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Remotely Quantifying the Mineralogic Composition of Planetary Surfaces with Hydrated Silicates: Lessons from the Laboratory and from Mars

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Abstract

Vibrational absorption features related to H_2O and OH in visible/near infrared (VNIR) spectroscopic data permit identification of hydrated silicate mineral phases even at small abundances. Radiative transfer modeling allows quantitative estimation of bulk mineralogy for planetary surfaces from VNIR data. Here, we discuss results from work in progress utilizing the Hapke and Shkuratov radiative transfer theories to quantitatively model mineralogy of (1) phyllosilicate-bearing particulate mixtures, measured in the laboratory and (2) Martian surfaces with phyllosilicates, using MRO/CRISM data that were atmospherically-corrected with DISORT processing. Model accuracy and uncertainties will be discussed.

1. Motivation

Diverse phyllosilicates identified on Mars from visible near infrared (VNIR) spectral data from the CRISM and OMEGA instruments indicate past environments with long-lived water-rock interaction [1-3]. Qualitative mineral identification and mapping permit identification of the deposits' geologic setting. However, to better constrain the extent and environment of aqueous alteration, quantitative estimates of composition, i.e. abundance of hydrated phases and surface modal mineralogy, are essential.

Linear deconvolution of thermal emission data permits volumetric abundances of coarse grain size mineral constituents in surface units to be determined to within 5-15% [e.g. 4-6] because the photon interactions are mostly singly scattered. In VNIR spectral data of particulate surfaces, multiple scattering dominates and spectral mixing is nonlinear. Laboratory studies have shown the Hapke [7-9] and Shkuratov [10,11] radiative transfer models predict modal abundance to within approximately 10% for well-controlled mixtures of mafic minerals. For Mars data, the Shkuratov model has been applied to estimate mineral abundances within phyllosilicate-bearing terrains using OMEGA data [13], providing a first comparison of variations in modal mineralogy.

The performance of Hapke and Shkuratov models for determining phyllosilicate abundance in mixtures has not yet been evaluated using laboratory data, however. Because of the considerable compositional variability of phyllosilicates and changes in spectral properties related to hydration state [e.g. 14], these alteration minerals may prove more challenging to model than mafic minerals. We have measured reflectance spectra of a suite of mixtures to assess the efficacy of both the Shkuratov and Hapke models in estimating modal mineralogy of phyllosilicate-bearing assemblages. Using lessons learned from the laboratory analysis, we have applied the same techniques to atmospherically-corrected VNIR MRO/CRISM data from Mars.

2. Methods

Pure mineral separates were prepared of nontronite, olivine, basaltic glass, basalt, and magnesite at multiple size fractions [15]. Optical constants were estimated by assuming an *n* (from literature data) and using the Shkuratov model to iteratively determine the imaginary index, *k*, for each endmember [11, 16]. These optical constants along with ferrihydrite, high-calcium pyroxene, plagioclase, and Martian dust [from 13] were used in subsequent modeling.

2.1 Laboratory Mixture Preparation

Mixtures (Table 1) were prepared with known proportions of endmembers, measured by weight

percent. The binary mixture suites contained endmembers at 5 wt. %, 10%, 30%, 50%, 70%, and 90% and ternary mixtures at 16 wt. %, 33%, 42%, 68%. Basalt in mixtures can be considered as a single component or as 5-components (plag., opx, cpx, olv. glass) since the its modal mineralogy is known from [6]. All suites were prepared using 45-75 µm size fractions for each constituent. For select samples, mixtures were prepared with different particle sizes in order to test particle size effects in retrieval accuracy. Reflectance spectra were measured in the RELAB bidirectional spectrometer at i=30º, e=0º.

Table 1: Prepared particulate mixtures.

Binary Mixture	Multi-size
nontronite-olivine	Y
nontronite-basaltic glass	
nontronite-basalt*	Y
olivine-basaltic glass	
nontronite-magnesite	
Ternary Mixture	
nontronite-olivine-basaltic glass	
nontronite-magnesite-olivine	
nontronite-magnesite-basalt glass	
nontronite-olivine-basaltic glass	

2.2 Hapke & Shkuratov Models

The Hapke model was implemented as described in [7] with an updated approximation of the multiple scattering function as described in [17]. Endmember abundance and particle diameter were determined by using a simulated annealing downhill simplex optimization algorithm to minimize the error between measured data and modeled data calculated from optical constants. For CRISM data analysis the surface phase function was assumed to be that measured at the Gusev landing site [18]. The Shkuratov model [10] was implemented using the techniques of [13].

2.3 MRO/CRISM data processing

CRISM data were processed to I/F with standard methods [19]. Eight images over the Mars Science Laboratory candidate landing sites were corrected using the DISORT radiative transfer code to remove atmospheric spectral features related to gas transmission and aerosols [e.g. 20]. Retrieved surface single scattering albedos were then used in modeling, with wavelength regions most strongly affected by atmospheric absorptions weighted less heavily in the optimization algorithm.

3. Lab Results & Future Work

As for [15] using the same version of the Shkuratov model and an older version of the Hapke model, laboratory data are generally accurate to +/-15%, with the highest discrepancies for mixtures with highest phyllosilicate content. Work is ongoing to understand sources of error, but subtle variable hydration state and consequent changes in band position and continuum brightness appear to be a principal source of error for mixtures with phyllosilicates in >30% abundance.

4. CRISM Results & Future Work

Results from MRO/CRISM modeling are ongoing and additional endmembers will be added to the library to test their effects on model results. In general, our first results for DISORT+Hapke modeling agree well with modeled abundances calculated with empirical volcano scan atmospheric correction+Shkuratov modeling [13]. Models incorporating image-derived phase functions for surface materials are presently being calculated.

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