THE APOLLO SAMPLE COLLECTION: 50 YEARS OF SOLAR SYSTEM INSIGHT. R. A. Zeigler[1], A. B. Mosie[2], J. J. Kent[2], C. H. Krysher[3], L. A. Watts[4], and F. M. McCubbin[1]. [1]Astromaterials Acquisition and Curation Office, NASA Johnson Space Center, Houston, TX, ryan.a.zeigler@nasa.gov. [2]GeoControl Systems Inc., Jacobs JETS Contract, NASA/JSC. [3]HX5, Jacobs JETS Contract, NASA/JSC. [4]Barrios Technology, Jacobs JETS Contract, NASA/JSC.

Overview: The Apollo program was the seminal moment in modern human history and the crowning technological achievement of the 20th century. In addition to the obvious historical, cultural, and technological significance of the Apollo program, scientific results from the Apollo samples have had a lasting impact on a range of scientific fields, none more so than on the fields of planetary science and cosmochemistry. Over the past five decades, studies of Apollo samples have yielded significant insights into planetary bodies throughout the solar system. Despite the Apollo samples being a static collection, recent and ongoing studies continue to make new significant discoveries. Here we will discuss the history of Apollo samples collection, curation, and study, and also look forward at expected new developments in the coming years.

Background: The Astromaterials Acquisition and Curation Office at NASA's Johnson Space Center (hereafter JSC curation) is the past, present, and future home of all of NASA's astromaterial sample collections [1-3]. Our primary goals are to maintain the long-term integrity of the samples and ensure that the samples are distributed for scientific study in a fair, timely, and responsible manner, thus maximizing the science return on each sample. JSC curation currently houses all or part of nine different astromaterial sample collections, with two more sample return missions underway: (1) Apollo samples (1969), (2) Luna samples (1972), (3) Antarctic meteorites (1976), (4) Cosmic Dust particles (1981), (5) Microparticle Impact Collection (1985), (6) Genesis solar wind atoms (2004); (7) Stardust comet Wild-2 particles (2006), (8) Stardust interstellar particles (2006), (9) JAXA's Hayabusa asteroid Itokawa particles (2010), (10) JAXA's Hayabusa2 asteroid Ryugu particles (2021), and (11) OSIRIS REx asteroid Bennu particles (2023). Additionally, JSC curation houses some combination of space exposed hardware, contamination knowledge samples, and spacecraft coupons for all NASA-led sample return missions, including future sample return missions like OSIRIS-REx and Mars 2020. Each sample collection and/or affiliated witness materials are housed in dedicated clean rooms tailored to the requirements of that sample collection.

Apollo Samples: From 1969 to 1972, the Apollo astronauts collected 382 kg of rock, regolith, and core samples from six geologically diverse locations on the Moon. Because of the dexterity, adaptability, and real-time decision making ability that astronauts provide, the Apollo samples span an incredible range of sample types, including: large rock samples (e.g., the 11.7 kg 61016); multiple rocks chipped from large boulders (e.g., 76235/55/75/95 from Boulder 1, Station 6, Apollo 17); bulk surface, trenched, and shaded lunar soils (e.g., 60500, 61220, and 69920/40/60 respectively); multiple 30-60 cm drive tubes and deep drill cores samples up to ~3 meters in depth (these preserved the regolith stratigraphy); and several different types of special vacuum-sealed regolith and drive tube samples [4].

In the 50 years since the Apollo samples were collected, there have been 3158 unique lunar sample requests. These have come from over 500 different Principal Investigators (PIs) in >15 different countries. The total number of samples allocated is not precisely known at this time, since pre-database records (<1984) have not been fully digitized yet, but a conservative estimate is >50,000 Apollo samples have been allocated over the past 50 years (Figure 1). Although demand for lunar samples has waxed and waned over the years (Lunar Puns!), studies of the samples have continued as new scientists and new instruments push the boundaries of what can be done with the samples. Currently 145 active lunar PIs are studying >8,000 samples in fields as disparate as biology, medicine, astronomy, engineering, material science, chemistry, and (of course) geology.

Discussion: Studies of the Apollo samples, both early and more recent, continue to yield significant insights into the formation, evolution, and maturation of the Earth-Moon system, as well as many other planetary bodies in both the inner and outer solar system. A comprehensive listing of significant results from the study of Apollo samples in this space is impossible (even in a long-form abstract), but listed below are a subset of results that highlight the wide-ranging, long-lasting, and diverse nature of studies of Apollo samples: (1) The Moon formed from the debris of a giant impact between the proto-Earth and a large bolide early in the solar system history [4,5]. (2) The Moon had a Lunar Magma Ocean, and evolved akin to a global (though asymmetric) layered-mafic intrusion [6,7]. (3) A prevalence of ~3.9 Ga ages of lunar impact melts suggests that there might have been a "Lunar Cataclysm" at that time, which would have affected all of the inner solar system [8]. (4) The potential prevalence of impacts ~600 Ma after solar system formation (i.e., the "Lunar Cataclysm") was one of the factors leading to new dynamical models for the evolution of the entire solar system, e.g., the Nice Model [9]. (5) By tying the ages of Apollo basalts to the crater densities in the regions of the

Apollo landing sites, relative crater counting ages can be given absolute ages on the Moon, as well as elsewhere in the inner solar system [10]. (6) Despite decades of null results for volatiles in lunar samples (e.g., H_2O), recent results [e.g., 11,12] have shown that the Moon is not "bone dry" and these volatile abundances inform the models for lunar formation. (7) The way light interacts with the surface of airless bodies changes over time due to space weathering caused by micrometeorite bombardment and solar wind implantation; studies of Apollo samples form the basis for understanding this process and thus correctly interpreting remotely sensed observations of these bodies [13]. (8) The composition of Apollo samples have directly contributed to the interpretation of remotely sensed data sets, including their use as ground truth for both Clementine and Lunar Prospector global geochemical maps [14,15]. (9) Studies of the toxicity of Apollo samples provide the basis for safe exposure limits for future human exploration of the solar system [16]. (10) Apollo samples have been requested as analogs for studies of Mercury, the martian moons, and near-Earth asteroids, as well as to better understand how to detect potential life on exoplanets.

Future Studies: Despite the Apollo Sample Suite being a static collection, "new" samples are still being made available for study through several avenues. NASA recently solicited proposals as part of the Apollo Next Generation Sample Analysis (ANGSA) program [17]. The ANGSA program includes previously unopened, vacuum-sealed drive tubes and bulk soil samples, cold-curated samples (-20°C), and samples only handled in a He-purged environment. Furthermore, JSC Curation can now scan samples using X-ray Computed Tomography (XCT); XCT scans of polymict breccias are expected to identify "new" lithic clasts for PIs to study. Similarly, there are 10,000s of small particles in the >110 kg of bulk lunar regolith, and a portion of these will also be classified and made available to PIs after a retroactive preliminary examination process utilizing XCT, micro X-ray Fluorescence, and Imaging micro-Raman Spectroscopy. Additionally, a new searchable database for lunar geochemical data called MoonDB has been brought online [18], and eventually "all" previously published lunar geochemical analyses will be available to help inform future studies.

Conclusions: As 50 years of study of Apollo samples on a wide-variety of topics and planetary bodies has shown, sample return missions are "the gift that keeps on giving." Many of the results highlighted in this abstract were not yet conceived of (or the instruments not yet invented) when the samples were first brought back. However, because the samples have remained available, and been maintained in a pristine manner, future generations of scientists continue to extract greater and increasingly novel value beyond the initial studies. Despite the costs, complexity, and risk (real or perceived) associated with sample return missions, the long-lasting legacy of scientific return for sample-return missions more than offsets these mitigating factors. This is not to say that sample-return missions and sample-related studies are the only type of planetary science that should be pursued, but rather that they are a key component of a holistic way of studying the solar system, combined with remote-sensing and *in-situ* missions, as well as modelling-based and experimental-based studies on Earth.

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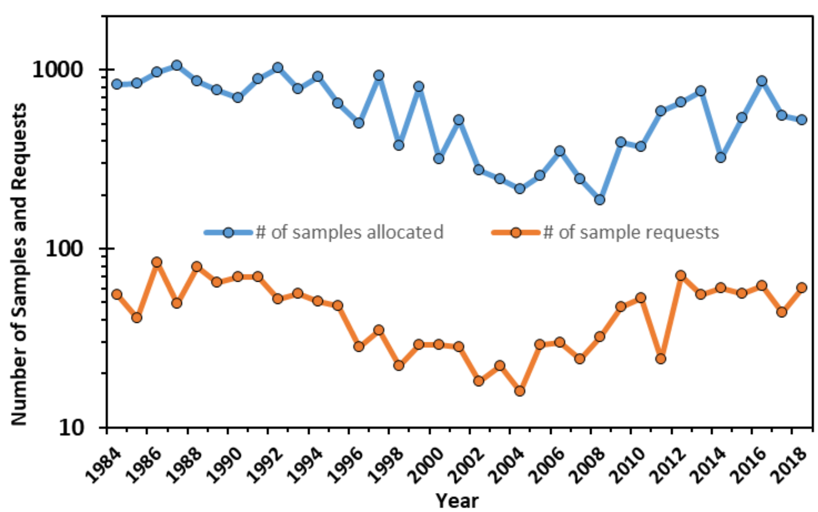

Figure 1: Number of Apollo sample requests and sample allocations per year since 1984. These represent about 40% of the total requests made since 1969.