PLANETARY SCIENCE

Enceladus with a grain of salt

John Spencer

The observation that water plumes erupt from cracks on Saturn's moon Enceladus has fired speculation about a possible subsurface ocean. The latest searches for sodium salts point to the existence of such an ocean.

Do the spectacular plumes of water vapour and ice particles seen on Saturn's icy moon Enceladus come from liquid water just below its frigid surface? That is the fascinating question addressed by Postberg *et al.*[1] (page 1098 of this issue) using data from the Saturn-orbiting Cassini spacecraft, and by Schneider *et al.*[2] (page 1102) using ground-based telescopes. Despite their very different techniques, the two teams use the same key element, sodium, in their search for Enceladan water.

Of all the icy moons orbiting the giant planets of our Solar System, Enceladus, just 500 kilometres in diameter, is the only one (so far) where we can watch, in detail, geological processes as they happen. Four relatively warm 120-km-long fractures, informally called tiger stripes, slice across Enceladus's south pole and eject supersonic plumes of water vapour and ice particles thousands of kilometres into space[3–7] (Fig. 1). The ice particles populate a dust ring around Saturn — the E ring, which is much larger and fainter than the planet's better-known main rings — and the vapour populates a torus of atoms and molecules encircling the planet. The chemistry of the plumes is of intense interest not only because it provides a unique opportunity to sample the interior of an icy moon directly, but also because the interior of this particular moon provides a potential habitat for extraterrestrial life.

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Figure 1 | Streaming into space. Saturn's icy moon Enceladus — backlit by the Sun and accompanied by a background star (top left) in this image taken by the Cassini spacecraft on 24 March 2006 — spews ice grains into space from jets at its south pole. The bright background sky, which makes the night side of Enceladus seem dark by contrast, is a small portion of Saturn's E ring, which is composed of ice grains accumulated from decades of output from the Enceladus jets. Analysis of these grains[1], and the gas that accompanies them[2], is providing new clues about a possible subsurface ocean that might supply the jets.

Life requires at least three ingredients: a source of energy, which in Enceladus is provided — at least in part — by tidal heating caused by the varying gravitational pull of its parent planet as Enceladus travels around its slightly eccentric orbit; a suitable mix of chemical elements, which seem to be present based on Cassini's analysis of the plume gases[4]; and liquid water. So the question of whether Enceladus's internal heat can provide that water, by melting a portion of the ice shell that comprises much of the moon's bulk, is one of the hot issues in planetary science today.

Sodium is a valuable tracer of possible liquid water for two reasons. First, it is highly soluble in water, and so any Enceladan water that has had prolonged contact with the moon's silicate core should be rich in sodium salts, like Earth's oceans. Second, when dispersed in its atomic form, sodium scatters sunlight with extreme efficiency at its resonant wavelength of 589 nanometres (the familiar orange–yellow colour of sodium street lights), and is thus easy to detect even in minute quantities.

Schneider *et al.*[2] use spectrographs on ground-based telescopes to search for sodium emission in Enceladus's gas plumes and Saturn's neutral torus. They find no sodium there to high precision, in striking contrast to the bright sodium emission seen in the output from Jupiter's volcanic moon Io, and even in the ultra-thin atmospheres of comets, Mercury and our own Moon. If there is salty water in Enceladus, some process must be very efficient in preventing most of the sodium from escaping into space.

Postberg *et al.*[1] focus instead on the ice grains from the plumes, using the Cosmic Dust Analyzer instrument aboard Cassini to determine their chemical composition directly as Cassini flies through the E ring. They find that, although all the grains are dominated by water ice, about 6% of them are quite salty, containing roughly 1.5% of a mixture of sodium chloride, sodium carbonate and sodium bicarbonate. The authors note that the grain composition is similar to the expected composition of an Enceladan ocean[8], and therefore suggest that these particles are derived from direct freezing of salty water from that ocean at the plume source. They propose that the rest of the ice grains, which have very little salt, may come from direct condensation of the plume vapour.

So the question that naturally arises is: are Schneider and colleagues' no-sodium-emission observations in conflict with Postberg and colleagues' findings? The short answer is no. Although the ice grains in the E ring eventually vaporize and liberate their contents into the neutral torus, their total cargo of sodium, when diluted by all the sodium-poor grains and the sodium-free gas, would be too small to be detected by Schneider and colleagues' ground-based observations.

The simplest, and perhaps most likely, inference from Postberg and colleagues' particle-composition data is that the plumes are directly derived from salty liquid water. But it's always possible that we are being fooled: for instance, the plume sources might currently be too cold for liquid water to exist, and the plume might be excavating the sodium-rich ice grains from some long-frozen salt pockets in Enceladus's crust. We also can't be sure that, if there is water at the plume source, it is connected to a salty ocean — Schneider and colleagues point out that the water might originally be salt-poor, only becoming salty by preferential evaporation of the more-volatile water vapour. But in any case, those salty grains provide our current best smoking (or steaming) gun pointing to present-day liquid water near the surface of Enceladus.

The salty water cannot, however, be boiling explosively straight into the vacuum of space, otherwise the sodium would be carried along and would have been easily detectable by Schneider and colleagues. Instead, the plume production process must leave most of the sodium behind. Distillation of fresh water vapour from salty water happens over Earth's oceans, of course, and could happen on Enceladus too if the evaporation proceeded slowly in pressurized chambers, for example, rather than in a vacuum. The plumes might then be supplied by leakage from the chambers along narrow fractures leading to the surface. Postberg *et al.*[1] point out that water evaporation must occur slowly for another reason: to prevent the water from freezing due to rapid loss of latent heat during the evaporation process (see online Supplementary Information to ref. 1).

Cassini will make four more close fly-bys of Enceladus before mid-2010, with the chance of an additional twelve fly-bys up to 2015, if NASA approves the 7-year extended mission currently in the planning stages. Many more discoveries are therefore likely, and with each one Enceladus becomes more exotic. Our picture of its subsurface must now be expanded to include the possibility of misty ice caverns floored with pools and channels of salty water, lurking beneath the tiger stripes. What else may lurk in those salty pools, if they exist, remains to be seen. ■

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STEM CELLS

The stress of forming blood cells

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The first heartbeat is an important moment in an embryo's life. The biomechanical forces created by pulsatile flow promote the formation of haematopoietic stem cells that equip the body with its mature blood cells.

Haematopoietic stem cells (HSCs) are rare cells that can self-renew and generate all types of mature blood cell. Adult HSCs reside in the bone marrow and function throughout life, but during embryonic development they are first formed in close association with the endothelial lining of embryonic blood vessels, before the marrow appears. The first 'definitive' HSCs, which are able to form all of the blood-cell types if transferred into a lethally irradiated host (whose marrow is destroyed), are found in the ventral wall of the aorta, where they seem to bud from the endothelium into the aortic lumen (Fig. 1). HSCs are thus formed in close contact with flowing blood, and two groups, Adamo *et al.*[1] writing in this issue of *Nature* (page 1131) and North *et al.*[2] writing in *Cell*, now show that blood flow provides a biomechanical trigger for HSC formation.

Blood flow is initiated in the embryo when the heart starts beating: at this stage, blood consists mainly of plasma and primitive red blood cells. Flow is needed to deliver oxygen and nutrients to tissues, but it also generates biomechanical forces, including fluid shear stress, which is required for the correct development of the heart[3] and blood vessels[4]. The close proximity of developing HSCs to embryonic arteries, especially the aorta, suggested that blood flow might influence HSC formation, but this idea had never been directly tested.

Adamo *et al.*[1] examined the role of fluid shear stress on haematopoiesis in cultures of mouse embryonic stem (ES) cells. They show that shear stress increases the expression of Runx1, which activates the transcription of genes required for the development of functional HSCs[5]. Also, shear stress increases the potential of cultured ES cells to give rise to colonies of haematopoietic cells — a potential that is characteristic of haematopoietic progenitors and HSCs. Notably, only a shear stress similar to that estimated to occur in the embryonic aorta could induce increased Runx1 expression and colony formation in cell-culture experiments, indicating that the induction of Runx1 requires flow conditions similar to those observed in living embryos.

To evaluate the effect of blood flow on HSC formation *in vivo*, the authors[1] studied mice in which the *Ncx1* gene had been deleted. Mice with this deletion have a defect in a protein found in large amounts in heart cells that pumps sodium and calcium ions across the cell membrane. In such mice, heartbeat and circulation fail to develop[6]. Although the mutation is lethal, *Ncx1*-knockout mouse embryos live long enough to allow isolation of the tissue surrounding the aorta.

Examination of this mutant tissue showed that the expression of endothelial markers was similar to that of normal littermates, indicating that the mutant tissue had developed vascular endothelium. However, *Ncx1*-mutant tissue expressed decreased amounts of Runx1, and its ability to form haematopoietic colonies was markedly reduced. These defects could be overcome by subjecting the mutant cells to shear stress. Adamo and colleagues[1] conclude that the mutant tissue can generate haematopoietic precursors, but that their embryonic development had not been triggered because of lack of exposure to the appropriate mechanical forces.

The formation of HSCs in the aortic wall has been observed in all vertebrate species examined, including fish, birds, mice, pigs and humans[7]. North *et al.*[2] show that blood flow also initiates HSC development in zebrafish, providing further evidence that biomechanical forces are an evolutionarily conserved trigger for HSC formation. They used a chemical genetic screen to identify compounds that affect HSC formation. Zebrafish embryos were exposed to a panel of chemicals, and the expression of *runx1* and another HSC-specific transcription factor, c-*myb*, was measured. Compounds that induced dilation of blood vessels and increased blood flow raised *runx1* expression, whereas compounds causing