BIOGEOGRAPHY

Bounty beneath the Nullarbor

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.

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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.

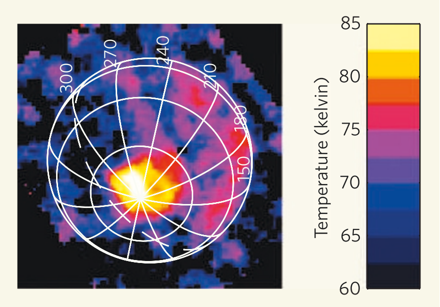

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Figure 1 | Hot cracks. A map of the surface temperatures on Enceladus made by the Cassini Composite Infrared Spectrometer (CIRS) on 9 November 2006 shows the excess heat radiation from the fractures in the southern polar region. Although the average 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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