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follicles must be being made somewhere in young mouse ovaries. They proposed an active population of germline stem cells as the most likely source.

Four lines of evidence from the new study⁴ strongly corroborate the existence of germline stem cells and the resultant ongoing follicle production in the ovaries of postnatal mice. First, Johnson *et al.* found a population of 63 ± 8 germ cells near the surface of the ovary that were outside follicles and that had the general characteristics of germline stem cells. They expressed a conserved germ-cell marker known as Vasa and were actively cycling — that is, they produced new cells.

Second, the authors found germ cells that had not yet developed into follicles in the ovary. This would be expected if the progeny of the germline stem cells were developing into new oocytes; indeed, Johnson *et al.*⁴ identified germ cells that expressed several markers of this process. The overall levels of these marker proteins in the ovaries amounted to 6–25% of the levels that occur in adult testes, which contain large numbers of cycling germline stem cells and their maturing progeny (which express these same proteins).

Third, that the progeny of germ cells went on to produce follicles was shown by grafting a small part of a fluorescently labelled ovary into an unmarked host ovary. Follicles that comprised fluorescently labelled oocytes surrounded by unmarked follicle cells could subsequently be found. Germ cells had therefore moved out of the graft and formed a follicle within the host ovary, something that would be expected only if follicle formation was ongoing.

Last, treating mice with the toxic drug busulfan, which selectively kills male germline stem cells, rapidly depleted the pool of young follicles. The rapid time frame in which it did so suggested that female germline stem cells in mice contribute an average of 77 new follicles per ovary per day. The group's findings⁴ all point to the existence of germline stem cells and a requirement for them in maintaining follicle numbers throughout the reproductive lifetime of female mice.

The finding raises many interesting and important questions. Determining the exact number and location of these functional germline stem cells will require tagging germ cells and showing that their descendants form follicles and, ultimately, mature oocytes. Such lineage-tracing experiments will also address whether the progeny of mouse germline stem cells differentiate directly into oocytes or whether they first increase their numbers by forming interconnected 'germ-cell cysts'. These structures are present during fetal stages⁵ and form after germline stem-cell division in most organisms.

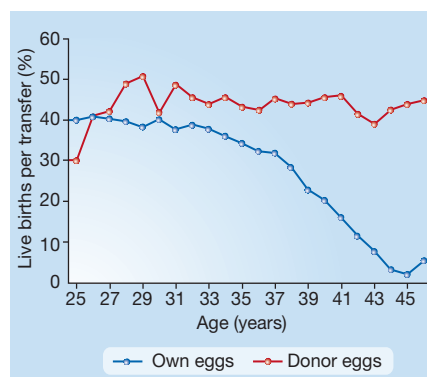


Figure 1 Falling fertility. The graph shows the decreasing success rates (live births) with increasing age for *in vitro* fertilization using embryos derived from a woman's own eggs compared with using eggs from a young donor.

Another issue will be to assess the relative use of follicles generated during fetal life compared with those produced by adult stem cells. Do the follicles produced before birth fail to survive to reproductive maturity, so that female fertility actually depends on the presence of young follicles produced recently from germline stem cells? And does the loss of these stem cells soon lead to follicle ageing, depletion and reproductive decline?

Now that germline stem cells in the mouse have been discovered, determining the cellular and molecular mechanisms that maintain them as such will be the mission of many a scientist. Previous work on *Drosophila* germline stem cells might usefully guide this quest. These stem cells reside in a niche where certain conditions are met to ensure that they continue to survive and function.

Planetary science

Secrets of the deep

Jonathan Aurnou

The magnetic fields of Uranus and Neptune are markedly different from those of other planets in the Solar System. Can this be attributed to structural differences deep inside the planets?

Several planets in the Solar System — including Jupiter and its moon Ganymede, Saturn and possibly Mercury¹ — have a magnetic field that is similar to Earth's. The magnetic fields resemble that of a bar magnet, with the alignment of north and south poles oriented close to the rotation axis of the planet. But data from NASA's Voyager 2 probe have shown that the magnetic fields of Uranus and Neptune are different from those of other planets. Their fields are effectively tipped over: instead of aligning along the rotational axis, the north–south axis of the field lies midway or closer to the equatorial

Germline stem cells have several requirements: contact with a specific body (non-gamete) cell type; a particular signal, a member of the 'bone morphogenetic protein' family; and the expression of a small number of special regulatory genes^{1,6}. Many of these mechanisms have probably been conserved between species. All these issues can now be addressed in mice by using existing technology.

Last, but far from least, the question on everyone's lips will be whether there are germline stem cells in the human ovary. Germline stem cells in humans might easily have been missed for the same reasons that they escaped detection in mice for so long. Indeed, the work of Johnson *et al.*⁴ raises the strong possibility that the reproductive decline seen in female thirtysomethings is due to the depletion of germline stem cells coupled with a high follicular age-dependent incidence of defects occurring during reductive divisions when oocytes mature⁷.

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plane. These unusual magnetic fields have been difficult to model. But on page 151 of this issue, Stanley and Bloxham's simulations² show that, by altering the description of the internal structure of the planets, complex magnetic fields can be generated that are similar in structure to those of Uranus and Neptune.

All models of the generation of planetary magnetic fields include the same essential ingredients. There must be a region of electrically conducting fluid and an energy source to drive the motion of that fluid. A model of Earth's field, for instance, simulates its iron-rich molten outer core (the

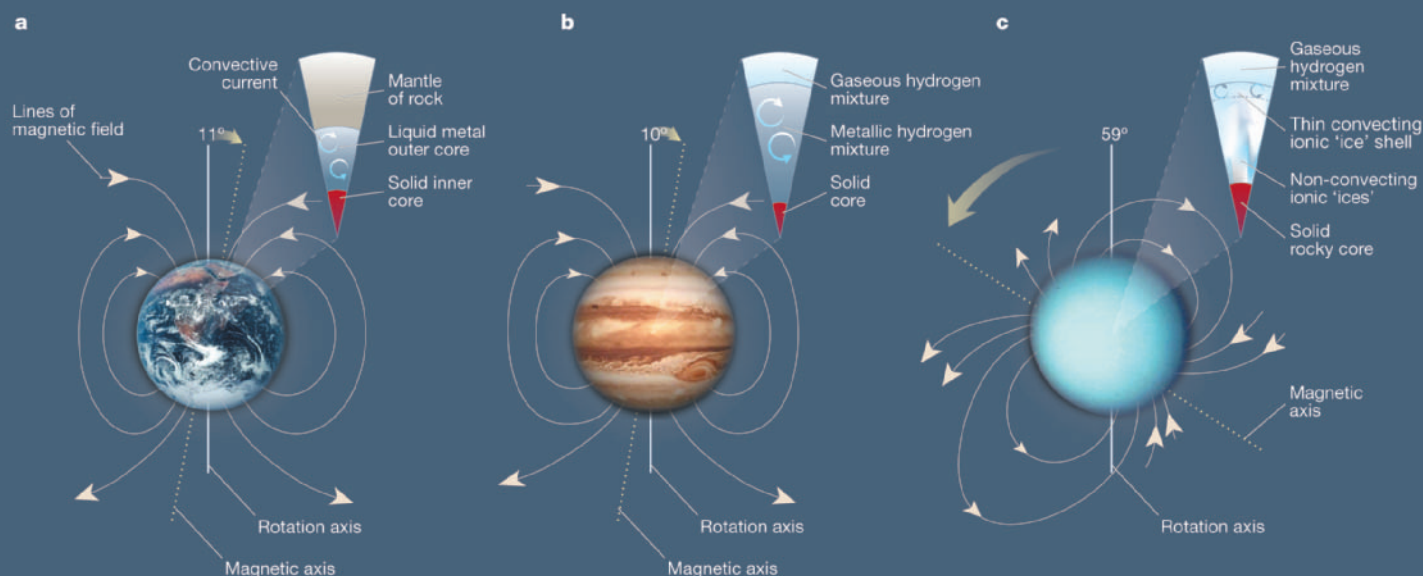


Figure 1 Magnetic fields and interior structures of the planets. **a**, Earth has a predominantly dipolar magnetic field, like that of a bar magnet. Magnetic north and the North Pole do not quite coincide: the magnetic axis is tilted by 11° relative to the axis of rotation of the planet. The field is generated by the dynamo action of convective currents in the molten outer core, around a solid conducting inner core. **b**, The gas giant Jupiter also has a strongly dipolar field, whose axis is aligned at 10° to the planet's rotational axis. In Jupiter's interior, convection occurs in a thick shell of metallic (dissociated) hydrogen that surrounds the

planet's small, rocky core. **c**, Uranus, in contrast, has comparable quadrupole and dipole components in its magnetic field. Strikingly, the magnetic-field axis is oriented at 59° to the planet's axis of rotation. Using a revised description of the planet's interior — with a much thinner convecting shell around a non-convecting but fluid inner region — Stanley and Bloxham² have devised a dynamo model that generates a magnetic field that is similar in structure to Uranus' (and Neptune's) anomalous field. (Rotation axes are artificially aligned vertically for ease of comparison.)

conducting fluid) as well as the planetary cooling (or radioactive heating) that drives convective currents in the planet's interior. Another necessary element is the planetary rotation that organizes the fluid motions: well-organized fluid motions can generate a large-scale magnetic field, but disorganized fluid motions produce fields that tend, on average, to cancel out. Only when all these conditions are met, in a model or a planet, is it possible for the moving fluid to create a dynamo that generates a planetary magnetic field³.

For Earth-like planets, convective motions are typically modelled in a thick rotating shell of electrically conducting fluid. That shell surrounds a relatively small, electrically conducting, solid inner core (Fig. 1a). The result is a dipolar, bar-magnet style magnetic field that is almost aligned with the rotation axis. A similar set-up holds for the gas giants Jupiter and Saturn (Fig. 1b): a very small rocky core is surrounded by a thick layer of convecting metallic hydrogen. (Hydrogen under very high pressure dissociates into free-moving protons and electrons, and is hence called 'metallic'.)

But such models are largely unable to capture the complexities of the magnetic fields of Uranus and Neptune. The measurements made by Voyager 2 around these planets revealed that their fields are not predominantly dipolar (like a bar magnet),

but also have a quadrupole component (as though produced by a combination of two bar magnets, with two north and two south poles). In addition, the main axis of their fields lies far from the rotation axis. On Uranus, the main magnetic-field axis is tipped over from the rotation axis by about 59° in latitude; on Neptune, the main axis is tipped over by about 47° .

Stanley and Bloxham² have constructed a model that simulates these characteristic differences. Instead of a thick convecting shell and a solid inner region, they consider Uranus and Neptune to have a comparatively thin outermost region of convecting ionized fluid surrounding a non-convecting ionized inner-fluid 'ocean'. This modified structure follows the suggestion of earlier work^{4,5}, based on anomalously low planetary heat-flow measurements, that deep convective fluid motions on Uranus and Neptune might be occurring in only a relatively thin shell of the planetary interior (Fig. 1c).

Stanley and Bloxham's model generates fields similar to those observed on Uranus and Neptune. Indeed, it seems that a relatively simple alteration in the structure of the convecting region can lead to a fundamental change in the type of magnetic field that a dynamo model produces. Why this fundamental change in magnetic-field structure should occur remains unclear. Stanley and Bloxham propose that the less constraining

effects of the fluid inner region allow more complex magnetic-field morphologies to develop. However, this argument does not explain how the complex magnetic fields are produced and maintained.

It also remains to be seen how robust this complex field behaviour is. Stanley and Bloxham present a single-case result in their study. Are complex fields produced in all cases with this internal structure, or only, for instance, in those that have convective motions of a particular strength? These questions aside, their model clearly and impressively demonstrates that the same fundamental process — convection in a rotating spherical shell of electrically conducting fluid — can explain the basic structure of all the dynamo-generated planetary magnetic fields presently observed in the Solar System.

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