

Figure 1 Effects of ammonium fertilizer on methane dynamics in a rice ecosystem. **a**, At the plant/ecosystem level, nitrogen increases plant growth and carbon supply to the methane producers, stimulating methane efflux from the soil. **b**, As Bodelier *et al.*¹ show, at the level of the microbial community, nitrogen stimulates the growth and activity of methane-oxidizing (methanotroph) bacteria, leading to reduced net efflux. **c**, At the biochemical level, ammonium inhibits methane consumption because of competition for methane monooxygenase, and so increases efflux. The balance between these processes may vary. But Bodelier *et al.*¹ find that effects at the level of the microbial community dominated the rice-ecosystem response to ammonium fertilization.

inhibitor and substrate. Methane concentrations are extremely high around a rice root, and plant nitrogen uptake may limit the exposure of bacteria to excess ammonium concentrations. These conditions should limit competitive inhibition. Equally importantly, because carbon (as methane) is readily available in rice soils, methanotrophs may become nitrogen-limited. So, at the level of the microbial community (Fig. 1b), addition of ammonium could stimulate methanotroph growth and activity to a much greater degree than it would inhibit them at the biochemical level (Fig. 1c). The net effect could be to reduce overall methane efflux from the ecosystem.

Bodelier *et al.*¹ show that, in a rice ecosystem, ammonium fertilization does indeed stimulate methanotroph growth and activity. Their research had three components: measurements of the rates of the reactions involved; studies using isotope tracers; and molecular analysis of the bacterial communities in the soil. The rate measurements showed a clear stimulation of methane consumption with fertilization. The tracer studies showed that, when ¹⁴C-methane was added, the ¹⁴C appeared in membrane lipids that are unique to methanotrophs. Finally,

DNA-based molecular analysis identified the species of methanotrophs present, and showed that the rice plant stimulated the growth of type I methanotrophs, the group that responded most favourably to nitrogen fertilization.

In a rice paddy, the interactions of nitrogen fertilizer and the methane cycle are complex, with different effects occurring at different levels of organization (Fig. 1). At the ecosystem and biochemical levels, fertilization would lead to increased methane emissions (Fig. 1a,c). As Bodelier *et al.* show, however, at the level of the microbial community, fertilization can stimulate methane consumption and reduce its efflux from the paddy (Fig. 1b). Which set of effects dominates the overall methane efflux may vary between systems, but responses at the level of the microbial community have generally not been considered. By incorporating these responses into their analysis, Bodelier *et al.* find that increasing rice production may not have such a severely detrimental effect on the atmosphere as has been assumed.

Further, their work highlights the importance of understanding ecological processes at the microbial-community level. This is a level of organization that has been little studied. Probably less than 1% of bacterial

species have ever been isolated⁶, and many microbial processes have been studied in only a few ecosystem types. Only recently have researchers begun asking meaningful questions about how variations within physiological groups of microorganisms (methanotrophs, for instance) affect ecosystem-level processes such as trace-gas fluxes⁷. In large part, this has been because the molecular tools necessary for analysing microbial communities *in situ* have become available only in the past decade. Bodelier *et al.* have identified a gap in our understanding of microbial-community dynamics. As research continues, we are likely to find that some predictions about ecosystem behaviour fail because we are unaware of other such gaps. ■

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Fluid mechanics

Jets from a singular surface

Michael P. Brenner

All theories of continuous systems begin with the assumption that there is a separation of scales between the macroscopic variables needed by the theory and the microscopic motions that are ignored. So, the bulk motion of fluid in a teacup stirred by a spoon occurs on a scale that is orders of magnitude larger than the distance between the molecules. When this basic assumption is violated for an instant in time, the consequences can be important and dramatic. On page 401 of this issue, Zeff *et al.*¹ describe such a violation that occurs when a tub of viscous liquid is shaken up and down. When done just right, a relatively modest shaking can produce extremely thin and violent jets, which spout upwards at velocities of more than 50 metres per second.

The fact that violent jets can be produced in this fashion was first observed by Longuet-Higgins², who invented this experiment during a study of bubble cavitation. It has long been known that negative pressure in a liquid can create bubbles whose subsequent collapse can severely damage solid surfaces. The damage is believed to result from the impact of high-speed jets that form as the bubble collapses³. Longuet-Higgins's experiment

suggested that the creation of such jets from an oscillating free surface is a general phenomenon and that there may be a unique underlying mechanism. Over the years, there has been an emerging consensus^{4–6} in the theoretical community that jet formation in many different situations is coupled to a singular event on a free surface, such as that shown in Fig. 1.

Now, Zeff *et al.*¹ demonstrate experimentally that the violent eruption of a jet does indeed arise out of a singular distortion of the free surface: the shape of the liquid–air interface develops an extremely high curvature an instant before the jet is produced. The release of this curvature produces the jet. Zeff *et al.* show that this singular event is driven by the inertia and surface tension of the fluid, and ultimately is stopped by the retarding influence of viscosity. When the inertia of the fluid is above a critical threshold, the high surface curvature produces both a jet and an air bubble, which reduces the velocity of the jet.

The dynamics described by Zeff *et al.* are an example of a finite-time singularity, where the continuum description starts to break down. The formation of a singularity is accompanied by a divergence of a physical

quantity, which necessitates a change in the description of the system. A singularity is therefore a mixed blessing for a hydrodynamicist — on one hand it signals the breakdown of a cherished theory, but on the other the creation of a structure on an extremely small scale is a possibility to be exploited. The difference in scales between the singular structure and the rest of the problem means that the detailed properties of the singularity should be largely independent of the way the system is prepared. For this reason, understanding a singularity gives an opportunity to learn about a broader class of problems than was initially intended.

Historically, there are many examples where understanding singularities led to fundamental insights. Larson's theory of star formation, for example, is based on a singular solution to the equations of gravitationally forced gas dynamics⁷. Choptuik's study of singularity formation during gravitational collapse (that is, the creation of small black holes) argued against the 'cosmic censorship' hypothesis⁸, which states that singularities such as black holes are always concealed from observers. A particularly penetrating use of a singularity was shown by the British scientist G. I. Taylor, who calculated the energy of an atomic test explosion from a wartime United States government publicity movie⁹. Taylor did this without complete information of the explosion, because the blast wave has properties that are independent of the details of how the blast is created.

Singularities have one other special property: the shapes occurring before the singular event are exactly the same, after rescaling of the axes. This property is called self-similarity. Very simple arguments can often be given for the time dependence of the self-similarity, based solely on dimensional considerations. Zeff *et al.* find that the law governing the singularity on the free surface is identical to

that discovered by Keller and Miksis¹⁰ for a different problem (the recoiling of a fluid wedge on a solid surface) — this law applies whenever the most important forces are surface tension and inertia. Not only do Zeff *et al.* demonstrate that the Keller–Miksis law is obeyed in their experiments, but they also use it to construct a solution of the equations for fluid motion that is consistent with the observed shapes.

An obvious question posed by the history of this problem is whether the singularity observed has any relevance to jet production in cavitation damage. If a singularity obeying the Keller–Miksis law occurred during the collapse of a cavitation bubble, then the formation of violent jets could be a result of the release of high curvature on the bubble. The strongest argument for this appealing idea is that, because the solution describing the singularity is essentially independent of the details of the forcing, this same solution could in principle occur in other situations (such as cavitation) in which an air–liquid interface is strongly forced. On the other

hand, because the singularity seen by Zeff *et al.* occurs only at a carefully controlled value of the forcing, it seems unlikely that something so special will occur during the collapse of an arbitrary vapour bubble. The tension between these two points of view will need to be resolved with more research. ■

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Intelligence

Evolutionary psychology meets *g*

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Homo sapiens may not always seem to be wiser than other animals, but we are inclined to believe that we are more intelligent. Scepticism on this point is usually rebuffed by pointing to the hard evidence of the size of our brain and its threefold increase over the course of human evolution. But what is the nature of this superior intelligence given us by our large brains? And if intelligence has been of such importance to human evolution, why does it vary so much, at least as measured by IQ tests, among people today? Do IQ tests measure intelligence? If so, does the existence of the general factor *g*, extracted by factor analysis of any IQ-test battery, imply that there is a unitary trait of general intelligence? Or is the modular (Swiss army knife) view of the mind, beloved of evolutionary psychologists, a more accurate or fruitful metaphor?

These are large questions. If they were not all answered to everyone's satisfaction at a recent symposium*, there was a fair measure of consensus on some of them and much of interest to report on others.

The psychometricians were united in their support of *g*, or general intelligence. There are great differences in the surface features of different IQ tests or sub-tests: some ask simply for the meanings of words or items of general knowledge; others ask

for the solution of abstract, diagrammatic analogies or series-completion problems; and yet others require one to imagine what a complex three-dimensional object would look like viewed from a different perspective. Nonetheless, the fact is that performance on one kind of test correlates with performance on all others. This 'positive manifold' means that factor analysis will always yield a large general factor, which cannot, despite the views of some critics, be made to disappear by statistical legerdemain.

But what is the underlying cause of *g*? One popular suggestion (A. R. Jensen, Univ. California, Berkeley) is that there must be a biological basis, something like the efficiency of the brain as an information-processing device. There are (surely unsurprisingly) some correlations between IQ scores and some measures of the brain, for example its size. But although it has been pursued with much enthusiasm for 20 years or more, the search for correlations between IQ and any measures of brain activity, such as event-related potentials, has met with little success and yielded few replicable results. Moreover, the concept of brain 'efficiency' hardly has the theoretical precision needed to advance our understanding of the nature of intelligence.

A second approach has been to look for correlations between measures of general intelligence and performance on various

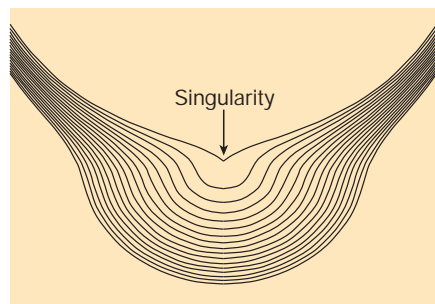


Figure 1 **Formation of a singularity.** Surface profiles from a model of a collapsing cavity, where the surface develops a singularity. The bottom profile corresponds to the earliest time, and the top profile to the latest. Zeff *et al.*¹ find a similar singularity occurring in a different situation, when a tub of viscous liquid is shaken up and down to produce violent jets. (Simulation by H. Oguz, Johns Hopkins University, and M. Longuet-Higgins, University of California at San Diego.)

*The Nature of Intelligence, Novartis Foundation, London, 30 November–2 December 1999.