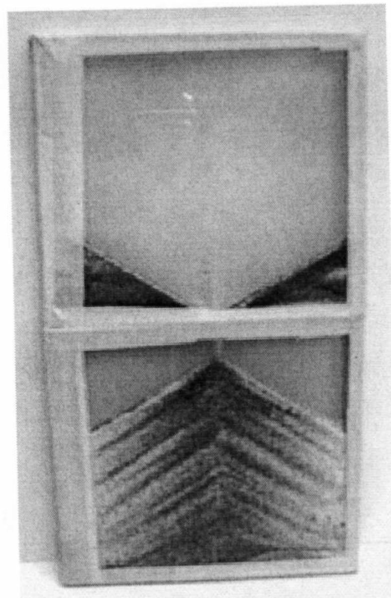
Avalanche



Materials

2 CD jewel cases (regular thickness, not ultra-thin), with the inserts that normally hold the CD removed
Masking tape
Black sand -- in California, this is sometimes "magnetic" sand, containing the mineral magnetite
Salt (ordinary table salt, not rock salt)
Measuring spoon, 1 Tablespoon
Paper or plastic cup, at least 3 ounces
4x6 card
Sheet of newspaper, or paper towel
Electric drill
Drill bit, 1/4 inch

Assembly

1. On one of the CD cases, drill a 1/4 inch hole halfway across **each** of the two **SIDE** edges (**NOT** the *FRONT or BACK edges*).
2. On the second CD case, drill a 1/4 inch hole halfway across **one** of the side edges.
3. Remove any plastic burrs or shavings from the holes and from the cases.
4. Use masking tape to carefully tape around all four sides of each case except where the holes are drilled. The case should be completely sealed shut with tape, including the open space formed by the removal of the plastic insert that normally holds the CD in place.
5. Tape the two cases together so that the hole in the CD case with one hole exactly matches up with one of the holes in the case that has two holes. (If necessary, slide the cases slightly sideways to get the holes to line up before taping.) This will leave one uncovered hole in one of the cases. What you should now have is in effect an hour-glass made from CD cases, with a hole in one of the chambers
6. Place newspaper on table so that the sand and salt will not get all over the place.
7. Make a funnel out of a 4x6 card so that the funnel opening will just fit into the uncovered hole. Use masking on the edge of the funnel so that it will retain its shape.
8. Measure 3 level Tbs (45 mL) of black sand and 3 level Tbs (45 mL) of salt into the cup, and use the paper funnel to pour it into the uncovered hole.
9. Put a piece of masking tape over the uncovered hole to seal it.

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To Do and Notice

Shake and tilt the CD "hour-glass" until all the sand-salt mixture falls to the "bottom" case (it doesn't matter which CD case this is), and is mixed to a reasonable extent.

Tip the whole CD case hour-glass assembly upside-down so that the sand-salt mixture starts falling through the hole. Carefully observe what happens. If all goes well, you should see the formation of a "hill," with alternating layers of sand and salt. Some trials will produce layering patterns that are more dramatic than others, so you may want to try this several times.

At the conclusion of one of your trials, without further shaking or tilting the assembly, look at the back side. Is there any difference in the black and white pattern when seen from the front as compared to the back? You may find that where the front looks quite black, the back will look quite white, and vice-versa.

Tip the case assembly upside down once again, but this time tilt it backward somewhat as the sand-salt mixture falls, rather than having it stand vertically. When it is finished, again look at the front and back. Is there any difference from previous trials? Is the black and white contrast between the front and back more noticeable?

With the case assembly vertical, tip it slowly to one side or the other (clockwise, or counterclockwise), and keep tipping in the same direction until the sand-salt mixture is about to start falling through the hole again -- or even past this point. You should again see some sorting and pattern formation. Tip the assembly back the other way, and you should see more sorting and patterning.

Hold the CD case assembly so that it is almost flat. Gently shake it back and forth for a few seconds. Note that the top portion of the mixture (that you are looking down at) is now fairly whitish, and is composed mostly of salt. Without further shaking or tilting, raise the assembly so that you can look at the bottom side -- this is now largely black, and is composed mostly of sand. Turn the whole assembly over and repeat the process, and note that you can do the sorting all over again.

What's Going On?

Two factors, the **angle of repose** and the **Brazil Nut Effect,** combine to create the sorting, layers, and patterns that occur in the sand-salt mixture as order emerges from chaos.

The **angle of repose** is the minimum angle at which a granular material can no longer support itself, and will flow under the influence of gravity, i.e., avalanche. (The term "granular" covers a wide range, since even large boulders that accumulate at the foot of a mountain have an angle of repose, and a rockslide or avalanche occurs if this angle is exceeded.) The steepness of the angle of repose is affected by such properties as the size and angularity of the grains. The angle of repose for the salt grains is different from that of the sand grains. In general, when the larger grains (the salt grains in our situation) have a larger angle of repose than the smaller grains (the sand), then layering tends to occur when the grains flow.

If you shake a can of mixed nuts, the largest nuts (the Brazil nuts) rise to the top. Hence the name **Brazil Nut Effect**. which now applies not only to the behavior of nuts, but also to the more general tendency of a large (but not necessarily less dense) particle existing amidst many small particles to rise when the whole collection is shaken oar agitated. This behavior has been known and studied for decades, but is still not completely understood (and in fact under certain conditions does not actually operate). In our Avalanche snack, the salt grains are larger than the sand grains, and they end up on top, thus displaying the Brazil Nut Effect.

The angle of repose and the Brazil Nut Effect work together in the Avalanche snack to produce the patterns of sorting and layering that you observe.

Credit

This snack is based on a previous version by Lori Lambertson, of the Exploratorium Teacher Institute. Hers, in turn, was a snack version of Eric Thogerson's Exploratorium exhibit. We would also like to acknowledge the contributions of Dr. Ken Brecher, while at the Teacher Institute in Summer, 2001, and of one of his graduate students prior to that time.

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From Cinderella's dilemma to rock slides

Jay Fineberg

A mixture of two different types of grain can undergo spontaneous stratification simply by being poured. This surprising behaviour may be significant in fields from pharmaceuticals to geology.

When Cinderella's (or Ashiepattle's, according to the brothers Grimm) wicked stepsisters threw her lentils into the ashes of her cooking fire, salvation came in the form of the friendly birds who helped her to sort them. But had she read the report by Makse *et al.* on page 379 of this issue[1], she might have come to a different solution to the problem of how one can go about separating two different species of intermixed granular materials. The answer may be as easy as pouring the mixture into a box. In the reported experiments, both the stratification and segregation of a mixture of two types of grain is observed to occur spontaneously as the mixture is poured into a narrow box.

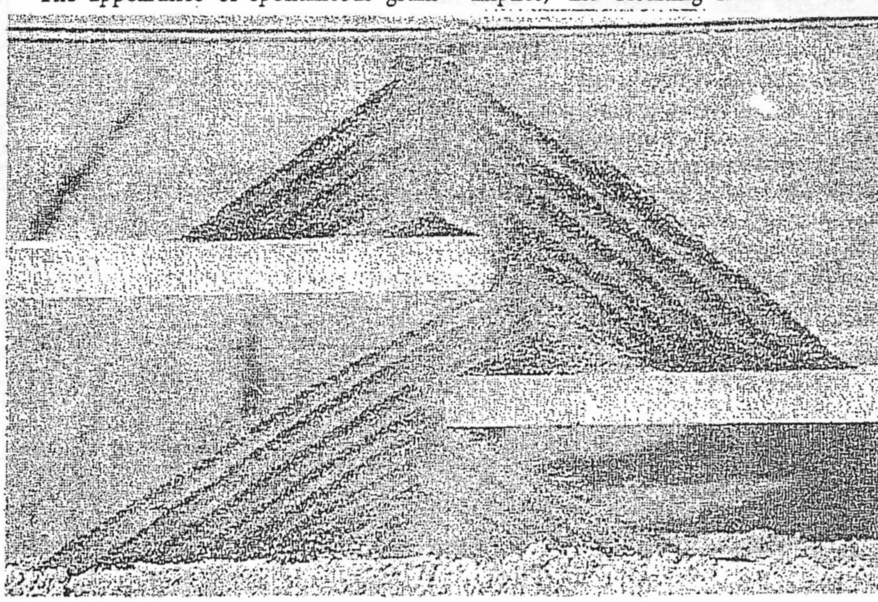
Granular media show a rich variety of surprising, and at times counter-intuitive, phenomena[2,3]. One might think, for example, that externally shaking or rotating a system composed of different types of particles would tend to induce disorder or randomize its components. In granular media the opposite occurs, as the vibration[4] or rotation[5] of two types of randomly mixed grain will cause them to segregate and thus *increase* the system's order.

A granular species can be described by the size and frictional characteristics (geometry, roughness and molecular attraction) of the grains composing it. The frictional characteristics can be characterized by the medium's 'angle of repose', the minimum slope for which gravitationally induced flow (or grain motion) can occur. Makse *et al.* prepare a random mixture of two different grain types and simply pour them into one side of a narrow container. As the slope of the 'sandpile' formed steepens, the mixture will flow.

When the angle of repose of the grains having a larger characteristic size is greater than that of the smaller component, the flow causes spontaneous stratification of the medium to occur, and alternating layers composed of large and small particles are formed, with the smaller and 'smoother' (lower angle of repose) grains found below the larger and 'rougher' grains (Fig. 1). The authors also find that within the layers, size segregation of the grains occurs, with smaller grains tending to be nearer the top of the pile. When the medium is chosen so that the larger grains are the 'smoother' of the two, there is no layering, and only segregation is observed.

The appearance of spontaneous grain stratification may have important implications in both industrial and geological processes. Many industries depend on the processing and transport of granular materials. In light of this work, the assumption that, on transport, an initially well-mixed compound will remain well mixed, may need to be re-examined. The potential ramifications of stratification by means of flow may be especially important in certain applications in the pharmaceutical industry where the precise concentration of the components of a given mixture may be crucial.

The same process may also play a part in unravelling the long-standing geological puzzle of long-runout rock slides. Long-runout rock slides result from a catastrophic event such as an earthquake, explosion or meteor impact that releases a large rock mass down a mountain slope. As the name implies, the resulting landslide has the



H. A. MAKSE

Figure 1 Spontaneous strata. Layers formed by a mixture of two types of grain, poured into a narrow container.

Figure 2 The long-runout rock slide that wiped out the town of Frank in Alberta, Canada, in 1903. After an initial one-kilometre fall, the slide travelled more than four kilometres across the valley below, and was finally stopped by the opposite slope. (Photo: National Geophysical Data Center, Boulder, CO; prepared by Allen M. Hittelman, Patricia A. Lockridge and Patrick J. Hayes.)

ng runout rock slides

ıus property that it does not stop at ıottom of the slope that drives it, but nues to slide over huge distances until ted. Events of this nature are not un- non, and have been known to destroy e towns that happened to lie in their (Fig. 2). These huge rock slides are ıcterized by abnormally low effective on coefficients (defined here as the ratio e initial fall height to the runout length), e order of 0.1.

he origin of this low effective friction been the subject of much speculation. fered explanations include an effective bearing' formed by the air trapped ath the rock mass[7] and the 'acoustic ization' of a narrow zone beneath the layer by high intensity sound generated e rock slide[8]. Recent simulations[9] based granular model using an ensemble of oth monodisperse disks qualitatively e with observed flows, but many issues ain outstanding.

Iow, for example, can a rock slide that ously consists of an ensemble of parti- of diverse sizes and degrees of roughness nimicked by such a simple model? An ınation may be provided by the observa- of Makse *et al.* Their results suggest that pontaneous stratification of large and l particles, with the selection of smooth ler particles at the bottom of a given layer, may provide an overall lubrication effect, as the best 'ball-bearings' are preferentially shifted to the bottom of the pile. In cases where acoustic fluidization occurs, this effect would tend to increase the fluidization of the medium.

As in the above example of long-runout rock slides, understanding the properties of granular materials is important. Although the subject of much active research, no underlying fundamental theoretical description of these materials yet exists. Experimental observations, such as those described by Makse *et al.*, help to provide the foundation upon which a theory for the rheology of granular materials can be based. □

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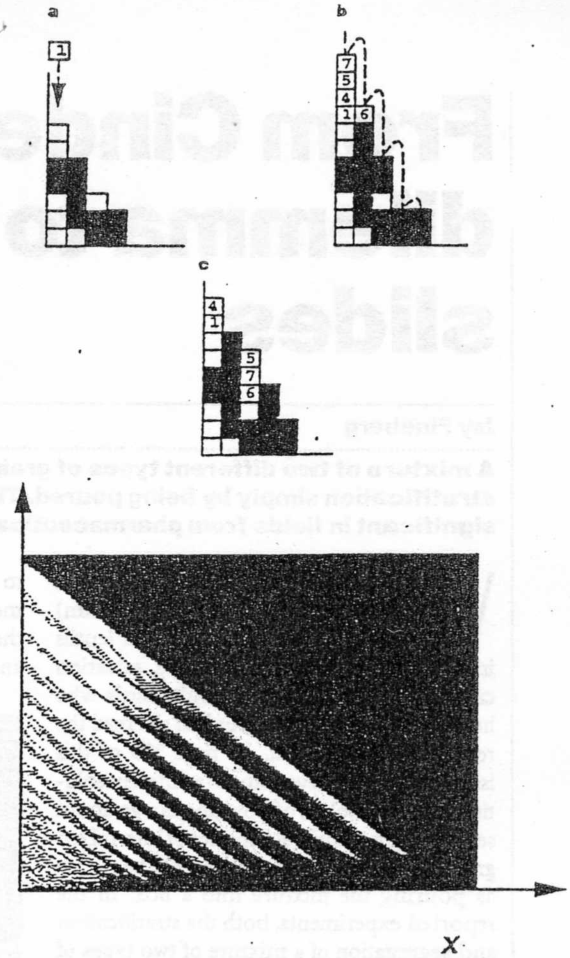

Figure 2 Results of modelling. **a**, The dynamics of the simplest 'mean field' mod are illustrated by this example with two sizes $H_1 = 1$ (white) and $H_2 = 2$ (red), ar threshold slopes $s_r \equiv \tan\theta_r = 2$ and $s_m \equiv \tan\theta_m = 3$. Suppose that, at a given instant, the sand pile is at the critical slope for repose s_r. To define the dynamical rules for the arriving grains, we consider the slope $s_i \equiv h_i - h_{i+1}$, where h_i denotes the height of the sand pile at coordinate i. We deposit a grain near the first column at the left edge of the lattice, where the actual column position is chosen from a narrow gaussian probability distribution centred at the wall edge. The non-zero width of this gaussian mirrors the fact that grains often bounce after reaching the pile. Newly arriving grains accumulate on the sand pile profile, following dynamics governed by the critical slope s_m; thus a grain moves from the initial landing point at column i to column $i+1$ if the slope $h_i - h_{i+1}$ is larger than s_m, then moves from column $i+1$ to column $i+2$ if $h_{i+1} - h_{i+2} > s_m$, and so forth. The grain stops at the first column k with $h_k - h_{k+1} \leq s_m$. Another grain is now added, and the same rules are followed. **b**, This entire process continues until a grain reaches the substrate at the furthest right column of the pile for first time (grain 8 in this figure). Now, as $s_i > s_m$ for all columns i, the sand pile has become 'unstable'. We note that s_i is calculated considering also the size of the rolling grain; as a result, the large grains more readily reach a slope that exceeds the two critical slopes s_r and s_m. **c**, We allow the sand pile to relax towards the repose slope s_r by moving each of the grains with slope larger than s_r to the nearest column satisfying $h_i - h_{i+1} \leq s_r$. Now the deposition starts again, and we iterate the algorithm until a large sand pile (of typically 10^6 grains) is formed. We can obtain stratification with constant 'wavelength' by stopping the accumulation process when a grain reaches for first time the column $l^{1/2}$, where l denotes the furthest-right column of the pile. **d**, Image obtained with the simplest 'mean field' model (for parameters $H_1 = 1$, $H_2 = 2$, $s_r = 4$ and $s_m = 5$); the smaller grains are white and the larger grains red. We find stratification and also reproduce the 'kink' mechanism explained in the text when we improve upon the simplest 'mean field' model by including four different angles of repose to take into account the fact that the angle of repose depends on the concentration of grains at the surface of the pile[23].

104