SAMPLE RETURN FROM HUMAN EXPLORATION OF NEAR EARTH OBJECTS: RATIONALE AND RECOMMENDATIONS

A white paper submitted to the Human Architecture Team in the Human Exploration and Operations Mission Directorate, NASA HQ by the Curation Analysis and Planning Team for Extraterrestrial Materials (CAPTEM).

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Introduction

Future human missions to near-Earth objects (NEOs) will offer exceptional opportunities to study these bodies and to better understand the history of the Solar System. The properties and origins of NEOs will be determined by a combination of remote spacecraft observations, human exploration, and analysis of returned samples.

Motivation for sample return

Sample return from asteroids and comets is scientifically compelling. Our understanding of the origin and history of the Solar System is largely based upon laboratory studies of meteorites that are predominantly samples of asteroids. Studies of meteorites have revealed the age of the Solar System, the timescales of planetary accretion and differentiation (Wadhwa & Russell 2000), the lifetime of the solar nebula (Huss et al. 2001), the nature of primordial organic matter (Pizzarello et al. 2005), the bulk composition of the Solar System for nonvolatile elements (Anders & Grevesse 1989; Palme & Jones 2003), and even intact samples of interstellar materials and stardust (Zinner 2004). Asteroids also have importance for astrobiology, as important sources of water and complex organics to the early Earth.

Sample return missions complement astronomical observations and spacecraft rendezvous. Remote sensing is used to determine the global properties of asteroids, and reveal subpopulations and compositional classes. Spacecraft rendezvous can globally survey individual objects, reveal planetary scale compositions, and their dynamical histories. But, sample return brings the ultimate level of detail. Once returned to Earth, there is no restriction on size, complexity or cost of scientific apparatus and samples can be studied by multiple instruments of a size and complexity that are impractical to carry on spacecraft. Samples can be preserved for future generations of scientists, who may have new ideas and improved analytical techniques. Sample return is necessary for certain types of studies that simply cannot be done in another way, such as identifying minor mineral components, describing petrographic relationships, measuring precise isotopic ratios, detailed molecular studies of organic matter, determination of ages and timescales for various processes, and establishing links between spectral features and material properties. These types of measurements are integral to unraveling the complex histories of these bodies and, therefore, of the Solar System.

Science goals for asteroid sample return

There is a strong need to obtain pristine surface samples of well-characterized asteroids to understand the mechanisms and material effects of space weathering. This knowledge would act as a firm anchor for spectral interpretation of the mineralogy, chemistry, and interrelationships of thousands of asteroids. Second, in situ collection from a carbonaceous asteroid would provide a truly clean (uncontaminated) sample of the solar system's primordial organic matter. While meteoritic organic matter has been studied extensively, these investigations are limited by uncertainty about the extent and nature of terrestrial contamination. Third, obtaining material from asteroids in a variety of orbits would allow measurement of the radial distribution (from the Sun) of key parameters for models of the evolving solar nebula; these parameters include the bulk oxygen isotopic composition, the abundance of volatile elements, the oxidation state, and the surviving fraction of presolar materials.

Scientific questions to be addressed by asteroidal sample return include:

- How is space weathering manifested in asteroidal surfaces?
- What is the origin and evolution of organic matter in the solar system?
- How did high temperature phases and delicate presolar materials come to coexist in meteorite matrices?
- What were the thermal processes that gave rise to refractory inclusions and chondrules found in primitive meteorites?
- What is the origin of the oxygen isotopic variability among planetary materials?
- What is the nature and extent of water-rock interactions on asteroids and is this sensitive to location in the asteroid belt?
- How similar are 'active' asteroids to comets?
- What are the origins of short-lived nuclides in the early Solar System?
- How do specific asteroids compare with meteorites already in our collections?

Protocols for asteroid sample handling during human missions to NEOs

The scientific value of the returned asteroidal samples will be strongly affected by how and where they are collected and how they are subsequently stored. In order to preserve the integrity of the samples and to maximize the scientific return from these missions, the samples should be selected, acquired, and stored according to the following guidelines:

1) The samples should represent the compositional diversity of the parent body;
2) The samples should be taken from areas of well-characterized geological contexts;
3) The samples should be taken from both the delicate uppermost surface material and deeper regolith material; and
4) The samples must be kept as clean as possible, with very low levels of terrestrial contamination and no cross contamination with other samples of the asteroid.

These considerations provide a guide for the best ways to acquire the samples and for the subsequent storage requirements.

Sample selection. Asteroids are geologically complex bodies that may have undergone melting and differentiation or may even be aggregates of different asteroids that came together in ancient impacts. Therefore, it is essential that the sampled asteroid be globally characterized as well as possible, principally by spectroscopy, prior to obtaining any samples. The asteroid survey should include both wide-field and narrow angle cameras capable of sub-mm resolution. This preliminary characterization of the NEO will provide the information necessary to identify the best sampling locations and the minimum number of sites from which samples should be obtained in order to fully represent the geological diversity of the body. This preliminary characterization should also have enough detail near the sample collection locations to enable placing the sample in a geological context. Finally, a major scientific priority is to obtain well preserved samples of both the uppermost surface material and unexposed asteroidal material. Other samples of interest may include deep drill cores (~ 3 m) to investigate the irradiation age of the asteroid surface and soils protected under large rocks.

Sample mass for planetary science investigations. With modern analytical methods, a wide range of chemical, isotopic, and mineralogical analyses can be performed on a relatively small amount of material. The sample mass requirements are based on (1) the minimum sample mass necessary to perform the analyses necessary to determine the age, origin, composition, and history of the samples. These measurements include mass spectrometric studies of extinct and radioactive nuclides, mineralogical studies by electron microprobe and transmission electron microscopy, organic studies, and noble gas analyses, (2) sufficient reserve mass to enable multiple, independent measurements by different laboratories and (3) reserve mass for ongoing future studies. With these considerations, we recommend that for each location sampled on the NEO, a *minimum* of 100 grams of asteroidal regolith/soil material be obtained. In addition, considerably larger rock samples (~1-5 kilograms) should be collected to enable asteroidal geological investigations. Each of these samples must be stored in individual sample containers and remain sealed (airtight) until Earth return.

ISRU samples. There may be some interest in performing engineering tests on returned asteroidal material to evaluate mechanical properties and methods for in situ resource utilization (ISRU). These materials should be handled with the same care as those samples used for scientific analysis. However, the minimum mass requirements for ISRU samples may differ from the scientific samples.

Total mass of returned material. Any considerations relating to the total mass of returned material must incorporate the minimum sample mass requirements for planetary science investigations noted above in addition to other requirements of samples for ISRU, engineering and biomedical applications as well as containers and other accessories. As a guideline, a review by a subcommittee of CAPTEM (Lunar Sample Acquisition and Curation Review) determined that future human missions to the Moon should return at least 250 kg of total mass in a given mission. As is the case with potential human missions to NEO, this baseline requirement included a range of scientific samples as well as ISRU and engineering samples, and sample containers. We recommend that this baseline requirement be adopted.

Preliminary sample analysis. There may be value in performing a basic level of sample characterization prior to the final sample collection for Earth return. This is related to the above discussion on sample selection – it is important to establish that the samples obtained are of high scientific value, representative, and diverse. As an example, potential sample selection sites may be examined in more detail spectroscopically to identify the mineralogy and/or organic content. However, *any preliminary sample analysis must be performed without damaging or contaminating the samples*. This leads us to the protocols for sample handling and storage (discussed below).

Sample handling and storage. Virtually all of our current samples of asteroids (meteorites) have a significant or measurable level of terrestrial contamination by exposure to weathering and contact with terrestrial materials (soil/fluids) and unsuitable handling and storage procedures. Thus, the cleanliness of returned samples greatly impacts their scientific value. *Asteroidal samples should be obtained using clean* *tools, and stored in sealed containers that separate them from terrestrial materials and, importantly, from other asteroid samples*. The use of adhesives or other embedding media to obtain samples is therefore strongly discouraged. Ideally, the sample containers will be purged with a high purity, inert gas. Finally, to ensure the integrity of the samples, they should be subjected to a minimum of handling or processing prior to Earth return. For some targets, it may be desirable to return samples under temperature-controlled conditions. In this case, it should be ensured that the capability for total mass of returned material (see above) incorporates the additional power and weight requirements for maintaining the specified temperature for the returned samples.

Final Comments

The CAPTEM has served in an advisory role for NASA in planning for sample collection, handling, curation, and allocation for all of NASA's sample return missions since Apollo. The expertise of this committee is readily available to NASA in planning for any future sample return missions, particularly for any human missions that may involve added complexity in terms of sample selection, handling and storage prior to Earth return. As such, we willingly offer our assistance and advise to the Human Architecture Team in the Human Exploration and Operations Mission Directorate on as as-need basis for such future planning activities.

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