

## PLANETARY SCIENCE

# Enceladus' hot springs

The detection of silicon-rich particles originating from Saturn's moon Enceladus suggests that water-rock interactions are currently occurring inside it — the first evidence of ongoing hydrothermal activity beyond Earth. [SEE LETTER P.207](#)

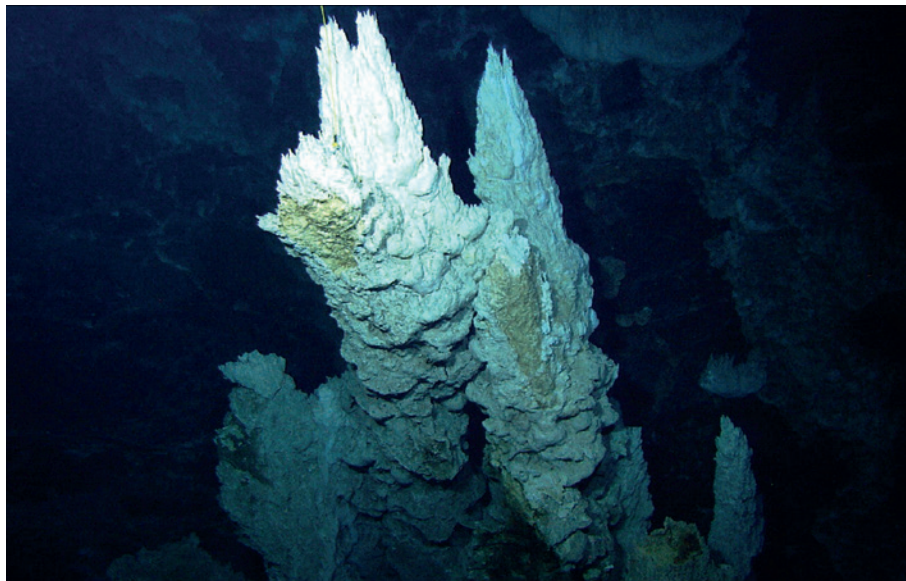
GABRIEL TOBIE

Many planetary bodies are thought to have produced hydrothermal activity — interactions between water and rock — as a result of hot-water circulation during the early stages of the Solar System, but Earth was the only one known to be sustaining such activity today. Then, in 2005, the Cassini spacecraft discovered eruptions of water vapour and ice emanating from long, warm fractures on the south pole of Saturn's moon Enceladus. The detection of salted, icy grains in Enceladus' erupting plume<sup>1</sup> clearly pointed to an ocean environment below its icy crust and to the leaching of rocks by warm water, at least in the past. On page 207 of this issue, Hsu *et al.*<sup>2</sup> report hints of presently active hydrothermal processes on Enceladus.

This story began about a decade ago during Cassini's approach to Saturn, when one of the spacecraft's instruments detected tiny dust particles, called stream particles, escaping into interplanetary space from the Saturn system<sup>3</sup>. Analysis of these particles revealed that they were mostly nanometre-sized and rich in silicon, in contrast to the ice-rich particles prevalent in the Saturnian environment. The origin of these particles has remained enigmatic for years.

Building on their earlier modelling work<sup>4</sup>, Hsu and colleagues simulated the dynamics of the particles' ejection, tracking them back to their most probable source region: Saturn's E ring, a tenuous ring mostly made of small ice grains, extending between the orbits of the moons Mimas and Titan. Because Enceladus is the source of particles in the E ring<sup>5</sup>, it must also be the ultimate source of the silicon-rich stream particles, which were presumably once incorporated in icy grains.

By analysing mass spectra of the stream particles, the authors concluded that the dominant constituent is silica (SiO<sub>2</sub>). This is much more probable than pure silicon or silicon carbide (SiC), two other potential candidates. Silica is extremely common on Earth, occurring mostly in the natural form of quartz. But finding silica nanoparticles in the Saturnian environment is unexpected. Hsu *et al.* ruled out fragmentation of larger grains as a possible process to explain the narrow size distribution



**Figure 1 | The Lost City hydrothermal field under the mid-Atlantic Ocean.** These limestone chimneys, which are up to 60 metres tall, vent fluids at a temperature of 90 °C. Hsu *et al.*<sup>2</sup> report evidence of a similar aqueous environment in Saturn's icy moon Enceladus.

of the stream particles. The composition and size distribution must therefore be inherited from the particles' formation process, which seems most likely to have been fast crystallization of silica nanoparticles from supersaturated aqueous solutions.

Using laboratory experiments, the authors finally showed that silica particles with the observed size distribution can be produced only under rather specific thermo-physical conditions, thus constraining the thermal state of Enceladus' interior. Specifically, a region of the rock core must have a temperature of at least 90 °C and be in contact with water of pH greater than 8.5 to dissolve silica in sufficient amounts; the oceanic salinity should be less than 4% and oceanic pH in the range of 8.5 to 10.5, to allow the formation of numerous nanometre-sized silica grains.

The inferred core temperature is unexpectedly high for a body the size of Enceladus (approximately 500 kilometres in diameter), especially given that deep water circulation should efficiently cool the core<sup>6</sup>. A strong heat source must exist to raise the core temperature above 90 °C — most probably tidal friction, and possibly also exothermic water-rock

reactions known as serpentinization reactions<sup>7</sup>. But modelling is needed to determine whether tidal flow and serpentinization in the core could provide sufficient energy at present to allow hydrothermal activity, and, if so, for how long.

Intriguingly, the conditions inferred by Hsu and colleagues in Enceladus' water-rock system are similar to those found on Earth in an atypical hydrothermal field called Lost City (Fig. 1), which was discovered in the early 2000s in the mid-Atlantic Ocean<sup>8,9</sup>. This hydrothermal field consists of limestone chimneys 60 metres tall, which vent metal-poor, basic fluids (pH 10–11) at a temperature of 90 °C; the fluids are rich in hydrogen, abiotically produced methane and other organic compounds. For comparison, most other known fields are fuelled by acidic (pH 3–5), metal- and sulfide-rich fluids at temperatures greater than 300 °C (ref. 8).

Because it is relatively cold, Lost City has been posited<sup>9</sup> as a potential analogue of hydrothermal systems in active icy moons. The current findings confirm this. What is more, alkaline hydrothermal vents might have been the birthplace of the first living organisms on

I.F. URIAO, UW, LOST CITY SCIENCE PARTY; NOAA/OAR/OER; LOST CITY 2005 EXP./CC BY 2.0

the early Earth, and so the discovery of similar environments on Enceladus opens fresh perspectives on the search for life elsewhere in the Solar System.

Hsu *et al.* also conclude that the silica particles must be transported from the core hydrothermal source to the plume source near the surface in a fairly short time — from months to years at most — to limit the particles' growth. This implies that samples of materials erupted from Enceladus' warm fissures would provide a unique opportunity to directly probe aqueous, possibly prebiotic, processes occurring deep in Enceladus' rock core, in almost real time. Cassini's discoveries, together

with Hsu and colleagues' findings, point to potentially complex chemical processes in Enceladus' watery interior. Cassini will fly through the moon's plume again later this year, but only future missions that can undertake improved *in situ* investigations<sup>10,11</sup>, and possibly even return samples to Earth<sup>11</sup>, will be able to confirm Enceladus' astrobiological potential and fully reveal the secrets of its hot springs. ■

**Gabriel Tobie** is at the *Laboratoire de Planétologie et Géodynamique, Université de Nantes, CNRS, UMR-6112, Nantes, France.* e-mail: [gabriel.tobie@univ-nantes.fr](mailto:gabriel.tobie@univ-nantes.fr)

1. Postberg, F., Schmidt, J., Hillier, J., Kempf, S. & Srama, R. *Nature* **474**, 620–622 (2011).
2. Hsu, H.-W. *et al.* *Nature* **519**, 207–210 (2015).
3. Kempf, S. *et al.* *Science* **307**, 1274–1276 (2005).
4. Hsu, H.-W. *et al.* *J. Geophys. Res. Space Phys.* **116**, A09215 (2011).
5. Kempf, S. *et al.* *Icarus* **193**, 420–437 (2008).
6. Travis, B. J. & Schubert, G. *Icarus* **250**, 32–42 (2015).
7. Malamud, U. & Prialnik, D. *Icarus* **225**, 763–774 (2013).
8. Kelley, D. S. *et al.* *Nature* **412**, 145–149 (2001).
9. Kelley, D. S. *Oceanography* **18**, 32–45 (2005).
10. Tobie, G. *et al.* *Planet. Space Sci.* **104**, 59–77 (2014).
11. McKay, C. P., Anbar, A. D., Porco, C. & Tsou, P. *Astrobiology* **14**, 352–355 (2014).

## CELL SIGNALLING

# Disarming Wnt

**The secreted enzyme Notum has been found to inhibit the Wnt signalling pathway through removal of a lipid that is linked to the Wnt protein and that is required for activation of Wnt receptor proteins. SEE ARTICLE P.187**

ROEL NUSSE

Cells signal to one other through secreted molecules that are conserved across the evolutionary spectrum. One class of these signals is Wnt proteins, which influence the balance between proliferation and differentiation in many cell types, including stem cells<sup>1</sup>. Because this balance is crucial for normal tissue maintenance, and overactivation of Wnt signalling can cause cancer, the activity of Wnt signals is tightly controlled by various extracellular molecules. In this issue, Kakugawa *et al.*<sup>2</sup> (page 187) describe an unexpected mechanism by which Wnt signals can be downregulated, showing how an extracellular enzyme called Notum renders Wnt inactive.

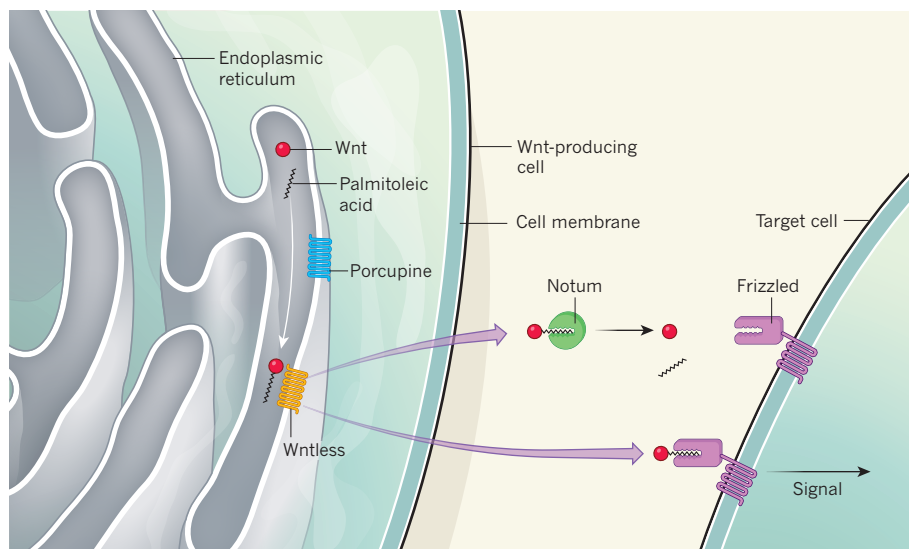
Detailed biochemical, structural and genetic experiments<sup>1</sup> reveal that Wnt signalling mechanisms are built from unusual elements. When Wnt proteins are made, an acyl group from palmitoleic acid (a monounsaturated form of the lipid palmitic acid) is attached at an evolutionarily conserved serine amino-acid residue, through a carboxyl ester link<sup>3,4</sup>. This modification is made by Porcupine, an enzyme located in a cellular substructure called the endoplasmic reticulum<sup>5</sup>. Such palmitoleoylation is essential for Wnt activity, because it is the acyl group that binds to Frizzled<sup>6</sup> — the transmembrane receptor protein for Wnt — through a hydrophobic cavity in the receptor on target cells. Wnt–Frizzled binding is imperative for receptor activation, and triggers many events in the cell, from modulating gene expression to changing cell shape.

As with many components of the Wnt signalling pathway, Notum was originally

discovered in fruit flies, in screens for genes that interact with the Wnt protein Wingless<sup>7,8</sup>. Loss of Notum in flies leads to abnormal wing growth, indicating that Wnt signalling (which drives wing growth and patterning) becomes unrestrained in its absence. Wnt signals also turn on the expression of the gene that encodes Notum, leading to negative feedback regulation that intrinsically limits signalling, as is often the case for

such pathways. Initial studies<sup>7,9</sup> suggested that Notum might act as a phospholipase enzyme, cleaving the link between membrane-bound glycoproteins called GPI anchors and glypicans — large polysaccharides that form complexes with extracellular molecules such as Wnt. Cleavage releases glypicans into the extracellular space, decreasing their ability to restrain Wnt activity.

Kakugawa *et al.*<sup>2</sup> unveil a different, previously undocumented function of Notum. The authors start with a structural analysis of human and fly Notum, and find that the protein has the overall structure of a hydrolase enzyme. But it also has a large hydrophobic cavity of around 380 cubic ångströms, which in theory could provide sufficient space for binding by acyl groups with chains of up to 16 carbons — the length of palmitoleic acid. Furthermore, the researchers' analysis of binding between Notum and acyl groups of various lengths and



**Figure 1 | Notum shoots the messenger in Wnt signalling.** In Wnt-producing cells, the Wnt protein is made in a cellular compartment called the endoplasmic reticulum. There, an acyl group from palmitoleic acid is added to Wnt by the membrane-spanning enzyme Porcupine. The Wntless protein then transports palmitoleoylated Wnt out of the cell. Secreted Wnt binds to its receptor protein Frizzled, which spans the membrane of Wnt target cells. This binding depends on the acyl group in Wnt, and triggers an intracellular signalling cascade. Kakugawa *et al.*<sup>2</sup> report that the Wnt–Frizzled interaction is inhibited by the extracellular enzyme Notum, which specifically removes the acyl group from Wnt.