Identification of Illite Polytype Zoning in Disseminated Gold Deposits Using Reflectance Spectroscopy and X-Ray Diffraction—Potential For Mapping With Imaging Spectrometers

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Identification of Illite Polytype Zoning in Disseminated Gold Deposits Using Reflectance Spectroscopy and X-Ray Diffraction—Potential For Mapping With Imaging Spectrometers

Fred A. Kruse and Phoebe L. Hauff

Abstract—X-ray diffraction studies of clay minerals from disseminated gold deposits in Nevada demonstrate that illite polytypes are often laterally and vertically zoned around ore bodies. Polytypes act as geothermometers indicating temperatures of ore deposition and thus proximity to the hydrothermal fluids during deposition. Visible/infrared reflectance spectroscopy for field identification and mapping of the illite polytypes is evaluated. Laboratory spectral measurements demonstrate that systematic changes occur as the illites progress from the lower temperature, less ordered 1M variety through the higher temperature 2M type. Distinctive absorption features near 1.90 and 2.20 μm and between 2.3–2.5 μm differentiate interlayer water, structural water (OH−), and some octahedral layer characteristics. These changes were also observed in the laboratory using a field portable spectrometer and in situ at a major disseminated gold deposit. The results demonstrate that reflectance spectroscopy can be used to assist gold exploration efforts by providing detailed mineralogical information in real time at the field location. As the new generation of imaging spectrometers is developed, it is likely that subtle spectral differences such as those between the illite polytypes will become useful for remote exploration for gold deposits.

I. INTRODUCTION

This paper describes a technique utilizing X-ray diffraction and reflectance spectroscopy for identification of potential economic ore zones in precious metal deposits. The deposits being studied are those termed “disseminated gold” as the gold found within them is distributed through a high volume of rock and is usually submicroscopic in grain size. A large number of these systems are found concentrated near or within the mountain ranges in the state of Nevada. The Carlin–Trend disseminated gold deposits of north-central Nevada are ideal for study of alteration assemblages. The geology is generally well-known, and gold assays already exist for many areas. The Carlin Gold mine in Eureka County, Nevada, was selected for the initial study because it is recognized as the type locality for the original sediment host disseminated gold deposit.

The clay mineral illite is associated with the gold mineralization in many disseminated gold systems [1]. Illite is an important mineral species in these deposits as it can reflect lateral and vertical zonation around gold ore bodies. Illites change crystal structure with temperature [2], [3] and may act as geothermometers indicating temperatures of ore deposition and proximity to hypogene and supergene fluids. The exploration method described here utilizes the structural ordering of the illite crystal lattice to predict zonal relationships within disseminated gold deposits.

Reflectance spectroscopy and multispectral remote sensing are proven tools for locating and mapping hydrothermally altered rocks [4]–[11]. Broad-band systems such as the Landsat Multispectral Scanner (MSS, four spectral bands) and Thematic Mapper (TM, six spectral bands) provide an operational capability that can be used by the exploration geologist to identify areas for more detailed study. These instruments, however, identify only general mineral groups such as carbonates, clays, and iron oxides. New imaging spectrometer systems with higher spatial and spectral resolution (up to 224 narrow spectral bands) make identification of individual minerals and mineral assemblages possible, thus permitting detailed site-specific mapping of alteration mineralogy.

II. X-RAY DIFFRACTION DETERMINATION OF ILLITE POLYTYPES

X-ray diffraction studies indicate that illite is an important mineral species in disseminated gold deposits, reflecting lateral and vertical temperature zonation around gold ore bodies [12]. To understand better what changes were occurring in the alteration zones of the deposits studied, a reference set of illites was assembled. Fig. 1 is a compilation of X-ray diffractograms showing the two most common illite species or polytypes. These range from the higher temperature well-ordered 2M to the poorly ordered lower temperature 1M variety.

Illite polytypes can be differentiated by automated X-ray diffraction [12]. Several diagnostic polytype peaks occur between 23°–32° 2θ (Fig. 1). The 2M from Japan (Fig. 1, scan A) is a classic high-temperature hydrothermal illite [13]. The 2M illite from the Marblehead location (Fig. 1, scan B) is of sedimentary origin. It is quite different from the Japanese sample in that its structure contains considerably more water from interstratified smectite. This is shown by the broad asymmetrical profile of its 10A (8.9°) peak and the higher background from 2° to 7°. The Silver Hill sample (Fig. 1, scan D), also sedimentary, has
been identified as a 1M_d, which indicates disorder in its stacking. The smaller peaks at ~25.5° and ~27°, diagnostic of the 1M polytype, are not as well-defined as in the Fithian sample (Fig. 1, scan C) which is considered to be 1M. It becomes obvious that extensive variation exists among the illites, and the lower temperature, more disordered varieties are not as easy to identify using X-ray diffraction as the 2M polytypes.

III. SPECTRAL MEASUREMENTS

Although several authors [13]–[17] have briefly discussed illites, no attempt has been made in the literature to document the spectral variation in polytypes systematically. Fig. 2 shows high spectral resolution (3.8 nm resolution, 1 nm sampling) laboratory reflectance spectra of the reference illites shown in Fig. 1. Changes in the illite reflectance spectra are observed as the illites progress from the lower temperature, less ordered 1M variety through the higher temperature 2M type. Distinctive absorption features for illites are summarized in Table I. Features near 1.40, 1.90, and 2.20 μm and between 2.3–2.5 μm differentiate interlayer water, structural water (OH−), and some octahedral layer characteristics. The reflectance spectrum for the 2M illite polytype is similar in appearance to that of muscovite [15]–[18]. The 2M illites typically have a sharp absorption feature at 2.2 μm caused by OH− in the mineral structure [18]. In the 1M polytype, this band is broader and asymmetrical toward longer wavelengths. The 1M_d spectrum from Silver Hill suggests that a secondary absorption feature near 2.5 μm may be the cause of the absorption band asymmetry. The presence of absorption bands at both 1.4 and 1.9 μm is indicative of molecular water as water of hydration or water trapped in the mineral lattice [18]. If the 1.4 and 1.9 μm bands are sharp, as they are in the 2M polytype (spectra A and B, Fig. 2), this indicates that the water molecules are located in well-defined well-ordered sites. When these bands are broad and asymmetrical, as they are in the 1M illite polytypes (spectra C and D, Fig. 2), then they indicate that the mineral is relatively disordered [18]. The occurrence of the 1.4-μm band without the 1.9-μm absorption band indicates the presence of hydroxyl (OH−) and the absence of molecular water. Additional weak absorption bands at 2.35 and 2.45 μm in illites are also better developed in the 2M polytypes (Fig. 2).

Additional illite spectra (Fig. 3) were measured in the laboratory using a field portable spectrometer: the Geophysical and Environmental Research (GER) dual-beam visible infrared spectroradiometer (VIRIS). The VIRIS has lower spectral resolution (~10 nm, with 5 nm sampling in the 2.0–2.5 μm range) than the laboratory instrument used for Fig. 2. This resolution is comparable to that used on NASA’s airborne visible/infrared imaging spectrometer (AVIRIS) and proposed for the high-resolution imaging spectrometer (HIRIS) to be launched during the late 1990’s [19]–[20]. The spectral variability between the 2M and 1M polytypes is still visible at the lower IRIS spectral resolution. The difference between the sharp 2.2-μm band in the 2M polytype versus the markedly asymmetrical 2.2-μm band in the 1M polytype is particularly clear and potentially could be used for remote identification of the polytypes using the imaging spectrometers.

### Table I

<table>
<thead>
<tr>
<th>Feature Position (μm)</th>
<th>Physical Basis</th>
<th>Strength (2M)</th>
<th>Strength (1M)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.4</td>
<td>molecular water</td>
<td>2M = sharp</td>
<td>1M = broad asymmetrical</td>
</tr>
<tr>
<td></td>
<td>+ structural water</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.9</td>
<td>molecular water</td>
<td>2M = sharp</td>
<td>1M = broad asymmetrical</td>
</tr>
<tr>
<td>2.2</td>
<td>OH− structural water</td>
<td>2M = sharp</td>
<td>1M = broad asymmetrical</td>
</tr>
<tr>
<td>2.3–2.5</td>
<td>octahedral layer cations</td>
<td>2M = better definition</td>
<td></td>
</tr>
</tbody>
</table>
IV. CARLIN DEPOSIT ILLITES

X-ray diffraction work at Carlin indicates that the 2M illite polytype is associated with proximity to high grade gold ore zones [12]. Fig. 4 contrasts the X-ray diffraction data for a 2M illite (upper scan) from a high gold bearing zone with a disordered illite (lower scan) from a barren silica-flooded alteration zone at the Carlin Mine. The contrast between the polytypes is striking.

Reflectance spectra were measured \textit{in situ} in the main Carlin pit with another GER portable reflectance spectrometer: the single-beam visible/infrared intelligent spectroradiometer (SIRIS) (Fig. 5). The spectral resolution of this instrument is nearly identical to that of the VIRIS instrument used for the laboratory spectra shown in Fig. 3. The spectra were measured in October, however, with a low sun angle and therefore tend to have a lower signal-to-noise ratio. Field spectrum C10885 is from alteration zone 3 of Bakken and Enaudi [14] (moderately silicified laminated beds), a typically high gold zone. The well-developed absorption bands at 2.2, 2.35, and 2.45 \(\mu\)m indicate that it is a 2M polytype. Field spectrum CAR88B, which exhibits less well-developed spectral features, is from alteration zone 5 (strongly silicified clastic beds) [14], a zone typically having low gold values. Both of these identifications are substantiated by the X-ray diffraction measurements. Although the difference between the reflectance spectra are quite subtle in this case, they do show that the polytypes can be identified and mapped in the field and that, with higher resolution field instruments, this method has potential as an exploration and mapping tool.

V. CONCLUSION

This combined X-ray diffraction/reflectance spectroscopy study of illite polytypes has established that sufficient spectral differences exist to allow identification using near-infrared reflectance spectroscopy. Field spectrometers have been used successfully to identify subtle distinctions between the polytypes. Additional work is required to develop this into a routine method, however, field reflectance spectroscopy can eventually be used operationally to assist exploration efforts by providing detailed mineralogical information in real time at the field location. The potential exists, given sufficient spectral and spatial resolution and instrument signal-to-noise ratio, to identify these polytypes from aircraft or satellite imaging spectrometers such as AVIRIS or HIRIS.

ACKNOWLEDGMENT

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REFERENCES


Fred A. Kruse received the B.S. degree in geology from the University of Massachusetts, Amherst, in 1976. He earned both the M.S. (1984) and Ph.D. degrees (1987) in geology from the Colorado School of Mines, Golden.

He served in the United States Army Corps of Engineers (1976–1981) and with the Remote Sensing Section of the U.S. Geological Survey, Branch of Geophysics (1982–1987). He is currently a Research Associate at the Center for Study of Earth from Space (CSES) at the University of Colorado, Boulder. His research includes developing models and techniques for use of multispectral remote sensing for mineral exploration, characterization and quantification of the electromagnetic properties of Earth-surface materials, development of artificial intelligence for geologic mapping, and investigating geologic applications of imaging spectrometers and Geographic Information Systems (GIS).

Phoebe L. Hauff did undergraduate work at the University of California at Berkeley and Colorado State University, and has done graduate work at the University of Colorado, Boulder. She worked for the U.S. Geological Survey (1968–1983) as a Mineralogist and supervised the Geologic Division Mineral Analysis Laboratory (1977–1983). Presently, she is a Professional Research Assistant and Supervisor of the Mineralogical Research Laboratory for the Center for the Study of Earth from Space at the University of Colorado. She is a Clay Mineralogist with interest in economic geology, specifically clays in mineralized, hydrothermal systems concentrating in disseminated gold deposits. Her specific areas of instrumental expertise are in X-ray spectroscopy and electron-beam microscopy. She has worked extensively in illicite and mixed layer clay suites, with particular emphasis on paragenetic sequences and resolution of polytypes. One current and important emphasis is on the integration of reflectance spectroscopy with detailed mineral characterization and the application of this to field-based problems.