SIEVING AS A FORCE MULTIPLIER FOR LUNAR SURFACE SAMPLING. Paul H. Warren[1], Bradley L. Jolliff[2], Randy L. Korotev[2] and Yang Liu[3]. [1]Earth, Planetary and Space Science, UCLA, Los Angeles, CA 90095, USA, pwarren@ucla.edu, [2]Earth and Planetary Science, Washington Univ. St. Louis, MO 63130, USA. [3]Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA 91109, USA.

Introduction: The lunar surface is ubiquitously blanketed by impact-processed regolith, which consists mainly (generally about 90 wt%) of lithic particles small enough to pass a 1 mm sieve. Bigger fragments occur, near-randomly scattered, but grow more and more scarce with increasing size. Regolith is thus the most accessible material for lunar sampling, but preferential sampling of its coarse component is needed for efficient collection of fragments large enough to serve as representative rock samples. (Ideally, a rock sample should be large enough to be representative for the most coarse-grained type of rock in the region, and also to allow for employment of a multitude of petro-analytical methods.) Future lunar missions will likely accomplish this preferential sampling by in-situ sieving, as the astronauts did, to some extent, with "rakes" on three Apollo missions. In-situ sieving should be doable with a reasonably sophisticated automated probe, such as a rover. The purpose of this work is to facilitate future mission planning by constraining relationships among various lunar soil grain size distributions, sieve-size range selections, and parameters such as average sieve fragment mass, yield of sieve fragments, and volume of soil needed to acquire a target amount (number or total mass) of sieve fragments.

Methodology: The first step is to constrain typical lunar soil grain-size distributions. Averages of the relevant data, conveniently compiled by [1] and [2], are plotted in Fig. 1, where the y-axis is wt% coarser on a "probability" scale. We evaluate two versions of the average/typical lunar soil. For both versions, we exclude a few Apollo 15 and 17 "soil" samples that are more or less pure clods of mare-pyroclastic glasses. One version goes further in excluding oddly situated soils such as boulder fillets and trench bottoms, and we take this selective version as our nominal, preferred model.

Figure 1 also shows distributions based on averaging the 5 most fine-grained and the 5 coarsest soils as subsets of the "selective" data set. Finally, we have evaluated the ultra-fine-grained Apollo 15 soil 15090.

Figure 1, and fitted curves to the various size-distribution models, constrain the wt% of soil within any selected sieve size range; and thus (indirectly) the average size of all the material in the sieve size range, i.e., the size at which half the mass (within the range) is below and half is above. For conversion between sieve size and equivalent spherical diameter, d_V, we use the result of Heywood [3] (cf. [4]) who found that lunar soil grains are on average fairly equant, such that $d_V/A = 1.24/1.28$, where A is the sieve size (length of each side in the sieve's square openings). For translation from volume to mass, we assume fragment density averages 2.8 g/cm^3. For any given soil type, calculated grain size results show highly systematic relationships to the sieving conditions (lower bound and range). Figure 2 shows just a few examples. To facilitate evaluation of the potentially infinite variations in combinations of sieving range and soil grain-size distribution, we derived equations (polynomial fits) to model the grain sizes implied by a wide array of sieving scenarios.

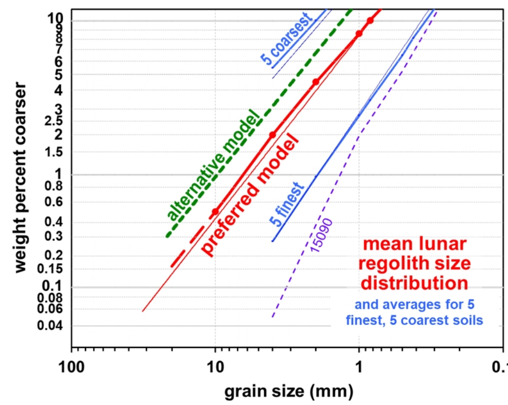

Fig. 1. Fragment-size distributions studied in this work.

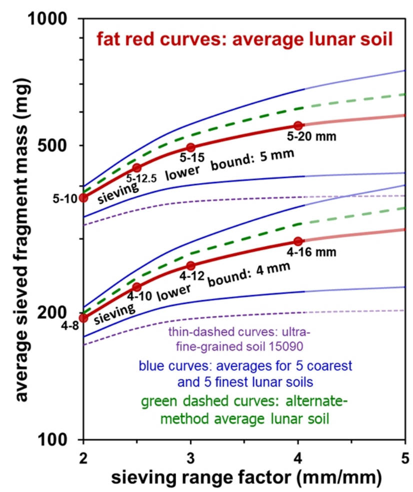

Fig. 2. Examples of sieve fragment mass as an orderly function of sieving range factor, sieving lower bound, and soil type.

Results from this method are confirmed by good agreement with averages from direct measurements of Apollo 2-4 mm and 4-10 mm coarse fines (Table 1). In application, density may be adjusted for anorthositic (Apollo 16-like) versus mare-basaltic lithic materials.

Trade-offs: Model-predicted yields from one set of sieving scenarios, based on our preferred mean lunar soil grain-size distribution, are illustrated in Fig. 3.

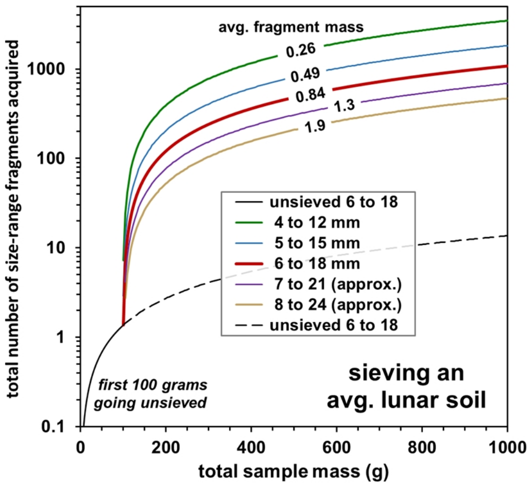

Fig. 3. Some results for sieve fragment yield as a function of mass acquired and sieving range, for typical lunar soil.

These scenarios all assume that sampling begins with 100 grams of unsieved soil, followed by up to 900 additional grams of sieve fragments. Some trade-offs are evident. Sieving at coarser scale results in fewer but larger sieve fragments. In any case, even a small proportion of sieved material results in vastly higher yields of the large fragments than would be obtainable from later, ex-situ processing of a simple unsieved sample.

Figure 4 illustrates another trade-off. Sieving at coarser scale results in larger fragment mass, but at the expense of needing to sieve through larger and larger volumes of regolith (we assume bulk soil density is ~ 1.6 g/cm^3 [12]). An automated system would likely be able to sieve many tens of liters, but >>100 L might pose an engineering challenge. Of course, Fig. 4's scenario of up to 1 kg of sieve fragments is somewhat arbitrary. A small fraction of that mass would still imply a vastly enhanced yield of large fragments (Fig. 3).

An in-situ sieving endeavor might inadvertently target a very uncommonly fine-grained soil, in which case the sieving volume requirement might conceivably be a major problem. The case of 15090 warrants special consideration (Fig. 4). For any given moderate choice of sieve-size range, compared to average lunar soil 15090 requires roughly 40 times more volume of soil being sieved for a given yield (total mass) of coarse fragments. However, it bears repeating: 15090 is a very exceptional soil (Fig. 1). Plus, a soil as fine-grained as 15090 can probably be avoided without much trouble. The area where 15090 was collected was "notable for its fine texture" with a conspicuous dearth of 1-10 cm sized fragments [13]. Conversely, for the case of a mission where the volume-to-sieve is a major concern, it should be easy enough to select an area in which cm-sized fragments are conspicuously abundant in surface imaging (with a slight risk that the coarse fragments might be to an unusual extent dominantly products of a

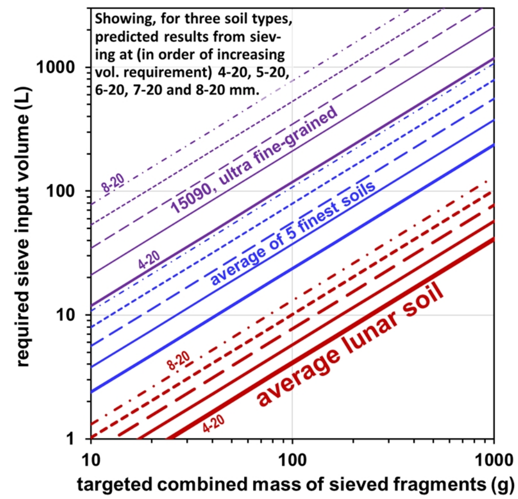

Fig. 4. Some model results for required sieving input volume as a function of sieved mass to be acquired and sieving range, for three different types of lunar soil.

single nearby crater-ejecta-deposition event).

Prospects: Apart from engineering considerations (mainly, what volume of soil can safely be accessed and sieved), sieving strategy for any given mission might be tailored to the anticipated rock types at the sieving location. A locale underlain by fine grained basalts might prompt a smaller choice of sieving size-range than a location where a key mission goal is to sample coarse grained plutonic rocks.

References: [1] Morris R.V. et al. (1983) NASA *Handbook of Lunar Soils*. [2] Graf J.C. (1993) NASA *Lunar Soils Grain Size Catalog*. [3] Heywood H. (1971) *Proc. Lun. SC* **2**. [4] Tschuchiyama A. et al. (2022) *Earth Pl. Space*. [5] Warren P.H. (2001) *JGR-Planets* **106**. [6] Marvin U.B. (1978) *Apollo 12 Coarse Fines*, NASA. [7] Kramer F.E. and Twedell D.B. (1977) *Apollo 14 Coarse Fines*, NASA. [8] Powell B.N. (1972) *Apollo 15 Coarse Fines*, NASA. [9] Marvin U.B. (1972) *Apollo 16 Coarse Fines*, NASA. [10] Meyer C. Jr. (1973) *Apollo 17 Coarse Fines*, NASA. [11] Ryder G. et al. (1988) *PLPSC* **18**. [12] Carrier D.W. III (2003) *J. Geotech. Geoenviron. Eng.* [13] Swann G.A. et al. (1971) *Preliminary Description of Apollo 15 Sample Environments*, USGS.

Table 1. Summary of mass/fragment constraints for Apollo coarse fines samples

	Apollo 12	Apollo 14	Apollo 15	Apollo 16	Apollo 17
4-10 mm fines (our average soil model predicts avg fragment mass = 231 mg)					
number of frags	314	610	910	1308	1965
avg mass (mg)	247	245	231	206	258
Std Deviation	333	211	117	125	207
SE of mean (%)	7.6	3.5	1.7	1.7	1.8
grain density*	3.2	3.1	3.14	2.9	3.3
rock density (est.)	2.82	2.73	2.76	2.55	2.90
d_V (mm)	5.51	5.56	5.42	5.36	5.54
2-4 mm fines (our average soil model predicts avg fragment mass = 25 mg)					
number of frags	1396	381	545	506	794
avg mass (mg)	24.5	27.4	<27.5	20.7	22.7
Std Deviation	12.8	17.4	-	8.7	17.9
SE of mean (%)	1.4	3.3	-	1.9	2.8
d_V (mm)	2.55	2.68	<2.7	2.49	2.46

* Mineralogical grain densities from [5]; estimated rock densities assume 12% porosity.
Data sources: [6-11], and (for 2-4's from Ap-14, -16 & -17) this work (R.K. & B.J.).