ENABLING THE INTERPRETATION OF DUSTY ASTEROIDS, THE MOON, AND OTHER AIRLESS BODIES WITH MID-INFRARED SPECTRA OF FINE-PARTICULATE MINERALS ACQUIRED UNDER VACUUM AND HIGH-TEMPERATURE CONDITIONS.

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Introduction: Many of the surfaces of airless bodies in our solar system, to varying extent, are coated in fine dust due to long-term impact processing. In order to better interpret remote-sensing data from those bodies, our team is developing a robust spectral library of *fine particles* (<10 μm) that will include a wide variety of minerals, meteorites, and lunar samples.

Our team is currently making spectral measurements of mineral samples at multiple labs with unique and overlapping capabilities to derive a vetted set of cross-calibrated laboratory spectra that extend from the far-ultraviolet through the far-infrared electromagnetic regions (~0.12 to 300 μm).

Here we present our *mid-infrared* analyses of fine-particle minerals acquired at 80 ºC (ambient P), 150 ºC (vacuum), and 300 ºC (vacuum).

Mineral Samples: We currently are analyzing a suite of 28 terrestrial mineral samples (Table 1).

Table 1. Terrestrial mineral samples for spectral measurements.

Forsterite Globe*	Pyrite
Forsterite SC*	Palygorskite (PFI-1)
Bytownite CB*	CaS (oldhamite)
Labradorite Chihuahua*	Hectorite (SHCa-1)
Labradorite ARSAA	Nontronite (NAu-2)
Diopside Herschel*	Na-montmorillonite (SWy-3)
Augite Harcourt*	Ca-montmorillonite (STx-1b)
Albite (AL-I)	Kaolinite (KGa-1b)
Anorthite (AN-G)	Serpentine (UB-N)
Spinel ARSAA	Serpentine (SMS-16)
Phlogopite Mica-Mg	Ilmenite
Enstatite (Zen 1)	Zinnwaldite (ZW-C)
Hematite <5 um	Fe metal <10 um
Hematite 3 nm	Graphite 7-11 um

*Samples being used by several SSERVI teams for cross-SSERVI collaborations & science linkages.
Samples in blue have already been measured. Samples in black will be measured in 2019.

We also will acquire and analyze fayalite, pigeonite, and amorphous carbon.

Particle Sizes: Our focus is on samples whose particle diameters are <10 μm, as supported by the returned samples from the asteroid Itokawa obtained by the Hayabusa mission. The Itokawa sample particles ranged in diameter from 3 to 40 μm, with the majority being <10 μm [1].

To verify that our bulk samples are fine enough, we analyzed each one using a particle size analyzer (either an Elzone or a Mastersizer). Our sample particles are typically closer to 1 μm diameter (Figure 1).

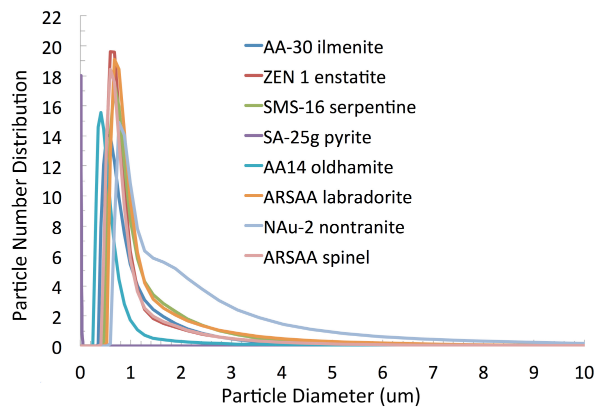

Figure 1. Determination of the particle size distribution of several bulk mineral samples.

Laboratory Details and Measured Environments: For direct application to airless bodies, laboratory spectra must be obtained under vacuum conditions over a range of representative surface temperatures because atmospheric pressure and surface temperature affect spectral characteristics, especially for fine-particulate samples wherein thermal gradients are enhanced.

Surface temperatures on targets of interest for SSERVI crewed missions (Moon, Martian moons, asteroids) vary dramatically due to the lack of atmosphere and can reach up to 300 ºC, as expected for typical Near Earth Asteroids [2].

Mid-infrared (MIR) emissivity measurements were made at the Deutsches Zentrum für Luft- und Raumfahrt (DLR, Berlin, Germany), using 2 different spectrometers:

Spectrometer 1 -- For the induction-heated, 80 ºC, ambient P emissivity data, a KBr beamsplitter and a cooled MCT detector were used (Figure 2).

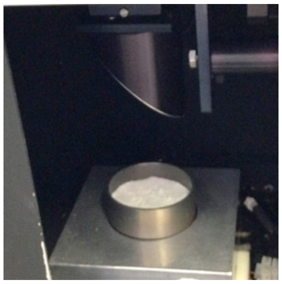

Figure 2:
Beamsplitter: KBr
Detector: cooled MCT
Purged atm
Induction heating to 80 ºC
Range: 2000 to 500 cm^{-1}

Spectrometer 2 -- For the induction-heated, 150 and 300 ºC, vacuum P emissivity data, a KBr beamsplitter and a cooled MCT detector were used (Figure 3).

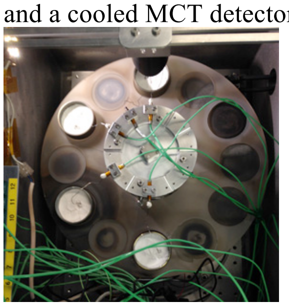

Figure 3:
Beamsplitter: KBr
Detector: cooled MCT
Vacuum atm
Induction heating to 150 and 300 ºC
Range: 2000 to 624 cm^{-1}

Mid-infrared (MIR) Spectra: Coarse-sample MIR spectra typically are dominated by fundamental vibrational modes (some overtones). However, for fine-particulate, high-porosity samples, the fundamental bands shrink and the spectra exhibit volume-scattering features [3,4]. These behaviors are shown in Figure 4. All of the dominant spectral features in the green spectrum (coarse olivine) are due to fundamental vibrations. These features weaken in the fine-particulate blue spectrum, and new volume-scattering features appear – such as the high-frequency roll-off short-ward of ~9 µm and the feature at ~ 12-14 µm.

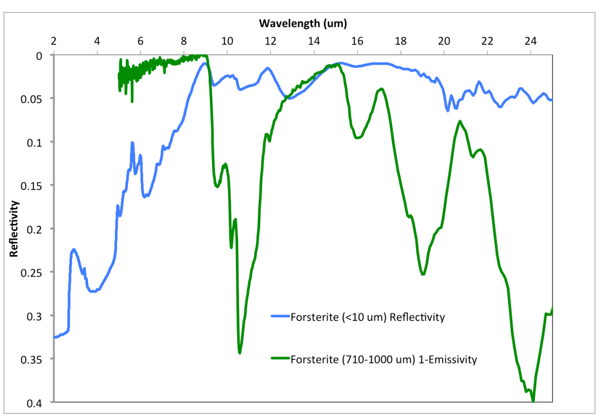

Figure 4. Spectra of a coarse (green) and fine-particulate (blue) olivine acquired at 80 ºC under ambient P.

When a fine-particulate sample is measured at higher temperatures and vacuum conditions, the spectra vary further. Figure 5 is representative of the spectral data we acquired for the minerals in Table 1.

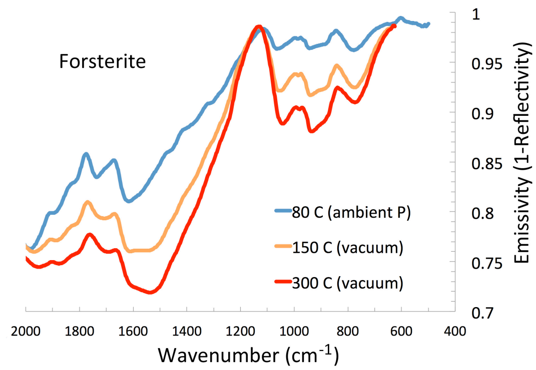

Figure 5. Spectra of fine-particulate forsterite olivine acquired at 80 ºC under ambient P (blue), at 150 ºC under vacuum P (orange), and at 300 ºC under vacuum P (red). Note: 1000 cm^{-1} is equivalent to 10 µm.

Effects of low-pressure (airless) and high-temperature environments. Under low atmospheric pressure conditions (minimal interstitial gas), fine particles on planetary surfaces are poor heat conductors and have an insulating effect, causing steep thermal gradients [5,6,7], effectively shifting the Christiansen Frequency to shorter wavelengths (higher wavenumbers) (Figure 5). (Coarser particles are not affected to the same degree.) Temperature can also affect MIR spectra [8,9] because increased temperature can cause structural expansion of the crystal lattice, thus changing the spectral bands. Due to the differences in spectra between those obtained under ambient conditions from those obtained under vacuum, typical 1-atm laboratory spectra are decreasingly useful for determining mineralogy on airless bodies, especially for fine-particulate surfaces.

Hence, the spectra from our study are important to have in a spectral library for studying airless bodies. Many more spectra will be presented at LPSC.

References: [1] Nakamura T. et al. (2011) *Science, 333,* 1113-1116. [2] Hsieh H. H. et al. (2015) *Icar., 248,* 289-312. [3] Ramsey M. S. and Christensen P. R. (1998) *JGR, 103,* 557-596 [4] Lane M. D. and Christensen P. R. (1998) *Icar., 135,* 528-536. [5] Hinrichs J. L. and Lucey P. G. (2002) *Icar., 155,* 169-180. [6] Logan L. M. and Hunt G. R. (1970) *JGR, 75,* 6539-6548. [7] Donaldson Hanna K. L. et al. (2012) *JGR, 117,* doi:10.1029/2012JE04184. [8] Helbert J. et al. (2013) *EPSL, 371-372,* 252-257. [9] Lee R. J. et al. (2013) *JGR, 118,* doi:10.1002/jgrb.50197.