The Role of Trapped Liquid in Magma Ocean Processing of Major Volatiles

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The inventories of volatiles in the bulk silicate Earth and mantle following the violent events of accretion and differentiation remain a significant puzzle. Despite the appeal of the late veneer hypothesis, evidence has accumulated that both inventories remember volatile addition and differentiation that preceded late addition events. This evidence includes interior reservoirs of nebular rare gases and the high BSE C/N ratio, which has been attributed either to core formation or to atmospheric blow off. The latter seems more likely because experiments to date suggest that C is more siderophile than N. Additional challenges are to understand Earth's H and C inventories, including their fractionations relative to chondritic sources and between surface and interior reservoirs. The high H/C ratio of the BSE can originate either by C sequesteration in the core or loss to space of a massive CO_2–rich atmosphere (accompanied by retention of a liquid ocean), but neither fully explains the comparatively C-rich residual mantle. This has lead to ideas about carbon pumps depositing C-rich phases during magma ocean (MO) solidification.

An important factor not fully incorporated in previous models is the residual melt trapped during MO solidification. Layered mafic intrusions demonstrate that crystal-liquid separation during segregation of cumulates is imperfect and that trapped liquid fractions increase with solidification rate. MO lacking solid carapaces crystallize more rapidly than layered intrusions We have simulated MO solidification coupled to an atmospheric degassing model with a gray-body greenhouse, incorporating compaction of cumulates. Mean trapped liquid fractions are approximately 6-8%, with greater values at the MO base and through the transition zone, where solidification is rapid. If the total volatiles delivered to Earth were chondritic and much greater in mass (~X 10) than the current inventory (as required by massive loss scenarios), much of the current mantle inventory of H and C could have been sequestered as trapped liquid. Such scenarios always produce mantle H/C greater than the surface reservoir (the opposite of the modern situation), but coupled to a subsequent epsiode of (CO_2-rich) atmosphere loss, may plausibly account for much of the major volatile distribution on Earth.