Overview

Visible and near infrared reflectance spectroscopy is an accepted method for identification of pathfinder minerals that serve as exploration vectors. The method is now widely used to assist in new deposit discovery as well as to provide key mineralogical information during mine development. The combination of portable instrumentation and automated analysis methods now allow for real-time identification of pathfinder minerals as well as the determination of associated geochemical and geothermal parameters.

The reflectance spectrum of white micas and chlorite group minerals contain information related to composition, crystallinity and metamorphic grade. The wavelength positions of Al-OH, Fe-OH and Mg-OH absorption features are highly correlated to chemical composition, b unit cell dimension, and Kübler index values. For white micas, both the Na-to-K ratio in interlayer sites and the degree of Fe or Mg substitution for Al in the octahedral layer influence the position and shape of the Al-OH absorption feature. The depth of absorption features associated with structural water in these minerals varies with thermal maturity. With the dehydration associated with increasing metamorphic grade, the ratio of the depth of the water absorption feature to the depth of Al-OH, Fe-OH and Mg-OH features decreases. Together, these parameters enable detailed mapping of geochemical and geothermal gradients, and have contributed to the discovery and development of a wide range of economic deposit types.

Pathfinder minerals that serve as vectors to economic deposits are present many geologic systems. Rapid reflectance spectroscopy enables their identification, as well as the determination of their associated compositional, crystallinity, and thermal maturity parameters, and provides the means to map geochemical and geothermal gradients in these systems. In many cases, the relationship between the properties of these minerals and the proximity to the ore zone provides a very useful exploration vector.

Automated Mineral Identification Algorithm

When examining a reflectance spectrum in an attempt to identify minerals contained in geologic samples, it is the shape and location of absorption features that provides the most diagnostic information. Any given absorption feature is produced either by a specific chemical bond or element within a mineral’s crystal lattice. While many minerals share the same basic chemical bonds, the structure of a mineral’s crystal lattice surrounding the bond influences the shape and position of the absorption feature to a degree that is usually sufficient to uniquely identify the mineral.

The automated mineral identification algorithm matches the features in a measured reflectance spectrum to a library of ~550 spectra representing ~125 different geologically important minerals. The samples used for the spectral library are from several well characterized collections, including USGS in Denver and the Univ. of Arizona RRUFF collection at the Univ. of Arizona. The collected unknown spectrum is analyzed using this library of known minerals:

- The best match library spectrum is fit to the collected spectrum.
- If the match is of sufficient quality, the best fit spectrum is subtracted from the collected unknown spectrum.
- Using the remainder of the unknown collected spectrum, the process is repeated to generate up to 2 mineral matches in the VNIR (250-1000 nm) and 5 matches in the SWIR (1000-2500nm) portion of the spectrum.

Spectral Scalars

A scalar is a parameter computed from the reflectance spectrum that describes some property of a mineral present in the sample. Once the mineralogy is determined, scalars provide information about crystallinity, composition and/or geothermal condition that serve as additional vectors to potential mineralization.

Scalars are shown on the right side of screen and describe properties of the identified minerals. Some scalars, such as the Al-OH and Mg-OH, are computed from the wavelength of a feature in the spectrum. Others, such as the ISM, are measures of depth or the relative depths of features. Below are some of the more commonly used scalars:

Al-OH Scalar: Many Al-OH containing minerals have subtle compositional variations that are indicative of the chemical alteration fluids. Since these compositional variations result in wavelength shifts of the Al-OH absorption feature, the position of this feature is an indicator of geochemical conditions at the time of the alteration event.

How is it computed: The value of the Al-OH scalar is the wavelength of the minimum reflectance in the 2160 to 2240 nm wavelength range.

Example Application: Various white micas form under different pH and temperature conditions. Once a mineralogical understanding of a deposit is gained, monitoring the Al-OH scalar can serve as a vector to mineralization. Numerous deposits exhibit systematic shifts in the Al-OH scalar. In the Cu-Au deposits at Western Tharsis, Tasmania, and Highwy Reward, Queensland, Australia, Herrmann et al. (2001) saw a consistent pattern of slightly sodic muscovite (shorter Al-OH values) proximal to the ore zone progressing to more phengitic (longer Al-OH values) white micas peripheral to the ore zone.

ISM (Illice Spectral Maturity) Scalar: Minerals in the illicite-muscovite group are produced over a broad range of geochemical conditions. With increasing metamorphic grade, changes in their reflectance spectrum track increasing dehydration and crystallinity. ISM scalar values greater than one are indicative of a higher metamorphic grade, while values less than one are associated with those produced by lower temperature or alteration events.

How is it computed: The value of the ISM scalar is the ratio of the depth of the Al-OH absorption feature divided by the depth of the water absorption feature.

Example Application: The ISM scalar is related to depth of burial in thrust-belt settings and the evaluation of sedimentary basins for hydrocarbon potential, and the mapping of hydrothermal corridors (Doublier et al., 2010). Guzman-Garcia (2013) mapped alteration intensity in the high-sulfidation Au and low-sulfidation Pb-Zn-Ag-Au deposits of the Rodalquilar Caldera complex in southern Spain using this scalar.

Mg-OH Scalar: Many Mg-OH containing minerals have subtle compositional variations that are indicative of alteration fluid chemistry. Wavelength shifts of the Mg-OH absorption feature near 2350 nm serves as an indicator of geochemical conditions.

How is it computed: The value of the Mg-OH scalar is the wavelength of the minimum reflectance in the 2310 to 2370 nm wavelength range.

Example Application: White et al. (2010) used wavelength of the Mg-OH feature to assist in the delineation of ore horizons in the Damang gold deposit, Ghana. Amero (2007) used the Mg-OH and Fe-OH wavelength scalars to variations in chlorite composition in association with a VMs-type deposit near the Gorob-Hope area of Namibia.

Fe3+ (Fe2+3 mineral type) Scalar: Iron oxides and oxyhydroxides are produced under a wide range of geochemical conditions. All the Fe2+3 minerals have a similar feature in the 750-1000 nm region. The position of this feature shifts depending on the identity of the Fe2+3 mineral. The hydroxide Fe2+3 minerals typically having Fe3t values >900 nm and the oxide Fe2+3 minerals with values <900 nm.

How is it computed: The value of the Fe3t scalar is the wavelength of the minimum reflectance in the 750 to 1000 nm wavelength range.

Example Application: This scalar can be useful for mapping of the oxidized zone of porphyry systems (Accame et al. 1983). Environmental applications, such as mapping of active drainage are possible since the mineralogy of Fe3t precipitates directly correlates to the pH of surface waters (Anderson & Robbins, 1998).

Summary

The ability to rapidly perform identification of pathfinder alteration minerals using reflectance spectroscopy is an integral to the wide-spread adoption of reflectance spectroscopy by mineral exploration organizations. The ability to perform automated analysis of dominant alteration mineralogy using the use of reflectance spectroscopy by a wide range of exploration personnel.

White Micas

The white micas are a diverse group of phyllosilicate minerals that include the true micas paragonite, muscovite, and phengite, as well as the K-deficient mica illite. Using the Al-OH scalar it is possible to track geochemical conditions while the illice Spectral Maturity (ISM) scalar provides an indicator of thermal maturity.

The wavelength of the Al-OH feature near 2200 nm varies with white mica composition (Clark et al. 1990). The sodic white mica paragonite and the corresponding paragonitic illite have the lowest wavelength features in the white mica group. The low silica / high aluminum potassic white mica phengite and phengitic illite have the highest wavelength features, while the high silica / low aluminum potassic white mica muscovite and illite have features that are intermediate in wavelength. These Al-OH wavelength shifts are seen below in the reflectance plots of a representative selection of white micas contained in the TerraSpec Halo mineral library.

The Al-OH feature wavelength correlates well with both the white mica’s aluminum content and b unit cell dimension (Velde 1980). As silica in the octahedral layer increases, octahedral aluminum (and other cations in the octahedral layer such as Cr3+ and Fe2+3) decrease. The inversion relationship between silica content and the wavelength of the 2200 nm Al-OH feature (see the figures below) is expected given the corresponding changes in b cell dimension.

With increasing metamorphic grade, illite converts to muscovite via dehydration and potassium enrichment (Eberl and Velde 1989). The Kübler Index (Kübler, 1964) is widely used to track this change with increasing metamorphic grade (Merriman & Peacok, 1999).

The NIR reflectance spectrum of white micas is strongly influenced by metamorphic grade. The key parameters are the depths of the 2200 nm Al-OH absorption feature and the 1900 nm H2O feature. With increasing thermal maturity, Al-OH feature depth increases relative to the H2O feature depth (Cuddy et al., 2008).