SOIL AND ROCK PHYSICAL PROPERTIES AT THE MARS EXPLORATION ROVER LANDING SITES: EARLY RETURNS. D. W. Ming[1*], R. C. Anderson[2], R. E. Arvidson[3], J. F. Bell, III[4], J. Biesiadecki[2], P. H. Christensen[5], S. P. Gorevan[6], B. L. Ehlmann[3], E. A. Guinness[3], T. G. Graff[5], R. L. Fergason[5], A. F. C. Haldeman[2], K. E. Herkenhoff[7], J. R. Johnson[7], B. L. Jolliff[3], G. A. Landis[8], M. T. Lemmon[9], R. Li[10], R. Lindemann[2], J. R. Matijevic[2], R. V. Morris[1], L. Richter[11], F. P. Seelos[3], P. H. Smith[12], J. Soderblom[4], N. Spanovich[12], S. W. Squyres[4], R. J. Sullivan[4], A. Yen[2], and the MER Athena Science Team. [1]NASA Johnson Space Center, [2]Jet Propulsion Laboratory, [3]Washington University at St. Louis, [4]Cornell University, [5]Arizona State University, [6]Honeybee Robotics, [7]USGS Flagstaff, [8]NASA Glenn Research Center, [9]Texas A&M University, [10]Ohio State University, [11]DLR Institut fur Raumsimulation, [12]University of Arizona, *e-mail: douglas.w.ming@nasa.gov.

Introduction: A wide range of soil and rock physical properties are being investigated by the Mars Exploration Rovers (MER) on the floor of Gusev Crater (Spirit) and on the plains of Meridiani (Opportunity). These investigations involve the full suite of Athena science instruments and the rovers' mobility systems [1]. Physical properties of soil units are being characterized by observations of wheel tracks (sinkage and tread casts) and trenches (dedicated operations) with the Panoramic Camera (Pancam), Mini-Thermal Emission Spectrometer (Mini-TES), Navigation Camera (Navcam), and Hazard Avoidance Cameras (Hazcams). The composition and particle sizes of surface materials and subsurface materials exposed by the wheels are being characterized by the Mossbauer (MB) Spectrometer, Alpha Particle X-ray Spectrometer (APXS) and Microscopic Imager (MI) on the Instrument Deployment Device (IDD). A known amount of force can be applied by the MB contact plate on soil surfaces to provide additional information on the strength of surface materials. Engineering data from the rover wheel/suspension system collected during rover traverses will allow determination of surface roughness, slopes, and other terrain characteristics. Compositional and textural surface units are being characterized and mapped by Mini-TES thermal inertia surveys. Additional textural information is being obtained by dedicated Pancam photometric observations of soils and rocks.

Pancam and Mini-TES observations are providing textural and compositional properties of rocks. The Rock Abrasion Tool (RAT) is being used to cut into rock surfaces to expose fresh unaltered rock material for compositional and textural observations by the full suite of Athena science instruments. The RAT operation will provide clues about overall rock competence and the presence or absence of weaker or stronger materials at the surface, e.g., rinds.

Dust accumulation on the rover deck is being monitored with Pancam and correlated with atmospheric opacity to understand the rate of dust air fall on the rover. Pancam and Navcam images are being acquired during rover traverses such that localization maps can be derived for the current rover position and previously visited rover sites to assure results can be related spatially between rover stops. These measurements taken together will improve our understanding of Martian surface properties.

The purpose of this paper is to report the "early returns" on the physical properties of soil units and rocks at the MER landing sites. Because we are still very early in the mission at Meridiani Planum, results from the Gusev Crater Landing Site are emphasized here.

Soil Physical Properties from Remote Observations: The surface immediately around the Spirit landing site is littered with rocks, ranging in size from gravel (2-4 mm) to small angular rocks (up to 50 cm across), set in a matrix of fine-grained material. The distribution of rocks at the surface suggests some type of "pavement" formation, i.e., concentration of rocks on the surface [e.g., 2]. A thin coating of dust that is spectrally analogous to Martian bright regions appears to cover most of the scene. This thin coating of dust is evident on rock surfaces, such as the rock dubbed "Adirondack," where the dust was removed by a simple sweeping of the surface with the RAT brushes.

MI images of the first fine-grained soil analyzed by the IDD next to the Spirit lander suggested the surface materials consisted of sand-sized aggregates of smaller particles. It is not clear whether these materials are held together by some type of chemical cement or by electrostatic forces.

Rock and soil exposures are very different at Opportunity's initial roving site within a shallow 20 m pit on the plains of Terra Meridiani. Exposures of very fine-grained (grains so far unresolved) bedrock are found in-situ around the interior walls. Small but resolvable spherules appear to be weathering out of this unit; they are also observed mixed with darker soil units above as well as below the outcrops. The dominant soil unit so far encountered is a dark, fine sand with the much larger spherules and spherule fragments. A rippled soil unit seemingly lacking spherules located near the lowest part of the pit is probably a concentration of the fine sand-sized particles transported and partly reworked by wind. Similar material may compose the highly asymmetric (potentially active?) transverse bedforms glimpsed on the plains outside the pit.

Soil Physical Properties Experiments Involving Soil/Wheel Interactions: Hazcam and Pancam images of rover wheel tracks immediately after egress onto the surface in Gusev Crater suggested a variety of surface textures. Traverses through depressions resulted in well-defined wheel track casts, suggesting that finer-grained materials accumulate at these depressions. In other areas, wheel tracks were not as defined and instead, some blocky fragments (5-10 mm thick) of apparent soil-like materials were displaced by the wheels. There were also areas where small rocks (1-2 cm) were pressed into an apparent indurated or "crust" material. The "crust" fracture strength was estimated to be between ~5 and ~15 kPa, based on the expected contact pressures on rocks displaced by rover wheels. The indurated or "crusty" soil-like materials may be similar to the cloddy to blocky materials seen at the Viking lander sites [3].

Assessment of initial rover tracks combined with experiences of slip on sloping surfaces at the Meridiani site suggest that soil cohesion in the uppermost near subsurface is low, and that particles finer than resolved by MI probably are also present along with the fine sand-sized particles.

Imaged-Based Localization and Topography Maps: The location of the rover is required to constrain observations in the context of traverses and from orbit. Topographical maps at the Gusev and Meridiani landing sites were developed from panorama and stereo images taken by Pancam and Navcam. Digital terrain models, orthoimages, and rover traverse maps are being developed from a combination of images during traverses.

Rover Deck Dust Accumulation: Rates of atmospheric dust deposition on the rovers are being measured by several different techniques. The decrease in current from the short circuit current (I_{sc}) monitoring cell as a function of time provides a direct measurement of obscuration by the dust layer. Measurements of the color of the three rings on the Pancam calibration target provide separate estimates of the thickness and spectral reflectance of the deposited dust. Over the first 30 sols of the mission in Gusev Crater, the Spirit rover showed an average dust-related loss of transmission of 0.16% per sol, considerably lower than the 0.28% per sol measured by Pathfinder over the first 30 sols [4], but comparable to the long term transmission loss seen by Pathfinder solar arrays. The fractional area covered by dust was 0.23% per sol assuming dust with the optical properties calculated by [5]. Depositional rates on both rovers will be monitored throughout the remainder of the mission.

Additional features on the rover deck, such as the solar cells and the Mini-TES external calibration target, have been imaged by Pancam on a repeating basis to also monitor for dust accumulation. Pre-flight measurements of the bidirectional reflectance function of the calibration targets and solar cells were made with the Bloomsburg University Goniometer [6]. Laboratory measurements were done with clean targets and targets coated with dust layers from 5 to 230 μm thick. These laboratory data will be compared to reflectance values extracted from Pancam data to constrain the thickness of dust accumulating on the rover [cf. 7].

Additional Planned Activities: At the time of this writing, a variety of soil and rock experiments and observations are being planned, but have not yet been implemented. These experiments include soil trenching with the front wheels into targets of opportunity, e.g., soils, drift materials. The IDD instruments will be used to analyze materials exposed by trenching to determine compositional and textural changes with depth. Engineering data (i.e., rover suspension telemetry, frictional wheel torques) and images of disturbed soils acquired during trenching will be used to determine angle of internal friction, cohesion, bulk density, and other physical properties

Mini-TES thermal inertia surveys and Pancam photometry sequences are currently underway to provide additional information on the textural and compositional properties of soil units. These surveys and measurements will be used during tactical operations to differentiate soil units for future "targets of opportunity" for analyses by the Athena science instruments.

The RAT will be used to remove dust and weathering rinds from rock surfaces such that the full suite of Athena instruments can determine compositional and textural changes of rock surfaces and interiors. Similar to the trenching operations, RAT engineering data will infer rock physical properties, possibly differentiating surface rinds from the interior rock.

Soil parameters related to trafficability of the rover can be determined from wheel sinkage into the regolith materials, wheel load on the surface, and slippage of wheels during traverse. These measurements will be formulated by a combination of theoretical and empirical approaches [1]. Additional information on the properties of the terrain will be obtained by sampling the 8 Hz telemetry engineering data during rover traverses. These engineering measurements and observations will be most useful once Spirit and Opportunity begin embarking on longer roving traverses.

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