

REVISED TAXONOMY OF FINE SAND- AND COARSE SILT- SIZE BROWN GRAINS ON MARS FROM PHOTOMETRY OF PHOENIX OM IMAGES.

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Introduction: The Microscopy, Electrochemistry and Conductivity Analyzer (MECA) on Phoenix Mars Lander (PHX) included an Optical Microscope (OM) that returned color images of soil material with a spatial resolution of 4 $\mu\text{m}/\text{px}$ [1]. The OM consists of a high-resolution fixed-focus, fixed-magnification optical imaging system and an active visible-light sample illumination system composed of four types of LEDs: Blue (B, $\lambda \sim 465$ nm), Green (G, 524 nm), Red (R, 636 nm), and UV (375 nm)/NIR (705 nm) [1]. The upper limiting grain-size imaged (200 μm) was determined by the sieve through which sample was introduced by the Phoenix Robotic Arm (RA) into the MECA instrument. The lower limiting size was determined by the 4 μm / pixel limit of the optical system [1]. Fine- and very- fine sand (200 - 62.5 μm) and all but the finest silt (62.5 - 4 μm) were imaged for eight samples from different portions of the periglacial patterned ground landforms within the Phoenix RA's workspace [2]. Previous research has used color OM images to develop a taxonomy of soil particles classified by grain size and color (strong variation in the red reflectance ($\lambda = 630 - 710$ nm) from particle to particle; in order of decreasing abundance (in vol.%), red and white fines, brown sand, and black sand) [2,3], described their optical and magnetic properties [2,3], determined (together with measurements from the PHX Atomic Force Microscope (AFM; [1])) particle sizes and size distributions [4], and compared grain form among different PHX grain types [5].

Orbital VisNIR spectroscopy of the vicinity of the PHX landing site showed weak broad NIR absorption features interpreted as pyroxene and olivine [6-8,4]. The spectrum-dominating minerals permitted by PHX OM BGR photometry data from the abundant red fines [2] in the PHX OM samples are nanophase ferric oxides, same as previous mineral identifications by orbital VisNIR spectroscopy elsewhere on Mars and specifically from the vicinity of the PHX landing site [6-8].

The introduction of color imagers on *Curiosity* (especially MAHLI) enabled sand-size grains in recent unconsolidated aeolian deposits at Gale crater to be characterized by color [9-12] in a manner similar to the

PHX OM classification [2]. Sand- and coarse silt-size grains described as brown, brown-yellow, or yellow \pm translucent, and red fines, are two grain types common to both Vastitas Borealis and Gale crater. Brown/yellow-yellow translucent sand grains were reported to constitute 21-34% of the Bagnold dune aeolian sands [11,12].

This presentation reports results of ongoing efforts to constrain the range of possible mineral phases present in brown grains of the coarsest-grained fractions of PHX samples from BGR photometry of OM images.

Samples and Methods: One region of interest (RoI) was selected for photometric characterization from each of 13 brown sand grains shown in Figure 6 of [2] or not previously published, and two (2) RoIs from one grain published image, for a total of 15 RoIs on 14 grains. Calibration of 3-point reflectance spectra from RoIs in OM images, with a fixed set of calibration parameters and including compensation for changes of the LEDs' radiant output over mission elapsed time during conversion to reflectance R^* , was as described by [2].

Results: Table 1 summarises the ranges of photometric peak brightness (always at 636 nm), BR (435 nm – 636 nm) slope, and linearity or non-linearity between B and R, as quantified by the curvature of the B-G-R spline, for the radiometrically corrected reflectances of the four (4) groups ($n \geq 2$) of RoIs identified in this study (arranged in order of increasing peak brightness), and the corresponding photometric parameters for PHX OM red fines (from [2] Fig. 18).

Discussion: Photometry. Brown grains at the PHX landing site can be subdivided into at least four groups based on photometric properties of peak brightness, slope, and curvature parameters. The photometric groupings identified in Table 1 are:

Red fines: Dull steep-slope concave-up ([2], Fig. 18 leftmost). The spectrum-dominating minerals permitted by PHX OM BGR photometry data from the abundant red fines ([2], Fig. 18) are nanophase ferric oxides, same as previous mineral identifications elsewhere on Mars and specifically from orbital VisNIR spectroscopy in the vicinity of the PHX landing site [6-8].

Brown sand grains: Fifteen (15) RoIs on 14 grains. Four photometric groups of 2-4 RoIs each plus three different unique RoIs, one each on three grains. The unique grains differ from grain/RoI groups in at least one photometric characteristic, and from each other in two photometric characteristics.

1. Dark shallow-slope straight-spectrum grains ($n = 2$). The photometric characteristics of this group are identical to those attributed to all brown grains after the first effort cycle ([2] Fig. 18 2nd from left).

2. Dull steep-slope (red-bright) concave-up (green absorption) grains ($n = 4$ RoIs). The photometric characteristics of this group are identical to those of the red fines as characterized in the first effort cycle ([2], Fig. 18 leftmost).

3. Bright intermediate-slope concave-up grains ($n = 4$).

4. Very bright steep-slope convex-up grains (red-green bright) ($n = 2$).

The pigmenting material responsible for PHX OM BGR photometry data specifically from fine and very fine sand-size “brown sand” grains occurs mainly as thin nano-patchy coatings on rounded, abraded surfaces of fine-sand to coarse-silt mineral sand grains; some occurs behind/beneath translucent and transparent grains. Group 2 grains would have contributed the same photometric BGR signature as the red fines to orbital spectra [6-8]).

Implications. The reflective material responsible for PHX OM BGR photometry data specifically from fine and very fine sand-size “brown sand” grains define four (4) photometric groups of PHX brown sand RoIs plus three unique RoIs. Photometric attributes of PHX OM brown sand grains range from slightly darker and less red-bright than nanophase ferric oxides (group 1, the original brown grains [2]), through photometrically identical to red-fines nanophase ferric oxides (group 2), to brighter and more red-bright (groups 3 and 4). Thus, PHX OM brown sand grains span a much larger range of photometric attributes than previously recognized ([2]).

Comparisons. The abundances of brown-yellow translucent grains in recent unconsolidated sands at Gale crater (21 - 34%; [11,12]) are similar to the abundances of olivine in the same samples as determined from CheMin XRD measurements (18 – 26%; [13-15]). This permits, but does not prove, an interpretation that the brown grains are olivine.

The darkest PHX OM grain has a higher peak reflectance and a steeper ~450 - ~640 nm slope than the brightest sand measured in or near the Bagnold Dune Field using MSL Curiosity’s Mastcam [16].

Conclusions: Reanalysis of OM images of brown fine sand- and coarse silt-size particles in soils at the PHX landing site in terms of 3-point reflectance spectra (465 nm, 524 nm, 636 nm) reveals greater photometric diversity of brown sand than previously recognized. Brown-yellow or yellow \pm translucent fine-/very-fine-sand- and coarse-silt-size olivine grains in recent unconsolidated aeolian deposits at Gale crater [9-12] may be similarly photometrically diverse and may justify further taxonomic subdivision based on photometric and physical properties imaged by the PHX OM and comparisons with terrestrial analogs.

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Table 1 – Photometric parameters of PHX OM red fines and brown sand groups

Group	Peak brightness (636 nm)	Slope (465-636 nm)	Curvature*	Adjectival
Red fines	0.250	0.00105	-0.017	Dull steep concave up
Brown sand gr. 1	0.180 – 0.195	0.00060 – 0.00072	0.002 – 0.004	Dark shallow straight
Brown sand gr. 2	0.252 – 0.276	0.00104 – 0.00123	-0.017 – -0.027	Dull steep concave up
Brown sand gr. 3	0.260 – 0.280	0.00079 – 0.00102	-0.006 – -0.020	Bright intermediate concave up
Brown sand gr. 4	0.340 – 0.350	0.00124 – 0.00136	0.007 – 0.011	Very bright convex up (green-red)

* > 0.002 convex up (“green”); < -0.002 concave up