REGOLITH TRANSPORT: SHAPE (AND SIZE) MATTER. D. Y. Wyrick[1], H. Başağaoğlu[1] and R. Patterson[1], [1]Southwest Research Institute (6220 Culebra Road, San Antonio, TX; dwyrick@swri.org).

Introduction: Regolith materials on dry, airless bodies such as the moon and asteroids are produced and modified by processes that grade grain shapes toward both high angularity and low sphericity [1]. Both angularity and sphericity influence grain aspect ratios and surface area availability at the microscale and bulk transport processes such as settling at the multi-particle macroscale. Grain sphericity and size distribution influence a material's overall porosity and may influence the resultant geomorphic expression [1,2].

On the moon, near-surface regolith has a high porosity (50%) in the top 15 cm [3]. This high porosity reflects the main emplacement process, ejecta fallout, on airless planetary bodies. However, at depths of >15 cm, penetration resistance increases rapidly, with resistance reaching greater than 1000 kPa within 50 cm of the surface [4]. Previous testing of ~44-74 µm material showed that highly angular, non-spherical particles achieved large angles of repose, in some cases nearly 90°, relative to round, spherical particles of the same size range [1]. As additional material is deposited, underlying material experiences increasing overburden pressure, compacting grains and decreasing porosity.

A proposed hypothesis is that the regolith grains foliate under increasing normal stress, allowing individual grains to rotate 90° to the normal stress and align along the shear stress direction [4]. For these highly angular and non-spherical grains, this foliation may rotate grains such that their long axis is aligned perpendicular to the normal stress and parallel to the shear stress. This is expressed by the material being very strong in the normal direction, perpendicular to the long axis of the grains, and very weak in the shear direction, where grains are individually aligned in a favorable orientation. After the material fails and transport of material is achieved, the regolith material acts much like a fluid, following the downslope gradient. Once it reaches the topographic level where it runs out of kinetic energy, the regolith material appears to revert back to its high angle of repose, with the grains once again locking into place. Over time, as more material is emplaced on the surface, buried regolith materials are put under increasing lithostatic normal pressures, which in turn may increase the grain foliation that leads to slope failure.

Motivation: The general dynamics of these materials may be described from a geomechanical perspective as strain hardening/strain softening behavior. Alternatively, this material may be described from the fluid dynamics perspective as a non-Newtonian, Bingham-fluid flow. It is this underlying fluid-like behavior that led to development of a lattice-Boltzmann (LB) approach to simulate flow particles in non-Newtonian fluid-flows. Early numerical models have been performed on single particle behavior under fluid (water) conditions and Earth's gravity to validate results [5].

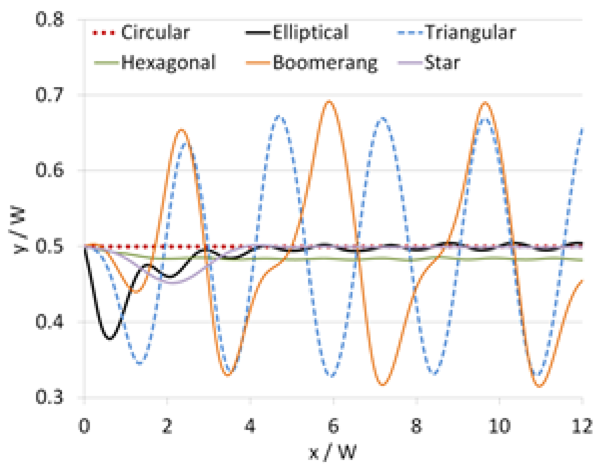

Fig 1. Settling trajectories of particles with different geometrical shapes [5].

These simulations suggest that grain particle shape has an influence on particle trajectories and angular rotation [5]. Particle shape (circular, elliptical, rectangular, hexagon, boomerang, star) influenced the settling (or flow) trajectories of particles in a fluid, as well as their angular rotation, resulting in different rates and locations of particle transport (Fig 1). These individual particle behaviors in turn influence the macroscale behavior of particle packing (porosity) and angle of repose (cohesion). Surface concavity also plays a role, wherein increasing the angularity of a boomerang-shaped particle results in different patterns of sediment transport (Fig 2). Particle sphericity also influences particle behavior, with non-spherical particles showing different settling rates with increasing aspect ratios (e.g., circular vs. elliptical shapes).

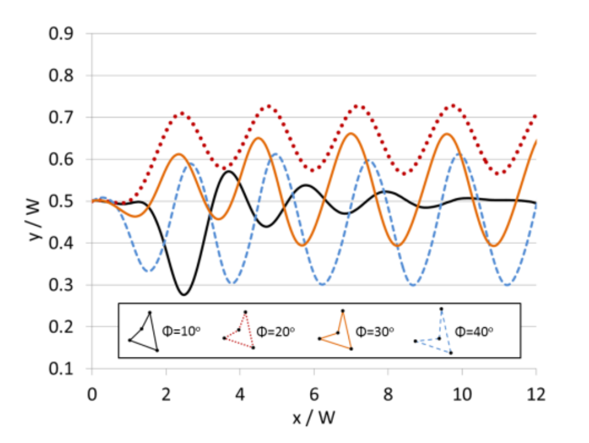

Fig 2. Settling trajectories of boomerang particles of different concavities. The surface area of the particles are the same. [5]

Grain size distribution also influences particle behavior. Settling simulations of 30 circular and 30 star-shaped particles with bimodal size distributions have been performed [5]. Model results of particles with bimodel size distributions show different behavior than single-size simulations (Fig 3).

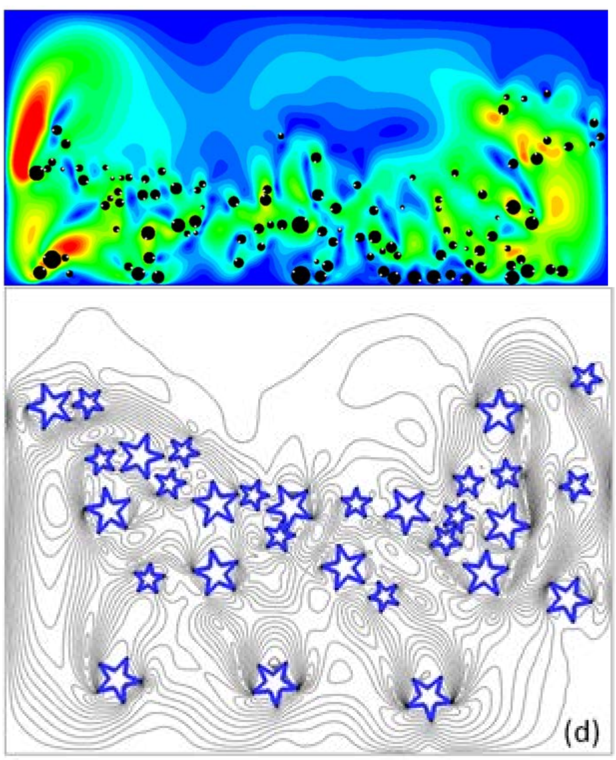

Fig 3. Gravity-driven settling (9.81 m/s^2) of 30 circular-shaped (top) and 30 star-shaped (bottom) particles in initially quiescent water. [5]

Future work: Numerical modeling continues, with efforts geared toward increasing the number of particles simulated, as well as increasing the particle-to-fluid density ratio to better replicate the lack of atmosphere. Model results to date suggest that a grain's angularity and sphericity, as well as grain size distribution, may strongly influence the micro- and macro-scale behavior of the regolith. Results from these simulations will help constrain regolith characteristics, such as porosity, and behavior, such as cohesion and angle of repose, on small airless bodies. These constraints in turn may be used toward understanding surface and near surface processes such as impact gardening and volatile sequestration on asteroids and the moon.

References: [1] Wyrick et al. (2017) 48th LPSC, #2776; [2] Wyrick D.Y. and D.L. Buczkowski (2006) 37th LPSC, #1195. [3] McKay, D.S. et al. (1991) In Lunar Sourcebook, Cambridge Univ Press, 285-356; [4] Carrier, W.D. III et al. (1991) In Lunar Sourcebook, Cambridge Univ Press, 475-594; [5] Başağaoğlu et al. (2018) *Scientific Reports*, in review.