towards the Earth's centre to form the core, whereas the silica-rich portions ultimately crystallized to form the mantle. Results of previous experiments suggest that the affinity of highly siderophile elements (HSEs) for iron is so strong that all of them should have sunk into the core with the iron.

Fortunately, the mantle abundances of these elements are not as low as experimentally predicted. One suggested explanation for these abundances is a 'late veneer' of meteoritic material, added after the core had completely formed (Fig. 1a)[2]. The late veneer is thought to be about 0.3% of the mass of the Earth. Late addition of a miniscule quantity of primitive meteoritic matter could have also contributed the amount of water, carbon and other volatile compounds necessary to the development of life on Earth (for example, ref. 4).

Meteorite impacts on the Earth lasted for tens to hundreds of million years, as shown by the ages of lunar craters, whereas the major episode of core formation took place in less than 60 million years: contribution of later material that never equilibrated chemically with the core seems inescapable. The question, therefore, is not whether a later veneer was involved, but instead whether it contributed significant amounts of noble metals and volatile compounds.

In order to understand the core–mantle partitioning of highly siderophile elements, Righter and colleagues determined experimentally the metal–silicate partition coefficient of palladium — the ratio of the amount of palladium that enters metal to the amount that enters silicate. Their experiments differ from previous ones in that they more realistically simulate the high-pressure conditions relevant to iron segregation in a magma ocean and chemical compositions relevant to the early Earth. The authors also found ways to resolve other experimental difficulties that might have biased previous studies.

The results suggest that the metal–silicate partition coefficient of palladium decreases with increasing pressure and temperature. Contrary to earlier findings, for reasonable estimates of pressure and temperature conditions in a magma ocean at depth, the amount of palladium left behind in the mantle after core formation could have been sufficient to account for its present concentrations in mantle-derived rocks (Fig. 1b).

If these results apply to other highly siderophile elements, the amount of gold and platinum observed in the mantle could be the natural result of metal–silicate partitioning at high pressure, assuming an initial composition of the Earth similar to those of primitive meteorites. A later veneer would therefore not be required to explain the mantle HSE concentrations. Furthermore, the late addition of primitive meteorites may not be the only explanation for the appearance of volatiles, including water. Instead, these compounds could have been contributed by impacting bodies during the accretion process[5].

The results by Righter and colleagues[3] do explain some palladium being left in the mantle; however, they cannot explain why the relative abundances of HSEs are so similar to primitive meteorites. Indeed, if the concentrations of all HSEs left in the mantle were determined only by metal–silicate partitioning, then their initial relative abundances (for example, the ratio of gold to palladium) would have been severely modified from those in primitive meteorites as each HSE has a different partition coefficient. To address this problem, Righter and colleagues[3] propose a hybrid model in which some of the HSEs, such as palladium, equilibrated with the core, whereas others were supplied after core formation by undifferentiated primitive material. Such a model was independently advocated previously to account for the peculiar osmium isotopic composition of the mantle[6].

It will be important in future studies to quantify the HSE contributions to the mantle by a late veneer as compared with those left behind during core segregation, because it has a strong bearing on the origin and distribution of these elements. This has considerable implications for how the Earth came to acquire water and other ingredients essential for the emergence of life.

### References

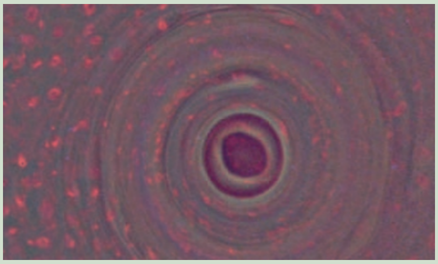
1. Limura, K., Lewis, S. R. & Anders, E. *Geochim. Cosmochim. Acta.* **38,** 683–701 (1974).
2. Chou, C. L. Fractionation of siderophile elements in the Earth's upper mantle. *Proc. 9th. Lunar Planet. Sci. Conf.* 219–230 (1978).
3. Righter, K., Humayun, M. & Danielson, L. *Nature Geosci.* **1,** 321–323 (2008).
4. Marty, B. & Yokochi, R. in *Water in Nominally Anhydrous Minerals* (eds Keppler, H. & Smyth, J. R.) 421–450 (Geochemical Society, Mineralogical Society of America, 2006).
5. Morbidelli, A. *et al. Meteorit. Planet. Sci.* **35,** 1309–1320 (2000).
6. Dauphas, N., Reisberg, L. & Marty, B. *Geochem. J.* **36,** 409–419 (2002).

## PLANETARY SCIENCE

# Saturn's southern eye

Vortices are common features of planetary atmospheres, and a multitude of different variants can be found in the solar system.

On Earth, hurricanes move swiftly over the oceans, sucking up thermal energy as they go along, and decay shortly after landfall. By contrast, the polar vortices in the Arctic and Antarctic regions are stationary and persistent, sufficiently so to isolate the polar air masses and support the formation of the southern ozone hole. The polar vortices on Venus come as dipoles with a warm centre, and Jupiter's Great Red Spot and white ovals are anti-cyclones — that is, they rotate in the opposite sense from terrestrial storm systems. Images taken by the Cassini mission's imaging science subsystem on 11 October 2006 suggest that some of these characteristics are combined in a unique way in the south polar vortex on Saturn (*Science* **319,** 1801; 2008).



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The upper atmosphere above the eye of the vortex (red in the image) is free of clouds. The eye wall clouds (green) are reminiscent of terrestrial hurricanes and appear to reach up to the tropopause — the boundary between the lower and upper atmosphere of the planet. Measurements from Cassini's Composite Infrared Spectrometer show that the core of the vortex is warmer than the surrounding region, by 3–5 K depending on altitude, and that it is centred around a low-pressure system.

Saturn's polar vortex appears like a stationary, larger version of a terrestrial hurricane: an interesting, and beautiful, beast.

**Heike Langenberg**