The Importance of Solar System Sample Return Missions to the Future of Planetary Science

March 5–6, 2011 • The Woodlands, Texas

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The Importance of Solar System Sample Return Missions to the Future of Planetary Science

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Preface

This volume contains abstracts that have been accepted for presentation at the Importance of Solar System Sample Return Missions to the Future of Planetary Sciences, March 5–6, 2011, The Woodlands, Texas.

Administration and publications support for this meeting were provided by the staff of the Meeting and Publication Services Department at the Lunar and Planetary Institute.

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CURATING NASA'S EXTRATERRESTRIAL SAMPLES – PAST, PRESENT, AND FUTURE.

Carlton Allen, Judith Allton, Gary Lofgren, Kevin Righter, and Michael Zolensky
NASA Johnson Space Center, Houston, TX 77058, carlton.c.allen@nasa.gov

Introduction: Curation of extraterrestrial samples is the critical interface between sample return missions and the international research community. The Astromaterials Acquisition and Curation Office at the NASA Johnson Space Center (JSC) is responsible for curating NASA's extraterrestrial samples. Under the governing document, NASA Policy Directive (NPD) 7100.10E "Curation of Extraterrestrial Materials", JSC is charged with ". . . curation of all extraterrestrial material under NASA control, including future NASA missions." The Directive goes on to define Curation as including "documentation, preservation, preparation, and distribution of samples for research, education, and public outreach."

Specifically, JSC is responsible for:

"The physical security, protection, preservation and environment of extraterrestrial materials in the JSC Curatorial Laboratories; and the suitable off-site storage of a representative sampling of the curated extraterrestrial materials."

"The development and maintenance of the system of detailed procedures through which the distribution of curated extraterrestrial materials are controlled, and the implementation of that system in conjunction with other NASA offices as necessary."

"The development and maintenance of a unified, thorough, and up-to-date set of procedures on control and security of curated extraterrestrial materials."

Extraterrestrial samples pose unique curation requirements. These samples were formed in environments strikingly different from that on the Earth's surface. Terrestrial contamination would destroy much of the scientific significance of many extraterrestrial materials. In order to preserve the research value of these precious samples, contamination must be minimized, understood, and documented. In addition the samples must be preserved – as far as possible – from physical and chemical alteration. The elaborate Curation facilities at JSC were designed and constructed, and have been operated for many years, to keep sample contamination and alteration to a minimum

At the current time JSC curates six collections of extraterrestrial samples:

- Lunar rocks and soils collected by the Apollo astronauts
- Meteorites collected on NSF-funded expeditions to Antarctica
- "Cosmic dust" collected by NASA aircraft
- Solar wind atoms collected by the Genesis spacecraft
- Comet particles collected by the Stardust spacecraft
- Interstellar dust particles collected by the Stardust spacecraft

Each of these sample sets has a unique history and comes from a unique environment. The JSC curators have developed specialized laboratories and practices over many years in order to preserve and protect the samples, not only for current research but "for studies that may be carried out in the indefinite future."

Lessons learned for the future from 40+ years curating NASA's extraterrestrial samples:

<u>The main point of any sample return mission is laboratory analysis.</u> Everything must be designed, built, and operated to get the highest quality samples to the best laboratories.

<u>Curation starts with mission design.</u> Samples will never be cleaner than the tools and containers used to collect, transport, and store them. It is critical to design and monitor spacecraft contamination control during manufacturing and operations.

<u>We must be ready for contingencies.</u> Really bad things can – and do – happen. Careful planning and dedicated people can sometimes save the day.

<u>Every sample set is unique.</u> Laboratories and operations must respond to the diversity and special requirements of the samples.

<u>We are in it for the long haul.</u> Samples collected years or decades ago are yielding new discoveries that totally change our understanding of planets, moons, and solar system history. These discoveries will inspire new generations of scientists and research questions, and will drive new exploration missions by robots and humans.

SAMPLE RETURN MISSIONS WHERE CONTAMINATION ISSUES ARE CRITICAL: GENESIS MISSION APPROACH. J. H. Allton[1] and E. K. Stansbery [1] Mail Code KT and KA, NASA/Johnson Space Center, Houston, TX 77058, USA, judith h.allton@nasa.gov.

Introduction: The Genesis Mission, sought the challenging analytical goals of accurately and precisely measuring the elemental and isotopic composition of the Sun to levels useful for planetary science, requiring sensitivities of ppm to ppt in the outer 100 nm of collector materials [1]. Analytical capabilities were further challenged when the hard landing in 2004 broke open the canister containing the super-clean collectors. Genesis illustrates that returned samples allow flexibility and creativity to recover from setbacks.

Long-term Teamwork: Engineering, Science & Curation: In addition to the management and engineering teams that design, build and fly the spacecraft, this sample return mission has a science analysis team and a sample curation team that were fully engaged from the initial planning, through spacecraft design, spaceflight, Earth recovery and continuing through curation of samples today. The Principal Investigator continues to encourage collaborative efforts and is hands-on with details. Early, the science team was involved in choosing, fabricating and certifying the purity and cleanliness of the collector materials. To measure specific objectives, a variety of collector types were selected, providing alternate means to achieve the same goal. From the beginning, the curation team was responsible for contamination control, and participated in mission design (to minimize effects of thrusters and spacecraft offgasing upon the cleanliness of the solar collectors during flight), and reviewed collector design and fabrication techniques to minimize contaminants.

Collector Materials: Cleanliness and Variety. The Genesis approach was to start with clean collectors and keep them clean; thus, all handling of collectors after cleaning was performed in ISO Class 4 (Fig. 1). The variety of materials selected for each type of analysis [2] also allowed a variety of post-mission cleaning techniques to be applied. In addition to bulk solar wind composition, collectors were deployed to sample specific regimes of the solar wind. These regime collectors were not only identified by position in the spacecraft, but by thickness of collector – which, due to the canister breakup, is now essential for identifying solar regime.

Super-clean Science Canister Assembly: Keeping the solar wind collectors clean was accomplished by cleaning and assembling the collector canister in an ISO Class 4 cleanroom (Class 10 by Fed. Std. 209E) at Johnson Space Center curation facilities. Cleaning of canister hardware, to particle level 50 (MIL-STD-1246C) or better, was done with ultrapure water, to avoid traces of cleaning fluid residues. Airborne molecular contamination levels during assembly were measured on polished witness plates at 10 ng/cm^2. Canister design isolated the lubricants from collector environment. The canister was sealed under ISO Class 4 and not opened until collection at Earth-Sun L1 began.

Reference Materials: Reference materials from collectors, spacecraft hardware and cleanroom were archived and proved critical for assessing blanks when measuring solar wind.

Summary: Science and curation teams participated in the mission planning from the very beginning, giving input on science cleanliness and contamination control requirements for all aspects of the mission. For many specific analytical objectives, a variety of collector types were designated, which allowed redundancy, multiple analytical techniques and multiple approaches to cleaning the collectors. All of which were especially useful after the hard landing. The collectors were isolated within a canister which was cleaned and sealed entirely under ISO Class 4 conditions.

References: [1] Burnett D. S. *et al*. (2003) *Space Sci. Rev*.,105, 509-534. [2] Jurewicz A. J. G. *et al* (2003) *Space Sci. Rev*.,105, 553-560. [3] Allton J. H. *et al (2002)* JSC-29742.

Fig. 1. Assembly of Genesis collectors in ISO Class 4 cleanroom at Johnson Space Center. Workers are enclosed in Teflon suits with HEPA-filtered exhaust.

ANALYSIS OF THE END TO END SCIENCE OF THE POTENTIAL MARS SAMPLE RETURN CAMPAIGN.

A.C. Allwood[1], C. Herd, D.W. Beaty, and the E2E-iSAG team (19 additional members), [1]Jet Propulsion Laboratory, 4800 Oak Grove Dr, Pasadena, CA 91109 Abigail.C.Allwood@jpl.nasa.gov.

Introduction: Returning scientifically selected samples from Mars has long been recognized as requiring more than one flight mission. The current thinking is that the "Mars Sample Return Campaign" would consist of: (1) a rover to establish the geologic context of the operations areas, select and acquire samples, and prepare a sample cache; (2) a lander with a "fetch" rover to recover the sample cache and a launch vehicle to put samples into orbit; (3) an orbiter/Earth return vehicle to transport the samples to Earth; and (4) a ground segment comprising Sample Receiving Facility (SRF), curation, and scientific sample analysis (Figure 1) [1]. Each of the four elements would need to support overall MSR campaign science objectives that are broader than the individual missions themselves. Therefore these overall objectives need to be understood in sufficient detail at an early stage in order to plan correctly the role of each of the component missions. The E2E-iSAG ("End to End International Science Analysis Group") was chartered by MEPAG (Mars Exploration Program Analysis Group) to undertake this task by building on the efforts of previous MEPAG-chartered groups. Preliminary results of the E2E-iSAG analysis are presented and discussed.

Scientific Objectives of the Potential MSR Campaign: A crucial step in planning for a potential MSR campaign is to define as specifically its potential scientific objectives. The E2e-iSAG's vision of these objectives will be shown in this presentation.

Derived implications of these objectives: From a prioritized list of scientific objectives, it is possible to derive a number of useful parameters, including:

- A prioritized listing of sample types of interest
- An understanding of which kinds of scientific questions are best addressed using a suite of samples, and which by single samples
- The importance of outcrop vs. float sampling
- Implications for the required/desired attributes of the sampling system.
- Implications for the instrumentation needed by the sampling rover to a). properly assemble the sample suites, and b) adequately document the context of the samples, which is necessary for interpretation.
- Definition of reference candidate landing sites on Mars where some portion of the samples of interest are expected to be present.
- Maximum allowed state of contamination of the returned samples, as received by the Earth-based analysts.

Discussion: All of the above is crucial science input into definition of requirements for a potential sampling mission to Mars. The potential planning timeline, as it exists at the time of this presentation, will be discussed.

Additional Information: Draft information on the science of the potential MSR campaign has been posted on the MEPAG web site at the following location (http://mepag/meeting/dec-10/E2E_AGU2010_report_v4_4c.pptx).

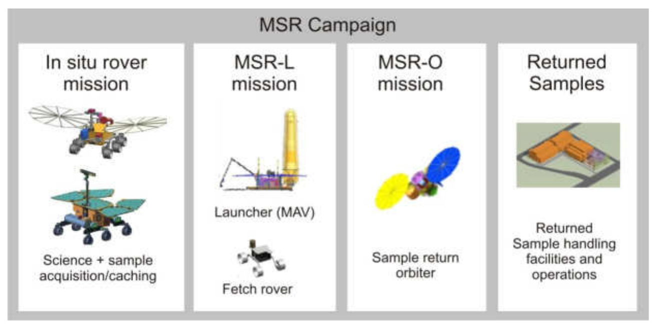

Figure 1: Conceptual illustration of the potential Mars Sample Return Campaign elements

Sample Return Propulsion Technology Development under NASA's ISPT Project

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In 2009 the In-Space Propulsion Technology (ISPT) project was tasked to start development of propulsion technologies that would enable future sample return missions. Sample return missions could be quite varied, from collecting and bringing back samples of comets or asteroids, to soil, rocks, or atmosphere from planets or moons. Given this new focus, the future technology development areas for ISPT are: 1) Sample Return Propulsion (SRP), 2) Planetary Ascent Vehicles (PAV), 3) Multi-mission technologies for Earth Entry Vehicles (MMEEV), and 4) Systems/mission analysis and tools that focuses on sample return propulsion. Sample Return Propulsion is further broken down into: a) Electric propulsion for sample return and low cost Discovery-class missions, b) Propulsion systems for Earth Return Vehicles (ERV) including transfer stages to the destination, and c) Low TRL advanced propulsion technologies. The paper will describe the ISPT project's future focus on propulsion for sample return missions. The SRP effort will continue work on HIVHAC thruster development in FY2010 and then transitions into developing a HIVHAC system under future Electric Propulsion for sample return (ERV and transfer stages) and low-cost missions. Previous work on the lightweight propellant-tanks will continue under advanced propulsion technologies for sample return with direct applicability to a Mars Sample Return (MSR) mission and with general applicability to all future planetary spacecraft. The Aerocapture efforts will merge with previous work related to Earth Entry Vehicles and transitions into the future multi-mission technologies for Earth Entry Vehicles (MMEEV). The Planetary Ascent Vehicles (PAV)/ Mars Ascent Vehicle (MAV) is a new development area to ISPT but builds upon and leverages the past MAV analysis and technology developments from the Mars Technology Program (MTP) and previous MSR studies.

BALANCING CONTAMINATION CONTROL AND BIOCONTAIMENT IN A SAMPLE RECEIVING FACILITY

D. S. Bass[1], D. W. Beaty[1], C. C. Allen[2] and K. L. Buxbaum[1], Mars Program Office, Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA, NASA Johnson Space Center, Houston, TX (Deborah.Bass@jpl.nasa.gov)

Facility Purpose: The return of unsterilized samples to Earth from Mars would require processing and initial analysis in a Sample Receiving Facility (SRF). The primary functions of an SRF would be to take delivery of flight hardware that lands, safely open any capsule while ensuring *biological containment* of potential non-terrestrial biological material and prevent *contamination* of the Mars samples by terrestrial contaminants. Samples in an SRF would undergo preliminary physical and chemical characterization as a first step in a predetermined process of biohazard assessment as presented in preliminary form in the Draft Test Protocol [1].

Additional geological, chemical, and biological studies would be conducted after the preliminary analysis had been completed, either within an SRF or in laboratories elsewhere. However, samples would be required to remain controlled under strict biocontainment until shown to be free of biohazards, consistent with international and national planetary protection policy.

An SRF would also handle the packaging of subsamples for scientific testing, including possible sterilization – if required – for analysis outside the SFR containment area. Equipment and facilities that have been in contact with extraterrestrial samples would also require sterilization on an on-going basis. Long-term curation may or may not be conducted at the SRF.

Drivers for Facility Design: The need to minimize sample contamination while ensuring sample containment will drive many of the decisions associated with an SRF. Because humans are a primary source of biological contamination, the closer humans get to the samples, the more challenging is the contamination control problem. While the cleanliness standards for Apollo era testing were excellent [2], the expectation is that samples returned from Mars would need to push beyond those levels based on both past experience and expectations of sample sensitivities. Establishment of the contamination control requirements could lead to the need to develop complex robotic designs depending upon the range of human-sample interaction. The Mars Exploration Program recently sponsored architectural studies to describe and estimate the size, functionality and budgetary requirements for a Mars SRF [3]. The three studies identified significant options for human-sample interaction, ranging from purely robotic handling of the samples to entirely human handling. The studies reported that the ability to ensure cleanliness levels of diagnostic instrumentation could drive the physical location of the instrumentation relative to the containment system.

Technology Development and Future Work: Current curation facilities are not designed to ensure biological containment, while biohazard level 4 (BSL-4) labs are not designed to prevent sample contamination. Some unique combination of the two would be required for an SRF. The development of double-walled Class III biosafety cabinets (BSCs) for primary containment in the initial sample processing steps [3] could provide a solution that would combine both factors. In addition, the development of ultraclean dexterous robots could enable the use of robotics to further reduce the risks associated with sample manipulation by human operators [4]. Equally important would be methods for removing organic, inorganic and particulate contaminants from BSCs, tools and robotic manipulators that come into contact with the samples or the sampling environment. These and other key technologies would need to be addressed in the development phases of building an SRF.

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MEASUREMENT AND SIGNIFICANCE OF COSMOGENIC NUCLIDES FOR RETURNED SAMPLES., M. W. Caffee[1], K. Nishiizumi[2], and R. C. Reedy[3], [1]Department of Physics, Purdue University, West Lafayette, IN 47907, USA (mcaffee@purdue.edu), [2]Space Sciences Laboratory, 7 Gauss Way, University of California, Berkeley, CA 94720-7450, USA (kuni@ssl.berkeley.edu), [3]Planetary Science Institute, 152 Monte Rey Dr., Los Alamos, NM 87544, USA (reedy@psi.edu)

Introduction: Sample return missions enable the use of state-of-the-art scientific instrumentation and techniques in labs on terra firma to investigate extraterrestrial samples. In addition to lunar samples, the Genesis, Stardust, and Hayabusa missions are excellent examples of the scientific yield made possible by sample return. The availability of even a small amount of sample allows multiple complementary techniques to be applied to the same sample.

Cosmogenic nuclides (CNs) are produced by cosmic-ray nuclear interactions with target nuclei in rocks, soils, ice, and the atmosphere. They are widely used for the investigation of solar system processes. Concentrations of stable nuclides, such as ^{3}He, ^{21}Ne, and ^{38}Ar, grow monotonically over time as the target material is exposed to cosmic rays. The concentrations of cosmogenic radionuclides, such as ^{10}Be, ^{26}Al, and ^{14}C also build up with exposure time but reach saturation values after several half-lives.

Cosmogenic Nuclide Production on Asteroids: Asteroids, which have neither atmospheres nor magnetic fields, do not impede incoming cosmic rays. Cosmogenic nuclide production rates and depth profiles should resemble those observed in surface samples and cores from the Moon and in large meteorites. Both the Moon and an asteroid present what is essentially an infinite plane (2π geometry) to cosmic-ray bombardment. Some near-surface differences between asteroidal and lunar production of CNs may arise as a result of differences in orbital parameters. These differences are important and can be interpreted in terms of the nature of the irradiation. Cosmic rays come from two distinguishable sources. Galactic cosmic rays (GCR), which do *not* normally contribute to the orbital sensitivity of production rates, originate outside the solar system and have relatively high energies. Their flux appears to have varied by less than ~20% over the last 10 Myr and their spatial gradient in the ecliptic plane does not exceed +2%/AU, where distance is measured going away from the sun. Today, with the aid of advanced computer programs such as the Los Alamos MCNPX (Monte Carlo N Particle eXtended) code, we can model GCR production rates for CNs in an asteroid with an accuracy of about 10%. The Sun is also a source of cosmic rays. Temporally sporadic and considerably lower in average energy than the GCR, the flux of solar cosmic rays (SCRs) is angularly and radially anisotropic. SCRs mainly produce CNs in the outer ~1 cm of an object [1].

Cosmogenic Nuclides on Planetary Surfaces: The CN production rates and depth profiles on planetary surfaces are similar to those on the Moon. The production rates of various CNs have been calculated using MCNPX, which has been well tested using a database of CN observations in lunar, meteoritic, and terrestrial samples. These results show that the production rates of CNs on planetary surfaces are 3 orders of magnitude higher than those on the Earth's surface. The case CN analyses of Martian return samples has been previously detailed [2].

Issues Addressed by Cosmogenic Nuclides Measurements: The measurement of cosmogenic nuclides in returned samples will elucidate the dynamic processes that sculpt the surface of the object. Cosmogenic nuclides directly address regolith gardening rates, exposure ages of surface materials and craters, erosion rates, and orbital histories for asteroids or dust.

Sample Requirements: The masses needed for measurement of CNs shown in Table 1 vary. Recent instrumental advances allow for analysis of masses as small as ~ μg for noble gas mass spectrometry and ~10μg for accelerator mass spectrometry.

Table 1. Selected cosmogenic nuclides.

Nuclide	Half-life (yr)	Major targets
^{54}Mn	0.855	Fe
^{22}Na	2.61	Mg, Si
^{60}Co	5.27	Co
^{14}C	5,730	O
^{41}Ca	1.04×10^{5}	Fe, Ca
^{81}Kr	2.3×10^{5}	Sr, Y, Zr
^{36}Cl	3.01×10^{5}	Cl, K, Ca, Fe
^{26}Al	7.05×10^{5}	Mg, Al, Si
^{10}Be	1.36×10^{6}	C, O, Mg, Si
^{53}Mn	3.7×10^{6}	Fe
^{129}I	1.57×10^{7}	Te, Ba, REE
^{3}He	Stable	O, Mg, Si, Fe
^{21}Ne	Stable	Mg, Si
$^{36, 38}$Ar	Stable	Ca, Fe
^{150}Sm	Stable	^{149}Sm
^{158}Gd	Stable	^{157}Gd

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GEOLAB CONCEPT: THE IMPORTANCE OF SAMPLE SELECTION DURING LONG DURATION HUMAN EXPLORATION MISSIONS. M. J. Calaway[1], C. A. Evans[2], M. S. Bell[1], and T. G. Graff[1]. [1]Jacobs Technology (ESCG) at NASA Johnson Space Center, Astromaterials Acquisition and Curation Office, Houston, TX 77058, michael.calaway@nasa.gov, [2]NASA, Johnson Space Center, Astromaterials Acquisition and Curation Office, Houston, TX 77058.

Introduction: In the future when humans explore planetary surfaces on the Moon, Mars, and asteroids or beyond, the return of geologic samples to Earth will be a high priority for human spaceflight operations. All future sample return missions will have strict down-mass and volume requirements; methods for in-situ sample assessment and prioritization will be critical for selecting the best samples for return-to-Earth [1,2].

Analog Studies: We conducted our first sample characterization tests during the 2010 Desert Research and Technology Studies (DRATS) field campaign near Flagstaff, AZ. The test involved two rovers and a supporting habitat; the rovers conducted scientific traverses for six days and then docked to NASA's Habitat Demonstration Unit 1 – Pressurized Excursion Module (HDU1-PEM). A first generation geological laboratory, GeoLab, was integrated into the HDU1-PEM. GeoLab activities tested HDU1-PEM science operations conducted by astronauts, and preliminary examination of samples to assist scientists making decisions about sample return priorities and concerns [3,4].

GeoLab Hardware: GeoLab was designed to provide a workstation and analog isolation containment system for preliminary examination, curation decisions, and return to Earth prioritization of geologic material collected on a planetary surface [3,4]. This first generation GeoLab was developed around a custom built positive pressure nitrogen environment glovebox equipped with three pass-through antechambers through the shell of the HDU1-PEM. The pass-through antechambers allowed geologic samples to enter (and exit) the main Glovebox chamber directly from the outside, minimizing potential contamination from inside the habitat. The glovebox also incorporates a state-of-the-art environmental monitoring system that can be remotely controlled. Four video cameras provide live situational awareness of the GeoLab workstation and EVA porch area. The 2010 suite of instruments included a stereomicroscope for microscopic inspection of collected samples and image capture; image data was downlinked to the science team. A handheld XRF spectrometer was integrated into the GeoLab for whole rock geochemical fingerprinting; data was also downlinked to the science team. The glovebox also contained a mass balance and ruler for collecting sample mass and dimensions. All instrumentation and cameras are controlled at the workstation with two touch screen computers which are integrated into the HDU1-PEM avionics system and can be fully viewed and controlled in real-time on the remote network for collaboration between the astronaut crew and a supporting science backroom.

Sample Handling and Examination: The first GeoLab tests tried to apply, to the extent possible, extraterrestrial sample handling protocols based on current JSC Astromaterials Curation practices, and proposed sampling methods for future exploration missions providing pristine and working ("sacrificial") subsets of geological samples collected during exploration activities [2]. During the 2010 DRATS tests, the GeoLab team treated the samples collected and chosen for examination in GeoLab as representative "sacrificial" subsamples, assuming that the other "pristine" portion of a sample was already contained in appropriately sealed containers for possible Earth return (minimizing sample contamination and compromise). The DRATS astronauts analyzed samples chosen by the science team; the data collected from GeoLab sample examination was used to help refine the working hypotheses regarding the geologic history of the area and to prioritize the pristine samples that would be selected for Earth return. From the point of collection until samples are delivered to Earth based laboratories for detailed analyses, the use of specialized sealed pristine sample containers, and a glovebox for manipulation of "sacrificial" samples are extremely important for protecting geologic material from contamination and preserving the scientific integrity of each extraterrestrial sample.

Future Plans: GeoLab is a unique workstation design that incorporates a curation glovebox and configurable analytical instrumentation for preliminary examination and characterization of samples for prioritization and curation of collected samples. GeoLab will remain integrated in the habitat for the 2011 DRATS field campaign. We plan to continue using GeoLab as a testbed with new instruments and evolving interfaces for the astronauts and supporting scientists.

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ESTABLISHING METEORITE PARENT BODIES AND UNDERSTANDING PLANETARY REGOLITHS BY NOBLE GAS ANALYSIS OF RETURNED SAMPLES. J. A. Cartwright[1] and U. Ott[1]. [1]Max-Planck Institute für Chemie, Joh.-Joachim-Becher-Weg 27, Mainz, Germany. julia.cartwright@mpic.de

Meteorite vs. Returned Sample: Noble gas analysis of meteorites has helped determine different physical and chemical properties including crystallisation ages, and the resolution of different sources (planetary/cosmogenic/solar) and components (interior/atmospheric) [1-6]. Such analysis is thus significant in resolving planet/moon/asteroid-specific noble gas signatures, which can further the understanding of parent body formation and evolution. In addition, the timing and severity of parent body ejection events responsible for our meteorite inventory can be better resolved by studying cosmogenic noble gases and cosmic ray exposure (CRE) ages [7]. However, the lack of returned samples from the inner planets, moons and asteroid belt represents a clear restriction in our ability to fully assign specific meteorite groups and their noble gas signatures to specific parent bodies. Moreover, terrestrial contamination of meteorites can lead to overprinting/ masking of primary noble gas components, particularly those similar to Earth's atmosphere [8]. Such contamination issues could be reduced with appropriate storage of returned samples. Here we describe the advantages of returned samples and associated noble gas analysis with case studies of the moon, Mars and asteroids.

Lunar meteorites vs. Apollo samples: The successful return of Apollo samples led to a significant reduction in "lunar" meteorites, as studies revealed that a number of suspected samples did not share similarities with recovered material (e.g. chondrites) [9]. Of the true lunar meteorites discovered later, many showed solar wind components identical to those found in the Apollo samples [1], confirming that returned samples are vital to understanding our meteorite inventory.

Martian meteorites vs. in-situ surface analyses: Direct proof for a Martian SNC (shergottite, nakhlite, chassignite) group origin was reported following noble gas analysis of trapped gas inclusions within EET 79001 [3], where Ar, Kr and Xe elemental and isotopic ratios identical to *in-situ* Viking Martian atmosphere data [10] were observed. However, *in-situ* surface analyses have clear accuracy and detection limitations, and for Viking a number of isotopes could not be measured (e.g. $^{21-22}$Ne). In the absence of returned Martian samples (which would also clarify an SNC Martian origin), we are forced to rely on SNC's to provide a better means of studying the Martian atmosphere.

HED meteorites vs. Asteroid observations: The HED (howardite, eucrite, diogenite) group likely originated from asteroid 4 Vesta [11-12], though in the absence of both surface measurements and returned samples, this cannot be proven. Noble gas analysis of HED's has revealed implanted solar wind in addition to cosmogenic gas [4]: the comparison with returned Vesta samples would help prove its parent body status.

Solar wind and impact gardening: A further research area that requires sample return lies in resolving the extent of impact gardening on planetary surfaces. This is important for understanding regolith formation processes, better defining the "genetic make-up" of soils from planet/asteroid surfaces, and understanding "regolithic" meteorites, which can be assessed by examining the extent of trapped solar wind noble gases within returned soil samples. As solar wind is only implanted in the top nanometers of solid material, extensive impact gardening of a regolith would show solar wind components at great depths within soil samples.

Lunar regolith: Lunar soils from depths up to 2.4 m showed clear solar wind components, indicative of thorough gardening [2], and the returned soil samples provide a useful record of solar activity.

Martian regolith: In principle, whilst solar wind cannot penetrate the Martian atmosphere, cosmogenic noble gases (e.g. $^{21}Ne_{cos}$) within Martian soil samples could be used constrain surface exposure ages and erosion rates in combination with analysis of short lived radioactive nuclides (e.g. ^{10}Be, ^{26}Al). This may help improve understanding of the dichotomy between the smooth, possibly younger northern hemisphere and the heavily cratered southern highlands.

Asteroid regoliths: As regolith formation processes in the asteroid belt are poorly understood, solar wind analysis of asteroid soil samples would help determine the extent of surface gardening. Of particular interest is the asteroid 4 Vesta, whose partially-demolished south pole may represent the source of the HED's [13]. Direct comparison of north and south pole soils could confirm a later impact event, which may help refine the timing of HED ejection (with CRE ages), and thus the extent of solar wind interaction in the south since then.

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A REGOLITH SAMPLE RETURN MISSION TO MARS. V. F. Chevrier. Arkansas Center for Space and Planetary Sciences, MUSE 202, University of Arkansas, Fayetteville, AR 72701, vchevrie@uark.edu.

Introduction: The major part of the martian surface is covered by a layer of regolith, which results from the interaction between the lithosphere, the atmosphere and the hydrosphere and is therefore ideal to understand the evolution of the surface conditions [1]. Moreover, the regolith is usually the most favorable environment for life, due to the abundance of nutrients, energy sources and the protection from UV radiations.

Although the regolith is a complex mixture of phases related to various periods and various processes, such complexity becomes an advantage when the number and mass of samples is very limited. Another significant advantage of the regolith is the facility of access and of sampling since it does not require complicated mechanical systems but sampling technologies that have already been used in previous missions like Viking or Phoenix.

This abstract summarizes some important mineralogical properties of the martian regolith, the possible processes at their origin and how these properties could be used by a sample return mission.

Weathering and hydrothermalism are the most important processes having affected the regolith either directly or indirectly by Aeolian remobilization of alteration phases [1]. Phyllosilicates and carbonates are typical phases resulting from aqueous alteration of the Noachian crust [2,3] and can therefore be used as proxies for the prevailing atmospheric conditions (oxydo-reduction, CO_2 / SO_2 partial pressures [4]). Although Ca-carbonates have been observed in the regolith [5], their origin could be related to ancient hydrothermalism, surface alteration in high p_{CO2} or in the present-day conditions [6].

The martian regolith usually contains high concentrations of highly soluble phases like ferric sulfate $Fe_2(SO_4)_3\ nH_2O$ (up to 30% in Gusev Crater [7]) or magnesium perchlorate $Mg(ClO_4)_2.nH_2O$ (~1% in the polar soils [8]), which both have eutectic temperatures as low as 205 K [9,10]. Thus these salts may be able to melt through deliquescence processes, providing a source of liquid brines under present-day cold conditions [10]. Moreover, since their hydration varies according to the humidity [11], these salts can provide clues on the water vapor cycle in the recent ages of Mars.

Another important class of minerals are the iron (oxy)hydroxides, especially since the martian regolith contains up to ~20% Fe_2O_3 (Fig. 1). These phases, often characterized by their magnetic properties, can be secondary or inherited from the primary basaltic material (Fig. 1, [12]). They could also result from extremely slow surface oxidation over 2-3 billion years [13]. Therefore, these phases could help quantify the contributions of various processes to the regolith.

Finally, impact gardening is also a major process for two reasons: first it contributes to the homogenization of the regolith and it modifies its chemical and mineralogical properties of the phases [14]. Determining the presence of high P,T phases in the regolith, as well as chemical modification would provide information on the degree of transformation of the regolith by impact processes.

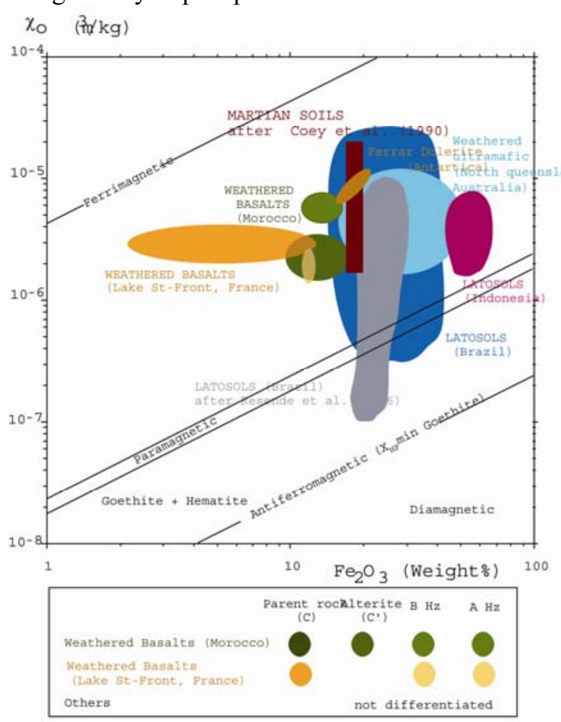

Figure 1. Magnetic susceptibility versus Fe_2O_3 content of the martian regolith compared to terrestrial soils [1]. The combination of paramagnetic and ferrimagnetic components suggest the presence of secondary and inherited phases.

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PLANETARY GEOCHRONOLOGY: WHAT CAN BE DONE IN SITU, AND WHAT NEEDS SAMPLE RETURN? B. A. Cohen, NASA Marshall Space Flight Center, VP62, 320 Sparkman Dr., Huntsville AL 35805 (Barbara.A.Cohen@nasa.gov).

Introduction: Geochronology is a fundamental component of planetary sample analysis, proving timing of major events recorded in rocks and thus context for the conditions prevailing on the planet at the time of the event. In terrestrial laboratories, the absolute age of events can be measured to ±1 Myr or better. But an age is more than just an isotopic ratio - it is an interpretation of that number, tying it to the petrogenesis of the rock. Geochronologists have largely shied away from in situ dating because its sensitivity is going to be much less than we are used to in the laboratory and the detailed understanding of the rock's petrogenesis can be difficult to achieve. However, appropriate application of in situ dating can overcome such objections in specific situations and become a fundamental capability for robotic probes.

The geochronology instrument must be integrated into a suite of other instruments and measurements to give the rock context. Commonly-used and highly-appropriate measurements include remote sensing for geologic setting, imaging and microscopic imaging for petrology, and microanalytical techniques for chemical and mineralogic composition and variation. These measurements must be made with as much contextual information about the sample's location, composition, and properties as possible to ensure that the fundamental dating assumptions are valid, namely that the samples forming the isochron are cogenetic and that the system is closed, and to enable a correct interpretation of the geologic event reflected in the radiometric age. Furthermore, in situ geochronology must generate an age that enables a geologic interpretation that clearly improves upon current knowledge. Many problems in geochronology require the resolution and sensitivity of a terrestrial laboratory and therefore cannot be solved by in situ instrumentation. However, several fundamentally important objectives on the Moon, Mars, and other rocky bodies could be met with this approach. Here we discuss three specific applications.

Flux of lunar volcanism: The relationship between basalt composition, location and age is crucial in understanding the nature of lunar magmatism. In the absence of sample return, our only way of understanding the ages of these rocks is via crater-counting techniques on orbital images. Recent missions have enabled discovery of basaltic units with crater-count ages as young as 1.2 Ga, including those in Oceanus Procellarum, the Aristarchus Plateau and Mare Moscoviense on the lunar far side [1, 2]. These young basalts are unknown in the returned sample collection but may be a clue to the origin of some lunar basaltic meteorites such as Kalahari 009 and NEA 003 [3]. Obtaining the age and composition of a young basalt flow and tying this information to the crater count and composition is therefore a desirable measurement [4, 5]. The age must have an uncertainty smaller than the derived model age from crater counting, which depends both on the uncertainty in the flux curve and in the crater counting itself. The uncertainties associated with these ages vary depending on the exact flow unit, but range from 0.05 to >0.7 Ga, with the mean uncertainty around 200-300 Ma. Therefore, obtaining an age within 100 Ma of a young or far side basalt will help distinguish between models where the lunar heat engine shuts down early or late and resolving whether progressively younger basalts have systematic compositional variations related to an evolving source region [6, 7]. However, in situ ages will not be able to provide source-region isotopic characteristics or detailed trace-element contents, both of which are crucial measurements [5]. Furthermore, there will not be enough in situ opportunities to sample the full range of compositions, and we will continue to rely on chance delivery of such lithologies to us as small clasts in lunar meteorites or as pieces tossed to sampled locations.

Lunar craters and basins: The lunar crater record provides the baseline with which we calibrate the absolute ages of all cratered surfaces in the inner solar system. While the lunar crater curve is well-bounded between ~1 and ~4 Ga, the curve on the older and younger ends is poorly constrained. Several high-priority activities for lunar science are tasks that help define this curve at its extremities.

The most important candidate on the Moon for absolute dating is the South Pole-Aitken (SPA) basin. It is the largest, deepest, and stratigraphically oldest impact basin on any terrestrial planet. Though collecting impact-melt rocks in situ from nearside basins such as Imbrium is impossible because of their mare basalt fill, the SPA basin appears not to be covered with basalt, but instead retains the signature of its impact melt sheet in remote sensing data [8]. The oldest age within the samples might be expected to correspond to the SPA basin age, for which an age uncertainty of ±100 Ma would be sufficient and could be achieved in situ. However, dating of younger basins within SPA such as Apollo and Ingenii would bound SPA and elucidate the subsequent impact history of the far side. Distinguishing between SPA melt itself and reworked material from these younger basins requires detailed trace-element analysis and geochronology by multiple techniques with laboratory precision [9].

The exact ages of young craters such as Copernicus provide important calibration points for the lunar chronology at young ages. Crater counts on the Copernicus ejecta blanket indicate an age of 1.5 Ga, but Apollo 12 samples collected on one of the rays of Copernicus crater have a significantly younger age of 800-850 Ma – in fact, virtually all Apollo 12 samples have a 600-900 Ma overprint [10, 11]. This could mean that we did not collect material from Copernicus or that the samples do not represent the surface material dated with crater counts. Dating material from within young craters to uncertainties of ±100 Ma, which may within reach of an in situ instrument, would significantly enhance the lunar calibration curve.

Another important science objective is to determine whether there was a lunar cataclysm, defined as the creation of several nearside basins (Imbrium, Serenitatis, Nectaris, Crisium, Orientale) within a short period (200-20 Myr) [12, 13]. Because the cataclysm is defined by multiple events closely-spaced in time, the uncertainty in age required is better than 0.02 Ga (20 Ma), along with detailed trace-element (ppb) analyses, to distinguish among samples from distinct impacts during this time. This level of precision is probably not achievable with in situ analyses, so this is a science question that may not be answerable except in terrestrial laboratories.

Martian history: The absolute ages of Mars's geological events, and thus the time history of the planet's evolution, will not be fully understood until the relative Martian chronology derived from stratigraphy is tied to an absolute chronology via radiometric dating of Martian rocks. Absolute ages of Martian surface units are uncertain by as much as a factor of two on older surfaces and disagreements can be an order of magnitude or more on younger, lightly-cratered surfaces [14, 15]. In situ age dating with an uncertainty of ±100 Ma would be a significant improvement, especially for sites in middle Mars history (late Hesperian through mid-Amazonian). Site(s) dated in situ would better constrain the Martian crater production curve, thereby improving estimates of the absolute ages of Mars's other geological units.

As with all samples, the rocks selected for in situ dating must be geologically well characterized to ensure our understanding of the provenance and geological history of the dated sample, and petrologically well-characterized to ensure understanding of the geochronologic results. And again, additional information on the source-region isotopic characteristics and detailed trace-element contents, only currently achieveable by laboratory analyses, are crucial to understanding Mars' magmatic history.

Some of the foremost objectives for understanding Mars have to do with fluids on the surface, with both geologic and astrobiologic implications. The geochronology of alteration minerals provides a context for the timing and duration of surface fluids and surface conditions. Such geochronology relies on careful separation of the altered phases, which are volumetrically small, from the host rock [16, 17]. Separation may be mechanical or by placement of small beams, but either way, requires dexterous manipulation and characterization of both the altered phases and the host lithology on scales that are not currently achievable with in situ analysis. Therefore, sample return is required to address this scientific issue.

Other bodies: Our knowledge of the absolute surface age on other bodies, such as Mercury, asteroids, and the outer planet satellites, relies wholly on the crater calibration record for the Moon. The factors that cause the crater flux to change in different areas of the solar system are complex, so providing even a rough absolute age for these bodies would go a long way toward calibrating the crater curve, enabling us to understand the surface history of the body itself as well as how the dynamic flux varied in different parts of the solar system throughout time. On the one hand, in situ techniques may be the only way to address geochronology, as sample return may be prohibitively expensive and samples do not arrive naturally to the Earth (except asteroids). On the other hand, significant challenges remain to in situ geochronology techniques on these bodies, including predicting the concentration of radiogenic elements, understanding appropriate characterization and handling techniques, and mission constraints for operation in extreme environments. Upcoming missions (MESSENGER, Dawn, Jupiter/Europa flagship) may help inform design of appropriate geochronology instruments for future missions.

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Planetary Protection for Sample Return Missions. C. A. Conley, NASA HQ

The process of exploring planetary environments and returning samples to Earth will result in an exchange of materials that must be appropriately controlled, in order to prevent unintended and possibly irreversible consequences. The introduction of biological materials from Earth into hospitable planetary environments could confound the search for life elsewhere in our solar system. Human activity has demonstrated that organisms introduced from one environment to another can cause significant disruption on Earth, thus the uncontrolled return of planetary samples that might contain hazardous or replicating entities must be avoided, in order to protect the environment of the Earth. Planetary protection policies and procedures have been developed over the past 50 years of space exploration, and are described in the international consensus policy maintained by the Committee on Space Research of the International Council for Science. Planetary protection policy imposes restrictions on exploration that are tailored according to the target object and type of mission, with exploration of most solar system objects requiring documentation only. In contrast, stringent cleanliness requirements and operational restrictions are imposed to protect the three objects in the solar system that are considered potential habitats for life.

THE IMPORTANCE OF LUNAR SAMPLE RETURN IN DETERMINING THE NATURE OF EJECTA PROCESSES.
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Introduction: Impact cratering is a fundamental geologic process that is ubiquitous in the Solar System. Impact generated meteorites and breccias allude to the intense energies required for their creation. A large volume of material displaced during impacts interacts with preexisting terrain [1,2]. Despite the scarcity of well-preserved ejecta blankets on Earth, those studied have greatly aided our understanding of the interaction of ejecta and local material [3,4]. The lunar surface is a uniquely preserved and accessible laboratory to characterize the nature of ejecta processes [5].

Sample Site Selection: To characterize the nature of ejecta and local material interaction, we need to

I. Target young and well-preserved craters. Although all planets have been affected by impacts, in most cases the evidence is masked or destroyed by weathering, resurfacing (*i.e.*, burial), or subsequent impacts. Target sites include the most recent impacts and planets with a long surface residence time.

II. Target sites with ejecta blankets distinct from underlying lithologies. The simplest method to determine compositional ratios of any two substances is to start with distinct end-members. The best candidates will be those craters near lithologic contacts or those that excavate through to underlying lithologies.

III. Target craters of variable size Ejecta velocity and volume increase proportionally to crater size. Scaling relationships have been developed from small-scale experimental impacts, high-energy explosions and a small number of terrestrial crater studies [1,6,7]. Their application for craters at all scales remains uncertain. To broaden and refine these models, a range of crater sizes should be investigated.

The Lunar Case:

I. Preservation The lunar surface is not subject to the same degree of weathering as that of Earth, Mars and other planets with atmosphere. Craters younger than ~1.1 Byr generally have readily distinguishable (*i.e.*, high albedo) ejecta deposits, and this time scale may be lengthened by compositional differences [8,9,10]. Subsequent impacts are the controlling factor in ejecta preservation. Microscale impacts rework the lunar surface at a rate of ~1.5 mm/m.y. [11].

II. Composition The lunar surface can be divided into general compositional groups including mare basalts and highland material. Craters impacting non-mare material and ejecting onto maria include Petavius B, Tycho, Letronne A and Hayn.

III. Size The Moon holds the most complete record of impact events in the Solar System. Crater sizes of interest range from <1 km up to ~1000 km diameter. The 120 identified Copernican craters range in size from ~1 to ~100 km diameter [12].

Scientific Multipliers Collection of impact melts and subsequent age dating will better constrain the crater density curve of the Moon and, therefore, the inner solar system. Larger craters also probe the lunar interior by exposing underlying lithologies in their structure (i.e. crater wall or central peak) and ejecta.

Mission Objectives: The goals of a sample return mission will necessarily vary depending on mission architectural constraints. The provenance of some clasts in Apollo impact breccia samples is uncertain. Apollo 12 landed on a ray from Copernicus, and Apollo 16 may have sampled basin material from the Imbrium, Serenitatis, and Nectaris basins [13]. Sample return from such key craters may be used in conjunction with previously collected material to constrain ejecta mixing and distribution models.

Adding mobility to a sample return mission greatly increases the scientific return. In collecting multiple samples at increasing radial distances from a crater, changes in the nature of ejecta-local material interaction can be better characterized. Multiple samples would also reduce the effects of unrepresentative sample collection. A 10- or 20-km mission radius (for missions with one or two rovers, respectively) could fully explore the majority of crater ejecta from craters up to ~30 km in size, such as Petavius B, Euclides M, Beer, and Conon. For larger craters such as Hayn (83 km) and Copernicus (93 km), the focus may instead be on characterizing ejecta interaction at key locations in the ejecta blanket.

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OSIRIS-REx ASTEROID SAMPLE RETURN MISSION. M. J. Drake, D. S. Lauretta, on behalf the OSIRIS-REx Team. Lunar and Planetary laboratory, University of Arizona, Tucson, AZ 85721. E-mail: drake@lpl.arizona.edu.

Introduction: Asteroids are direct remnants of the building blocks of the terrestrial planets. Carbonaceous asteroids are an important source of volatiles and organic matter to the Earth. The Space Studies Board of the US National Research Council has identified sample return from a carbonaceous asteroid as high priority [1]. The **O**rigins, **S**pectral **I**nterpretation, **R**esource **I**dentification, and **S**ecurity–**R**egolith **Ex**plorer (OSIRIS-REx) mission will return the first pristine samples of carbonaceous material from the surface of a primitive asteroid. OSIRIS-REx's target – asteroid (101955) 1999 RQ36 (see Figure) – is the most exciting, accessible volatile and organic-rich remnant from the early Solar System, as well as the most potentially hazardous asteroid known to humanity.

Characteristics: RQ36 has a semi-major axis of 1.126 AU [2]. Lightcurve observations give a rotational period of ~4.3 hours. It is a B-class asteroid characterized by a linear, featureless spectrum with bluish to neutral slope [3]. B-class asteroids in the main-belt are known to be some of the most volatile-rich small bodies in the inner Solar System [4]. Near-infrared spectroscopic data suggest a very low albedo that is consistent with a carbonaceous surface. The best spectral analogs for RQ36 are the CM, CR, or CI chondrites, though none are a perfect match.

RQ36 was observed with the Arecibo and Goldstone Planetary Radar Systems in 1999 and 2005. [5]. Delay-Doppler imaging provides shape information at a spatial resolution of 7.5 m/pixel. The data reveal an ~575-m diameter asteroid undergoing retrograde rotation. The radar polarization ratio suggests a smooth surface of fine-grained material. These data provide high confidence in the presence of regolith on the surface of RQ36.

Assuming a plausible density of 1.4 g/cm^3 we find a subdued slope distribution for this asteroid at the spatial resolution of the shape model, with maximum slopes of 33°, near zero slopes in the equatorial region and an average slope of 13°. This range is consistent with a regolith-covered body with a relaxed surface.

RQ36 was observed with the Spitzer Space Telescope in May 2007 [6]. The Spitzer data yield a thermal inertia of 600 J m^{-2}s$^{-1/2}$K^{-1}, suggesting that the regolith is comprised of fine gravel (4-8 mm). These data also strongly support the concept that there is abundant regolith on the surface available for sampling.

Importance: The Earth sterilized itself during formation, melting to a depth of at least 1000 km, perhaps repeatedly [7]. Yet we are here, so organics must have either self-assembled from carbon atoms or have been delivered from space where they are abundant. No such material survives Earth entry as meteorites without experiencing substantial contamination. Hence OSIRIS-REx will provide the first material for study that might have led to life on Earth.

In addition, we use spectra obtained by telescopes and spacecraft to infer the composition of asteroids, but asteroid surfaces suffer from space weathering while meteorite analogs are freshly ground surfaces. OSIRIS-REx will return a pristine sample of RQ36 regolith surface for direct comparison between laboratory instruments and telescopic and spacecraft measurements.

One day humans will venture far from Earth and may need local resources to function effectively. OSIRIS-REx will provide a resource inventory of materials available on a carbonaceous near-Earth asteroid.

Finally, RQ36 is a potential Earth impactor. The probability of an impact in the late 22nd century is 10^{-3} [8]. The primary source of uncertainty is the dynamical model of its orbital evolution. The main non-gravitational orbit perturbation is due to the Yarkovsky effect, which results from anisotropic thermal re-emission of incident solar energy [9]. A mission provides for an increase in position knowledge, leading to a better understanding of the threat.

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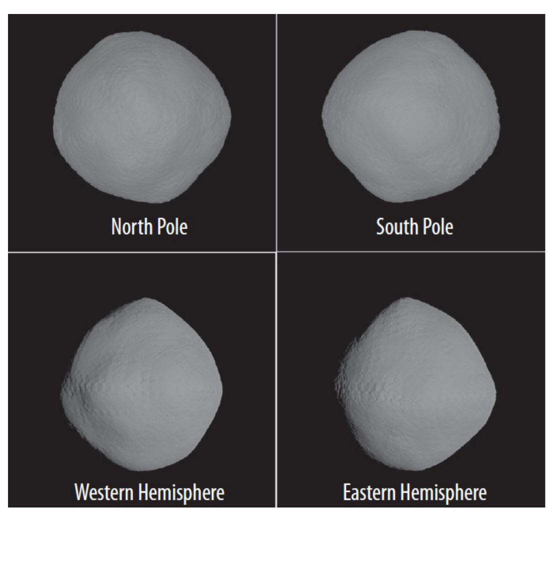

DIVERSITY, CONTEXT, PRECISION, AND MOBILITY: LESSONS FOR SAMPLE RETURN SITES AND SYSTEMS FROM MARS RECONNAISSANCE ORBITER RESULTS. Bethany L. Ehlmann, Institut d'Astrophysique Spatiale. U. Paris-Sud 11. Orsay cedex 91405, France. bethany.ehlmann@ias.u-psud.fr

As successive planetary missions return new data, assessment of likely gains from sample return and criteria for selection of sampling sites must continually be re-examined, and perhaps revised, in light of new knowledge. Here, based on synthesis of recent data from Mars, particularly results from the Mars Reconnaissance Orbiter (MRO), I discuss four key requirements for optimizing Mars sample return science: sample/environmental diversity, geologic context, precision landing, and sampler mobility.

Three payload elements on MRO, which began science operation in 2006, have provided the highest spatial resolution datasets for surface morphology and mineralogy to date: the High Resolution Imaging Science Experiment (HiRISE, 25 cm/pixel, three color IR, R, G) [1], the Context Imager (CTX, 5m/pixel, single band) [2], and the Compact Reconnaissance Imaging Spectrometer for Mars (CRISM, 18m/pixel, 544 channels from 0.4-4.0 μm) [3].

1. Sample/Environmental Diversity: MRO has revealed a rich geologic record from ancient Mars, including evidence for water-related volcanic processes [4], unaltered mafic and ultramafic rocks [5], thousands of exposures of altered crust [6], and diverse carbonate, sulfate, and hydrated silicate phases [7-9]. An emerging paradigm is that the mineralogic and morphologic diversity represents nearly a dozen aqueous chemical environments, varying in space and time [10], i.e. early Mars hosted multiple potentially habitable environments. Furthermore, surface ices at high-latitudes [11] and near-surface ices at mid-latitudes [12, 13] may be a source for intermittent brines that could sustain life today [14].

MRO-revealed diversity complicates sample return landing site selection because it is clear that the Mars system, especially the ancient Mars system, was complex and variable. Ideally, several sample return missions would interrogate rocks preserving multiple environments, ranging from igneous to aqueous. However, realistically, an initial sample return effort will visit a single landing site. To best understand and characterize the Mars system (1) sample return should be done with the knowledge that a subset of important questions about Mars' evolution will remain outstanding, necessitating a complementary program of future in-situ science (or additional sample returns) and (2) to maximize science, the single site selected for a sample return mission should allow sampling multiple environments and collection of multiple samples.

2. Geologic Context: Both MER rovers have discovered in-situ evidence for aqueous activity. The ability to relate Opportunity findings at Terra Meridiani to a large-scale surface unit whose age is known has provided more constraints on the nature and timing of regional/global aqueous processes [15, 16], relative to sulfates, silica, and carbonate found by Spirit at Gusev crater [17,18]. There, disrupted stratigraphy and alteration within units too small to be dated by crater counting techniques obfuscates geologic context.

Sampling large-scale coherent stratigraphies with ages relatable to Martian geologic epochs provides the best opportunity for samples to contribute to understanding the evolution of the Mars system. Most exposures of aqueously altered materials on Mars are associated with craters, where stratigraphy is disrupted and the timing and setting of mineral formation are unclear [6]. However, MRO has recently characterized several exemplary large stratigraphic sections where rock units vary in texture and mineralogy, and ages of units are clearly bracketed. These include (1) the mid-Noachian to early Hesperian Nili Fossae/NE Syrtis stratrigraphic section with a sequence of Fe/Mg smectite-, carbonate-, Al-phyllosilicate-, and sulfate-bearing units, bracketed in time by the Isidis impact and Syrtis Major lava flows [19], (2) the walls of Valles Marineris, especially near Coprates Chasma, where Noachian to Hesperian lavas and phyllosilicate units are recorded in a 7 km-thick sequence [10], (3) Terra Meridiani, with a phyllosilicate-bearing Noachian basement overlain by Hesperian sediments [20], and (4) Mawrth Vallis, a sequence of nontronite and Al-phyllosilicate layered units, capped by an unaltered Hesperian unit [21].

3. Sampler Mobility: Mobility during sampling is essential since this would maximize sample diversity and allow assessment of the nature of environmental change (gradual, abrupt), by traversing and characterizing geologic contacts of distinct units.

4. Precision Landing: With MRO orbital assets, landing sites can be evaluated for safety and best outcrops identified at meters-scale. Fully exploiting this capability requires landing ellipses to be precise, delivering a payload nearest to the best site of sampling (preferably <5 km), minimizing risks of failure along a long traverse. Enhanced tolerance of a landing system for surface roughness is also necessary to achieve closest access to these best sites, since topographic relief is a hallmark of well-exposed stratigraphies.

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Comparative Planetology: Impact Melt Sample Return from the Moon, Mercury, and Mars. A. L. Fagan[1] and C. R. Neal[2], [1,2] Dept. of Civil Eng. & Geo. Sci., University of Notre Dame, Notre Dame, IN 46556, USA (abacasto@nd.edu; neal.1@nd.edu).

Introduction: Extraterrestrial impact melt samples provide invaluable information that has enhanced our understanding of impact processes and the composition of impactors. Using impact melt samples, we can constrain bombardment histories [e.g. 1] throughout the inner solar system using Ar-Ar age dating [e.g. 2] as well as identify potential impactors using Highly Siderophile Elements (HSE, [e.g. 3]). Additionally, the whole-rock and individual crystal chemical compositions can constrain the target and thus can estimate the composition of a planetary body's crust and, for basin-sized impacts, possibly the interior. In situ impact melt samples could also constrain models of melt sheet differentiation (e.g. Sudbury, Canada [4]), and the impact crater scaling laws of [5-8]. Finally, as reflectance properties of impact melts can be nearly indistinguishable from igneous rocks [9], sample return is imperative to better constrain remote sensing data. Impact melt samples can be distinguished from igneous products using HSE analyses and, in a recent development, crystal size distributions [e.g. 10].

Models show that the majority of impact melt is contained within the transient crater cavity of an impact crater, the size of which can be estimated by the proportional growth model of [11] while the melt volume can be estimated by eqn # 2 in [4] or eqn # 6 in [7]. As such, the most likely place to find impact melt samples is nearest the center of a crater or basin, though some craters, such as King Crater on the Moon, have pools of impact melt situated on wall terraces.

Moon. Recent remote sensing studies have focused on potential impact melt veneers, flows, and ponds within lunar craters [e.g. 12-13]. Two of the more popular subjects are the Maunder formation of Orientals [e.g. 14] and the spectacular features in Giordano Bruno [e.g. 13] shown in new Lunar Reconnaissance Orbiter Camera (LROC) images. Although the lack of an atmosphere limits the amount of weathering allowing samples to be taken directly from the surface, care should be taken when selecting a potential site as many basins are filled with pristine mare fill that may obscure impact melt. Selected sites should consider craters that are large enough to have substantial impact melt, and that have little to no mare fill or this fill is distinct from the impact melt [15].

Mercury. Peak-ring basins occur on Mercury at smaller diameters than the Moon and Mars due to its circumsolar environment causing higher impact velocities accelerated by the sun's gravity [16]. Peak-ring basins result when the depth of melting from the impact is near that of the depth of the transient crater cavity [5-8, 16]; these peak-ring basins would be ideal targets for sampling compositions of the lower Mercurian crust. As with the Moon, the lack of an atmosphere eliminates rampant weathering, so samples can be collected directly from the surface. Target sites should remain within the peak-ring, as most of the impact melt will have pooled there. A site of particular interest could be the Nervo Formation in Caloris Basin, which is considered a stratigraphic marker on Mercury [e.g. 17].

Mars. Unlike the Moon and Mercury, impacts into the Martian surface have the potential to hit sedimentary target materials, generating differing volumes of impact melt than would be modeled for impacts into an igneous target [e.g. 18]. Sampling such melts may aid in models of impact melting into a sedimentary substrate. However, given the Martian atmosphere, it is nearly impossible to find pristine surface manifestations of impact melt; samples would need to be accessed via drill cores. Tooting Crater has been the subject of several recent studies with regards to its impact melt features [e.g. 19-20] and may be a target site for sample return missions that explore Martian impacts.

Necessary Precursor Studies: Before robotic or human missions are sent to any of these suggested targets for the return of impact melt samples, detailed remote sensing studies should be conducted for ideal site selection. Spectral instruments such as the Moon Mineralogy Mapper (M^3) and on the MESSENGER spacecraft can provide broad compositional data to help narrow down areas of potential impact melt pools. Digital Elevation Models (DEM) derived from instruments such as the Mars Orbiter Laser Altimeter (MOLA) or its Lunar counterpart (LOLA) would impart valuable slope maps necessary for landing site selection as well as for identifying potential traverses for rovers or astronauts.

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GEOCHEMICAL DIFFERENCES BETWEEN SURFACE BASALTS AND MARTIAN METEORITES: THE NEED FOR MARTIAN SAMPLE RETURN. J. Filiberto, Rice Universiy Department of Earth Science, MS 126, 6100 Main Street, Houston, TX 77005 Justin.Filiberto@rice.edu.

The SNC meteorites are crystallized basaltic magmas and cumulate igneous lithologies that represent our only samples of the Martian surface. They have been extensively investigated to explore the geochemistry of the Martian interior and crust [e.g., 2]. Yet, there remain many questions about Martian petrology that cannot be answered from these meteorites alone.

The exact location of origin of the SNC meteorites on the Martian surface is unknown, which limits their utility for studying crustal mineralogy. Further, all of the basaltic SNCs are relatively young [4], which makes understanding changes in mantle and crustal composition through time difficult. Finally, most of the SNC meteorites contain cumulate phases, have experienced alteration (either on Earth or Mars), and/or show evidence for re-equilibration all of which complicate the use of these samples in producing Martian geochemical models [2, 5-6]. This work focuses on the basaltic and ol-phyric shergottites because they represent the closest to being near magma compositions.

Robotic explorations of the Martian surface have provided a wealth of new geochemical and mineralogic data that can be used to better understand the SNC meteorites, and combined with data from the meteorites to better understand the Martian igneous history. The data from the global surface and surface basalts represent a wider range in age than the SNC meteorites, which can help constrain how the geochemistry and mineralogy of the Martian crust has changed through time [e.g., 7].

The FeO content (fig 1) of the surface basalts (basalts in Gusev Crater, Bounce Rock in Meridiani Planum, and Pathfinder "dust" free rock composition [8-13]) are consistent with, but have a larger range in bulk composition than, the shergottites [14], suggesting that the shergottites do not represent the full compositional range of the Martian crust.

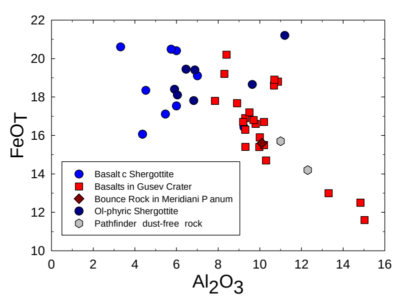

Fig 1. FeO vs Al_2O_3 bulk compositions for basalts in Gusev Crater, Bounce Rock in Meridiani Planum, Pathfinder "dust" free rock composition, and basaltic and ol-phyric shergottites

The Mg/Si vs. Al/Si ratios of surface basalts are significantly different from those of the basaltic SNC meteorites (fig 2 modified from [6]). The ~3.6 Ga basalts in Gusev Crater [15] have compositions similar to those of terrestrial basalts, while Bounce rock in Meridini planum has a composition similar to some of the shergottites.

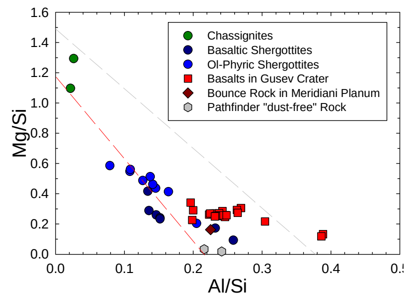

Fig 2. Mg/Si vs. Al/Si compositions for Martian basalts and the two chassignites. Data and symbols are from fig 1. Gray dashed line is terrestrial crust line [1] and the red dashed line is the Martian crust line [3].

Experimental petrology [16-17] and thermobarometer modeling [18] studies reveal significantly different temperatures and pressures of formation for the surface basalts compared to the shergottites. This suggests that the source regions for the shergottites and surface basalts are different. Hypotheses that might explalin these differences include: 1) there was a change in mantle composition through time; 2) surface basalts are more representative of average Martian basalt compositions while the shergottites are products of more localized melt; or 3) surface basalts are localized melts while the shergottites are more representative of an average Martian basalt.

Mars sample return is our best tool to resolve the differences between the SNC meteorites and surface basalts. Ideally, returned samples would represent an average Martian basalt. However, ideal samples are not the only way to resolve these differencse. A "grab and go" sample of regolith (soil and rock mixture) from a known, well studied, locale (which would be less expensive) would still help resolve a lot of these issues. A grab and go sample of the Martian regolith could be extensively studied using the same tools and techniques we already utilize for the SNC meteorites, providing more detailed information (e.g., ages, REE's, light elements, noble gases [19]) than is possible from a robotic exploration. This would bridge the gap in data between the SNC meteorites and the data from robotic explorations, and greatly help to constrain Martian geochemical and mineralogic history.

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THE IMPORTANCE OF SAMPLE RETURN IN ESTABLISHING CHEMICAL EVIDENCE FOR LIFE ON MARS OR OTHER SOLAR SYSTEM BODIES. D. P. Glavin[1], P. Conrad[1], J. P. Dworkin[1], J. Eigenbrode[1], and P. R. Mahaffy[1], [1] NASA Goddard Space Flight Center, Greenbelt, MD 20771, daniel.p.glavin@nasa.gov.

Introduction: The search for evidence of life on Mars and elsewhere will continue to be one of the primary goals of NASA's robotic exploration program over the next decade. NASA and ESA are currently planning a series of robotic missions to Mars with the goal of understanding its climate, resources, and potential for harboring past or present life. One key goal will be the search for chemical biomarkers including complex organic compounds important in life on Earth. These include amino acids, the monomer building blocks of proteins and enzymes, nucleobases and sugars which form the backbone of DNA and RNA, and lipids, the structural components of cell membranes. Many of these organic compounds can also be formed abiotically as demonstrated by their prevalence in carbonaceous meteorites [1], though, their molecular characteristics may distinguish a biological source [2]. It is possible that *in situ* instruments may reveal such characteristics, however, return of the right sample (i.e. one with biosignatures or having a high probability of biosignatures) to Earth would allow for more intensive laboratory studies using a broad array of powerful instrumentation for bulk characterization, molecular detection, isotopic and enantiomeric compositions, and spatially resolved chemistry that may be required for confirmation of extant or extinct Martian life.

Here we will discuss the current analytical capabilities and strategies for the detection of organics on the Mars Science Laboratory (MSL) using the Sample Analysis at Mars (SAM) instrument suite and how sample return missions from Mars and other targets of astrobiological interest will help advance our understanding of chemical biosignatures in the solar system.

Sample Analysis at Mars (SAM): SAM consists of 3 instruments (gas chromatograph, quadrupole mass spectrometer, and tunable laser spectrometer) used to measure volatile species in the atmosphere and released from rock powders heated to temperatures up to 1000°C under He gas flow [3]. For the atmospheric measurements, the presence of volatile hydrocarbons such as methane can be detected directly by the tunable laser spectrometer above the part per billion level and the $^{13}C/^{12}C$ ratio of CH_4 can also be determined. The measurement of more complex hydrocarbons in solid samples will be accomplished by three different experiments: (1) pyrolysis QMS analysis mode will enable the identification of characteristic alkane fragments and simple aromatic compounds such as benzene and methylbenzene; (2) pyrolysis GCMS mode will be used to separate and identify complex mixtures of larger alkanes and up to 4-ring aromatic hydrocarbons; and (3) chemical derivatization and GCMS analysis mode enables the extraction and identification of non-volatile molecular species such as amino acids and carboxylic acids that are not detected by the other two modes.

Biosignature Detection: The SAM instrument suite on MSL will provide the most sensitive measurements of the organic composition of rocks and regolith samples ever carried out *in situ* on Mars. MSL is not a life detection mission. However, if MSL stumbles upon biosignatures, the search for non-disputable chemical evidence of life on Mars may require measurements that go beyond *in situ* instrument capabilities including an analysis of chiral organic molecules, compound-specific isotopic measurements, as well as, isotopic and molecular spatial resolution of organic materials. Currently these measurements require more complex sample preparation and state-of-the-art laboratory instruments such as ultra performance liquid chromatography time of flight mass spectrometry, gas chromatography combustion isotope ratio mass spectrometry (GC-IRMS) [4,5], confocal Raman spectroscopy, and secondary ion mass spectrometry.

One of the current challenges with *in situ* measurements of organic compounds is that a robust analysis of soluble and insoluble organic matter requires a series of chemical extraction steps from the mineral matrix prior to analysis of the extracts that is extremely difficult to implement on flight missions. For example, one-pot, single-step chemical derivatization experiments have been developed for SAM [6] and COSAC [7] on the ESA Rosetta comet lander mission due to their simplicity, however in some cases derivatization efficiency of organics could be inhibited due to reactions between the derivatization agents themselves and the minerals. These *in situ* flight experiments will have limited time and resources and changes to experiments in response to discoveries are not always possible. This is not the case for laboratory studies where time and resources are more plentiful. Ultimately return of a carefully selected sample from Mars will be required for a robust screening of chemical biosignatures.

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Cold Curation and Handling of the Tagish Lake Meteorite: Implications for Sample Return. C. D. K. Herd[1], R.W. Hilts[2], D.N. Simkus[1], and G.F. Slater[3], [1]Department of Earth and Atmospheric Sciences, 1-26 Earth Sciences Building, University of Alberta, Edmonton, AB, Canada, T6G 2E3, herd@ualberta.ca. [2]Department of Physical Sciences, MacEwan University, Edmonton, AB T5J 4S2. [3]School of Geography and Earth Sciences, McMaster University, Hamilton, ON L8S 4K1.

Introduction: Meteorites collected within a few days of fall represent a unique opportunity both to study planetary materials that are relatively uncontaminated by exposure at the Earth's surface, and to examine and trace the source(s) of contamination. Such studies inform protocols and minimum standards for curation and handling of pristine planetary samples, including material from Solar System Sample Return missions. Here we highlight a unique example, that of the Tagish Lake meteorite, and outline the implications of its study for Sample Return.

Background: The Tagish Lake meteorite fell January 18, 2000 onto the frozen surface of Tagish Lake in northern British Columbia, Canada. Specimens of the meteorite were recovered within a week of the fall and kept frozen and untouched by hand. These are the world's most pristine meteorites, having been kept under near-optimum conditions of preservation of volatile elements and compounds. These pristine specimens, are in cold (< -25 °C), secure conditions at the University of Alberta and the Royal Ontario Museum.

Given the mobility of organic compounds and their ubiquitous presence at the Earth's surface, our research has focused on determining the suite of organic compounds in the pristine Tagish Lake specimens, includeng any terrestrial contaminants. Our focus has been primarily on the soluble organic compounds, with the hypothesis that these compounds are the most likely to have been affected by terrestrial contamination during collection and storage, and are also the most likely to be affected by curation and handling.

Tagish Lake is an organic carbon-rich, ungrouped type 2 carbonaceous chondrite with affinities to CI and CM meteorites [1]. We have analyzed several pristine Tagish Lake specimens for soluble organic compounds, complemented by studies of insoluble organic matter, mineralogy and petrology [2-4]. Soluble organic compounds were extracted using dicholoromethane (DCM), toluene-methanol or ultrapure water, with the solvent added to a cold sample in order to capture all volatile compounds. Methods are described in [5].

Terrestrial Contaminants: Analysis of the DCM extracts by GC-MS reveals variable complements of reduced organic compounds in the Tagish Lake specimens. Of 67 compounds identified in one specimen (11v), ten were unequivocally terrestrial contaminants. The second-most prevalent compound in specimen 11v is 9-octadecenamide, a plasticizer used in the manufacture of resealable plastic bags. The source of this contaminant was traced to the Ziploc bag in which the sample was stored after collection. Phthalates and other compounds that can be traced to exposure to plastics were also identified; however, these compounds are present at trace (ppm) levels. Limonene, a cyclic terpene produced in citrus fruits, was found in another specimen (11i). Isotopic analysis of this compound by GC-IRMS at McMaster University yields $\delta^{13}C = -28 \pm 1‰$ and $\delta D = -170 \pm 30‰$, having a composition consistent with that of terrestrial limonene. The source of this potential contaminant is not known.

Indigenous Organic Compounds: Among the non-contaminant (indigenous) organic compounds in the Tagish Lake meteorite are several that are reactive or volatile. Naphthalene was found within both DCM and toluene-methanol extracts. A detailed study of monocarboxylic acids [6] showed that formic acid is present in at unprecedented concentrations (up to 200 ppm). Both formic acid and naphthalene are volatile compounds, and would have been partially lost had the meteorite not been kept at low temperatures since its recovery.

Amino acids in Tagish Lake meteorite specimens determined by analysis by GC-MS [2, 7] yield concentrations greater than those found in Tagish Lake samples collected during the spring thaw that were exposed to meltwater [8], demonstrating the rapidity with which meteoritic samples can be contaminated with biological molecules at the Earth's surface.

Implications for Solar System Sample Return: Based on our Tagish Lake results, we recommend that low temperature conditions be considered for any returned samples in which organic compounds are expected. A facility in which the Tagish Lake specimens will be curated and handled under low temperature conditions (- 20 °C) in a neutral atmosphere is under construction, and provides a potential testbed for investigating curation and handling methods.

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SAMPLES FROM DIFFERENTIATED ASTEROIDS; REGOLITHIC ACHONDRITES. J.S. Herrin[1,2], A.J. Ross[3,4], J.A. Cartwright[5], D.K. Ross[1,2], M.E. Zolensky[1], and P. Jenniskens[6]. [1]NASA Johnson Space Center, Houston, Texas, USA [2]ESCG Astromaterials Research Group, Houston, Texas, USA [3]Centre for Planetary Sciences, Joint UCL/Birkbeck Research School of Earth Sciences, London, UK, [4]IARC, Department of Mineralogy, The Natural History Museum, London, UK, [5]Max Planck Institut für Chemie, Mainz, Germany [6]SETI Institute, Mountain View, USA.

Introduction: Differentiated and partially-differentiated asteroids preserve a glimpse of planet formation frozen in time from the early solar system and thus are attractive targets for future exploration. Samples of such asteroids arrive to Earth in the form of achondrite meteorites. Many achondrites, particularly those thought to be most representative of asteroidal regolith, contain a diverse assortment of materials both indigenous and exogenous to the original igneous parent body intermixed at microscopic scales. Remote sensing spacecraft and landers would have difficulty deciphering individual components at these spatial scales, potentially leading to confusing results. Sample return would thus be much more informative than a robotic probe. In this and a companion abstract [1] we consider two regolithic achondrite types, howardites and (polymict) ureilites, in order to evaluate what materials might occur in samples returned from surfaces of differentiated asteroids and what sampling strategies might be prudent.

Interior components and the igneous history of parent bodies: Howardites and polymict ureilites provide examples of asteroid regolith that frequently contain diverse components from distant regions of the interior of their igneous parent body within individual meteorites [2,3,4]. This is advantageous for sample return because it demonstrates that large regions of the parent interior could be represented within a single modest-sized surface sample.

Exogenous lithologies: Meteorite evidence suggests that the surfaces of differentiated asteroids are littered with chondritic material that could comprise a significant fraction of any returned sample. A variety of chondrite types occur in both howardites and polymict ureilites, intermixed with indigenous components. The Almahata Sitta fall was a predominantly ureilitic asteroid consisting of 20-30% chondritic material [5,6]. The majority of individual specimens recovered from this fall, however, are monolithologic. From the Almahata Sitta example it is evident that a random "grab sample" taken from the surface of an asteroid might not give an accurate impression of bulk composition and might not be consistent with the reasons for which a particular asteroid were selected for sampling. Thus, by employing some type of smart sampling technology, a sample return mission would be more likely to recover materials representative of the target asteroid.

Exogenous water: Water might be an important consideration in targeting an asteroid or portion of an asteroid for sample return. Three recent Antarctic howardite finds, the paired Mt. Pratt (PRA) 04401 and PRA 04402 and Scott Glacier (SCO) 06040, are notable for their high proportion of hydrous carbonaceous chondrite clasts [7]. We interpret the carbonaceous chondrite material as a relative latecomer to these breccias, likely added to the parent asteroid by impacts that occurred well after differentiation of the igneous parent. They appear CM2-like, comprised largely of fine-grained hydrous phyllosilicate minerals. Low totals (80-90 wt%) from electron microprobe (EPMA) analyses of these clasts can give us some impression of the amount of water they contain (herein we use "water" as a generic term for either H_2O or structurally-bound OH- in minerals, phyllosilicates can contain both structural OH- as well as adsorbed water [8]). PRA 04401 is particularly chondrite-rich, with chondritic clasts >1 mm occupying more than half of the modal area of the sections we examined. This meteorite demonstrates the potential for hydrous lithologies with >5 wt% water to occur locally upon a nominally anhydrous parent. Delivered by impacts, hydrous materials might be concentrated in certain locations on an asteroid surface and observable by remote sensing instruments. Sampling missions could either target or avoid these regions, depending on the type of sample desired.

Implications and conclusions: Regolithic achondrites provide a preview of what samples might someday be recovered from the surfaces of differentiated and partially-differentiated asteroids. The diversity of materials fequently occurring within small volumes of these meteorites could be better examined in terrestrial labs than by robotic spacecraft. Spacecraft collecting samples from surfaces of differentiated asteroids should employ some form of selective sampling or perhaps impact randomization in order to ensure acquisition of desired sample types.

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Acknowledgments: ANSMET, University of Khartoum, D. Mittlefehldt, K. Johnson, P. Buchanan.

WATER IN THE MOON: SAMPLING THE PYROCLASTIC DEPOSITS. H. Hui and C. R. Neal, Department of Civil Engineering and Geological Sciences, University of Notre Dame, Notre Dame, IN 46556 (hhui@nd.edu, neal.1@nd.edu).

Introduction: The Moon has been thought to have lost its water during the catastrophic proto-planet collision (believed to have created the Moon) and during the production and crystallization of the lunar magma ocean. However, recent studies have challenged this view of a "dry" lunar interior with the detection of hydroxyl ions in lunar volcanic glass beads [1] and lunar apatites [2,3]. These studies indicate that parental magmatic water contents in these lunar basalts can be as high as 850 ppm (Table 1), which is similar to water contents (700-4800 ppm) measured in undegassed mid-ocean ridge basalts [4], though another study shows that lunar mantle is essentially anhydrous with as little as ~10 ppb water inferred from Cl isotopic ratios in various lunar samples [5]. Dissolved water can alter the structures of silicates, and hence influence mantle melting temperature, magma crystallization temperature and the style of volcanic eruption. Hence, the discoveries of indigenous water in different pyroclastic and mare deposits by several independent groups not only raise the possibility that the Moon were never fully outgassed, but may also revolutionize our understanding of lunar formation and evolution. Due to these reasons, additional samples from other areas of the Moon are needed to further evaluate indigenous water contents within the Moon.

Table 1: Water contents in parental melts inferred from those in apatites (95% crystallization) and glass beads.

Sample	Water (ppm)	Method	Age (Ga)	Ref.
14053,241 High-Al basalt	100~200	SIMS, Apatite	3.92	1,6
15404,51 Soil	10~140	SIMS, Apatite	-	2
NWA 2977 Meteorite	360~850	SIMS, Apatite	2.86	2,7
15427,41 Volcanic glass	~745	SIMS, Glass beads	3.41	3,8

Sample Requirements: To determine indigenous water content in the Moon, we need

- Volcanic rocks not disturbed by the impacts.
- Volcanic rocks that do not contain hydrogen implanted by solar wind.
- Volcanic rocks that contain grains (e.g., glass, apatite), which can be prepared for water measurements using current technology (e.g., SIMS, FTIR).

To evaluate water distribution in the lunar interior and evolution in the lunar history, we need

- Volcanic rocks that crystallized at different ages, especially pre-Nectarian basalt [9].
- Volcanic rocks that are from different locations.

Potential sample sites: Pyroclastic flows exist all over the Moon. This gives us potential to sample the Moon at different ages and different locations. Cryptomare deposits are mare basalts that represent the earliest mare volcanism [10]. Candidate targets include the Langemak (3.92-4.1 Ga, [11]), Australe (3.8-4.0 Ga, [11]). Using the temporal and spatial distributions of mare basalts determined by remote sensing data [12,13,14], Oceanus Procellarum (1.2-3.93 Ga, [12]), Mare Imbrium (2.01-3.57 Ga, [13]), Antoniadi crater (2.58 Ga, [14]), and Mare Moscoviense (2.57-3.55 Ga, [14]) are recommended for younger mare basalts.

KREEP basalts are thought to represent the late stage melts of magma ocean crystallization [15] and are enriched in incompatible elements. Water is incompatible during magmatic processes. Hence KREEP can potentially have high water content. However, only limited mass of pristine KREEP basalt is left in Apollo collection. It is critical to have more pristine KREEP basalts for this (and other) study. Candidate targets are Mare Imbrium (2.01-3.57 Ga, [13]), Dewar Crater (3.2-3.85 Ga, [16]) based on Th abundance maps [17].

Scientific Merits: In addition to give more accurate constraints on water contents in parent melt and further in the source region, these new samples can be used to (i) estimate the water budget of the Moon after lunar magma ocean solidification, (ii) constrain magmatic evolution on the Moon, (iii) compare to surface water contents measured by recent spacecraft missions, (iv) evaluate the indigenous water content over an extended period of lunar evolution. Once indigenous lunar water contents are better constrained, they can then be evaluated as a potential resource to support human return to the Moon.

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IN-SITU K-Ar GEOCHRONOLOGY: AGE DATING FOR SOLAR SYSTEM SAMPLE RETURN SELECTION. J. Hurowitz[1], O. Aharonson[2], M. Channon[2], S. Chemtob[2], M. Coleman[1], J. Eiler[2], K. Farley[2], J. Grotzinger[2], M. Hecht[1], J. Kirschvink[2], D. McLeese[1], E. Neidholdt[1], G. Rossman, M. Sinha[1], W. Sturhahn[1], K. Waltenberg[2,3], P. Vasconcelos[3], W. Zimmerman[1], B. Beard[4], C. Johnson[4]. [1]Jet Propulsion Laboratory, California Institute of Technology, [2]Div. of Geological and Planetary Sciences, California Institute of Technology, [3]School of Earth Sciences, The University of Queensland, [4]Dept. of Geoscience, University of Wisconsin-Madison.

Introduction: The development of an in-situ geochronology capability for Mars and other planetary surfaces has the potential to fundamentally change our understanding of the evolution of terrestrial bodies in the Solar System. For Mars specifically, many of our most basic scientific questions about the geologic history of the planet require accurate knowledge of the absolute time at which an event or process took place. For instance, what was the age and rate of early Martian climate change faithfully recorded in the mineralogy and morphology of surface lithologies (e.g., [1])?

Currently, our only means of assessing the absolute age of a surface on a planetary body is through the use of crater counting statistics. This technique is fraught with uncertainty for planets with active geologic surfaces, on the order of billions of years in some cases (e.g., [2]). Accordingly, there is much room for improvement in our understanding of the absolute chronology of the surfaces of rocky planetary bodies.

Age Characterization Prior to Sample Return: While returned samples will receive in-depth analytical treatment in terrestrial geochronology laboratories, the ability to characterize the ages of samples in-situ would provide an invaluable dataset, ensuring that the samples selected for Earth return would capture those periods in the geological evolution of a planet that are of greatest interest to the scientific community. In October 2009, the Keck Institute for Space Studies and JPL made a major award to a group of Caltech scientists, and JPL scientists and engineers, respectively, to investigate a broad range of concepts for in-situ age dating, with an emphasis on Mars. Below, we briefly describe one of the more promising in-situ techniques we are developing using miniaturized flight hardware.

Methodology & Instrument Development: In the methodology we are currently developing, a powdered or fragmental rock sample would be positioned in a crucible that has been loaded (prior to flight) with a Li-based fluxing agent and a solid double-spike containing ^{41}K and ^{39}Ar. Under vacuum, the sample-flux-spike mixture would be fused at low-T (≤ 1000°C) via resistance heating and the $^{40}Ar_{Sample}/^{39}Ar_{Spike}$ ratio measured using a focal plane miniature mass spectrometer (MMS), detailed in [3]. The sample would then be cooled to a glass, and sampled with a 1064 nm pulsed Nd-YAG laser. The ablated K-neutrals are ionized by electron impact and the $^{39}K_{Sample}/^{41}K_{Spike}$ ratio

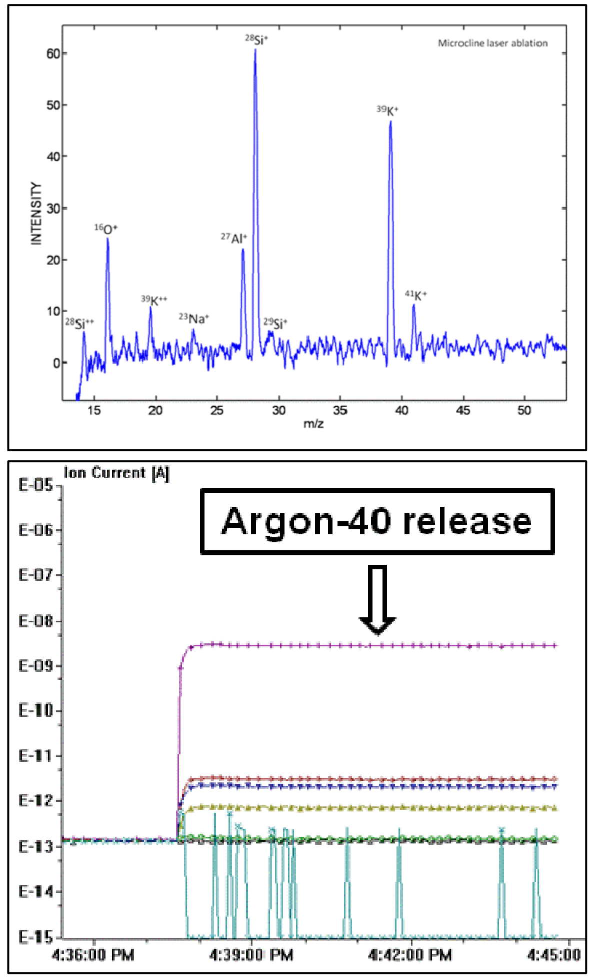

Fig. 1A (top): Intensity (arbitrary units) vs. m/z during laser ablation sampling of K-feldspar and analysis on the MMS. **1B** (bottom): Ion current on a quadrupole MS vs. time during melting of K-feldspar in Li-tetraborate flux at 1000°C.

analyzed on the MMS. Whole rock ages can then be calculated from measured sample/spike ratios. To date, we have built testbed instrument systems that have made measurements demonstrating: (1) low-T Ar-release, (2) sample-spike equilibration, (3) quench glass formation, and (4) K-isotope measurement by laser ablation at ~1 wt% levels. Example results are shown on **Figs. 1A, B**.

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THE LUNAR ROCK AND MINERAL CHARACTERIZATION CONSORTIUM: INTEGRATED ANALYSES OF MARE BASALTS.
P. J. Isaacson[1], C. M. Pieters[1], R. L. Klima[1], T. Hiroi[1], A. Basu Sarbadhikari[2], Y. Liu[2], and L. A. Taylor[2], [1]Dept. Geological Sciences, Brown Univ., Providence RI, 02912 [Peter_Isaacson@Brown.edu], [2] Planetary Geoscience Inst., Dept. Earth & Planetary Science, Univ. Tennessee, 37996.

Introduction: Analysis of returned samples is a powerful tool for unraveling the evolution of planetary bodies. Laboratory analysis of returned samples leads to direct science advances, often quite revolutionary [e.g., 1]. However, analysis of returned samples also supports remote sensing investigations, as many compositional remote sensing techniques rely in large part on sample ground truth [e.g., 2]. The Lunar Rock and Mineral Characterization Consortium (LRMCC) [3] has conducted integrated mineralogy/petrography/spectroscopy analyses of a suite lunar basalt samples, following the work of the Lunar Soil Characterization Consortium (LSCC) [4, 5], which conducted similar analyses of a suite of lunar soil samples. The LRMCC results support science investigations enabled by sample return, and also provide critical ground truth data for remote sensing investigations.

Overview of Samples and Approach: The LRMCC analyzed four mare basalt samples (15058, 15555, 70017, 70035). The Apollo 15 samples are low-Ti basalts, and the Apollo 17 samples are high-Ti basalts. Samples were provided as slabs and paired thin sections. Slabs were used to prepare mineral separates by hand picking, and the thin sections for analyses of modal mineralogy and petrography by electron microprobe analysis (EMP). Mineral separate composition was evaluated by EMP analysis of grain mounts. Mineral separates and particulate bulk sample splits were used for controlled reflectance spectroscopy measurements in the RELAB at Brown University.

Results: The LRMCC results are discussed by [3]. They include analyses of modal mineralogy and mineral composition in thin section and mineral separates, as well as reflectance spectra of mineral separates and bulk samples measured at distinct particle sizes.

Science Applications: The results of the LRMCC project have applications to a wide range of sample-based science investigations and as ground truth for remote sensing. For example, the LRMCC results represent a robust test for spectral unmixing models, which are one of the primary means for evaluating modal mineralogy from remote sensing data [e.g., 6-10]. The LRMCC reflectance data also represent important ground truth data, as they allow remote measurements to rely on real samples rather than analogues, in which subtle characteristics of real samples vs. analogues can have substantial implications for the utility of the resulting ground truth data. The LRMCC results also suggest avenues for fundamental sample-based research, such as the effect of fine-grained opaques on the spectral reflectance of mare basalts [3, 11].

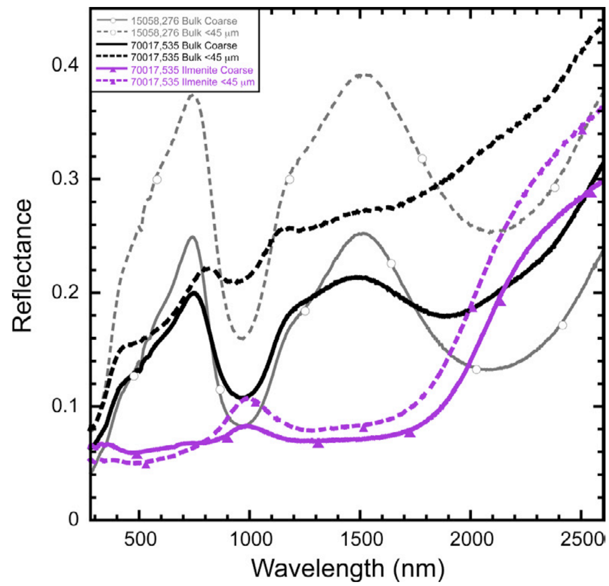

Figure 1: Subset of bulk mare basalt and associated mineral separate reflectance spectra of collected by the LRMCC. These spectra illustrate the prominent effect of ilmenite on reflectance spectra of mare basalts. These data are an example of both the ground truth for remote sensing applications of returned samples as well as the fundamental research enabled by the return of planetary samples.

Analysis of returned samples is critical to realizing NASA's goals for solar system exploration. The LRMCC results are an excellent example of how returned samples contribute to the advancement of research techniques, enable fundamental research into the nature of planetary samples and thus of planetary bodies, and contribute to other diverse and important science and exploration activities.

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CAROLINE: A SEARCH FOR THE SOURCE OF EARTH'S WATER Geraint H. Jones[1], Jessica Agarwal[2], Christopher S. Arridge[3], Neil Bowles[4], Mark Burchell[5], Andrew J. Coates[3], Michele K. Dougherty[6], Samuel Duddy[5], Alan Fitzsimmons[7], Amara Graps[8], Henry Hsieh[9], Carey Lisse[10], Stephen C. Lowry[5], Adam Masters[3], Holger Sierks[11], Colin Snodgrass[11] and Cecilia Tubiana[11], [1]University College London, Holmbury St. Mary, Dorking, Surrey UK, [2]Institut fuer Physik und Astronomie Nichtlineare Dynamik, Universitaet Potsdam, Germany. [3]Mullard Space Science Laboratory, University College London, UK. [4]Atmospheric, Oceanic and Planetary Physics, Department of Physics, University of Oxford. [5]Centre for Astrophysics and Planetary Science, University of Kent, Canterbury, UK. [6]The Blackett Laboratory, Imperial College London, UK. [7]Queen's University Belfast, UK. [8]Southwest Research Institute, Boulder, USA, [9]University of Hawaii, USA. [10]Johns Hopkins University Applied Physics Laboratory, USA, [11]Max Planck Insitut fuer Sonnensystemforschung, Katlenburg-Lindau, Germany.

Introduction: The small body population of the Solar System has traditionally been divided into asteroids and comets (with sub-classes of each). Recently a new class of object has been discovered: Main Belt Comets (MBCs), which span this basic divide. These objects appear to have outbursts which are comet-like, but are located in the asteroid belt in stable, low-eccentricity orbits. Since the initial discovery of activity on 133P/Elst-Pizarro in 1996, several more MBCs have been found.

The Caroline mission: Here, we present *Caroline: A Search for the Source of Earth's Water*, recently proposed as an M-class mission of ESA's Cosmic Vision programme. This would follow the successful sample return missions to a comet (81P/Wild 2 by the NASA Stardust mission [2]) and an asteroid (Itokawa by the JAXA Hayabusa mission [3]). Named after the prodigious comet-finder Caroline Herschel (1750-1848), the spacecraft would visit a main belt comet, capture dust from its tail, and safely return it to Earth for detailed laboratory analysis. The proposed target is 133P/Elst-Pizarro – observed over three activity cycles to date, but other MBCs can be reached within the mass and cost constraints.

Scientific Value of MBCs: MBCs are more than just a scientific curiosity - an understanding of their nature and origin offers a chance to better understand the formation processes in the proto-solar disk. Further, the outer asteroid belt, where 133P/Elst Pizzaro is located, has been speculated to be a possible source of the Earth's water. Thus understanding icy bodies in such a region has a potential to greatly influence our view of the terrestrial planets' development.

What sort of sample return mission? One of the great strengths of the Stardust mission to comet 81P/Wild 2 was that the spacecraft collected its dust samples by flying through the coma surrounding the comet nucleus. The dust that was collected was thus ejected by the comet; no landing or active sampling system was needed, and the use of aerogel and aluminum foil as collectors was sufficient. Aerogel is a low density, highly porous medium (see [4] for a review of its use as a cosmic dust collection medium in space). When materials hit it, even at the high speed of the Stardust encounter (6.1 km s^{-1}) the dust tunnels into the aerogel and is captured relatively intact. "Relatively intact" is the key phrase. The dust still experiences a shock of about 900 MPa in aerogel of density 20 kg m^{-3}. But the experience of the Stardust mission shows that collecting dust grains in this way can return samples to the laboratory on Earth which can be analyzed by a wide variety of techniques [5]; we propose that this technique be used for Caroline.

Combined analysis methods: Caroline would also carry remote sensing instruments to characterize the nucleus during the encounter, and a dust detector to constrain the nature of the object's dust coma and tail. MBCs' activity is suspected to be driven by ices exposed by impacts. Temperature mapping of the surface would help better understand the emission rates from the body and characterize the active areas. Another observation, key to the possible role of MBCs in delivering water to a young terrestrial planet, would be a measurement of the D/H ratio on the body. In parallel with the mission would be a continued programme of astronomical observations of the target, to link the space mission data to remote observations.

Is it feasible? The success of the Stardust mission clearly showed that sample return using collection of dust in aerogel is a viable method of obtaining data from a comet-like body. The costs are modest compared to missions which require a lander and active sample collection. Despite this, the scientific return would be high, shedding light on a wide range of important scientific issues. We propose that if one new sample return mission was to be carried out to a minor body, then it should be to an MBC. Caroline would achieve that goal.

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COMMUNICATIONS WE NEED TO HAVE (AND SOMETIMES DON'T) TO OPTIMIZE SAMPLE RETURN SCIENCE. A. J. G. Jurewicz, Center for Meteorite Studies, ASU, Tempe AZ 85287-1404 Amy.Jurewicz@asu.edu.

Introduction: "A NASA Mission is like a train running at full speed: people get on, people get off, but it has a momentum all it's own" [1]. Yet, those hard working people who are along for only a transient portion of the ride contribute to the eventual science return in a myriad of very important ways. Especially for sample return missions (where small amounts of spacecraft outgassing, terrestrial contamination, or the use of incompatible materials in an adjacent component can ruin future analyses), it is important that the science team works equally with the engineers, machinists, and technicians to develop appropriate processes for making the instruments. Just as important, it is necessary to document procedures and collector-characteristics in real time and to archive those notes, so that details are available decades later, when the science is being gleaned.

Details: Issues which effect the science return are sometimes very subtle, especially when we are looking for trace elements and isotopes (Genesis) or when small particles are returned (Stardust). Some of the Genesis solar-wind collectors were commercially made: since commercial processes are often proprietary, it is important to explain to the vendor why their standard procedures (e.g., fabricating under Ar) would be important later. Sometimes they can change their procedures if you tell them it will hurt/help the future science; but, at the least, they will often tell you (in a general way) about their fabrication process so that you will know for future reference. Remember that the vendors are likely to be as excited about working on the flight project as is the science team.

More frequently, as for Stardust and for many Genesis collectors, instruments which collect sample are hand made, either *in house* or by an outside contractor. Unless the "technicians" who do this work are also on the science team – as was my case for Genesis – those people are likely gone from the project long before spacecraft assembly, let alone years later in-Phase F. You can assume that they <u>won't</u> be available to communicate with the preliminary examination team when the sample comes back. Worse, for *in house* work, aerospace contractors know that once they are done with their work on *your* project, they are out of funding unless they have another project to jump to. Their new flight project will be under a tight a time constraint by definition, and they will have a hard start date. Except for generalized HRCR and/or quality assurance documentation, recording what they've done for you is usually not considered part of the job. So, it is up to a representative from the science team to ask them the right questions ahead of time, or to officially require detailed notes and other fabrication documents not usually provided.

When there are multiple collectors which were individually made as in Stardust and Genesis, it is very important that each individual collector is tracked from inception to installation on the spacecraft, and that excess flight-spare material *from each lot* is archived so that unanticipated questions can be answered.

For example, a few questions from Stardust and Genesis: How well was the Stardust aerogel precursor screened for terrestrial particulates? Did the Genesis AuOS solar-wind collectors all have the same pump-down times during fabrication: can we pick a "hanging shard" with an especially low N content? Which piece of aerogel is lowest in organics; do you have a piece we can check? What caused the brown coloration on the Genesis concentrator-target fixturing? What was the density profile of Stardust aerogel piece C1027?

Most importantly, can a researcher easily find the answers to these questions 15 -20 years after the fact ? What about in 50 years? Just last year, there was an issue with the Stardust archive. It turned out that Microsoft had changed it's Office software in 2003 so that it could no longer read earlier files, which were considered to be a security risk. Worse, the pre-flight aerogel density data appeared to be missing: luckily, a copy was recorded on a 2Gb JAZ disc and, although 2Gb Jaz drives are obsolete at NASA facilities, they could still be found at universities.

Summary: Sample return missions, like other NASA flight projects, tend to be very compartmentalized. Delegating work is efficient, but it means that the science team rarely talks with the folks building the sample collectors. Yet, the actions of the people who actually *do* the building can profoundly affect the future science return. Technicians probably won't be available when the sample is returned. Good communications between "technicians" and the science team pre-flight are imperative for getting the most science from the returned sample. These communications and fabrication notes must be archived with someone who will stay with the project for it's duration. Moreover, both documents and sufficient amounts of cataloged flight-spare material, need to be formatted for general access in a manner that can be retrieved in the foreseeable future, and given to the curator for archive.

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ASTEROID SURFACE SIMULATION FACILITY AT UNIVERSITY OF HELSINKI. T. Kohout[1, 2], [1] Department of Physics, University of Helsinki, Finland, [2] Institute of Geology, Academy of Sciences, Prague, Czech Republic.

Introduction: In near future several sample return missions from extraterrestrial bodies including asteroids are under preparation. Before these space missions will materialize, extensive laboratory research and modeling of various asteroid surfaces has to be done. Among important parameters to be determined in situ on an asteroid surface are physical properties as density, porosity, magnetic susceptibility or thermal properties.

Knowledge of asteroid bulk physical properties as well as these of its surface is important scientifically as well as from an engineering point of view. The grain size, density and porosity can tell us about the regolith structure, strength and its evolution through impact processes. Thermal properties are important in modeling of asteroid thermal state and Yarkovski effect. Magnetic susceptibility can bring information on regolith maturity, amount of metallic iron and its grain size and help in identifying meteorite analogues.

In order to get such information, measurement methods and instrumentation for asteroid in-situ exploration has to be developed and tested. To partly address these needs an Asteroid Surface Simulation Facility (ASSF) is under construction at Department of Physics, University of Helsinki. The facility will consist of small thermally controlled vacuum chamber and set of Asteroid Surface Simulant Materials (ASSMs) to mimic an environment on the surface of various asteroids – potential targets of future robotic exploration (fig. 1).

Asteroid Surface Simulation Facility: ASSF is currently under development and consists of a simple small scale vacuum chamber with thermal control (from 190°C up to +200°C). The chamber is being constructed based on commercially available components. Cooling will be achieved using liquid nitrogen while for heating an infrared source is being considered. The chamber is equipped with remote control port and window so it can be fitted with a simple instrumentation and test-measurements can be performed directly in the chamber under simulated asteroidal surface environment.

Asteroid Surface Simulant Materials: ASSMs are being prepared for most common asteroid compositions. Two types of materials are used. Synthetic equivalents to asteroidal compositions are prepared from generally available minerals and materials. More advanced simulant materials are being developed directly from specific meteorite materials.

Future research using the ASSF facility: The ASSF will be subsequently used to experiments mainly focused on testing of simple, readily available instruments for physical properties measurements in order to demonstrate their capability, resolution and sensitivity on simulated asteroidal surfaces. Further experiments will focus on space weathering and light scattering simulations of asteroid surfaces. ASSF will be also offered to other potential users of the scientific community.

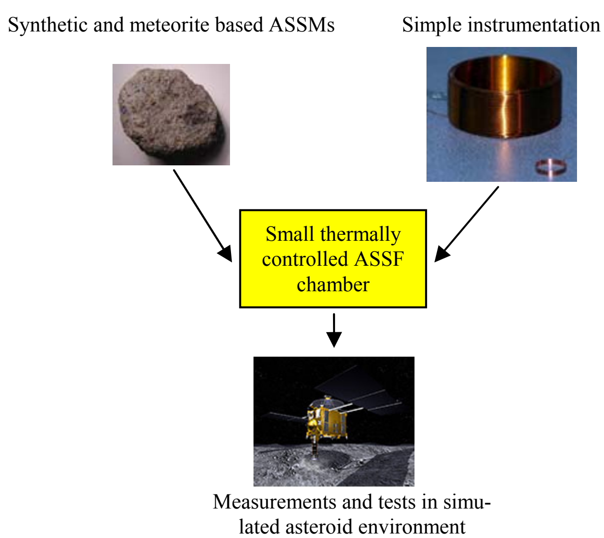

Fig. 1: Outline of the proposed Asteroid Surface Simulation Facility

SAMPLING THE AGE EXTREMES OF LUNAR VOLCANISM: THE YOUNGEST LUNAR BASALTS

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Introduction: Understanding the timing and compositional range of basalts on the lunar surface is key information for interpreting the origin and geologic evolution of the Moon, with implications for comparative terrestrial planetology. Here, we advocate an automated sample return mission to specific basalts to address key questions about the composition of the lunar crust. Sampling these basaltic materials can be cost-effectively done in a manner that complements currently proposed missions [e.g., 1] and helps prepare for future human exploration.

Background: The Moon preserves records that have been largely erased on the Earth, Venus, and Mars [2]. The Moon is the only extraterrestrial body from which we have contextualized samples, yet unanswered questions remain: we lack important details of the Moon's early igneous history, the full compositional and age ranges of its crust, or the bulk composition of crust, mantle, and whole Moon.

Mare basalts cover ~17% of the lunar surface, primarily topographic lows on the nearside [3]. Lunar basalts form through partial melting of the mantle and are the most direct window into the composition of the interior. Analysis of remote sensing datasets shows that the full range of mare basalt compositions and ages has not yet been sampled [4,5]. Knowledge of the duration of mare volcanism comes from (a) radiometric dating of Apollo and Luna samples and lunar meteorites and (b) crater counting of mare surfaces from remote sensing data. Mare volcanism reached its maximum volumetric output between 3.8 and 3.2 Ga [6], but began as early as 4.3 Ga [7-9] and may have persisted until as recently as 1.2 Ga [5,10]. This uncertainty requires disambiguation.

Some of the basalt flows on the Moon are more recent than the youngest Apollo basalts [10]. [5] mapped 60 spectrally homogenous basalt units in Oceanus Procellarum. Crater counting methods determined that 5 of these units have model ages ranging from ~1.5-2.0 Ga. Unit P60 (Fig. 1) directly south of the Aristarchus Plateau has the youngest model age (1.2 Ga). The analysis of returned samples from unit P60 would increase our knowledge about isotopic and trace-element variations in lunar basalts, help to distinguish differences in basalt source regions/reservoirs and eruption rates over time, and significantly improve the Moon's absolute chronology. The nearside location makes this an ideal location for an automated sample return; the proximity to the Aristarchus Plateau (a high-priority target for future human exploration and development) also renders this an attractive site as a precursor mission for human lunar return.

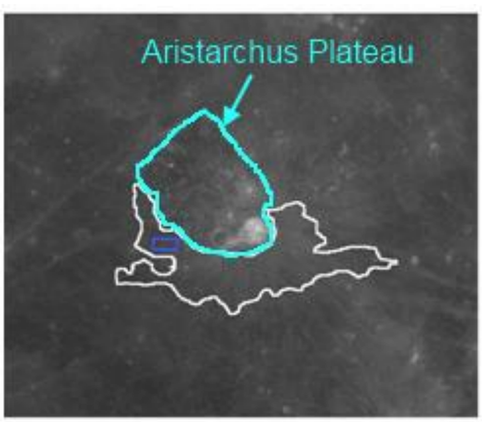

Figure 1. The P60 area of [5] outlined in white. The crater counting region used to derive the model basalt age is in dark blue. Returning basalts from this region would provide a much-needed calibration of crater-derived age dates. The location of the Aristarchus Plateau is outlined in cyan for reference.

Notional Mission Strategy: We advocate an automated lunar sample return mission functionally similar to the Soviet Luna 24 mission and the recently proposed MoonRise mission [1]. The advanced scouting capabilities provided by the NASA Lunar Reconnaissance Orbiter enable precisely targeted landings. The notional spacecraft would consist of a single landed element with sampling capabilities and a sample return system. After landing, a robotic arm would collect and store a scoop of bulk regolith, then collect no more than a kilogram of 1-4cm rocklets by raking or sieving. Following collection, the samples would be returned to Earth. The mission duration would be less than a lunar day; no-long-duration survival for the landed element is needed.

Sample Return is Key: The Apollo experience demonstrates the importance of returning planetary samples to Earth [11]. To achieve the objectives discussed here, detailed analyses of compositions, mineralogy, rock textures, and physical properties in addition to radiometric ages are required. Important measurements could be made using in-situ instrumentation, but terrestrial laboratories offer more capability for the foreseeable future. Samples become resources, so new measurements can be made as analytical techniques improve. For sample return missions to be successful, the scientific community must maintain key capabilities, including lunar sample curation, lunar remote sensing data analysis, and laboratories staffed with experienced planetary scientists. Sample return missions will also play an important complementary role towards human lunar return by giving the next generation of lunar scientists experience analyzing new lunar samples prior to the seventh human lunar landing.

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PHOBOS AND DEIMOS SAMPLE RETURN: IMPORTANCE, CHALLENGES, AND STRATEGY. Pascal Lee[1,2,3], [1]Mars Institute (NASA Research Park, Bldg 19, Suite 2047, Moffett Field, CA 94035-0006, USA, pascal.lee@marsinstitute net), [2]SETI Institute, and [3]NASA Ames Research Center.

Summary: The nature and origin of the two moons of Mars, Phobos and Deimos, are still unknown [1, 2]. Selective sample return from both objects is the only assured and practical way to resolve this mystery.

Background: Decades of Earth-based spectroscopy and Mars orbital observations have not been able to establish the composition, nature, and origin of Phobos and Deimos. Are they i) captured asteroids [3,4], ii) remnants of circum-Mars accretionary materials [5], iii) remnants of a once larger moon(s) - itself possibly a captured object or a circum-Mars accretionary body [6]; iv) reaccreted Mars impact ejecta [7]? Phobos and Deimos are at the crossroads of major and outstanding questions in solar system science, bridging topics from planet formation to satellite and small body evolution, impact cratering to interplanetary medium processes, and many more. Their origin is the single most important science question to be answered in their exploration [2]. Phobos presents two major spectral units: a "red" unit, and a "blue" unit (see [8] for a review and latest data). The "red" unit is almost global in extent and matches D-type asteroids. The "blue" unit is associated with fresh-looking material exposed near the rim of Stickney Crater. The "blue" unit is consistent with dehydrated carbonaceous chondrites. Deimos is globally reddish and spectrally similar to the "red" unit on Phobos, although its *streamers* are bluer [8] (Fig.1).

Remote Observations Impasse. Several lines of reasoning suggest that the surface of Phobos and Deimos is not representative of their interior: 1) On Phobos, the "red" unit might be a superficial veneer, and the "blue" unit represents mostly buried materials; 2) Phobos and Deimos's low bulk densities imply that that their interiors are highly porous, possibly H_2O-rich, in contrast to their surface which does not reveal unusually high porosities or high H_2O content [7]; 3) Phobos and Deimos continuously accrete (space-weathered) asteroidal dust [9]; 4) Phobos and Deimos might be coated with martian impact ejecta; although macroscopic fragments of martian ejecta directly accreted onto Phobos or Deimos are likely few [9], impact ejected dust and electromagnetically entrained upper atmospheric dust from Mars might have contributed substantial polluting veneers over time on both Phobos and Deimos, perhaps accounting largely for their reported "Mars-like" spectral features [10].

Efforts to infer the bulk composition of Phobos and Deimos from remote observations have hit an impasse. Phobos and Deimos likely do not look like what they truly are.

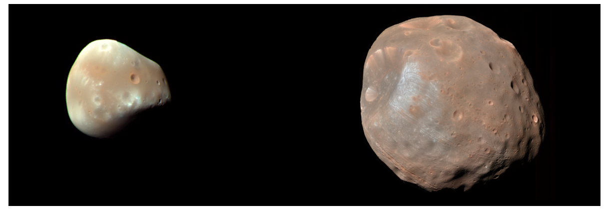

Figure 1: MRO Hi-RISE images of Phobos (right) and Deimos, shown to scale. (NASA/JPL/JHUAPL)

Ejecta Blocks: Phobos and Deimos have large blocks on their surface, the vast majority of which must be impact ejecta blocks [11-13]. These blocks are the only reliable sources of materials representative of Phobos and Deimos's bulk, available at their surface.

***In Situ* Investigations *vs* Sample Return:** Resolving the mystery of Phobos and Deimos's origin requires that *ejecta blocks* materials be examined and analyzed. *In situ* investigations that are able to access/contact ejecta blocks may resolve the origin question *if* Phobos and Deimos are unambiguously identified with known asteroid or meteorite types. However, sample return will be the only assured way of addressing the broader range of possibilities. Sample return will be required for isotopic analyses to determine whether Phobos and Deimos are related to Mars (same original materials), and whether they are related to each other. A Phobos-Deimos SRM would also be a valuable precursor/rehearsal for MSR.

Conclusion. Sample return from *both* Phobos and Deimos is the only assured and practical way of resolving the question of their origin. Samples of *ejecta blocks* (not regolth grab samples) need to be acquired. A New Frontiers class Phobos and Deimos SRM targeting ejecta blocks is under development: *Hall* [14].

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ASTROGEOBIOLOGY SAMPLE RETURN AND IN-SITU SCIENCE IN ANTARCTICA: UNDERSTANDING TRADES BETWEEN SCIENCE OBJECTIVES AND OPERATIONS ACROSS SCIENTIFIC DISCIPLINES. Joseph S. Levy[1] [1]Portland State University, Department of Geology, Portland, OR, 97201, USA. jlevy@pdx.edu

Introduction: The McMurdo Dry Valleys of Antarctica represent one of the most Mars-like environments on Earth [1-3]. Accordingly, astrobiological field research into the structure, functioning, and preservation of extreme Antarctic ecosystems provides a testbed for planning sample-return-based science in remote planetary settings.

Although terrestrial analog research does not provide a precise duplication of planetary conditions, it does provide a valuable case study in addressing questions that are of primary concern to sample return mission planners: 1) What is the best approach to selecting samples for competing scientific constituencies with different research goals and different sample-handling requirements? 2) How can in-situ measurements be used to select representative and/or high-priority samples for return to home labs while still conducting meaningful field science? 3) How can humans and/or robots rapidly characterize surface and subsurface (and relict) ecosystems under strict time constraints?

Antarctic Site and Research Team. The McMurdo Dry Valleys Long Term Ecological Research program (www.mcmlter.org) is a multi-investigator, ecosystem functioning and characterization research project focused on analysis of the physical environment, biological community, and relict ecosystems present in Taylor Valley, Antarctica (77.7^{o}S, 162.8^{o}E). Taylor Valley contains examples of permafrost, cold-based glaciers, ephemeral streams, and ice-covered lakes [4]—a cold desert landscape that supports a nematode-dominated community based on algal primary production [5]. The MCMLTER supports an integrative science program with researchers representing a wide range of disciplines, including limnology, microbiology, hydrology, geology, glaciology, genetics, remote sensing, geophysics, meteorology, and geochemistry. Accordingly, the MCMLTER represents a microcosm of the scientific community most interested in sample return from planetary environments.

Interdisciplinary research projects, for example, analysis of the ecological effects of water-regolith interactions [6] require multiple researchers to make use of the same limited sample—for example, rock, soil, or ice that has been collected during a short summer field season, or during an even more abbreviated day trip to a remote field location. Analyzing splits of the same sample ensures that all disciplines have access to a sample that is minimally heterogeneous (large changes in ice content, salinity, chemical composition, and organic carbon content occur at meter-scales in Antarctic environments [5]. As a result, the selection and curation of these samples needs careful planning to ensure that the sample preservation requirements of each discipline is met.

Sample Return Insight From Antarctica. Several key lessons relevant to planetary sample return can be learned from Antarctic planetary analog research.

1) *There is no single, ideal sample that will address every scientific constituency.* Different disciplines have different material interests. Selecting samples that characterize the diversity of a science site (soils, ices, stream water, biological matter) requires a diversity of sample acquisition and handling devices.

2) *High quality in-situ science is essential for selecting representative and anomalous samples.*. Field measurements (e.g., soil conductivity, reflectance spectra, etc.) provide a quantitative assessment of the research site. They are necessary to select samples that represent the diversity of materials at the site. High-quality in-situ measurements also reduce risk by ensuring science return in the event that samples are compromised in transit.

3) *Sample curation for multiple disciplines requires meeting each researcher's needs through a sequential curation plan.* Samples often require different temperature, humidity, chemical storage conditions. Sequential splitting of samples to ensure that no discipline's sample is compromised by the curation techniques of another discipline requires prior planning and tactical oversight.

4) *The effective selection of sample return targets requires both strategic and tactical input from all scientific discipline groups*. Interdisciplinary science groups—whether working in Antarctica or Mars—are often complementary by design. When programmatic constraints reduce resources available for science, research groups can become competitive. Strategic prioritization of sample collection and curation (conducted with a transparent end-goal, for example, of maximizing diversity in the return sample) provides a framework for making fair and scientifically justified scoping decisions.

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Earth-Orbit Crossing Asteroids: Testbeds for mechanisms of space weathering. Y. Liu[1] and Kevin G. Thaisen[1], [1]Planetary Geosciences Institute, Department of Earth and Planetary Sciences, University of Tennessee, Knoxville, TN 37996 (yangl@utk.edu).

Earth-orbit crossing asteroids provide a unique opportunity for addressing several important questions in planetary science, as well as a possible source of future resources [1].

Main Scientific question to be answered:

Classification of asteroids is based on the spectral characteristics of the surface of the asteroids [2,3]. However, many asteroid spectra display space weathering effects, which camouflage the true mineralogy exposed at the surface. Seeing through the space weathering effects has been the goal for spectroscopists. Much of our understanding of space weathering has been obtained through the study of returned lunar samples [4,5]. The nanophase iron in the fine fraction of the lunar soil and in the vapor deposited glass coatings of soil particles contributes to the reddening of the spectral continuum of lunar soils. These nanophase iron particles are generated through solar wind sputtering and micrometeorite bombardment [4,5]. However, the mechanisms and timescales of space weathering on asteroids remain controversial [6,7]. Because of the different orbits of asteroids and their distances from the Sun, solar wind and micrometeorite bombardment are expected to contribute in different proportions to space weathering on the surface. Unfortunately, this can only be verified through returned samples from asteroid bodies.

Recent studies have also suggested that the surface of near-Earth asteroids with an orbit within 16 earth radii is reset by the tidal stress generated during their close encounters with Earth [8-9]. If this is true, these asteroids can contribute to understanding the time-scale of space weathering and why near-Earth asteroids of similar compositions can have different spectra. A sample return mission will provide ground-truth to study the effect of these processes and to determine the mechanisms of resetting.

Other Scientific questions to be answered:

The recent findings of surface absorbed water on the Moon [10-12] suggest that space weathering may also impart chemical changes to the surface of airless bodies. Returned samples will also be able to determine whether this chemical alteration also plays a role on asteroid surfaces.

In addition, abundant water and organic materials have recently been identified on main-belt asteroids; these may have been the source of water and life on Earth [13-14]. The isotopic composition of water can be tested through direct sampling of the Earth-orbit crossing asteroids.

Finally, except for the lunar, HED and SNC's, the majority of meteorites still have unknown parent bodies. Samples returned from these asteroids may help to pair these meteorites with their parent bodies.

Advantages: The orbit of near-Earth asteroids are well calibrated, some of which are tracked for possible impact with Earth. Because of the orbital configuration of Earth-crossing asteroids, there are two sampling opportunities. Surface of Earth-crossing asteroids can be well characterized during their approach to Earth. The near-zero gravity of many Earth-crossing asteroids makes them easy sampling targets.

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OPTIMIZING LUNAR SAMPLE RETURN: LESSONS LEARNED FROM A ROBOTIC PRECURSOR LUNAR ANALOGUE MISSION AT THE MISTASTIN IMPACT STRUCTURE, LABRADOR, CANADA.

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Introduction: The return of samples from the South Pole–Aitken (SPA) basin and other regions of of the Moon is a high priority target for the Canadian, U.S., and international scientific communities [1]. In order to prepare and test protocols for future lunar sample return missions, our team is carrying out three “analogue” missions, funded by the Canadian Space Agency. The first analogue mission took place over three weeks in August and September 2010 and aimed to simulate a robotic precursor mission to the SPA. This will be followed by a second analogue mission to the same location in 2011, which will include a human sortie element. The precursor mission involved robotic surveying and prospecting of Sites of Interest (SOIs) in preparation for human field geology operations. The Mistastin impact structure, Canada, which represents an exceptional lunar analogue site [2], was chosen as the target site for this analogue mission.

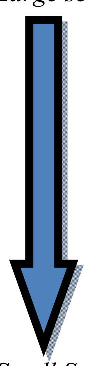
Objectives: The operational goals include: the development of mapping, sample site selection and analysis protocols; and characterizing the scientific decision making processes regarding outcrop mapping and sample site selection. Technical objectives include determining science instrument requirements and limitations of existing off-the-shelf-instrumentation. This analogue mission is driven by the paradigm that the operational and technical objectives are conducted in line with the overarching scientific objectives: to further the understanding of impact chronology, shock processes, and impact ejecta,

Field Approach, Mistastin 2010: The 2010 Mistastin deployment comprised two distinct groups: the mission control team and the field team (“the rover”). The mission control team was based at the University of Western Ontario located in London, Ontario. They directed the “rover” activities and made all science decisions for the deployment based on returned data from the field. No mechanical robot was used on this deployment. Instead, a field team of four to five people acted collectively as the robot - they made traverses with the instruments, collected data as requested by mission control, and sent the data to the remote mission control team using satellite communication. Instruments used in the field included:

- Light detection and ranging (LIDAR) for making 3-D intensity models of the surrounding area (range: up to 1 km);
- Mobile scene modeller (mSM) for making 3-D colour models at outcrop scale (range 2-5 m);
- Ground penetrating radar (GPR) for imaging the subsurface (depth ~10 m);
- Digital camera with Gigapan mount for making panoramic high resolution colour images;
- X-ray fluorescence spectrometer (XRF) for measuring major and trace elemental abundance in rocks.

Operations: A general sequence of activities for this field deployment was based on the principals of mapping the geology of an unknown area: by first providing a regional context and then progressively focusing the geographic area of study.

Large scale



- o Remote Sensing Data
- o Landing Site Survey (LIDAR, digital camera and Gigapan mount)
- o Conduct GPR scan
- o Zoom in on Site of Interest (using the following sequence):
  - LIDAR scan and digital panorama
  - mSM
  - Macro digital camera
- o Choose specific spot for geochemical and mineralogical analysis (XRF)

Small Scale

Lessons Learned: The focus of this analogue mission was not in testing the capabilities and constraints of a rover, but in testing the scientific instruments that would be carried by a rover and assessing the usefulness of the returned data for future sample return during the 2011 deployment. Initial lessons learned highlight the situational awareness capabilities and limitations of the field instruments. Recommendations emphasize the need to optimize the resolution required for vision system data products for each progressive step (see flow chart above) and to improve visualization software that would allow seamless data integration of different data sets.

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Acknowledgments: Canadian Space Agency; Annemarie Pickersgill, UWO; Timothy Barfoot, U of T; Timothy Haltigin, CSA; Ho-Kong, MDA.

JAROSITE MORPHOLOGY AS INDICATOR OF WATER SATURATION LEVELS ON MARS K. Miller[1]
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Introduction: Jarosite, which has been identified on Mars [1] is an extremely sensitive recorder of environmental conditions. Water saturation levels are reflected in jarosite's distinctive morphologies. Sample return of jarosite would allow for the identification of these morphologies, providing evidence for the behavior/abundance of water on Mars. This work focuses on SEM images of jarosite collected at Davis Mine, in Rowe, MA. These images reveal two distinct morphologies, which are controlled by water saturation levels. The first, variable jarosite, requires abundant water; the second, donut jarosite, requires a minimal amount of water. The donut morphology may not have been previously described. Its presence suggests that jarosite can form with a very small amount of water, possibly just a film no more than a few microns deep.

Discussion: Samples for this work were collected by hand-auger from cores located in spoil piles and acid sulfate soils at Davis Mine. XRD analysis provided mineral identifications and relative quantification. SEM/EDS analysis confirmed mineral identifications and provided morphological data.

Variable jarosite (Figure 1) was collected from the stream area of a spoil pile. The sample was taken from within the water table fluctuation area. Water samples from this area measured a pH of about 3, and evidenced the high ion concentrations typical of acid mine drainage waters. Seasonal variations in pH and ion concentrations have been noted. [2]

Variable jarosite is identified by variability in size, from about 1 to 5 microns, variability in morphology, from pseudocubes to lathes, and some crystal dissolution. This morphology indicates a consistent water flow, with possible variations in ion concentration.

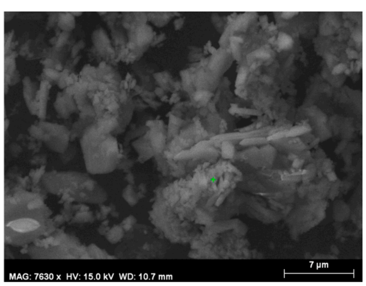

Figure 1. Variable jarosite, showing rounded pseudocubes, lathes, and an extensive size range.

Donut jarosite (Figures 2,3) was collected from the acid sulfate soils adjacent to the spoil piles. This jarosite morphology is distinguished by a size of less than .5 microns, consistent pseudocubic morphology, no evidence of dissolution, and crystal placement within a mantle only a few microns deep. This morphology suggests minimal water abundance. Therefore, identification of this jarosite type on Mars could suggest that liquid water, while present, could be very scarce, at least at this jarosite formation location.

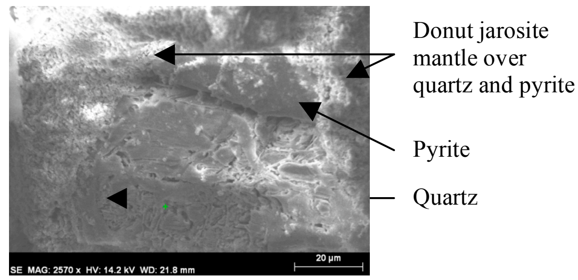

Figure 2. Donut jarosite mantle draped over substrates.

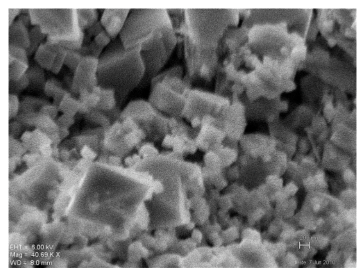

Figure 3. Donut jarosite. Magnification=40.69 K X

These two morphologies differ from that of jarosite produced by acid sulfate fog, which can take a rosette form [3], and from evaporite jarosite crystals, which can show little variation in size or morphology, but appear to be about 2 microns in diameter, with evidence of dissolution.[4]

Conclusion: Jarosite morphologies vary significantly, and provide information about water saturation levels. This work adds to the library of jarosite morphologies that can be linked to water flow behavior. Sample return would permit the analysis of Martian jarosite morphologies. This visual information can provide information about the subtle behavior of water on Mars.

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SAMPLING THE UPPERMOST SURFACE OF AIRLESS BODIES. S. K. Noble[1] L. P. Keller[2] and R. Christoffersen[2], [1]NASA GSFC Mail Code 691 Greenbelt MD 20771, sarah.k noble@nasa.gov, [2]NASA JSC Mail Code KR, Houston TX 77058.

Introduction: The uppermost surface of an airless body is a critical source of ground-truth information for the various remote sensing techniques that only penetrate nanometers to micrometers into the surface. Such samples will also be vital for understanding conditions at the surface and acquiring information about how the body interacts with its environment, including solar wind interaction, grain charging and levitation [1]. Sampling the uppermost surface while preserving its structure (e.g. porosity, grain-to-grain contacts) however, is a daunting task that has not been achieved on any sample return mission to date.

Apollo sampling: The importance of collecting a sample of the uppermost lunar surface was recognized during Apollo, and resulted in the design and deployment of the clam shell sampling devices (CSSDs) on Apollo 16 [2]. The two devices used Beta cloth (69003), similar to the outer layer of Apollo space suits, and velvet (69004) to collect the topmost ~100 and ~500 μm of the soil, respectively. Unfortunately, the CSSDs faced a couple of problems. First, sampling undisturbed soil is very difficult and the sampling protocol required the astronaut to “sneak up on a rock” and then reach behind it and sample in a largely blind maneuver on uneven ground. As a result, little material was collected, likely because of poor contact with the ground (Fig.1).

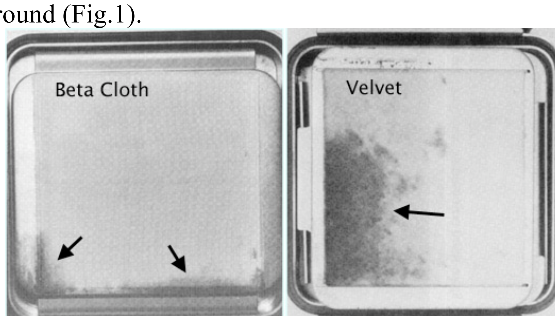

Figure 1. Apollo 16 Clam Shell Sampling Devices. Black arrows indicate the collected material.

Second, for the material that was collected there is evidence that various sampling biases were introduced. Some of the material, particularly the larger grains, fell off of the fabric in transit. Further, recent analysis has shown that at least the beta cloth fabric preferentially collects ultrafine grains (<2 μm) [3]. Similar tests have not yet been performed for the velvet, however, the velvet sample faces additional challenges because there are few techniques available to efficiently remove the particles from the velvet fibers. These sampling biases render the samples useless for assessing parameters such as the size distribution of the uppermost layer.

Potential samples: Sampling of the undisturbed uppermost surface of the lunar regolith should be integrated into operational plans for most, if not all, future robotic and human lunar surface missions. The goals should be to determine the degree to which the state of space weathering, and the composition, and/or particle size distribution differs from the bulk soil. Of particular interest would be lunar swirl sites. It has recently been postulated that transport of a very fine dust component may be responsible for swirl formation [4]. An examination of the uppermost surface would be the ideal way to test this hypothesis.

Previous asteroid missions have shown that both Eros and Itokowa have regions (“ponds”) of finer material, indicating significant transport of fines. Samples from the uppermost surface of such ponded areas, as well as from more coarse-grained regions might shed light on the mechanisms controlling this process.

Future strategies: The solution to this sampling problem is challenging and will require new efforts to develop the proper collection mechanisms and protocols for both lunar and asteroidal sampling.

The ideal collection mechanism would uniformly collect the upper roughly 100 μms of undisturbed soil as well as a bulk soil from the top ~10 cm from the same location for comparison. Rather than fabric, a fly paper-like “sticky” substrate might be effective, though removing the sample could prove difficult, unless the substrate could be dissolved without compromising the sample. An alternate approach would be to impregnate the soil from above with a spray adhesive. This would be more logistically challenging, but would have the advantage of preserving grain orientations and any other delicate structures. Here again, the adhesive would have to be dissolvable so the grains could be extricated or strong and stable enough that the sample could be thin sectioned. Both methods would unfortunately introduce organics to the sample, which is problamatic for analysis of asteroidal soils.

Sampling on an asteroid is made more complicated by the very low gravity. Sample collection here is probably best accomplished robotically or through teleoporated methods prior to any human interaction. In order to ensure undisturbed soil, this sample should be collected before any other direct interaction with the body occurs.

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ROBOTIC SAMPLE CURATION, HANDLING, MANIPULATION, AND ANALYSIS: THE FUTURE OF SAMPLE RETURN FACILITIES?

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Introduction: One of the major driving forces for robotic and human exploration of the solar system is the return of samples for subsequent study on Earth. Future plans include missions such as MoonRise, a current NASA New Frontiers contender to return samples from the South Pole-Aitken Basin on the Moon [1], and the long-term goal of a Mars Sample Return mission. The return of Martian samples to Earth-based labs, in particular, will offer an unprecedented opportunity to search for life in such returned samples.

The analysis of returned planetary samples requires the coordinated development of expertise in analysis of astromaterials, including the training of highly qualified personnel, together with curation and handling astromaterials in the context of biohazard and cold material storage. To this end, and to address the program objectives of the Canadian Space Agency (CSA), a concept for a Canadian Astromaterials Facility (CAF) has been developed [2]. One of the unique aspects of this concept, which is the focus of this current contribution, is the integration of robotics-enabled infrastructure for materials curation, handling and non-destructive analysis.

Why use robotics? Internationally, astromaterials curatorial facilities vary widely in terms of technology level and availability of analytical instruments. Most facilities involve humans handling and manipulating samples via sterile glove boxes, with most, if not all, analyses being conducted outside of these cleanroom facilities in standard analytical laboratories. There are several drawbacks to these current techniques and technologies, particularly with respect to future Mars Sample Return, where astrobiology is a driver. Indeed, the need for sterile curatorial and analysis facilities is driven largely by planetary protection protocols. We need to protect these pristine materials from contamination with the Earth's biosphere, and we need to develop a suite of life detection protocols to protect Earth from any extraterrestrial life forms. To do this, we must ensure that samples returned to Earth suffer no compositional or morphological changes during collection, transit to Earth, entry into Earth's atmosphere, impact on the surface, and long-term curation [3]. For the latter, it is widely acknowledged that samples must be kept in a Class 100 clean lab at temperatures below -30°C [3], which will ensure that the samples will remain in their pristine state. This requirement is due to the fact that much of the research done on extraterrestrial samples involves measuring very small differences in composition so even tiny amounts of Earth materials can contaminate analytical measurements. Planetary protection protocols have not been decided upon by the international community but it may be that the sample return facolities also be equipped to Level 4 biocontainment standards. No facility in the world currently exists that is equipped to such standards. This provides the motivation for this study.

Robotic sample curation, handling, manipulation, and analysis: This concept involves the development of new robotic capabilities for planetary science and exploration. These novel technologies will ensure that extraterrestrial samples are handled, used and preserved in a safe manner. By using robots – and not humans – to handle, sub-sample, and carry out initial non-destructive characterization, the goal is to ensure that pristine planetary samples will remain intact and uncontaminated.

In order to achieve these goals, the core of the facility utilizes aseptic sample curation, sample characterization, classification and initial non-destructive sample analysis, all contained within a Class 100 clean room kept at -20°C. A draft operations concept and plans for such a facility have been drawn up and will be presented during this workshop.

Most notably, ALL of the following operations would be done robotically: initial sample viewing, sample receiving, sample storage and retrieval, automated sample preparation (includes polishing, inspection, cutting, coring, grinding), and automated sample analysis (includes incorpation of instruments to carry out initial NON-destructive analyses: 3D volume measurements, density and porosity measurements, X-Ray diffraction and X-Ray Fluorescence analyses, and UV-Vis-NIR/IR spectroscopy). In order to ensure a pristine environment for astromaterials handling and preparation, the key requirement of the facility is a teleoperated robotic system. Safe and accurate handling of the samples also requires that both the motion of the robotic end-effectors and the force of interaction with the samples be monitored as well as controlled, i.e., bilateral teleoperation.

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CONSTRAINING THE END OF THE BASIN FORMING EPOCH WITH SAMPLES FROM ORIENTALE BASIN.

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Introduction: Determining the early solar system impact flux is the top priority outlined by the National Research Council [1]. Specifically, to date the formation of the South Pole Aiken Basin (SPA), because it is the oldest and largest of the basins in our solar system.

Sample return from basins on the Moon would also address the impact flux over time. Since there is already a SPA sample return mission being developed, the next priority would be to date the youngest basins on the Moon to bracket the entire basin forming epoch. Based on superposition and crater counting, Orientale Basin is the youngest on the Moon e.g. [2]. Orientale is a 960 km diameter multi-ringed basin with a large central impact melt sheet that is partially covered by mare basalt. The purpose of this study is to identify unmistakable Orientale impact melt material and to identify accessible landing areas where it can be collected. A robotic sample return mission would then guarantee a date of the youngest basin on the Moon.

Methods: We plan our mission based on a low cost lander with no roving capabilities. We use a combination of Lunar Reconnaissance Orbiter Camera (LROC) images (Figure 1), USGS geologic maps (Figure 2) [3], and Clementine FeO maps (Figure 3), to determine locations of Orientale impact melt (prime location circled in yellow). Previous authors found that that the Maunder formation (*Iom*, Fig 2) is Orientale impact melt [2]. In addition, FeO maps also show low concentrations in this area. We only looked at potential sites in the far eastern side of the basin because that is the only portion on the near side of the Moon, thus making a sample return mission far easier than if on the far side. In addition to the geologic requirements, a robotic lander with a simple scooping mechanism requires a relatively large (~5 km square) smooth landing surface.

Results: Using the imagery and requirements described above, we identified candidate landing sites outlined in Fig 1. Landing sites within the outlined area would provide unmistakable Orientale impact melt, and when returned to Earth could be used for radiometric dating.

Conclusions: Orientale presents a unique opportunity to sample impact melt in situ with a sample return robotic mission. Dating the Moon's youngest basin will constrain the end of the basin forming epoch and the early impact flux curve of not just the Moon, but of the entire inner solar system.

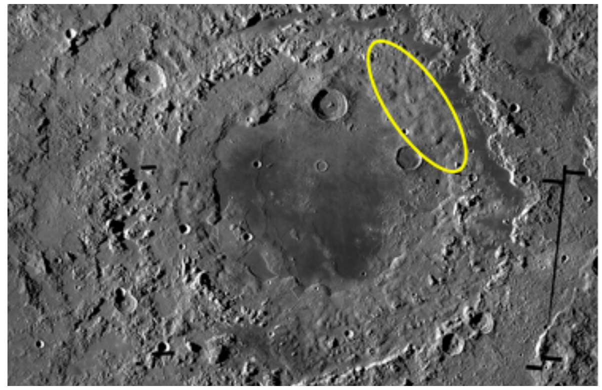

Figure 1. LROC Wide Angle Camera mosaic of Orientale. Area outlined in yellow is target of landing sites.

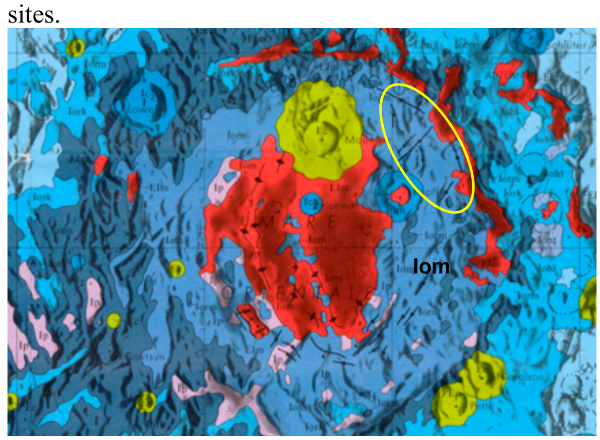

Figure 2. Geology map of Orientale Basin [3]. Blue colors are Orientale materials, red colors are younger mare basalt, green craters are Eratosthenian in age.

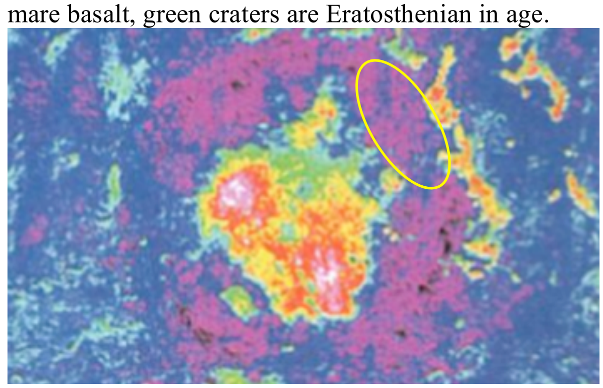

Figure 3. Clementine Fe map of Orientale Basin. Blue to purple has <6 FeO% and green to red has >8% FeO.

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THE NEED FOR SAMPLE RETURN MISSIONS AND THE CASE FOR THE SOUTH POLE-AITKEN ROBOTIC LUNAR SAMPLE RETURN. D. A. Papanastassiou[1], B. L. Jolliff[2], C. K. Shearer[3], L. Alkalai[1], and L. E. Borg[4]. [1]JPL, Caltech, Pasadena, CA 91109 (dap@jpl.nasa.gov); [2]Washington University, St. Louis, MO 63130; [3]University of New Mexico, Albuquerque, NM 87131; [4]LLNL, Livermore, CA 94550.

Introduction: The exploration of planets in our solar system has progressed in a rough sequence, from observations from Earth, to observations from fly-by, orbital, in-situ landed instruments, to sample return missions, with sample return being prominent for the Apollo Program and for STARDUST. Each new class of missions improved on the previous class and dispelled some of the uncertainty, inferences and myths of the prior observations. For several destinations sample return missions should be the next step, even though complexity and cost may require fewer missions.

Need for returned samples: Some analyses cannot be done in-situ, with the chronology of rocks being one key example. Dating of samples requires detailed chemistry and mineralogy as well as the analysis of minerals and mineral separates. Analyses to micrometer to nanometer scales are needed. Furthermore, because the radiogenic isotope effects for long-lived parent-daughter systems are small, high precision mass spectrometry is needed. For current state-of-the-art instruments in our labs, the precision is better than 10 ppm for isotope ratios, and the resulting precision in ages is better than 10 Ma. Measurements require analyses in terrestrial laboratories and with a sequence of sophisticated, state-of-the-art instrumentation. For chronology, it is also important to apply multiple techniques (long-lived parent-daughter systems: K-Ar, Rb-Sr, Sm-Nd, Lu-Hf, U-Th-Pb) to establish the degree of age concordancy, since different parent-daughter systems can be differentially modified by secondary processes. Analysis of returned samples is essential for providing the ground truth for the interpretation of orbital and in situ data (see next Section).

The Apollo Samples: For Apollo, the return of samples resulted in a complete change of our understanding. For example, once Apollo samples were analyzed on Earth, the spectroscopy of the lunar surface was extensively recalibrated to take into account the presence of glass, agglutinates, and nanophase, reduced Fe, from reaction with solar wind hydrogen. The formation of an anorthositic crust on the Moon was suggested by Surveyor, in situ, alpha back-scattering measurements, inferred from the presence of anorthositic rocklets in the Apollo 11 returned samples, and greatly amplified by suites of anorthosite samples from subsequent Apollo missions. All crater chronology and inferred lunar evolution underwent a paradigm shift: the lunar surface was neither dead for the 4.6 Ga age of the solar system nor extremely young. The crater chronology for the Moon and inner solar system was drastically modified to reflect the apparent preponderance of ages for impact melts of 3.9-4.0 Ga and the observation that radiogenic Pb produced between 4.5 and 4.0 Ga was remobilized over the whole surface of the Moon at 3.9-4.0 Ga ago. These observations led to the Terminal Lunar Cataclysm hypothesis [1]. Such a late spike in the impact rate on the Moon has not been simple to explain. The current theory, the Nice model [2] allows for such a late intense bombardment of the inner solar system based on the sudden realignment of the orbits of the giant planets. If the impactors hurled into the inner solar system originated in the Kuiper Belt, the time scale for these impactors would span ~35 Ma; if the impactors originated in the asteroid belt, the time span would be ~150 Ma.

The MoonRise Mission: The post-Apollo, recognition of the South Pole-Aitken basin as the oldest basin on the Moon, with a distinct chemical signature, provides a mechanism to confirm the hypothesis of the TLC and of the Nice model as its mechanism. The proposed South Pole-Aitken Sample Return Mission, currently in a Phase A Concept study and competition, in the New Frontiers Program, plans to address this solar system-wide evolution model. Hence, we consider this mission capable of providing a paradigm shift in our understanding of the evolution of our solar system. This consideration defines this mission as a New Frontiers mission and is the reason why the last Decadal Survey rated such a mission to be of high priority [3]. The proposed mission would land in the interior of the South Pole-Aitken basin and would collect thousands of small rocks, in the size range 3 to 20 mm, and return them to Earth for analyses in state-of-the-art laboratories, by multiple analytical techniques. The large number of returned rocklets would address the diversity of samples at any landing site within the basin and the possible influence of younger impacts within the SPA basin. The prime goal of the proposed mission is dating the formation of the SPA basin and either confirming or rejecting the TLC hypothesis and the Nice model. This mission is a prime example of the case where a sample return mission can address solar system-wide evolution mechanisms and hypotheses. It also marks the importance of returned samples in addressing key scientific questions about our solar system.

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ALMAHATA SITTA AND BRECCIATED UREILITES: INSIGHTS INTO THE HETEROGENEITY OF ASTEROIDS AND IMPLICATIONS FOR SAMPLE RETURN. A. J. Ross[1,2], J. S. Herrin[3], L. Alexander[1], H. Downes[1,2], C. L. Smith[2] and P. Jenniskens[4]. [1]Centre for Planetary Sciences, Joint UCL/Birkbeck Research School of Earth Sciences, London, UK (aidan.ross@ucl.ac.uk), [2]IARC, Department of Mineralogy, The Natural History Museum, London, UK, [3]NASA Johnson Space Center (ESCG), Houston, TX 77058, USA. [4]SETI Institute, CA, USA.

Introduction: Analysis of samples returned to terrestrial laboratories enables more precise measurements and a wider range of techniques to be utilized than can be achieved with either remote sensing or rover instruments. Furthermore, returning samples to Earth allows them to be stored and re-examined with future technology. Following the success of the Hayabusa mission, returning samples from asteroids should be a high priority for understanding of early solar system evolution, planetary formation and differentiation.

Meteorite falls provide us with materials and insight into asteroidal compositions. Almahata Sitta (AS) was the first meteorite fall from a tracked asteroid (2008 TC3) [1] providing a rare opportunity to compare direct geochemical observations with remote sensing data. Although AS is predominantly ureilitic, multiple chondritic fragments have been associated with this fall [2,3]. This is not unique, with chondritic fragments being found in many howardite samples (as described in a companion abstract [4]) and in brecciated ureilites, some of which are known to represent ureilitic regolith [5-7]. The heterogeneity of ureilite samples, which are thought to all originate from a single asteroidal ureilite parent body (UPB) [5], gives us information about both internal and external asteroidal variations. This has implications both for the planning of potential sample return missions and the interpretation of material returned to Earth. This abstract focuses on multiple fragments of two meteorites: Almahata Sitta (AS); and Dar al Gani (DaG) 1047 (a highly brecciated ureilite, likely representative of ureilite asteroidal regolith).

Ureilite fragment compositional heterogeneity: We have examined six unbrecciated ureilite fragments of Almahata Sitta. These have varying olivine core compositions between samples but little variation within a single fragment. Combining our data with that of [2] and [3] we find that the distribution of olivine Mg# in AS spans almost the entire range seen in all previous unbrecciated ureilites [5]. This means that the ~4m diameter asteroid from which AS originated encompasses the entire range of ureilite compositions represented in meteorite collections. Examination of DaG 1047 reveals that the entire range of ureilitic olivine compositions are present in a single cm-sized sample [8], agreeing with other ureilitic breccias [5,6].

Chondritic fragments in ureilites: Chondritic clast types previously recognized in ureilites include: ordinary chondrites, R-chondrites, E-chondrites and dark clasts that may represent carbonaceous chondrites [5,6]. We have identified multiple chondritic clasts of different types in DaG 1047. We classify a chondritic fragment associated with AS (#41) as an EH impact melt. The wide variety of chondritic fragments in ureilites contrasts with HED samples, where CM and CR chondrites are the most abundant impactors [4,9].

Asteroidal inferences: The asteroid from which Almahata Sitta originated (2008 TC3) has been determined to be a rubble-pile representing an aggregation of fragments from the UPB post-break-up [10]. Itokawa was the first confirmed rubble-pile asteroid [11] with several other small asteroids also thought to be rubble-piles. It is possible that these asteroids may share a similar history to AS [10], namely accretion and (some) differentiation followed by break-up (whether catastrophic as in the case of the UPB or through a series of small disruptions) and re-accretion to form rubble-piles incorporating foreign materials.

Implications for sample return: Given the high cost of sample return missions, it is vital to maximize the amount of data that can be extracted from samples. Whilst interior samples, such as those exposed at impact craters, may lead to more useful material for determination of asteroidal processes, sampling of regoliths can yield a wider range of compositions from less material. However, any returned regolith material would probably include exogenic contaminants, which would dilute the material from the target asteroid and complicate the interpretation of data. Hence there is a trade-off between sampling of a wider range of asteroidal material and keeping the samples returned free of unwanted impactor material. Sampling rubble-pile asteroids would enable access to a wider variety of accessible surface material then solid asteroids.

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A MICROBE ON THE MOON? SURVEYOR III AND LESSONS LEARNED FOR FUTURE SAMPLE RETURN MISSIONS. John D. Rummel[1], Judith H. Allton[2], and Don Morrison[3]; [1]Flanagan 250, East Carolina University, Greenville, NC 27858, <rummelj@ecu.edu>, [2]Mail Code KT, NASA/Johnson Space Center, 2101 NASA Pkwy, Houston, TX 77058, <judith h.allton@nasa.gov>, [3]2440 Glen Ridge Dr., Highland Village, TX 75077, <donmorrison1@juno.com>.

Introduction: A continuing program of sample return missions can provide an essential link connecting solar-system reconnaissance missions and remotely sensed data to the realities of solar system materials at the molecular and atomic scale. In many cases, the results from such missions can be used to focus future exploration in a dynamic fashion, and the physical and chemical attributes of planetary samples can be established in a stepwise fashion that combines mission results and laboratory analyses on Earth. This can be true for a wide variety of fields that make use of planetary materials, including astrobiology and the search for life. In fact, so promising is the potential for such missions that the NRC in its 2008 strategy for the astrobiological exploration of Mars stated that "the greatest advance in understanding Mars, from both an astrobiology and a more general scientific perspective, will come about from laboratory studies conducted on samples of Mars returned to Earth" [1]. Nonetheless, there are important caveats that must qualify that finding—in particular, a concern about the ability of some astrobiological analyses to be conducted on returned samples free of contamination introduced once the samples are returned to Earth.

One particular example that demonstrates the difficulties of dealing with possible biological contamination, after the fact, was introduced as a result of the 1969 *Apollo 12* mission, where astronauts landed on the Moon near the site of the *Surveyor III* spacecraft and returned portions of it to Earth for analysis.

Fig. Apollo 12 astronaut Pete Conrad and a photographer with the Surveyor III camera prior to bagging and storage (NASA JSC photo S-69-62290).

The Case of the *Surveyor III* Camera: *Surveyor III*, had landed near the eastern shore of Oceanus Procellarum in April 1967. When the *Apollo 12* crew returned to Earth, they also returned the *Surveyor III* TV camera and other selected parts. Subsequently, the camera was partially disassembled, and portions [2, 3] subjected to microbial sampling and analysis. The results of this sampling reported to the Second Lunar Science Conference [3], and in contractor reports [4] were that a live microbe—*Streptococcus mitis*—had been isolated from the foam between circuit boards within the camera body. The authors of those reports hypothesized that a small colony of *S. mitis* had made the round trip to the Moon and back, and survived.

But did that really happen? The result was first reported in the mainstream biological literature by Taylor [5] in the *Annual Review of Microbiology*, but not as a primary result, and it has occasionally been cited by other scientists and by hordes of print and broadcast reporters, as proof that Earth microbes could survive the harsh lunar environment. Thanks to the WWW, that story will likely never disappear entirely, but does that make it true? Not really, but proving the truth in such a situation is difficult, if not impossible.

Nonetheless, recent analysis of the photograph record of the processing and examination of the camera body at the Manned Spacecraft Center suggest that there were multiple opportunities for contamination to be introduced during the handling of the camera, and particularly during the microbial sampling of the camera body [3, 4]. The presentation of this analysis will include specific concerns and lessons learned for future sample return missions.

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GRAB AND GO: A SAMPLE TRIPLET FROM MARS FOR NOBLE GAS INVESTIGATION. S. P. Schwenzer[1], S. P. Kelley[1] and U. Ott[2], [1]CEPSAR, The Open University, Walton Hall, Milton Keynes MK7 6AA, United Kingdom; s.p.schwenzer@open.ac.uk; s.p kelley@open.ac.uk , [2]Max-Planck Institut für Chemie, J.-J. Becherweg 27, 55128 Mainz, Germany, uli.ott@mpic.de.

Introduction: When returning a sample from Mars, the strategic question is whether to explore and return a carefully selected sample or to "grab-and-go". While both have advantages (see decadal survey white papers [1], especially [2] and [3]), "grab-and-go" sample return is less complex [3] and hence more likely feasible in the near future. Here we lay out the science that would be possible with a "grab-and-go" sample geared towards preservation of noble gas signatures. This set of samples would combine investigation of noble gases in the atmosphere and rocks with the petrology of the solid samples to complement the remarkable achievements of the rovers and orbiters currently observing Mars [e.g., Filiberto, this conference].

Martian noble gases in the atmosphere were measured, albeit imprecisely, in situ by the Viking lander [4]. Noble gas signatures of shergottites have been interpreted as indicating both Martian atmosphere and mantle signals [e.g., 5], and the noble gas signature in ALH84001 has been interpreted as ancient atmosphere [6]. Nakhlites appear to exhibit a fractionated Martian noble gas reservoir. The interpretation of this fractionated component gave rise to several hypothesis, including incorporation by adsorption or alteration; atmospheric variation over time or for seasonal reasons; and incorporation from a secondary source such as sediments [7-13]. Support for fractionated adsorption comes from terrestrial analog and laboratory studies [11,14,15], but a vigorous debate continues.

Samples: Many of the issues over Martian noble gases and thus the evolution of the Martian atmosphere and mantle system could be addressed with a set of samples that include an atmospheric sample to measure today's Martian atmospheric noble gas signature, a surface soil sample to investigate atmospheric interaction with Martian rocks, and an unaltered solid igneous rock.

Science to be addressed: The first question is if the Martian meteorites are indeed from Mars. Any rock with known Martian provenance would allow the measurement of noble gases, oxygen, and a full set of petrologic investigations to establish the relationship (or not) of the meteorites to this sample. Since Viking's measurement did not include all isotopes (e.g., no ^{21}Ne) and others were measured imprecisely [4], the new samples measured with terrestrial instruments would be the first direct comparison of Mars' and Earth's atmosphere. If the mission residence time on the surface allowed, a sequence of samples would be able to detect seasonal variations in the noble gas elemental ratios. Together with the nakhlite data, the modern data would provide insights into the behaviour and evolution of Mars' atmosphere. The soil sample would provide a Martian atmosphere/adsorbed atmosphere pair giving insight into the processes acting on the Martian surface and allow comparison with the nakhlite meteorites. This could inform us about Martian surface, potentially even climatic, information over the past 1.3 Ga. This, in turn, would allow further disentangling of the fractionated component. If the component in ALH84001 is fractionated atmosphere, then this is the only planetary atmosphere known to survive since 4 Ga. Overall, a set of returned samples could provide unique and invaluable insights into the current state of the Martian atmosphere and thus evolution of the mantle/atmosphere system over time.

Age and cosmic exposure: In addition, the sample set would provide insights into excess Ar incorporated into rocks on Mars, which is critical for in situ age dating by future missions [16, 17], complementing the lunar samples [e.g., 18], and addressing the impact history of the inner solar system. Moreover, returned samples will not have been exposed to any significant cosmic irradiation during space travel, and would therefore provide direct information on their Martian irradiation history. That could lead to surface ages, and potentially to insights into the conditions of the Martian atmosphere and the state of Mars' magnetic field through time.

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MULTISPECTRAL MICROIMAGING AS A TOOL FOR IN SITU PETROGRAPHIC ANALYSIS AND SELECTION OF SAMPLES FOR POTENTIAL RETURN TO EARTH. R. G. Sellar[1], J. D. Farmer[2], and J. I. Nuñez[2], [1]Jet Propulsion Laboratory, California Institute of Technology (glenn.sellar@jpl nasa.gov), [2]School of Earth and Space Exploration, Arizona State University.

Introduction: Achievement of the astrobiological goals of a proposed Mars Sample Return program would depend on the ability to correctly select, prioritize and cache target rocks for potential return to Earth, according to two driving criteria: (1) indications of formation in a *habitable environment*; (2) high potential for long-term *preservation* of biosignatures. Combination of microtextural analysis of rocks with microscale, co-registered, mineralogical information constitutes a powerful dataset for assessing the origin of a rock. Armed with such information, a trained geologist can assign a rock to one of three basic petrogenetic categories (igneous, sedimentary or metamorphic) and can begin to interpret past geological processes based on microtextural and compositional information.

Successful acquisition of microtextural information at the hand-lens scale on planetary surface missions has been demonstrated by the Microscopic Imager (MI) on the Mars Exploration Rovers (MER) [1] and the Robotic Arm Camera on Phoenix [2]. However, while much of the basic information needed to interpret the paleoenvironmental context of a rock can be obtained with such images, mineral identifications require more sophisticated lab analyses, such as petrographic microscopy or x-ray powder diffraction (XRPD). While these are common capabilities of many terrestrial geology labs, their robotic counterparts for *in situ* exploration of other planetary environments are limited by the need to be small, lightweight and flight-ready. A petrographic microscope requires complex and precise sample preparation; i.e. mounting of rock slices on glass slides and grinding to a thickness so that they are transparent to visible light. XRPD (such as the Chemin instrument on the Mars Science Laboratory) requires powdered samples, the preparation of which destroys important microstructural information.

Contact instruments that can analyze the both texture and mineralogy of rocks and soils at the microscale have a clear advantage over other *in situ* methods, in requiring little, if any, sample preparation. This approach preserves important microspatial information (microtextures and phase distributions), considered crucial for interpreting the petrogenesis of a rock.

Multispectral Microscopic Imager: The Multispectral Microscopic Imager (MMI) provides microtextural an mineralogical information similar to that provided by a petrographic microscope, but without the need to prepare a thin section. This instrument employs multi-wavelength light-emitting diodes (LEDs), a focal-plane array (FPA) detector, and no moving parts, to provide multispectral, microscale images in 21 wavelength bands extending from 0.47 µm (blue) to 1.7 µm (shortwave infrared). LED illumination wavelengths are activated singly, in succession, as images are acquired by the FPA, providing a dataset comprised of spatially co-registered microimages. Similar to its predecessor, the MI onboard the MERs [1], the MMI provides a spatial resolution (62 µm), field of view (40 x 32 mm), and depth of field (5 mm) comparable to that provided by a geologist's hand lens.

Results: Multispectral microimaging in the 0.47 to 1.7 µm spectral range can identify major Fe-bearing silicates and oxides, detect hydrated minerals, place minerals in a microtextural context, and support petrogenetic interpretations. Fig. 1 illustrates one example of data acquired by the MMI.

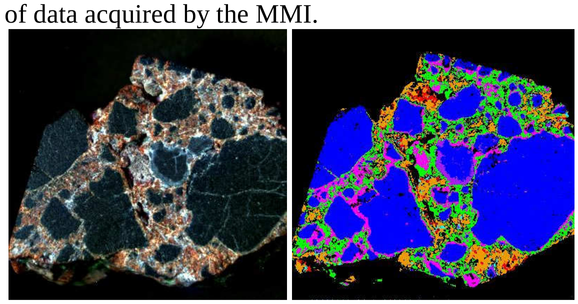

Fig. 1: 30 x 30 mm subframes acquired with the MMI with 62 µm/pixel. **Left:** Natural-color composite of three MMI bands (470, 525, 660 nm);.**Right:** Mineralogical map based on 21-band reflectance spectra. **Spectral matches:** hydrated mineral (green); nontronite (Fe-bearing clay; ochre), augite (light blue); Fe-oxide (red); hydrated mineral (magenta); basalt (dark blue).

Interpretation: Volcanic breccia composed of basaltic clasts cemented by Fe-oxides and possibly amorphous silica and/or crystalline clays. Angular to subrounded clast shapes indicate moderate transport from the source. The uniformity of clast texture and composition (monolithologic) is consistent with derivation from a single volcanic source. The composition of the alteration mineral assemblage is consistent with palagonitic alteration of basalt at hydrothermal temperatures.

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Sampling the Inner Solar System: Scientific Rationale, Potential Targets, and Sample Return Technology Investment and Capabilities.
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Introduction: Sample return missions provide a unique perspective not offered by either orbital or surface missions. This unique perspective is based on scale (down to angstroms), precision, sample manipulation capability, and the ability to modify analytical experiments as logic and technology evolves. These unique observations based on samples returned have a strong symbiotic relationship to both surface and orbital observations. Sample return provides fundamental chronological, mineralogical, and geochemical ground truth that enhances the value of both orbital and surface observations far beyond their stand-alone importance. Here, we explore Solar System scale scientific problems that may be addressed through sampling of the terrestrial planets. Although Mars, asteroids, and other moons are highly relevant to this discussion, we purposely focused upon the Moon, Venus, and Mercury as it is anticipated that Mars and small bodies will be the focus of other presentations at this workshop.

Exploring the Solar System through sample return from the terrestrial planets: Numerous scientific problems that link the origin and evolution of terrestrial planets can be addressed through a progression of sample return missions to the inner Solar System.

Bulk Composition of the Planets: Test models of Solar System nebula and planetary accretion. Did a temperature gradient in the nebula led to differences in planets? How were water and other volatiles delivered to (and lost?) and stored in the terrestrial planets? Did accretion involve material throughout the inner Solar System? What is the role of giant impacts in the final composition of the terrestrial planets?

Primary Differentiation: Test models for planetary differentiation and establish timing of initial differentiation. Did all the terrestrial planets differentiate through a common process (magma ocean)? Was initial differentiation rapid or protracted?

Bombardment History of the Inner Solar System: Test the Cataclysm hypothesis [1] and thereby constrain the process (es) that led to the early heavy bombardment (e.g., Nice model [2]). Do the inner planets share an early bombardment history? What is the response of early planetary crusts and mantles to the early bombardment? What is the role of the bombardment history of the inner Solar System on the evolution of environments for early life and extinctions on Earth?

Magmatic and Thermal History: Test models for the magmatic and thermal evolution of terrestrial planets of different sizes. What are the structures, compositions, dynamics, and dynamical histories of planetary mantles? What is the composition and history of the crust of terrestrial planets?

Surface Processes: Test models for the evolution of planetary surfaces. How is the interaction between a planetary surface and space/atmosphere reflected in remote sensing measurements? How do planetary surfaces interact with exosphere/atmosphere?

Examples of Specific Planet Measurements: (1) Determine compositions precisely to infer bulk planet composition and hence test models for the solar nebula and planetary accretion (Mercury, Venus). (2) Determine ages and isotopic composition of basalts to help understand magmatic history, composition of the mantle, and timing of primary differentiation (Mercury, Venus, Moon). (3) Determine the volatile composition of basalts to understand planetary volatile reservoirs (Mercury, Venus, Moon). (4) Detailed microanalysis of regolith to understand solar wind-regolith and exosphere-regolith interactions (Moon, Mercury). (5) Detailed microanalysis of surface material and atmosphere to understand rock-atmosphere interactions (Venus).
(6) Determine the ages of large impact basins to test models of early bombardment (Mercury, Venus). (7) Determine the isotopic and chemical analysis of surface volatile reservoirs (Moon, Mercury).

Technology Investment and Capabilities: The price paid for the unique and valuable information offered by sample return is increased cost and risk relative to other types of missions. Sampling the inner planets in the Solar System presents technology challenges tied to their widely different and hostile surface environments. To conduct sample return missions from a wide range of planetary environments on a regular basis, cost and risk must be minimized. Rather than looking at sample return as single point missions, each requiring their individual technology development, it would be much more advantageous to examine sample return technologies as threads linking simple missions (both sample return and non-sample return missions) to more complex missions and include them at the onset or early in the development of an exploration strategy. This approach, which is not planetary body specific, would result in an evolving technological heritage and thereby reduce cost and risk in each subsequent sample return mission.

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Sample Return from the Moon's South Pole-Aitken Basin (SPA): Enabling Solar System Class Science and Sample Return Missions to Other Destinations. C.K. Shearer[1], B.L. Jolliff[2], L. Alkalai[3], D.A. Papanastassiou[3], P. Warren[4], M. Wieczorek[5] and the MoonRise Team. [1]University of New Mexico, Albuquerque, NM 87131 (cshearer@unm.edu); [2]Washington University, St. Louis, MO; [3]Jet Propulsion Lab, Pasadena, CA 91109; [4]UCLA, Los Angeles, CA 90024; [5]Institut de Physique du Globe de Paris, France.

Introduction: The Moon is an exceptional target for sample return (SR) because it is easily accessible, a witness plate for early Solar System events (e.g. impact history), preserves a record of early terrestrial planet processes that may be applicable to other planetary bodies (e.g. differentiation), exhibits an extended thermal and magmatic history of an evolving planet, and provides a near-Earth environment to demonstrate sample return technologies that may feed forward to more distant destinations and complex mission architectures. The Moon's SPA has been identified as a high-priority target for SR by numerous NRC reviews and NASA advisory committees. Here, we explore both the Solar System class science that can be accomplished with a SR mission from the SPA and illustrate how such a mission enables other SR missions to the Moon and beyond.

Exploring the Solar System through SPA-SR: A SPA-SR mission accomplishes science objectives that are important to establishing the chronology of events in the Solar System and understanding fundamental process that shape the evolution of the terrestrial planets, the present configuration of the Solar System, and the development of the Earth as an abode for life.

Determine SPA Basin chronology: As the largest and oldest clearly recognizable impact basin on the Moon, SPA basin harbors a record of the early cataclysmic bombardment of the Moon. Determining the chronology of the SPA basin will establish the impact history of the inner Solar System at a critical time in the evolution of early habitable environments on Earth and possibly Mars, and test the Cataclysm hypothesis thereby constraining the process(es) that led to the heavy bombardment (e.g., Nice model). Samples are needed to conduct the analyses of radiometric systems lithologic relationships of components that can resolve ages with accuracy to 10 Ma, to constrain unambiguously the early events.

Understand giant impact basin processes: The SPA basin is the only giant impact basin in the Solar System that we are able to study in detail due to its preservation and accessibility. Combining sample data and orbital remotely sensed data for SPA will enable tests of models for the response of the Moon's crust and mantle to a giant impact event and its subsequent evolution. Samples are needed to identify the sources of materials that were excavated by the SPA event and determine when it happened in order to understand the state and response of the crust resulting from the impact.

Investigate the crust/mantle transition: An SPA-SR mission will return material from a lunar terrane unsampled by previous lunar missions. Analysis of lower-crust and possibly upper-mantle components preserved in impact-melt rocks and breccias of the SPA enable assessing models for the origin, evolution, and diversity of the lunar crust. This investigation is fundamental to understanding processes at work during the differentiation and subsequent evolution of the terrestrial planets. Samples are needed to investigate the lithologic components contained in SPA materials, which are mixed and difficult at best to determine from orbit.

Determine the lithologic distribution of thorium (Th): In the terrestrial planets, slow decay of the naturally radioactive elements provides the heat to melt rock at depth and allows convection in a hot mantle. Deciphering the distribution of Th in the Moon and on its surface is important for understanding the early chemical differentiation of the lunar interior and the Moon's thermal evolution. Samples are needed to determine the lithologic hosts, sources, and distribution of the heat-producing elements.

Understand the far-side mantle through the use of mare basalts as mantle probes: Mare basalts are important because they represent materials produced by melting of the lunar interior. Basalts returned from SPA Basin can be used to determine the composition of the mantle from which the basalts were derived, as well as the depth and extent of melting. These results can be used to test a variety of models relevant to the primordial differentiation of the Moon, origin and nature of lateral asymmetry in the Moon's mantle and its relationship to the well-defined crustal asymmetry. Samples of basalt, including cryptomare and volcanic glasses, are needed to determine the chemistry, petrology, and history of the sub-SPA mantle.

SPA-SR Feeding Forward to other SR Missions: Developing an end to end flight system and the associated systems engineering experience of returning samples from the Moon as part of the New Frontiers MoonRise mission, represents a pathfinder for future sample-return missions from other planetary bodies.. Whereas each planetary destination has its own unique attributes, the MoonRise experience in sample acquisition and transfer and the Ascent Phase will be particularly applicable to other SR opportunities.

IMPROVING THE AQCUISITION AND MANAGEMENT OF SAMPLE CURATION DATA. N. S. Todd[1], C.A. Evans[2], and D. Labasse[3] [1]Jacobs Technology (NASA JSC, Mail Code KT, 2101 NASA Parkway, Houston, Texas 77058, nancy.s.todd@nasa.gov), [2]NASA (NASA JSC, Mail Code KT, 2101 NASA Parkway, Houston, Texas 77058 cindy.evans-1@nasa.gov), [3]Jacobs Technology (NASA JSC, Mail Code KX, 2101 NASA Parkway Houston, Texas 77058 dan.labasse-1@nasa.gov)

Introduction: This paper discusses the current sample documentation processes used during and after a mission, examines the challenges and special considerations needed for designing effective sample curation data systems, and looks at the results of a simulated sample result mission and the lessons learned from this simulation. In addition, it introduces a new data architecture for an integrated sample Curation data system being implemented at the NASA Astromaterials Acquisition and Curation department and discusses how it improves on existing data management systems.

Role of Data Management in Sample Curation: Data management is integral to successful sample curation. A sample curation data system must: document sample acquisition process and conditions during sample collection, provide a complete history of all data collected and all actions taken on a sample from the moment it is collected and throughout its lifecycle, provide all information needed about a sample to assist scientists in the selection of samples for future study, compile collection statistics that allow Curators and allocation committees to make decisions regarding the allocation and disposition of samples, and document allocation and analysis history of a sample.

Current Sample Curation Documentation Processes:

Sample Documentation During the Mission. During the Apollo missions, samples were documented through any of the following: photographic documentation of sample prior to collection in its native, photographic documentation of area of sample collection after specimen is removed, correlation of photo numbers to samples collected, documentation of collection conditions, locations, sample descriptions, and sample storage through transcripts of mission conversations, and tracking of samples through container numbers used for storage and transport.

During the unmanned Genesis and Stardust missions, samples data was collected prior to the mission through the documentation and tracking of collector materials, including photographic documentation. All other documentation occurred after the missions were completed.

Sample Documentation After Mission Completion. Existing data systems are mission-specific. Every sample collection is tracked in disparate data repositories that vary depending on the sample type. Access to data is done through different interfaces but each collection also contains data from common repositories. Some systems directly interface to the common data repositories while others rely on lab processors entering the appropriate data from the other systems. Collection metrics are generated using ad-hoc querying methods against data.

Important Considerations in the Design of Sample Curation Data Management Systems: In designing a new data and user interface architecture for documenting samples, there are many factors that need to be considered. Perhaps the most important is that data acquisition should start as early as possible to ensure data preservation and integrity. The recording of collection conditions is crucial because such conditions can help uncover relationships that would otherwise be hard to envision. For example, to properly study a sample, we need to be able to provide precise recording of time and location of sample collection, sample orientation, remarkable features, tools used, analyses performed, possible sources of contamination, and any other data compiled throughout a mission. In addition, ample photo documentation of the collection process is a must to maintain sample context information.

Proper sample management should include the ability to properly tag, store, and record all transactions. Also, data acquisition from lab equipment should be tightly integrated with the sample curation system. Data collection should be as unobtrusive as possible and well suited for the particular environment. Improving sample documentation workflows is a vital part of any new system design.

Architecture of an Integrated Sample Curation Data System: The design of an improved system for maintaining sample curation data will be discussed. The system is comprised of a modular implementation that separates common functionality and data repositories from collection specific functions, which are encapsulated outside these functional units so they can be changed depending of a collection's needs. The system would include data interfaces to lab equipment to allow for the automatic collection and processing of sample data with minimal intervention of lab processors. File handling modules allow users to upload, categorize, process and associate documents and photos to specific samples, including searchable image annotation. Built in data/document generation capability will produce all required data products from data repository.

GEOGRAPHIC INFORMATION SYSTEM FOR RETURNED SAMPLES: PLANNING, ORGANIZING, AND CORRELATING ANALYSES. A. Treiman, J. Gross, B. Fessler, C. Mercer. Lunar and Planetary Institute, 3600 Bay Area Boulevard, Houston TX 77058. <treiman{at}lpi.usra.edu>.

Sample returns are among the most important goals of NASA's Science Mission Directorate [1,2], based on the paradigm-shifting science from returned lunar and comet samples [3] and meteoritic planetary samples [4]. Returned samples in the near future are likely to be small, and it will be crucial to organize and coordinate analyses of many sorts by many laboratories on the same samples.

Geographic Information Systems, GIS, provide a convenient platform for organizing, planning, and correlating the many sorts of analyses that can be done on sample surfaces (e.g., thin sections), including: optical & NIR, Raman, fluorescence, XRF, EMPA, X-ray absorption, EBSD, XRD, SIMS, LA-ICPMS, magnetization, etc. GIS has been used occasionally for rock surfaces, mostly for quantitative textural analysis (e.g., [5]). GIS has been applied only once as an organizational framework for thin section data [6].

Sample and Methods: We used ArcGIS 9.3.1 [7], with distances are real units, and coordinate system set to 'Unknown.' Input data includes images and mosaics from: optical microscopy, back-scattered electrons (BSE), and emitted X-ray intensities at characteristic $K\alpha$ wavelengths. The latter were obtained at Johnson Space Center, with their Cameca SX-100 microprobe and JEOL 7600 FEG-SEM.

For proof of concept, we chose thin section 9 of lunar highland meteorite ALHA 81005 [8,9] (Fig. 1), a highlands regolith breccia. We focused on two troctolitic rock fragments, one rich in Mg-Al spinel [9,10].

GIS Implementation: Thin section data were organized into a GIS file (Fig. 2), registering images from the several methods. Data on clasts were similarly co-registered and linked to their locations in the thin section. Locations of quantitative EMP analyses were annotated onto the clasts' BSE frames. Quantitative data and derived parameters (e.g., Mg#) were imported into the GIS, and were linked to external files of meta-data.

Advantages: The GIS format has strong advantages for collection and interpretation of data, on small samples, by multiple methods and analysts. GIS provides a common platform for locating and reporting analyses – interesting areas can be re-occupied, repetition avoided, and degraded areas marked. Further, the GIS format allows ready comparison of data taken by many methods and for spatial interpretations of those data. For instance, one could ask how the locations of macromolecular carbons (of a particular crystallinity) are spatially related to excursions in the Li isotope ratio, and Mg# and Fe^{3+}/Fe^{2+} in adjacent silicate minerals. This ability to compare and analyze disparate datasets will lead to more robust interpretations of the histories and origins of returned planetary samples.

We are grateful to D. K. Ross and A. Peslier for assistance with X-ray maps and quantitative analyses.

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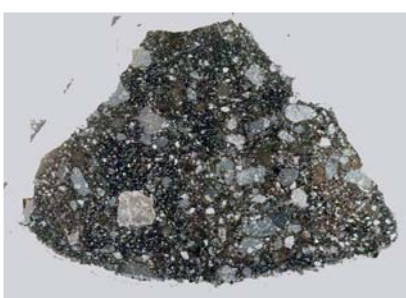

Fig. 1. Transmitted light microscope mosaic of thin section ALH81005,9. ~2 cm across.

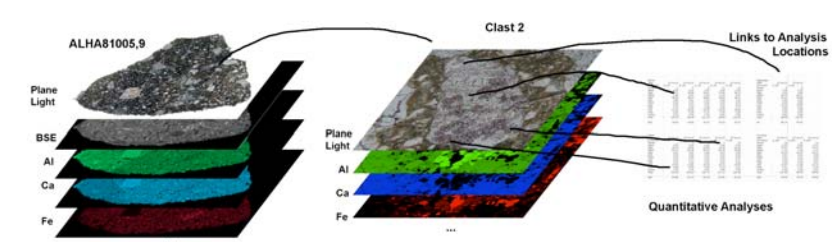

Fig. 2. Generalized structure of GIS file for rock sections. Colors arbitrary, and not inherent to the GIS. Data on individual clasts (like Clast 2, a spinel troctolite [9,10]) is linked to their locations in the full thin section. Analyses locations are annotated onto the clast image, and linked to the data (in ArcGIS) and to meta-data in external files.

POST-CURATION PRESERVATIONAL BIASES AFFECT EVAPORITE MINERALS IN MARTIAN AND ASTEROIDAL METEORITES: A CASE FOR SAMPLE RETURN AND STRICT ENVIRONMENTAL CONTROLS. M. A. Velbel, Department of Geological Sciences, Michigan State University, East Lansing, MI 48824-115 U.S.A. e-mail: velbel@msu.edu.

Introduction: Meteorites are naturally delivered samples from a variety of parent bodies throughout the solar system [1]. Soluble mineral products of aqueous alteration (e.g., carbonates, sulfates, and halides) occur in several classes of meteorites and provide evidence for various aspects of the presence and nature of water at different episodes in Solar System evolution. However, some minerals are so reactive in the presence of water (even as vapor) that even exposure to water in ostensibly dry environments (including laboratory atmosphere) results in elemental mobilization and formation of secondary minerals (usually evaporites) [2-4]. Consequently, these same minerals are highly vulnerable to modifying processes upon arrival at Earth. Achondrites from Mars, and chondrites from small primitive, undifferentiated asteroidal parent bodies, have been shown to have been affected by redistribution of soluble minerals after recovery, during curatorial storage and processing. This contribution reviews published accounts of these phenomena, and briefly explores their implications for sample return.

Evaporite minerals on Antarctic stony meteorites: Two generations of hydrous Mg-carbonates occurred as effloreceescneces on the Antarctic ordinary chondrite find LEW 85320 [2,3]. The first was present in the field when the meteorite was collected, the second appeared during curatorial storage [2,3].

Meteorites collected by the U.S. Antarctic Search for Metorites (ANSMET) program are assigned a weathering category that includes an indication of whether evaporite efflorescences were observed by unaided eye during collection and/or curation [4]. Examination of the geographic and temporal distiribution of evaporites in the ANSMET collection reveals that a larger proportion of samples collected in 2003 had evaporites than the averages for the same collecting areas over the entire duration of the ANSMET program [5]. However, meteorites collected during the 2003 season were stored in a freezer that experienced a loss of power [5]. One specific consequence noted by the curatorial staff was the appearance of evaporites [5]. Thus, the higher-than-field-average evaporite abundances for 2003 acquisitions are almost certainly due to the laboratory environmental-control failure, and not to unique field conditions in collecting year 2003.

Evaporite minerals in and on Mars meteorites: Some of the inventory of halite in Nakhla (fall) is known to occur in fractures and vugs in the fusion crust and therefore post-dates Earth arrival [6]. Elemental redistribution and formation of halite has occurred during curatorial exposure of the ANSMET Mars meteorite find ALH 84001 to laboratory-atmosphere fluctuations in relative humidity [7].

Evaporite minerals in and on carbonaceous chondrites: "Weathering" in the curatorial environment has been documented for falls of several C chondrite groups. Sulfate minerals have been redistributed, apparently by exposure to moisture in laboratory atmosphere, during curation of Orguiel (CI) [8]. Carbonate minerals have been similarly redistributed during curation of Vigarano (CV3) [9].

Summary: Curatorial redistribution of soluble minerals and their constituent elements and isotopes complicates the interpretation of these minerals and their significance for pre-terrestrial aqueous alteration on both primitive and differentiated parent bodies. Acquisition of samples directly from their parent bodies, without the intermediate mineral-modifying processes that affect meteorites, would improve scientific understanding of aqueous-alteration phenomena. However, intentionally returned samples containing soluble minerals would be just as vulnerable to post-acquisition modification of their indigenous inventory of soluble minerals as are meteorites.

Low-preservation potential aqueous alteration features (e.g., evaporite minerals in their indigenous hydration states) will not survive intentional excursions of T and r.h. during thermal sterilization for planetary protection, or excursions in which environmental controls for the sample-return container and curatorial process are either limited by design or fail. Temperature and relative humidity must be strictly controlled during sample return missions, including curation and examination, if preservation of soluble and hydrated minerals in their indigenous hydration states and textures is a goal of sample return.

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Sample Return Propulsion Technologies under the NASA SMD In-Space Propulsion Technology Project.
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Abstract: In 2009, the In-Space Propulsion Technology (ISPT) program was tasked to start development of propulsion technologies that would enable future sample return missions. Sample return missions can be quite varied, from collecting and bringing back samples of comets or asteroids, to soil, rocks, or atmosphere from planets or moons. Given this new focus, the future technology development areas for ISPT are: 1) Sample Return Propulsion (SRP), 2) Planetary Ascent Vehicles (PAV), 3) Multi-mission technologies for Earth Entry Vehicles (MMEEV), and 4) Systems/mission analysis and tools that focuses on sample return propulsion. Sample Return Propulsion is further broken down into: a) Electric propulsion for sample return and low cost Discovery-class missions, b) Propulsion systems for Earth Return Vehicles (ERV) including transfer stages to the destination, and c) Low TRL advanced propulsion technologies. The SRP effort will continue work on High-Voltage Hall Accelerator (HIVHAC) thruster development in FY2010. Then it transitions into developing a HIVHAC system under future Electric Propulsion for sample return (ERV and transfer stages) and low-cost missions. Previous work on the lightweight propellant-tanks will continue under advanced propulsion technologies for sample return with direct applicability to a Mars Sample Return (MSR) mission and with general applicability to all future planetary spacecraft. The Aerocapture efforts will merge with previous work related to Earth Entry Vehicles and transitions into the future multi-mission technologies for Earth Entry Vehicles (MMEEV). The Planetary Ascent Vehicles (PAV)/Mars Ascent Vehicle (MAV) is a new development area to ISPT. It builds upon and leverages the past MAV analysis and technology developments from the Mars Technology Program (MTP) and previous MSR studies. This paper will describe the ISPT project's future focus on propulsion for sample return missions.

TO BRING BACK THE NEEDLES FROM A HAY STACK – SELECTING SAMPLES DURING MARS SURFACE EXPLORATION AND MONITORING SAMPLE STATUS DURING THE RETURN TO EARTH. Alian Wang, Dept. of Earth and Planetary Sciences and the McDonnell Center for the Space Sciences, Washington University in St. Louis (One Brooking Drive, St. Louis, MO, 63130, alianw@levee.wustl.edu).

Sample Selection: Observations during the recent exploration of the martian surface (Mars Exploration Rovers and Phoenix lander) demonstrated that the surface materials are spatially heterogeneous at a very local scale [1, 2,] (Figure 1a & 1b). With severe limitation on total mass of samples for return, careful selection of the spot (on rock or in regolith) where the sample will be taken is absolutely essential, i.e., selecting a few shining needles from several hay stacks at a few representative locations.

Fig. 1a. Mazatzal rock in Gusev crater after RAT. Light-tones materials are shown in the vein across the RAT hole and in clusters.

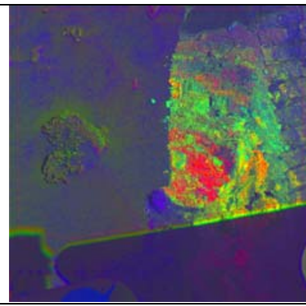

Fig. 1b. Decorrelation stretch of a Pancam image cube to emphasize the spatial heterogeneity of salty soils at Dead Sea area in Gusev.

Sample selection should be based on knowledge of the chemistry and mineralogy (and potential for biosignatures for MSR) of the sampling spots. *The technical tools that inform the sample selection should be non-destructive.*

Sample status monitoring: Similar observations (MER and Phoenix) have also demonstrated that subsurface materials are not necessarily in equilibrium with the current surface atmospheric conditions. For example, dehydration occurred after the excavation of sulfate-rich subsurface regolith at Gusev [3]. Phase transitions may also occur during the transit to Earth (including the materials that may host biosignatures). Laboratory simulation experiments confirm the potential for phase transitions under conditions relevant to handling of planetary subsurface materials (especially the secondary mineral phases [4, 5, 6, 7, 8]).

To understand potential changes that may occur between the in-situ characterization of the collected samples and later terrestrial laboratory investigations, it is desirable to have a means to monitor the integrity and status of collected samples at several critical stages during the long chain of their collection, storage, in transit to Earth, and prior to opening containers [Fig. 2, at minimum, after the first and before the last stages].

The technical tools for such monitoring should be nondestructive, and, especially, to be non-invasive, i.e., should not break the seals of sample containers.

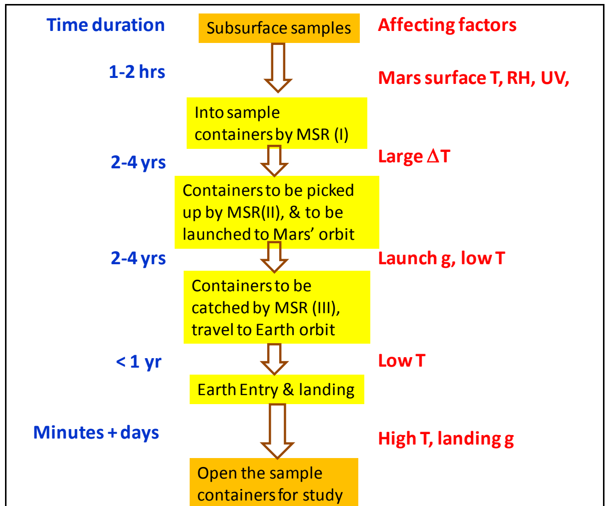

Figure 2. critical stages through a three steps Mars' sample return mission (time duration and affecting factors).

Planetary *in situ* Laser Raman Spectroscopy is a molecular spectroscopy working in the visible spectral range. It provides identification and characterization of molecules (organic and inorganic) or solid materials (minerals and amorphous). The method is non-destructive, molecular vibrations (not vaporization) is used. It is also non-invasive, the excitation laser beam and the induced Raman photons both penetrate through an optically transparent window on a sample container.

The flight model, *Mars Microbeam Raman Spectrometer (MMRS)*, has high TRL and was ranked category one during the MSL payload review. It is an *in situ* Raman sensor deployed by robotic arm, and will make mineralogy (or molecular) characterization of the samples at mm to cm scale. Its detailed application for the sample selection at the planetary surface and for the monitoring of the sample status during its journey back to Earth will be discussed at the workshop.

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PALEOMAGNETIC STUDIES OF RETURNED PLANETARY SAMPLES. B. P. Weiss[1], [1]Department of Earth, Atmospheric and Planetary Sciences, Massachusetts Institute of Technology, 54-814, 77 Massachusetts Avenue, Cambridge, MA 02139, bpweiss@mit.edu

Science from paleomagnetic studies: When magnetic minerals crystallize, cool, or are aqueously deposited in presence of a magnetic field, they will magnetize in the direction of the local magnetic field with an intensity that scales with the field intensity. As a result, paleomagnetic studies of rocks yield two main pieces of information: the *paleointensity* and the *paleodirection* of past fields.

Because the original orientations in which all meteorites and returned lunar samples acquired their magnetizations are unknown, all paleomagnetic studies to date on extraterrestrial materials have only been able to infer the field paleointensity. *By comparison, paleomagnetic studies of returned, oriented samples afford: (1) the first opportunity to infer the paleodirection of extraterrestrial paleofields; (2) geologic context; (3) the opportunity to obtain semicontinuous time sequences of paleomagnetic measurements; (4) measurements of samples unaffected by shock processing associated with planetary ejection of meteorites.*

1-3. Paleodirectional data, geologic context, and time sequences. Oriented, stratigraphically bound sample suites from known geologic locations could be used for three very important investigations: a) testing whether ancient magnetic fields were due to a core dynamo or other postulated field sources, b) characterizing the temporal behavior of any dynamo and c) chronicling local and planetary scale tectonics. Similar datasets from Earth rocks played key roles in establishing the plate tectonics hypothesis, the magnetostratigraphic timescale, and understanding the geodynamo.

a) It is thought that dynamos once operated on Mars [1] and possibly the Moon [2] and asteroids [3]. These putative dynamos have critical implications for planetary thermal evolution and differentiation, the nature of chondrite parent bodies, and the evolution of planetary atmospheres. However, a key alternative hypothesis for planetary paleomagnetism is that it is the product of fields generated by impact-produced plasmas [4]. The dynamo and impact hypotheses can be directly distinguished using paleodirectional data: oriented rocks of similar ages magnetized by an axial geocentric dynamo like that of the Earth should have average magnetization pointing to either spin paleopole with inclination given by a characteristic latitudinal dependence, while magnetization from impact-produced fields should be random or at least extremely nondipolar on a global scale.

The paleomagnetism of some chondrites has traditionally been ascribed to external magnetic fields like the protoplanetary disk [3, 5]. The latter fields are thought to have played an essential role in mass and momentum transfer. However, it has recently been suggested that the paleomagnetism of at least CV carbonaceous chondrites is from a core dynamo on a partially differentiated parent body [5]. Analyses of oriented samples could resolve this debate.

b) Measurements of sequences of oriented samples from stratigraphically bound sections can be used to infer the secular variation and reversal frequency of the field. These data can constrain the nature of core convection, the mechanism of field generation, and possibly the age of any solid inner core [e.g., 6]. Furthermore, both oriented and unoriented samples can yield the paleointensity of the ancient field through time, which would indicate when the field was active.

c) Measurementes of oriented samples can be used to test the hypothesis that body has experienced plate tectonics, local tectonics, and/or true polar wander.

4. Lack of shock effects. Nearly all lunar and Martian meteorites appear to have been shocked above ~15 GPa during ejection from these bodies [8]. Because even weak (< 1 GPa) shocks can remagnetize rocks [3], returned samples could be more pristine than the meteorite suite.

Sampling and curation strategy. *The ideal targets for paleomagnetic studies are oriented samples taken from coherent bedrock with well-defined paleohorizontal indicators.* Samples should be orientated with respect to the global planetary coordinate system and to vertical. Samples should ideally not be heated above ambient temperatures and not be exposed to fields greater 100 μT. The latter requirement can be fulfilled if the samples are shielded inside of a high magnetic permeability container for the return trip to Earth. On Earth, samples should be stored in a magnetically shielded environment to prevent remagnetization in the Earth's field.

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THE NEXT ASTREOID SAMPLE RETURN MISSION OF JAPAN - HAYABUSA-2. M. Yoshikawa[1], [1]Japan Aerospace Exploration Agency, 3-1-1 Yoshinodai, Chuo-ku, Sagamihara-shi, Kanagawa 252-5210, Japan, e-mail: yoshikawa makoto@jaxa.jp.

On June 13, 2010, Hayabusa spacecraft finally came back to the earth and it returned the capsule on the earth safely. Later we found the material from Itokawa, although the amount of the material is quite small. Hayaubusa has a quite dramatic story and we had a lot of experiences about planetary mission. And now we have proposed Hayabusa follow-on mission, Hayabusa-2. It is an asteroid sample return mission again, but the type of the target asteroid is C-type, which is different from the target of Hayabusa, Itokawa (S-type). The scale of the spacecraft is similar to Hayabusa, but many parts will be modified so that we will not have the troubles that we experienced in Hayabusa. Also the spacecraft has new equipment, which is called impactor. The impactor will make an artificial crater on the surface of the asteroid, and we will try to get the sample inside the crater. Then we can get much fresh material. The planned launch year is 2014 or 2015, arriving at the target asteroid 1999 JU3 in 2018, and coming back to the earth 2020. In this paper, we present the current status of Hayabusa-2 mission.

THE IMPORTANCE OF SAMPLE COLLECTION STRATEGY AND CURATION IN PLANETARY SURFACE EXPLORATION. K. E. Young[1], K. V. Hodges[1], and C. Evans[2], [1]School of Earth and Space Exploration, Arizona State University, Tempe, AZ 85287. Kelsey.E.Young@asu.edu [2]Johnson Space Center, Houston, TX, 77058.

Introduction: As humans prepare themselves to once again explore other planetary surfaces, technology must be developed to support this new phase of exploration. While curation policies and procedures once the samples have been returned to Earth are a crucial part of sample acquisition, another important step is the high-grading and curation of samples by humans or robots while on a planetary surface. Technologies must be developed and tested now so future generations of explorers are ready when the next step of exploration takes place. We are investigating technologies such as a handheld spectrometer as well as a habitat laboratory for humans to use to process samples while in the field.

Handheld Spectroscopy:

Technology Overview: Conducting field geology on Earth often involves return trips to one field area as the observer develops multiple working hypotheses that seek to explain the area's geologic history. Terrestrial geologists seeking to evaluate a unit's geochemistry often collect samples from the field to analyze in research laboratories. Planetary explorers will likely not have the chance to return to their sampling locations, so having real-time access to compositional data is key in developing hypotheses that would potentially impact the rest of the traverses in one surface excursion.

Field Testing of Technology: We have been developing the use of handheld x-ray fluorescence (XRF) technology to use as a planetary field tool. We have deployed this technology in three different modalities. The XRF was placed on a reconnaissance robot (the K10 robot developed by the Intelligent Robotics Group at NASA Ames) in order to evaluate its effectiveness on a robot operating remotely on another surface. The XRF was also evaluated in a habitat lab setting in NASA's Desert Research and Technology Studies (D-RATS) field test. Astronauts simulating a 14-day traverse to a planetary surface traveled in two habitat rovers across a volcanic field, collecting samples and making initial interpretations about the geologic history of the region. Following their traverses, they ran selected samples through instruments in this habitat lab in order to choose which samples should be returned to Earth. Lastly, we are developing this technology in a handheld modality in order to test its effectiveness on an extravehicular activity (EVA), or spacewalk.

Sample High-Grading and Curation: The future of planetary surface exploration will most likely involve long-term habitation of other planetary bodies. We will have the opportunity for astronauts to bring samples back from these bodies for geologists on Earth to analyze. In order to select the most scientifically diverse collection of samples to return to Earth, strategies for sample collection will have to be developed. The D-RATS field test is already evaluating these strategies to determine how to best train astronauts in sample collection. This test places one trained field geologist and one astronaut in each habitat rover to allow for the maximum amount of experience in both science and mission operations. Each EVA is carefully planned between the crewmembers to make sure all local units are analyzed and sampled and any key observations are noted and recorded. This data acquisition process is a crucial part of any sample return from other planetary bodies and must be examined and tested before humans once again return to planetary surfaces.

Preserving the motivation behind each sample collection while in the field is crucial in preserving the development of each traverse in the area. The sample must then be processed and transferred to the case in which it is returned to Earth. The D-RATS mission field tests the Pressurized Excursion Module (PEM), a habitat laboratory designed to initially process collected samples and prepare them for return. The GeoLab, or the unit of the PEM that deals solely with scientific pursuits, contains a handheld XRF and macro- and microscopic imagers with which astronauts can assess the samples on the surface of interest before prepping them for return. If the astronauts discover that many of the collected samples are similar geochemically, they can high-grade this collection to ensure the geologic diversity of all samples returned to Earth. This additional curation step while on the surface will yield greater scientific return than with the lack of initial sample processing.

Conclusions: The development of mature sample collection strategies, as well as the initial assessment and curation of collected samples on a planetary surface, is key if the next generation of planetary explorers hope to make the most of traverses conducted on the Moon, Mars, or an asteroid. The work discussed in this abstract helps to develop these strategies by deploying technologies in the NASA D-RATS field test. The results that will be discussed highlight the importance of training and preparation for the next round of sample returns from another planetary body.

LESSONS LEARNED FROM THREE RECENT SAMPLE RETURN MISSIONS. M.E. Zolensky[1] and S.A. Sandford[2], [1]ARES, NASA Johnson Space Center, Houston, TX 77058, USA (michael.e.zolensky@nasa.gov), [2]M/S 245-6, NASA Ames Research Center, Moffett Field, CA 94035, USA.

Introduction: We share lessons learned from participation on the Science Teams and Recovery/Preliminary Examination/Curation teams for three recent sample return missions: (1) the Long Duration Exposure Facility (LDEF), which returned to Earth with interplanetary dust and spacecraft debris particles in 1990 [1], (2) the Stardust Mission, which returned grains from comet Wild-2 and fresh interstellar dust to Earth in 2006 [2], and (3) the Hayabusa Mission, which returned regolith grains from asteroid Itokawa in 2010 [4].

Sample Contamination Issues: For Stardust and Hayabusa, especially, contamination control procedures were integral to flow of spacecraft manufacture, assembly, testing, flight and recovery. The science teams took a very active role in planning and implementing contamination control measures. We monitored contamination through numerous witness materials, which were all archived for later analysis. However, despite these precautions the Stardust spacecraft outgassing was sufficient to degrade camera operations, and the aerogel capture media was significantly contaminated during manufacture. We also never completely solved the problem of defining useful limits for organic contaminants of spacecraft hardware, which haunts us as we rather unexpectedly captured primitive cometary organics. It is critical to devise improved contamination control efforts. It is also critical to appoint contamination control leads from within the mission team for the lifetime of the mission. The mission team should also prepare for the mission to be more successful then is generally anticipated.

Spacecraft Recovery Operations: The mission Science and Curation teams must actively participate in planning, testing and implementing spacecraft recovery operations. The Genesis crash underscored the importance of thinking through multiple contingency scenarios and practicing field recovery for these potential circumstances. Having the contingency supplies on-hand was critical. A full year of planning for Stardust and Hayabusa recovery operations was insufficient, adding strain to the field teams. Care must be taken to coordinate recovery operations with local organizations and inform relevant government bodies well in advance .Recovery plans for both Stardust and Hayabusa had to be adjusted for unexpectedly wet landing site conditions. Documentation of every step of spacecraft recovery and deintegration is necessary, and collection and analysis of landing site soil was critical. The recovery of LDEF by the Space Shuttle was bungled, severely degrading the science return from the mission – concerns for human comfort outweighed important LDEF mission goals. We found the operation of the Woomera Text Range (South Australia) to be very robust in the case of Hayabusa, and in many respects we prefer this site to the domestic Utah Test and Training Range (used for Stardust). Recovery operations for all three spacecraft significantly suffered from the lack of a hermetic seal for the samples, probably in many additional ways which will only become apparent in the future. Mission engineers should be pushed to true seals for returned samples.

Sample Curation Issues: Many Curation issues are treated by Carl Allen's abstract for this meeting [3], but we can make additional suggestions. More than two full years were required to prepare curation facilities for Stardust and Hayabusa. Despite this seemingly adequate lead time, major changes to curation procedures were required once the actual state of the returned samples became apparent. Two years of Curation preparation are insufficient. The sample database must be fully implemented before sample return – for Stardust and LDEF we did not adequately think through *all* of the possible sub-sampling and analytical activities before settling on a database design. Also, analysis teams must not be permitted to devise their own sample naming schemes. Remote storage of a sample subset is critical.

Preliminary Examination (PE) of Samples: There must be some determination of the state and quantity of the returned samples, to provide a necessary guide to samples requesters and the inevitable oversight committee tasked with sample curation oversight. Sample PE must be designed so that late additions to the analysis protocols are possible, as new analytical techniques become available. We prefer an inclusive PE with in-depth investigation of a limited, but representative, subset of the returned samples (<10%). By being as inclusive as possible during PE information return was maximized and a broader community become acquainted with both the scientific value and problems associated with the samples in the shortest possible time

References: [1] Zolensky M.E. et al. (1991) The Journal of Spacecraft and Rockets, 28, 204-209; [2] Sandford S.A. et al. (2010) *Meteoritics and Planetary Science* **45**, 406-433; [3] Allen C. et al. (2011) This meeting; [4] Please see numerous LPSC 2011 abstracts.

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