

REFLECTANCE SPECTRA OF SOME ALTERATION MINERALS -
A CHART COMPILED FROM PUBLISHED DATA
0.4 μ m - 2.5 μ m

by

Keenan Lee

U.S. Geological Survey, Denver, Colorado 80225
Colorado School of Mines, Golden, Colorado 80401

and

Gary L. Raines

U.S. Geological Survey, Denver, Colorado 80225

.Open-File Report 84-96

1984

This report is preliminary and has not been edited or reviewed for conformity with U.S. Geological Survey standards.

ABSTRACT

Reflectance spectra have been published for many minerals that are products of hydrothermal alteration and other geologic processes. These spectra have been published in diverse journals, at different scales, and covering different spectral regions. The purpose of this report is to bring together some of the most useful mineral spectra in one large reference chart. The chart includes reflectance spectra, at a scale of 0.2 μ m/inch, for alunite, calcite, diaspore, gypsum, jarosite, four micas, three clays, and four iron oxides.

INTRODUCTION

This chart contains reflectance spectra of a suite of minerals that commonly are associated with hydrothermal alteration. Included are minerals that form during the alteration process (for example, kaolinite) and during subsequent weathering (for example, goethite). For the most part, these mineral spectra are well known, and with the exception of the ferrihydrite spectrum, all have been published previously. The difficulty with the spectra, as published, lies in their differing scales and lack of reference grids for determining wavelength.

This report does not represent original research results; mineral spectra are taken from the work of others. In all cases, sources are cited, and the reader interested in more details may refer to the literature. In some cases, it was found useful to combine published work with our laboratory data, simply for clarity. For example, diagnostic spectral features for hematite and goethite occur at wavelengths shorter than 1.2 μ m. Hunt and Ashley (1979) show these absorption features well (considerably more clearly than the 0.4 - 2.5 μ m spectra of Hunt and others, 1971a), but their spectra go only to 1.3 μ m. For clarity then, we have chosen Hunt and Ashley's data and added our data from 1.3 to 2.5 μ m.

All reflectance spectra represent measurements of actual samples. Thus the spectrum labeled "chlorite" represents an actual specimen of a mineral in the chlorite group. More research is warranted on spectral variation within these mineral groups.

Where the wavelengths of reflectance minima are given to the third decimal place (nearest nanometer), the figures come from Hunt (1979, Table 1). Where wavelength is given to the second decimal place (nearest 10 nanometers), the figure was determined by measurement from a published spectrum or from our lab measurements.

The following discussion of generalized spectral features is a brief review of material documented in many individual papers. A much more complete synthesis of these spectral properties is found in Hunt (1980).

GENERAL SPECTRAL FEATURES

Numerous spectral features in the 0.4-2.5 μ m region are indicative or diagnostic of minerals commonly found in hydrothermally altered rocks. Those spectral features that appear at wavelengths shorter than 1.2 μ m are caused by electronic transitions, almost entirely associated with iron. Beyond 1.2 μ m,

useful spectral features are caused by vibrational processes occurring in molecular groups, especially in hydroxyl-bearing minerals.

In the 0.4-1.2 μ m region, electronic transitions in iron minerals yield fairly diagnostic spectral features. The intervalence charge transfer between O^{-2} and Fe^{+3} causes an intense absorption, centered in the ultraviolet, that produces steep slopes in the visible reflectance of the iron minerals, which in turn produce the characteristic yellow-red colors. Superimposed on this broad, deep absorption band are spectral features caused by crystal field transitions involving Fe^{+3} in crystalline structures. A small, but sharp absorption at 0.43 μ m is diagnostic of jarosite. A weak absorption around 0.65 μ m, appearing usually as a shoulder, is more common in goethite than in hematite. A minimum at 0.85 μ m serves to identify hematite, whereas a broader minimum beyond 0.9 μ m is characteristic of goethite. The synthetic solidified hydrous ferric oxide gel shows absorption in the visible part of the spectrum due to the O^{-2} to Fe^{+3} charge transfer, but lacks the crystallinity to produce strong crystal field transitions around 0.9 μ m, producing only a broad shoulder at this wavelength. Ferrihydrite(?) most closely resembles the hydrous ferric oxide gel.

The spectral region from 1.2-1.6 μ m shows features caused primarily by overtones and combination tones of the fundamental OH-stretching modes (Hunt, 1979). Gypsum has a unique band at 1.2 μ m, caused by its molecular water, and alunite has a combination Al-O-OH and OH absorption feature at 1.27 μ m (Hunt and others, 1971b). Laboratory analyses can beneficially use the 1.4 μ m band for all OH-bearing minerals, including, possibly, ferrihydrite. Although numerous spectral features occur in this wavelength region that help to identify alteration minerals in the laboratory, atmospheric absorption by water vapor and CO_2 around 1.4 μ m severely restricts remote sensing. The absorption bands for alunite at 1.424 μ m and 1.467 μ m, just outside the atmospheric band, might be useful in remote sensing. Jarosite also absorbs at 1.475 μ m, but lacks the 1.42 μ m feature.

Most minerals show a reflectance maximum near 1.6 μ m, which, when combined with high atmospheric transmittance, serves as a useful reference for remote sensing. Only alunite and gypsum have absorption features in this spectral region, but their minima, 1.762 μ m and 1.745 μ m respectively, fall on the band edge of atmospheric water absorption.

The 1.8-2.0 μ m region is useful only for lab analyses, because water vapor absorption renders the atmosphere opaque. Most mineral spectra with features in this region have combination tones involving molecular water, such as montmorillonite, 1.899 μ m, gypsum, 1.93 μ m, and probably ferrihydrite, 1.92 μ m. Jarosite has a characteristic Al-OH doublet at 1.849 and 1.862 μ m, and calcite shows two fairly weak CO_3^{-2} absorption bands at 1.875 and 1.993 μ m.

The 2.0-2.5 μ m region is one of the more promising spectral regions for remote sensing, with well defined Al-OH absorption bands near 2.2 μ m. Minerals that exhibit these features include: lepidolite, 2.20 μ m; muscovite, 2.208 μ m; pyrophyllite, 2.166 μ m; montmorillonite, 2.205 μ m; kaolinite, 2.162 and 2.209 μ m doublet; and alunite, with a 2.165 and 2.208 μ m doublet. A similar band, related to the Mg-OH association, occurs near 2.3 μ m, for example, phlogopite at 2.33 μ m and chlorite at 2.32 μ m. Jarosite, an Fe-OH mineral, has a spectral band centered at 2.264 μ m, intermediate to the Al-OH and Mg-OH minerals. The

only other spectral feature in this region, not related to OH groups, is the CO_3^{-2} absorption band, as shown by calcite at $2.337\mu\text{m}$.

SOURCES OF REFLECTANCE SPECTRA

All spectra shown on the chart have appeared in published articles with the exception of that of ferrihydrite (?) and partial spectra generated at the U.S.G.S. to complete some spectra over the full wavelength range. The source of each mineral, where known, is given below, and the method of spectral measurement is described briefly. Any use of names or trademarks in this publication is for descriptive purposes only and does not constitute endorsement by the U.S. Geological Survey.

Alunite

Hunt and others' (1971b) alunite Sample No. 295B, from Utah, was ground in an aluminum mortar and sized in standard sieve sets. The particulate alunite was then measured on a Cary Model 14 spectrophotometer with a bidirectional modification (Hunt and Ross, 1967). The reflectance was run from $0.35\mu\text{m}$ to $2.5\mu\text{m}$, and the amplitude of the spectrum is reflectance relative to freshly prepared MgO .

Calcite

Colorless and transparent calcite (Hunt and Salisbury, 1971; No. 48B, Cherokee County, Kansas) was used for this spectrum, which shows the characteristic carbonate bands beyond $1.8\mu\text{m}$. A broad, weak band at $1.1\mu\text{m}$ and the strong ultraviolet absorption are caused by minor ferrous ion (0.09% by weight) substituting for calcium. Measurement procedures were as described above.

Chlorite

Hunt and Salisbury (1970) published two spectra for chlorite; the spectrum from the purer sample, chlorite Sample No. 179B from Colorado, is reproduced on the chart. The actual curve shown was run by F. Kruse, USGS, referenced to Halon, but it was the same sample used by Hunt and Salisbury, and the spectra appear essentially the same. The weak bands at 0.7 and $0.9\mu\text{m}$ are due to ferric ions, whereas the band at $1.1\mu\text{m}$ is due to ferrous ions (Hunt and Salisbury, 1970). The small, sharp absorption band near $1.4\mu\text{m}$ is caused by OH^- , as are the deeper features beyond $2.2\mu\text{m}$. The main absorption feature at $2.32\mu\text{m}$ probably represents a Mg-OH combination, similar to the phlogopite.

Diaspore

The sample of diaspore was Hunt and others' (1971a) Sample No. 416B, from Rosebud, Missouri. From their description, the diaspore was "not a pure sample, but rather a typical mixture of bauxite minerals, probably including gibbsite, kaolinite and a very small amount of ferruginous material." Measurement procedures were as described above for alunite.

Ferric Oxide Gel, Hydrous

Evans and Adams (1980) state that "amorphous ferric iron oxide-rich materials are common end products of terrestrial weathering". To provide a spectral characterization of such material, Evans and Adams synthesized the solid hydrous ferric oxide gel "by precipitating dissolved FeCl_3 in a strong base". The gel was "dissolved in excess NaOH with sodium silicate and precipitated in HCl to form iron and silica gels". The gel was solidified, and its diffuse reflectance was measured on a Beckman DK-2A ratio-recording spectrophotometer. The spectrum was reported as "scaled reflectance", from $0.4\mu\text{m}$ to $2.5\mu\text{m}$.

Ferrihydrite (?)

The ferrihydrite (?) sample was provided by Les McFadden, University of New Mexico, as a probable ferrihydrite. The sample, a silty sand from the Mojave Desert, gave analytical results of $\text{Fe}_2\text{O}_3 = 1.51$ (wt.%), where Fe_2O_3 was described (L. McFadden, written commun., 1982) as "oxalate-extracted iron oxyhydroxides, most of which soil chemists believe is ferrihydrite." This sample was measured at the U.S.G.S. using a Beckman UV5270 with an integrating sphere to give total reflectance, measured from $0.4\mu\text{m}$ to $2.5\mu\text{m}$, and reported as reflectance relative to BaSO_4 .

Goethite

The short wavelength (0.4 – $1.3\mu\text{m}$) end of the spectrum is from Hunt and Ashley (1979). The specific sample was not identified, and measurement techniques similarly were not described. Perhaps this spectrum came from Hunt and others' (1971a) goethite Sample 36 from Biwabik, Minnesota. (Comment: This latter published spectrum was not used on the chart because of poor detail.) The long-wavelength portion of the spectrum was run at the U.S.G.S., using methods as described above for ferrihydrite, on a sample of crushed specular goethite obtained from the Colorado School of Mines Geology Museum.

Gypsum

The short-wavelength end of the spectrum (0.4 – $1.3\mu\text{m}$) was recorded at the U.S.G.S., using methods as described above for ferrihydrite, on a sample of alabaster obtained from the Colorado School of Mines Geology Museum. The spectrum beyond $1.3\mu\text{m}$ is from Hunt's (1979) "homogeneous, well-characterized sample", measured as described above for alunite.

Hematite

The short-wavelength end of the spectrum (0.4 – $1.3\mu\text{m}$) is from Hunt and Ashley (1979). The specific sample was not identified, and measurement techniques similarly were not described. The long-wavelength portion of the spectrum was run at the U.S.G.S., using methods described above for ferrihydrite, on a sample of oolitic hematite (from Alabama) obtained from the Colorado School of Mines Geology Museum. (See "comment" under Goethite.)

Jarosite

This spectrum is from Hunt and Ashley (1979). The specific sample was not identified, nor were the measurement techniques. Hunt and others (1971b) published a spectrum that was better documented, but which, unfortunately, showed little detail.

Kaolinite

This spectral reflectance curve is from Hunt and Salisbury's (1970) kaolinite Sample No. 218B from Macon, Georgia. The measurement procedure was that described above for alunite.

Lepidolite

This spectrum is from Hunt and others' (1973) lepidolite Sample No. 167B, from Keystone, South Dakota. The authors note that the minor absorption features at wavelengths shorter than $0.8\mu\text{m}$ are due to substituted ferric ion. The spectrum derives from measurement techniques described above for alunite.

Montmorillonite

The montmorillonite spectrum is from Hunt and Salisbury's (1970) Sample No. 222B from Amory, Mississippi. Measurement techniques were those described above for alunite. The authors comment that the weak absorption bands near $1.0\mu\text{m}$ and $0.5\mu\text{m}$ are probably due to substituted ferrous ion.

Muscovite

This spectrum is from Hunt and Salisbury's (1970) muscovite Sample No. 24 from Effingham Township, Ontario. Measurement techniques were those described above for alunite.

Phlogopite

The phlogopite spectrum is from Hunt and others' (1973) Sample No. 23B from Ontario. See alunite for sample preparation and measurement methods.

Pyrophyllite

The spectral reflectance of pyrophyllite was measured from Hunt and others' (1973) Sample 221B from Robbins, North Carolina. Measurement techniques were those described above for alunite.

NOTES ON CHART CONSTRUCTION

The compilation of reflectance spectra of alteration minerals onto a common chart was done to provide a reference that would (a) enable comparisons to be made between different minerals and (b) permit comparisons of spectra of "unknown" minerals and rocks with known standards. For both purposes, a large scale is preferred; for the latter purpose, a scale of $0.2\mu\text{m}/\text{inch}$ was chosen to match the scale commonly used for spectra at the Remote Sensing Section of the U.S. Geological Survey. The finer grid lines at $0.02\mu\text{m}$ intervals permit

wavelength resolution of 0.01 μ m.

The vertical dimension of the chart is "relative reflectance". There can be no absolute scale, because the actual percentage reflectance is variable, depending upon method of measurement (bidirectional, diffuse, total), reference standard used (MgO, BaSO₄, Halon), nature of measured surface (rough, polished, particulate), particle size, and whether the mineral is transparent, opaque or trans-opaque.

REFERENCES CITED

- Evans, D. L., and Adams, J. B., 1980, Amorphous gels as possible analogs to martian weathering products: Proceedings 11th Lunar Planetary Science Conference, p. 757-763.
- Hunt, G. R., 1979, Near-infrared (1.3-2.4 μ m) spectra of alteration minerals - potential for use in remote sensing: Geophysics, v. 44, no. 12, p. 1974-1986.
- _____, 1980, Electromagnetic radiation: the communication link in remote sensing, in Siegal, B. S., and Gillespie, A. R., eds., Remote sensing in geology: New York, John Wiley, p. 5-45.
- Hunt, G. R., and Ashley, R. P., 1979, Spectra of altered rocks in the visible and near-infrared: Economic Geology, v. 74, p. 1613-1629.
- Hunt, G. R., and Ross, H. P., 1967, A bidirectional reflectance attachment for spectroscopic measurements: Applied Optics, v. 6, p. 1687-1690.
- 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.
- _____, 1971, Visible and near-infrared spectra of minerals and rocks: II. carbonates: Modern Geology, v. 2, p. 23-30.
- 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-infrared spectra of minerals and rocks: VI. additional silicates: Modern Geology, v. 4, p. 85-106.