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Buoyancy in Earth's core and possible melting of the inner core (Arthur Holmes Medal Lecture)

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The geodynamo is driven by cooling controlled by the mantle. This causes freezing from the bottom up, leading to slow growth of the inner core and release of light material near the inner core boundary. This chemical buoyancy is the main driver for convection in the liquid core. Mantle convection produces large lateral variations in heat flow across the core-mantle boundary (CMB) that influence core convection, as can be seen in features of the geomagnetic field that correlate with lower mantle structure. Geodynamo simulations confirm the validity of the mechanism connecting heat flow variations with geomagnetic features but require weakened convection in the uppermost core. Convection could be suppressed there by a steepened adiabatic gradient or, more strongly, by slow dissolution of oxygen from the mantle subsequent to core formation (Hernlund, personal communication). The layer cannot be thicker than about 100 km or it would suppress some secular variation features, including the formation of reverse flux patches in the southern hemisphere that has occurred in the last 150 years. Seismology has revealed another stratified layer, about 150 km thick, at the bottom of the liquid core. Geodynamo simulations also reveal narrow downwelling jets contrasting with broad upwellings. Furthermore, lateral heat flux variations at the CMB create even larger lateral heat flux variations around the inner core boundary, in rough proportion to the difference in surface areas of the two boundaries. Numerical estimates suggest the heat flux variations may be so large as to make the inner core melt in places; in fact narrow downwelling and broad upwelling could mean the inner core is melting over the greater half of its surface while still losing heat overall. Inner core melting has interesting consequences. First, it can explain the stratified layer at the bottom of the core by releasing a heavy component into the liquid that fails to remix beyond the 150-km layer above the ICB. Secondly, provided the inner core is gravitationally locked to the mantle and is not rotating, it can easily explain any lateral variations in seismic properties near the surface, with high Q, Vs occurring where melting has uncovered compressed inner core material and low Q, Vs occurring where narrow downwelling jets cause freezing and deposition of loosely consolidated mush. Finally, allowing for large lateral variations in heat flux reduces significantly the heat loss required to drive the geodynamo because the adiabatic gradient must only be exceeded in one place to allow convection to mix the entire core: the mean temperature gradient can be subadiabatic yet still allow the whole core to convect. This increases estimates of inner core age and decreases the fraction of geological time in which the dynamo is driven by heat alone.