Jules Verne’s travellers in his 1864 science fiction novel *Journey to the Centre of the Earth* encountered “crystals… like globes of light”. One hundred and fifty years later, the study of crystals is poised to shine new light on the deep Earth.

The journey to our planet’s centre began a century ago when William Henry Bragg and his son, William Lawrence, used X-ray diffraction to reveal the atomic configuration of common minerals such as halite, diamond, fluorite and calcite. Decades of challenging experimental work to unravel how the structures of such minerals are altered by the extreme pressures and temperatures found in the deep Earth culminated in 2004 when researchers discovered that the main mineral of the lower mantle, iron-bearing magnesium silicate ((Mg,Fe)SiO$_3$) perovskite, transforms to a compact configuration known as post-perovskite at conditions similar to those at the core–mantle boundary.

Post-perovskite’s characteristics explain many of the unusual seismic properties of a distinct 200-kilometre-thick zone at the base of the mantle, a layer that might be a remnant of Earth’s formation. This region plays a key but poorly understood part in the thermal structure of the planet.

Ten years on from its discovery, the post-perovskite story remains incomplete. The roles of crystal deformation, chemical variation and temperature in controlling the deep mantle’s characteristics are yet to be fully understood. And work on the iron alloys that make up the core is only just beginning.

New crystallographic techniques will usher in a deeper understanding of crystal structures and their connection to our planet’s architecture, composition and evolution.

**PHASE TRANSITIONS**

Earth’s rocky mantle extends 2,900 kilometres below the surface. About one-quarter of the way down (at about 660 kilometres) it divides into an upper and lower mantle, a discontinuity visible as a sharp change in the speed of seismic waves traversing the boundary. Since geophysicist Francis Birch of Harvard University in Cambridge, Massachusetts, proposed the idea in 1952, this division and other more
complex seismic structures in the mantle have been attributed to phase transitions of the constituent minerals.

Birch's prediction has been verified experimentally over the decades as the technologies to examine minerals at ever higher pressures and temperatures have developed and matured. The requisite pressures are substantial, ranging from 24 gigapascals (GPa) at 660 kilometres to 135 GPa at the core–mantle boundary. Because 100 GPa corresponds to 1 million bars of pressure, the difficulty in simulating deep-mantle conditions is known as the megabar barrier. Temperatures of more than 2,000 kelvin, exceeding that of molten steel, must be achieved at the same time to reproduce the deep-Earth conditions in the laboratory.

UNDER PRESSURE
The diamond anvil cell is the primary tool for high-pressure and temperature mineral studies. Samples of minerals less than 50 micrometres across are compressed between the tips of gem-quality diamonds. Then researchers fire lasers or X-rays through the diamonds at the samples, to heat them and to investigate their structures using crystallographic methods.

The picture that has emerged is that the main minerals found in the upper mantle — olivine, pyroxene and garnet — undergo a series of phase transitions to denser forms with increasing depth. The lower mantle is composed of more dense minerals, which are stable over a wide range of thermodynamic conditions.

(Mg,Fe)SiO$_3$ perovskite is an array of SiO$_6$ octahedra with magnesium atoms sitting in spaces in between (iron atoms can sometimes replace magnesium ones). Materials with perovskite's structure are of great interest because they exhibit superconductivity and unusual magnetic behaviour and have applications in fuel cells and memory devices. The other major mineral of the lower mantle is ferropericlase, (Mg,Fe)O, which adopts the rock-salt crystal structure.

So it was a surprise in 2004 when a new deep-Earth mineral form was discovered. In laboratory experiments, perovskite transforms to a tightly layered arrangement called post-perovskite at the pressures and temperatures of the core–mantle boundary. Researchers quickly realized that the properties of this new phase could explain the puzzling presence of a seismically distinct layer in the deepest 200–300 kilometres of the mantle, known as D" (see ‘Inside Earth’).

\textbf{“The impressive improvements in pressure-generating technology must continue.”}
New ways of supporting the anvils in the diamond cell expand the angular access to target minute single crystals (of around micrometres) between the diamond tips. Samples are heated by infrared laser and fragility of diamond-cell samples. Previous difficulties owing to the small size of the tiny sample from the diamond anvil cell are now met to complete our journey to the centre of Earth — and beyond to the makings of the gas giants and extraterrestrial planets.

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