SCIENTIFIC APPLICATIONS OF IMAGING SPECTROMETERS FOR LANDED MISSIONS: EXAMPLES FROM TERRESTRIAL FIELD DEPLOYMENTS. R. N. Greenberger[1], B. L. Ehlmann[1,2], R. O. Green[1], D.L. Blaney[1]. Jet Propulsion Laboratory, California Institute of Technology, 4800 Oak Grove Drive, Pasadena, CA, 91109; Rebecca.N.Greenberger@jpl.nasa.gov. [2]California Institute of Technology, 1200 E. California Blvd., Pasadena, CA 91125.

Introduction: Visible-shortwave infrared (VSWIR) imaging spectroscopy from orbiter missions has revolutionized our understanding of the history of solar system bodies (e.g., most recently, CRISM on MRO, M^3 on Chandrayaan-1, VIR on Dawn). New technological advances in instrument miniaturization now enable imaging spectroscopy at sub-cm spatial resolution in landed packages (<2-3 kg mass), which has exciting geological applications on Earth and other solar system bodies [4]. Here, we show three science applications of imaging spectroscopy in different environments at scales relevant to landed planetary missions (landscape to microscopic) highlighting the utility of this technique, which combines information on morphology and composition in a single dataset. The imaging spectrometers used in the following examples are commercially available but are similar in wavelength coverage, spatial resolution, and data output to those developed to TRL 6 for spaceflight (e.g., the Ultra Compact Imaging Spectrometer, packaged in mast- or microscope mode [1-3]).

Example 1 – Sedimentary unit sequence stratigraphy: Sedimentary processes have been discovered on Mars and Titan. Changing compositions of minerals and ices recorded in layered units provide insight into the type of environments in which the sediments were deposited and record environmental change. For example, [5] used imaging spectroscopy to map lithologies of the Green River Formation, Utah (Fig. 1). The lithologies identified include carbonates (incl. distinctly calcite- and dolomite- rich units), silicates (hydrated), and organic-rich units. A general transition from siliciclastic to carbonate facies indicates deepening of the basin's lake, consistent with previous, traditional field-based geologic mapping [6]. Key new results also include identification of a dolomitized stratum as well as gypsum in enriched lenses and as a weathering product [5]. The ability to remotely map sedimentary lithologies during a planetary mission would provide a significant advance in spatial resolution (and thus paleoenvironment temporal resolution) vs. orbital data and identify the most crucial locations for further in situ investigations.

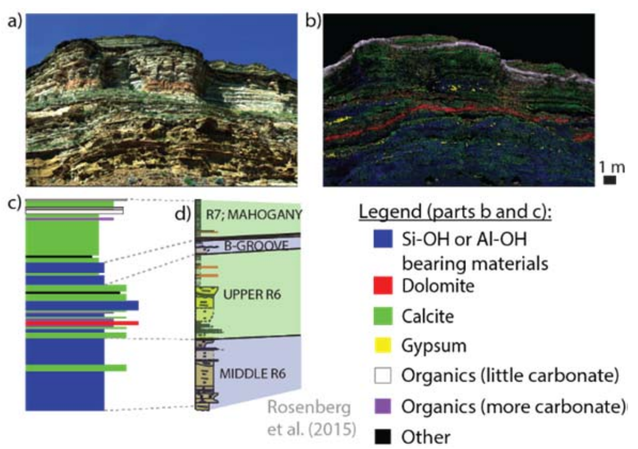

Fig. 1. a) Approximate true color image of outcrop of Green River Formation outcrop. b) Lithologic map from spectral image. c) Lithostratigraphy from (b). d) Stratigraphy made with traditional geologic methods by [6]. Modified from [5].

Example 2 – Interpretation of volcanic and hydrothermal processes: Volcanism occurs on bodies throughout the solar system, and the resulting mineralogies characteristic of different temperatures, pressures, and source compositions have unique spectral signatures at VSWIR wavelengths [e.g. pyroxenes, olivine, ilmenite, spinel, anorthites; 7]. Furthermore, VSWIR imaging spectroscopy is a powerful technique to discern hydrothermal alteration and weathering of volcanic materials. For example, a microimaging spectroscopy study of lacustrine pillow lavas from the Hartford Basin, Connecticut, identified the composition of the lavas and then multiple episodes of fluid interaction that could be time-ordered: (1) initial >400°C temperature formation of calcic clinopyroxenes and aegirine, (2) lower temperature formation of Fe/Mg-smectite and chlorite along with fine-grained hematite, and (3) two episodes of calcite precipitation and albitization [8]. Small areas of datolite ($CaBSiO_4OH$), significant because of its flagging of the existence of past boron-rich fluids, were also identified with imaging spectroscopy that were not apparent through visual inspection of the sample. The results of these detailed micro-scale analyses were then scaled to the larger samples and outcrops using imaging spectroscopy, highlighting alteration trends at a larger scale. Imaging spectroscopy is a key technique for a planetary mission to integrate individual point measurements to the surrounding outcrops.

Example 3 – Impact cratering and investigation of subsurface-derived clasts: Impact cratering is the most ubiquitous geologic process in the solar system, affecting every planetary body. Ground-

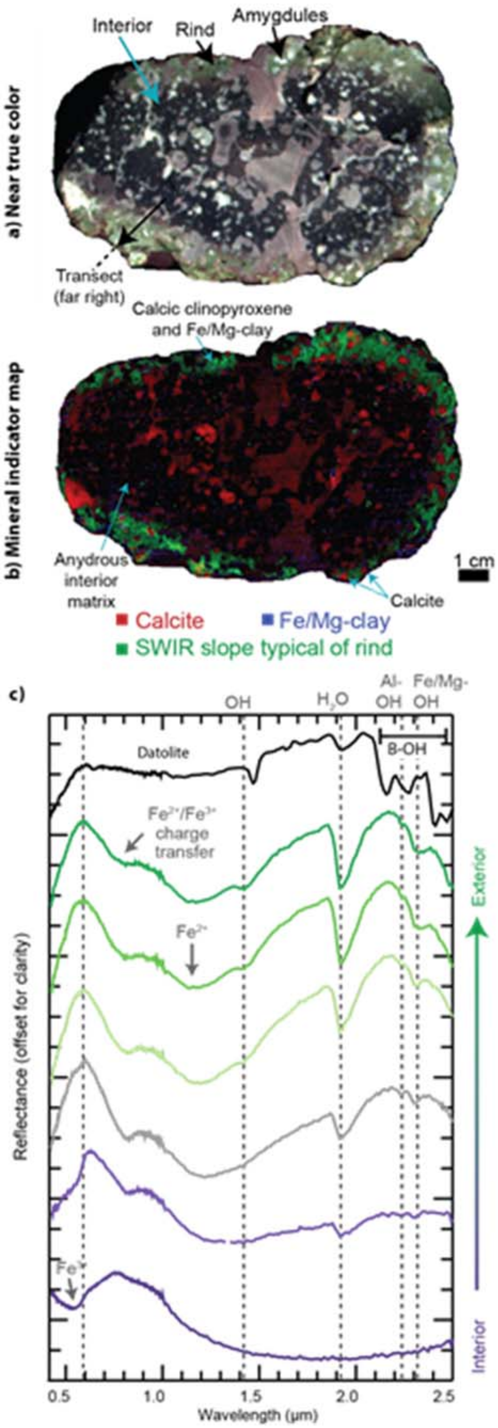

Fig. 2. a) Approximate true color image of lacustrine pillow lava cross-section. b) Spectral parameter map. c) Spectral transect across alteration rind and spectrum of small patch of datolite. Location of transect shown in (a). Figure modified from [Greenberger 4, 8].

based imaging spectroscopy field campaigns have been conducted at the Haughton impact structure, Nunavut, Canada in 2013 [9] and 2016 [10]. Using imaging spectroscopy, lithologies within highly heterogeneous, impact-disrupted materials can be identified and mapped, permitting identification of rare lithologies that might otherwise be missed. On water-bearing bodies such as Mars and Ceres, the heat from meteorite impacts can generate hydrothermal systems [e.g., 11-12]. Those deposits and their weathering products can be mapped, providing insights into the chemistries and temperatures of the fluids and guiding sampling to search for evidence of microbial colonization (Fig. 3).

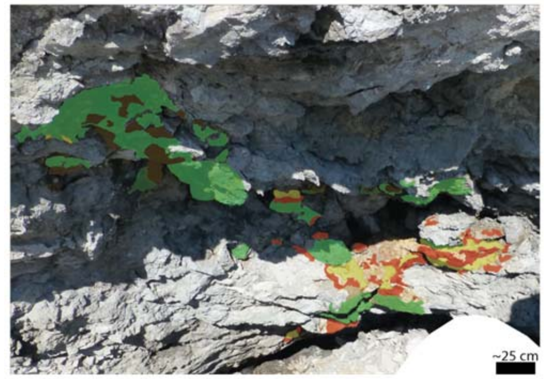

Fig. 3. Mapping of primary and weathering lithologies at a hydrothermal calcite-marcasite vug, Haughton impact structure, Canada. Green=marcasite, brown=thin sulfate and oxide coatings on marcasite, yellow=copiapite+fibroferrite, red=gypsum+Fe^{3+}-oxides and sulfates (fig. modified from [9])

Conclusions: Imaging spectroscopy on a landed planetary mission is uniquely suited to remotely mapping lithologies in a variety of terrains, combining morphology and composition in a single dataset to determine geologic histories. The results guide tactical mission planning, identifying the most promising sites for in situ sampling and finding rare compositional components that may be key to understanding the geologic and/or aqueous history. Finally, field tests on Earth provide opportunities to characterize and test the instrumentation and develop the analytical methods to maximize the science return from future missions.

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Acknowledgments: R.N.G. is supported by the NASA Postdoctoral Program with an appointment at the Jet Propulsion Laboratory, California Institute of Technology, administered by Universities Space Research Association under contract with NASA.