NEWS & VIEWS

EARTH SCIENCE

Probing the core's light elements

A fine marriage between seismic data and laboratory experiments carried out at the extreme conditions of Earth's deep interior indicates that the planet's liquid outer core is poor in oxygen. SEE LETTER P.513

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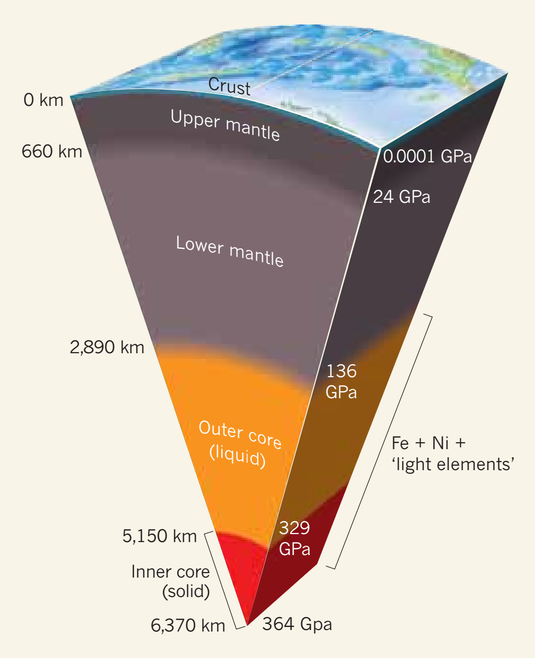

Figure 1 | Cross-section of Earth's interior. Depths for the various regions are indicated on the left and corresponding pressures (in gigapascals) on the right. The core is mainly composed of iron (Fe) and nickel (Ni), with some unknown lighter elements. By comparing laboratory measurements with seismic data, Huang *et al.*[3] place new constraints on the identity of these light elements in the core.

Earth's core accounts for one-third of the planet's mass and has a central role in Earth's overall energy budget and dynamics. Although the core has long been known to be composed mainly of iron, together with some nickel[1,2], the identity of the lighter elements that make up about 8% of the core's mass has been an enigma for nearly 60 years. Work reported in this issue by Huang *et al.*[3] (page 513) combines the results of laboratory experiments with geophysical data for the core to address this long-standing mystery. Better knowledge of the core's main light element (or elements) will shed light on heat flow in Earth's deep interior, on the origin and growth of the core's solid inner region, and on the generation and evolution of Earth's magnetic field[4].

But which element is it? Here we can bring out the line-up of usual suspects: sulphur, oxygen, silicon, carbon and hydrogen. Each is geologically abundant and can dissolve in liquid iron under the right ***[for what?]***range of pressure and temperature conditions. Geochemical arguments for and against each can be constructed[5]. Each also has its own implications for core formation and evolution of the early Earth[6]. For example, an oxygen-dominated core would imply that oxidizing conditions were present during much of core formation, whereas a silicon-dominated one would require mostly reducing conditions. Hence, unmasking the identity and abundance of the core's main light elements will also be a major step forward in understanding Earth's geochemical evolution.

Seismic data[7] provide robust constraints on density and sound velocities throughout the core. These data reveal that the core is divided into a large, liquid outer core with a radius of about 3,500 kilometres, within which is embedded a smaller, solid inner core with a radius of about 1,200 km (Fig. 1). The differences in seismic velocity and density between the liquid outer and solid inner cores are also known, as is the existence of weak seismic anisotropy in the inner core. One interesting feature is that the abundance of light elements in the inner core seems to be only about half of that in the outer[8]. All of these observable aspects provide important conditions that the successful light-element candidates must satisfy. However, directly probing potential core materials against these geophysical criteria is challenging because of the extreme conditions that exist in the core — pressures of 135–364 gigapascals and temperatures of about 4,000–6,500 kelvin.

Shock-compression experiments, which subject samples to high-velocity impactors, provide one of the best routes to simulating core conditions in the laboratory. These are dynamic experiments that generate very high pressures for microsecond durations. One advantage of shock-wave experiments is that high temperatures are necessarily generated along with high pressure. For samples with iron-rich compositions, the pressure–temperature states achieved under shock loading are fortuitously close to those expected to occur in the core[9,10]. Although the temperatures are somewhat uncertain, the need for large extrapolations of laboratory results to core conditions, as is common for room-temperature experiments using diamond anvil cells for example, is avoided. The shock experiments are also conducted under conditions in which the sample has been transformed into the liquid state and thus are more directly comparable to the liquid outer core.

Shock-wave experiments traditionally measure the density achieved under high-pressure loading. However, density data alone cannot provide a unique constraint on core composition. Huang *et al.*[3] overcome this problem by also measuring the sound velocity of the shocked material. By comparing measurements of both density and sound velocity with the seismic data for the core, it finally becomes possible to affirm or rule out certain compositions.

Huang and colleagues used one oxygen-rich and sulphur-poor (8 weight per cent O and 2 wt% S) composition for their experiments and one oxygen-poor and sulphur-rich composition (2.2 wt% O and 5.3 wt% S). They found that the oxygen-rich composition yields sound velocities substantially higher than those of the liquid outer core. For compositions within the iron–sulphur–oxygen system, those with more than about 2.5 wt% oxygen are not able to simultaneously match both the density and sound-velocity profiles of the core. By contrast, they showed that sulphur-rich compositions can indeed match both density and sound velocity. Does this mean that sulphur is the dominant light element? Not necessarily. Models of Earth's accretion have generally concluded that the amount of sulphur in the core must be small[11]. Therefore, it is essential to perform similar experiments on a wider range of components. As noted previously, carbon and silicon are both plausible candidates on geochemical grounds, and so experiments on these materials are needed.

Further efforts to nail down core composition would require examining how potential light elements partition between the core's solid and liquid portions at its temperature and pressure conditions. This is necessary to explain the compositional differences between the solid and liquid parts of the core. A theoretical study[12] addressing this question suggests that oxygen — not sulphur — may have the right partitioning behaviour, in conflict with Huang and colleagues' experimental results[3]. The extreme conditions of the core make a laboratory test of this partitioning behaviour highly challenging, but experimental capabilities are making rapid advances on several fronts in high-pressure–temperature science. The past few decades have seen remarkable progress in uncovering the state and structure of many features of the deep Earth, with the light elements of the core remaining a stubborn puzzle. The work reported here suggests that a solution to the problem may finally be at hand. ■

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