritic plagioclase-olivine basalt flow, is similar to basalts interbedded with the Siebert at Goldfield. The uppermost Tertiary unit is the Thirsty Canyon Tuff whose source is the Black Mountain caldera located 50 km to the southeast (Noble and others, 1964). Two members are represented here: the Spearhead Member (lower) and Trail Ridge Member (upper) both devitrified sanidine-bearing sodic peralkaline rhyolite ash-flow tuffs, and each comprising a single simple cooling unit. Several potassium-argon dates for the Spearhead Member indicate an age of 7 m.y. (Ashley and Silberman, 1976). The Trail Ridge Member, based on knowledge of the eruptive history of the Black Mountain caldera, must be almost the same age (Noble and Christiansen, 1974). The large felsite dikes west of Highway 95 contain alkali feldspar and scarce biotite phenocryts, and are probably of rhyolitic or trachytic composition. Although their age is unknown, they probably were intruded along north-trending Basin-Range faults, suggesting that they may be the youngest Tertiary rocks in the area.

Prealteration faults include north-trending Basin-Range faults west of Highway 95 and in the north part of the area east of Highway 95, and a complex pattern suggesting doming in the south part of the area east of Highway 95. Displacements are generally no more than a few tens of meters except for the north-trending Basin-Range fault that juxtaposes Єh and Ts on the west side of Highway 95. Displacement on this fault is about 200 m. The structural complexities in the Єh and Єms southwest of the altered area, including steep and variable dips, dominantly northeast trending high-angle faults, and a few thrust faults, are probably mostly pre-Tertiary in age. Dips in Tertiary rocks are generally low throughout the area.

HYDROTHERMAL ALTERATION

The altered rocks are divided into three groups that form mappable zones: silicified rocks, opalized rocks (opalite), and argillized rocks (fig. 2). Silicified rocks are the most intensely altered and argillized rocks are the least intensely altered. Relict textures are well preserved in all but the most strongly leached silicified rocks.

The silicified rocks exposed typically contain abundant quartz, some calcite, and minor alunite and kaolinite. The calcite may be a posthydrothermal product, having replaced former opal. Outcrop surfaces are vuggy and locally boxworklike, with numerous closely spaced quartz ribs in diverse orientations outlining fractures that formed channelways for the hydrothermal solutions. Prospect pits and trenches show that within 1 meter below the weathered surface, the vugs and boxworks are filled with friable aggregates of porous white quartz. Locally, where hydrothermal leaching apparently was extreme, the friable quartz aggregates are predominant. Weathered surfaces in the silicified zone typically have 10-30 percent desert varnish.

Opalized rocks form the most widespread alteration zone. In addition to opal, variable amounts of alunite and kaolinite are present. Hydrothermal quartz is scarce but primary quartz phenocrysts, where present in the original

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rock, remain as relicts. Unaltered sanidine phenocrysts remain in some alunite-free opalized rocks. Calcite is a common minor component; again, it probably replaced opal.

Locally within the opalized zone or at the edge of the altered area is soft, poorly exposed material mapped as argillized rock. Primary quartz and sanidine here are unaltered, whereas plagioclase is altered to kaolinite, biotite is partly bleached, and glass is altered to opal, montmorillonite, and kaolinite.

Limonite content of most of the altered rocks is less than 5 percent, and large volumes of altered rock are nearly limonite free. Variations in limonite content reflect pyrite content prior to oxidation. Relatively limonite-rich opalized and argillized rocks are visible as small red spots on the color aerial photograph (fig. 3). Hematite is the dominant limonite mineral. Silicified rocks commonly have no more than a few percent limonite; here goethite is the dominant limonite mineral.

All Tertiary units shown on the geologic map, including Trail Ridge Member of the Thirsty Canyon Tuff, are at least locally altered. Almost all exposures of units Ts and Tw are altered. Thus, the hydrothermal system that produced the acid-sulfate alteration at Cuprite was active less than 7 m.y. ago. Alluvial deposits of all types, however, are younger than the alteration, so activity probably ceased before Quaternary time.

ACQUISITION OF SPECTRAL DATA

Areal spectral coverage was obtained with the Bendix 24-channel multispectral scanner (MSDS). The scanner has an instantaneous field of view of 2 milliradians, and was flown at an altitude of 5,600 m above the ground, resulting in maximum spatial resolution of about 10 m. The instrument has 11 bands in the visible-near infrared (VNIR) region, as follows:

Channels between 0.4 and 2.5 μm, MSDS Scanner

Channel	Bandwidth (μ m)	Channel	Bandwidth (μ m)
3	0.46-0.50	9	0.82-0.87
4	0.53-0.57	10	0.97-1.05
5	0.57-0.63	11	1.18-1.30
6	0.64-0.68	12	1.53-1.73
7	0.71-0.75	13	2.10-2.36
8	0.76-0.80		

Ground spectra, which provide a link between mineralogical data and aircraft scanner response, were obtained with the JPL portable field reflectance spectrometer (PFRS). The field of view of this instrument is between about 100 cm^2 and 200 cm^2 depending upon height of the sensor head above the ground at a particular instrument station. Spectral resolution is moderate ($\Delta\lambda/\lambda = 0.04$ from 0.45 to 0.7 μm and 0.015 from 0.7 to 2.5 μ m). The PFRS data enabled us to predict which bands would be optimal among the 11 available in the scanner in the visible-near infrared range. The PFRS data also provide a check on spectral behavior predicted from petrographic examination of samples.

Details of data reduction and image processing are described by Goetz and others (1975) and Soha and others (1976).

Figure 3.--Color aerial photograph of the Cuprite mining district.

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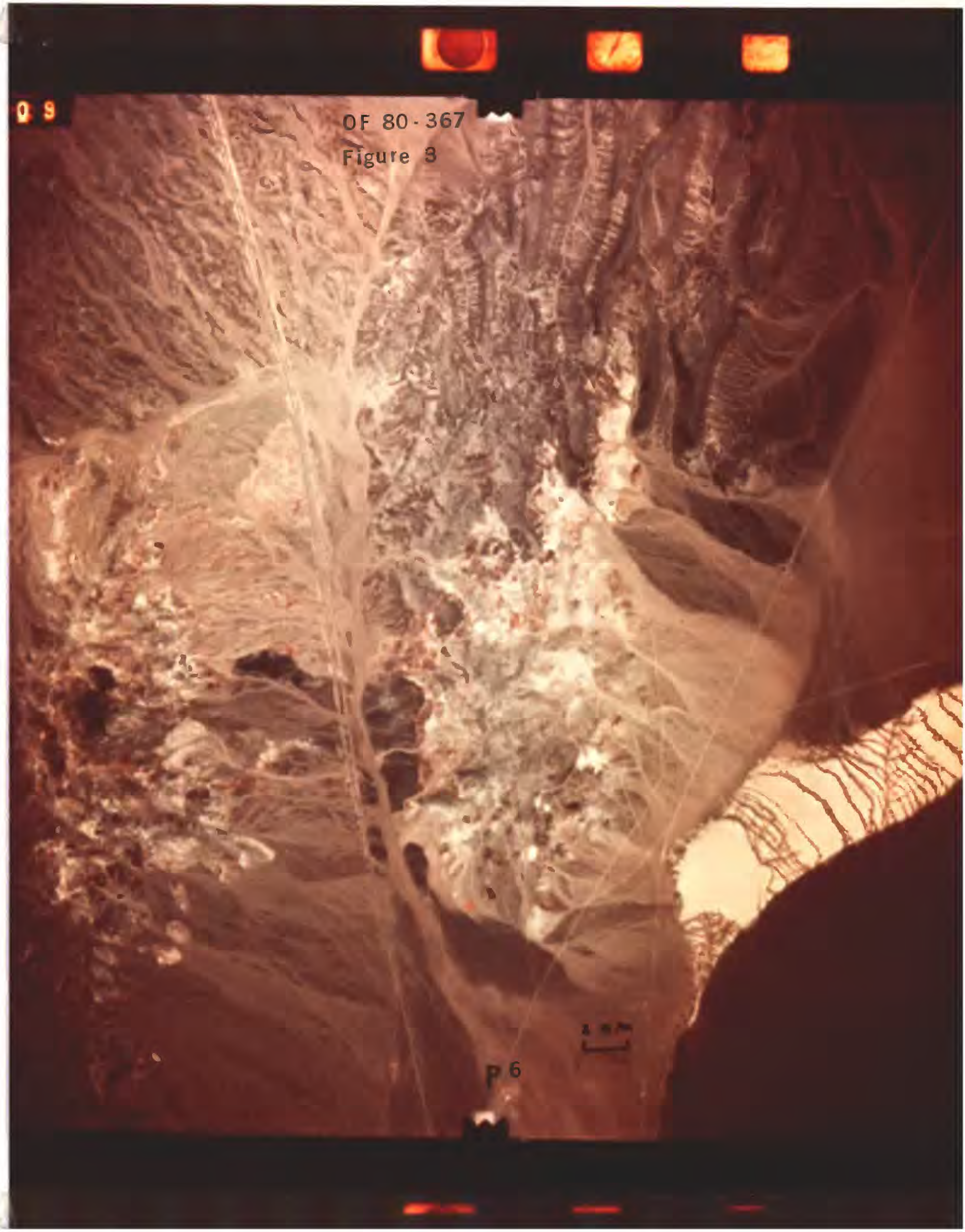
Figure 8



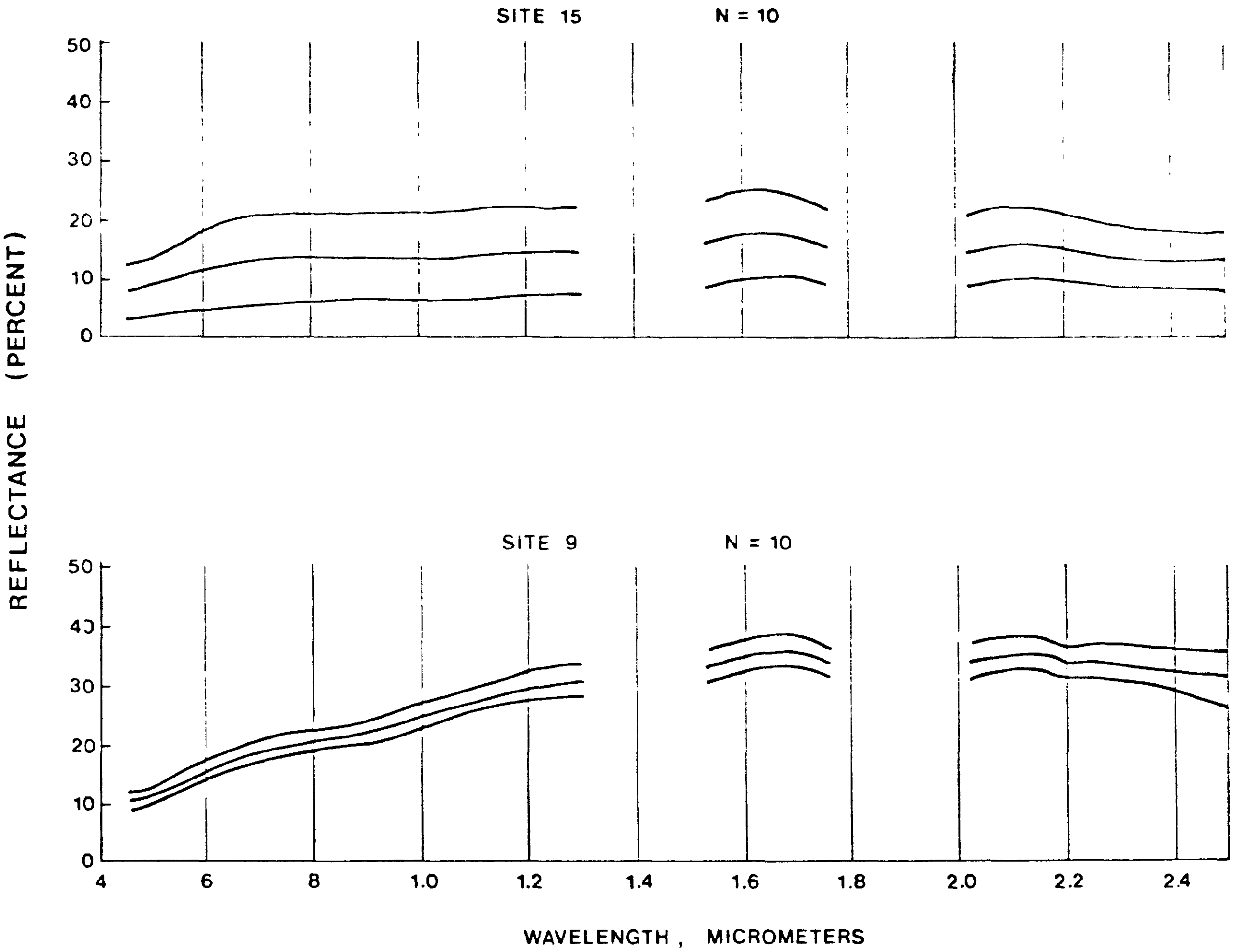


Figure 4.--Average spectral reflectance curves with one standard deviation envelopes for unaltered rocks of the Cuprite mining district including basalt (site 15) and Spearhead member of the Thirsty Canyon Tuff (site 9).

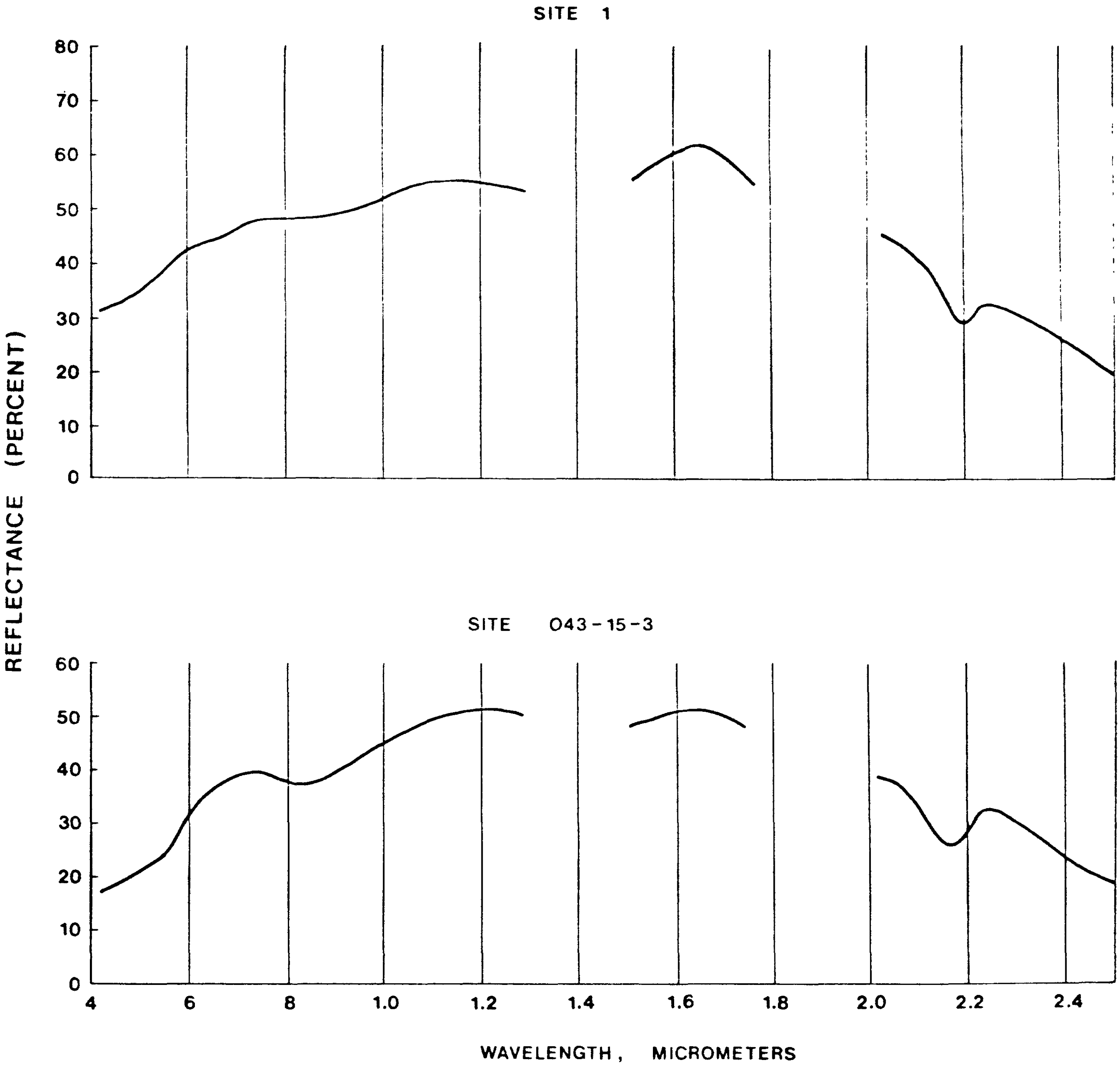


Figure 5.--Spectral reflectance curves for two sites in opalized rocks.

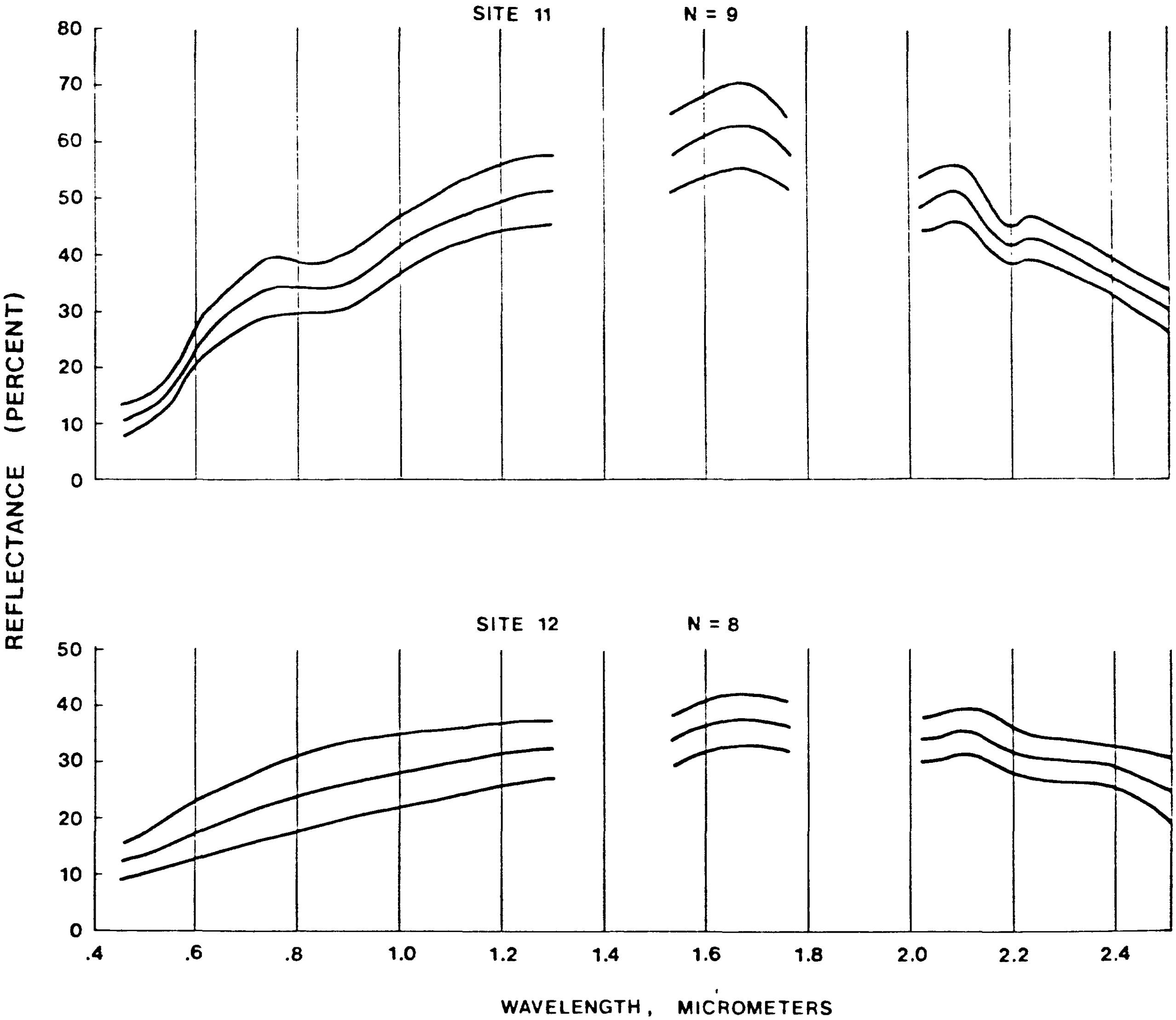


Figure 6.--Average spectral reflectance curves with one standard deviation envelopes for argillized rocks (site 11) and silicified rocks (site 12).

MSDS COLOR-RATIO COMPOSITE

The field spectra show which MSDS spectral bands are likely to be most effective for detecting ferric- and hydroxyl-bearing minerals. These are bands 3, 12, and 13 centered at about 0.48 µm, 1.6 µm, and 2.2 µm, respectively. One or more bands between 0.6 and 1.0 µm may also be useful.

For this investigation we combined five bands into three ratios as follows: 1.6/2.2 µm, 1.6/0.48 µm, and 0.6/1.0 µm. The first ratio was chosen to delineate altered rocks having high reflectance near 1.6 µm relative to 2.2 µm owing to the presence of hydroxyl-bearing minerals. The second ratio was selected to display variations in surficial ferric iron content, with high ratio values indicating high concentrations and low values indicating low concentrations. The third ratio was chosen to distinguish rocks with only moderately sloping spectra, including playa, tuff, basalt, and bleached iron-deficient altered rocks. Black-and-white images generated from these three ratios were combined to form the color-ratio composite image (CRC) in a color additive viewer (fig. 7). The red component depicts the value of the ratio 1.6/2.2 µm, the green component represents the value of 1.6/0.48 µm, and the blue represents the value of 0.6/1.0 µm. The higher the value of each ratio, the higher the intensity of the corresponding color component.

The silicified rocks appear dark red to brown and locally bluish purple to blue on the image indicating slight dominance of the 1.6/2.2 µm ratio over the other ratios. This is consistent with the mineralogy and the field spectra; 1.6/0.48 (green) is low, whereas 0.6/1.0 and 1.6/2.2 are generally moderately high but variable.

Opalites range in color from magenta to red and yellow. All have large amounts of hydroxyl-bearing minerals resulting in a very strong red component in the image. Where ferric iron is lacking, such as in the highly leached opalites (site 1), the 0.6/1.0 µm ratio is moderately high, but 1.6/0.48 µm is very low, resulting in a significant blue contribution, which, when added to red, produces the magenta color seen in these areas. As the limonite content increases, the slope of the spectral curve increases, resulting in higher values of 1.6/0.48 µm, and lower values of 0.6/1.0 µm. In the image this produces first red, then yellow (site 043-15) as green component (1.6/0.48 µm) increases and the blue component (0.6/1.0 µm) decreases.

The argillized rocks (site 11) on the west edge of the area are predominantly yellow-green, reflecting concentrations of both hydroxyl-bearing and ferric minerals.

Unaltered volcanic rocks and surficial materials are dominantly dark green and blue to almost black in the CRC image and therefore readily distinguished from the altered rocks. Much of the unaltered Thirsty Canyon Tuff appears nearly black on the image because all three ratios are relatively low, producing dark gray tones in the black-and-white film transparency for each ratio, and thus black or very dark colors on the CRC image. Subtle variations in the small amount of hematite present must determine whether the 1.6/0.48 µm ratio or 0.6/1.0 µm ratio is relatively greater, producing dark green or dark blue, respectively. Presumably the dark blue areas have less hematite. The lack of hydroxyl-bearing minerals accounts for the absence of red component. Much alluvium in the scene and the playa have very little limonite (1 percent) and are blue.

Figure 7.--Color ratio composite image for the Cuprite mining district. See text for explanation. Localities shown are referred to in figures 4-6.

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Figure 7

1.6/2.2 μm DENSITY SLICE

Preliminary laboratory studies with a high-resolution reflectance spectrometer indicate that the depth of the 2.2 μm absorption band is directly proportional to the abundance of the mineral(s) producing the band (Graham Hunt, unpub. data). Since alunite and kaolinite are the only hydroxyl-bearing minerals in opalized and silicified rocks at Cuprite, and these two minerals have very similar 2.2 μm absorption bands as seen with a moderate-resolution spectrometer, the 1.6/2.2 μm ratio should be directly proportional to the total alunite-plus-kaolinite content of these rocks. The density slice (fig. 8) shows the spatial distribution of pixels with 1.6/2.2 values in the ranges shown. The ranges are color coded instead of being assigned to a gray scale. The white, pink, and red, representing materials with low 1.6/2.2 μm are unaltered rocks, mainly devitrified Thirsty Canyon Tuff, but also basalt and Harkless Formation siltstone, and alluvium derived from the tuff. The orange, yellow, chartreuse, and green are mainly alluvium composed of both unaltered and altered rock fragments in various proportions. Mottled orange and yellow, with some red, characterize silicified rocks, whereas green is the most common of the above four colors in other altered rocks. The pale blue, dark blue, purple, brown, and black occur mainly in opalized rocks and argillized rocks, although the latter form a relatively small part of the scene. Opalized areas with the highest 1.6/2.2 (black or brown) are ringed by areas with progressively lower 1.6/2.2, indicating that the margins of kaolinite plus alunite-rich areas are gradational. Comparison of the density slice with the geologic map indicates that concentrations of these minerals commonly follow fault zones. The faults, however, could only be detected in the field where offsets between stratigraphic units were discovered. Kaolinite and alunite concentrations revealed by the density slice that do not coincide with known faults are generally in areas of homogeneous lithology, and may actually follow faults that were not detected in field mapping. Approximate ranges of alunite-plus-kaolinite contents corresponding to various 1.6/2.2 ranges in the opalized rocks are: green (1.6/2.2 = 1.23-1.28), 15-25 percent; light blue (1.29-1.34), 25-30 percent; dark blue (1.35-1.40), 30-35 percent; purple (1.41-1.50), 35-43 percent; brown (1.51-1.60) 43-50 percent; black (1.61-1.97), >50 percent. In rocks containing more than about 30 percent total alunite and kaolinite, alunite predominates. Owing to difficulties in obtaining reliable alunite and kaolinite determinations on individual samples, as well as sampling error at the scales of PFRS sites and MSDS pixels, the percentage estimates are approximate at this stage of the investigation.

0.75/0.48 μm DENSITY SLICE

It should be possible to utilize the ferric iron spectral absorption features below 0.55 μm and at 0.85 μm to map variations in limonite abundance, in the same way that the 1.6/2.2 μm density slice can be used to map total alunite and kaolinite abundance. However, between 0.4 and 1.7 μm both limonite abundance and overall reflectance of the rock affect the shape of the spectral reflectance curve, so that no ratio of two bands below 1.7 μm responds only to limonite variations. Because the 0.55 μm absorption band of ferric iron is stronger than the 0.85 μm band, MSDS channel 3, centered at 0.48 m, is particularly sensitive to limonite abundance. If channel 3 is ratioed against any channel from 4 through 12, however, the resulting ratio will be influenced to some extent by the overall reflectance of the rock,

Figure 8.--Color-coded density slice for 1.6/2.2 μm, Cuprite mining district.

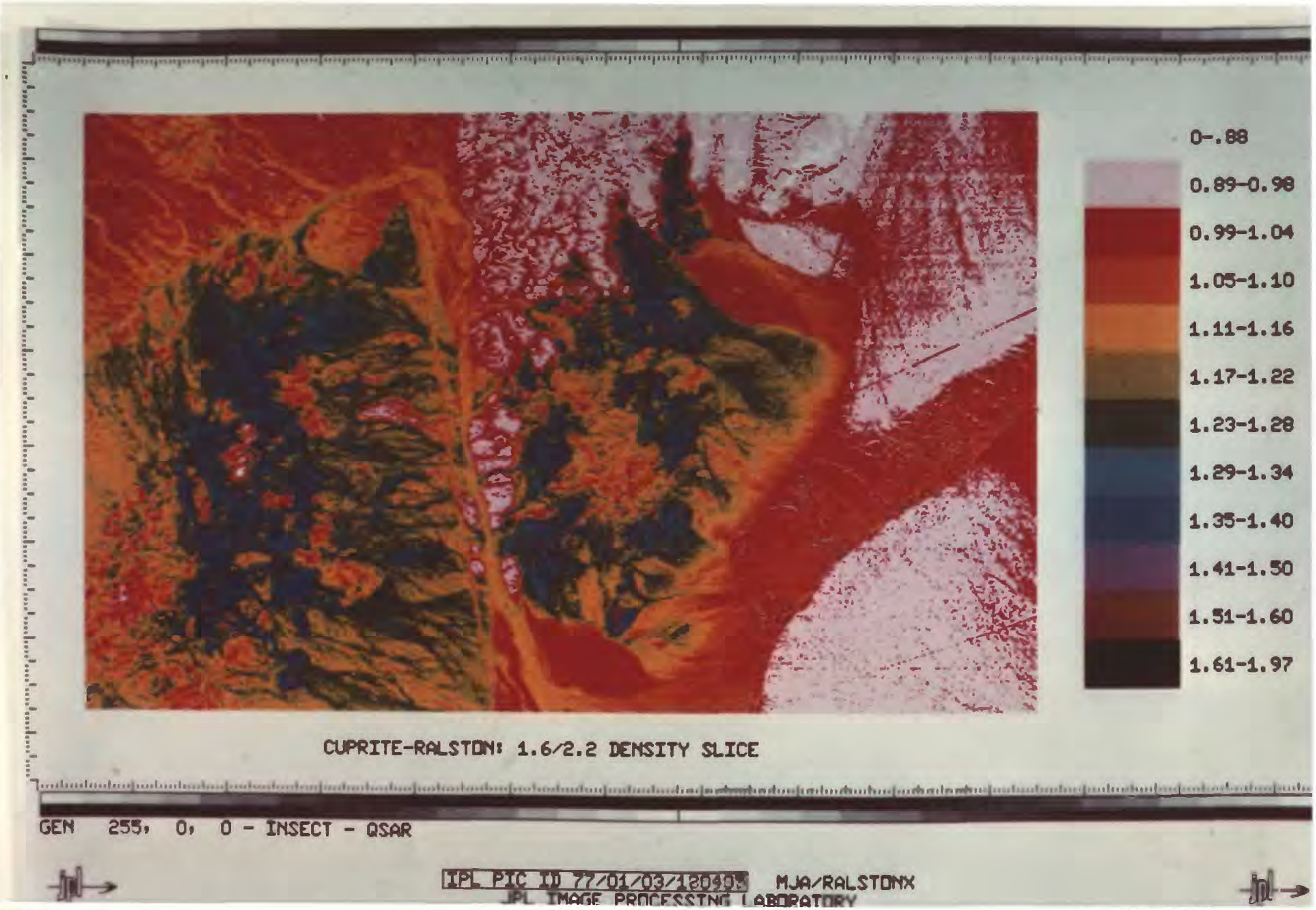

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Figure 8

which in bright rocks usually reaches a maximum at about 1.7 µm. Looked at another way, more limonite is required to notably steepen the slope of the spectral curve between 0.4 and 1.7 µm in the case of an unaltered rock with low overall reflectance than is required to notably steepen the slope in an altered rock with high reflectance. Use of a channel below 0.8 m, such as channel 7 (0.71-0.75 µm), to ratio against channel 3 minimizes but does not eliminate variation due to differences in overall reflectance between rock types. Thus, in the channel 7/channel 3 density slice image (fig. 9), extremely low 0.75/0.48 ratios, shown as white and pink, are found in basalt containing as much as 5 percent limonite, in siltstone containing several percent limonite, and in opalite containing only a trace (much less than 1 percent) limonite. The red areas common in devitrified Thirsty Canyon tuff contain several percent disseminated hematite, whereas red areas in opalite contain 1 percent or less limonite. Orange and yellow areas are common both in silicified rocks (less than about 10 percent limonite) and opalite (less than about 5 percent limonite). Yellow, chartreuse, and green are common in alluvium, presumably because mixing of rock fragments having various limonite contents and albedos yields materials with intermediate spectral characteristics. In bedrock areas, materials that are light blue or have colors corresponding to even higher ratios are in almost all cases altered. The limonite contents required to produce ratios from 1.21 to greater than 1.46 are not yet established, but probably range from about 10 percent to more than 30 percent in opalized rocks. The gradational character of the boundaries of limonite-rich areas is more readily established using this image than the color aerial photograph.

APPLICATIONS

The technique described above provides a rapid method for evaluating the alunite resource potential of acid-sulfate hydrothermally altered areas, requiring relatively few surface samples, necessary only to determine the amounts of alunite in areas having intense absorption at 2.2 µm. Relative amounts of limonite, an undesirable contaminant in alunite deposits, can also be determined. The technique may facilitate mapping of certain alteration zones in several hydrothermal environments; for instance, advanced argillic zones in acid-sulfate areas (an application similar to alunite resource evaluation), argillic and quartz sericite zones in porphyry copper alteration systems, and bentonitic alteration of tuffs and tuffaceous sedimentary rocks.

Figure 9.--Color-coded density slice for 0.75/0.48 μm, Cuprite mining district.

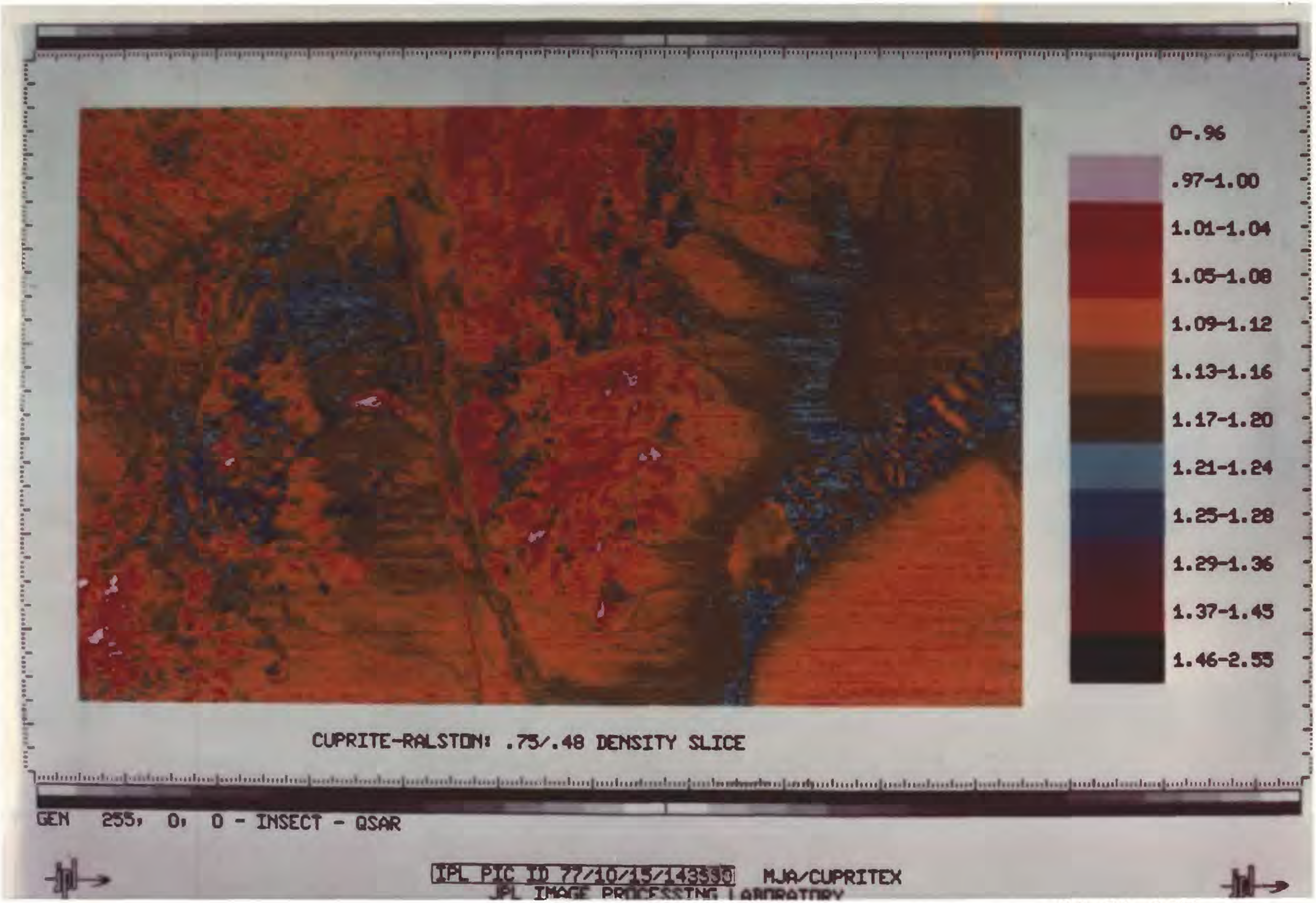

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Figure 9

REFERENCES

Abrams, M. J., Ashley, R. P., Rowan, L. C., Goetz, A. F. H., and Kahle, A. B., 1977a, Use of imaging in the 0.46-2.36 μm spectral region for alteration mapping in the Cuprite mining district, Nevada: U.S. Geological Survey Open-File Report 77-585, 18 p.

_____1977b, Mapping of hydrothermal alteration in the Cuprite mining district, Nevada, using aircraft scanner imagery for the 0.46-2.36 μm spectral region: Geology, v. 5, p. 713-718.

Ashley, R. P., 1974, Goldfield mining district, in Guidebook to the geology of four Tertiary volcanic centers in central Nevada: Nevada Bureau of Mines and Geology Report 19 p. 49-66.

Ashley, R. P., and Abrams, M. J., 1977, Mapping of limonite, clay mineral and alunite contents of hydrothermally altered rocks in the Cuprite mining district, Nevada, using aircraft scanner imagery for the 0.46-2.36μ m spectral region [abs.]: Geological Society of America, Abstracts with Programs, v. 9, p. 883.

Ashley, R. P., and Silberman, M. L., 1976, Direct dating of mineralization at Goldfield, Nevada, by potassium-argon and fission-track methods: Economic Geology, v. 71, p. 904-924.

Goetz, A. F. H., Billingsley, F. C., Gillespie, A. R., Abrams, M. J., Squires, R. L., Shoemaker, E. M., Lucchitta, I., and Elston, D. P., 1975, Application of ERTS images and image processing to regional geologic problems and geologic mapping in northern Arizona: JPL Technical Rept. 32-1597, NASA Jet Propulsion Lab., California Institute of Technology, Pasadena, Calif., 188 p.

Hunt, G. R., and Salisbury, J. W., 1970, Visible and near-infrared spectra of minerals and rocks--I. Silicate minerals: Modern Geology, v. 1, p. 283-300.

Hunt, G. R., Salisbury, J. W., and Lenhoff, C. J., 1971a, Visible and near-infrared spectra of minerals and rocks--III. Oxides and Hydroxides: Modern Geology, v. 2, p. 195-205.

_______1971b, Visible and near-infrared spectra of minerals and rocks--IV. Sulphides and sulphates: Modern Geology, v. 3, p. 1-14.

_______1973, Visible and near infra-red spectra of minerals and rocks--VI. Additional silicates: Modern Geology, v. 4, p. 85-106.

Noble, D. C., Anderson, R. E., Ekren, E. B., and O'Connor, J. T., 1964, Thirsty Canyon Tuff of Nye and Esmeralda Counties, Nevada, in Short papers in geology and hydrology: U.S. Geological Survey Professional Paper 475-D, p. D24-D27.

Noble, D. C., and Christiansen, R. L., 1974, Black Mountain volcanic center, in Guidebook to the geology of four Tertiary volcanic centers in central Nevada: Nevada Bureau of Mines and Geology Report 19, p. 27-34.

Soha, J. M., Gillespie, A. R., Abrams, M. J., and Madura, D. P., 1976, Computer techniques for geologic aplication, in Proceedings of Caltech/JPL conference on image processing technology, data sources, and software for commercial and science applications: JPL SP 43-30, NASA-Jet Propulsion Lab.-California Institute of Technology, Pasadena, Calif., p. 4-1--4-21.