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IRON OXIDE GENESIS AND ITS INFLUENCE ON THE SPECTRAL REFLECTANCE PROPERTIES OF GOSSANS

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ABSTRACT

Gossans in the Mt. Bross area of the Alma mining district, Colorado, were characterized by use of iron oxide mineralogy and spectral reflectance as a possible aid to mineral exploration using remotely sensed data. Mine site gossan samples produced by the weathering of lead-zinc replacement deposits were found to be composed primarily of goethite, and nonmine samples produced by the weathering of pyrite in the local country rock were found to be composed primarily of jarosite. A three stage genetic model was proposed to explain the observed iron oxide assemblages, whereby goethite precipitated early and was followed by jarosite and hematite.

Bidirectional reflectance factor was measured on undisturbed sample surfaces with an Exotech 20C spectroradiometer from 0.5 µm to 2.35 µm. A pressed barium sulfate powder reference was used for calibration. The samples were organized into two groups. The first contained goethite as the major oxide. The spectra showed a 0.65 µm shoulder, broad 0.94 µm absorption, and low reflectance factor in the visible and near infrared (13 percent at 0.75 µm). The other group was mainly hematite; the spectra showed a weak 0.65 µm shoulder, sharp 0.85 µm absorption, and high reflectance factor (37 percent at 0.75 µm.) It appeared that hematite, although a minor constituent in the nonmine gossans when compared to jarosite, was spectrally dominant.

Exploration programs, using spectral reflectance studies to characterize gossan types, should be undertaken with care because iron oxide genesis is influenced by a number of physio-chemical factors that can produce similar mineralogies and spectral characteristics from different parent sulfide assemblages. In the Alma district, the observed spectral differences between gossans appeared to be indirectly a function of wall rock chemistry and not parent sulfide assemblage.

I. INTRODUCTION

A gossan is an accumulation of iron-rich material derived from the weathering of iron-sulfide bearing rocks. Gossans are commonly found overlying ore deposits and can be used on the surface to explore for certain base metal sulfides.[1-9] The present study is a mineralogical and spectral comparison of gossans produced by the weathering of lead-zinc deposits and pyrite-rich country rocks in the vicinity of Mt. Bross, Alma Mining district, Colorado, as a possible aid to exploration using remotely sensed data.

In order to understand residual iron oxide mineralogy and spectral character as produced by the weathering of different parent sulfides, it is important to understand the chemical variables that influence weathering systems. Several factors effect iron oxide genesis: Eh, pH, temperature, ionic speciation, and relative humidity,[10-13] which are for the most part controlled by climate, parent sulfide assemblage, and host rock chemistry. Ultimately, the resultant spectral signatures observed in the field or laboratory will be greatly influenced by sample mineralogy.

The spectral characteristics of iron oxides are particularly pronounced below 1.2 µm with broad absorption features in the ultraviolet and 0.9 µm regions. These minima as well as the much less intense 0.65 µm feature are due to an electronic transition of the iron atom. The location and intensity of these minima may vary with mineralogy and are detectable using reflectance spectroscopy.

II. GEOLOGIC SETTING

The Alma District is located in the northeastern portion of the Colorado Mineral Belt approximately 100 km southwest of Denver (Figure 1). Paleozoic sedimentary rocks overlying Precambrian schist and gneiss dip eastward 10° to 25° and are intruded by Tertiary sills and dikes. Talus and glacial deposits are pronounced in the area and soil is weakly developed on dip slopes and valleys. The study area is located above the tree line between an elevation of 12,000 and 14,000 feet and is covered by snow from October to April.

III. METHODOLOGY

Hand samples were collected from mine tailings on the east side and from outcrops (nonmine) on the west side of Mt. Bross. Preparation of the samples for mineral identification with X-ray diffraction was minimized to avoid structural damage to any clay and iron oxides present. Care was taken to prepare only the iron oxide surface coating or residue by hand grinding and mounting as a slurry on glass slides. The samples were analyzed with a Philips vertical goniometer equipped with a diffracted beam graphite monochrometer. Scans were obtained using Cu $K\alpha$ radiation from 5° to 50° 2θ at a scan rate of 1° 2θ/minute.

Bidirectional reflectance factor[14] was measured on nine samples at the Laboratory for Applications of Remote Sensing, Purdue University. An Exotech 20C spectroradiometer[15, 16] was used to collect data from an undisturbed 3 cm diameter area of each sample from 0.5 to 2.35 μm. An illumination zenith angle of 10° and viewing zenith angle of 0° were used. A pressed barium sulfate powder surface was used for calibration.

IV. RESULTS

The gossans from the mine tailings were found to be composed primarily of goethite (FeOOH). Commonly, the samples were preserved as pseudomorphs or had a porous three-dimensional structure where in-situ replacement of sulfide by iron oxide had occurred. The host rock was predominantly dolomite, with quartz and barite gargue in the sulfide veins.

The gossans from the nonmine sites were found to be composed of goethite, jarosite (KFe_3 $(SO_4)_2$ $(OH)_6$) and hematite (Fe_2O_3) with jarosite the dominant phase. It was impossible to determine the order of deposition since the oxides were in the form of a thin (<1 mm) surface coating although sample Nos. 19 and 26 contained coarse dark goethite as a uniform layer (<1 mm thick) and patches (1-10 cm in diameter) of yellow powdery jarosite (<1 mm thick), with a very thin coating of red-colored hematite on top. When viewed in thin sections the iron oxide occurred exclusively as a surface coating. The host rock, schist and gneiss, was found to be least altered where pyrite could be seen as small enhedral grains, and most altered where only holes and iron oxide pseudomorphs of the pyrite remained.

The spectra for the mine samples and the X-ray data indicate that goethite is the major oxide present (Table 1). In contrast, the nonmine spectra (with the exception of sample Nos. 4 and 26B) all show hematite as the major oxide, not in agreement with the X-ray data that indicate jarosite is the main oxide present. The samples can be organized into two groups. The first contains goethite as the major oxide; the 0.65 μm shoulder and broad 0.94 μm absorption being characteristic,[17] as well as a low, bidirectional reflectance factor in the visible and near infrared (Figure 2, variation in the spectra due to system noise

is less than $\pm$ 2 percent). The other group appears to be mainly hematite; the spectra show a weak 0.65 μm shoulder but a sharp 0.85 μm absorption feature. These samples have a high reflectance factor, around 37 percent at 0.75 μm, more than twice that of the goethite samples (Figure 3).

Because nonmine sample Nos. 19 and 26 both contain a layer of jarosite capped by a thin layer of hematite, they appear red on the surface, although when scratched, yellow colored jarosite can be seen. The hematite in these samples is apparently the major oxide detected by the spectroradiometer. Unfortunately, the diagnostic jarosite absorption at 0.43 μm is below the range recorded. However, the 0.85 μm feature for hematite would be at 0.93 μm if jarosite was dominant, suggesting that only the hematite was detected.

Although two of the nonmine spectra contain the 2.2 μm OH - alumina bending feature indicative of kaolinite or muscovite, only sample No. 5 shows it as a sharp absorption band (Figures 4 and 5). In agreement, the X-ray data for sample No. 5 show muscovite to be a major constituent.

V. DISCUSSION

It appears that reflectance spectroscopy is very sensitive to mineralogy and can be used for mineral identification. However, because different geologic conditions can produce the same iron oxides, it is important to understand the processes that produce the various oxides before interpreting spectral curves.

For the Alma district, a three-stage genetic model is proposed, which relates the physio-chemical conditions that influence iron oxide precipitation to a hypothetical weathering sequence for sulfides. In Stage 1, as sulfides are attacked by groundwater, iron and sulfate are released and the pH begins to drop. During Stage 2, as more sulfide dissolves, iron and sulfate concentration increase and the pH drops even lower, promoting wall rock hydrolysis and the release of potassium and aluminum ions. As sulfide dissolution slows or ends, during Stage 3, pH begins to rise and sulfate activity drops below jarosite saturation.

Geothite precipitation dominates during Stage 1, jarosite in Stage 2, and hematite in Stage 3. If the wall rocks do not have a strong neutralization capacity, then Stages 1 through 3 can develop. If the wall rocks are reactive (such as carbonates), then the pH is kept high, there is little wall rock hydrolysis, and goethite is the preferred oxide (Stage 1). It should be noted that local variations in the chemistry of the system can produce different oxide assemblages from the same bulk starting material, and thus correspondingly different spectral signatures can result. These local variations are particularly important when generalizing the presence or absence of a key mineral to indicate an economic versus noneconomic parent sulfide. Because of this, deposits should be evaluated individually so that geochemical criteria may be established to help characterize the observed spectral response curves for that area.

The analysis of spectral curves of Landsat data gives a general idea of what the response would be for an area rich in iron oxides. However, it is important to remember that the resolution of Landsat is approximately 80 m, whereas that of the laboratory data is about 3 cm. The relatively poor resolution of Landsat combined with the fact that the first three bands are 0.1 μm wide, makes it difficult to directly apply subtle variations in laboratory spectra to the analysis of satellite data.

VI. CONCLUSION

Spectral reflectance studies can be used to evaluate local iron oxide mineralogy and thus help characterize gossans as a possible aid to exploration programs. However, care should be taken since many local variables influence iron oxide genesis and can produce similar mineralogies and spectral characteristics from different parent sulfide assemblages. In the future, high resolution sensors should be able to provide us with detailed spectral information that, when combined with sound geochemical reasoning, will be a powerful tool in the assessment of mineral resources.

VII. ACKNOWLEDGEMENTS

VIII. BIBLIOGRAPHY

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Table 1. Spectral Reflectance Results.

Sample #	Local	Absorption Wavelength (μm)					BRF (%) @0.75 (μm)	Major Oxide Spectral	X-ray
4	nonmine	0.66	0.92	1.45	1.96	–	12.7		
12	mine	0.66	0.925	1.44	1.98	–	12.8	G	G
17	mine	0.66	0.92	1.45	1.96	–	10.3	G	G
24	mine	0.66	0.92	1.425	1.94	–	16.2	G	G
26B*	nonmine	0.64	0.92	1.42	1.95	–	16.1	G	G
								G	G
5	nonmine	–	0.88	1.42	1.94	2.225	43.1		
16	nonmine	–	0.88	1.42	1.93	2.225	49.1	H, M/K	M, J, G/H
19	nonmine	–	0.88	1.46	1.97	–	35.0	H, M/K	J, M, G/H
26R**	nonmine	–	0.89	1.42	1.93	–	35.0	H	M, J, G/H
29	nonmine	–	0.88	1.42	1.97	–	41.3	H	J, G/H
								H	M, J, G/H
Absorption Feature		Fe^{+3}	Fe^{+3}	OH	OH H_2O	OH Al-O-H			

* Brown part of sample.
** Red part of sample.

J = Jarosite
G = Goethite
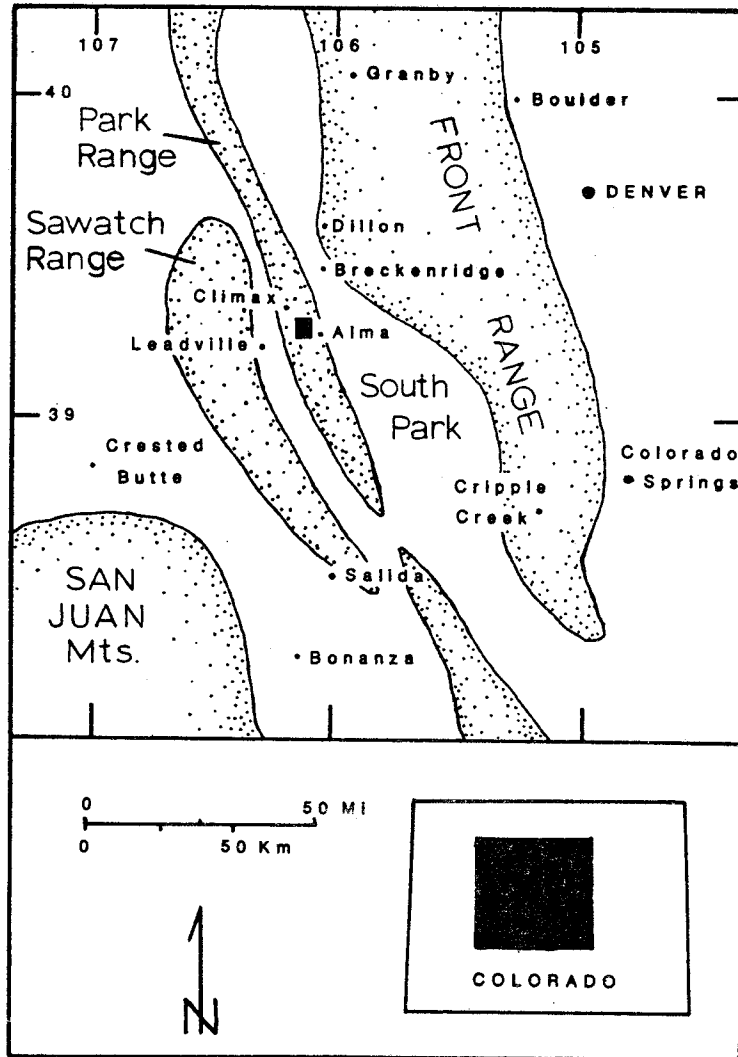
G/H = Goethite & Hematite
M = Mica
K = Kaolinite

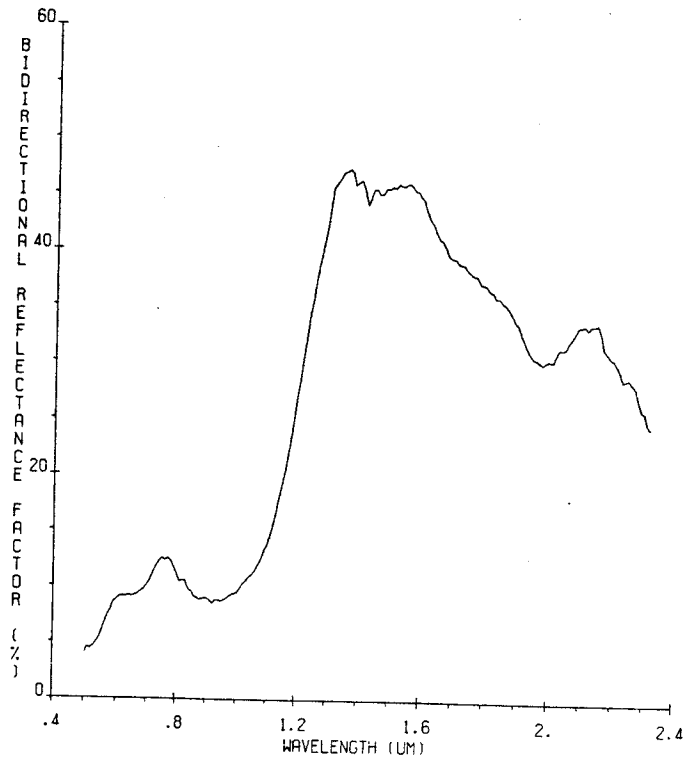Figure 1. Location of the Alma Mining District.

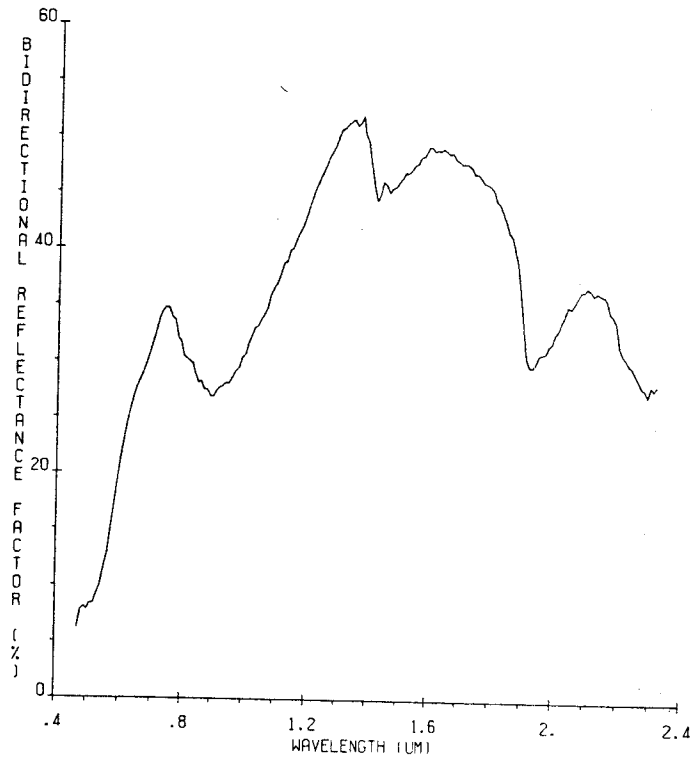Figure 2. Representative Spectra of Goethite Rich Samples (No. 4).

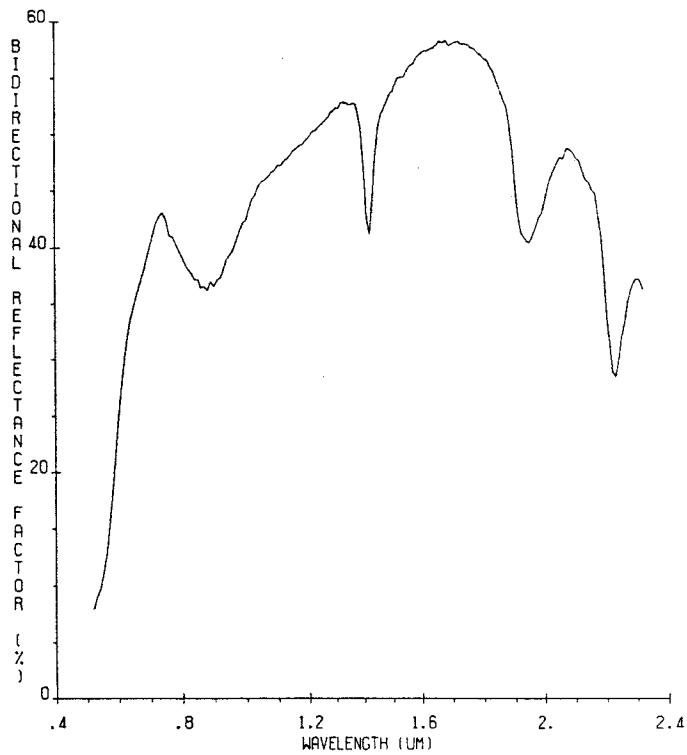Figure 3. Representative Spectra of Hematite Rich Samples (No. 26R).

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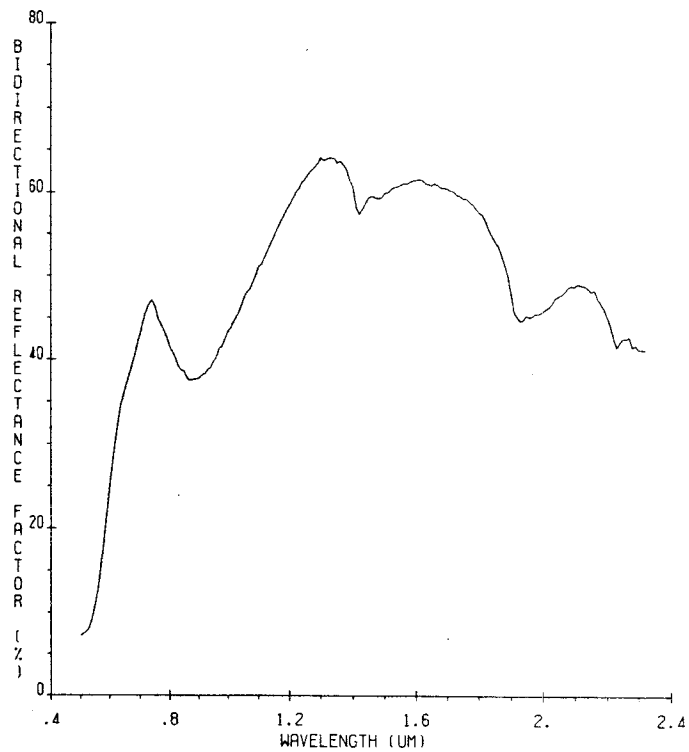Figure 4. Spectra of Sample No. 5 Showing the 2.2 m OH – Alumina Bending Feature.

Figure 5. Spectra of Sample No. 16 Showing A Weakly Developed 2.2 m OH – Alumina Bending Feature.

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