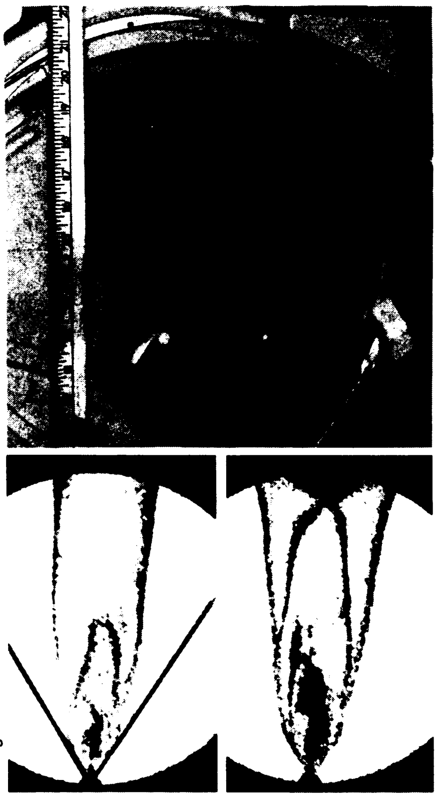
# X-ray movies reveal sand flow patterns

Coal tumbling out the bottom of a silo can literally shake the silo apart, causing it to collapse. The same kind of potentially destructive vibrations occur when sand and other granular materials flow out of a hopper. The causes of such vibrations have long mystified researchers, but now they have a clue in the form of X-ray images showing the spontaneous development of density fluctuations that propagate like waves within flowing sand.

"As far as I know, no one has ever seen this before," says physicist Robert P. Behringer of Duke University in Durham, N.C. "What goes on inside a hopper as the sand comes out is really quite intriguing. There is a great deal of structure." Behringer reported his findings last week at an American Physical Society meeting in Baltimore.

Behringer and graduate student G. William Baxter did their experiments using a flat, acrylic plastic hopper containing a wedge of sand 1.27 centimeters thick and about 30 cm high. By placing the hopper in front of a hospital X-ray machine, they could study what happens inside the hopper as sand flows out.



*By placing a flat, acrylic plastic hopper containing sand in front of an X-ray machine (top), researchers obtained images showing the formation of propagating patterns in flowing sand (bottom). Slanted black lines (bottom left) indicate the hopper's walls. Lower-density sand shows up as darker bands. As the sand drains out, a black notch appears, showing the location of the sand's top surface (bottom right). The time elapsed between the two X-ray images is roughly 3.3 seconds.*

Behringer

"We were fortunate enough to use a fancy X-ray machine capable of taking 10 pictures per second, which allowed us to follow the details of the flow," Behringer says. The pictures were then pieced together into a movie.

The X-ray pictures show distinctive patterns of dark, sloping bands, which correspond to areas where the sand is more loosely packed, or less dense, than elsewhere in the hopper. The bands form within a well-defined, narrow central region extending from the hopper opening to the top of the sand wedge. As sand flows out, these bands gradually move upward while new bands form just above the outlet.

Behringer and Baxter studied the effects of changing the flow rate, the width of the bottom opening and the hopper angle, but the most striking differences appeared when they tried different types of sand. They found that propagating patterns form in flowing sand consisting of rough, faceted grains but not in sand consisting of smooth, rounded grains of the same size.

"What matters is the orientability of the particles," Behringer says. In other words, patterns form when sand particles are more like rice grains, which tend to align themselves, than smooth spheres, which have no preferred orientation. By experimenting with mixtures of faceted and smooth sand, the researchers determined the threshold at which propagating patterns begin to form.

Their work demonstrates how little is known about granular flows despite the need to understand such flows in solving a variety of problems encountered in the storage and handling of bulk materials. The new research furnishes important clues useful for developing mathematical equations for describing and predicting granular flow.

"The theoretical understanding of granular flow is really very limited," says Duke mathematician David G. Schaeffer. Such flows differ considerably from those of ordinary liquids such as water. "Even a very fine powder doesn't behave like a fluid," he says.

New mathematical models may, in turn, help researchers interpret experimental results. "We're trying to understand where the propagating modes come from," Behringer says. "We hope part of that understanding will come from mathematical analysis." *— I. Peterson*

# Body's protein does malaria's dirty work

The often-deadly anemia brought on by severe malaria has long puzzled researchers because its victims' red blood cells perish much faster than the malaria parasite alone should destroy them. Now two scientists have implicated a villain that normally plays the hero — an immune-system protein called tumor necrosis factor, or TNF.

The body makes TNF to aid in healing and to fight infections or tumors, but in excess this potentially toxic substance can devour red blood cells. Infection by *Plasmodium berghei*, the deadliest and most prevalent strain of malaria parasite, can spur production of excess TNF.

Scientists first suggested a connection between malaria and TNF in 1981 after observing that TNF given to cancer patients and laboratory animals brought on the same symptoms as malaria. In the May INFECTION AND IMMUNITY, Kathleen L. Miller, Paul H. Silverman and colleagues of the Lawrence Berkeley Laboratory in Berkeley, Calif., report the first evidence that TNF exacerbates the anemia that kills many malaria patients.

Miller and Silverman mimicked malarial anemia by injecting TNF into healthy mice. They noted that the TNF destroyed the precursors to red blood cells. In another experiment, the team partially reversed anemia in malaria-infected mice by giving them antibodies to TNF, which restored many of the depleted red blood cells. The antibodies worked by binding up the infection-induced TNF.

Miller thinks TNF antibodies could someday alleviate malarial anemia in people, but she cautions that blocking a normally useful protein might cause unforeseen harm. On the other hand, the benefits of a TNF-antibody treatment might outweigh its potential risks. Miller notes, for instance, that malaria victims in Africa face potentially AIDS-tainted blood transfusions. She hopes further research will lead to a safe treatment based on carefully controlled doses of TNF antibodies to neutralize only the pathologically excessive TNF.

Scientists discovered TNF's tumor-fighting properties at the turn of the century after observing that cancer patients often improved when infected with bacteria. They later found that bacterial toxins stimulated the patients' bodies to produce more TNF, which in turn cut off the blood supply to their tumors. But when massive cancers or parasite infestations spur the body to produce too much, TNF can bring debilitation and death. Researchers once thought a separate substance, called cachectin, caused the "wasting away" so often seen in severe cancer cases. In 1985, they discovered that the "good" TNF and the "bad" cachectin are one and the same. *— F. Flam*