MICROSCOPIC VIEWS OF MARTIAN SOILS AND EVIDENCE FOR INCIPIENT DIAGENESIS. W. Goetz[1], M.B. Madsen[2], N. Bridges[3], B. Clark[4], K.S. Edgett[5], M. Fisk[6], J.P. Grotzinger[7], S.F. Hviid[8], P.-Y. Meslin[9], D.W. Ming[10], H. Newsom[11], R. Sullivan[12], D. Vaniman[13], and R. Wiens[14], [1]Max Planck Institute for Solar System Research (MPS), Göttingen, Germany (goetz@mps.mpg.de), [2]Niels Bohr Institute, Univ. of Copenhagen, Denmark, [3]APL, Laurel, MD, USA, [4]SSI, Boulder, CO, USA, [5]MSSS, San Diego, CA, USA, [6]Univ. of Oregon, Corvallis, OR, USA, [7]Caltech, Pasadena, CA, USA, [8]German Aerospace Center (DLR), Berlin, Germany, [9]Univ. Paul Sabatier, CNRS, Toulouse, France, [10]NASA JSC, Houston, TX, USA, [11]Univ. of New Mexico, Albuquerque, NM, USA, [12]Cornell Univ., Ithaca, NY, USA, [13]PSI, Tucson, AZ, USA, [14]Los Alamos National Laboratories, NM, USA.

Introduction: Mars landed missions returned images at increasingly higher spatial resolution (Table 1). These images help to constrain the microstructure of Martian soils, i.e. the grain-by-grain association of chemistry and mineralogy with secondary properties, such as albedo, color, magnetic properties, and morphology (size, shape, texture). The secondary characteristics are controlled by mineralogical composition as well as the geo-setting (transport and weathering modes, e.g. water supply, pH, atmospheric properties, exposure to radiation, etc.). As of today this association is poorly constrained. However, it is important to understand soil-forming processes on the surface of Mars. Here we analyze high-resolution images of soils returned by different landed missions. Eventually these images must be combined with other types of data (chemistry and mineralogy at small spatial scale) to nail down the microstructure of Martian soils.

mission & instrument	imaging characteristics
Mars Pathfinder, IMP	~120 µm/px (diopter lens), gray scale
Mars Explor. Rovers, MI	~30 µm/px, gray scale
Phoenix, OM	~4 µm/px, color
Phoenix, AFM	~0.1 µm/px
Curiosity, MAHLI	~20-100 µm/px, color

Table 1. High-resolution imaging of soils by landed missions on Mars. Instruments: IMP = Imager for Mars Pathfinder, MI = Microscopic Imager, OM = Optical Microscope, AFM = Atomic Force Microscope (not an "imager" sensu stricto), MAHLI = MArs Hand Lens Imager. All imagers except MAHLI are fixed-focus instruments.

Observations: Fig. 1 shows sandy soils at Gusev crater, (a) at the (dust poor) El Dorado dune field and (b) some 100 sols earlier in the Columbia Hills. The latter image shows both loose dust infill and bonded (presumably dust-rich) material between the grains. Bonding is revealed by fracture lines and must have developed after these coarse sand grains became immobile. Similar forms of weak diagenesis have been observed at the Rocknest deposit in Gale crater [1].

Fig. 2 shows images acquired by the Optical Microscope (OM) onboard the Phoenix lander at the silt-to-fine sand scale (< 100 µm). These are the highest-resolution images acquired to date (Table 1) of soil grains either as separated grains accumulated one by one on magnetic targets inside the microscope (a) or as a mixture of grains and dust (b). Black particles were interpreted to be more pristine than brown ones [2] and may contain a large fraction of glass [3]. Also it was inferred that black grains are more strongly magnetic than brown ones. Putative broken grains show a dark weathering rind (though at the limit of resolution) [2].

Figures 3 and 4 show, respectively, top surface and shallow subsurface of two aeolian deposits (Rocknest and Dingo Gap) explored by the Curiosity rover. Both deposits form clods and crust fragments with angular outlines and signs of layering near the top surface. No clear signs of chemical alteration were found. In-situ acquired LIBS data (Laser-Induced Breakdown Spectroscopy) suggest that crust formation at the Rocknest deposit is mediated by an iron-rich agent [1].

Finally, images of very fine sand at the Kimberley site (Fig. 5) document the downward slide of platy top-surface crust fragments, again providing evidence for weak bonding of top-surface soils.

Discussion and Conclusions: Martian (silt and sand) grains are most often coated by a weakly adhering dust mantle masking the grains' diversity. When this mantle is missing (either due to natural processes or due to onboard sample preparation or analysis) high-resolution images reveal a rich diversity in albedo and color. This was clearly demonstrated in the case of Phoenix soil particles. Onboard the Phoenix lander the grains' dust mantle was efficiently removed by capturing these grains on magnetic targets prior to imaging them by the OM [2, 5]. The LIBS instrument (ChemCam) onboard the Curiosity rover can remove the grains' dust mantle by laser impact and thus explore their intrinsic chemistry. High-resolution images (MER-A, Phoenix, MSL) also reveal wide-spread crust formation indicating slow, but ongoing diagenesis. Fractures in the top-surface crust open views into the shallow subsurface and show layering in some cases. Chemical characterization of this layering is ongoing.

References: [1] Goetz, W. et al. (2014), JGR (submitted). [2] Goetz W. et al. (2010) *JGR*, *115*, E00E22. [3] Horgan B. and Bell III J. F. (2012) *Geology*, doi:10.1130/G32755.1. [4] Goetz, W. et al.

(2010) *LPS XLI*, Abstract #2738. [5] Hecht M. H. et al. (2008) *JGR*, *113*, E00A22.

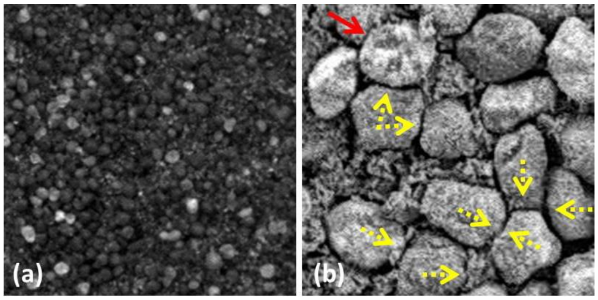

Fig. 1 Medium (~300 μm) and coarse sand in Gusev crater. Each image is 6 mm wide. (a) El Dorado dune field, sol 710 (detail from #189393476). Note a significant population of bright particles. (b) Columbia Hills, sol 612 (detail from #180692664). Some particles have checkered appearance (likely bright and dark minerals, red solid arrow). Dotted yellow arrows highlight fracture lines that are interpreted to document weak diagenesis and bonding between sand grains. Very similar features observed at Rocknest, Gale crater (MSL, sol ~ 60).

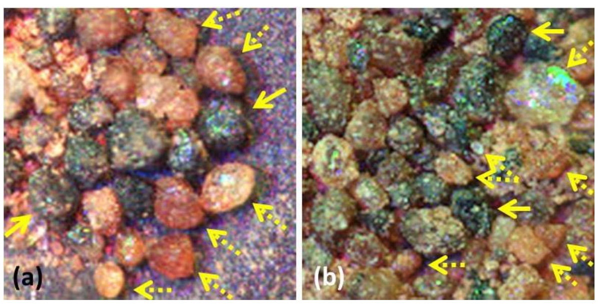

Fig. 2 Silty soils at the Phoenix landing site. Each image is 0.5 mm wide. Note the diversity in albedo (like Fig.1a, [4]) as well as color. Two types of grains are distinguished: Black (solid arrows) and brown grains (dotted arrows), the latter type displaying a wide range in size and translucence (from opaque to almost transparent). (a) sol 58, img. #4163, (b) sol 148, img. #1698. Most grains are 50-100 μm in size and have a fairly smooth shiny texture giving rise to specular reflections of light from illuminating monochrome LEDs.

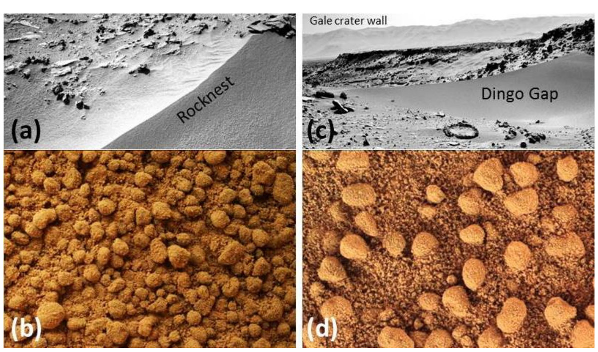

Fig. 3 Top surface of Rocknest (a, b) and Dingo Gap (c, d). (a,c) Context images (a: sol 58, NRA_402648966, b: sol 527, NRB_444283159). Both deposits extend over several meters. The circular feature (foreground in (c), clastic pipe?) is ~50 cm across. (b, d) Details (20 mm wide, largely undisturbed) from MAHLI images (0060MH0036001002E1, 0531MH0003490000201320R00) show Dingo Gap's sand armor to be coarser and less dense.

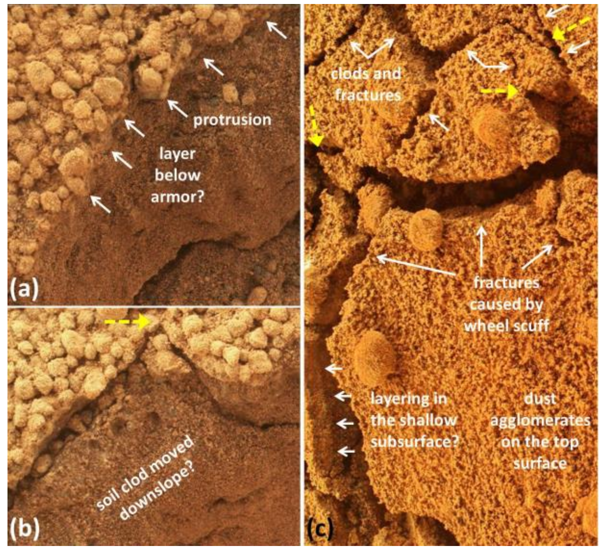

Fig. 4 Shallow subsurface of Rocknest (a, b) and Dingo Gap (c). Each image is 14 mm wide. Subsurface is exposed by either scooping (a, b) or wheel scuff (near right edge of c). Sharp corners and re-entrants (dashed arrows) reveal weak bonding in the shallow subsurface. The type of diagenesis is not necessarily the same at Rocknest and Dingo Gap. Image ID: 0067MH0079000006R0 (a), 0067MH0079000016R0 (b), 0531MH0003490000201312R00 (c).

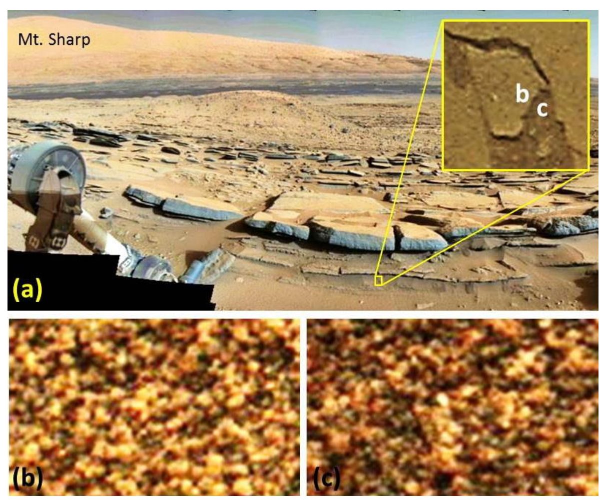

Fig. 5 Soil (Sophie Downs) at the Kimberley site. (a) MCAM-34 mosaic for context (sol 584, mcam02407, white-balanced color). The inset (~30 mm wide, 0576MR0023680150304138E01) specifies the location of zooms (b) and (c) (each zoom is 3.2 mm wide, detail from 0584MH0001700000202423R00). (b) Bright top-layer. (c) Darker layer below. Bright, weakly bonded top-layer material slid down exposing darker material below. Both units are very fine sand (~100 μm) and poor in dust.