ASTEROID MODAL MINERALOGY USING HAPKE MIXING MODELS: TESTING THE UTILITY OF SPECTRAL LOOKUP TABLES.
S. J. Lawrence[1], P. G. Lucey[1], and G. J. Taylor[1]. [1]Hawai'i Institute of Geophysics and Planetology, SOEST, 1680 East-West Rd., Honolulu, HI, 96822 (slawrenc@hawaii.edu)

Introduction: The spectral properties of asteroid surfaces are governed by the properties of the asteroid regolith, including the mineralogy, physical properties, the amount of impact-produced glass, and the degree of space weathering. Hapke's formulations [1,2] and the recent work of [3] have enabled the creation of a model that produces a simulated spectrum of an airless planetary surface given a modal mineralogy, within simplifying assumptions. This model was first introduced in [4], and the ability of this model to accurately reproduce eucrite and diogenite spectra was shown in [5]. Here, we discuss the current progress of our efforts to evolve this model into a robust method for the accurate determination of asteroid surface mineralogy through the addition and utilization of a spectral lookup table.

Model Description: As outlined in [4] and discussed again in [5], the model is based extensively on the work of Hapke [1], who showed how VNIR spectra of mineral mixtures could be computed from their optical constants at arbitrary grain sizes and relative abundances. In [2], Hapke presented the method for the computation of the optical effects of submicroscopic iron (SMFe), which has an important role in the optical effects of space weathering processes.

Olivine, orthopyroxene, clinopyroxene, plagioclase feldspar, troilite, Fe-Ni metal, Fe-bearing glass (as volume percent) and the abundance of SMFe (in parts per thousand) are input into the model and used to calculate the reflectance spectrum. The model requires optical constants for all input components. The method of [3] is used to calculate optical constants for olivine and pyroxene. The chemistries of olivine and orthopyroxene are linked to conform to the relationship between olivine and pyroxene Mg-number in ordinary chondrites from [6]. The optical constants for Fe-bearing glass were calculated in [3]. The method of [3] is also used to compute the iron-dependent optical constants of plagioclase, utilizing reflectance spectra of plagioclase from the U.S.G.S. Denver library. The methods of Hapke [1,2] are used to compute the single scattering albedos of all transparent components using the input SMFe abundance, the calculated optical constants, and the input grain size. The SMFe is assumed to be pure iron, coating the transparent minerals and distributed uniformally. This may or may not be an accurate representation of actual asteroid space weathering processes, owing to the unknown influence upon space weathering effects of the larger quantities of nickel present on asteroid surfaces. The single scattering albedo of troilite is computed from a fit to the derived single scattering albedos of three different sizes of troilite. The single-scattering albedo of FeNi metal for the input grain size is computed from Mie theory. All components are assumed to be spherical particles, with the size of all component assumed to equal the input particle size. The calculated single-scattering albedos are subsequently combined using Eq. 17 of Hapke [7]. The methods of [8,9] are used to calculate the single particle phase functions. Finally, the mixture single scattering albedo is converted to reflectance using Eq. 37 of [7].

Lookup Table Description: In the original form of this spectral model, the operator input and iterated on an initial guess to produce a simulated spectrum grossly consistent with the unknown spectrum, then a gradient descent algorithm was applied to refine the fit parameters and report a final modal composition. However, this initial guess is operator-dependent and greatly affects the final modal abundance produced by the model. As described in [5], the model is capable of accurately reproducing the reflectance spectrum of a meteorite when the initial guess can be constrained by foreknowledge of the modal mineralogy. Since our long-term goal is to extract reliable modal mineralogical information from asteroid reflectance spectra by inverting the model, a method of constraining the initial guess is required.

We therefore used the model to create a spectral lookup table for a comprehensive range of plausible modal mineralogies and mineral chemistries. The grain size, Mg number, and degree of space weathering were assumed to be constant for all elements of the lookup table. We also created a lookup routine that compares the unknown spectrum to each element of the spectral lookup table; the output of the lookup routine is the modal mineralogical abundance that generated the closest spectral match. The modal mineralogy produced by the lookup routine is then used as the initial guess for the gradient descent algorithm.

Methodology: To verify the ability of this lookup routine to accurately constrain the modal mineralogy from a reflectance spectrum, we input RELAB spectra of the polymict eucrites Y74450 and ALHA76005, the eucrites Stannern and Juvinas, and the L4 ordinary chondrite Saratov [10,11]. The RELAB standard viewing geometry is incidence = 30°, emission = 0°, and phase = 30°. A representative match is shown in Figure 1.

For the eucritic meteorites, the output modal abundances were compared to previously published modes [12,13]. To determine the modal mineralogy of the Saratov meteorite, X-ray elemental maps were acquired from a Saratov petrologic thin section in the Collection of the University of Hawaii using the wavelength dispersive spectrometers (WDS) on the University of Hawaii's electron microprobe. These elemental maps were combined and used to create a mineral map using the technique of [14], which involves the classification of mineral phases using the ENVI image processing software more accurately than possible using optical point-counting methods.

Finally, we input a representative selection of asteroid spectra from the 52-color survey [15], using the albedo information of [16]. The extracted modal mineralogies are provided as Table 1.

Discussion: Figure 2 shows that there is a correlation between the measured and extracted modal mineralogies. By using the lookup routine, the modal mineralogy of the input spectrum can be extracted to an absolute accuracy of approximately 20 volume percent. This increases confidence in the ability of this method to provide useful mineralogical information about asteroids.

The mineral modes displayed in Table 1 represent our initial results using the model for this purpose, and therefore represent a work in progress. However, in general, the results are consistent with current knowledge of S-Class asteroids: Most of the extracted mineralogies are mixtures of olivine, pyroxene, and metal.

Future Work: Efforts are ongoing to calibrate and improve this model concurrently with the continuing use of the model on the 52-color survey. Coordinated spectral and petrological studies are underway on ordinary chondrites, since relatively few coordinated ordinary chondrite modes and reflectance spectra are currently available.

References: [1] Hapke B., Theory of Reflectance and Emittance Spectroscopy, Cambridge Univ. Press, Cambridge, 1993. [2] Hapke B., *JGR 106*, E5, pp. 10,039-10074, 2001. [3] Lucey P. G., *JGR 103*, E1, pp. 1703-1714, 1998. [4] Clark B. E. et al. (2001) *MAPS* 31, pp. 1617-1637. [5] Lawrence S. J. and Lucey P. G., (2004) *35*, Abstract #2128. [6] Keil K. and Fredrickson K., *JGR 69*, pp. 3487-3515, 1964. [7] Hapke, B., *JGR 86*, pp. 3039-3054, 1981. [8] Helfenstein, P. et al., *Icarus 107*, pp. 37-60, 1994. [9] Helfenstein, P. et al., *Icarus 120*, pp. 48-65, 1996. [10] Hiroi, T., et al. *MAPS 29*, pp. 394-396, 1994. [11] Brown University/Keck NASA RELAB spectral catalogue, accessed online at http://lf314-rlds.geo.brown.edu/default.asp [12] Prinz M. et al., *Proc. LPSC XII*, pp. 1055-1071, 1980 [13] Delaney J. S. et al., *Proc. NIPR Sym. Ant. Met. 8*, pp. 206-223, 1983. [14] Hicks T. L. et al. (2002) *LPSC 33*, Abstract #1055. [15] Bell J. F. et al. *LPSC 19*, pp. 57-5, 1988. [16] Tedesco E. F. (1989) "Asteroid magnitudes, UBV colors, and IRAS albedos and diameters," in *Asteroids II*, pp. 1090-1138

Figure 1. *Comparison of RELAB spectrum to closest lookup table match*

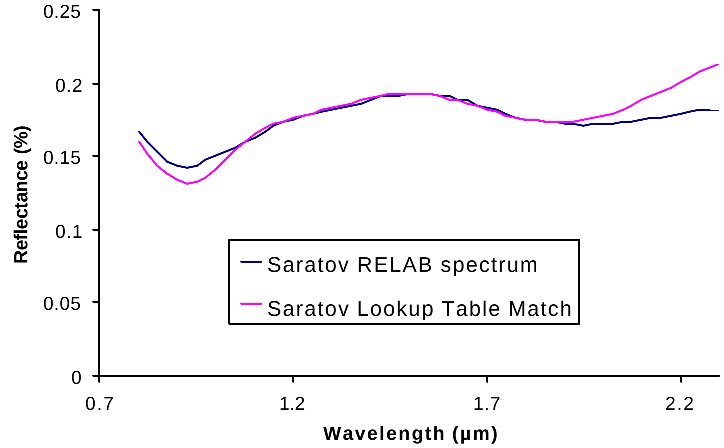

Figure 2. *Measured vs. Spectrally Extracted Modal Mineralogy*

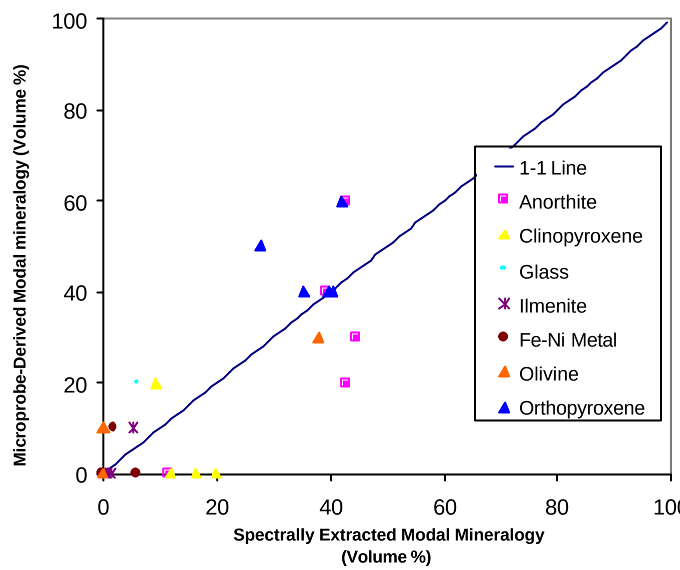

Table 1. *Extracted asteroid modal mineralogies*

Asteroid	*Class*	*Ol*	*Opx*	*Cpx*	*An*	*Troi*	*Glass*	*Met*
42 Isis	S(I)	24.11	1.10	21.69	27.58	7.82	-0.02	29.65
113 Amalthea	S(I)	38.96	-0.02	15.48	8.98	0.10	8.04	21.19
26 Prosepina	S(II)	24.92	3.22	28.29	33.50	10.53	-0.02	-0.02
39 Laetitia	S(II)	4.77	-0.02	17.12	48.59	-0.02	21.90	2.84
68 Leto	S(II)	11.46	-0.02	21.13	31.13	1.73	21.51	-0.02
15 Eunomia	S(III)	16.43	-0.02	18.39	28.68	2.51	12.57	29.19
532 Herculina	S(III)	47.55	7.35	24.26	0.18	9.07	2.02	17.88
3 Juno	S (IV)	17.85	22.33	4.27	49.94	9.40	4.06	19.02
6 Hebe	S (IV)	-0.02	9.83	10.91	37.26	3.35	16.82	36.76
7 Iris	S (IV)	-0.02	4.01	3.83	15.02	1.27	4.08	30.65
18 Melpomene	S(V)	1.23	-0.02	12.95	22.52	0.74	6.12	75.41
20 Massalia	S(VI)	16.38	21.31	28.66	30.82	9.89	3.39	3.89
57 Mnemosyne	S(VII)	2.90	25.04	3.02	65.27	9.86	2.86	0.13

Ol = olivine, Opx = orthopyroxene, Cpx = clinopyroxene, An = Anorthite
Troi = troilite, Met = Fe,Ni-metal