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Laboratory construction and curation scheme for returned samples of the chang'e-5 mission

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Abstract

The analysis of samples returned from a planetary body is important to understand the origin, composition, evolution, and interactions with space or atmospheric weathering of the planet. In particular, pristine rocks, which are not affected by weathering, can be collected during sampling work. The analysis of samples will significantly promote the calibration, verification, and interpretation of remote sensing data and will improve the knowledge of interior materials using geophysical measurements. The Chang'e-5 lander, the first Chinese science project involving the return of lunar samples, launched on November 24, 2020 and drilled a core sample that is almost 1 m long, and acquired less than 2 kg during this mission. Because of the preciousness of the returned samples, the CLESEC (China Lunar Exploration and Space Engineering Center) is planning to construct at least two laboratories, determine regulations for preserving samples from the Moon and other planets in future missions and develop non-damaging and/or minimally damaging technologies to analyze the returned samples. The CLESEC also announced standardized technologies and documentary regulations for preservation, measurement, and sharing schemes with scientists around the world. Based on the Apollo experiences, we have established detailed requirements and standardized conditions for constructing laboratories and curation with the aid of advanced technologies. We also discuss six potential demands for future sampling missions. Finally, we developed high-level criteria for future returning sample missions and relative curations that are beneficial to Chang'e-5 research and as well as preparation for other extraterrestrial samples in the near future.

Keywords: Chang'e-5, Lunar sample, Sampling and returning, Sample laboratory construction, Sample curation and preservation, Regulations on curation of samples

Introduction

To rapidly realize the properties of materials on a planetary surface, remote sensing has thus far been a primary approach for determining mineralogical and petrological features in the current epoch of explorations of solar systems. To acquire shallow subsurface features hundreds of deep below a planetary surface, radar observations can be employed. The materials deep in the shallow surface have mostly been affected by the atmosphere, as on Mars or Venus, as well as by high-energy particles and debris from small bodies in space, as on the Moon or Mercury (Wehner et al. 1963). Furthermore, impact events caused by any small planetary bodies result in layered structures on the planetary surface with depths reaching several kilometers in the impacted areas, called regolith (McKay et al. 1991; Lucey et al. 2006). The overlying structures result in deviation from the reasonable geological interpretation of the planet using remote sensing data, and adversely influence the understanding of the interior substance and impede reasonable geological interpretation of geophysical measurements, including the operations

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of the Apollo Program (Porcello et al. 1974; Sullivan et al. 1994; Konopliv et al. 1998; Lai et al. 2016) and gravitational or radar satellite missions. In addition, the composition of an asteroid is affected by many factors during its long path to the planet, and scientists cannot trace their origins.

For this reason, sampling activities on planetary surfaces such as the Moon have been commonly considered a key method to identify, distinguish, and understand the materials sourced from the surface and the deep, and aid in determining processes related to geological and space events. Analysis of the returned samples using the most sophisticated instruments can improve the knowledge of their characteristics in mineralogy, petrology, physics, chemistry, and chronology. The results can further improve our understanding of the composition and evolution of the planet and significantly contribute to instrument calibrations and reasonable geological interpretations. Carefully selected candidate landing sites for sampling to collect the materials sourced from depth, such as those erupted by volcanic activities or excavated by an impact event (Pieters et al. 1997; Dhingra et al. 2011; Spudis et al. 2013; Lemelin et al. 2015; Spudis 2015), can provide fruitful evidence to interpret geophysical measurements and improve our knowledge of deep materials. Apollo and Martial activities on planetary surfaces also provide similar experiences that the analysis of samples can contribute to the development of Rover payloads and related systems or manners of sampling under certain geological environments in subsequent missions. These valuable experiences can increase the possibility of acquiring pristine samples and enhance the comprehensive understanding of the composition and evolution of the planets.

On December 1, 2020, the Chang'e-5 Sampling Station landed at 43.058 N, 51.916 W (Qian et al. 2018, 2021; Robinson 2020; Wang et al. 2021), to the north of Mons Rümker in the northern part of Ocean Procellarum of the lunar nearside, and returned home the samples 1731 g in total after 16 days with a drilling core almost 1 m long and around 250 g weight, and some shoveled samples. Based on comprehensive studies on the laboratory requirements for curating Apollo-returned samples and their physical and chemical characteristics, in this paper, we establish standard requirements for the preservation, proceeding activities, and curation of China's lunar samples returned from the Moon and other planetary bodies in the future. To magnify the scientific value of the returned samples, there are six requirements to consider: (1) Strict conditions for experimental laboratories for preservation and proceeding activities; (2) A planned ratio of usage to preservation for future experiments and even candidate missions; (3) Specification of techniques for measurement; (4) Multi-disciplines measurements and comprehensive research on samples; (5) Digitalization of the derived results and data sets from standard measurements; (6) Opportunities to open data to the public. A relative official document file was announced in January 2021. With the establishment of the official standardized requirements for preservation and techniques for measurement and curation, we hope to promote future cooperation among Chinese scientists in a variety of disciplines and with international scientists and magnify the scientific value of these samples and comprehensive related research.

Review of sampling in the Apollo program and principles for constructing standardized conditions for chang'e-5 laboratories

From 1970 to 1972, the Soviet Union missions Luna 16/20/24 collected three core samples of 0.3 kg total (Meyer 2009a, b, c) with the support of three landers and drilling arms. A total of 381.7 kg of lunar samples were collected in extravehicular activities (EVAs) during all six manned lunar missions from the Apollo 11 mission in 1969 to Apollo 17 in 1972 (Shoemaker et al. 1970a, b; Warner 1970; Schmitt 1973; Muehlberger et al. 1980; Ulrich et al. 1981; James and Hörz 1981; James 1981; Spudis 1984; Spudis et al. 1988; Heiken et al. 1991; Shearer et al. 2007). They upgraded the capability of human activities and sampling works to expand the region near the lander to multiple sites far from landing regions with the assistance of lunar rover vehicles. The collection and sampling methods mainly relied on picking up, digging, scooping, and drilling holes with drive cubes (Allton 1989). Most of the collected samples are commonly believed to originate from lunar regolith (unconsolidated materials that overlie solid rocks or bedrock on the lunar surface) (McKay and Williams 1979), except on the last mission, Apollo 17, where one sample of rock was chipped from a large rock by a geologist (Schmitt and Cernan 1973; Wall 2019) from a location on the surface, not from bedrock. Until now, no bedrock samples have been collected on any lunar mission. Furthermore, the characteristics of sampling rocks on the lunar surface represent distinctive weathering caused by high-energy particles from the Sun and other space rays and heavy impacts from meteorites or small planetary bodies, all of which have formed regolith and ejecta overlaid on the lunar surface.

In general, four types of lunar rocks have been collected by human missions to date, including pristine highland anorthosites (e.g.,Warren 1990; Jolliff et al. 2000), mafic and ultramafic rocks (such as dunites, troctolites, and norites (e.g.,Dymek et al. 1975; Papike et al. 1998), and especially extrusive mare basalts (Neal and Taylor 1992) containing KREEP, potassium K, rare-earth elements REE, and phosphorus P (e.g.,Hubbard et al. 1971; Spudis and Hawke 1986), metamorphic rocks (Simon and Papike 1985; Korotev 2000; Pernet-Fisher and Joy 2021) and varieties of breccias (e.g., Stoffler et al. 1980) induced by impact processes. Overlaid on lunar bedrocks, a 10-km thick layer structure named mega-regolith (Heiken et al. 1991; Korotev and Kremser 1992) has formed due to a large number of impact events in the long geological history. The uppermost overlying layer is fine-grained with thicknesses from 10 m to several kilometers and is named regolith (McKay and Williams 1979). The regolith is a mixture of impact-induced breccias (originating from a mixture of feldspathic highland, basaltic mare, and the components of meteorites colliding) and volcanic extrusive and pyroclastic rocks and/or glass. Most Apollo samples consist of lunar regolith particles less than 1 cm, and lunar soil particles less than 1 mm (McKay and Williams 1979). After careful analysis, the pristine rocks that have not been affected by impact events consist of only a small portion of the Apollo samples, yet there is no consensus on where they originated and how they evolved. The identified minerals in Apollo samples consist of silicate minerals such as pyroxene, plagioclase, and olivine; phosphates, such as apatite; sulfides, such as troilite and sphalerite; oxide minerals such as ilmenite and spinel, metal alloy, and metallic iron (Lucey et al. 2006).

A total of 24 drilling cores were acquired in the Apollo Program. Their maximum length is three meters, and their minimum length is 13.5 cm. Three drilling cores with length from 35 cm to 1.6 m were acquired in the Luna missions using auto-drilling machines (Waltz 1975, 1976, 1977; Duke and Nagle 1976; Allton and Waltz 1980; Allton et al. 1981; Meyer 2007a, b). Many distinct layered structures could be recognized in each of the cores if the layered structures could be protected the samples from being mixed by forces such as they flew through the atmosphere of the Earth (Korotev and Gillis 2001).

Research integrated remote sensing observations with lunar samples results has shown that metal iron and ferrous iron (such as ilmenite $TiFeO_3$ and even unusual pristine ferrous anorthosite) have been discovered (McKay and Williams 1979; Warren et al. 1987; Papike et al. 1998). The discovered minerals demonstrate that the lunar surface is characterized by extreme reduction. This special condition is decisive in establishing standardized requirements for the lab to preserve returned samples, relative curations and techniques.

The samples collected in the Apollo Program are the largest in quantity compared to those from other lunar sampling missions. However, they are still limited in category and in representation of the geological terranes compared with those collected from Earth geological investigations. Based on the analytical results and experiences from Apollo samples, most are formed mixtures of breccias induced by repeated impacts, and only 260 sample rocks are identified as possible and relatively high-confident pristine rocks, the sizes of which are less than 1 mm to 30 mm (Warren 1993). The 260 rocks comprise just one 30-mm sample, an additional 5 rocks greater than 10 mm, and > 90% that are less than 1 mm. Consequently, it is essential to consider the details of regulations to protect the information in returned samples. In addition, strategies for long-term storage should also be considered for future advanced instruments and measurement skills and possible subsequent missions. To preserve samples, many standardized regulations have been developed and strictly operated in detail concerning with preservation, curation, and usage. We researched and discuss the following aspects with some support from Apollo's experiences:

The distribution (ratio of usage for research to storage for subsequent missions, future advanced techniques, or newly developed approaches) is necessarily taken into detailed consideration

The ratio of open Apollo samples for research to unopened samples for preservation

All of the Apollo samples were returned in sealed containers and preserved in a special laboratory in safe, low-temperature, vacuum conditions, similar to those on the lunar surface. The sealed containers could not be opened until a formal application for research was approved by peer review. Due to their scarcity, most Apollo samples have not been available to scientists or to the public. Even until now, just 15 percent (Michelsonhn 2019) have been open for research, and others that are not open will be unpacked for future advanced instruments and techniques, for subsequent missions with high-priority scientific goals and for backup storage if contamination accidents caused by natural disasters occur. In 2019, the 50th anniversary of Apollo 11, NASA officially unpacked previously sealed sample number 73002 for testing research with the most advanced measuring techniques and for scientific demands for Artemis missions in the near future (Michelsonhn 2019). In addition, because of their scarcity, to maximize their scientific value and fulfill demands for multi-disciplinal research and varied testing approaches, approximately 2200 Apollo samples were split into more than 110,000 individually numbered available subsamples.

Principals for distribution and repeatable usage

For investigations on Earth, a single Earth sample should be large enough to acquire an averaged representative composition through grinding processes without any other interference. Nevertheless, due to the scarcity of lunar samples, only a small quantity of pieces or repeatable usable slices, even lunar regolith simulant, such as CUMT-1 (McKay et al. 1994; Quan et al. 2018; Li et al. 2022), are permitted to be investigated. If the demands for such investigations cannot be fulfilled, petitioners can submit an application with detailed descriptions of special scientific demands, and a slightly larger slice of samples could be prepared for the investigator after acceptance by scientific peer review (Zeigler et al. 2007; Zhang et al. 2020).

Comprehensive studies on lunar sample laboratory

The returned lunar samples are securely stored into two locations. One is a special place for the storage of representative samples against unexpected calamity or sudden contamination, and the other is a laboratory for preservation, preparation, research, and testing that is equipped with necessary facilities. Both places have the capabilities to permanently preserve lunar samples in physically secure and noncontaminating environments protected against natural disasters (such as floods, hurricanes, and earthquakes).

The lunar sample laboratory equipped with required facilities for such special purposes was constructed at the Johnson Space Center in 1979. It comprises eight sub-labs: the Change Rooms and Air Shower, the Pristine Sample Lab, the Pristine Sample Display Case, the Core and Saw Room, the Pristine Corridor and Vault, the Experiment Lab, the Return Sample Vault, and the Observation Room.

The conditions to prevent contamination of the returned samples are critical in construction of the laboratory. We discuss several important aspects below:

Contamination

Contamination, one of the primary factors, should be carefully considered in the construction of a laboratory. It comprises solid particles (such as tiny dust) in the air, and gaseous materials (such as oxygens, hydrates, or gases, which may contaminate the composition of isotopes in the lunar samples). In addition, potential threats from harmful ingredients contained in the extraterrestrial samples may also injure our Earth (Conley and Rummel 2008). To protect from contamination, all rooms in the lab must have particularly clean air. The water and oxygen concentrations in the air of the glove box cabinet (see Fig. 1) must be maintained at less than 20 molecules of oxygen and 50 molecules of water for every one million molecules of nitrogen (which is 1000 times cleaner than that in a standard clean laboratory). Furthermore, the levels of all standards in all rooms of the lab must be monitored in real time and an alarm should be activated when anomalies occur. To prevent lunar samples from contamination and protect human from injury, samples must be stored in sealed glove box cabinets equipped with airtight gloves made of Teflon and neoprene and with tools made of aluminum and stainless steel (Fig. 1).

Air pressure conditions

As time goes on, contaminated air may slowly leak into the cleaned room and even into the cabinet. Therefore, the nitrogen gas pressure in the cabinet should be kept slightly higher than the air pressure in the Pristine

Fig.1 Glove box Cabinet (left) and typical tools (right) to process lunar samples made of special materials that are allowed to touch samples (Lunar Sample Laboratory Tour, 2016)

Sample Laboratory and the cleaned air pressure should be kept higher than that in the Change Rooms. Slightly higher pressure inflates the gloves outward all the time (see Fig. 2). Moreover, after long-term operation, the oxygen and water from staff arms may slowly penetrate the cabinet through the gloves, so the flow of nitrogen air must be recycled to protect it from concentrating gases.

A vacuum container is used to store and preserve lunar samples and is under vacuum until the container of required samples may be opened for research. The special container was processed into vacuum condition before humans landed on the lunar surface. After the sampling and collection extravehicular activities, the lunar samples were packaged in the container, returned to Earth, and kept in that condition until opening; they are kept away from any contamination throughout the whole process.

Temperature required

A low controlled temperature can preserve lunar samples in a similar environment to that on the lunar surface and decrease chemical reactivity to prevent contamination induced by weak but durable chemical reactions.

Dissection and preparation of samples

The sawing of samples must be performed in a sealed cabinet filled with nitrogen to protect against contamination. The saw blade is made of stainless steel and coated with diamonds on the cutting edge. On Earth, lubricants and water are normally used for cooling high temperatures during rock sawing but, to protect lunar samples from contamination, sawing work is performed in a very dry and very slow process without any cooling materials. Before that, the related application for this sawing work was submitted for peer review. If the application was not accepted, only previously prepared sliced pieces are allowed to be used for research or measurement.

Maintaining staff safety

Because of the slightly higher nitrogen gas pressure than the air pressure in room, the room will be filled with nitrogen if the cabinet leaks, which would harm the ability of staff to breathe. Therefore, the level of oxygen in the room must be continuously monitored.

Regulations for china's sample return, processes, and preparation

Construction of the conditions of the lunar surface and the occurrence of contamination events

On the lunar surface, the atmosphere is almost a vacuum with a concentration of $10^4 \sim 2 \times 10^5$ particles per centimeter square, and the temperature ranges from 123 K (−150 ℃) to 383 K (110 ℃). These parameters of the lunar surface environment will be considered required conditions for the construction of sample curation laboratory (Heiken et al. 1991).

Chemical activity of lunar samples

Before collection, lunar rocks and samples lay on the lunar surface under vacuum conditions. In the humid Earth atmosphere, water molecules, oxygen, and other active suspended materials undergo chemical reactions with the lunar samples to produce new substances. The tiny particle of pure iron in a lunar sample is extremely capable of causing oxidizing reaction with oxygen in the Earth's atmosphere. Glass and some minerals such

Fig. 2 Gloves in the sealed cabinet inflate outward all the time (Lisa 2019)

as feldspar in a lunar sample can produce some sorts of clays. Nitrogen in the glove box cabinet can prevent the primary chemical reactions from occurring.

Required conditions to construct the laboratory

The regulations for the Chang'e-5 laboratory to preserve return samples consider the Apollo curating lab, true conditions on the lunar surface, and contamination events that have occurred (Fig. 3).

In addition to the conditions of the Apollo curation lab, the following factors should be considered for the construction of the Chang'e-5 sample lab. (I) Varied required rooms must be built for the returned Lunar samples, including a Cleaner Change Room with a dust cleaner, a Frozen Sample Preservation Room, a Sample Test and Preparation Room, and an Observation and Monitoring Room. The role of the Cleaner Change Room with the dust cleaner is to remove dust and particles from the bodies of staff through the changing of clothes and shoes with the standard limits to a maximum cleanliness level up to $10^4 \sim 2 \times 10^5$ particles per centimeter square. The dust cleaner removes all particles appended in the air or the bodies of staff. (II) The special Teflon gloves in the cabinet should be regularly replaced with cleaned gloves to avoid water leaks or entry of other contaminating materials from humans into the cabinet. (III) Inert gases protect the samples from contamination, as they are key to studying chemical components or isotopes from the space environment as well as the evolution of the Moon. (IV) The concentration of nitrogen and aridity in the cabinet should be kept higher than those in the rooms. (V) There must be a frozen cabinet at a low temperature similar to that on the Moon in the Frozen Sample Preservation Room. Freezing can decrease chemical activity to prevent contamination of the samples. (VI) Some special materials can be allowed to touch the samples, such as

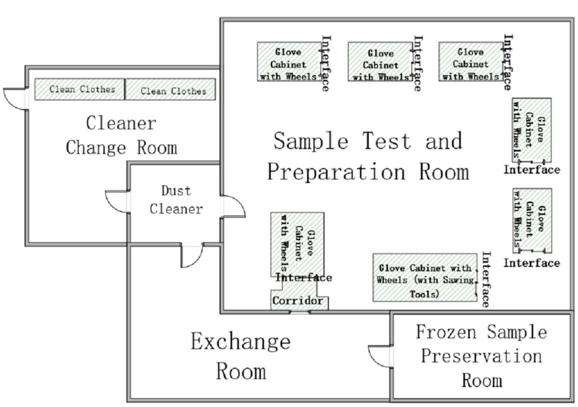


Fig. 3 Layout of the China Returned Samples Laboratory

stainless steel or aluminum used for cabinets, tools, and preservation containers, and Teflon used for gloves and sealed bags, which do not allow for chemical processes occur,. (VII) HD cameras with multiple-angle views and variable focal lengths must be set up in several corners of the cabinet, as well as thermometers and hygrometers. Real-time cameras or monitors should also be mounted in all rooms. (VIII) X-ray and CT instruments should be set up in the Sample Test and Preparation Room to analyze sections of returned samples to make decisions regarding which parts should be used for research and/or storage. (IX) Imperative applications are needed for the preparation of a new required sample pieces by sawing after being subject to peer review. The processes will be integrated with images of sections reduced from the X-ray detector. (X) The magnetism of samples must be detected as quickly as possible to avoid slow magnetization reduction upon exposure to the Earth's magnetic field.

Opening, dissection, preparation, and preservation of returned samples

Strict curation and preservation rules and regulations are implemented for the Chang'E-5 returned samples. They entail public, fair, and strict regulations and encouragement of public involvement during the whole process from the packaging, return, preservation, distribution, application and curation. Regular inspection and review work will also be performed.

For the safety of the Chang'e-5 returned samples, the following rules and required procedures must be implemented: (I) Sealed stainless-steel containers afford protection from contaminating by air, water molecules, or other chemical matter and from magnetization by Earth's magnetic field. (II) The returned container must be sealed until reaching the lab or the time of opening and preservation in similar conditions to those on the Moon (and when packaging on the Moon). (III) Acquiring information on the inner structure and grain size of sealed sample cores as soon as possible is significant in determining the ratio between packaging for lasting preservation and unpacking for research, as well as targeting sections of samples with essential scientific value. (IV) The residual intensity of magnetization of lunar samples should be acquired as soon as possible to avoid the results being affected by the magnesium of the Earth's field. (V) Unopened samples will be transported to the lab, opened and sawed in the cabinet, and dissected for research or lasting preservation for developed technologies or future missions. (VI) For the open samples, dissection and sawing can be performed during the preparing process and subsequent research. Some necessary information steps must be performed, such as marking with a code number, identification of types of rocks and minerals, measurements of weight and volume, analysis of chemical components, taking photos of samples and microscopic images of rocks and minerals, and measurements of physical properties. (VII) For repeatable use of a single sample, the related regulations for processing it must be followed according to the level of destructiveness, from non-destructive, minimally destructive, destructive and necessary, and consumable operations. Moreover, the investigators must summarize the data derived from each process. (VIII) In particular, consumable research must be performed after the related application is subject to strict peer review. (IX) To maximally extent the value of the samples, multiple disciplinary processes can be implemented on a single sample according to the destructive level. (X) The largest quantity of samples should be preserved for a long time and for future missions or advanced technologies, considering their scarcity and value. (XI) Information on the application process, approval and basic data sets derived from research will be available on the official website. (XII) The CLESEC has announced the official document 'Procedures for Requesting Lunar Samples', which contains curating regulations, rules on the percentage of preservation and unpacking, peer-review method, and application materials.

Outline of returned samples processing

Based on the laboratory construction and features of the returned samples mentioned above, the flowchart in Fig. 4 was established for testing, preservation, and public announcement after return of samples to Earth. In particular, sampling work must be performed using an airtight vacuum tube in similar condition to that on the Moon. The ratio of packaging to unpacking must depend on the rarity of the sample, which is determined after scanning the inner structures of the sample in a sealed tube. Measurements of the residual magnetization should be performed as soon as possible. All measurements will be recorded and publicly shared in a digital format, which is helpful to extend the scientific results and promote multi-disciplines research and worldwide cooperation.

Principles for curation of sample research

Similar to the highest authority institutions in charge of curation of Apollo samples, such as CAPTEM (Curation and Analysis Planning Team for Extraterrestrial) or NASA, the China Committee for Lunar Samples have the same high authority and responsibility for the returned sample curation, review, supervision, and related works. The committee members are comprised of experts in multiple disciplines, including mineralogy, petrology, geochemistry, petrophysics, chronology, remote sensing, geophysics, and biology. The obligation of the committee is to assist CLESEC in holding science conferences and reviewing all applications for sample research to widely expand interactive communications and extend the scientific results. The committee is responsible for establishing regulations on the curation, archiving, data management and results, laboratory upgrades, new measurement technologies, and proposals for future planned missions.

The main principles for the curation of the returned samples are presented below:

(1) Official Procedures for requesting lunar samples shall be applicable to the overall process of unsealing, classification, preparation, documentation, storage, application, distribution, transportation, use, return, dispositioning, management of information, and documentation of results.
(2) China National Space Administration (CNSA) is the management authority of lunar samples, in charge of all responsibilities; CNSA's Lunar Exploration and Space Engineering Center (LESEC) has been granted to execute the concrete managements of lunar samples. LESEC has the responsibilities including reviewing operating procedures requested by applicants, establishing an expert committee on lunar samples, supervising the processing of lunar samples, publishing or updating relating information on samples, and monitoring the derived results.
(3) The lunar samples are not stored in a single place to protect them from any catastrophe and for backup.
(4) There are in principle four types of usage permitted: permanently stored samples, permanently stored backup samples, researching, and presentations for the public
(5) In view of the precious nature of lunar samples, any requested samples for research should be used in a safe and save manner. Any destructive testing must be reduced to the minimum and supplemented with relating detailed explanation in the application files and executed with required operations.
(6) Every applicant must sign a 'Lunar Sample Loan Agreement' with LESEC, and the approved request application materials must return to LESEC.
(7) Publication of papers, academic exchanges and other relative activities that use the samples must be appended with 'Lunar Sample Provided by CNSA.'
(8) CNSA encourages lunar sample-based joint international research, and supports the international sharing of science results.

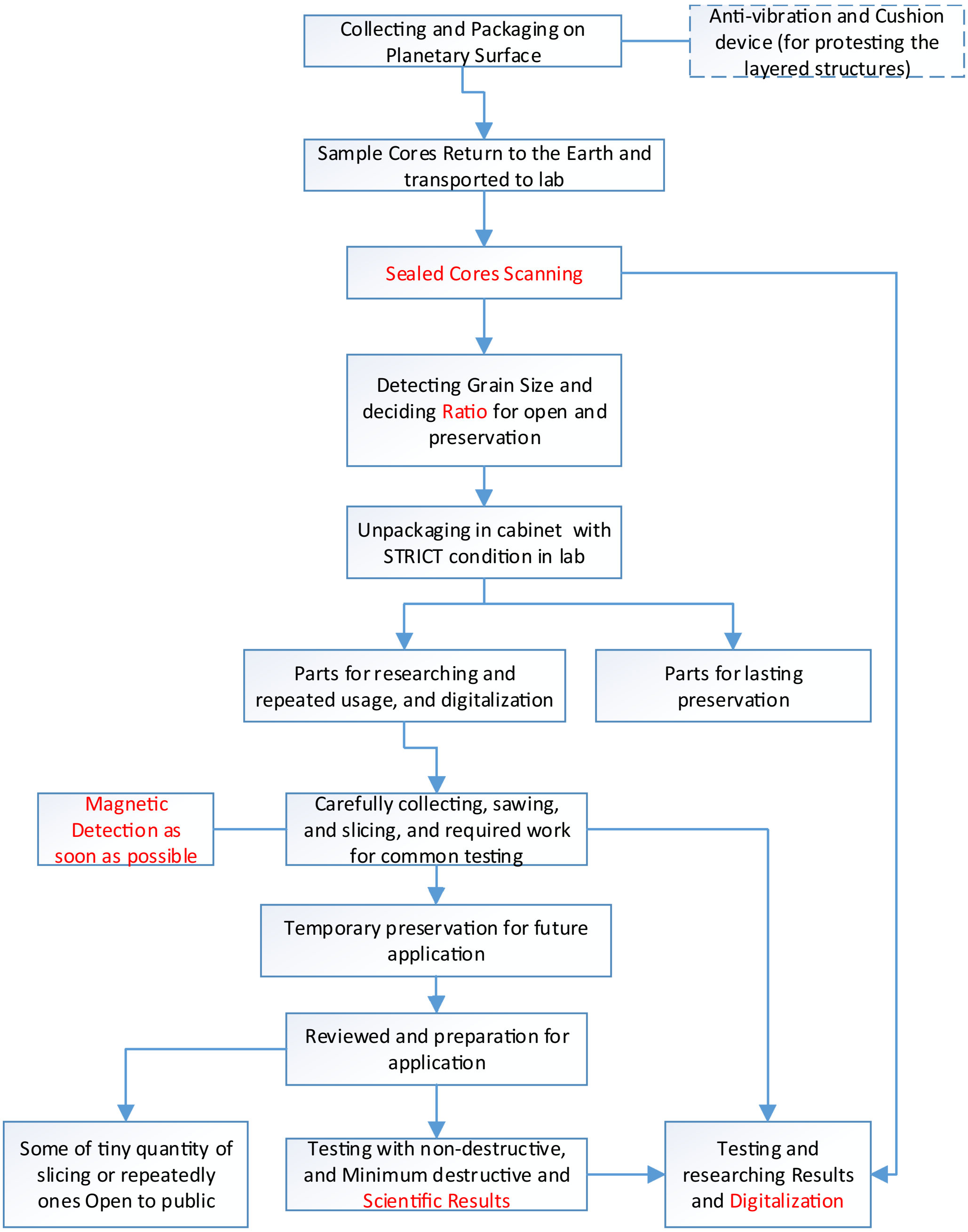


Fig. 4 Flowchart of the returning processing, preservation, and public announcement of samples collected from the Chang'e-5 or possible from extra-terrestrial missions (the words in red indicate steps that are significant during the process of sample preservation and/or processing of the Chang'e-5 mission)

Expected scientific results of samples and extensive utilization of digitalized data sets

The allowed research for testing samples includes but is not limited to intact, damaged, open needed, or sealed analyses

- Nondestructive/intact techniques (do not need to open)

  – X-ray and CT to acquire 3D models of the inner structures of the samples

  - Thermal conductivity measurements

- Nondestructive techniques (opening needed): optical or spectral characteristics measurement, density detecting, neutron spectrometry, gamma spectrometry, X-ray spectrometry, etc.
- Minimal destructive techniques: SHRIMP dating (leading to micrometer-scale damage), etc.
- Destructive techniques:

  - Varied Mass Spectrometry (to acquire composition and constitution): IRMS-dating, TIMS, Neutron Mass Spectrometry, Inert Gas Mass spectrometry, AMS, SSMS, LA–ICP–MS
  - Residual magnetism detection

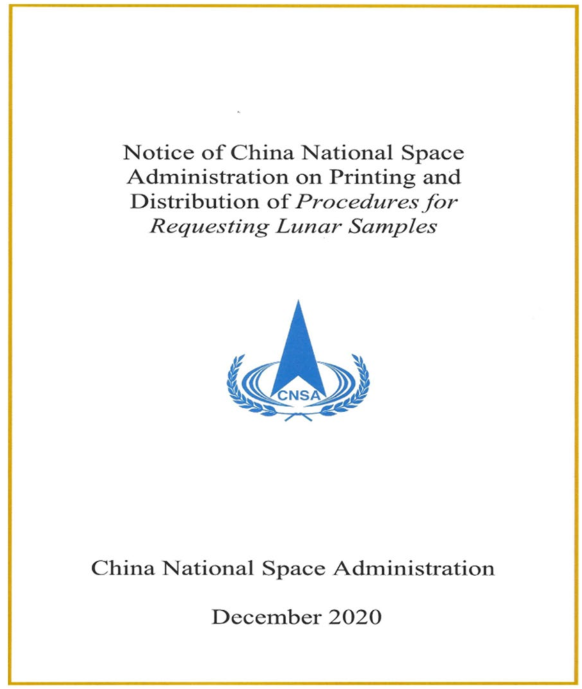
Extensive utilization of digitalized data sets from samples and publicly available information through the official website

Standard information acquired from the unpacked samples will be archived and open to worldwide experts, including but not limited to photos, CT image of the 3D structure, common information of compositional or petrological types, detection of mineral and chemical compositions from slices, trace elements detecting, Raman spectrometry, and other spectrometry. Some data sets or results based on published papers or materials will be archived in official formal.

For repeatable utilization for the public, some additional information should be uniformly archived, including records on the location, contamination, and use history. For more detailed information, refer to the official document, "Procedures for Requesting Lunar Samples (Fig. 5)". To realize the state of the applications and related results, refer to the official web page 'Lunar and Deep Space Exploration Science Data and Sample Release System (http://202.106.152.98:8081/moondata/web/datainfo/main.action#)' and 'China's Lunar and Deep Space Exploration (http://www.clep.org.cn/)'.

Discussion

Chang'e-5 is China's first mission to acquire samples from the Moon and return them to the Earth. The goal of this paper was to build the first laboratories for preserving and curation of lunar samples and other extraterrestrial samples for future preparation. The paper discusses and establishes the required principals, qualifications, and techniques for testing and curation and enacts them as national standards for lunar samples returned in the Chang'e-5 mission. To increase the value of the limited quantity of lunar samples, further work should be done to advance sampling technologies, preserving conditions, and testing skills, extend the use of publicly available digital data, and improve curations for the future. The following are some of the important issues for future consideration:


Notice of China National Space Administration on Printing and Distribution of *Procedures for Requesting Lunar Samples*

CNSA

China National Space Administration

December 2020

Fig. 5 Official Document: "Procedures for Requesting Lunar Samples" (Online: http://www.gov.cn/zhengce/zhengceku/2021-01/18/content_5580772.htm)

(1) Developments in sampling techniques and approaches on planetary surfaces. Much more intensive developments to advance sampling skills or strategic plans on planetary surfaces are important factors in effectively sampling and collection of samples with the best scientific value. In addition, reduction in the cost of collection on other planets should be considered.
(2) The proposed landing site candidates are worthy of research. Through intensive research on geological settings and the most valuable scientific goals for future landing sites, the choice of landing site could avoid disturbance by space weathering or asteroids impact, targeting the pristine rocks formed by the planet or the Moon itself. In addition, acquisition of samples formed on bedrock and experiences from geologists and geophysical observations are increasingly important to understand the composition of the planet and the history of its evolution.
(3) Careful planning for ratio of open to unopened. Consideration of the ratio of opening for research

to unopened samples for lasting preservation is necessary for strategic planning according to the concrete conditions and value of the sample. Sawing and dissecting are the most common approaches for enlarging the quantity of samples. However, the value of returned samples will gradually increase as new techniques or approaches progressively advance in the future. Thus, the percentage of lasting sample preservation should be as large as possible for future preparation. Required work or special work dealing with hot scientific issues could be carefully considered to test samples using special work dealing with the highest accuracy to consume the least quantity. Further support in the use of digitalized data and increasing the repeatability of sample testing is promising for lasting preservation and to increase the value of returned samples.

(4) Advances in testing technologies. A long-term view that considers nondestructive and minimally destructive technologies in research can dramatically increase the value of returned samples. In addition, advanced technologies will accelerate research and development with new instrument payloads in future missions.
(5) Scientific curation and integrated usage of samples. According to the scientific requirements and official standards, the testing results will be digitalized and gradually open to global scientists and experts, which can comprehensively expand the use of the samples and promote in-depth and integrated research in multiple disciplines to broaden global cooperation.
(6) Opening for public assess. Cutting-edge sciences will contribute to the advancement of technology as well as the rapid spread of science knowledge to the public. Some slices with less scientific value or possible repeated use can be displayed to the public with an informative introduction.

Conclusions

Collection of samples from the surface of the Moon or other planets in future missions is significant to acquire pristine rocks, interpret remote sensing observations, and understand the composition, origin and evolution of planets. Lunar samples were obtained on the Chang'e-5 mission, China's first mission to acquire `samples from an extraterrestrial planet. By integrating characteristics of Chang'e-5 samples with experiences from Apollo lunar samples regarding their curation, testing, preparation, and preservation, our paper developed public and strict rules and regulations for the preservation and testing operations for the freshly returned samples. We also designed at least two special laboratories to carefully protect them from contamination. Through a strategic program that considers both current research and future missions, we plan to open some samples when necessary. To optimize their scientific use for research, careful unpacking of the samples, multi-discipline measurements, and digitalization of the observations must be performed during the sampling processing procedures. We hope that the regulations and laboratories will be helpful in long-term research to significantly promote the scientific values of the returned samples.

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Author contributions
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