SAMPLING STRATEGIES FOR LUNAR SAMPLE RETURN MISSIONS. G. Jeffrey Taylor[1], Hawaii Institute of Geophysics and Planetology, Univ. of Hawaii, Honolulu, HI 96822; gjtaylor@higp.hawaii.edu.

Introduction: Sample return missions are a central part of any future lunar exploration strategy. Sample studies are synergistic with orbital and other types of landed missions by providing ground truth and strikingly accurate and precise data on ages, isotopic compositions, major and trace element concentrations, mineralogy, and rock textures. The major problems in lunar science have been outlined in numerous reports, the most recent of which is [1]. Here I discuss which of three sample collection strategies address these important questions: (1) rover missions equipped with advanced instruments for *in situ* analysis, (2) simple sample return missions (no rover, one landing site), and (3) sample return accompanied by extensive field studies. For each, I outline how they contribute to achieving the goals listed in Table 1 and give examples of types of landing sites; a large list (somewhat outdated now) of landing sites is given by [2]. (In Table 1, the numbers and letters indicate science goals identified in the NRC report [1], omitting those where sample return does not contribute. Wording of goals has been shortened in some cases. Lunar polar volatiles have not been considered in this paper.)

***In Situ* Sample Analysis.** The Mars Exploration Rovers have demonstrated how valuable robotic field work can be if the proper instruments are carried. Teleoperated robots, operated from Earth or from a lunar outpost, can study large areas and analyze geologic units quantitatively [3,4]. Advances in technology will lead to continuously improved analyses. It may be possible to measure ages, for example of mare basalts, to ~10% relative accuracy [5]. An example of a rover mission is to determine the mineralogy, concentrations of major and minor elements, and ages of numerous mare basalt units while traversing within several adjacent maria. This will provide a broad characterization of mare basalts and help calibrate the impact-flux curve by dating specific surfaces. Another example is for rovers to visit a large number of relatively young (<1 Gy) impact craters to test for variations in the flux of projectiles over the past billion years. The ages could be determined by mass spectrometric measurements of cosmic-ray produced isotopes, perhaps to 5–10% relative accuracy. Sample returns from such craters would provide much more accurate ages, but it is unlikely that we will be able to return samples from enough craters (hundreds are needed).

Simple Sample Return Missions. These are Luna-type missions in which there is no or limited mobility. Samples might be cores but are more likely to be bulk regolith and sieved regolith containing particles in the ~ 4–20 mm size range. Such sample returns are useful for reconnaissance (broad characterization) or to address specific questions (e.g., precise age of the youngest mare basalt) [3]. An example is collection of samples from the floor of South Pole-Aitken (SPA) basin aimed in part at testing the idea of a lunar bombardment cataclysm, but mostly for improving our understanding of the compositions and petrology of the rocks composing its floor.

Sample Return Accompanied by Field Studies. The goal of field studies is to understand geologic processes and units at all levels of detail. It is long duration and iterative, necessitating the return to a site. It absolutely requires human observational ability, intelligence, and experience. Field work has been been done on the Earth and Moon directly by humans, but through teleoperated robots [3,4]. Telerobitic field work is a component of *in situ* analysis, and field studies can benefit by *in situ* analysis. In general, field studies and sample return should be applied to complex sites and problems, such as testing the cataclysm hypothesis by searching for samples of the SPA impact melt so the basin can be dated directly. A particularly important and unambiguous field study would be to examine and sample the walls of trenches excavated meters into the regolith to understand its structure and evolution. Searching for ancient regolith between layers of datable basalt also requires field study to sample properly and to put the samples into geologic context, to understand the origin of the regolith and the record of the Sun it potentially contains.

References: [1] National Research Council (2007) *The Scientific Context for Exploration of the Moon* , http://www.nap.edu/catalog/11954.html. [2] Ryder, G., Spudis, P.D. and Taylor, G.J. (1989) *Eos* **70**, 1495, 1505-1509. [3] Taylor, G.J. and Spudis, P.D. (1990) *Engineering, Construction, and Operations in Space II*, 246-255. ASCE, New York. [4] Spudis, P.D. and Taylor, G.J. (1992) *The Second Conference on Lunar Bases and Space Activities of the 21st Century* (W.W. Mendell, ed.), NASA Conf. Pub. 3166, 307-313. [5] Anderson, F. S. (2007) *Astrobiology*, submitted.

Table 1. Science problems and their relation to *in situ* analysis, and simple and complex sample return missions.

Science Goals	***In Situ* Sample Analysis**	**Simple Sample Return**	**Field Studies + Sample Return**
1a,b. Test cataclysm hypothesis	Not possible because ages need to accurate to ± 0.01 Gy (0.25%).	Significant progress can be made by sampling SPA basin, but may not identify the SPA melt rock. Samples from other basins (e.g., Nectaris) *might* be less ambiguous.	Could remove most of ambiguity, but may require numerous sites, particularly to date basins superimposed on SPA. Other basins, such as Nectaris, might also require field work.
1c. Establish a precise absolute chronology (of the early solar system)	Not possible because ages need to accurate to ± 0.01 Gy (0.25%).	Several well-chosen sites could constrain the ages of stratigraphic markers (e.g., Copernicus and the Orientale and Nectaris basins).	Not necessary, except possibly for Nectaris.
1d. Assess the recent impact flux	It may be possible to date numerous (100s) craters younger than ~ 1 Gy by measuring cosmogenic isotopes to an accuracy of ~5–10% (rel).	Individual craters can be dated by returning samples from ejecta or impact melt sheets. Though valuable for calibration, 100s of craters need to be dated.	Not necessary.
2d. Characterize the thermal state of the interior (includes the mantle, hence samples are important)	No.	A properly chosen site (e.g., in SPA) could contain samples of the mantle	Searching for mantle samples in SPA and other basin deposits, and xenoliths near vents of pyroclastic eruptions benefit from extensive field work. Paleomagnetic measurements require oriented samples.
3a,b Determine full range of compositions of lunar crustal rocks	MER-type missions could provide vital information about diversity of rocks on the lunar surface.	Well-chosen sites on diverse terrains identified from orbital data would provide valuable samples.	Samples collected during field studies provide details about their relation to one another.
3c,d,e Composition of lower crust and megaregolith	Useful if sent to places where lower crust has been excavated; e.g., basin impact melts, central peaks	Well -chosen sites in and around basins (e.g., SPA) would provide useful samples.	Field studies enhance odds of finding appropriate samples and provide their geologic context.
5a,c Variability of mare basalts and pyroclastic deposits	Broad compositional characterization can be done with *in situ* measurements	Remote sensing data allows selection of landing sites (many) that provide the full range of mare basalts	Field studies could reveal the details of processes operating inside lava flows
5b Ages of youngest and oldest mare basalts	Youngest could in principle be dated *in situ* to ~10% (rel) accuracy, sufficient to help calibrate the crater flux curve.	The youngest basalts have been identified by crater counting, hence could be collected readily. The oldest requires sampling dark-halo craters.	No need to target the youngest basalt for field work. Additional information is needed to understand cryptomaria. The oldest mare basalts are in highland breccias; their collection requires field observations.
6a–d Study the impact process	Useful for studies of impact features.	Limited role.	Essential for understanding the impact process in detail.
7a–d Regolith processes	Limited use.	Limited or no use.	Essential to find buried ancient regolith and for studies of regolith exposed by trenching.