conformation. This would cause the E2~UBL bound to E1 to clash with UBA3, promoting the departure of E2~UBL. This ingenious mechanism ensures an irreversible flow of UBL molecules from E1 via E2 to a substrate bound to E3.

Some mechanistic aspects of the E1–E2 transfer process remain to be addressed. The A-site and the T-site of E1 are separated by the prominent crossover loop of UBA3 (Fig. 1a). How, then, does the topologically challenged transfer of the UBL between these sites occur? Two mechanisms suggest themselves: either the adenylated tail of the UBL changes conformation and comes close to the active cysteine in the T-site, or the UBA3 catalytic domain undergoes a conformational change that allows this cysteine to reach the A-site. It might be possible to distinguish between these two mechanisms by determining the structure of an E1 in complex with an adenylated UBL.

Finally, an interesting parallel can be drawn between the mechanism proposed by Huang *et al.*[4] and the E2–E3-catalysed attachment of ubiquitin to its protein targets. A structural model of an E2–E3 complex has been proposed[9] in which there is a large gap between the active cysteine of E2 and the substrate that is bound to E3. Could the conformational change reported by Huang *et al.* be a model mechanism for other reactions in signalling pathways involving UBLs? ■

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PLANETARY SCIENCE

Inside Enceladus

John Spencer and David Grinspoon

Chemical analysis of a plume emanating from near the south pole of Enceladus indicates that the interior of this saturnian moon is hot. Could it have been hot enough for complex organic molecules to be made?

Tiny, icy Enceladus is, at a mere 500 kilometres in diameter, Saturn's sixth-largest moon. But thanks to the discovery in July 2005, by NASA's Cassini Saturn orbiter, of a remarkable water-rich plume jetting from warm fractures near Enceladus's south pole[1–3] (Fig. 1), the satellite has rivalled the giant moon Titan as a focus of attention in the Saturn system. In a paper to be published in *Icarus*, Matson *et al.*[4] suggest that the plume may be the external manifestation of a chemically rich, subsurface hydrothermal system that reaches temperatures of more than 200 °C.

This activity offers planetary scientists the first real possibility in the Solar System of studying cryovolcanism — volcano-like activity involving ices, rather than the molten silicates of earthly volcanoes — as it happens. The plume is also an unprecedented opportunity for direct analysis, with Cassini's instruments, of material that was in the interior of an icy satellite only minutes earlier. Of the issues to be resolved on Enceladus, one of the most interesting is that of the moon's internal temperature distribution. This controls its potential for sustaining liquid water, the chemistry that is possible, and even the potential suitability of the moon as a habitat for life.

The highest surface temperatures measured directly by Cassini's thermal infrared imaging instrument are about 145 K (–128 °C)[2], although a temperature of at least 180 K at the plume's source can be inferred indirectly. It has been suggested[3] that the comparable masses of gaseous and solid H_2O in the plume calculated from the Cassini data are produced most easily if the plume is generated by the boiling of liquid water into the vacuum of space, implying a temperature near the surface of at least 273 K (0 °C), the melting point of ice. But this startling conclusion is by no means certain. For one thing, the gaseous water in the plume seems to be moving much faster than most of the ice particles[1,3]. Thus, to sustain the ratio of ice particles to gas in the plume, which is measured to be near 1, much more gas must be produced than ice. Direct condensation from the vapour phase, without involvement of liquid water, may be sufficient to produce the ice particles at the observed rate. The plume might also be produced[5] by explosive release of gas from 'clathrate' water ice, which has other molecules trapped in its crystal lattice, at temperatures well below 0 °C.

Whatever Enceladus's near-surface temperatures, things are presumably warmer deeper down. A subsurface ocean of liquid water, as is now thought to exist under the icy crust of Jupiter's moon Europa, is also possible on Enceladus — although direct evidence for such a thing is so far lacking. Matson *et al.*[4],

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50 & 100 YEARS AGO

50 YEARS AGO

Swifts in a Tower. By Dr. David Lack — The domestic life of the swift...was until lately almost unknown, because it nests in holes which are commonly inaccessible, on high buildings, and often too far into these to be reached in any event. This book, however, describes ten years of observation of nesting swifts 'from the inside'. The opportunity was offered by the colony in the ventilation holes in the tower of the University Museum at Oxford (associated in memory with the historic debate on evolution between Huxley and Wilberforce); it was ingeniously taken, by the insertion of nesting boxes with lids and glass panels to study the birds at closest quarters from within the tower. Many ornithologists and others have climbed the tall interior ladders to see the birds, which are unafraid of approach in these circumstances; but it is to many hours of patient observation by the author, and by his wife and other assistants, that we owe the wealth of information now presented in such attractive form. The results are of great interest, and are illustrated by remarkable electronic flash photographs by Mr H. N. Southern.

ALSO

Mr. Duncan Sandys, Minister of Housing and Local Government, has confirmed an order establishing the Gower Peninsula, Glamorgan, as an area of outstanding natural beauty... the first of its kind under the National Parks and Access to the Countryside Act, 1949.

From *Nature* 26 January 1957.

100 YEARS AGO

The pipe line conveying petroleum from Baku to the Black Sea has been completed. It is 550 miles long, and is capable of passing 400,000,000 gallons of oil yearly. Another important oil-pipe line has been built for transporting Texas and California petroleum across the Isthmus of Panama. It is 8 inches in diameter and fifty-one miles long.

From *Nature* 24 January 1907.

BIOGEOGRAPHY

Bounty beneath the Nullarbor

G. J. PRIDEAUX

Over a period of several hundred thousand years, many visitors dropped into Leaena's Breath cave beneath the Nullarbor plain in southern Australia but never left. The remains of these hapless animals, in this and two associated caves, constitute a palaeontological bounty for understanding past conditions in the region during the middle Pleistocene. The discoveries and their environmental context are described by Gavin Prideaux and colleagues elsewhere in this issue (G. J. Prideaux *et al. Nature* **445,** 422–425; 2007).

The small entrance to Leaena's Breath cave was the undoing of a large number of mammals and reptiles. They evidently fell through this hole, dropping some 20 metres to the cave floor. If they were not killed by their injuries, they later died of thirst. By far the commonest remains are fossils of various marsupials such as wombats, opossums and especially kangaroos; many species of these animals were previously not known, and many did not survive the Pleistocene. Prideaux *et al.* applied a battery of techniques to date the fossils and the layers in which they were buried. Their results produce ages ranging between 780,000 and 200,000 years ago.

The Nullarbor plain is vast and empty, and today appears as it is in this photograph: flat, dry, shrubby and almost treeless. From their analyses of isotope ratios in samples of herbivore tooth enamel, both ancient and modern, and the faunal composition, the authors conclude that in the past the Nullarbor had a more diverse flora, and a mixture of woods and shrubland that contained more plants with palatable leaves and fruits. But given that the species that did become extinct seem to have been as well adapted to dry conditions as those that did not, the authors also think the environment was as arid then as it is now.

Instead of invoking climate change, that common suspect, they argue that the best explanation for the different flora was an increased incidence of bushfires. The result is the impoverished, but more fire-resistant, vegetation of today.

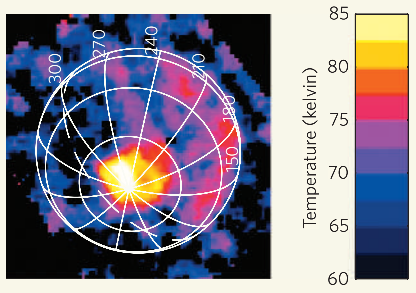
Tim Lincoln

however, find evidence in the composition of the gases ejected from Enceladus for interior temperatures even higher than those needed for liquid water. The gas composition, measured by Cassini's Ion and Neutral Mass Spectrometer (INMS)[6], is 91% water, 3.2% carbon dioxide, 4% nitrogen and 1.6% methane, with probable trace amounts of the organic gases acetylene and propane. Ammonia gas, NH_3, which has often been proposed as a significant component of icy satellite interiors[7] and an enabler of cryovolcanism (it is a potent antifreeze), is conspicuous by its absence.

Matson and colleagues address the origin of these non-water species by drawing analogies to the atmosphere of Titan, which is dominated by nitrogen gas, N_2. The European Space Agency's Huygens probe, carried by Cassini to Titan two years ago, measured a huge depletion of the argon isotope ^{36}Ar relative to N_2 in Titan's atmosphere[8]. The implication of this finding is that Titan is unlikely to have formed at temperatures low enough that N_2 could have been incorporated directly, as a pure ice or trapped in water-ice as a clathrate: ^{36}Ar, which has a similar volatility, would then have been incorporated into Titan too. It's more likely that Titan's nitrogen came in the form of NH_3, which can survive as a solid at higher temperatures that would drive off both N_2 and argon[9]. Ultraviolet photolysis in Titan's atmosphere is proposed to have dissociated the NH_3, later to yield the observed N_2.

By extension, Enceladus, which accreted from the same circum-saturnian nebula as Titan, is likely to have acquired NH_3, but not N_2. Thus the N_2 we see in the plume today is probably ultimately derived from NH_3. But how? In contrast to Titan, photolytic conversion is unlikely: Enceladus's feeble gravity could not have prevented the escape of any N_2 produced by photolysis of NH_3 on the surface, as could have happened on the larger Titan. Matson *et al.* instead suggest that the interior of Enceladus is warm enough for thermal decomposition of NH_3 to N_2 — a process that requires temperatures of at least 575 K, even in the presence of a catalyst.

At these temperatures, other interesting chemistry would be possible, if appropriate catalysts were available. Methane (CH_4) could be generated from carbon monoxide with the addition, say, of hydrogen from NH_3 decomposition — although it is also plausible that the methane seen on Enceladus is primordial. Higher-mass hydrocarbons such as the propane and acetylene tentatively detected by the INMS could also be produced, and there is the potential to generate many other, more complex organic molecules. Admittedly, we can't be sure when this high-temperature chemistry might have occurred: as Matson *et al.* point out, it is possible that most of the action was early in Enceladus's history, and that lower temperatures now prevail.



NASA/JPL/GSFC/SOUTHWEST RES. INST.

Figure 1 | Hot cracks. A map of the surface temperatures on Enceladus made by the Cassini Composite Infrared Spectrometer (CIRS) on 9 November 2006 shows the excess heat radiation from the fractures in the southern polar region. Although the average south polar temperature is only 85 K, the CIRS spectra show that small regions reach at least 145 K. Matson *et al.*[4] suggest much warmer temperatures at Enceladus's interior.

The inevitable question is whether life might have arisen in this warm, wet, chemically rich environment. Europa's ocean has long been a favoured potential oasis for life in the outer Solar System. But Europa's secrets are locked beneath kilometres of ice. Enceladus, by conveniently venting its guts into space where we can study them, gives us a far better opportunity to not just ask, but perhaps to answer, that enormous question.

Cassini is by no means finished with Enceladus. The fly-by of 2005 merely skirted the edge of the plume, and Cassini can analyse gas hundreds of times denser by flying closer to the plume source. That could yield much more precise constraints on the chemistry of its interior. The next close Enceladus fly-by will be in March 2008, and at least five more close fly-bys are likely in Cassini's extended mission, now being planned for the period from mid-2008 to mid-2010. If there is life there, or even complex prebiotic organic chemistry, these encounters will increase our chances of catching its chemical scent. Future missions to Enceladus, the possibility of which is now being studied, could provide more definitive answers. ■

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