Unveiling the Mysteries of Mars with a Miniaturized Variable Pressure Scanning Electron Microscope (MVP-SEM)

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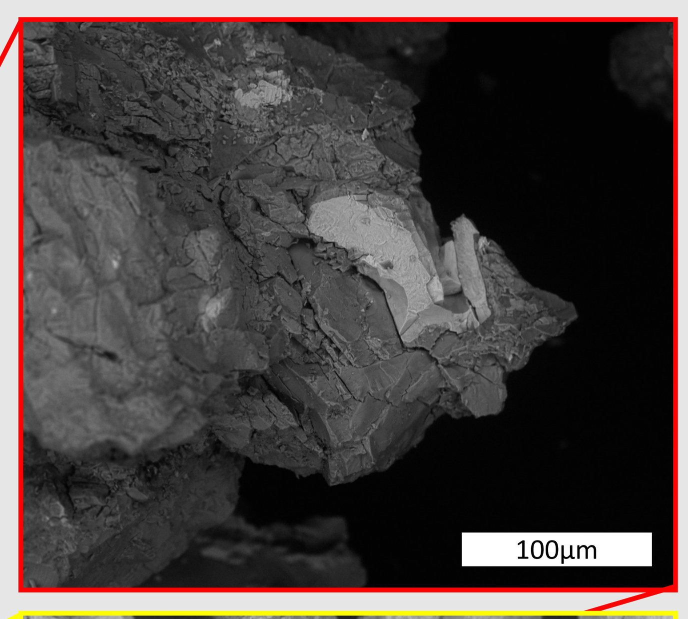
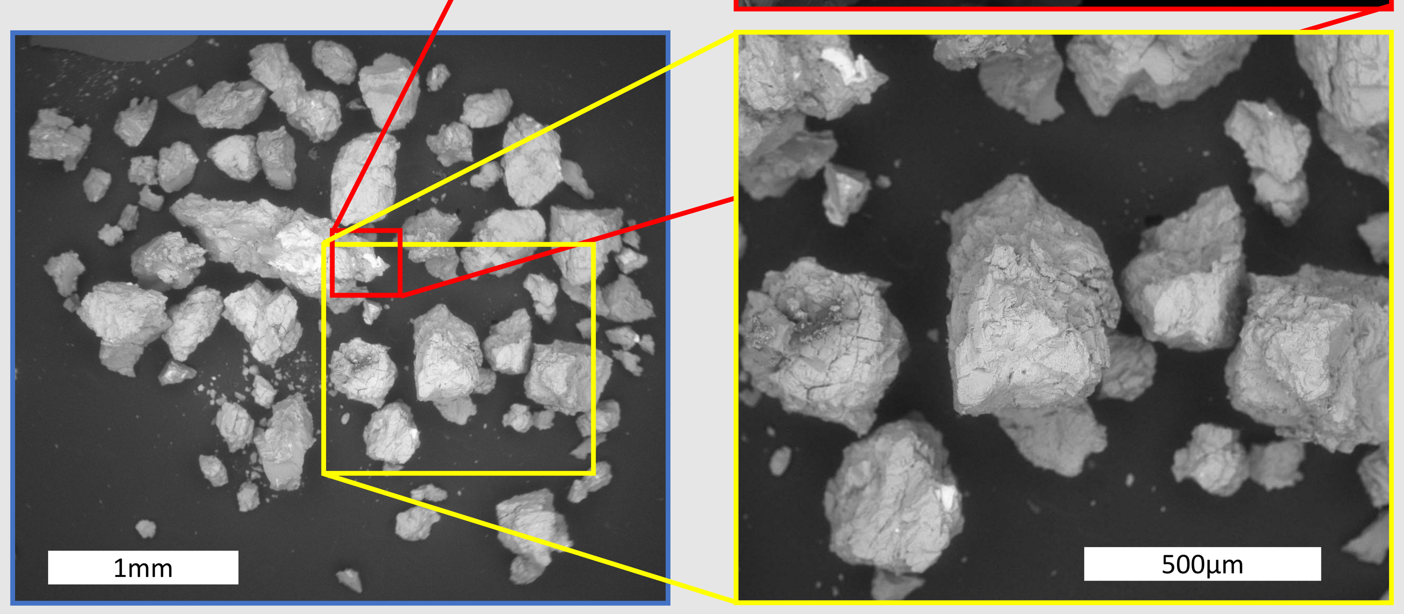
INTRODUCTION

A Scanning Electron Microscope (SEM) is typically the first instrument geologists use to characterize meteoritic samples on Earth, as the analysis is generally non-destructive, and sample preparation is straightforward and often does not require extensive and time-consuming work. Sample preparation techniques commonly used on Earth (e.g., thin sectioning, polishing, and carbon coating) are not readily available on Mars. Thus, an Environmental SEM (ESEM) is ideal for the study of martian materials in-situ, particularly if the instrument can operate with Mars atmosphere CO_2 gas instead of terrestrial N_2-rich or water vapor-rich atmospheres. The MVP-SEM Team is currently developing a lander- or rover-ready instrument that will allow secondary electron (SE) and backscattered electron (BSE) imaging, as well as chemical analysis through Energy Dispersive Spectrometry (EDS), for Mars in-situ analysis. This work will provide a method of acquiring both spatial and chemical data for microscopic samples on Mars.

Figure 1: SE images of grains from the martian meteorite Zagami, showing potential textures to be observed in grains on Mars (image credit: G. Jerman).





STANDARDS

The Team plans to investigate the use of the following materials for use as standards. Synthetic minerals (used to accommodate planetary protection concerns) would provide a way to verify functionality of the instrument after landing, quantify any contribution from the martian atmosphere to the EDS signal, and monitor the health of the instrument over time. The listed minerals will be assessed to determine their usefulness in this manner and reduced accordingly.

Anorthite	Jarosite	Pyroxene
Basaltic Glass	Kamacite	Sodium Chloride
Dolomite/Siderite	Magnetite/Titanomagnetite	Taenite
Gypsum	Montmorillonite	Teflon
Hematite	Olivine	

EXAMPLE INVESTIGATIONS

Over the course of 2016, a question was posed to numerous planetary scientists: "What would you study with a SEM on Mars?" Answers varied widely; many mysteries of Mars remain unsolved to this day. The following summarizes the majority of responses and relates them to the MVP-SEM Science Requirements in the table below.

Determine the general petrology of an area

The identification of mineral phases using EDS, combined with imaging that can determine the texture, is invaluable in the determination of a rock's provenance. Mineralogical modes, grain boundary types, identification of melt pockets, the presence of amorphous phases, and mineral zoning are key ingredients in characterizing the environment of formation of the rock. Assessing the extent of alteration in a sample, including mechanical weathering, will provide information on the sedimentary and weathering processes active in the area. This investigation would meet NASA goals in the Exploration and Knowledge, and Support Missions categories.

Characterize microtextures

Micro-fabrics that originate in phyllosilicates and metamorphosed rocks will be apparent, and the conditions under which the microfabric formed will be determined by comparison with terrestrial examples [e.g., 1]. Other microtextures, including flow banding in amorphous samples, can be observed. This investigation would meet NASA goals in the Exploration and Knowledge category.

Study features that indicate the presence of fluids

Characterize the minerals deposited on vein walls which indicate the composition of the fluid from which they formed. Other fluid / rock interactions in the form of concretions, nodules, and alteration products will be studied in micro-scale. This will also provide information on martian diagenetic processes. This investigation would meet NASA goals in the Exploration and Knowledge, and potentially Astrobiology, categories.

Characterize dust and other small particles

The dust-sized particles on the surface of Mars are not well-characterized in size and chemistry; lofted grains are easier to characterize by size with remote sensing techniques. The MVP-SEM is well-suited to characterize samples that are microns in size and how they are aggregated. Dust has been identified a significant risk to crewed missions on planetary surfaces. This investigation would meet NASA goals in Exploration and Knowledge, and Support Mission categories.

Identify biosignatures and confirm evidence of past life (if possible)

Some chemical and morphological signs that resemble activity from life can also be formed abiotically [e.g., 2]. Thus, it is important to characterize the signs as well as the surrounding environment to conclusively determine if the sign is, in fact, a biosignature. The MVP-SEM will have the capability to note morphological evidence on a sub-micron scale, and will have the capability to note the chemical disequilibrium that is often a sign of biological activity. Minerals such as greigite, green rust (fougerite), and clays will be studied in detail for evidence of life. This investigation would meet NASA goals in Exploration and Knowledge, and Astrobiology categories.

Help provide ground truth for remote sensing observations

For example, remote sensing signals indicate a variable distribution of chlorine on the surface [3]. The MVP-SEM will be capable of determining the composition of salts and other phases that contain chlorine, providing a point of reference for the remote sending observations. This investigation would meet NASA goals in the Exploration and Knowledge, Support Missions, and Astrobiology categories.

Provide data that would be useful to crew (if they precede the MVP-SEM)

A device to study microfractures and the effects of space weathering (such as micrometeorite hits) on the habitats and other structures used during a crewed surface mission will be necessary. This instrument can be modified with a compatible sample chamber system for in-situ analysis of the infrastructure elements. This investigation would meet NASA goals in the Support Missions category.

Assess the soil for toxicity to humans and provide data for terrestrial simulants

Identification and quantification of materials that are hazardous to humans (e.g., arsenic salts, perchlorates) is as important as being able to sufficiently reproduce the characteristics of the martian soil in simulants for technology development. This investigation would meet NASA goals in the Exploration and Knowledge, and Support Missions categories.

MVP-SEM SCIENCE REQUIREMENTS

NASA Goals	MVP-SEM	Primary Instrument Requirements	Secondary Instrument Requirements
Exploration & Knowledge Expand the frontiers of knowledge, capability, and opportunity in space Perform space, earth, and applied science Characterize the geology of Mars Ascertain the content, origin, and evolution of the solar system and the potential for life elsewhere Discover how the universe works, explore how it began and evolved, and search for life on planets around other stars **Support Missions** Develop new technologies that significantly improve instrument measurement capabilities for planetary science missions Perform science to enable human exploration **Astrobiology** Determine whether life ever arose on Mars Search for life	**SEM Characteristics** Characterize an area through geochemical analysis to a sensitivity of 2 weight percent Characterize an area through microscopic imaging to a resolution of 100nm Provide the capability to characterize a sample prior to ejection, caching, or transfer to another instrument for analysis **Information to Obtain** Characterize the dust component on the surface of Mars Determine if any components of the martian surface are toxic to humans Provide sufficient information to replicate the martian surface for technology development simulants (grain size, grain shape, and bulk composition) Characterize Mars surface samples ranging from a few nm up to 2mm in size Determine if biosignatures exist on the martian surface Provide data to the Planetary Data System for public use	**Location** The instrument shall operate on the surface of Mars on a rover or lander **Chemistry** The instrument shall have an Energy Dispersive Spectrometer to provide the chemistry of Mars surface samples to a sensitivity of 2 weight percent The instrument shall have the capability to detect non-gaseous elements between atomic numbers 6 (carbon) and 82 (lead) **Morphology** The instrument shall have Secondary Electron Imaging capability with a resolution of 100nm to adequately characterize the topography of Mars surface samples The instrument shall generate a focused electron beam to provide 100nm resolution on the sample surface The instrument shall have Backscattered Electron imaging capability with a resolution of 100nm to tie texture to chemistry The instrument shall have adjustable magnification between 5000X and 20,000X **Samples** The instrument shall have the capability to contain dust grains (<20µm in size) for analysis The instrument shall have the capability to analyze samples up to 2mm in size The instruments shall not require conductive coating that will alter the chemistry or morphology of the samples The instrument shall have a sample system capable of ejecting samples or transferring them to another analytical or storage device **Data** The instrument shall have the capability to acquire data and relay data for transmission to Earth	**Location** The instrument design shall minimize power consumption The instrument design shall minimize mass The instrument shall survive vibration during launch The instrument shall survive in a decompressed cabin during space transport The instrument shall survive impact during landing The instrument shall have a spacecraft-compatible electromagnetic interference The instrument shall be radiation-hardened The instrument shall function during surface conditions between 130K (-143C, -225F) and 295K (21C, 70F) The instrument shall function at 10 Torr and below The instrument shall be capable of operating in a CO_2-rich atmosphere The instrument shall have contamination mitigation **Chemistry** The instrument shall generate a strong enough electron beam to measure elemental concentrations to a sensitivity of 2 weight % The instrument shall have a pressure monitoring system for subtracting out any contribution of the atmosphere to the carbon and oxygen analyses The Energy Dispersive Spectrometer shall have an energy window of 0.2-15keV **Chemistry & Morphology** The electron beam current shall be TBD The electron beam voltage shall be adjustable with a maximum of 15keV **Morphology** The Field of View of the instrument shall be a 1 + 0.5mm diameter circle **Chemistry, Morphology, & Samples** The instrument shall use a variable pressure system to avoid coating the samples for charge dissipation The instrument shall have the ability to autofocus The instrument shall have the capability to move samples and standards relative to the detection devices for optimization of analysis with a precision of ±0.05mm **Samples** The instrument shall have a sample system capable of ejecting the sample **Data** The instrument shall have software to compress data for ease of downlink The instrument shall return data associated with the health and optimization of the instrument to assure accuracy of the data The instrument shall have software and hardware capable of diagnostics programs

FUTURE WORK

The team is refining the Concept of Operations to incorporate a feature recognition library. This library will help autonomously characterize the samples and accommodate an expected quick turn-around between daily downlink and uplink activities.

At the end of this PICASSO effort, the team will continue development of the instrument through the Maturation of Instruments for Solar System Exploration (MatISSE) ROSES opportunity. The team would like to thank the PICASSO program and reviewers for supporting our project, as well as the survey respondents!

REFERENCES

[1] Merriman (2005) *Eur. J. Min.*, 17, 7-20. [2] D. C. Golden et al. (2004) *Am. Min.*, 89, 681-695. [3] Keller et al. (2006) *J. Geophys. Res.*, 111, doi: 10.1029/2006JE002679.