Earth-sized core, and they assume that the magnetic field from a body of this size must be about the same as the Earth's at the surface of the core. Thus, they conclude that the magnetic-field strength at cloudtop levels is about 10^{-2} gauss.

The proponents of a strong cloudtop magnetic field (≥ 0.6 gauss) for Uranus have become quiet apologists for the radio noise that has not been detected by Voyager: the radio emissions might be beamed away from the spacecraft; the aural electrons may be too low in energy (< 1 keV) to support the excitation of radio emissions; there may not be enough background thermal plasma for the auroral beams to become unstable to radiofrequency oscillations; the magnetic field of Uranus may be so strong that the radio emissions are above the sensitive range of the Voyager radio receivers; the magnetosphere may be rather quiescent so that energetic particles that lose their energy through synchrotron radiation are not

quickly replaced; and so forth.

Vociferous arguments in either side are lacking. The reason is plain — some of us are going to be embarrassed. Also, we have learned from other planetary encounters that nature is so clever at putting things together in completely unexpected ways that we now almost count on being astounded by what we find.

One cannot but wonder how, in a distant future, a community of, say, pulsar theorists will behave when an interstellar probe is about to fly by a pulsar for the first time. Rotating neutron star indeed! □

1. Clarke, J.T. *Astrophys. J.* **263**, L105 (1982).
2. Hill, T.W. & Dessler, A.J. *Science* **227**, 1466 (1985).
3. Desch, M.D. & Kaiser, M.L. *Nature* **310**, 755 (1984).
4. Curtis, S.A. & Ness, N.F. *Geophys. Res. Lett.* **12**, 855 (1985).

A.J. Dessler is Director of the Space Science Laboratory (ESOI), NASA Marshall Space Flight Center, Huntsville, Alabama 35812, USA.

Earth sciences

Perovskites and plate tectonics

from Geoffrey D. Price

OUR ignorance of the dynamics of the Earth's mantle is such that it is still considered debatable whether the mantle convects as a whole, or in layers, divided one from another by a phase change or chemical boundary at the 670-km seismic discontinuity that separates the upper and lower mantle. Even though magnesium silicate perovskite probably makes up the vast majority of the lower mantle, and perhaps up to 40 per cent by volume of the entire Earth, little is known about its phase relations, its flow characteristics or its physical properties, all of which will critically influence the rheology and convective behaviour of the mantle. It is therefore essential to have a full knowledge of the nature of silicate perovskites if we are to understand the thermo-mechanical and chemical evolution of the Earth. The paper by Knittle *et al.* on page 214 of this issue attempts to provide the first data needed to begin such a task.

The lack of data on silicate perovskites is quite understandable, as it is not yet technically possible to measure the structural and physical properties of materials at the high pressures ($> 200,000$ atm) and temperatures ($> 2,000$ K) thought to characterize the lower mantle. To date, therefore, most of the theories concerning the behaviour of mantle-forming perovskite have been derived from the study of the behaviour of non-silicate perovskites. For example, O'Keeffe and Bovin (*Science* **206**, 599; 1979) as well as Poirier *et al.* (*Phys. Earth planet. Inter.* **32**, 273; 1983) have suggested that mag-

nesium silicate perovskite may behave like NaMgF_3 or KZnF_3 , which are solid electrolytes at high temperatures.

Until now, work on magnesium silicate perovskite itself has been confined to its synthesis, its structure determination and the study of its phase relations in the MgO-FeO-SiO_2 system. The study of the

A polyhedral projection of the orthorhombically distorted perovskite structure adopted by magnesium silicate perovskite under ambient conditions. Magnesium ions (large filled circles) sit in the distorted cages formed by the outlined corner-sharing SiO_6 octahedra.

thermal expansion of magnesium silicate perovskite by Knittle *et al.* is therefore to be welcomed as the first direct determination of any physical property of this mineral, and assumes particular significance when it is realized how difficult it is to use the diamond anvil cell to synthesize the quantity of perovskite that was needed for

the thermal expansion study. Such cells are notorious for producing impurities, because of the heterogeneous nature of the pressure and temperature distribution within the cell, but Knittle *et al.* have obviously overcome these problems to the extent that they have produced material which behaves in a systematic and reproducible fashion.

Because of the metastability of magnesium silicate perovskite under ambient pressure conditions, when studying its thermal expansion behaviour Knittle *et al.* were restricted to temperatures below 840 K. To address questions concerning mantle processes, they were therefore forced to extrapolate from their data to the pressures and temperatures found in the lower mantle. They are on relatively firm ground in doing this when discussing the variation in the physical properties of perovskites with changing environment. But, unfortunately, crystal chemical models are less robust to extrapolation than are equations of state, and consequently their conclusions concerning the possible changes in the structure of perovskite with increasing depth within the mantle are conjectural in the extreme. Silicate perovskites develop an orthorhombic distortion (see figure) under ambient conditions, but the nature of possible changes in the perovskite structure at high pressures and temperatures has excited considerable debate (for example, O'Keeffe, M. *et al. Phys. Chem. Minerals* **4**, 299; 1979), and Knittle *et al.* cannot really shed light on this aspect of perovskite behaviour.

From their analysis of the thermal expansion behaviour of silicate perovskite, Knittle *et al.* infer that the lower mantle must be enriched in iron or silica relative to the upper mantle, and reasonably conclude that the upper and lower mantle must convect separately, and that mantle-wide chemical mixing is impeded. The experimental difficulties involved in studying these high-density silicates are such, however, that the uncertainty in their measurements are large: indeed the results are compatible with perovskite thermal expansion coefficients that range from 2×10^{-5} to 6×10^{-5} K^{-1} . Although not discussed in detail, it is to be expected that such uncertainties are too large to enable the conclusions drawn by Knittle *et al.* to be considered definitive. Nevertheless, their approach must be pursued, as it will only be from such investigations that we will be able to determine the true nature of mantle behaviour and thereby understand the fundamental processes involved in plate tectonics and the evolution of the Earth. □

Geoffrey D. Price is a Royal Society 1983 University Research Fellow in the Department of Geological Sciences, University College London, London WC1E 6BT, UK.