

PRECISION SUBSAMPLING SYSTEM FOR MARS SURFACE MISSIONS. W. B. Brinckerhoff¹, G. Paulsen², B. Mellerowicz², I. L. ten Kate³, K. Zacny², P. Conrad¹, C. M. Corrigan⁴, X. Li⁵, P. R. Mahaffy¹, ¹Planetary Environments Laboratory Code 699.0, NASA Goddard Space Flight Center, Greenbelt, MD 20771 (william.b.brinckerhoff@nasa.gov), ²Honeybee Robotics Spacecraft Mechanisms Corp., 398 W. Washington Ave, Suite 200, Pasadena, CA 91103 (zacny@honeybeerobotics.com), ³Dept. Earth Sciences, Faculty of Geosciences, Utrecht University, Utrecht, The Netherlands, ⁵Center for Research and Exploration in Space Science and Technology (CRESST), University of Baltimore, Howard County, Baltimore, MD, ⁷Department of Mineral Sciences, Smithsonian Institution, Washington, DC (corrigan@si.edu).

Introduction: The ability to analyze heterogeneous rock samples at fine spatial scales would represent a powerful addition to our planetary *in situ* analytical toolbox. This is particularly true for Mars, where the signatures of past environments and, potentially, habitability are preserved in chemical and morphological variations across sedimentary layers and among mineral phases in a given rock specimen. On Earth, microbial life often associates with surfaces at the interface of chemical nutrients, and ultimately retains sub-mm to mm-scale layer confinement in fossilization. On Mars, and possibly other bodies, trace chemical markers (elemental, organic/molecular, isotopic, chiral, etc.) and fine-scale morphological markers (e.g., micro-fossils) may be too subtle, degraded, or ambiguous to be detected, using miniaturized instrumentation, without some concentration or isolation. This is because (i) instrument *sensitivity* may not be high enough to detect trace markers in bulk averages; and (ii) instrument *selectivity* may not be sufficient to distinguish such markers from interfering/counteracting signals from the bulk. Moreover from a fundamental chemostratigraphic perspective there would be a great benefit to assessing specific chemical and stable isotopic gradients, over mm-to-cm scales and beyond, with higher precision than currently possible *in situ*.

We have developed a precision subsampling system (PSS) that addresses this need while remaining relatively flexible to a variety of instruments that may take advantage of the capability on future missions. The PSS is relevant to a number of possible lander/rover missions, especially Mars Sample Return. Our specific PSS prototype is undergoing testing under Mars ambient conditions, on a variety of natural analog rocks and rock drill cores, using a set of complementary flight-compatible measurement techniques. The system is available for testing with other contact instruments that may benefit from precision sampling.

PSS Design: The PSS concept (Fig. 1) couples sampling, subsampling, manipulation, preparation, transport, analytical, and caching functions in a *single integrated system* saving significant payload mass, lowering development risk, and amplifying science benefit compared with separated instrument developments. The focus of PSS development has been on a

secondary sampling scenario, in which the primary samples such as cores, loose specimens, or rock cuttings have been acquired by a separate device and presented to the PSS such as shown in Fig. 1. The Pre-View Bit [2] design of Honeybee Robotics has demonstrated the plausibility of subsampling a core directly from the bit (not requiring ejection). However, it is possible to consider primary precision subsampling, with the localized cutting tool applied directly to Mars surface material and with a specialized capture device.

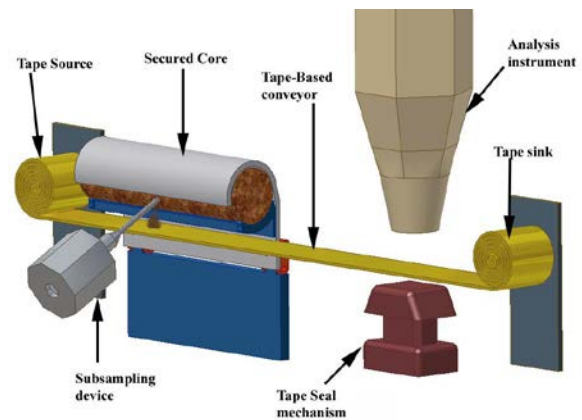


Fig. 1 Schematic arrangement of Precision Subsampling System (PSS) components, for the case of a ~1 cm diameter core sample. Sizes of and distances between the subsampling device, the conveyor, the seal mechanism, and the analysis instrument are notional and may be adjusted as needed.

Subsampling. The requirement for subsampling is to obtain an adjustable quantity of sample (10 μg – 1 mg) from any point on a core localized to a 1 mm or narrower “layer” (laminations normal to the core axis) or other feature. The core is assumed to be sufficiently consolidated at the sampling site for stable operation. The most direct approach tested uses a small rock grinding device with a robust universal bur or set of exchangeable burs. Following numerous tests of grinding tools over parameters including speed, rock hardness, grinder lifetime, powdering efficiency, and fines spatial scatter [1], a cut-off type wheel approach with a polycrystalline diamond grinding edge was selected for implementation in the prototype PSS (Fig. 2).

Collection and Transport. The prototype follows a simple tape-based passive collection approach previously demonstrated in a terrestrial aerosol collection time-of-flight mass spectrometer [3]. The tape with various surface structures (e.g., divots, fine mesh) and treatments (e.g., adhesives, electrostatic anchors) supports entrapment of particulates on a substrate for both imaging/contact sensors as well as laser desorption, which can be done *in vacuo* with the tape serving as a demountable vacuum sealing gasket. With appropriate material selection, and treatment, the tape-based system has been found to efficiently collect a thin, localized layer of subsample. In this approach each of potentially hundreds of mm-scale subsamples occupies a pristine section of tape. Precise “forward” and “reverse” motion are supported with a single rotational drive.

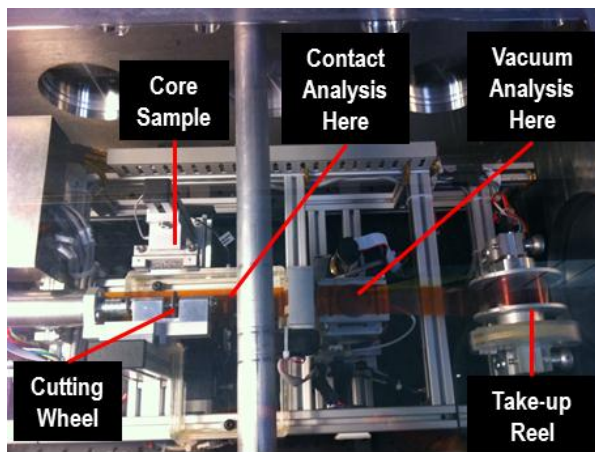


Fig. 2 The PSS prototype operating in a Mars atmosphere chamber is being tested to understand grinding behavior, particle size, flow, and electrostatic characteristics, to optimize subsampling, collection, and transport protocols. Direct analysis of subsamples with breadboard flight instruments such as a fluorescence microscope, a Raman spectrometer, and a laser mass spectrometer (not shown) are accommodated at positions arrayed on a linear tape-like substrate.

Analysis. Subsamples may be sequentially analyzed under Mars ambient or high vacuum conditions. As an example, a microscope combined with point spectrometers using UV fluorescence, Raman, and/or IR reflectance could probe both the core and the subsample to determine the presence of organic compounds which could then be thoroughly studied with a mass spectrometer using laser sampling [4] or microfluidic-based chemical extraction steps. Such “surface” probes typically only require a smooth and continuous focal plane of a few mm diameter, and therefore sample masses only in the mg range and below.

A number of chemically heterogeneous samples including dolomite/shale layered cores from Australia, nontronite clay and stilpnomelane/quartz specimens, and cryptoendoliths in sandstone have been subsampled for evolved gas and laser mass spectrometry and mineralogy to demonstrate the system's benefits [1].

PSS for MSR: Precision subsampling would be a particularly powerful capability on a Mars sample return mission. As returning a given hand sample or full sample core would represent a significant mass investment, analysis of subsamples would be effective at enabling triage (keep/drop) characterization of the core at scales closer to the microanalyses eventually to be performed on Earth, lowering science risk. In addition, the PSS was designed to permit direct caching of subsamples following triage-mode analysis, using the take-up reel approach. Considering the greatly reduced volume and mass of a collection of high-value subsamples compared to their host rock or core, returning the subsample cache itself would deliver a far greater variety of rocks and/or microenvironments (both type and site) than possible with the nominal “bulk sample only” return approach. This advantage propagates through both science and human exploration precursor goals, given the driving challenge to assure we are sampling a sufficiently diverse set of materials in the mission’s mobility horizon.

The take-up reel is one of several possible approaches to caching a large number of subsamples. Its benefits include (i) compactness, (ii) uncomplicated coupling to the PSS architecture, (iii) the ability to tailor the tape for a variety of sample types and particle sizes, and (iv) the built-in separation between subsamples. Its disadvantages include (i) the potential loss of volatiles during subsampling or subsequent steps, (ii) the need to retain samples as they move around in the reel, and (iii) the need to separate the reel for hermetic sealing and coupling to the fetch rover/return vehicle. However, other approaches face similar challenges. On balance we foresee the incorporation of some or all PSS capabilities as enabling technology for high-fidelity *in situ* science and human precursor analysis as well as for MSR.

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References: [1] Brinckerhoff W. B. et al. (2010) *Am. Soc. Civil Eng. Conf. Proc.*, 366, 123-140.. [2] Paulsen, G. et al. (2011) *LPS XLIII Abstract #1151*.. [3] Anderson C. W. and Carlson M. A. (1999) *JHU/APL Tech. Digest*, 20, 352-362. [4] e.g., Corrigan, C. M., W. B. Brinckerhoff, et al. (2007). *Meteoritics Planet. Science* **42**: A33-A33.