GEOPHYSICS

Tectonics in the Earth's core

The complex three-dimensional structure of the Earth's solid inner core reveals how it has grown through time. Numerical simulations of the solidification process suggest that part of this structure has resulted from recent tectonic activity.

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The solid inner core, with an average radius of 1,220 km, is the most remote part of the Earth and would seem to be an unlikely place to find a record of the evolution of our planet. Yet, among all of the primary subdivisions of the Earth, the inner core seems to be the youngest and possibly the most rapidly growing. The inner core has reached its present size in less than 2 billion years[1], and possibly within 600 million years[2]. Calculations by Deguen and Cardin[3], discussed on page XX of this issue, show that the structure of the inner core provides clues about the later stages of the chemical differentiation of the Earth. More surprisingly, it preserves evidence of active, gravity-driven tectonics.

Considerations of the rate at which heat is being lost from the planet's deep interior indicate that the inner core is crystallizing from the iron-rich, fluid outer core at a rate of 4–5 million kilograms per second[2]. The rapid growth traps heat and chemical heterogeneity, and the inner core has acquired a remarkably complex structure. For example, recent seismic imaging has revealed differences between the deepest parts of the inner core[4,5] and regions close to the inner-core boundary — the contact between the inner and outer cores. Whereas the innermost parts seem to be anisotropic, the region immediately below the inner-core boundary shows an isotropic texture as well as differences between the eastern and western hemispheres[6].

As the inner core solidifies through crystallization, it develops a radial thermal gradient due to the release of latent heat: that is, it is hottest in the central part. This gradient tends to destabilize the inner core by inducing convective overturning. But the inner core also has radial gradients in the concentrations of light elements such as oxygen, sulphur and silicon, which are enriched in the outer parts of the inner core during the solidification process. These gradients lead to a stabilization of the density distribution throughout the inner core and thereby act to prevent convective instabilities. The two processes act in competition with each other, and their relative importance depends on the particular stage in the inner core's growth.

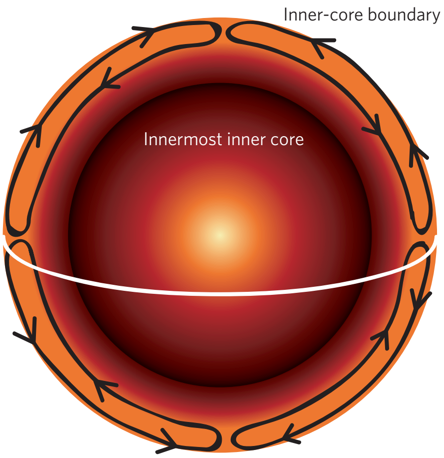

Figure 1 | Inner core tectonics. The schematic sketch shows gravity-driven overturning in a shallow layer below the inner-core boundary. Deguen and Cardin[3] suggest that late in the history of inner-core growth, this activity became decoupled from the deeper parts owing to stable compositional stratification imparted by the distribution of light elements, which is indicated by shading. The white curve denotes the topographically elevated inner-core equator.

Another complication in the growth process is introduced by the non-uniform rate of solidification at the inner-core boundary. Owing to the influence of fluid motions in the outer core, the removal of heat from the inner-core boundary is expected to be greater near the inner-core equator than at other latitudes. The inner core therefore cools and crystallizes preferentially in the equatorial regions; as a result, these regions are [**AUTHOR: or are expected to be?**] topographically higher[7]. Preferential heat loss from the equatorial regions is related to the north–south alignment of the geomagnetic dipole, although the higher topography at the inner-core equator produced by the more rapid crystallization induced by such heat loss has not been directly observed.

Deguen and Cardin[3] use numerical simulations to determine how these various processes, including the thermal gradients and light element distribution as well as preferential crystallization at the equator, conspire to produce the heterogeneous inner core that seismology reveals. They model the evolution of the inner core from its inception to its current state. The calculations suggest that when the inner core was very small, preferential solidification at the equator and thermal convective overturning produced a nearly uniform solid texture. At this stage, no perceptible compositional stratification due to enrichment of light elements in the uppermost regions had developed.

The situation seems to have changed, however, as the inner core approached its present-day size. The researchers suggest that as the growth rate decreases, there is enough time available for a gradient in light element concentration to develop, the stabilizing effects of which now come to dominate inner-core evolution. Instead of the thorough convective churning typical of the early stages, thin sheets slide off the equatorial topographic high and are thrust over one another, just below the inner-core boundary (Fig. 1). This deformation is loosely analogous to the style of tectonics seen in mountain belts, where thin slabs of the continental upper crust are stacked upon each other.

The evolutionary model proposed by Deguen and Cardin[3] may help to explain the structural variations in the fabric of the inner core. For example, the shearing induced by the tectonic activity in the outermost parts of the inner core over the past 100–200 million years may help to homogenize the material just beneath the inner-core boundary, thereby providing a possible mechanism for the isotropy inferred from seismic data. The model also implies that the innermost regions would not be affected by deformation during the later stages of inner-core growth. It is therefore plausible that the fabric in the deepest parts of the inner core is an ancient one, potentially providing information about ancient processes.

Of course, the simulations do not cement the case for active tectonics on the top of the inner core. The researchers' explanation is intriguing, but complicating factors remain. For one, the seismic exploration of the inner core is still incomplete and the proposed model cannot yet be fully tested. And almost certainly, tectonic deformation is not the only process that affects the structure and fabric of the inner core[8].

Interpreting the three-dimensional structure of the Earth's inner core and its evolution is a difficult problem, especially because multiple physical processes — for example, convection, solidification and grain deformation — operate simultaneously. Deguen and Cardin's modelling work not only provides new insights into the history of Earth's deep interior but may also be a first step on the way to understanding the interiors of other planets in the Solar System.

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