ON A SURFACE-SAMPLE COLLECTION STRATEGY FOR MARS, WITH LESSONS FROM LUNAR SAMPLING.

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The lunar surface: All the samples from the Moon, whether Apollo samples, Luna cores, or lunar meteorites, are materials from regolith. The lunar regolith was produced by impacting meteoroids ranging in size from tens of kilometers to micrometers. The impact process excavates and destroys rocks, distributes the fragments widely, produces breccias and melts (which become crystalline melt breccias and glassy materials), and mixes materials from different provenances into deposits that extend substantial distances from the impact site. Thanks to this mixing, the lunar regolith is well suited to a simple grab-sample strategy, although that is not the best approach. One could learn much about the nature of, say, the giant South Pole-Aitken basin from a grab sample taken almost anywhere within it because that sample would contain rock fragments from local and distant areas. Except those from the mare regions, where lava flows and pyroclastic eruptions postdated the largest impacts, the lunar samples are almost exclusively polymict breccias and glassy materials, with a few fragments of monomict, mainly plutonic igneous rock. For general information about the Moon, see [1].

The martian surface: On Mars, impact cratering also produced a regolith, but additional processes have modified it. These include probable fluvial activity, possible large and small scale lacustrine activity, almost certain hydrothermal alteration, possible surface chemical weathering, and abundant aeolian activity, all active beyond the time of heavy impact bombardment. The martian regolith is thus locally not dominantly rubble from meteoroid bombardment.

We have a general picture of martian materials from the thermal emission spectrometer (TES) experiment on the Global Surveyor and the observations of the Viking and Pathfinder missions, and we have samples from Mars (the SNC meteorites). Exposed crustal bedrock appears to be dominantly mafic and little weathered [2], like the SNCs; there is no evidence for early crust other than basaltic. Wind-borne dust is the result of erosion, comminution, separation, and mixing. The presence of hydrous minerals is anticipated, based on spectral measurements [e.g., 3], knowledge of terrestrial weathering processes [e.g., 4,5], morphological features associated with aqueous activity, and the near certainty of hydrothermal activity. Patches of crystalline hematite seen from orbit have been interpreted as chemical precipitates rather than products of weathering [6]. A variety of soils, aeolian dust, and duricrust, all bearing Fe^{3+} and S, were observed at the landing sites [5,7]. No carbonate, sulfate, or hydrous minerals have been reported from the TES experiment [2]. *Hydrous* ferric oxides have been only tentatively observed by on-surface measurement [8]; they do not have the characteristics of hydrolytic or sulfuric weathering processes considered so far [4].

A grab sample? Logistically, a grab sample may be the easiest kind to get from Mars. A grab sample is a limited and risky means of sampling a landing site, however. A simple lander may find itself out of arm's reach of material of suitable variety. Mars has both mixing and significant secondary separation processes. Sedimentary sorting has significantly affected the regolith. Sand and pebble deposits have been described at the Pathfinder site [9]. Samples of all types should be collected, and this requires mobility.

Evidence for the origin of life is best sought at this stage of Mars exploration on collected samples in terrestrial laboratories. The widest possible variety of material that a landing site has to offer for mineralogical and chemical evidence of action by water should be analyzed using instruments too sophisticated to deploy on the surface. Success will require clever choices of landing sites, the ability to discover the full range of materials available at each site, and collecting the full variety for transport to Earth. Sample selection should be done in full geologic context, with orbital imagery and on-surface robotic characterization of accessible materials at close range.

Lunar sampling: What types of sample might be the most useful? We have insight from lunar sampling. The Apollo astronauts took several main types of sample: individual rocks (typically >100 g), smaller rocks ("walnuts") separated with a rake, and regolith (soil) as scooped bulk samples and in drill cores and drive tubes. Bulk soils were sieved into four size ranges: <1 mm (fines), and 1–2 mm, 2–4 mm, and 4–10 mm "coarse fines." The coarse fines contain recognizable fragments of the same rock types as the large rocks, but are more variable and numerous enough to allow useful statistical sampling. The average chemical compositions of the larger size fractions do not in general match those of the <1 mm fines, because of mixed provenances

contributing unequally to different size ranges. Each size has its advantages. For calibration of some remote techniques, the fines are more important than the rocks. Also, bulk <1-mm fines give definitive information about the regolith, its formation and evolution, and its interaction with solar and cosmic radiation. Sampling of large rocks was biased, intentionally, as the astronauts strove for variety. For a given mass of sample, however, less has been learned about lithologic variability from the large rocks than from the rocklets (mainly 1–4 mm).

For lunar petrology and geochemistry, 2–4 mm particles (mass range ~10–100 mg) have proved ideal for many purposes. A single sample can be analyzed for trace and some major elements by instrumental neutron activation analysis (INAA), then sawed in two and a thin section prepared of one half for petrographic study and mineral chemical analysis by electron probe microanalysis (EMPA). The other half can be used to obtain an age (if properly planned in advance) or can be melted for precise major-element analysis of the resulting glass bead. We have analyzed hundreds of these small lunar samples by INAA and have done petrography and EMPA mineral and bulk major-element analysis on samples selected on the basis of the INAA results [e.g., 10–12]. A few representative large rocks provide context for evaluating the textural and compositional variability of small samples, and some isotopic methods require larger samples. Most large non-mare rock samples are breccias consisting of small rock fragments that are most fruitfully studied as individual rocklets, as done for the coarse fines. Chemistry and petrography can be done on individual 1–2 mm coarse fines [e.g., 13], but the limited mass restricts the number of experiments and the representativeness of the samples. An early first-order observation about the Moon was made from the study of 1–4 mm particles in the Apollo 11 regolith [14]. Unexpectedly for a regolith dominated by mare basalt, 5% of the particles were anorthositic, leading to the robust hypothesis that the highland crust was predominantly cumulus, low density plagioclase.

Suggestions for martian sampling: Based on our experience with lunar samples, we offer these suggestions for sampling on Mars [see also 15,16]. Assume we can bring back ~0.5 kg of material from a landing site. The "large rock" sample size should not exceed ~5 g so that 10–20 such samples (≤100 g) can be collected without compromising the acquisition of bulk fines and larger regolith particles. The Mars style would be selection of large rocks for sampling on the basis of on-surface sensing, followed by coring or chipping. Spalling of the larger rocks at the Pathfinder site by meteorite bombardment has been documented [17], so small samples of large rocks should also be available in the local regolith. At least half of the material to be collected could sensibly be rocklets in the ~1–5 mm size range. Although this size is chosen on the basis of lunar materials, the grain size range of the martian meteorites suggests it could be appropriate for the study of martian rocks, as well. If rocks of larger grain size are encountered, we could infer their presence from large mineral grains among the 1–5 mm materials, as was done for the discovery of lunar anorthosite [14]. Pervasive alteration would render this size fraction less useful for characterization of larger rocks or precursors on Mars than on the Moon, but the weak alteration of the SNCs and the observation that the dark regions of Mars are little altered [2] suggest the risk of this is minimal. These rocklets should be collected at different locations and in the context of the local geology. The Apollo 17 mission illustrates the need for mobility to investigate a geologically complex landing site where a grab sample out of context would be confusing [18]. Duricrust should be sampled. Obviously sorted deposits should be sampled with a scoop or as short cores; 10 g per sample should suffice for sands or granules, but sampling of small pebble deposits (<0.8 g each) might require ~20 g per sample. Among the sand-pebble samples, we should find the available variety of rock types, whether gathered by a stream from a broad provenance, or unsorted from an impact-dominated regolith. Finally, 10–25-g samples of bulk regolith should be collected from several sampling stations. Bulk material from the Mars regolith will be an important part of the sample suite from any landing site; it is particularly important for the first sample return because it is clearly different from the martian meteorites and because it is the material that most influences remotely sensed compositional and mineralogical information.

References: [1] Heiken, G. et al., eds., 1991, *Lunar Sourcebook*, Cambridge; [2] Christensen, P. et al., 2000, *JGR* **105**, 9,609; [3] Calvin, W., 1997, *JGR* **102**, 9097; [4] Morris R. et al., 2000, *JGR* **105**, 1757; [5] McSween et al., 1999, *JGR* **104**, 8679; [6] Christensen, P. et al., 2000, *JGR* **105**, 9623; [7] Clark, B. et al., 1982, *JGR* **87**, 10,059; [8] Bell, J. et al., 2000, *JGR* **105**, 1721; [9] Moore, H. et al., 1999, *JGR* **104**, 8729; [10] Jolliff, B. et al., 1991, *Proc. Lun. Planet. Sci. Conf. 21*, 193; [11] Jolliff, B. et al., 1996, *Meteor. Planet. Sci.* **31**, 116; [12] Zeigler, R. et al., 2000, *Lun. Planet. Sci.* **31**, abs. no. 1859; [13] Blanchard, D. et al., 1975, *Proc. Lun. Sci. Conf.* **6**, 2321; [14] Wood, J. et al., 1970, *Proc. Apollo 11 Sci. Conf.*, 965; [15] Korotev, R. & Haskin, L.,1988, *Workshop Mars Sample Return*, M. Drake, ed., LPI Tech Rpt. 88-07; [6] Korotev R. et al., 1997, *7th Goldschmidt Conference*, abstr. p. 116–117, LPI Contribution 921; [17] Hörz, F. and Cintala, M., 1999, *Lun. Planet. Sci. 30*, abs. no. 1641; [18] Schmitt, H., 1973, *Science* **182**, 681.