W.M. Keck Institute for Space Studies Postdoctoral Fellowship Final Report

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W. M. Keck Institute Prize Postdoctoral Fellow Annual Report

I. Introduction

The W.M. Keck Institute for Space Studies Postdoctoral Fellowship provided me with an amazing opportunity to significantly advance both my research and career goals. Having the flexibility to design my own research program allowed me to tackle exciting, high risk-high reward scientific problems, which are described in more detail below. This freedom provided by the program also gave me the chance to develop my voice as an independent scientist.

In addition to research, the KISS fellowship was also invaluable for allowing me to become part of a multidisciplinary community of extraordinary scientists and engineers. The people I met at KISS workshops, lectures, dinners, and other events cemented my connection between Caltech campus and JPL and helped me achieve my top career choice as a job as a JPL research scientist.

II. Scope and aim of work

1. *Detailed coordinated orbital mapping of lower Mt. Sharp using next generation data products.*

Curiosity is currently exploring the lower flanks of Mt. Sharp – a 5 km high mound of sedimentary material in the center of Gale Crater. Curiosity's ground based explorations benefit greatly from synergistic analysis of orbital datasets, which provide a broad scale geologic context for Curiosity's narrow focused observations and are also important for rover path planning to help locate the most efficient routes towards scientifically interesting targets.

During my time as a KISS postdoc I generated a refined stratigraphy (mapping of rocks in time ordered depositional events) of Mt. Sharp. This work was novel because I used newly derived, highest possible resolution data products that were generated with the help of several research collaborators. These new orbital data products included thermal inertias which for the first time explicitly modeled Mt. Sharp's large elevation and albedo variations in their derivations, a high resolution color mosaic made from careful spatial registration and scene to scene albedo normalizations of 13 HiRISE scenes, and visible short wavelength spectral data that had been collected using along-track oversampling and regularized to higher than nominal spatial resolution. This work was also novel because I performed qualitative cross comparisons of the datasets to extract additional information that only became apparent after the coordinated studies.

The Mt. Sharp stratigraphic group consists of seven relatively planar units delineated by differences in texture, mineralogy, and thermophysical properties.
Two additional units, distinguishable by unique morphology and high thermal inertia values, unconformably overlie the Mt. Sharp group, recording a period of substantial deposition and exhumation that followed the deposition and exhumation of the Mt. Sharp group. Several spatially extensive silica deposits associated with veins and

fractures show late stage silica enrichment within lower Mt. Sharp was pervasive. At least two laterally extensive hematitic deposits are present at different stratigraphic intervals, and both are geometrically conformable with lower Mt. Sharp strata. The occurrence of hematite at multiple stratigraphic horizons suggests redox interfaces were widespread in space and/or in time, and future measurements by the Mars Science Laboratory Curiosity rover will provide further insights into the depositional settings of these and other mineral phases.

The results of this study were published in the Journal of Geophysical Research: Planets (Fraeman et al., 2016a), and this paper is appended to the end of this report.

2. *Exploring microimaging spectroscopy as a tool for planetary sample analyses.*

Microimaging spectroscopy is an emerging technique that can be to assess the composition of geological samples at the micrometer scale. While this technique was initially developed for use on an arm mounted instrument on planetary missions, its ability to rapidly and non-destructively collect data on samples requiring little to no preparation makes it a potentially powerful analysis method in terrestrial laboratories. Additionally, microimaging spectroscopy provides a unique opportunity to link meter to kilometer scale orbital and telescopic spectral observations with the micrometer scale processes that may be affecting these large scale data.

I explored this technique by analyzing a variety of samples, including altered basaltic drill cores, deep marine carbonates, and various classes of meteorites (Martian meteorites, carbonaceous chondrites, and the howardite, eucrite, and diogenite (HED) suite), and explored the datasets. The HED meteorite suite in particular provided intriguing first results because the data had clear spectral signatures with deep absorption bands and were constrained to well-known and limited number of mineralogical components. These meteorite samples are also interesting to study in more detail because they have a known parent body (Vesta) that has already been investigated extensively by the Dawn spacecraft, and therefore provide a unique opportunity to explore spectral links from the micrometer to the orbital data scale.

I was fortunate to be able to delve more deeply into the HED data with the help of an undergraduate summer student, Geraint Northwood-Smith. Using a combination of manual and automated hyperspectral classification techniques, we identified four major spectral classes of materials based on VSWIR absorptions that include pyroxene, olivine, Fe-bearing feldspars, and glass-bearing/featureless materials. Although this project is still ongoing, the preliminary results already demonstrated microimaging spectroscopy is an effective method for rapidly and non-destructively characterizing small compositional variations of meteorite samples and for locating rare phases for possible follow-up investigation. Future work will include incorporating SEM/EDS results to quantify sources of spectral variability, systematic use of DEMUD machine-learning algorithm to locate rare phases, and placing observations within a broader geologic framework of the differentiation and evolution of Vesta.

The preliminary results of this work focusing on HED meteorites was presented at and published in the proceedings of the IEEE Workshop on Hyperspectral Image and Signal Processing Conference (Fraeman et al., 2016b), and the paper is appended to the end of this report.

3. *Curiosity mission activities.*

In addition to research, I also continued to participate as a member of the Curiosity Science team. In this capacity I served in several tactical planning roles related to science plan development and path planning, presented results of my research at science team meetings, and helped contribute to general team science discussions. I was also deeply involved with planning and execution of Curiosity's multi-week science campaign in the Bagnold Dunes. Finally, I wrote a proposal for and was awarded a NASA ROSES grant to continue my participation on the Curiosity science team as a Participating Scientist at the conclusion of my KISS postdoc.

III. Publications and presentations

First author peer reviewed publications:

Fraeman, A., Ehlmann, B., Arvidson, R., Edwards, C., Grotzinger, J., Milliken, R., Quinn, D., and Rice, M. 2016a. "The Stratigraphy and Evolution of Lower Mt. Sharp from Spectral, Morphological, and Thermophysical Orbital Datasets," *JGR-Planets, in press.*

Fraeman, A., Ehlmann, B., Northwood-Smith, G., Liu, Y., Wadhwa, M., Greenberger, R. "Using VSWIR Microimaging Spectroscopy to Explore the Mineralogical Diversity of HED Meteorites," 2016b. *IEEE Workshop on Hyperspectral Image and Signal Processing*.

First author conference abstracts:

Fraeman, A., Ehlmann, B., Northwood-Smith, G., Liu, Y., Wadhwa, M., Greenberger, R. "Exploring the Mineralogical Diversity of HED Meteorites with Microimaging VSWIR Spectroscopy," poster presentation at LPSC (2016).

Fraeman, A., Ehlmann, B., Arvidson, R., Edwards, C., Grotzinger, J., and Rice, M. "The Stratigraphy and Evolution of Lower Mt. Sharp from Spectral, Morphological, and Thermophysical Orbital Datasets," oral presentation at LPSC (2016).

Fraeman, A., Edwards, C., Ehlmann, B., Arvidson, R., Horgan, B., Rice, M. "A Detailed Investigation of Lower Mt. Sharp using Coordinated Orbital Datasets," oral presentation at GSA Annual Meeting (2015).

Fraeman, A., "Deciphering the History and Habitability of Gale Crater with Orbital and

Rover Datasets," oral presentation at 11th Recontres du Vietnam, Planetary Systems Conference (2015).

Fraeman, A., Arvidson, R., Ehlmann, B., Bridges, N., Clark, B., Cousin, A., Des Marais, D., Gellert, R., Johnson, J., Lapotre, M., Schroder, S., Stein, N., Sullivan, R., Wellington, D., "Physical and Material Properties of Gale Crater Sandy Deposits: From Rocknest to Pahrump", poster presentation at LPSC (2015).

Fraeman, A., Edwards, C., Ehlmann, B., Arvidson, R., and Johnson, J., "Exploring Curiosity's Future Path from Orbit: The View of Lower Mt. Sharp from Integrated CRISM, HiRISE, and THEMIS Datasets," poster presentation at LPSC (2015).

Fraeman, A., Edwards, C., Ehlmann, B., "Habitable Environments Preserved in Lower Mt. Sharp: Exploring Curiosity's Future Path from Orbit," poster presentation at 3rd ELSI International Symposium (2015).

IV. Acknowledgments

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