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The ASTER Spectral Library Version 2.0

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Abstract

The Advanced Spaceborne Thermal Emission Reflection Radiometer (ASTER) on NASA's Terra platform has been widely used in geological and other science studies. In support of ASTER studies, a library of natural and man-made materials was compiled as the ASTER Spectral Library v1.2 and made available from http://speclib.jpl.nasa.gov. The library is a collection of contributions in a standard format with ancillary data from the Jet Propulsion Laboratory (JPL), Johns Hopkins University (JHU) and the United States Geological Survey (USGS). A new version of the library (v2.0) is now available online or via CD, which includes major additions to the mineral and rock spectra. The ASTER library provides a comprehensive collection of over 2300 spectra of a wide variety of materials covering the wavelength range 0.4-15.4 µm.

Introduction

Remote-sensing measurements made *in situ* and from airborne and spaceborne platforms provide valuable information for research studies. The Advanced Spaceborne Thermal Emission Reflection Radiometer (ASTER) on NASA's Terra platform provides such measurements and has been widely used in geological and other studies (Rowan et al. 2003; Hellman and Ramsey 2004; Hubbard and Crowley 2005; Vaughan et al. 2005; Ducart et al. 2006; Zhang et al. 2007; Rockwell and Hofstra 2008; Vaughan et al. 2008). ASTER is a multi-spectral imager, which provides observations in the visible and near infrared (VNIR, 0.4-1.0 μm), the short wavelength infrared (SWIR, 1.0-2.4 μm) and the thermal infrared (TIR, 8-12 μm) parts of the electromagnetic spectrum. As part of the ASTER activities, a library of over 2000 spectra of natural and man-made materials was compiled as the ASTER Spectral Library and made available from http://speclib.jpl.nasa.gov. The library includes contributions from the Jet Propulsion Laboratory (JPL), Johns Hopkins University (JHU) and the United States Geological Survey (USGS). The library includes spectra of rocks, minerals, lunar soils, terrestrial soils, manmade materials, meteorites, vegetation, snow and ice covering the visible through thermal infrared wavelength region (0.4-15.4 μm). The first version of the library (version 1.2) was released in July 1998 and since that time over 4000 copies of the spectral library have been distributed to over 90 countries. More recently, complimentary spectral libraries have been made available from other collections, for example: http://speclib.asu.edu (Christensen et al. 2000), http://pds.geosciences.wustl.edu/missions/mro/spectral_library.htm and http://speclab.cr.usgs.gov (Clark et al. 2007).

The JPL portion of the ASTER spectral library has now been extensively updated and the version number of the library increased to Version 2. In this paper, we summarize the additions and changes in Version 2. Additions include new spectra from 0.4-15.4 µm of 100 rock samples and new measurements of the original 160 JPL mineral samples (3 particle size fractions) found in version 1.2 of the library. Initially, the approach used to identify and measure the JPL portion of the library is described. This is followed by a description of the new library organization. No new contributions have been included from the USGS and Johns Hopkins University collections.

JPL Library Source Materials and Purity

The minerals samples used to generate the JPL mineral spectra were obtained from the Ward's Natural Science Establishment, the Burnham Mineral Company, the Source Clay Mineral Repository and/or from the JPL collection. The characteristics of these minerals are described in the ancillary data accompanying the ASTER Spectral Library.

The purity and composition of each mineral sample was determined using standard X-ray Diffraction analysis. Diffraction lines were identified by comparison with the Mineral Powder Diffraction File Search Manual and Data Book (Standards 1980). Sample purity was assessed based on the number and intensity of diagnostic peaks. Additionally, chemical composition data were acquired by Cameca CAMEBAX electron microprobe analysis at the University of California, Los Angeles for the mineral samples that were known to deviate significantly from idealized end-member compositions.

The rock samples used to generate the JPL rock spectra were obtained from the Ward's 100 North American Rock Collection, which contains 100 examples of the most common igneous, metamorphic and sedimentary rocks. Detailed information, including microscopic and megascopic descriptions is available for each sample from Wards and has been included with the ancillary data accompanying the library.

JPL Sample Preparation

The mineral samples at JPL were prepared by crushing the samples with a steel percussion mortar. For 135 of these minerals, where there was sufficient quantity of the sample, the crushed samples were ground with mortar and pestle and wet sieved with distilled water or 2-proponal to achieve size fractions of 125-500 µm, 45-125 µm and < 45 µm. Three particle size fractions were measured to demonstrate the effect of particle size on reflectance (Hunt and Vincent 1968; e.g. Salisbury and Eastes 1985). Particulate samples were poured into aluminum sample cups that measure 3.2 cm in diameter and 0.5 cm in depth. The upper surface of the sample was smoothed with a metal spatula with care taken not to introduce preferred grain orientation.

The Wards' rock samples are approximately 3" x 4" and fresh surfaces were analyzed as whole rock samples.

JPL Sample Measurement

The spectra were acquired in two wavelength ranges: 0.4-2.5 µm and 2-15.4 µm. Version 1.2 of the spectral library contains hemispherical reflectance data of minerals that were measured with the Beckman UV5240 Spectrophotometer from 0.4-2.5 µm.

The Beckman incorporates a single pass monochromator and utilizes a diffraction grating as its dispersing element. The sampling interval is 0.001 µm from 0.4-0.8 µm and 0.004 µm from 0.8-2.5 µm. The instrument was modified with an integrating sphere rotated 90 degrees, which facilitates the measurement of particulate samples by allowing the sample holder to remain in a horizontal position. The sample was placed in the sample compartment where it and a Halon reference standard were illuminated alternately by monochromatic radiation from a high-intensity halogen lamp source.

Directional hemispherical reflectance was also measured in this wavelength range with a newer Perkin-Elmer Lambda 900 UV/VIS/NIR spectrophotometer equipped with a gold-coated integrating sphere manufactured by Labsphere (Salisbury et al. 1991; Johnson et al. 1998). The spectrophotometer is an all-reflecting double monochromator optical system in which holographic gratings are used in each monochromator for the UV/VIS and NIR range. Spectra are acquired at 0.01 nm increments with an integration time of 0.52 s from 0.05 to 5.00 nm (UV/VIS) and at 0.04 nm increments for 2.12 s from 0.2 to 20 nm (NIR). The samples are illuminated by radiation from either a deuterium (UV) or halogen (VIS and NIR) source. A Peltier-cooled PbS detector is utilized for the NIR spectral range and a photomultiplier is utilized for the NIR range.

Mineral and rock samples spectra were acquired in the infrared, from 2.5-15 µm, with the Nicolet 520FT-IR spectrometer equipped with a Labsphere integrating sphere. 1000 scans at 4 cm^{-1} spectral resolution were acquired over ~15 minutes per sample and averaged together. The Nicolet FT-IR utilizes an internal HeNe laser to monitor the position of the moving mirror within each scan. Since the wavelength of the laser is accurately known, this laser also provides an internal wavelength calibration standard. A background spectrum was acquired using a diffuse gold plate and used to remove background radiation from the sample spectrum.

JPL Standards and Potential Errors

Standards were measured multiple times during the acquisition of sample spectra to ensure that there were no major deviations in instrument performance. Liquid water and pyrophyllite were used as standards for the VIS and IR spectral ranges respectively. The pyrophyllite spectra showed some variation in absolute reflectance as a function of variations in reflected light but there was no variation in spectral shape or feature position (Figure 1A). The liquid water spectra had negligent variability with each spectrum falling within the noise of another (Figure 1B).

Library Organization

There is one spectrum per file and a naming convention is used that allows each filename to be unique. Specifically, the filename describes the laboratory where the sample was measured, the spectrometer used, the type of sample, the class and subclass if appropriate, followed by the grain size and finally the sample number. The spectral files are given the suffix “spectrum.txt” and the ancillary data are given the suffix “ancillary.txt”. The ancillary file includes information that is not part of the standard spectral file format, e.g. X-Ray information. For example, the spectrum of 125-500 µm anhydrite ($CaSO_4$) measured at JPL on the Perkin-Elmer spectrometer (VNIR-SWIR) will have the filename jpl.perkins.mineral.sulfate.none.coarse.so01ac.spectrum.txt. The naming convention is further explained in Table 1. Included with each spectral text file is header information specific to that file. The header information is in a standard format and contains such information as the sample name, type, class, particle size, wavelength range, and sample origin. Examples of the header information available for each mineral and rock sample are given in Table 2. The spectral files always have the same number header lines.

Ordering the Library

The complete ASTER Spectral Library is available on CD and can be ordered from http://speclib.jpl.nasa.gov/. The data are contained on the CD as text files, which are named to describe each file uniquely as noted in the library organization section. Individual spectra can also be viewed and downloaded at the website.

Results and Discussion

Samples of the library spectra from JPL measurements are shown in Figure 2 (minerals) and 3 (rocks). Figure 2A and 3A show the 0.25-2.5 µm spectral range and Figure 2B and 3B show the 2-15 µm spectral range. The IR rock spectra have increased water vapor, which causes a noticeable saw tooth appearance in the short wavelength region of the spectra (2-3 µm). For most samples, there is a slight offset between the two spectral ranges due to the difference in the reference standard (halon vs. gold). In order to avoid this offset, the spectra provided by the JHU Spectral Library were normalized to a gold standard, thereby shifting the VIS/SWIR spectra to high reflectance. No similar attempt was made to normalize the spectra measured at JPL.

Surface radiance collected by ASTER in the TIR is converted to emissivity using the temperature emissivity separation (TES) (Gillespie et al. 1998). Typically, for comparison of surface emissivity to laboratory data, Kirchhoff's Law ($R = 1 - \varepsilon$) (Nicodemus 1965) is used to convert to emissivity from hemispherical reflectance. With the addition of the data from JHU Spectral library, the IR spectra for most samples are available in both bidirectional and hemispherical reflectance. However, Salisbury et al. (1994) have shown that the directional nature of the radiation measured by biconical reflectance does not adequately account for radiation scattered in all directions. Therefore, the newer hemispherical reflectance spectra acquired at JPL provide a more accurate comparison to ASTER surface emissivity. The biconical reflectance data are included since they cover an expanded spectral range.

Summary and Conclusions

Version 2 of the ASTER Spectral Library contains over 2300 spectra. This new version includes major additions to the mineral and rock spectra. The ASTER library continues to provide one of the most comprehensive collections of spectra covering the wavelength range 0.4-15.4 µm and includes spectra of minerals, rocks, lunar and terrestrial soils, manmade materials, meteorites, vegetation, snow and ice.

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Figure Captions

Figure 1. Mean and standard deviation of pyrophyllite and distilled water standards measured during sample measurement. Pyrophyllite was used for the visible to shortwave infrared (0.4-2.5 μm) (A) and liquid water was used for the infrared (2.0-15.4 μm) (B) spectral ranges respectively. At least one standard measurement was taken with each spectrometer a year between 1999 and 2007.

Figure 2. Examples of JPL mineral library reflectance spectra of several classes demonstrating the variety in spectral shapes across both the visible to shortwave infrared (0.4- 2.5 μm) (A) and infrared (2.0-15.4 μm) (B) wavelength ranges. Spectra are offset for clarity.

Figure 3. Examples of JPL rock library reflectance spectra for igneous, sedimentary and metamorphic rocks demonstrating the variation in spectral shapes across both the visible and shortwave infrared (0.4- 2.5 μm)(A) and the infrared (2.0-15.4 μm)(B) wavelength ranges. Spectra are offset for clarity.

Table 1. Library Nomenclature Examples

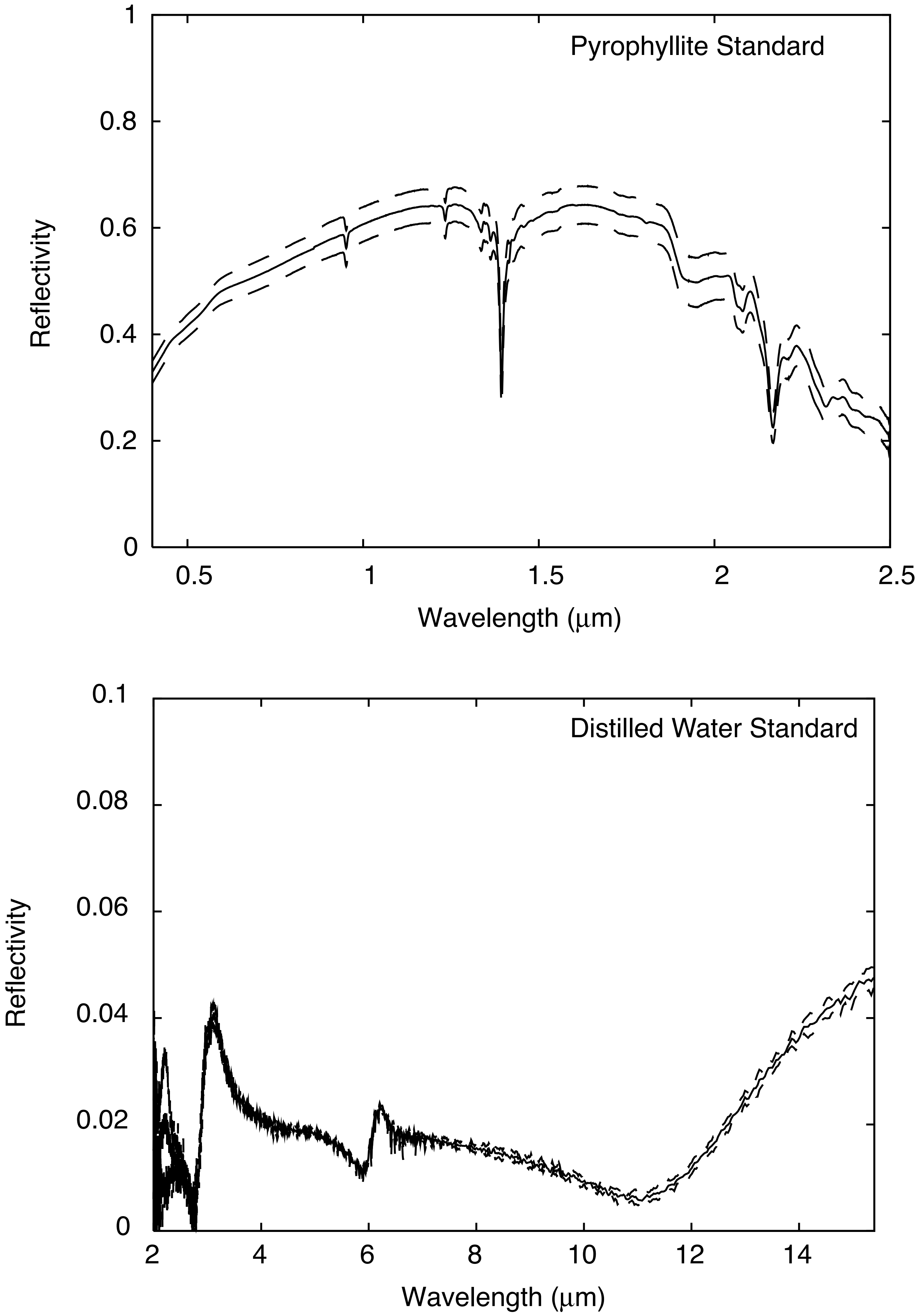
Location	Instrument	Type	Class	Subclass	Particle Size	Sample Number	File Type
JPL	Nicolet	Mineral	Silicate	Phyllosilicate	Powder		Spectrum
JHU	Perkin	Rock	Sulfate	Tectosilicate	Fine		Ancillary
USGS	Beckman	Manmade	Carbonate	Felsic	Medium		
	Perknic	Soil	Sedimentary	Mafic	Coarse		
		Lunar	Igneous	Ordinary chondrite	Solid		
		Meteorite	Stoney	Dry grass	Packed Powder		
		Vegetation	Grasses				

Example:
jpl.nicolet.mineral.sulfate.none.coarse.so01ac.spectrum.txt

Table 2. Header File Example

Each header file has 26 lines and adheres to the following form:
Name: Barite BaSO_4
Type: Mineral
Class: Sulfates
Subclass:
Particle Size: 125-500um
Sample No.: SO-3A
Owner: JPL
Wavelength range: IR
Origin: USA, South Carolina, Cherokee County, Kings Creek
Collected by Ward's
Description:
Measurement: Hemispherical reflectance
First Column: X
Second Column: Y
X Units: Wavelength (micrometers)
Y Units: Reflectance (percent)
First X Value: 15.3853
Last X Value: 2.00032
Number of X Values: 2256
Additional information: so03aa.txt

Figure 1



Pyrophyllite Standard
Reflectivity
1
0.8
0.6
0.4
0.2
0
0.5
1
1.5
2
2.5
Wavelength (μm)
Distilled Water Standard
Reflectivity
0.1
0.08
0.06
0.04
0.02
0
2
4
6
8
10
12
14
Wavelength (μm)

Figure 2

Figure 2.

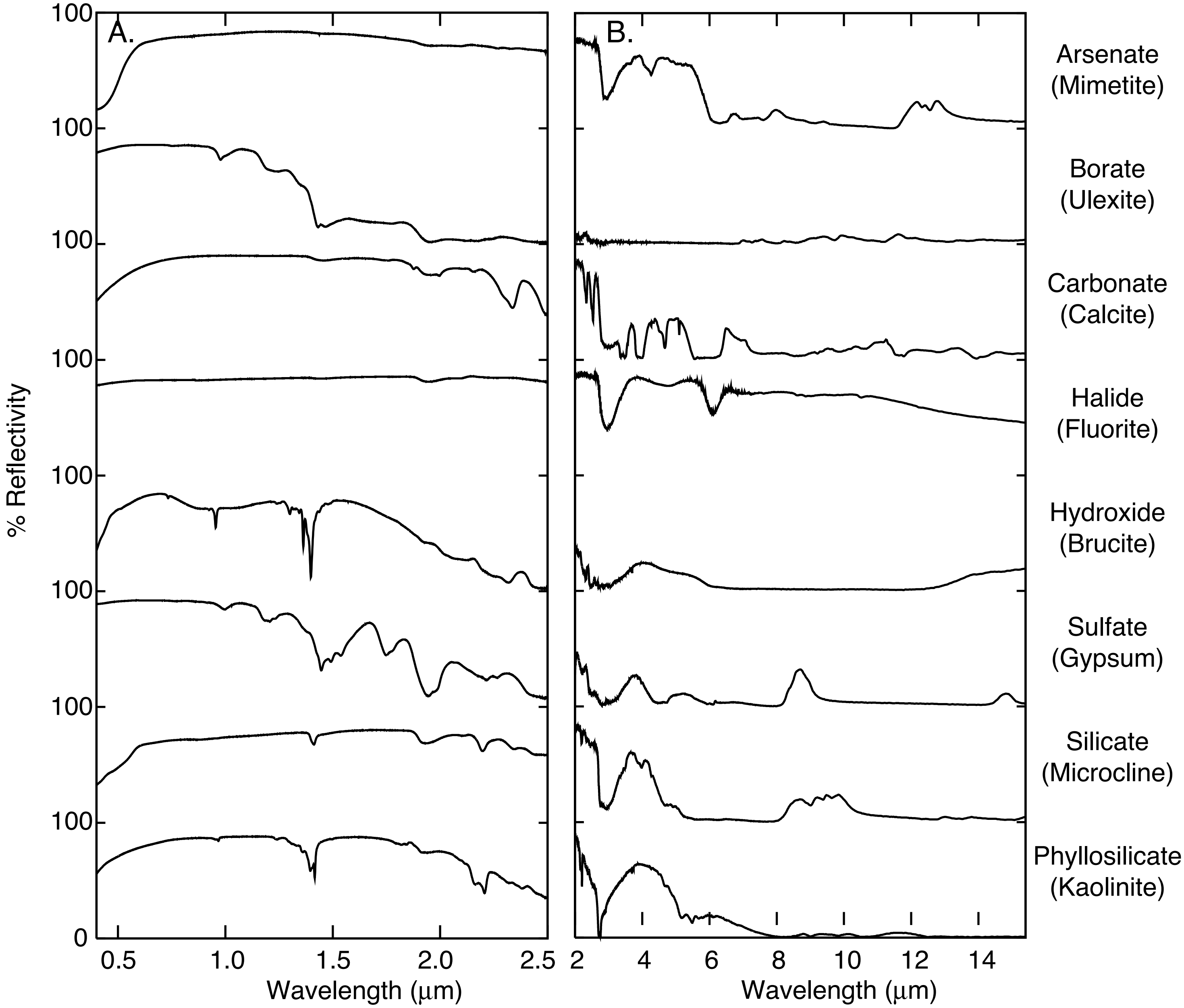


Figure 3

Figure 3.