

THERMAL EVOLUTION OF EARTH'S CORE DURING ACCRETION: A PRIMORDIAL SOLID INNER CORE? J. Arkani-Hamed, Dept. of Physics, University of Toronto, Toronto, Ontario, Canada, (Jafar@physics.utoronto.ca).

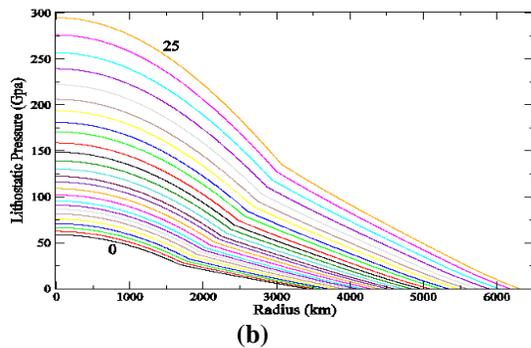
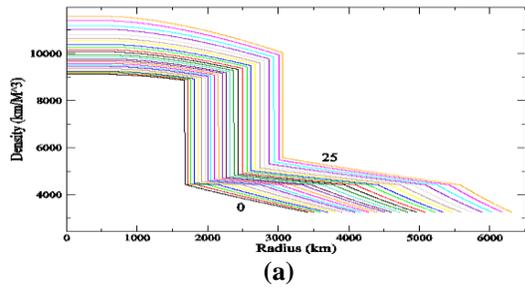
Introduction: The formation of solid inner core has conventionally been explained in terms of secular core cooling [1,2]. A solid inner core may also form if the pressure in the core of a growing proto-Earth exceeds a threshold value and the existing core temperature becomes lower than the pressure-dependent melting temperature of the core. Assuming a Mars-type initial proto-Earth, the lithostatic pressure at the center increases from ~60 GPa to ~300 GPa during the accretion, implying a high probability of a solid inner core growth. The latter scenario is investigated assuming that Earth is formed by inelastic accretion and complete merging of 25 Moon to Mars size planetary embryos, creating a self-gravitating and compressible Earth model.

Modeling: We start with a Mars size differentiated planetary embryo with a liquid iron core and a solid silicate mantle as an initial proto-Earth. The proto-Earth increases in size as other planetary embryos with similar chemical composition accrete. The following major processes are investigated after each embryo impact, chronologically: (1) The shock wave produced by the impact propagates and heats the interior of the proto-Earth within 20 to 60 minutes depending on the size of the proto-Earth. (2) The impacted proto-Earth retains spherical symmetry within a few days [3]. (3) Merging of an embryo to the proto-Earth increases the lithostatic pressure which in turn enhances the pressure-dependent melting temperature of the core [4] and increases the temperature in the mantle and the core through compressional heating. (4) The differentially heated, fast rotating low viscosity liquid core dynamically overturns and stably stratifies in a few thousand years, producing a spherically symmetric core temperature that is increasing with radius [5]. (5) The iron core of the impacting embryo which is mixed with the silicate mantle through impact processes rains as iron droplets and ponds at the base of the impact-induced molten and partially molten zone created in the upper mantle of the proto-Earth. It then sinks as an iron diapir in the solid mantle beneath and arrives at the core-mantle boundary within a few tens of thousand years depending on the distance it descends and the viscosity of the surrounding mantle [6]. (6) The compressional heating enhances the temperature of

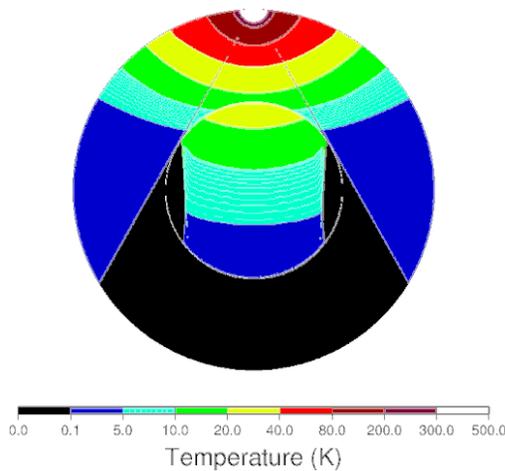
the descending diapir as it moves from low pressure upper mantle toward high pressure core, while the proto-Earth's stratified core cools to the mantle by conduction. (7) The gravitational energy released by the descent of a diapir is transferred to heat through viscous friction, heating the surrounding mantle and the diapir. (8) Depending on the density of a diapir when it arrives at the core-mantle boundary it may spread over the existing core as a hot and low-density iron layer, or sink into the proto-Earth's core if its density is higher than that of the upper parts of the core. In the latter case, the diapir descends to a neutrally buoyant depth inside the core while releasing more gravitational energy and being further heated by compression. (9) The core size increases when the diapir merges to the core, and (10) the enlarged core cools to the mantle until the next impact. In certain times during accretion, the pressure-dependent melting temperature of the core exceeds the existing temperature and results in pressure-induced solidification. The solidification initiates further processes, the most important ones are: (a) Latent heat of melting is released causing an increase in the temperature. (b) Solidification increases the density in the core by a factor of ~1.05, estimated from the PREM model [7], and the core viscosity by several orders of magnitude. (c) A high-density and high-viscosity solid inner core does not partake in the dynamic overturn in the process of core stratification and confines the overturn to the outer liquid part, which increases the mean temperature of the resulting stratified liquid region. (d) Due to solidification the volume of the core shrinks and results in further release of gravitational energy, assumed to heat the entire core uniformly. Because the lithostatic pressure increases immediately after each impact, the pressure-dependent solidification is very fast and may not allow the core to chemically differentiate, hence it solidifies with the same composition of the liquid core.

Core stratification after each impact takes a very short time and renders a stably stratified core. The heat transfer in the core is mainly by conduction except in the upper most convecting thin shell. The thermal evolution of the growing core is simulated assuming spherically symmetric heat transfer and using radial grid spacing of 100 m in the entire

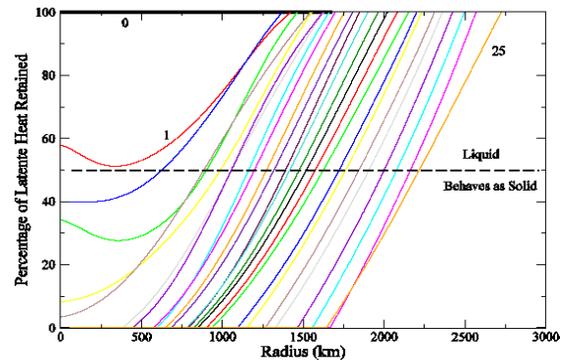
calculation domain that includes the core and an overlying 300 km thick mantle boundary layer.



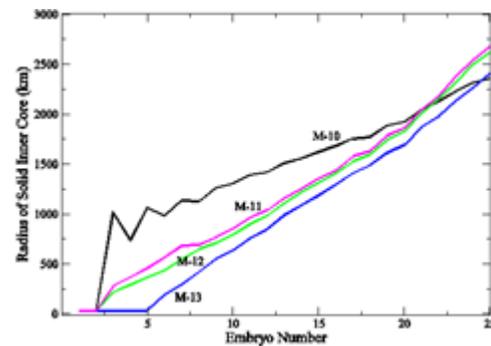
Density (a) and lithostatic pressure (b) inside the growing proto-Earth. The numbers on the curves are 0 for the initial proto-Earth and 25 for the completely accreted Earth model.



Axisymmetric temperature increase inside the initial proto-Earth by the impact of the first embryo, determined using shock pressure scaling laws [8]. The black area does not receive direct shock wave.



The latent heat retained in the core during accretion of the Reference Model. The core is completely solid when it contains 0% latent heat.



The growth of an inner core during accretion of 4 different models. Model M-10 is the Reference model with almost pure iron core. The other models are for the core with increasing impurities.

References: [1] Gubbins, D., T.G. Masters, and J.A. Jacobs (1979) *Geophys. J. R. Astron. Soc.* 59, 57-99. [2] Buffett, B. (2013) *Physics Today* 66, 37-41. [3] Canup, R.M., A.C. Barr, and D.A. Crawford (2013) *Icarus* 222, 200-219. [4] Anzellini, S., A. Dewaele, M. Mezouar, P. Loubeyre, and G. Morard, (2013) *Science*, 340, 464-466. [5] Arkani-Hamed, J. and P. Olson (2010) *Geophys. Res. Lett.*, 37, L02201. [6] Monteux, J. and J. Arkani-Hamed, (2014) *J. Geophys. Res., Planets*, 119, doi:10.1002/2013JE004587. [7] Dziewonski, A.M., and D. L. Anderson, (1981). *Phys. Earth Planet. Inter.* 25, S297-356. [8] Monteux, J., Arkani-Hamed, J., (2016) *Icarus*, 264, 246-256.