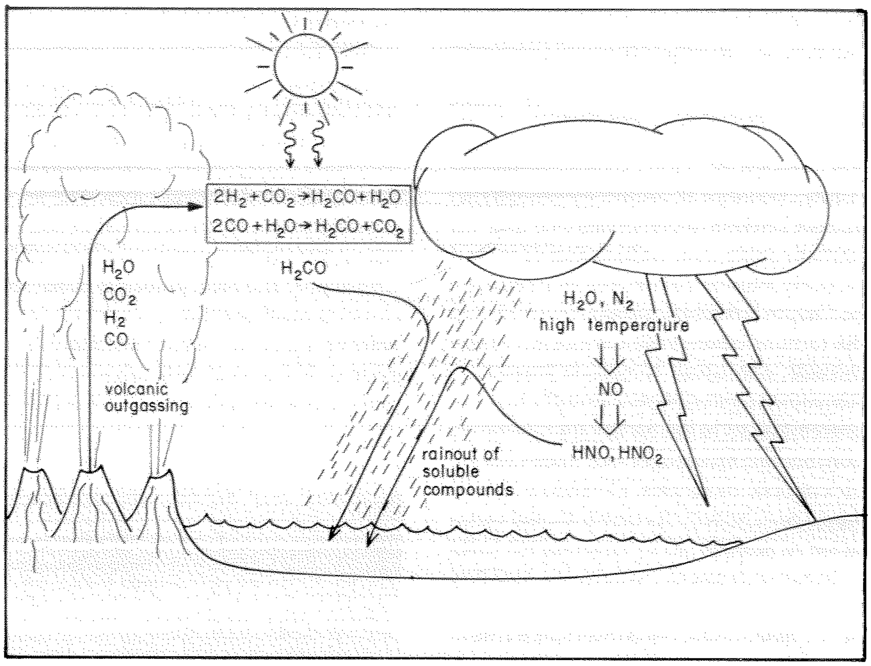
Research in Progress

Pre-Life Amendment

Life emerged from an organic soup, the classical assumption says. Theories vary, however, on how the organic compounds got into the soup in the first place because life has neatly consumed the clues to its own origins and added products of its own to the biosphere and the atmosphere. Scientists can only guess at the original ingredients and the processes that cooked them up.

All that may change now that various Mariners, Vikings, Voyagers, and other space missions have sent back information giving hints about how other planets and their atmospheres could have been formed, and some scientists are suggesting new theories that differ sharply from the older ones on how Earth's atmosphere, and eventually life, might have evolved. Using modeling studies of hydrocarbons in other planetary atmospheres, Yuk Yung, assistant professor of planetary science, and graduate student Randall Gladstone (along with Joseph Pinto of the Goddard Institute for Space Studies) suggest that photochemical reactions in Earth's primitive atmosphere could have created organic compounds, specifically formaldehyde (H_2CO).



A new scenario for the formation of life on Earth postulates an atmosphere of hydrocarbons released from the planet's interior through volcanoes. Photochemical reactions could produce organic compounds (such as formaldehyde), and reactions between nitrogen and water around lightning discharges could generate nitrite and nitrate. Sufficient concentrations of these ingredients rained into the oceans would provide conditions very favorable for life.

Yung, Gladstone, and Pinto think that Earth's primitive atmosphere was much the same as it is now—minus the oxygen, which was added later by biological processes. Its composition would *not* have been determined by the primordial solar nebula, the cloud of gas and dust out of which all the objects in the solar system were originally formed, which is responsible for the massive atmospheres of the giant planets. Instead, like Venus, Mars, Io, and Titan, Earth's atmosphere was probably created out of the volcanic release of gases from the planet's interior—*after* the core had already been formed and iron had been removed from the upper mantle. The absence of iron would preclude the previously theorized hydrogen-rich, highly reducing atmosphere. Yung, Gladstone, and Pinto propose a mildly reducing atmosphere with as its major constituents molecular hydrogen, nitrogen, water vapor, and carbon dioxide with small amounts (but larger than those observed today) of reduced gases—molecular hydrogen and carbon monoxide.

Assuming these constituents, they set out to determine whether the atmosphere could have been the chemical engine to generate organic compounds (such as formaldehyde) out of inorganic ones. This reaction is quite easy in the photochemical reaction of photosynthesis, where organic compounds result from carbon dioxide and water; but could it have been managed without pre-existing reduced organic compounds around to help out?

By adding together in a computer model all the known reactions of the theorized hydrocarbons in the atmosphere, including a couple of reactions only recently studied in the laboratory, the planetary scientists derived two possible photochemical pathways to formaldehyde. These pathways result in the net reactions:

$$2CO + H_2O \longrightarrow H_2CO + CO_2$$

$$2H_2 + CO_2 \longrightarrow H_2CO + H_2O$$

Even though 99 percent of this formaldehyde would be destroyed by photolysis, enough could be incorporated into raindrops to dump three million tons of it annually into the oceans, where it would be "happy" (that is, not exactly stable but forming other stable compounds). At this rate, after about 10 million years, formaldehyde would exist in sufficient concentrations in the oceans for it to be polymerized by sunlight into more complex organic molecules. Conditions would then be very favorable for the evolution of life.

In earlier research (with M. B. McElroy of Harvard) Yung also modeled an analogous situation for the delivery of nitrite and nitrate to the oceans by reactions between nitrogen and water in the air surrounding lightning discharges. Large amounts of nitrogen and organic carbon create conditions so favorable that the emergence of life would be "nearly inevitable." Gladstone and Yung also plan to construct a similar model for the atmospheric generation of hydrogen cyanide (HCN), a key compound that can form important amino acids. Their studies of inorganic-to-organic reactions are not limited to those on primordial Earth—Saturn's moon Titan has an atmosphere rich in methane, another likely candidate for producing more complex organic molecules and in older theories thought to be the precursor of life on Earth. □

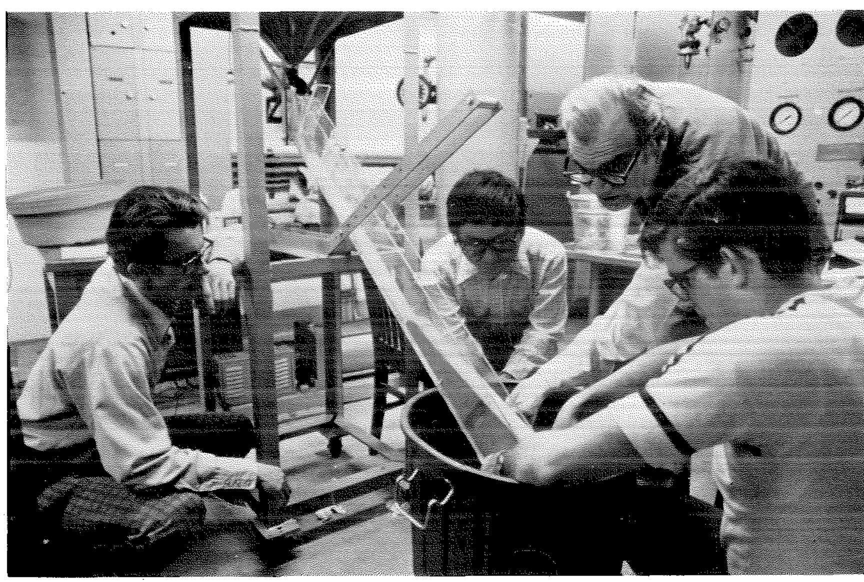
Going Against the Grain

Granular materials flow somewhat like fluids — but with enough differences to flow right into the cracks between the traditional disciplines of classical fluid mechanics, kinetic theory, and soil mechanics. While the flow of liquids and gases has been studied for centuries, the properties of granular flow are not well understood.

Rolf Sabersky, professor of mechanical engineering, stumbled onto this surprising interdisciplinary crack several years ago when he heard about a heat exchanger in which hot soap granules were cooled by pouring them over water pipes. The interesting problems encountered in this seemingly simple operation led him and Christopher Brennen, associate professor of mechanical engineering, to begin a research project on granular materials in general. Many such materials — coal, gravel, ores and grains of all kinds, fertilizers, even plastic stock — are transported and handled in enormous bulk quantities.

Heretofore, the rather simple transport contraptions — hoppers, chutes, conveyors — as well as more complex processing machinery have been designed by trial and error with very little scientific knowledge of how the material moved through them. As energy and construction costs increased, however, the benefits that might be derived from more effective designs have also become more apparent. In addition, many of the suggested solutions to the energy situation involved transporting and processing even greater quantities of bulk material, such as coal and shale.

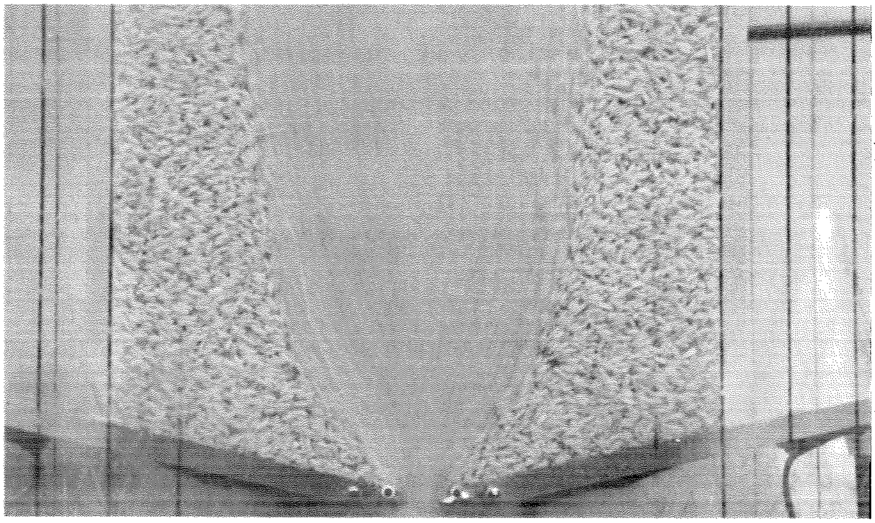
Nature also presents problems of granular flow — mud and rock slides and avalanches. Scientists are interested in how the sand patterns recently discovered on Mars and Venus might have been formed



As sand flows down the chute, it is partially backed up behind a gate while a layer of sand continues flowing over the top, a phenomenon known as a hydraulic jump when it occurs in water. Rolf Sabersky points out an element of the flow to students Henry King (center) and Bill Ledeboer. Christopher Brennen observes at left.

and in how the soil of the Los Angeles basin might behave during a great earthquake.

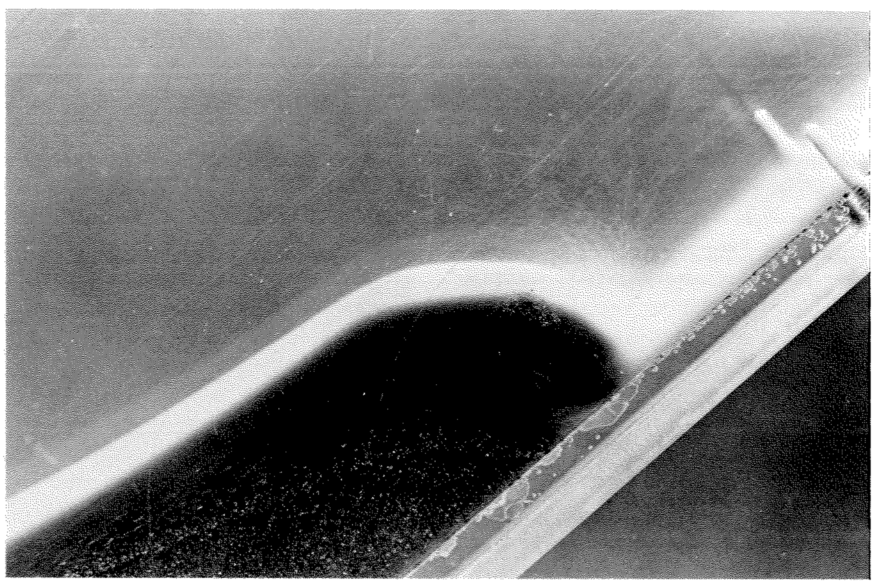
Brennen and Sabersky's research, which has been funded by Union Carbide and the National Science Foundation, deals with both the theoretical and experimental aspects of these flows, which are two-phase flows, that is, a mixture of solid and fluid (air or water). In very low concentrations, such as dust in wind, the mixture behaves as a normal fluid with stresses determined by the suspending medium (air). But as concentration of the solid increases to the point where particles collide with sufficient frequency, the stress communicated by the collisions may increase to the point where it dominates that transmitted by the suspending medium. Of course, many granular flows are determined by both of these effects — collisions and the viscous forces in the suspending medium.



Rice grains remain stagnant at the sides of this hopper, while only the center moves as a "funnel flow." Most hoppers are designed to avoid stagnant regions.

These particle collisions have an analogy in kinetic, or molecular, theory but with two problems that make granular materials more difficult to deal with than gases: their high density, or solids fraction, and the inelasticity of the collisions; that is, energy is dissipated every time a particle collides with another. (Energy is conserved in collisions of atoms or molecules.) The flow behavior involves the relationship between the stresses, or pressure, on the one hand and the solids fraction and the random motion of particles (analogous to temperature in molecular theory) on the other.

Work in Sabersky and Brennen's groups (currently including graduate students Charles Campbell, Scott Patton, and Karel Spelt) involves postulating certain of these relationships, putting them in the equations of motions, solving for certain flows, and then comparing them with experimental results from relatively simple flows in hoppers and chutes. They are developing new instrumentation and techniques to get inside these flows in order to measure velocity and density at particular points. They also have simulated flows on a computer. One of the problems they have encountered in the experiments is the buildup of electrostatic charge. Friction between particles can turn a hopper into a Van de Graaff machine, creating substantial voltage differences. This phenomenon may in fact be involved in some of the explosions in grain elevators.



The backed up stationary layer of sand can be seen in this cross-sectional view of the "hydraulic jump" experiment. There is another very interesting spot of stationary granules near the top of the curve, where a vortex is created adjacent to the main flow. Lighting from above makes the top surface appear light.

Substantial progress has already been made in a specific engineering problem — designing hoppers to avoid "funnel flow," which leaves stagnant regions along the sides. To achieve the desired mass flow, Brennen and Sabersky investigated the geometry of the hopper; its height and width, the shape of its parts, and the shape of the particles intended to flow through the hopper (for example, the elongated grains of rice) are all factors that needed to be considered.

Experimenting with granular flow means carrying a lot of sand around (or rice, mustard seed, glass beads, or plastic granules), and this has generated some transport problems of a local nature. Bucket brigades from the bottom of the chute to the top of the hopper are one solution, but it becomes more complicated when the stuff must be trucked to another floor so it can descend steeper chutes. A hole in the basement of Spalding to accommodate the lower end of the chute will soon solve that problem. Students researchers carrying buckets, however, will probably continue to joke about majoring in sandbox. □