GRAIN SIZE AND DENSITY SEPARATION ON ASTEROIDS: COMPARISON OF SEISMIC SHAKING AND FLUIDIZATION.

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Introduction: One of the most important discoveries of the NEAR Shoemaker mission to Eros was the “ponds”, flat regions (relative to surrounding terrain) inside craters that exhibit a slightly bluer reflectance spectra than most of the asteroid [1]. Ponds have been interpreted as being composed of finer-grained material than the rest of the asteroid surface. Formation processes for ponds include electrostatic levitation, seismic shaking, and fluidization [2,3]. In each case, a force (charging from solar wind, shaking from meteoroid impacts, or gas flow from the interior, respectively) results in a separation of fine-grained material on the surface which, due to down-slope movement, results in formation of accumulation of fine-grained material in depressions. Here, we present results of experiments assessing the effects of shaking and fluidization on chondritic-like analogs. We have previously conducted laboratory and micro-gravity fluidization experiments on chondrite analogs [4,5,6].

Freely moving/flowing particles exhibit behavior intermediate between solids and liquids [7]. One result is that grain-size sorting can occur in shaken or flowing groups of particles, analogous to grain-size sorting that occurs in more dilute aqueous systems such as lakes and rivers. However, particle-based systems exhibit some unusual properties, including “inverse” size-sorting, where large particles can be preferentially sorted to the top of a particle flow (sometimes called the “Brazil nut effect”) [8]. Importantly, grain-size sorting in these systems solely reflects the movement of particles, and thus does not require any pore gas or fluid, and thus could occur on anhydrous bodies.

Methods: For our experiments, we used chondrite analog “regolith” composed of sieve-sorted quartz sand and iron metal grains. This mix is not intended to be a chemical analog of typical asteroid regoliths, which are inferred to be mixtures of feldspar, pyroxene/olivine, and (probably) iron metal and sulfides (based on meteorites and reflectance spectra of asteroids) [e.g., 9]. Rather, the mixture is intended to be a grain-size/density analog of an asteroidal regolith, with the sand grains serving to mimic silicates and the iron metal intended to simulate both iron metal and sulfides. We use several grain size fractions of both sand and metal to bracket the grain sizes observed in meteorites. We combined grain-size separates of iron and sand, or different grain-size separates of sand (Table 1). Each mixture was then shaken laterally between 50-80 times, and the grain-size structure of the result noted.

Results: Our results are summarized in Table 1. We find that for both our sand-metal and sand-sand mixtures, there was a general tendency for the larger grains to move to the top of the bed during shaking (Fig. 1). In some mixtures, however, the end result was a homogeneous mixture, or a segregated layer of grains a few millimeters below the surface (experiment #3). Homogenous mixtures resulted from nearly equivalent grain-sizes. Grain size sorting, when it occurred, occurred rapidly after start of shaking, typically within 10-20 lateral cycles. Sorting, when observed, tended to be very efficient, with nearly complete separation (Fig. 1c). The result appeared to depend on the degree of difference in grain size (Fig. 2), with large differences in grain sizes showing the greatest tendency to produce strong layering. For comparison, gas fluidization results at 1g for the same mixtures are given in Table 1.

Discussion: Our major observations are:

(1) For “chondritic” mixtures, grain-size separation typically occurs easily with shaking, with the larger grains tending to go to the top of the bed.

(2) Lateral shaking, used here for reproducibility, is not considered as efficient at producing grain-size separations in particle beds as vertical shaking [8]. This may explain the results of experiment #3, with production of a partial separation with a layer forming within the main mass of the bed.

Table 1. Summary of experiments at earth gravity using mixtures of sand and iron metal grains.

No.	"Ave" Sand (microns)	"Ave" Metal (microns)	Shaking Result	Fluidization Result*
1	310	60	Metal to bottom	Metal to top
2	310	360	Mixing	Metal to bottom
3	200	60	Metal to bottom#	Mixing
4	200	360	Metal to top	Metal to bottom
5	260	360	Metal to top	Metal to bottom

*For “metal-poor” (<15% iron metal by volume) mixtures.

Partial segregation. Metal layer formed 4-5 mm below surface, but above bottom of vessel.

“Ave” = average grain size.

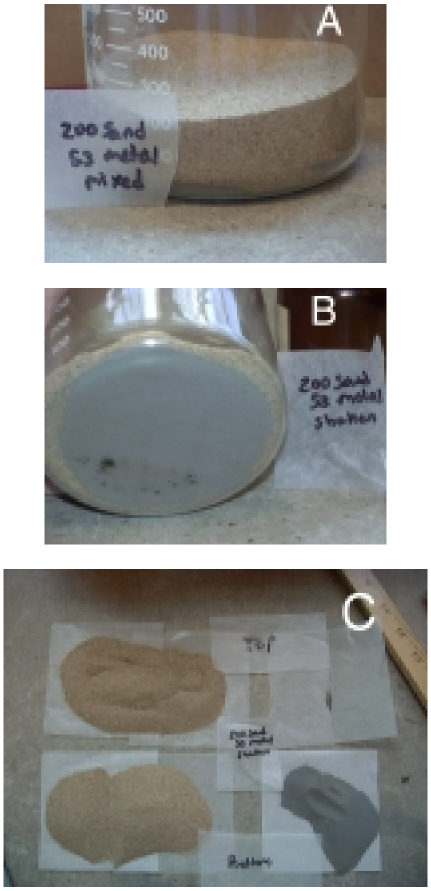

Fig. 1. A shaking experiment using a sand/iron metal mixure. A homogeneous mixture (A) was shaken laterally, resulting in rapid grain-size sorting, with fine-grained metal to the bottom (B). A sample taken from the top half of the experimental charge has only traces of iron metal (top of C) but a sample from the bottom of charge is rich in iron (bottom of C).

(3) If shaking, such as that generated by meteoroid impacts, is significant on "chondritic" asteroid regoliths, our experiments suggest that grain size separation should occur, with coarse grains rising to the surface. Depending on whether metal or silicates are coarser-grained, this could result in radical changes in the surface reflectivity properties, as we have seen in experiments in the Andromeda planetary environmental chamber. It does not, however, appear possible to concentrate finer-grained material on the surface, as suggested for pond formation.

Our experiments fail to simulate asteroids in some obvious ways, notably in the pore atmosphere in our experiments that should be lacking on asteroids, and the presence of a significant gravitational force, compared to the microgravity of asteroids. In addition, our experiments do not encompass the full range of sizes of "grains" observed on asteroids (which range up to meter-sized boulders), and our regolith analogs do not mimic inferred asteroidal regoliths in terms of mineral composition. The presence of pore gas should, if anything, act as a "frictional" force to slow down or prevent grain-size separation. Shaking separation is based on grain size rather than mineral composition, unless the grains deviate significantly from spherical shapes, or have natural "stickiness". The difference in gravity regimes is more difficult to assess, as the shaking process implicitly uses gravity as a force to aid in separation. We have run two sets of experiments using sand/iron grain mixtures on the NASA KC-135 "vomit comet" testbed [5,6]: These experiments differ from those described here because (1) No attempt was made to actively shake the systems under microgravity, so the systems were only shaken by the aircraft's vibration, and (2) the gravity regime of the experiments was not constant, ranging from 2g to negative g over a period of less than a minute. Despite these differences, we noted a tendency in unfluidized beds for larger silicate grains to rise to the surface in a bed containing 5% finer-metal grains (by volume) in the microgravity experiments, consistent with the present results. In contrast, during microgavity experiments with fluidization by gas flow, grain/density separations are similar to those noted for 1g experiments (Table 1).

Conclusions: We suggest that processes other than vibration or seismic activity, such as fluidization by gas flow which produces grain size separation dependent on both density and grain size, are more likely to produce fine-grained ponds on asteroids. The difference should be apparent in future asteroid missions, such as the HERA mission [10]. Seismic grain-size separation should occur on all airless bodies (subject to impacts), while fluidization should only occur on bodies with a volatile source, such as buried ice.

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