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Role of sample return and sample science in low cost missions

Eileen K. Stansbery*, David S. Draper

NASA, Johnson Space Center, Astromaterials Research and Exploration Science, Mail Code KA, 2101 NASA Parkway, Houston, TX 77058, USA

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ABSTRACT

Sample return is an essential component of solar system exploration. Samples provide a unique data set that is critical for understanding formation and evolution of our solar system. This uniqueness is based on the scale of observations, precision of measurements, the ability to modify experiments as logic and technology dictate, and the ability to use instruments free of the constraints on mass, power, reliability, and data rate of flight instruments. Advances in analytical capabilities in recent years enable fundamental measurements to be made on extremely small samples, greatly reducing mass constraints on robotic sample return spacecraft. Sample studies provide irreplaceable ground truth for remotely-sensed data on planetary surfaces and fit within a variety of architectures for human exploration of the solar system.

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1. Introduction

Sample return missions enhance the understanding of our solar system acquired with fly-by, orbital, or surface missions, by bringing material from another planetary body to study on Earth. The ability to perform analyses in well equipped terrestrial laboratories enables scientific progress not possible with analyses performed in situ during a mission. These include, but are not limited to, much higher precision, replication of results, investigations at very small scales (down to nanometers), sample manipulation capability, and the ability to modify analytical experiments as logic and technology evolves. Analysis of returned samples contributes fundamental chronological and geochemical ground truth of planetary materials that enhances the value of both remotely sensed and surface observations beyond their stand-alone importance. Further, sample return is a critical component of the human exploration program for human health and safety issues as well as resource detection and characterization. The price paid for this unique and valuable information is often an increased cost and risk relative to other types of missions. To conduct sample return missions from a wide range of planetary bodies (Moon, Mars, asteroids, comets, planetary satellites, and Venus) on a regular basis, these factors must be minimized [1].

Many aspects of solar system exploration are enabled by detailed sample analysis such as: understanding the bulk composition and structure of planets, the nature of planetary accretion and origin of a planet's water reservoirs, the nature of primary planetary differentiation, the magmatic and thermal history of a body, early solar system bombardment, and surface processes (e.g. weathering and space weathering) [2].

1.1. Importance of sample return

Sample return missions provide a large science return on investment enabling the analysis of detailed material properties (isotopic, chemical, mineralogical, etc.) that record processes and events in solar system formation and evolution. With proper long-term curation, samples are available for analysis in the future when new questions arise. Because they are available essentially indefinitely, analysis can be iterative and not limited by preconceived ideas.

One of the chief concerns in low-cost missions is the development of advanced instrumentation for the science payload. For sample return missions not all of the instruments

* Corresponding author. Tel.: +1 281 483 5540; fax: +1 281 244 8892.
E-mail addresses: eileen.k.stansbery@nasa.gov (E.K. Stansbery), david.s.draper@nasa.gov (D.S. Draper).

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must fly; most of the analytical muscle applied to a mission can remain on Earth unconstrained by mass, power, volume, data rate, and other flight mission concerns. The mission is also not required to have all its ground based analytical instruments qualified at the mission Critical Design Review, unless it is needed during the flight portion of the mission to assist in interpreting flight data. In addition, whenever better instruments are developed, they can be used on curated samples.

The *raison d'être* for planetary missions is to answer scientific questions about our solar system; to interpret measurements. A key benefit of terrestrial laboratory analysis of returned samples is the ability to replicate results. Important, unexpected, or ambiguous results can be verified by independent experimental techniques and independent laboratories. Another advantage is that large numbers of scientists get a chance to participate usefully in mission data analysis.

NASA's Administrator Bolden challenges the Science Mission Directorate to "do the ***best*** science, not just more science," in the Agency goal for planetary science to ascertain the content, origin, and evolution of the solar system and the potential for life elsewhere [3]. Investing in sample return missions as a complementary piece of a diverse exploration and science mission portfolio specifically responds to this direction.

1.2. Science and exploration

From the perspective of understanding the Universe in general and our solar system in particular, the terms *science* and *exploration* have extremely similar definitions and the practical relationship is tightly coupled. Robotic and human exploration missions ultimately comprise significant components associated with performing scientific measurements even though they may also include technical capability development.

Science investigations have a major role in providing the data needed to make human exploration safer, sooner and more capable, in addition to answering fundamental scientific questions. In particular, there are detailed analyses necessary to prepare for human exploration missions that are best addressed by samples. Some human health issues such as dust toxicity can be addressed only through laboratory studies. Studies sponsored by the Lunar Airborne Dust Toxicity Advisory Group (LADTAG) [4,5] and NASA's Human Research Program [6–10] have expanded beyond investigating airborne lunar dust and its toxicity to the respiratory system to include dermal toxicity (skin irritant/allergic responses, and abrasion effects including issues associated with the breach of dermal water barrier) and ocular toxicity (eye irritant/allergic responses, and abrasion effects, including scratches and particle embedding) [11,12]. Effects of dissolution of lunar dust on toxicity in human systems, as well as development of acute and chronic (time based) exposure limit standards for inhalation (pulmonary) toxicity and human risk criteria, require Earth-based laboratory investigation based on detailed understanding of the chemistry and surface characteristics of lunar material.

In addition to investigations necessary to assess human health and safety issues, the development of engineering for specific environments requires detailed understanding of planetary materials. Sample analyses are sometimes the only means to resolve certain kinds of material compatibility and interaction effects. Of particular interest for lunar exploration are abrasion issues arising from the characteristics of surface dust deposits, such as sharp edges formed from bombardment by meteorites; these sharp edges never wear down in the airless lunar environment [13].

2. Sample science

Unlike the Apollo missions to the Moon, robotic sample return missions, especially low-cost missions, will likely result in the return of relatively small samples. Recent advances in analytical instrument resolution and nanoscale material handling techniques demonstrate that small sample size and mass need not equate to small science return [14–17]. On the contrary, dozens of recent publications, by many research groups both within NASA and from academia, have shown that these small samples allow scientists to peer into the earliest history of the solar system. However, any returned samples are scientifically more valuable when they can be placed within a planetary geologic context through orbital observations and when information concerning planetary-scale processes and conditions can be extracted from them. Conversely, samples give remotely sensed data ground truth. That is, they act as a "calibration standard" for these data allowing a much more comprehensive global view to be constructed.

2.1. Depth of scientific understanding

Research on lunar samples illustrates how information can be extracted from small samples and then extended to planetary and solar system scales. Multi-analytical and experimental studies of small (10–500 μm) glass beads representing near-primary magmas provide constraints on the composition and condition of the lunar mantle, the style of early planetary differentiation, the history and character of early mantle dynamics and melting, and the isolation of the lunar mantle from late-stages of lunar accretion. Trace element analysis of individual mineral grains via ion microprobe and isotopic analysis of small rock fragments representing some of the oldest and youngest periods of lunar magmatism can be used for both fingerprinting distinct episodes of lunar magmatism and reconstructing their evolutionary sequences. In addition, mechanisms for primitive planetary mantle degassing and volatile transport on airless bodies can be understood by the analysis of volatile coatings on glass and mineral fragments in the lunar regolith [18].

The ability to distinguish among rock types of similar bulk compositions and mineralogy but with different origins requires textural and mineralogical imaging with spatial resolution of 1–100 μm. A lithology with a basalt chemistry and mineralogy could potentially represent a product of mantle melting, impact melting, or brecciation. Therefore, the precisely determined radiometric age could represent an age of crystallization, impact, or reflect a mixing process that has no chronologic significance.