

TOOLBOX FOR RESEARCH AND EXPLORATION (TREX): INVESTIGATIONS OF FINE-GRAINED MATERIALS ON SMALL BODIES. D. L. Domingue,¹ J.-P. Allain², M. Banks³, R. Christoffersen⁴, M. Cintala⁴, R. Clark¹, E. Cloutis⁵, A. Graps¹, A. R. Hendrix¹, H. Hsieh¹, M. D. Lane⁶, S. Lederer⁴, J.-Y. Li¹, E. Noe Dobrea¹, T. Prettyman¹, D. W. Savin⁷, N. Schorghofer¹, K. Stockstill-Cahill¹, F. Vilas¹, and the TREX team. ¹(domingue@psi.edu) Planetary Science Institute, Tucson AZ, 85719, USA. ²University of Illinois at Urbana-Champaign, Urbana IL, USA. ³NASA Goddard Space Flight Center, Goddard MD USA. ⁴Johnson Space Center, Houston TX USA. ⁵University of Winnipeg, Winnipeg CA. ⁶Fibernetics LLC, Lititz PA, ⁷Columbia University, New York NY USA.

Introduction: The Toolbox for Research and Exploration (TREX) is a NASA SSERVI (Solar System Exploration Research Virtual Institute) node. TREX (trex.psi.edu) aims to decrease risk to future missions, specifically to the Moon, the Martian moons, and near-Earth asteroids, by improving mission success and assuring the safety of astronauts, their instruments, and spacecraft. TREX studies will focus on characteristics of the fine grains that cover the surfaces of these target bodies - their spectral characteristics and the potential resources (such as H₂O) they may harbor. TREX studies are organized into four Themes (Laboratory-Studies, Moon-Studies, Small-Bodies Studies, and Field-Work). In this presentation, we focus on the work targeted by the Small-Bodies Theme.

The Small-Bodies' Theme delves into several topics, many which overlap or are synergistic with the other TREX Themes [1,2,3]. The main topics include photometry, spectral modeling, laboratory simulations of space weathering processes relevant to asteroids, the assembly of an asteroid regolith database, the dichotomy between nuclear and reflectance spectroscopy, and the dynamical evolution of asteroids and the implications for the retention of volatiles.

Photometry: For the purposes of this project, photometry is defined as the study of reflected light as a function of illumination (incidence angle) and viewing (emission angle) geometries, and how its properties are correlated to the physical structure of the regolith. The Laboratory Studies group [1] will be acquiring photometric laboratory measurements of fine-grained (<10 μm) mineral samples; the role of the Small-Bodies group is to examine and model those measurements to identify distinguishing signatures of regolith composed of fine particulate material (referred to as fine-grained regolith). This provides a remote-sensing tool for explorers (human or robotic) to quantify the fine-grained regolith component in their study site.

Spectral modeling: Using modeling techniques based on the principles of radiative transfer [e.g. 4, 5], this topic examines the ability to decipher mineral content. Once again, in partnership with the Laboratory-Studies group, the laboratory mineral and mineral-mixture measurements will be modeled to characterize the strengths and weaknesses in the current spectral-modeling approaches. The results will feed into the Field Work Theme's [3] derivation of autonomous

software to guide decision making during *in situ* field analyses and sample selections.

Space weathering: Asteroids are subject to the effects of space weathering from both solar radiation and micrometeoritic impacts. The Small-Bodies group will be studying the effects of both processes in the laboratory on minerals and mineral assemblages relevant to both C-type and S-type asteroids.

The most reliable laboratory simulations of space weathering by solar-wind ions require: 1) regolith-like loose powders; 2) sample generation in an inert environment, to avoid atmospheric contamination; 3) irradiation using a solar-wind-like dual-species beam of $\sim 95\%$ H and 5% He ions; 4) beam energies to match that of the solar wind at ~ 1 keV/amu; and 5) *in situ* and *in vacuo* diagnostics to prevent atmospheric contamination of the samples.

No simulation to date has met the first three of these requirements. Our proposed work, to be performed at University of Illinois at Urbana-Champaign (UIUC) in the IGNIS (Ion-Gas-Neutrals Interaction with Surfaces) facility, will meet all of the above five requirements. These studies will generate quantitative information regarding the optical properties of regolith-like loose powers. All data will be generated as a function of fluence. We will also explore the effects of varying: 1) He/H ratio of the irradiating beams, 2) the beam energy, 3) sample temperature, and 4) grain-size distribution. We will thereby provide critically needed quantitative data on space weathering and also help to determine the degree of applicability of previously published studies.

In partnership with NASA's Johnson Space Center (JSC), we are supplementing their studies of micrometeorite impact effects on minerals relevant to comets and asteroids (e.g. 6, 7). Using their experimental setup within the NASA/JSC Experimental Impact Laboratory, we will examine the ultraviolet to far-infrared spectral effects of micrometeorite impacts into fine-grained regoliths composed of phyllosilicates.

Asteroid Regolith Database: This collection of the properties of the surface layers of hundreds of asteroids will provide a foundation for future asteroid research and exploration. It includes remote sensing measurements (spectral reflectance, radar, polarization), spacecraft data, and laboratory data obtained from meteorites to provide information regarding grain

density, grain size, near-surface bulk density, and porosity.

Nuclear versus reflectance spectroscopy: The suite of remote sensing instruments used to determine surface composition is sensitive to different chemical and mineral species and probes a wide range of depths and spatial scales. These instruments measure the elemental composition of the bulk regolith to depths on the scale of centimeters to decimeters, whereas reflectance spectrometers (UV-VIS-NIR (NIR $\sim 2.5 \mu\text{m}$)), whose measurements are used to identify mineral composition, provide information on the mineralogy of the thin, outermost layer (10 – 100's microns). The spatial resolution of elemental measurements is usually much broader than that for mineral measurements. As a result, there are often mismatches or disconnects between the interpretation of the mineral composition of a surface and the elemental measurements from each class of instrumentation. This topic explores the sources of these mismatches and techniques for reconciling crustal compositions based on observations from both categories of spectrometers.

Dynamical evolution and volatile retention: The retention and depletion of volatiles is a function of heliocentric distance over time. These studies are to be applied to the orbital evolution of near-earth objects (NEOs) to explore the probabilities of finding volatiles or needed resources based on an object's orbital evolution and history. Ice in NEOs is of scientific and resource exploration interest, but small airless bodies gradually lose their ice to space by outward diffusion. We calculated the time it takes a porous airless body to lose all of its interior ice, based on an analytic solution for the interior temperature field of bodies in stable orbits. In addition, an analytic solution is obtained for the depth to ice as a function of time. Bodies covered with fine-grained material maintain ice in their interior much longer than bodies covered with coarse-grained material.

Collaboration between TREX Themes: The tasks and products of each Theme within TREX are intertwined and connected. The Laboratory-Studies Theme's products are inputs to the photometric and spectral studies of this Theme. The laboratory data will be used not only to validate the models, but will be used also as direct inputs for modeling spacecraft observations of asteroid surfaces. The models will in turn be inputs to the Field-Studies Theme for use in creating autonomous decision-making software packages [3].

All laboratory studies on regolith-like materials to date have used samples generated in an atmosphere, where the sample surfaces can readily become contaminated with or altered by H_2O , O_2 , and CO_2 . At UIUC we will grind our samples in an inert environment to generate fresh surfaces, insert the ground samples into

a vacuum suitcase, and transport them to our test chamber. There we will characterize the optical and surface properties of the samples with *in-situ* diagnostics to ensure contamination is minimized, and compare the findings to materials generated in an ambient atmosphere. We will also use our vacuum suitcase to transport samples to laboratories associated with TREX's Laboratory-Studies Theme so researchers in that theme could also evaluate the effect, if any, of atmospheric contamination in their studies.

Collaboration between SSERVI nodes: While TREX continues to explore studies of mutual interest between the SSERVI nodes, the projects described below are a few of the collaborations that have been set in motion.

VORTICES (Volatiles, Regolith and Thermal Investigations Consortium for Exploration and Science): TREX team member Karen Stockstill-Cahill is collaborating with Rachel Klima and Andrew Rivken from VORTICES (Johns Hopkins University/Applied Physics Laboratory) to study the spectral signature of adsorbed water for nominally anhydrous minerals in ordinary chondrites. The team will collect VIS-NIR spectra under ambient conditions to test for spectral signatures of adsorbed water present under terrestrial ambient conditions. Under vacuum conditions, the team will collect UV, VIS, and SWIR of samples before slowly heating samples to $\sim 100^\circ\text{C}$ to drive off adsorbed water. Collection of UV-NIR spectra will be repeated again post-heating, while still under vacuum. Comparison of the spectra before and after heating will allow the team to ascertain the effects of adsorbed water on the spectra of ordinary chondrites.

SEED (Evolution and Environment of Exploration Destinations: Science and Engineering Synergism): TREX team member Thomas Prettyman is collaborating with SEED PI Carle Pieters (Brown University) to investigate and explore the connections between remotely determined elemental and mineral compositions of surfaces. The differences between the suite of instruments used to determine surface composition presents some challenges as well as opportunities to improve surface characterization. In this collaboration we will explore the joint analysis of elemental and mineral data to provide a more complete picture of the physical and chemical mineralogies of small-body surfaces, providing constraints on regolith, crustal, and interior processes.

References: [1] Lane et al., this volume, [2] Banks et al., this volume, [3] Noe Dobra et al., this volume. [4] Clark et al. 2012. *Icarus* 218, 831 – 860. , [5] Stockstill-Cahill et al. (2017) LPSC XLVIII, Abstract #2673 [6] Jensen, E., et al. 2014. AAS, DPS meeting #46, id. 305.03 [7] Lederer et al. 2014. AAS, DPS meeting #46, id. 209.22