Earth science

The mantle deformed

Sébastien Merkel

What happens to minerals under the conditions characteristic of the Earth at great depths? Experiments performed under such conditions illustrate how the main constituent of the lower mantle may behave.

Until the middle of the twentieth century, it was thought that the Earth is a solid body and that no internal movement of matter could occur. Then, with the discovery of plate tectonics and mantle convection, a whole new understanding of the planet's dynamics emerged. Matter can indeed flow within the seemingly solid regions of the deep Earth, and these processes often control the surface dynamics. Yet the microsopic mechanisms controlling flow remain poorly understood. That is scarcely surprising: it is no easy matter to simulate the conditions to which materials in, for example, the lower mantle or the inner core are subject. So the plastic properties of those materials have remained largely unknown.

On page 837 of this issue, however, Cordier *et al.*[1] describe new results on the plastic properties of the main constituent of the lower mantle, a mineral known as silicate perovskite (Fig. 1). They have exploited both experimental and theoretical advances to demonstrate that dislocations in silicate perovskite can be activated under the conditions of the lower mantle. This implies that silicate perovskite could develop large-scale anisotropic structures — that is, with physical properties that depend on the direction of observation — and that it may be possible to measure these structures using seismological methods.

Materials inside the solid layers of the Earth are not perfect crystals but rather aggregates of crystalline grains — polycrystals — that are undergoing plastic deformation. The process is governed by the interaction between deformation within individual grains (through the movement of dislocations), sliding and diffusion along grain boundaries, and the stress and strain fields applied by the environment. Dislocations are line defects within the crystal structure and their motion in the lattice causes slip and plastic deformation within the grain. Depending on external conditions such as pressure and temperature, and the physical properties of the crystal, slip is observed to occur in specific planes and directions, known as slip systems.

If dislocations dominate the deformation, grains will deform preferentially in certain directions and the polycrystal will develop anisotropy in such physical properties as elasticity and electrical conductivity. In the Earth, the anisotropic elastic properties can be studied using seismic techniques, which measure the directional dependency of seismic velocities. Thereafter, a combination of rheological and seismological measurements can be used to interpret the dynamic geological processes deep inside the Earth[2].

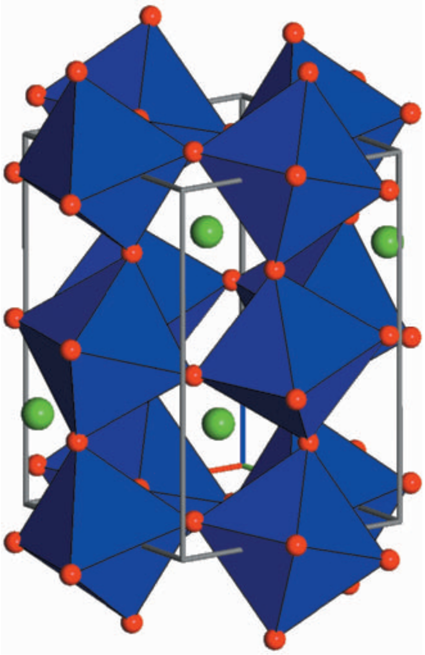

Figure 1 **The structure of silicate perovskite $(Mg,Fe)SiO_3$. Red circles represent oxygen atoms and green circles magnesium or iron. The silicon atoms are located at the centre of the blue SiO_6 octahedra. Cordier *et al.*[1] add new data on how this material deforms under the conditions of the Earth's lower mantle, and so on anisotropic structures that might be evident with seismological methods.**

The transformation of mantle minerals into silicate perovskite $(Mg,Fe)SiO_3$ and magnesiowustite $(Mg,Fe)O$ at a pressure of about 23 gigapascals marks the limit between the upper and lower mantle at a depth of 660 km. On the evidence of high-pressure experiments, seismological measurements, geochemistry and numerical modelling, perovskite is believed to account for about 80% of the lower mantle. Understanding its properties is therefore essential to understanding the physical and geological processes that occur within this layer. Unfortunately, silicate perovskite is unstable under low pressure and high temperature, and it is also highly sensitive to the electron irradiations used in microscopy. So silicate perovskite cannot be studied with the techniques used to investigate the plastic properties of crustal or upper-mantle minerals, and the microscopic processes controlling its plasticity remain unknown.

To address this issue, experiments have been carried out on analogues that have the perovskite structure. These studies led to the conclusion that, under lower-mantle conditions, diffusive processes should dominate perovskite deformation. This in turn implied that silicate perovskite could not generate anisotropic structures in the lower mantle[3]. But it has also been shown that deducing the plastic properties of perovskite-structured materials from analogues can be misleading. So the analogue approach has to be treated with caution[4], and direct investigations of silicate perovskite are necessary.

In recent years, techniques have been developed that allow the experimental deformation of minerals under pressures and temperatures close to those of the lower mantle. But analysing the properties of the sample to identify the deformation mechanisms involved is a further challenge. Cordier *et al.* have overcome that challenge by adapting an approach — X-ray peak broadening analysis — developed in metallurgy. As in electron microscopy, where dislocation contrast is strong or disappears depending on certain conditions, X-ray diffraction peaks become broader or narrower. These peaks can be used to characterize dislocations within the material.

Taking full advantage of the new techniques, Cordier *et al.*[1] have produced the first experimental evidence that dislocations can indeed be activated in silicate perovskite under lower-mantle conditions. They were also able to identify the most active slip systems — that is, the plane and direction in which the slip occurs. Key questions, such as the influence of grain size, strain rate or phase mixing, remain to be solved. Nevertheless, these new results force us to reconsider our thinking about lower-mantle rheology. Seismological observations identify highly anisotropic patches at the bottom of the Earth's lower mantle, whereas the bulk of the deep mantle seems largely isotropic[5–7]. But numerical modelling indicates that other regions could also exhibit anisotropy, for instance in the vicinity of subducting slabs where the Earth's crust is driven back into the mantle[8].

For many years, investigations of the dynamics of the Earth's lower mantle were neglected because of the lack of appropriate seismological and rheological data. Before too long, however, the new interdisciplinary interactions between areas such as high-pressure mineralogy, studies of mineral plasticity, engineering, seismology and geodynamics look set to revolutionize understanding of our planet's deeper layers. ■

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Cancer

Enzymes play molecular tag

Deborah K. Morrison

The B-RAF protein is often mutated in human cancers, contributing to their development. Although most known mutations stimulate its catalytic activity, others, surprisingly, impair it — yet still cause cancer.

Like most other cellular events, cell proliferation is tightly regulated by signals from the surrounding environment. These cues are relayed from the cell surface to the nucleus by defined signal-transduction cascades. The core components of one such pathway are the RAS, RAF, MEK and ERK proteins. If this pathway is constantly switched on, it can cause cells to proliferate wantonly, resulting in cancer.

Researchers have known for some time that there are cancer-promoting mutations in the RAS protein that keep it permanently 'on'. Recently, large-scale genomic screens have also detected mutations in one member of the RAF family of proteins — B-RAF — in 65% of malignant melanomas[1] and many colorectal[2], ovarian[3] and papillary thyroid[4,5] cancers. How these mutations alter B-RAF's function is the topic of an elegant study, published in *Cell*, by Wan and colleagues[6]. The paper also provides structural information that should help to guide the search for more effective inhibitors of this protein family.

The RAF enzymes are central intermediates in this fundamental signalling cascade, transmitting signals from RAS to the downstream enzymes MEK and ERK (Fig. 1a, overleaf). In mammalian cells there are three members of the RAF family, A-RAF, B-RAF and C-RAF. Working out how these proteins are regulated has been a daunting task, largely because of the complexity of the process. There seem to be several mechanisms, including self-inhibition (involving a regulatory domain located at one end, the amino terminus, of the proteins), interactions with binding partners such as RAS and the 14-3-3 protein, and the phosphorylation of (covalent linkage of phosphate groups to) inhibitory and activating sites on the proteins[7,8].

The activation of RAF is typically

Developmental genetics

Bittersweet evolution

Structures that occur in closely related organisms and that look the same are usually considered to be homologous — their similarity is taken to arise from their common ancestry. Common sense suggests that the more complex such structures are, the less likely they are to have evolved independently and the more valuable they should be for studying systematics. But what if 'obviously' identical organs have arisen through two mutually exclusive developmental routes?

Beverley Glover and colleagues have revealed one such case (*Gene* **331,** 1–7; 2004). It occurs in the floral organs of the genus *Solanum* from the nightshade family. In one group of these species, the anthers — the flower's pollen-producing organs — are arranged as a cone, which functions like a 'pepperpot' (see the yellow, cone-like structures in a and b, right). In the pepperpot of bittersweet (*S. dulcamara*), the anther surfaces are held together by a glue-like secretion (a). In another species from the same group, tomato (*S. lycopersicum*), they are instead linked by interlocking hairs, or trichomes, along the edges of the anthers (b).

Glover *et al.* find that tomato trichomes are clearly required for pepperpot formation. In one form, the *dialytic* mutant, which lacks them, the pepperpot fails to develop (d). In bittersweet, however, trichomes surprisingly prevent pepperpot formation. Glover *et al.* show this using transgenic plants in which expression of a gene from snapdragon leads to the development of hairs on bittersweet anthers. The hairs push the glue-bearing surfaces apart, preventing pepperpot formation (c).

This result makes it unlikely that the tomato-type pepperpot originated from the bittersweet type, or vice versa, because the development of anther hairs in bittersweet-type cones would probably have caused the cone to fall apart, whereas the addition of glue to tomato-type cones already supported by trichomes would probably have carried no selective advantage. So the most plausible conclusion is that pepperpots originated twice independently in the lineages that led to tomato and bittersweet.

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Molecular systematic analysis confirms that tomato and bittersweet are closely related, and the traditional view would be that their pepperpot cones are obviously homologous. But genetic tinkering and mutant analysis show that they probably are not — that they are convergent, having taken different routes to the same end. Life's potential to invent complex structures more than once may worry systematists, who depend on reliable characters to reconstruct relationships between organisms. But it will please anyone who admires nature's innovative power. **Günter Theißen**

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