Modeling the Movement of Magma

The periodic spewing of molten lava from the inner mantle of the earth is a well known, sometimes violently evident, phenomenon. But just how magma finds its way to the surface is less clear. What mechanism along its path controls or triggers the episodic eruptions of volcanoes or the variation in the chemistry of lavas? And how does a continuous pool of magma in the mantle get channeled into regularly spaced volcanoes along mid-oceanic ridges where new seafloor is born? These are some of the mysteries, remaining largely unsolved, that scientists have grappled with as they debate the dynamics and anatomy of volcanoes.

Now, two papers have been published, each bringing to the surface possible physical models for magma ascent. Both theories individually address some of the important questions about volcanism, but opinions vary as to the significance of each. Some researchers, including an author of one of the recent papers, are so excited by both that they have begun formulating an even newer model that incorporates the two theories into one.

In spite of the fact that lava originates in the mantle, most of the mantle is thought to be made of solid rocks; the pressures are so great that melting does not occur even though the temperatures are high. As the solid mantle rocks slowly rise at places like mid-oceanic ridges, they reach a point in the upper mantle region where the temperature catches up with the suppressing effect of pressure and partial melting occurs. The materials in the rock grains having the lowest melting point liquefy first and come out of the rocks to form magma, or melt.

The recent papers take a new look at what happens just after the melt forms. David R. Scott, a graduate student in geophysics, and David J. Stevenson, a planetary geophysicist, both at the California Institute of Technology in Pasadena, applied a differential equation called Darcy's law that governs the flow of a liquid through a porous medium, such as the movement of water through sand.

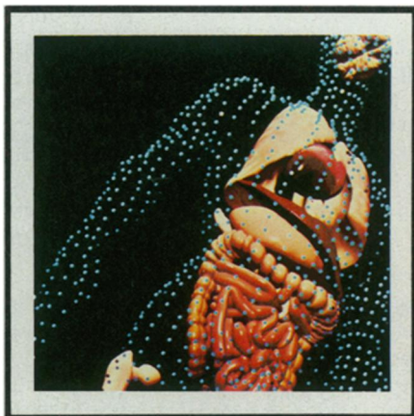
When the researchers allowed the solid rock crystals, through which the melt moves, to deform, they found that the liquid melt tends to clump together as a wave. This kind of shape-preserving wave is known as a soliton and is found in many other natural systems, from the oceans and atmosphere to solid-state physics (SN: 3/3/84, p. 135). The magma soliton, or "magmon," as the researchers call it in their November Geophysical Research Letters paper, is triggered when the flux of the melt through an overlying region of mostly solid rock becomes large.

What's most exciting and controversial about the magmons, says Stevenson, is that depending on the values of viscosity and permeability one chooses for the model, the magmons might be large enough to be observed geologically. They might then explain, for instance, how the steady-state generation of magma results in periodic eruptions of lava. Magmons might also be responsible for variations in the chemical content of lavas during a volcano's history, since the chemical makeup of a high-melt magmon differs greatly from that of the more solid material through which it migrates.

However, while patterns in the geochemistry of lavas originally inspired Scott, in particular, to study porous flow, the actual data are just suggestive at best, he says, so more geological work is needed. In addition, say the researchers, their analysis has been done in one dimension only, with solitons rising as a sheet. They are now extending their study to see how solitons might look, if they exist, in two and three dimensions — whether, for example, they might become plumes or blobs of melt.

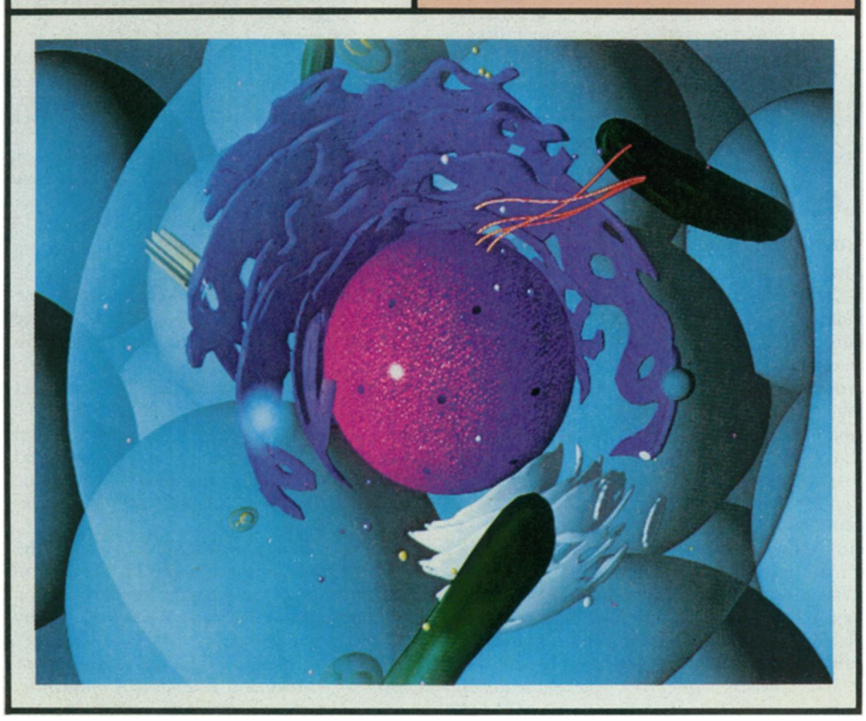
The second paper, appearing in the Nov. 8 Nature, was written by fluid dynamist John A. Whitehead, petrologist Henry J.B. Dick and geophysicist Hans Schouten, all at Woods Hole (Mass.) Oceanographic Institution. These researchers applied a model, previously developed for island-arc volcanoes by Bruce Marsh at Johns Hopkins University in Baltimore, to describe volcanism at mid-oceanic ridges.

In this model, a layer of low-density melt, sandwiched between denser regions of mantle rocks, developed what is known as a Rayleigh-Taylor instability so that the melt forms into little globs at intervals



Stredney/Garabis

Computer graphics may soon cut the "3D illiteracy" rate, say anatomists who are beginning to represent the human body, tiny cells and physiological processes in what look like three-dimensional images that can be peeled apart, examined from different angles, and put back together before the viewer's very eyes. Images of a transparent human body (left) and the inner workings of a cell (below) are just a sampling of what some physicians think could be a valuable new tool in the education of the physician and layman alike (see story on next page).



Garabis

Whitehead/WHOI

Whitehead demonstrates how a thin line of a water-glycerin mixture injected into a more dense glycerin bath develops periodic instabilities after 45 seconds. Each plume represents molten rock ascending toward a magma chamber.

along the sheet, which then buoyantly rise toward magma chambers beneath volcanoes. This kind of gravitational instability has been well studied in fluid mechanics. In fact, Whitehead performed a simple experiment to demonstrate the effect (see photograph).

The researchers believe that in the earth, this periodic array of magma instabilities accounts nicely for recent seismic and geological data indicating that lava comes out of discrete volcanic centers spaced every 50 kilometers along the Mid-Atlantic Ridge. (Previously, a long belt of lava was envisioned to ooze out of the ridge.) The distance between the magma plumes, and hence between volcanoes, is determined by the thickness of the magma layer and the difference in viscosity between the low- and high-melt regions.

According to Dick, the model also accounts for the composition of the crust at fracture zones, the lines that bisect and separate the volcanic centers. Dick and others have noted that the topmost layer there is thin and in some regions completely devoid of crustal material, consisting only of exposed mantle.

Moreover, says Dick, dredged samples suggest that the mantle material has undergone a high degree of melting but has had its melt removed. This is consistent with the instability model, he explains, because it says that melt is drained away from the mantle rocks beneath the fracture zone and toward the volcanic centers long before the rocks reach the surface layers. The previous theory for fracture zones says that melting and melt migration are inhibited by the chilling effect of the cold plates at fracture zones.

Some scientists argue that neither the instability nor soliton model really improves on the existing theories for magma ascent. But Dick is convinced that the geological data support the instability model. He's also excited by the soliton idea and wants to incorporate the two. "How you get melt, dispersed through hard rock, to migrate and coalesce into a discrete blob of lava has baffled geologists for a long time," he explains. The solitons provide a way of segregating the melt from the mantle rocks at any depth, he says. And once the soliton sheet starts moving through the mantle it could give birth to magma plumes by going unstable.

—S. Weisburd

3D graphics 'peel apart' human body

The human body can be a three-dimensional nightmare to beginning anatomy students, as they struggle to piece together from textbooks and dissected cadavers the way organs harmoniously pulse, throb and ooze in living beings.

"It's like asking you to learn a language by handing you a book of poetry in that language, and telling you to dissect it," says Roy A. Meals, an orthopedic surgeon at the University of California at Los Angeles. "Cut the poetry into small fragments, and you've destroyed the relationships between them. You can learn the language that way, but it's tedious."

Three years ago, Charles A. Csuri, an art professor at Ohio State University in Columbus, started a computer graphics firm, Cranston-Csuri, which by 1983 was receiving international acclaim for its work, primarily in television network sports and news. From the beginning, says Don Stredney, an animator with the firm, the company was also interested in using the graphics to teach anatomy and physiology in a new way.

The curved, irregular shapes found in the body have proven more difficult to animate than most other projects, says Stredney, who taught anatomy at Ohio State before joining Cranston-Csuri. However, by combining the artist's eye for detail and perspective with the computer's ability to store information about color and transparency from a variety of viewpoints, and rotate the resulting figure in space, the firm has developed the beginnings of a computerized 3D library of the human body (see facing page). At the Eighth Annual Symposium on Computer Applications in Medical Care held in Washington, D.C., recently, Stredney demonstrated some of the first fruits of the team effort: animated clips from "The Living Body," a 24-part television series produced by the British firm, Goldcrest Multimedia.

One segment of the film, which is now airing in Britain and France, shows a lifelike heart beating under the wings of inflating lungs; another illustrates the chemical codes of the reproductive system, as a message moves from the pituitary to the adrenal glands and gonads. With the help of the computer, the viewer can "see through" the surface of the body, to get a good feel for underlying structures. In the blink of an eye, perspective can change from a tour around the outside of the brain to the interior of a single neuron. Stredney and José Garabis served as chief animators for the project.

Michael Shaw, a physician and film producer with Health Science Media in New York, says Cranston-Csuri is "10 light-years ahead of where we were just a few years ago," especially in terms of image texture and resolution, and the size of their data base.

From 1976 to 1979, Shaw served as medical adviser to the National Medical Audiovisual Center in Atlanta, affiliated with the National Institutes of Health. One of his projects was to try to develop 3D computer animation of the heart, to help convey to medical students and residents how different abnormal heart sounds, heard through the chest, are generated by the particular configuration of the beating organ inside. The project was never completed, but could be done fairly easily today with less expense, he says.

Just the same, the new techniques are far from cheap, costing an estimated $1,000 to $3,000 per second to generate, Stredney says. That price could eventually come down, he suggests, as future projects build on information already in the computer, rather than starting from scratch each time.

Stredney dreams of an interactive "surgery simulator" to train young physicians, analogous to flight simulators that permit pilots to practice take-offs and landings without leaving the ground. "But that's a long way away," he says, adding that films for patient education and training aids for drug firms require less detail and probably will be among the first markets for the animation. *— D. Franklin*

Baby Fae dies

The longest-lived recipient of an animal heart died last week in the Loma Linda (Calif.) University Medical Center, where the transplantation had been performed (SN: 11/31/84, p. 276). The one-month-old baby, known to the public only as Baby Fae, died after 20 days with a baboon heart, from heart and kidney problems, following her body's attempt to reject the new heart.

A Loma Linda University spokesperson says there are no immediate plans for a second attempt, pending evaluation of the procedure.

Baby Fae was born with hypoplastic left heart syndrome, a usually fatal condition in which the main pumping chamber of the heart, the left ventricle, is extremely underdeveloped. A surgical reconstruction procedure has proven somewhat successful. Surgeon Leonard L. Bailey was criticized for not fully exploring this possibility with the baby's parents, not having published scientific papers relating to cross-species transplantation and not divulging details about the consent agreement signed by the parents. He has not responded publicly to the criticism. Animal rights activists joined in by complaining that the baboon's rights had been violated. □