THE SCIENCE CASE FOR A SCANNING ELECTRON MICROSCOPE ON MARS. J. Edmunson[1], J. A. Gaskin[2], G. A. Jerman[2], M. Salvatore[3], Z. E. Gallegos[4], and the MVP-SEM Science and Instrument Development Teams, [1]Jacobs ESSCA Group, NASA Marshall Space Flight Center (MSFC), Huntsville AL 35812, Jennifer.E.Edmunson@nasa.gov, [2]NASA MSFC, Huntsville AL 35812, Jessica.Gaskin@nasa.gov Gregory.A.Jerman@nasa.gov, [3]Northern Arizona University, Flagstaff AZ 86011, Mark.Salvatore@nau.edu, [4]University of New Mexico, Department of Earth and Planetary Sciences, Albuquerque NM 87131, zeg@unm.edu.

Introduction: A Miniaturized Variable Pressure Scanning Electron Microscope (MVP-SEM) is under development through the Research Opportunities in Space and Earth Science Planetary Instrument Concepts for the Advancement of Solar System Observations Program [1, 2]. This instrument will be capable of imaging uncoated samples with a resolution of 100 nm or better as well as calibrated energy dispersive spectroscopy for geochemical analysis on Mars [1].

The Science Case for a SEM: The *in situ* use of this instrument on a future Mars mission would answer numerous outstanding questions about the petrology, evolution, and habitability of Mars, such as:

What is the makeup of martian dust? A major roadblock in the characterization of martian dust is the size of the material (<10 μm) [e.g., 3]. With the exception of an atomic force microscope's surface imaging, fine-grained dust is too small be imaged by most instruments. Thus far, the chemistry of the dust has been derived from orbital observations [e.g., 4] and assumptions of rock compositions with dust covering (i.e., the assumed rock composition is subtracted from the bulk analysis to determine the elements most likely in the dust). The only way to truly characterize this material is to image it and exclusively analyze its geochemistry; this will be possible with the MVP-SEM.

What is the "amorphous component"? As indicated by numerous instruments, a large component of the martian soil appears to be amorphous. Because of their lack of long-range order, amorphous materials cannot be characterized with methods that rely on crystal structure for definitive identification. Mass balance calculations are often used to determine the bulk chemistry of the amorphous component [e.g., 5]. Direct characterization of this material would require both microscopic imaging (to determine flow banding or other indicators of formation) as well as microscopic geochemistry with a technique insensitive to crystal structure to quantify any heterogeneity in the material.

What can we learn about the evolution of the martian surface from analysis of microscopic samples? To determine the history of a rock and, by association, a geologic region, analyzing the geochemistry, texture, zoning of minerals, evidence of mineral resorption, and degree of alteration are all required. The MVP-SEM will allow for *in situ* quantification of mineral zoning in fine-grained materials, the detection of grain resorption by a magma, and quantification of the degree of alteration on a single mineral grain.

Is, or was, there life on Mars? If present, the extinct or extant life in martian soils is expected to be similar to terrestrial bacteria, fungi, algae, or single-celled archaea [6]. These organisms are extremely small, requiring microscopic methods for identification and characterization. Optical microscopes at ≥250X magnification have depth of field issues that prohibit resolving fine particles, including potential biosignatures. It is well understood that confirmation of present or past life on Mars will require positive detection by multiple instruments. Complementary instruments to assist the MVP-SEM in definitively identifying biosignatures would include a Raman spectrometer, multispectral camera, and a Mössbauer spectrometer.

Can humans live (safely) on Mars? Assessing the potential of the martian surface for human habitability is critical for future crewed missions. Identification of phases that could be harmful to the crew or its life support systems, particularly phases that are small and easy to transport like dust, must be completed prior to a human mission to Mars. Also, identification of *in situ* resources such as hydrated minerals and metal/silicate feedstock can provide sustainable mission necessities such as an appropriate media for plant cultivation.

Flight Instrument Comparison: Everything we know to date about the surface of Mars, specifically through *in situ* fine-scale imaging and soil/rock geochemistry, has been through the work of the instruments discussed below. Despite the great strides made in our understanding, these instruments have not been able to conclusively provide answers to the questions above. This review presents some limitations of flight heritage instruments with respect to microscopic imaging and micro-spatial geochemical analysis, with the recognition that these instruments can also provide complementary data for MVP-SEM to help provide concurrent evidence for any conclusions drawn.

X-ray Fluorescence Spectrometer (XRFS): The energy-dispersive XRFS on the Viking landers analyzed Mars soil samples using proportional counter detectors, which provided bulk geochemical analyses, although errors of 8.5% or greater were determined [7]. This technique does not allow for spatially resolved geochemical analyses, nor for the analysis of individual grains smaller than 10 μm in size [8].

Alpha Particle X-ray Spectrometer (APXS): These devices were flown on all rover missions and rely on radioisotope decay for the release of alpha particles and X-rays, which interact with a sample's atomic nuclei thus producing distinctive chemical X-ray spectra. The Sojourner instrument required cold nighttime temperatures on Mars (less than -50°C) for high precision measurements [9]. The Mars Exploration Rovers (MER) completed most measurements at night, and required at least 10 hours of signal accumulation time [e.g., 10]. The Curiosity APXS can be used during day or night, and can provide geochemical analyses in timeframes between 10 minutes and 2-3 hours on surfaces approximately 2.25 cm^2 [11, 12]. Two draw-backs to APXS are the reliance on a radioactive source and the time required for analyses. One other drawback to the APXS is that it cannot separate contributions of dust from that of rocks and sediments because "everything within the field of view of the sensor head contributes to the measured signal" [9]. Thus, inclusion of the Rock Abrasion tool on the MER and the Dust Removal Tool and drill on Curiosity provided the sample preparation for fresh surfaces to be analyzed.

Miniature Thermal Emission Spectrometer (Mini-TES): Mini-TES on the MER measures thermal emission from geologic surfaces, which can be converted to emissivity and linearly unmixed to determine mineral abundance to ~5% accuracy [13]. The results provided by the Mini-TES are impacted by instrument calibration, dust and thermal effects [14].

Microscopic Imager (MI): The goals of the instrument, employed on the MER, included imaging fine-scale features, including textures, of samples analyzed by other instruments [15]. MI has a field of view of 1024 x 1024 pixels and a maximum spatial resolution of 30 µm per pixel [15].

Microscopy, Electrochemistry, and Conductivity Analyzer (MECA): The focus of the microscopy portion of the MECA on the Phoenix lander was the characterization of grains with respect to their size, shape, and surface texture using both optical and atomic force microscopes [16]. The optical microscope resolution was set to 4 µm per pixel, and the atomic force microscope had the capability to resolve surface features greater than 50 nm in size [16]. These microscopes provide very little chemical data, requiring additional analysis with a wet chemistry laboratory; only four samples were fully analyzed [16].

Mars Hand Lens Imager (MAHLI): The MAHLI instrument on Curiosity is a color camera with a two megapixel image size and a resolution of 14 µm per pixel at the minimum working distance (WD) of approximately 2.1 cm [17]. The depth of field is 1 mm at the 2.1 cm WD [17]. MAHLI's capabilities include determination of grain shape, mineral cleavage and luster, fluorescence under ultra-violet light, and texture for coarse silt or larger grains (very fine sand size) [17].

Chemistry and Camera (ChemCam): The ChemCam instrument on the Curiosity rover is composed of two complementary instruments, a laser-induced breakdown spectrometer (LIBS) and a remote micro-imager. The LIBS device provides a chemical breakdown of the target material with a spot size of 350-550 µm and, with multiple analyses (>50 laser pulses), 10% accuracy for major elements within a 7 m standoff [18]. This allows for depth profiling as each laser strike volatilizes deeper into the rock. The remote micro-imager uses the LIBS-optimized telescope to roughly image the sub-mm LIBS target, for context, from LIBS operation distance [18].

Chemistry and Mineralogy (CheMin): This device on the Curiosity rover uses powder X-ray diffraction and fluorescence to determine the minerals present within a sieved powder (e.g., drill dust); precision (10% relative) and accuracy (15% relative) requirements were emplaced knowing amorphous phases, clay minerals, and some hydroxide phases can impact both [19].

Conclusion: A prototype MVP-SEM will be tested in a Mars chamber at the Jet Propulsion Laboratory in early 2018 to prove imaging capabilities at a resolution 100 nm or better in a Mars-like environment. EDS will be integrated in the future. Development and flight of this instrument, which requires minimal sample preparation, is key in the resolution of questions remaining about the history, present state, and habitability of Mars.

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