WHY AN “EARLY” MARS SAMPLE RETURN: LESSONS FROM APOLLO. D. A. Papanastassiou, Science Division, Jet Propulsion Laboratory, California Institute of Technology, MS 183-335, 4800 Oak Grove Drive, Pasadena, CA 91109-8099, Dimitri.A.Papanastassiou@jpl.nasa.gov.

Introduction: The return of samples by the Apollo astronauts permitted the culling of a plethora of scientific expectations and predictions, which were en vogue, prior to sample return. Many of these expectations about the Moon were not confirmed by the analysis of returned samples. Neither the expectations of a very primitive surface of the Moon, nor of a very young surface and ages, based on observed crater-size frequency curves proved to be correct. The surface of the moon was not primitive, but was in part covered with intermediate-age lava flows, although without evidence of volcanic craters. Some of the physical-chemical processes on the surface of the Moon, such as glass formation and isotope fractionation due to escape of volatilized materials from the Moon were not anticipated. In a similar fashion, mechanical properties of the lunar soil and soil gardening processes were not well known. Certainly, predictions of significant “sinking” in the lunar soil were not correct.

Discussion: One of the main characteristics of science on Apollo samples was the infusion of physicists, chemists, and geologists into the new field of interdisciplinary planetary sciences and the wholesale development of advanced analytical techniques and laboratory instrumentation. These techniques were later applied to terrestrial work and to meteorite research, including Martian meteorites, and have led to major advances. Many of the analytical techniques, which we now take for granted, were developed during and shortly after Apollo, as the result of key science investigations of Apollo samples. I review several such key developments:

Age Dating. The crater size frequency curves could not have “guessed” the actual age distribution of rocks on the lunar surface, which reaches a steep peak at 4.0 Ga ago, with mare basalts essentially limited in age between 3.9 and 3.0 Ga ago. The recalibrated crater size frequency spectrum, based on Apollo sample ages, now peaks either at ~4.0 Ga (according to the Terminal Lunar Cataclysm hypothesis) or is a very steeply increasing curve at ~4.0 Ga, which prevents the identification of earlier surfaces and events. Analytical capabilities for age dating were developed in anticipation of the return of lunar samples and also as the result of the returned samples: a) isotope dating prior to Apollo included the introduction of new high precision (0.01 to 0.005%) isotope ratio determinations and their application to Rb-Sr dating; this success subsequently led to commercial instruments for similarly high precision isotope ratios, introduced in the late 70s; b) the ^{40}Ar-^{39}Ar technique was improved and applied extensively to lunar samples. It was established as a reliable technique, least subject to artifacts from Ar diffusion and ^{39}Ar recoil loss (from fine-grained, interstitial phases, during sample activation in a neutron reactor), when used for the measurement of plagioclase mineral separates from mare basalts; c) in response to the very high U/Pb ratios on the Moon and the low ^{204}Pb abundances, sufficiently low-blank techniques were developed for U-Th-Pb only after the end of the Apollo missions. These techniques enabled mare basalt dating and the work on highland breccias and anorthosites, which established the nature of the parentless, mobilized, radiogenic Pb on the Moon and led to the Terminal Lunar Cataclysm hypothesis; d) the Sm-Nd technique was developed well after the Apollo missions, but to a large extent based on the earlier development of rare earth element chemical separations and solid source mass spectrometry techniques for Gd (and then Sm), developed on meteorites, in full anticipation of secondary neutron capture effects in the returned lunar samples. The Sm-Nd technique has revolutionized lunar, other extraterrestrial, and terrestrial sample dating and the development of fundamental planetary evolution models. This was clearly recognized by the 1986 Crafoord Prize award, in geosciences; e) during Apollo, the rough concentrations of platinum group elements (mostly Ir, with Re measurements being scarce, due to blanks) were obtained by neutron activation. The development of the Re-Os technique, in the early ‘90s, long after the Apollo missions, has permitted the precise measurement of Re and Os systematics and the identification of well-defined exotic meteorite components on the lunar surface and in lunar breccias, as a function of the time of their formation.

Cosmic Ray Irradiation effects. The measurement of cosmic ray irradiation effects used established and improved sensitivity techniques and addressed the range of exposure ages on the lunar surface, which was larger than typical exposure ages of chondritic meteorites. Detailed depth profiles in rocks (including in rocks with documented orientation on the lunar surface) were obtained. In addition, regolith gardening processes were studied as a function of depth down to 2.5 m using thermal and epithermal secondary neutron capture in Gd and Sm isotopes with large neutron capture cross sections. The deposition of meter-thick ejecta, without subsequent disturbance for ~0.5 Ga was established. Based on the results on the first missions, it was even possible to design, qualify for (human) space flight, and fly an in situ secondary neutron detector, the neutron probe, which was returned to Earth for the nuclear track measurements. The techniques for Gd and Sm also led directly to Sm-Nd dating, as addressed above.

Micrometeorite Bombardment and Glass formation. The presence of glass in the Apollo 11 returned samples was a complete surprise, and a source of some fun and wonder, in finding glass, glass spheres and dumbbells, hollow glass spheres, plus micro meteorite craters on the various glasses, termed “zap pits”. By contrast, we now fully expect the formation of glass and agglutinates on an airless planetary surface, exposed to micrometeorite bombardment. However, at the time, the formation of glass as well as the reduction of Fe by the solar-wind hydrogen in Fe-bearing silicates, which resulted in darkening of Fe-bearing minerals and the overall modification of their spectroscopic signatures in the VIS-NIR were important for orbital science. This required a substantial recalibration of the spectroscopy of the surfaces of airless bodies and substantial improvements.

For stable isotopes, the earliest recognition of isotopically heavy oxygen and then silicon (as well as small effects for Ca, in weak acid leaches of soils) on the surfaces of lunar soil grains also established a new process of isotope fractionation on airless surfaces, presumably through meteorite and cosmic ray bombardment, accompanied by preferential gravitational loss of the lighter isotopes.

Lessons for Mars: The case of Mars is admittedly more complicated than the lunar case, because of the presence of water, of an atmosphere, and an expected magmatic evolution that is potentially less restricted in time than the lunar case. But precisely because of extensive data from orbital and in situ missions, it is imperative that ground truth be obtained through returned samples. Much of the complexity envisioned on the surface of Mars dictates the need for a more complex sampling process for returned samples than, for example, a simple grab-and-go mission that can be used for the Moon. However, any proposed complexity of sample collection techniques for a Mars sample return mission would need to address the quality of instruments, available to characterize samples prior to their return and the complexity of sample collection techniques. It would be a mistake to expect to do extensive, in situ instrument-based field work on Mars, prior to selecting samples for return. Based on our experience with Apollo, our ability to characterize complex samples, in situ, in the potential presence of igneous, sedimentary, and altered rocks, and in the presence of wind-blown fine materials is limited. It would make sense to seek diversity of rocks in the returned samples through the collection of different components based on relatively simple characterization (visual and IR spectroscopy), and field location. It is good to remember that even for Apollo 11, a contingency sample was quickly obtained and then returned. It was from this contingency sample that rather major conclusions of lunar evolution were drawn, including the observation of anorthositic fragments (interpreted as evidence of a lunar-wide anorthositic crust) and a granitic fragment (dubbed Luny Rock 1) which allowed the identification of a Rb-Sr model age much older than the age of the local basalts, and close to the age of the solar system. Arguably, this fragment was a harbinger of the KREEP-rich component on the lunar surface, recognized primarily based on Apollo 14 samples and its extent on the lunar surface, later, by orbital data.

Conclusion: This long list of achievements indicates the importance of returned samples, the recognition of new processes, based on analysis of returned samples, and our distinct lack of anticipation of processes on the surface of another planet from orbital and in situ data. It is also important to keep in mind that, even an “early” proposed Mars sample return mission, e. g., by 2020, would be more than 12 years in the future and sufficiently distant for further significant analytical instrument developments in terrestrial laboratories. Such improvements will certainly come in surface science, following the developments fueled by the GENESIS and STARDUST missions and returned samples (and funded by NASA SRLIDAP). Certainly, improved sensitivity would be in order, for all investigations, since any sample collection, returned from Mars, would be considerably smaller (by a factor of about 1000) than the amount of materials returned by Apollo.

Acknowledgement: This review and perspective is based on innumerable published results, by a myriad of investigators, over decades. A formal reference list is not possible. It is hoped that those who participated in these developments will fondly remember their effort and excitement. The Apollo generation blossomed nearly forty years ago. It is time for a Mars return sample generation to blossom and interact with the extensive work based on orbital and in situ science, already in hand and ongoing. Government sponsorship acknowledged.