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What the Deep Interiors of Earth and Mars Reveal About Planet Formation

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Determining how — and from what — Earth formed requires an understanding of the composition of our planet as a whole. Yet most of the Earth, particularly the lower mantle and core, which together comprise approximately 80% of Earth's mass, defies direct analysis. These deep reservoirs exert a profound influence on Earth's thermal evolution, magnetic field generation, volatile budget, and potentially its long-term habitability. Nevertheless, their compositions remain among the most fundamental uncertainties in geochemistry.

Geophysical observations, principally from seismology, constrain seismic wave velocities and discontinuity structure, which, together with gravity and normal mode data, define Earth's density distribution. However, translating these measurements into composition requires interpretation through high-pressure and high-temperature experiments. By recreating deep Earth conditions in the laboratory, we can determine the mineralogical and melt properties responsible for seismic structure and use these data to test models based on specific bulk compositions. In complementary experiments that reproduce the chemical fractionation accompanying planetary differentiation, we can place constraints on the conditions and starting materials from which Earth's interior layering developed.

The principal challenges of this approach are that the required experiments operate at the limits of current technology, and that geophysical observations do not uniquely determine chemical models. I will discuss the difficulties and uncertainties that arise from these limitations, and also examine new constraints emerging from an improved understanding of Mars' internal structure.

Mars may represent a planetary embryo — a type of body from which Earth formed through a series of giant impacts. Seismic data from NASA's InSight mission provide new constraints on the size and density of the Martian core. These observations must also be interpreted in conjunction with experimental property measurements, phase equilibria, and metal–silicate partitioning in order to determine core composition and volatile content. By combining constraints from Earth's lower mantle and core with insights from Mars, we can try to resolve the building blocks of the Earth and understand the conditions under which it formed.