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Editorial: Stratification in the Cores of Earth and Other Planets

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Editorial on the Research Topic

Stratification in the Cores of Earth and other Planets

Based on mineral physics and seismic studies, it has been proposed that parts of the liquid outer core of the Earth and other planets are stably stratified, in particular near the boundaries. Such stratification may have profound impacts on the convective state of these cores and the morphology of the generated magnetic fields. Stratification at the top of Earth's core may have consequences for interpretations of the secular variation (SV), including magnetic flux concentration, diffusion, and dipole changes. It has also been suggested that a stratified layer (possibly slurry) prevails above the inner core boundary. Such a layer may be associated with the growth and/or internal dynamics of the inner core and the release of light elements to the outer core which is the primary source of energy for the geodynamo. Chemically stratified layers may be primordial or form slowly through differentiation, such as the solidification of the inner core or bulk precipitation of a minor species. Stratification may prevail in other planets as well. For example, the weak intensity of Mercury's magnetic field and the axisymmetry of Saturn's magnetic field may both be explained by a skin effect due to stratification at these planets. The scope of this Research Topic encompasses evidence for (or against) stratification at the outer cores of Earth and other planets, and their dynamical consequences for core convection and the generated planetary magnetic fields. The Research Topic involves multiple disciplines, including mineral physics, seismology, geomagnetism, dynamo simulations, thermal history models, and more.

Mineral physics inferences of thermal conductivity have consequences for the convective state at the top of the core (e.g., Pozzo et al., 2012). The anisotropy of the thermal conductivity of hcp iron was experimentally examined using synchrotron X-ray diffraction experiments and thermal conductivity measurements by Ohta et al. They found that the thermal conductivity of single crystal hcp iron along c axis is significantly larger than that along a axis, which could have caused the controversial values of thermal conductivity of hcp iron at Earth's core conditions. Gomi and Yoshino carried first-principles calculations on the band structure and the impurity resistivity of substitutionally disordered hcp and fcc Fe based alloys. Their results provide a model for the heat flux across the thermal boundary layer at the bottom of the mantle which favors thermal stratification at the top of Earth's and super-Earth's cores.

Geomagnetic as well as geodetic observations may provide evidence for or against stratification (e.g., Buffett, 2014). Glane and Buffet proposed a new coupling mechanism that relies on the presence of stable stratification at the top of the core to explain length of day (LOD) variations. Steady core flow over boundary topography promotes radial motion, but stratification opposes it.

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Steep vertical gradients develop in the resulting flow, causing horizontal electromagnetic forces in the presence of a radial magnetic field. The associated pressure field exerts a net horizontal force on the boundary and stresses that are sufficient to account for the observed changes in LOD. Huguet et al. proved that non-zero SV of the total geomagnetic energy on the core-mantle boundary (CMB) requires presence of radial motions extending to the top of the core. Using geomagnetic field and SV models, they found comparable balance of sources and sinks of the SV of the total geomagnetic energy and the SV of the geomagnetic dipole intensity and tilt, indicating that upwelling/downwelling reach the top of the core, hence providing observational evidence for either no stratified layer or its penetration.

These observations constrain dynamical models, which in turn provide insights to the impact of stratification on convection and the induced magnetic fields (e.g., Christensen, 2006). In addition, such simulations may unravel the mechanisms for the construction, destruction or penetration of stratified layers. Olson et al. compared magnetic fields produced by numerical dynamos with heterogeneous CMB heat flux and stable thermal stratification at the top of the shell vs. observed geomagnetic field models. They found that reversed flux patches and stratification are difficult to reconcile. They concluded that the thermal stratified layer in Earth's core is up to 400 km and permeable. Using numerical dynamos with non-diffusive compositional convection, Bouffard et al. obtained self-consistent formation of a chemically stratified layer at the top of the shell caused by the accumulation of chemical plumes emitted at the bottom boundary. Application to Earth's core conditions suggest weak stratification. Dietrich and Wicht applied their numerical investigation to Saturn's dynamics by setting a sandwiched stable stratified layer surrounded by two convective zones. They found that the mean penetration depth of the layer is controlled by the ratio of stratified and unstratified buoyancy gradients, i.e., independent of rotation. However, the penetration depth depends on latitude, since in the rapidly rotating regime axial convective columns pierce predominantly outside the tangent cylinder.

Simpler models may also shed light on the nature of stratified layers (e.g., Labrosse et al., 1997). For example, Takehiro and Sasaki designed a 1D thermal and compositional balance model of the Earth's core. They showed that a thermally stable layer becomes thinner when the effect of compositional convection is considered compared with the results of previous studies where the existence of a stable layer is evaluated based on the convective flux only.

In summary, the eight papers that comprise this Research Topic tackled the problem of core stratification using various approches—experimental, observational, numerical, and theoretical. Applications included various bodies—primarily Earth but also Saturn and super-Earths. The papers addressed various aspects of stratification—existence, erosion, penetration, and signature on observable quantities. We anticipate that stratification will continue to stimulate deep planetary dynamics research. For example, recovering geomagnetic field morphology with a stratified layer is still elusive. For Jupiter, reconciling new magnetic field models inferred from the Juno mission (Moore et al., 2018) with alternating zonal jets is a major challenge. Erosion of a stratified layer by core convection has not yet been fully addressed. Such open questions guarantee that this topic will likely grow in interest in the future.

AUTHOR CONTRIBUTIONS

All authors listed have made a substantial, direct and intellectual contribution to the work, and approved it for publication.

REFERENCES

Buffett, B. A. (2014). Geomagnetic fluctuations reveal stable stratification at the top of the earth's core. *Nature* 507, 484–487. doi: 10.1038/nature13122

Christensen, U. R. (2006). A deep dynamo generating Mercury's magnetic field. *Nature* 444, 1056–1058. doi: 10.1038/nature05342

Labrosse, S., Poirier, J. P., and Le Mouël, J.-L. (1997). On cooling of the earth's core. *Phys. Earth Planet. Inter.* 99, 1–17.

Moore, K. M., Yadav, R. K., Kulowski, L., Cao, H., Bloxham, J., Connerney, J. E. P., et al. (2018). A complex dynamo inferred from the hemispheric dichotomy of Jupiter's magnetic field. *Nature* 561, 76–78. doi: 10.1038/s41586-018-0468-5

Pozzo, M., Davies, C., Gubbins, D., and Alfè, D. (2012). Thermal and electrical conductivity of iron at Earth's core conditions. *Nature* 485, 355–358. doi: 10.1038/nature11031

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