**THE FATE OF MAGMAS IN PLANETESIMALS AND THE RETENTION OF PRIMITIVE CHONDRITIC CRUSTS** Roger R. Fu[1] and Linda T. Elkins-Tanton[2], [1]MIT, 77 Massachusetts Ave., Cambridge MA 02138, USA, (rogerfu@mit.edu); [2]DTM, Carnegie Institution, 5241 Broad Branch Road NW, Washington, DC 20015, USA.

**Introduction:** Several lines of evidence suggest that some early-accreting planetesimals retained primitive chondritic crusts while undergoing interior melting and differetiation. Paleomagnetic experiments on CV and CM carbonaceous chondrites show that these parent bodies likely harbored magnetic core dynamos even though the chondritic samples themselves escaped melting [1, 2]. Chondrites that experienced minimal parent body heating in the CR, CM, and CV groups have been associated with metachondrites that experienced heating at up to 1000˚C [3, 4, 5]. In additional to meteoritic evidence, Ceres, Pallas, and Lutetia exhibit surface compositions consistent with carbonaceous or enstatite chondrite material [6, 7]. These asteroids have high densities or global figures that likely require internal differentiation [8, 9].

The hypothesis of a partially differentiated body, with a primitive lid overlying a differentiated interior, requires the stability of the overlying crust against foundering or destruction via pervasive melt ascent. Previous models of melt migration on planetesimal-sized bodies concluded that volatile exsolution may readily drive melt ascent to the surface for bodies smaller than 500 km in diameter [10].

However, progressive heating of the chondritic protolith may result in extensive devolatilization before mobile silicate melts are formed. Furthermore, lithostatic pressures inside planetesimals result in finite volatile solubilities. Both effects can hinder exsolution and volatile-driven eruption.

Here we consider the fate of volatiles in internally heated planetesimals and assess the role of volatiles in driving melt ascent. We then calculate the buoyancy of the silicate melts for several chondritic compositions and identify parent bodies for which chondritic crusts are expect to survive interior differentiation.

**Volatiles exist as free phases before silicate melting:** Although cold chondritic materials on early planetesimals were volatile-rich, these volatiles must have persisted until the formation of the first mobile silicate melts to drive magma ascent.

We first consider the fate of water. At the pressures relevant to subduction zones on Earth (>2 GPa), hydrous phases are stable at temperatures immediately below the solidus, which ensures that water is present during melting. In contrast, at the much lower lithostatic pressures in planetesimals (Fig. 1), no hydrous silicate phase remains stable up to the silicate solidus for peridotitic compositions [11]. Amphibole, the highest temperature hydrous phase, breaks down at ~950 °C. Given that the solidus of chondritic silicates is approximately 1050-1150˚C [12], a large gap in temperatures exists in which there is no stable hydrous silicate phase. Corroborating these phase relations, progressive heating of the Semarkona chondrite showed that the most stable hydrous phases decomposed by 600-750˚C [13].

Similarly, other volatiles including $CO_2$ and $N_2$ are released from the host chondrite below ~800˚C. Finally, the release of CO and Cl may require heating up to ~1255 and ~1300˚C. The bulk of these phases are released below 1250˚C, at which temperature the first silicate melts are mobilized [14].

Therefore as short-lived radionuclides progressively heat the interior of planetesimals, volatiles will be released as free phases before the mobilization of silicate melts. If the free phases migrate away rapidly, volatiles would not be available upon melting to drive the ascent of silicate melts.

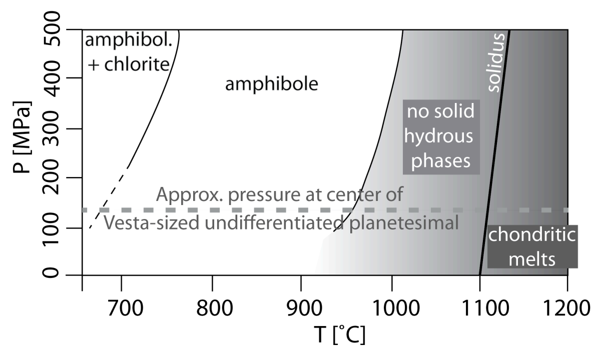


**Fig. 1.** Stability of hydrous silicate phases in a peridotitic bulk composition. At low pressures, no hydrous phase is stable for a wide temperature range below the solidus.

**Free volatiles migrated rapidly from melt regions:** The ability for the free volatile phases to migrate away from the melting region depends on a competition between the upward flow velocity of the volatiles and the rate of heating of the body. We therefore calculate the Darcy flow velocity of free volatiles in planetesimals and compare the required timescale of ascent to that of radiogenic heating.

The Darcy flow velocity of a volatile phase depends on its viscosity and density. Water would exist in the gas phase or as a supercritical fluid (SCF) above the critical temperature of 374˚C. For planetesimals with radius smaller than ~110 km all water in the heated interior would be converted to vapor. Other volatiles such as $CO_2$ and CO are also expected to exist in the gas or SCF phases. Water vapor and SCF at ~900˚C and the pressures relevant to planetesimal interiors have very low viscosities of the order $5\times10^{-5}$ Pa s and densities <100 kg $m^{-3}$ [15, 16]. Given grains sizes of 0.001 m, porosity of 0.1, and density of 3,700 kg $m^{-3}$ in the surrounding chondritic material, the ascent velocity of volatiles is expected to be >1 km $yr^{-1}$ [17]. The delivery of free volatiles from the interior due to buoyancy therefore requires no more than ~100 years. In comparison, even in the fastest possible case of instantaneous accretion at the time of first CAIs, the planetesimal's interior reaches 1250°C in approximately 0.1 My.

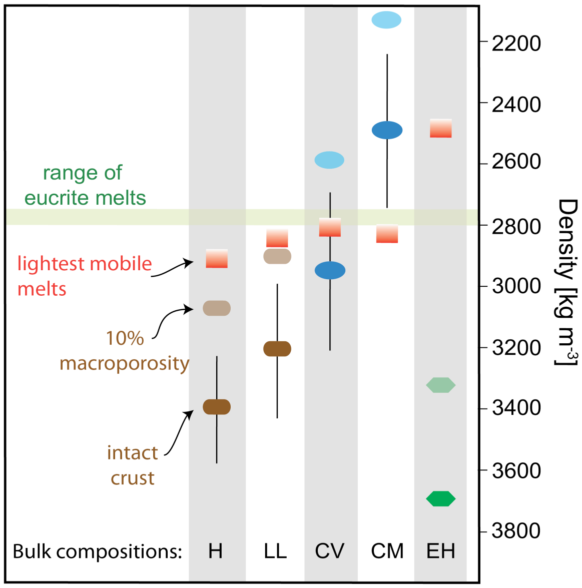


**Fig. 2.** Densities of dry melts of selected chondritic compositions compared to the densities of hand samples and crusts with 10% macroporosity. Hand sample densities from ref. [18].

Thus, volatiles would be liberated and percolate upward via Darcy flow efficiently long before the melting point of the silicates is reached, which is consistent with the very low volatile contents of achondrites and highly metamorphosed chondrites. The volatile budget of the planetesimal's interior would be limited to the amount remaining in nominally anhydrous phases, which corresponds to <<200 ppm $H_2O$, ~ 100 ppm Cl, and <<100 ppm of other volatiles at the relevant pressures [13, 19, 20]. Volatiles at such low concentrations do not undergo exsolution at planetesimal interior pressures [21]. Therefore, volatiles cannot drive the ascent of melts on planetesimals, and the fate of melts depends on the relative densities of dry melts and the overlying chondritic crust.

**Dry melts may be denser than chondritic crusts:** We calculate the densities of dry melts of a range of chondritic compositions using experimental data [14, 22] and melt density code after Kress and Carmichael [23].

For macroporosities of ~10%, chondritic crusts with CV and CM compositions are less dense than the dry silicate melts on the same parent bodies (Fig. 2). Processes that can increase crust density such as viscous porosity closure and dehydration do not alter this conclusion. As such, melts on these planetesimals are unlikely to ascend, leading to the preservation of the primitive chondritic crust as implied by paleomagnetic studies [1, 2]. The densities of silicate melts from ordinary chondrite parent bodies are marginally lower than that of the overlying crust. In the case of enstatite chondrite compositions, light melts readily ascend through the planetesimal crust. Such bodies are therefore expected to exhibit achondritic surfaces. The aubrites are an achondrite group that may have formed from the melting of an enstatite chondrite-like protolith [24]. The observation of aubritic spectra on the surface of E-type asteroids [25] further supports that enstatite chondrite melts ascended readily.

**Conclusions:** We have shown that, in early accreting planetesimals, volatiles such as $H_2O$ exist as free gas or supercritical phases at temperatures below the mobilization of silicate melts. Furthermore, the buoyant ascent of these free volatiles via Darcy flow was rapid. Therefore, volatiles likely did not contribute to the buoyancy of silicate melts on planetesimals.

Considering the buoyancy of such volatile-depleted melts, planetesimals with CV and CM chondrite compositions may internally differentiate but never erupt magmas onto their surfaces. Planetesimals with ordinary or enstatite chondrite compositions may generate buoyant melts and therefore have achondritic surfaces.

Further details of this work is found in ref. [26].

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