

The thermal state of the Earth: Geochemical solutions to geophysical problems?

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Recent geophysical arguments for radioactive elements in the core are motivated by inconsistencies in thermal models for the evolution of the core. Predictions based on typical estimates of heat flow from the core (e.g. 5 to 10 TW) yield a young inner-core age and an implausibly hot temperature at earlier times. Such high heat flows are difficult to avoid because current estimates of the present-day core temperature yield a large temperature drop across D", and this normally implies a large core heat flow. High heat flow may also be required to supply the power needed to drive the geodynamo, particularly at early times when the inner core was small or absent. However, high heat flow from the core is not easily sustained over the age of the Earth without additional energy sources. Radioactive elements in the core offer one possible explanation if the concentration of elements is sufficiently high.

Other solutions are possible, but none are without their own problems. Arguments for low power consumption by the geodynamo can lower the necessary heat flow and circumvent the problem of high temperatures at early times. However, a low heat flow still needs to be reconciled with estimates of the present-day core temperature. Low heat flow is also permitted by reducing the thermal conductivity of the core, but the same problem applies. Both of these explanations are contingent some means of lowering heat flow when the core temperature is high. Sequestering radioactive elements in D" is one option, but this imposes another set of demands on the distribution of radioactive elements.

Progress in resolving these questions is likely to rely on many different disciplines. For example, isotopic evidence for an enriched primitive layer at the base of the mantle bolsters arguments for heat sources in D". Seismic evidence for a phase transition (or transitions) near the base of the mantle would help to constrain the temperature, although the complex dynamics of the region may frustrate any attempt to extrapolate this temperature to the top of the core. It is also possible that the thermal models are incomplete. An important (but neglected) source of gravitational energy is possible if the solubilities of mantle components in liquid iron change as the core cools and the inner core grows. Difficult experiments are needed to quantify core-mantle geochemistry, but the effort may ultimately resolve an important geophysical problem.

A natural analog of "boron-mullite" in granulite-facies metapelites from Mount Stafford, central Australia

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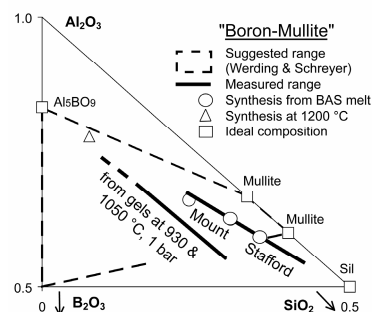
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Werner Schreyer and his colleagues gave the name "boron-mullite" to ternary mullite-like phases synthesized in the B_2O_3 - Al_2O_3 - SiO_2 (-H₂O) system. These phases have been synthesized at 1200 °C from mullite + B_2O_3 , 1520-1600 °C from BAS melts and at 500-1050 °C, 1 atm-8 kbar from gels (e.g., Figure). A possible natural analog resembles sillimanite; optical properties are in the range for mullite: $\alpha = 1.627(1)$, $\beta = 1.634(1)$, $\gamma = 1.649(1)$, $2V_\gamma = 56(1)^\circ$. It is heterogeneous on a very fine scale; compositions range from close to sillimanite to nearly half way to Al borate (B determined by EMPA); FeO and MgO contents rarely exceed 1 wt%. "Boron-mullite" is found in silica-undersaturated, boron-rich metapelites dominated by sekaninaite (Fe-cordierite), hercynite and K-feldspar. "Boron-mullite" typically forms overgrowths mostly <0.1 mm long on the Fe-dominant analog of werdingite, commonly in the vicinity of andalusite or sillimanite, but in one section, it also occurs as prisms up to 0.4 mm long in fringes overgrowing sillimanite bundles. Ominelite (Fe-grandidierite) and biotite are present in most sections; tourmaline is present locally. Granulite-facies conditions reached at least 775-785°C, at 3.3-4 kbar. "Boron-mullite" appears to be prograde and might have formed from incongruent melting of werdingite in the presence of granitic melt, a possibility suggested by the melting of werdingite at 1200 °C, 1 bar under nearly anhydrous conditions in MgO-BAS (Werdning & Schreyer 1992), but occurring at lower temperatures and under higher pressures in the more complex natural system.



References

Werdning, G. and Schreyer, W., (1992), *Eur. J. Mineral.* **4**, 193-207.