The Return of Samples by the Apollo Program Shaped Our Understanding of the Solar System. C.K. Shearer, Institute of Meteoritics, Department of Earth and Planetary Science, University of New Mexico, Albuquerque, NM 98122. (cshearer@unm.edu)

Introduction: The Apollo Program remains the only set of missions that enabled humans to land and explore the surface of a planetary body. Apollo 17 illustrated the powerful combination of mobility, science driven, sample site selection, human boots-on-the-ground geological observations, and sample collection that makes it a prototype for future human missions to planetary surfaces. One of the crowning achievements of the Apollo program was to collect and return approximately 381.7 kg of rock and soil from six landing sites located in the central part of the Moon's nearside. It is nearly impossible to decouple sample observations from observations made on the lunar surface and from orbit in examining the fundamental lunar science accomplished by the Apollo Program. Each type of observation provides a variety of perspectives that enrich all observations. For example, whereas samples provide ground truth for remotely sensed data, remotely sensed data provide a regional and planetary context to place returned samples. Here, I attempt to decouple these observations in order to illustrate the important role of samples in redefining how the solar system works and the scientific limitations of an Apollo Program if it did not return samples.

New Concepts of the Solar System derived from Apollo Program Sample: There were numerous concepts derived from the samples returned by the Apollo Program. Many of these concepts were initially proposed during the Apollo Program and continued to evolve over 40 plus years of sample analysis. This presentation explores the role of samples in defining mechanisms for early planetary differentiation, the origin of the Earth-Moon system, and the late, heavy bombardment of the inner Solar System.

Mechanisms for the differentiation of the terrestrial planets: Following the return of Apollo 11 samples, the concept of a lunar magma ocean (LMO) was first introduced based on the recognition that the lunar highlands are composed primarily of Ca-rich plagioclase. This concept was further tested and refined with other sample observations such as: (1) antiquity and geochemical uniqueness of the ferroan anorthosites, (2) complementary europium anomalies of ferroan anorthosites (primordial lunar crust) and mare basalts (derived from LMO cumulates), (3) ancient and variable mantle sources for mare basalts and (4) uniformity of incompatible trace-element ratios that may represent the last dregs of a LMO (i.e. KREEP). The early differentiation of the Moon via a lunar magma ocean has been viewed as an end-member differentiation process that has been extended to other terrestrial planets (Earth, Mars, asteroids).

Late, heavy bombardment of the inner Solar System. In the early-1970s, it was recognized that most highland samples exhibit a Pb-U fractionation that was essentially due to Pb volatilization during metamorphic events in the interval 3.85-4.00 Ga. It was proposed that highland samples from widely separated areas bear the imprint of a series of events in a narrow time interval which were identified with a cataclysmic impacting rate of the moon at ~ 3.9 Ga. This concept was further tested with chronological studies of impact derived lunar lithologies returned by the Apollo Program. This concept is further being tested and modeled to decipher the impact history of the inner solar system and link it to the alignment and potential reorientation of the giant planet hundreds of millions of years after accretion of the planets.

A giant impact origin for the Earth-Moon system: Numerous models had been proposed for the origin of the Earth-Moon system prior to the Apollo Program. However, dynamical constraints and celestial mechanics were not sufficient to pin down the origin of this two planet system. Geochemical measurements of lunar samples provided some contrasts with materials from the Earth with regards to differences in Mg#, oxygen isotopes, refractory elements, and volatile elements. In the mid-1970s, combining the geochemical characteristics of lunar samples, and arguments for a LMO with other constraints led to the concept of the Giant impact model. The recent sample observation that the Moon is more H-rich than concluded after the Apollo Program is not inconsistent with this model. Current missions LRO and GRAIL and potential future missions such as a lunar geophysical network and a sample return from the South Pole-Aitken basin will shed additional light on the bulk composition of the Moon. This will provide additional tests for the Giant impact concept.