the strong gravitational interaction arising from the giant planets. This raises the number of planets in the HZ, particularly for more massive stars.

This is a step beyond the early efforts of Dole and others, but it is only an early exploration of the problem. As more observational evidence is gathered on the nature of disks around young stellar objects, this type of study will gain more focus and insight.

One immediate implication, however, is that around stars roughly similar to the Sun there is a reasonable chance of finding planets suitable for providing life with a place to start. The probability is not one, but neither is it a tenth of a per cent.

It should be noted that this expectation is only for stars that have planetary systems at all, and we have no observational evidence to tell us whether the majority of stars have such systems, or whether the Sun is unusual in that regard. Wetherill's study alone will not alter current tactics in the 'search for extraterrestrial intelligence' (SETI), but combined with the results from searches for planetary systems that will emerge in the years to come it could well affect the approach to SETI.

Another aspect of the new study is of interest. The past year has seen the discovery of substellar-mass companions to a handful of stars[7–9]. What has been surprising is that all of these companions are located close to their parent star — the companion to 51 Pegasi is just 0.05 AU away — and they are all of about one Jupiter mass or greater. As shown by Wetherill's study, this result is more than counter-intuitive: it is inconsistent with the basic concepts of our current understanding of planetary system formation. Did these companions form at great distance and migrate inwards[10]? That might account for one system, but it is unlikely that all of the newly discovered systems can be accounted for in this way. It is much more likely that these objects formed more or less where they are at present, and that they are not planets. Are they low-mass brown dwarfs, or are they a new class of object[11]? ☐

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MATERIALS

Foams flow by stick and slip

David A. Weitz

FROM the top of a beer to the meringue on a pie, from shaving cream to a bubble bath, we encounter foams everywhere. But consider their properties; they are fascinating materials. They are made only of gas and liquid, materials that flow freely, yet foams can be rigid solids like the whipped cream on a dessert. This solid-like behaviour results from the foam microstructure, gas bubbles in a fluid, with interfaces stabilized by surfactant. But foams also flow easily, as anyone savouring the whipped cream of the dessert will affirm. What makes foams solid? How do they flow? Important new insight has come from a recent experiment[1] by A. D. Gopal and D. J. Durian and a computer simulation[2] by Durian. The results emphasize the critical importance of the disordered packing of the bubbles, and show that foam flow occurs through topological rearrangements of bubble positions, sharing many features with the highly non-linear dynamics of the avalanches observed in granular flow and the intermittent 'stick–slip' dynamics of earthquakes.

IMAGE UNAVAILABLE FOR COPYRIGHT REASONS

Warner Bros (Courtesy Kobal)

Ensign Pulver (Jack Lemmon) discusses his foam problems with two colleagues (Henry Fonda and William Powell). From *Mister Roberts* (1955).

Most of the recent theoretical work on foams has concentrated on the behaviour of the thin film between the bubbles, because simple rules can be used to describe its properties[3–6]. The challenge has been to generalize these rules to the more complex microstructure of real foams. While progress has been achieved, many uncertainties persist, particularly for the three-dimensional packing of real foams. Furthermore, these simple rules are strictly applicable only to dry foams, with no liquid between the bubbles. In reality, most foams contain enough liquid that more general physical concepts must be used to describe their properties. Durian takes a completely different tack: he concentrates on the bubbles as entities, and models their behaviour by considering the interactions between neighbours, thus directly including the critical length scale that controls the dynamics and properties of a foam.

To investigate the flow of foams experimentally, Gopal and Durian used novel imaging methods which exploit multiply scattered light[7] to probe the bulk of a foam flowing under an applied shear. They observed a pronounced change in the dynamics once the applied distortion exceeded unity, so that the bubbles were forced to move beyond their local neighbours. The foam flowed by random discrete rearrangements of neighbouring bubbles, distinguished by a characteristic rate constant, implying that the topological rearrangements were localized to a well-defined size.

These experimental conclusions were supported by the simulations, which also looked directly at the behaviour of bubbles through their interactions with their nearest neighbours. This allowed Durian to analyse the local motion, at least in the two-dimensional packings studied. The intermittent stick–slip motion of the bubbles was observed both in their motion and in the resultant stress on the walls, which decreased sharply when an avalanche-like rearrangement of the neighbouring bubbles occurred. These rearrangements were highly localized — one central bubble moved the most, with the remainder of the motion restricted to a halo of near neighbours.

The localized rearrangements observed by Durian contrast with the predictions for ordered model foams[3], where the rearrangements occur simultaneously throughout the sample. They also contrast with the predictions for two-dimensional dry foams, which exhibit long-range, power-law correlations, reminiscent of self-organized criticality[6,8]. Such behaviour does not appear to be important for real foams, or even for two-dimensional model foams that are not dry.

The simulations also predict the elastic modulus of the foam and the osmotic pressure (the pressure that must be applied to deform the bubbles to achieve a given volume fraction of gas), and agree, at least qualitatively, with experiment.

The imaging of foam dynamics is limited by the high opacity of the foams, and Durian's simulations were restricted to two dimensions. This limitation has been overcome in a three-dimensional simulation by LaCasse *et al.*[9], using a similar model. Although restricted to static behaviour, their results were in quantitative agreement with experiment, both for the elasticity and the osmotic pressure. While validating Durian's basic conceptual approach, they incorporated more microscopic information about the bubble interactions, showing that the model of harmonic springs adopted by Durian is modified by the non-local nature of the shape deformations.

The properties of foams have puzzled scientists for centuries. They are not only important for understanding the behaviour of cosmetics and foods, but are also crucial for designing improved foams for other technologically important uses, such as fire-fighting and a wide range of chemical separation processes. Durian's results give us a new perspective on these questions by concentrating on the length scale of the bubbles, rather than that of the films between them. That should lead to significant progress in this fascinating field. Moreover, the results may be applicable to many other granular or particulate systems. □

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VOLCANIC ERUPTIONS

Turbulent times at Taupo

Tim Druitt

As silica-rich magma ascends from deep beneath a volcano, dissolved water and carbon dioxide come out of solution violently, fragmenting it into a mixture of hot particles and gas that erupts explosively at the surface. If this mixture is lighter than air it ascends buoyantly as an eruption plume, often high into the stratosphere. But if denser, it collapses back like a fountain and pours over the landscape as a ground-hugging 'pyroclastic flow'. On page 509 of this issue[1] Dade and Huppert present a new model of the transport and sedimentation of the particularly violent Taupo pyroclastic flow which erupted 1,800 years ago in New Zealand, and covered 20,000 km^2 of the North Island under a blanket of red-hot pumice and ash.

Some pyroclastic flows, those with small volume, are hot, dense avalanches of rock and dust which travel as valley-confined tongues for up to several kilometres. Their deposits have the steep fronts, side levees and lobate morphologies typical of other highly concentrated geophysical dispersions such as mud flows and cold rock avalanches[2].

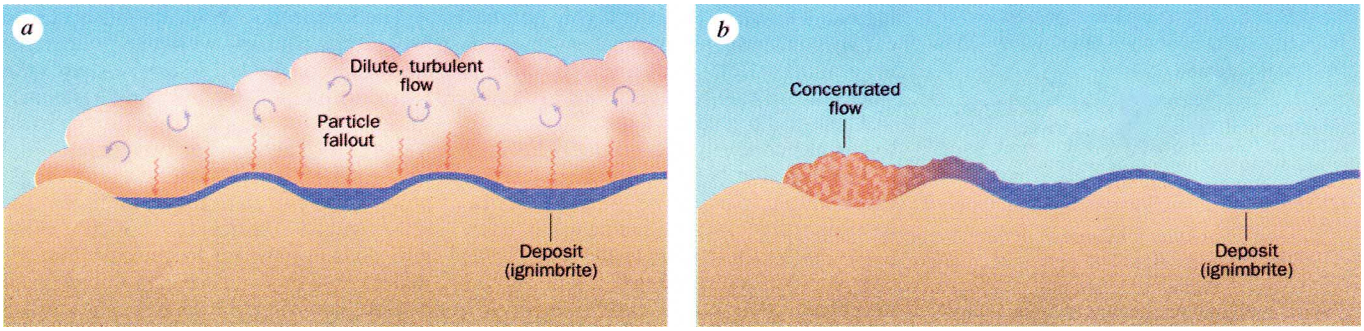
On a much larger scale, flows from single eruptions may have volumes of tens or hundreds of cubic kilometres. Their deposits, termed ignimbrites, must be very fluid at the moment they are laid down, because they form flat-topped ponds in valleys and depressions[3]. Large-scale ignimbrite eruptions are rare on a human timescale — even the 1991 eruption of Mount Pinatubo in the Philippines discharged only 5 to 7 km^3 of ignimbrite.

The volcanic record has also yielded evidence of pyroclastic flows of exceptional violence. They produce low-aspect-ratio ignimbrites, which are relatively thin but spread very widely. One is the exceptionally well documented Taupo pyroclastic flow, which travelled 80 km in all directions from its erupting vent and surmounted obstacles over 1,500 m in elevation, implying a very high velocity[4]. The Taupo flow laid down a veneer of sediment all over the mountainous terrain, thickening in valleys and depressions into the flat-topped accumulations more typical of ignimbrite.

Since the mid-1970s, it has been believed that large pyroclastic flows, like their small-volume equivalents, travel as concentrated particle dispersions[3]. In this interpretation it is the high density of the flow that permits the transport of coarse volcanic debris over large distances. Ignimbrites are poorly sorted by size, which is attributed to the flows' having solid-concentrations of several tens of per cent, inhibiting segregation of particles of different sizes. The concentration of large, frothy pumice blocks at the tops of many ignimbrites is explained by the flotation of these low-density 'clasts' in the fluidized dispersion of ash, volcanic rock and gas that constitutes the flow. Laboratory fluidization experiments appear to support this model[5].

However, some researchers have begun to question this picture, particularly for those low-aspect-ratio ignimbrites formed by fast flows. Valentine[6] showed that a dilute, highly turbulent flow could transport coarse debris further than previously calculated. Perhaps some high-velocity pyroclastic flows travel as dilute suspensions in which intense turbulence replaces high concentration as the main support mechanism. In this model, depositional features such as pumice flotation are acquired at a late stage in the sedimentation process, and do not reflect the nature of the dilute transport system.

The dilute model gained some support from the volcanic blast that occurred on 18 May 1980, at Mount St Helens in



Two contrasting models for the emplacement of the Taupo ignimbrite. *a*, In the dilute model (refs 1 and 6) the flow particle concentration is very low. The sediment layer is at first highly fluidized by escaping gases and drains into topographic lows, leaving only thin veneers on ridge crests and valley sides. *b*, In the second model (ref. 4), the flow is relatively thin and highly concentrated (tens of per cent), and the deposit is laid down by the tail of the flow. The dilute flow can traverse mountainous terrain readily because its thickness is greater than, or comparable to, the topographic roughness. The thin, highly concentrated flow can do so only if its velocity is high.