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Reduced gravity causes larger-volume and lower-angle granular avalanches with less stratification

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1. Introduction

In geosciences and material sciences it is often assumed that angles of repose, formed during avalanching of sediments, are ***independent*** of gravity. We will test this.

Avalanches in nature occur subaerially on hillslopes and wind dunes and subaqueously at the lee sides of deltas and dunes. Resulting landscape features are important markers for the inference of present morphodynamics and past climate from surface morphology of planetary bodies. But do they differ on Mars?

Some important definitions:

- **angle of repose:** steepest angle of a slope of a pile of granular material.
- **static angle:** just before avalanche starts;
- **dynamic angle:** angle moments after the ending of the avalanche (and is always lower than the static angle)

2. Problem definition

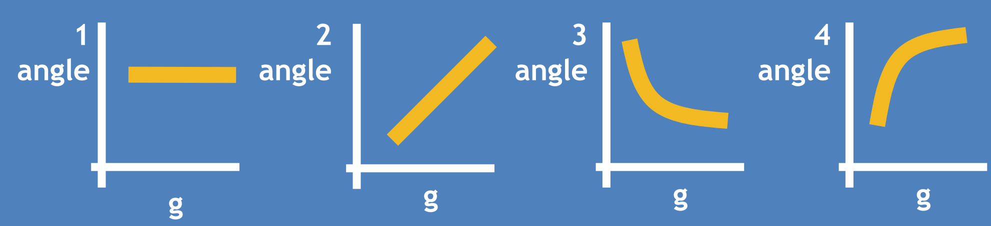
Hypotheses in our study are based on the concepts of:

- Rolling of particles: overcoming friction is easier in low-g
- Mass flow in avalanche: driving force *and* friction ~*mg*
- The sum of 'mechanical' friction $F_{friction}$ (resulting from particle morphology) and interparticle forces F_{inter} (resulting from mineralogy and scales with distance) needs to be overcome to initiate an avalanche.

Known influences on angles of repose and types of friction:

- angularity, particle size and interstitial fluid
- wall friction, static electricity
- avalanche volume affects run-out length

Aim of this study: determine if angles of repose of avalanching sediments depend on gravity and thus differ on planet Mars or the Moon compared to Earth:



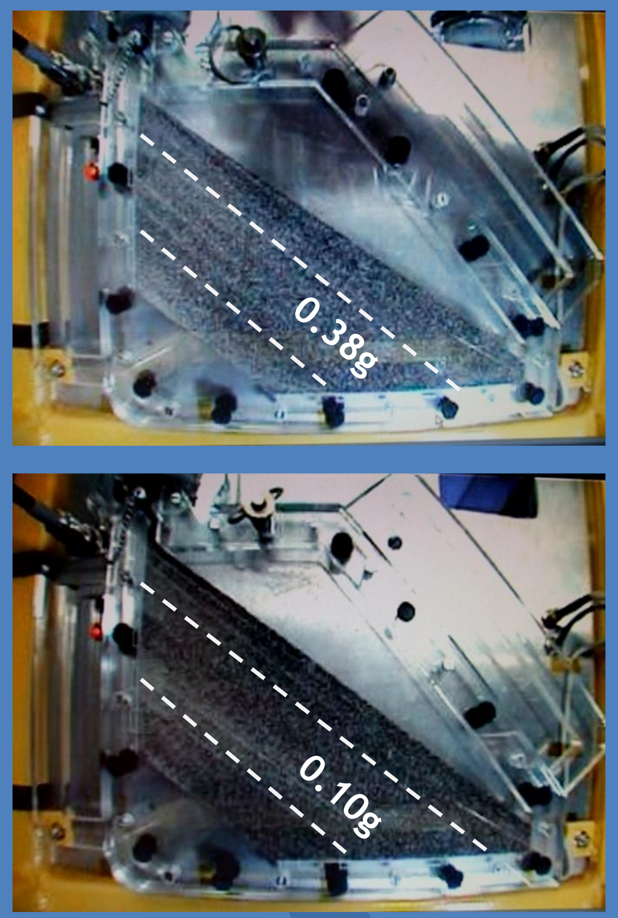


Figure 4.3 *Reduction of stratification in low gravity with the same sediment mixture and set-up as in figure 4.2. Stratification is significantly reduced in 0.38g and absent in 0.10g*

3. Method and materials

46 parabolic manoeuvers were flown to reduce the gravity vector. These carefully controlled flights were executed using a low-gravity flight director that was developed for these types of research flights. We studied discontinuous avalanching in 0.1g , 0.38g and 1g (where g=9.81ms^{-2}). The obtained low-gravity environment during these maneuvers had overall accuracies of 0.05g for ~15 seconds.

- **In a rotating drum set-up** we used various sediments to study the influence of the properties on the angles of repose of sediments: rounded / angular sediments, fine / coarse sediments and air / water as interstitial fluid.
- **Avalanche aquariums (hele-shaw cell)** was used to study the influence of gravity on auto-organization processes using bi-dispersed sediments that produce stratified or segregated deposits, and their individual grain species (angular & rounded particles and glass beads).

Image analysis and data filtering were used for the measurements of the angles and LED time markers were used to link the image frames to the recorded multi-axis acceleration and flight data.

Figure 3.1 *Our flying laboratory aircraft: the Cessna Citation II (left), the rotating drum set-up to test various sediments and interstitial media (centre) and the hele-shaw cells.*

Experiment work flow

Sediments with various properties were selected. In the rotating drums we used sands (0.1-3 mm) and glass beads (0.2-2 mm). In the hele-shaw cell we used mixtures of rounded river sands, angular volcanic sand and glass beads.

Parabolic flights were flown during two flights in stable weather conditions above the North Sea along the Dutch coast; the test flight and the actual production flight logged 46 parabola (27 provided good data).

Experimental set-up excluded the effects of interstitial fluid, particle size, sediment mixtures, aircraft motion, static electricity and drum rotation. We claim that the measured effects are due to differences in gravitational acceleration.

4. Results & discussion

The response in low-gravity of the static and dynamic angles of repose (figs 4.2 and 4.3) were observed in both experimental set-ups. In partial-gravity the:

- static angle of repose ***increases***
- dynamic angle of repose ***decreases*** (Fig. 4.4)
- average angle of repose remains ***constant***
- difference between the static and dynamic angles leads to larger avalanche volumes and run-out lengths

In comparison with literature we observe an opposite trend! We explain the opposing results with Klein and White (1990) by a possible static electricity build-up in their experiments.

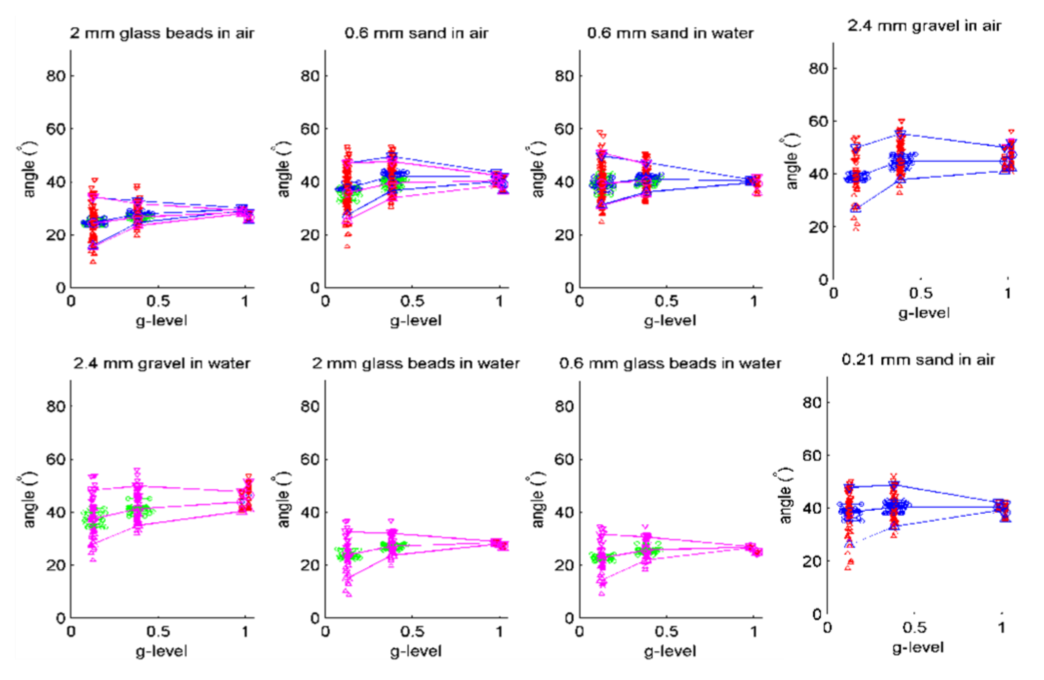


Figure 4.1 *Angle of repose in the rotating drum experiments. Data has been corrected for aircraft motion and drum rotation. For all sediments the dynamic angles of repose decrease with g-level, average angles of repose remain approximately constant and static angles of repose increase with g-level. Avalanche frequency decreases with g (not shown).*

Reduced stratification in the hele-shaw cell experiments (fig.4.3) indicates a decrease in kinematic sieving efficiency in low-gravity. We hypothesize that this marks a reduction in packing. If this hypothesis is correct, then, in low gravity:

- number of interparticle contacts decreases, distances increase
- → component F_{inter} in ($F_{friction}$+F_{inter}) reduces
- → reduction of total friction, lowering the threshold angle during avalanching,
- which implies that the addition of a surface force by e.g. static electricity would increase the total friction, leading to an increase in the repose angle. This effect is observed in one of our rotating drum experiments and possibly in the experiments of Klein & White (1990).

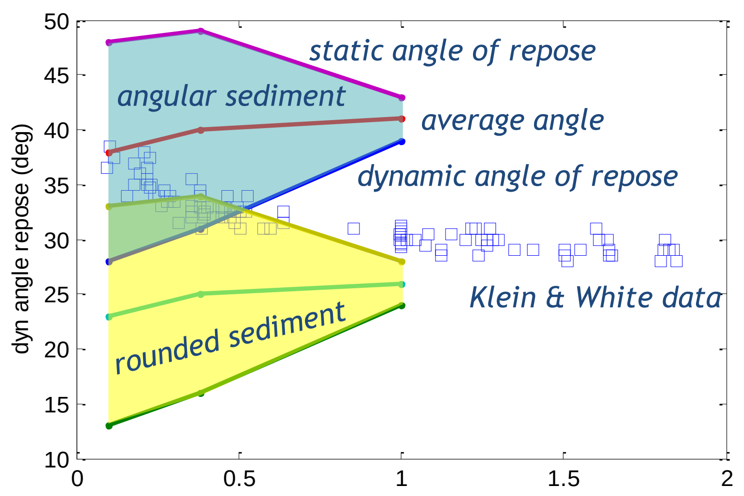


Figure 4.4 Trends of *angles of repose observed in the rotating drums for rounded and angular sediment.*

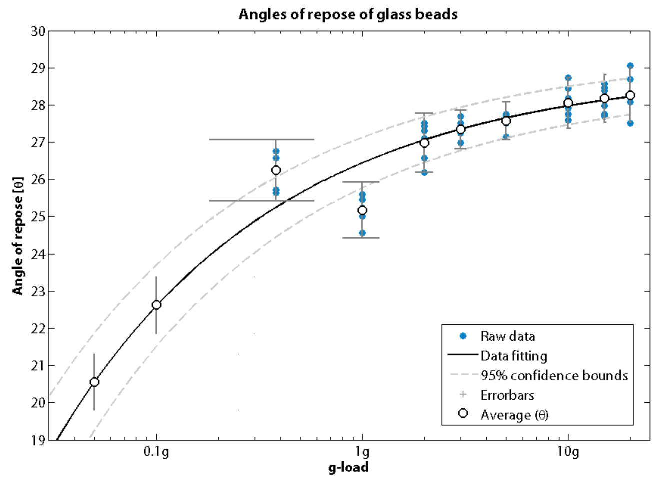


Figure 4.2 *Reduction of the dynamic angle of repose observed in the hele-shaw cell set-up for one sediment. Centrifuge data (1-20g) demonstrates that this effect is exclusive for low-gravity.*

Conclusions

- **Angles of repose depend on gravity:** in low-gravity, the static angle of repose increases and the dynamic angle of repose decreases, leading to larger-volume avalanches
- Effects of particle momentum, particle dimensions, fluid drag and groundwater dynamics were excluded.
- If sorting pattern indicates particle behaviour inside avalanches, then decreased stratification marks a reduction of interparticle spacing, which reduces friction caused by interparticle forces so that the dynamic angle angle of repose is smaller in lower g.
- At planetary surfaces, the lower dynamic angles of repose are expected to be preserved as these follow triggering events such as earthquakes and meteorite impacts.

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