Substructure of the inner core of the Earth
(nuclear fission/chondrite/oxidation state/seismology/composition)

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ABSTRACT The rationale is disclosed for a substructure within the Earth’s inner core, consisting of an actinide subcore at the center of the Earth, surrounded by a subshell composed of the products of nuclear fission and radioactive decay. Estimates are made as to possible densities, physical dimensions, and chemical compositions. The feasibility for self-sustaining nuclear fission within the subcore is demonstrated, and implications bearing on the structure and geodynamic activity of the inner core are discussed.

Chemical Considerations

For more than a century, ideas about the internal compositions of planets, especially the Earth, have been inspired by observations of meteorites, particularly chondrites, and technological knowledge of steel-making. Only five elements (Fe, Mg, Si, O, and S) constitute approximately 95% of the mass of each of the hundreds of anhydrous chondrites and, by inference, each of the terrestrial planets. Fig. 1 shows that the mass ratio of opaque to translucent minerals of chondrites is related to the relative abundance of oxygen, even though chondrites differ somewhat from one another in major-element compositions. The mass ratio of opaque to translucent minerals of individual chondrites, shown in Fig. 1 and calculated from mineral and chemical data incorporating both major and minor elements, is essentially the chondrite’s alloy-to-slag ratio, which is essentially the chondrite’s (metal + sulfides)-to-silicates ratio. Comparable core-to-mantle ratios for the Earth, calculated from seismic-based data and indicated in Fig. 1, show that the Earth as a whole has a state of oxidation similar to certain highly reduced enstatite chondrites and unlike other types of chondrites.

The fundamental differences between the Earth’s being of enstatite-chondrite composition and its being like other, more oxidized, types of chondrites, as previously thought, arise from the limited relative abundance of oxygen. Enstatite chondrites formed under such oxygen-deficient conditions that certain lithophile (oxiphile) elements, such as silicon, magnesium, calcium, and uranium, occur in part as nonoxides and, together with sulfur, iron, and nickel, constitute the alloy portion corresponding to the Earth’s core. Lithophile elements, such as calcium, are incompatible in an iron-based alloy and tend to form metallurgical precipitates (15). In the core of the Earth, one may anticipate the collection–location of high-temperature precipitates to be related to their respective densities relative to the densities of the fluid core and the inner core. At the core–mantle boundary, one may expect low-density, high-temperature precipitates, such as CaS and MgS, and, at the center of the Earth, one or more high-density, high-temperature precipitates. The highest density and most important high-density, high-temperature precipitate would be uranium or a compound thereof (9, 16).

Unfortunately, experimental investigations of the consequences of Ca and Mg on phase relations for the system Fe–Ni–S–Si have not been conducted at core pressures, ~3.6 Mbar (1 bar = 100 kPa) although metallurgical behavior at near ambient pressure in a portion of the Ca–Fe–S system is known (15). Mineralogical investigations of enstatite meteorites presently provide the best reference as to the natural behavior of this highly reduced assemblage.

In enstatite chondrites the trace element uranium occurs concentrated in sulfide minerals (17); leaching experiments suggest its chemical behavior to be chalcophile (18). As other normally lithophile, incompatible elements, such as calcium and magnesium, precipitate as monosulfides in enstatite-chondrite matter, the tentative assignment of uranium as a monosulfide is not unreasonable.
uranium (and thorium) in the core may be expected to lead to uniformity of the transition zone, mantle boundary, thus accounting for the observed lack of core precipitates—e.g., CaS and MgS—collecting at the core–mantle boundary, possibly even to be a slurry or a fluid. The densities of the subcore (26 g/cm³) and subshell (23 g/cm³) were calculated from a published Thomas–Fermi–Dirac equation of state (20). The substructure dimensions, shown in Fig. 2A, may be underestimated as a consequence of ignoring other possible high-density, high-temperature precipitates.

I have demonstrated the feasibility of a concentration of uranium metal at the center of the Earth undergoing self-sustaining nuclear fission reactions and have made estimates of resultant energy production. Unlike previously envisioned planetary-scale energy sources that change gradually and generally change in only one direction through time, variable and intermittent output is possible from nuclear fission reactors, for example, as a result of changes in composition or position of fuel or reactor poisons. I have further suggested that reversals of the geomagnetic field have their origins in intermittent or interrupted nuclear reactor operation (9, 16). Concomitant to the above calculated substructure, the nuclear fission feasibility of a concentration of uranium monosulfide is demonstrated in Fig. 3.

From nuclear reactor theory, the condition for sustained nuclear reactor operation is that the infinite multiplication factor k_e is ≥ 1 (22). Fig. 3 shows the infinite multiplication factor as a function of time before present for a theoretically infinite accumulation of US and, for reference, U metal. Approximately 3000 million years ago and earlier, the terrestrial 235U/238U ratio was sufficiently great for a ‘theoretically infinite’ critical mass of uranium monosulfide (~10⁷ kg) to undergo self-sustaining nuclear fission chain reactions; the continuity of nuclear fission to the present would depend upon the nature of fuel breeding reactions.
iron metal, is often thought to occur within the fluid core and/or at the boundary between the inner core and the fluid core. By contrast, energy production from a uranium (and thorium) subcore would be expected to occur at the center of the Earth, deep within the inner core. Implications, necessarily sketchy considering the unknowns and uncertainties involved, are briefly mentioned, mainly as guideposts for interested specialists. For brevity, I reiterate neither estimates of nuclear energy production nor implications of variable or intermittent nuclear fission energy output on global geophysical parameters, such as magnetic field reversals (9, 16).

Geophysical activity within the deep interior of the Earth is manifest at the surface as the geomagnetic field, the existence, direction, and, to a more limited extent, intensity of which are documented through geological time by paleomagnetic techniques. Since early investigations (23, 24), the idea that the geomagnetic field arises through the mechanism of a self-sustained nuclear fission (9, 16). In this paper I have described the inner-core substructure expected to result therefrom and have briefly indicated certain important implications. The above-described substructure should be discernible with sufficiently precise seismic data, if not now, then when precision is improved, through technology and/or as the result of additional data from future, powerful, deep-seated earthquakes.

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