

A hot time in the old lava fields

More than 2.5 billion years ago, extremely hot lava, behaving more like water than like molasses, splashed and tumbled its way across the earth's surface. This komatiite lava, as it is called, was so hot that it melted the rock over which it passed, eroding deep channels and taking up minerals from the ground.

This is the picture that emerges from a recent study of the physics and fluid dynamics of a komatiite lava eruption. "We conclude that komatiites probably flowed turbulently and cooled in part by convection," write Herbert E. Huppert and R. Stephen J. Sparks of the University of Cambridge in England and their colleagues in Australia and West Germany. Their report, which tries to account for many of the characteristic properties of komatiites, appears in the May 3 *NATURE*.

Komatiite lavas, originally recognized 15 years ago in South Africa and later found in Canada and Western Australia, are very rich in the mineral olivine, which contains a high proportion of magnesium oxide. These lavas show "all sorts of wonderful textures," says Euan G. Nisbet of the University of Saskatchewan in Saskatoon. The most distinctive feature is the "spinfex" texture (named for a needlelike, cloth-piercing Australian grass) that reveals itself in the form of long, shardlike plates of crystalline olivine. In contrast, olivine normally crystallizes into a stubby, rhombic form.

In order to be molten and to erupt, these lavas had to be at a starting temperature of at least 1,600°C, says Nisbet. Contemporary lavas don't get this hot. Because komatiites appear to be fairly common among rocks dating back more than 2.5 billion years and extremely rare in later rocks, this suggests that the earth's mantle, the layer of material beneath the earth's crust, may have been hotter then than it is now. Nisbet says, "Essentially, komatiites seem to be a direct window into the early mantle."

The high temperature and the high magnesium oxide content in the lava mean that the liquid had a low viscosity allowing it to flow easily and rapidly. Basing their work on this assumption, Huppert and his group calculated that komatiite lavas likely flowed turbulently. In such turbulent flows, heat is transferred much more quickly than in smooth or laminar flows. As a result, komatiites could have melted and assimilated underlying sediments and rock like basalt. The researchers note that other scientists have suggested that a similar thermal, lava erosion process may have carved some of the sinuous channels now visible on the moon's surface.

Huppert and his colleagues estimate that the lavas could have assimilated as much as 10 percent of the ground over which they flowed. This would contami-

nate the lavas by altering their composition and the proportions of trace elements present. As a result, it would be difficult to tell just by studying the lava samples whether particular elements originated in the mantle or came from eroded rock. The scientists also suggest that erosion of sulfur-rich sediments would account for the association between komatiites and deposits of nickel-bearing sulfide ores in some areas, especially in Western Australia.

After the lava settled into place, it would have continued to cool rapidly, helped by strong convection currents within the liquid, the researchers say. Under these conditions, olivine crystals would begin to grow and hang down in sheaves from the top surfaces of some komatiite flows to form the characteristic spinfex texture. The researchers simulated the development of this texture by observing crystallization within saturated aqueous solutions of sodium carbonate cooled from above. Their results confirmed the im-

Gathering string in the cosmos

One of the serious difficulties in making theories of cosmology is accounting for the formation of galaxies. The universe is supposed to have started out smooth and undifferentiated, and so something somehow has to have initiated the concentrations of matter that developed into galaxies.

Now there is a plausible candidate for the position of trigger of galaxy formation. It is called cosmic string. String is a topological defect in the structure of space-time. Cosmologists first noticed it as a mathematical curiosity. Now, after more than a year of discussion, they are talking about observations that may show whether some of it exists.

String is an artifact of a phase change in the state of the universe. Most cosmologists like to believe that the universe began in a smooth, undifferentiated state, a state of very basic symmetry, as they put it. In this symmetric state the different kinds of matter and the various modes of interacting, of exerting forces and other influences, that we have today were unknown. The present variety arises from breaks in the primal symmetry, each break bringing into existence particular material particles or a particular mode of interaction. The breaks are spontaneous, arising for reasons embedded in the original nature of the universe. These breaks are phase changes, analogous to the change of water into steam or the formation of a crystal out of a cooled liquid. Such phase changes do not always occur instantaneously, perfectly and completely. Water boils away gradually; crystals often form with defects.

portance of convection currents within the liquids for producing the kind of texture seen in komatiites (SN: 2/11/84, p. 90).

The work of Huppert's group "tells us an awful lot about the physics of how these lavas flowed," says Nisbet. "The work they've done is very important indeed." However, he adds, "Their contamination argument is in some ways an annoying nuisance. But they've pointed it out, and it's there, and we've got to take it into account."

David Walker of the Lamont-Doherty Geological Observatory, associated with Columbia University in New York, says that the contamination effect "presents a rather extreme example of a process that is known to go on in eruptions today... so it's not surprising it would have gone on in the past."

Nisbet says, "Perhaps the recognition that contamination took place will help in resolving controversies about the extent of variation in chemistry of mantle source regions. More likely it will add to our uncertainty and send komatiitophiles scurrying back cheerfully to their field areas and to isotope laboratories."—*I. Peterson*

Cosmic string is such a defect. After a particular phase change in the history of the universe, long thin tubes of space-time are left behind in which the state of affairs before the change still prevails, analogous to the boiling water surrounding bubbles of vapor or to defects in a crystal. According to Alexander Vilenkin of Tufts University in Medford, Mass., who described them at last week's Inner Space/Outer Space conference held at Fermilab in Batavia, Ill., these relics of a previous age are thin and endless. Either they can be infinitely long or, as in most cases, they can close on themselves and form loops.

These loops are far from negligible, Vilenkin says. They contain something like 10^{14} to 10^{15} times the mass of the sun, and they move through the surrounding space-time (which has gone over to the new state of affairs) at very high speeds. Under the circumstances string could come to dominate the universe. Such an outcome would be very bad for cosmological theory, as today we manifestly do not live in a string-dominated universe.

Fortunately, Vilenkin points out, string loops contain the mechanism of their own destruction. There is a great tension along the length of the string, which causes the loop to wiggle. When something as massive as this wiggles, it produces gravitational radiation, undulations of gravitational forces that spread out through space the way light emanates from a bulb. Gravitational radiation carries away energy, and as its energy diminishes, the loop of string shrinks until it disappears.

While they are in the universe, however, the loops of string provide a signal service:

They trigger the formation of galaxies. The gravitational field of cosmic string is a little strange, as the tension along it cancels some ordinary gravitational effects. A straight string, or a piece of a loop so close as to amount to the same thing, will not attract nearby objects, it merely deflects their trajectories to the side. However, for objects far enough from a loop that they see it whole, so to speak, the ordinary sort of gravitational attraction occurs.

Thus, strings moving through space can collect assemblages of matter surrounding them, but residing at some distance from them. These assemblages could become the star-forming disks of galaxies. Meanwhile, the loops would be slowed by the drag of the assembling matter to a point where they could assemble second collections of matter much closer to themselves. These second agglomerations could become the dense, energetic centers of galaxies. The string loops would eventually disappear but they would leave behind galaxies.

Could there be string in the universe today? Vilenkin says only the largest loops at the time of formation could survive until now. String's ability to bend trajectories of light beams could make its presence apparent by a gravitational lens effect, producing several images of a single object. Five examples of gravitational lens effect are known, in the form of double images of quasars. This does not prove the existence of cosmic string, as galaxies and black holes can also produce this effect. Vilenkin suggests looking for lines of double images of galaxies, tracing out the extent of a string. Another test might be the observation of strong gravitational radiation from no visible source, but that has to wait until gravitational radiation is detected.

Finally the question of what happens to human beings near strings. Vilenkin says the head and feet of such a person would move toward each other at a speed of 10 kilometers a second, "which is unhealthy. So avoid these things if you possibly can."

—D. E. Thomsen

Ozone and light accelerate corrosion

The corrosive effects of sulfur-containing atmospheric pollutants, such as hydrogen sulfide (H_2S), are well known. But the magnitude of their impact on the environment now appears to be a function of the company they keep, according to new research by three chemists at AT&T Bell Laboratories in Murray Hill, N.J. The scientists have shown that the ability of these compounds to corrode copper, for instance — forming copper sulfide — can be doubled when exposure to them occurs in the presence of sunlight, and tripled if exposure to the gases occurs in the presence of ozone. Of course, it is virtually impossible to avoid exposure to either or both of these corrosion enhancers.

"The thing that is a little puzzling," notes Thomas Graedel, one of the experimenters, "is that when we have them both at once, we don't see an additive effect" — that is, a quintupling in corrosion. Instead, he says, "we see an effect that's about equal to what we see with the ozone by itself. That suggests to us that there's some process that limits the amount of corrosion that can occur."

Levels of H_2S and ozone used in their experiments were high but within the range of recorded values for polluted regions. The researchers chose these levels to speed up their results since earlier work had shown that lower concentrations over longer exposure periods would ultimately produce comparable corrosion.

Ozone is a potent oxidizer, that is, it readily enters into chemical reactions that involve the exchange of electrons. What's not clear, the researchers say, is whether the corrosion enhancement they witnessed with ozone was due to that chemical or reactive products, such as hydroxyl radicals (OH), that form when ozone re-

acts with water. "Corrosive processes are very much less efficient where it is dry," notes Graedel. And except where it is extremely dry, metal surfaces in the environment tend to be covered with a thin film of water.

Graedel says "reaction centers" appear to develop within this liquid film; it is here the reactive chemicals combine. These "may not end up being the sites that are corroded," he explains, "but sites that temporarily grab molecules and assist in their transformation."

In a report of their work in the May 11 SCIENCE, the researchers speculate that ozone may also contribute to the development of structural defects in the metal's surface that somehow enhance the diffusion of copper ions up from the solid metal to these reaction sites. However, though they have studied the surface with electron microscopy, they still haven't identified the suspected defects.

They also found indications that the corrosion rate was limited by the rate at which copper ions could free themselves from the metal surface and diffuse to the reaction centers. If the ozone-mediated reactions that produce copper sulfide were already tapping copper ions as fast as they became free, that might explain, Graedel says, why the double whammy posed by light and ozone is no worse than exposure to ozone alone.

The AT&T researchers believe that if ozone and sunlight can enhance corrosion, other reactive oxidants probably can too. By characterizing exactly how they do this, the chemists hope eventually to be able to tailor more protective coatings for easily corroded metal surfaces. But Graedel admits, "it's too early in the game to do that now."

—J. Raloff

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