ASTEROID PARTIAL MELTING AT THE SOLAR SYSTEM'S SNOW LINE. T.J. McCoy and K.G. Gardner-Vandy, Dept. of Mineral Sciences, Smithsonian Institution, Washington DC 20560-0119 USA (mccoyt@si.edu)

Introduction: Conceptual models of asteroid differentiation are typically divided into high-temperature differentiation of rock from metal [1] and low-temperature differentiation of rock from ice [2]. The incorporation of ice provides a thermal buffer, with aqueous alteration substituting for high-temperature thermal metamorphism or partial melting [3]. However, the recognition of wide-spread partial melting in the meteorite collection [4] coupled with the assertion of a core dynamo on the CV chondrite parent body [5] spurs us to re-examine partial melting in the presence of significant ice accretion.

End Members: Numerous factors would influence the nature of partial melting on an ice-bearing asteroid, including composition and physical state of the starting material; peak temperature; the scale of mixing of silicates, metal and ice; and oxygen fugacity. Here, we assume a peak temperature sufficient to produce low-degree partial melts (~1100°C), recognizing that this choice is arbitrary and actual peak temperature depends on numerous factors, including time of accretion. Instead, we focus on only two critical parameters – water:rock ratio and parent body size. We examine the end members of these two scenarios with roughly defined "low" water-rock ratio (abundances of ice insufficient to alter chondrules and all metal) and "high" water:rock ratios (those sufficient to cause significant alteration). Likewise, we consider large and small asteroids, with a conceptual boundary between the two of ~100 km diameter.

Partial melting on a small, ice-bearing asteroid: Figure 1 illustrates a schematic representation of partial melting on a small asteroid, with the insets representing cm-scale time-integrated views of areas with low water:rock and high water:rock ratios.

Low water:rock ratio. The case of low water:rock ratios on a small parent body is probably the most straightforward. At low water:rock ratios, aqueous alteration would largely be confined to the fine-grained matrix, leaving larger chondrules and metal particles minimally altered, akin to CR2 chondrites. Dehydration and partial melting of the minimally-altered material would liberate bound water, followed by Fe,Ni-FeS melting at ~950°C, and basaltic partial melting at ~1050°C. The melting of CR chondrites to form the partially-melted acapulcoites and lodranites has been suggested. A preliminary experiment on CR2 melting supports efficient dehydration prior to formation of mixed plagioclase-metal-sulfide melts. Melts liberated would migrate, probably largely along fractures in a body where the tensile strength of the rock exceeds the gravitational strength of the body. Water reaching the surface would undoubtedly be lost from the body. The fate of partial melts is less clear, although if sufficient volatiles remained at the time of partial melting, explosive volcanism and removal of the basaltic and Fe,Ni-FeS melts is possible [6]. Alternatively, the metal-sulfide melts might migrate to form a small core if dehydration prior to melting efficiently removed volatiles.

High water:rock ratio. Although producing partial melts at high water:rock ratios is significantly more problematic, it is instructive to examine. Alteration of the protolith could be extensive, including chondrule alteration, and alteration of metal and troilite to produce magnetite and sulfides such as pentlandite or pyrrhotite, akin to CM2 chondrites. Although often considered highly refractory [7], melting of magnetite and monosulfide solid solution (mss) can occur at 1050°C [8]. Thus, the major difference might not be in process, but in material. Formation of a small magnetite-mss core might occur under such conditions, with implications for the magnetic signature of the asteroid.

Partial melting on a large, ice-bearing asteroid: Figure 2 illustrates melting on a large (~>100 km) asteroid. As with melting on a smaller parent asteroid, the major effect of water:rock ratio is the degree of alteration of the protolith and subsequently generated partial melts. The significant difference on a larger parent asteroid is the retention of melts generated from the interior. The most obvious result of this is the possible formation of a hydrosphere as a result of dehydration. That hydrosphere would solidify, perhaps retaining liquid until significant heating of the asteroid ceased. [2] considered such a scenario for Ceres. As in the case of a smaller parent body, the fate of metal-sulfide, magnetite-mss, or silicate partial melts is less clear. [2] argued that heat might build up at a boundary between unaltered silicates in the core of the body and overlying, less conductive altered silicates, allowing partial melting. Melts might migrate along dikes to the surface. Given likely dike geometries on small bodies, effusion rates might be relatively low, perhaps producing pillows upon extrusion into the hydrosphere. If the hydrosphere were largely liquid, magma extrusion might have relatively little influence on the hydrosphere, akin to the minimal impact of pillow basalts on the sea floor. Alternatively, if the hydrosphere were largely solidified, remelting might induce fracturing and resurfacing (ala, Zamboni effect).

Future work: Although largely a theoretical construct at this point, the exploration of Vesta and Ceres by the Dawn mission has the potential to bookend these two broad styles of differentiation. With new insights from missions and new discoveries from the meteorite collection, understanding hybrid styles of differentiation promises to become increasingly important.

References: [1] McCoy T.J. et al. (2006) MESS II, 733. [2] Castillo-Rogez J.C. and McCord T.B. (2010) Icarus 205, 443. [3] Grimm R.E. and McSween H.Y. Jr. (1993) Science 259, 653. [4] Mittlefehldt D.W. et al. (1998) Planetary Materials, 4-1. [5] Elkins-Tanton L.T. et al. (2011) EPSL 305, 1. [6] Wilson L. and Keil K. (1991) EPSL 104, 505. [7] Castillo-Rogez J.C. (2011) Icarus 215, 599. [8] Naldrett A.J. (1969) J. Petrol. 10, 171.

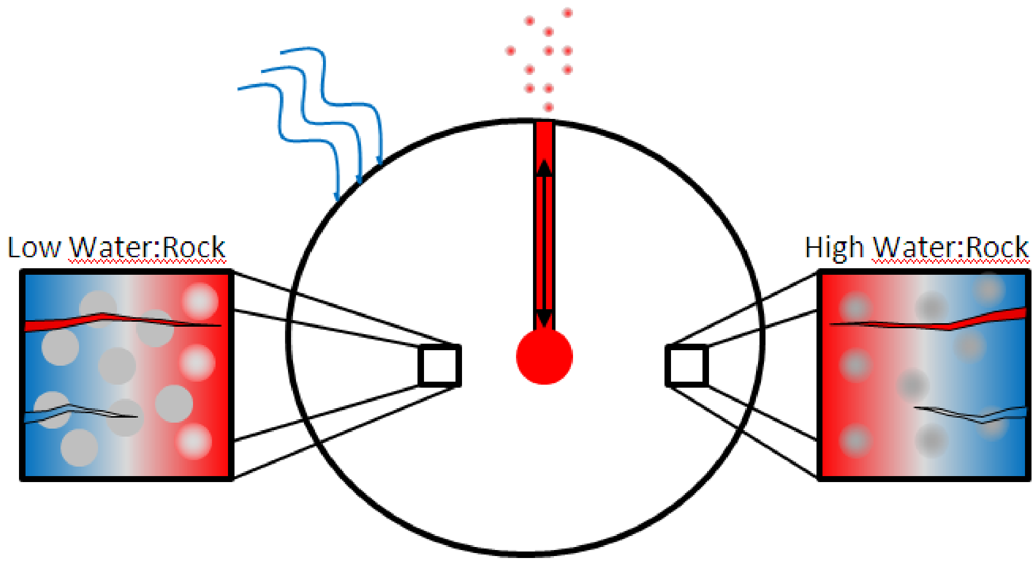

Figure 1. Schematic of melting on a small (~<100 km) parent asteroid. Insets represent an ~1 cm scale view with chondrules and metal particles (gray filled circles) in a fine-grained matrix. Hydration (blue) and alteration (including alteration of chondrules and metal at high water:rock ratio) followed by dehydration (gray) and partial melting (red) occurr with time, producing associated fracturing and removal of volatiles and partial melts. Volatiles migrating to the surface would be lost, as might be partial melts owing to volatile-driven explosive volcanism. A small core might be produced if insufficient volatiles exist to produce buoyancy in dense melts.

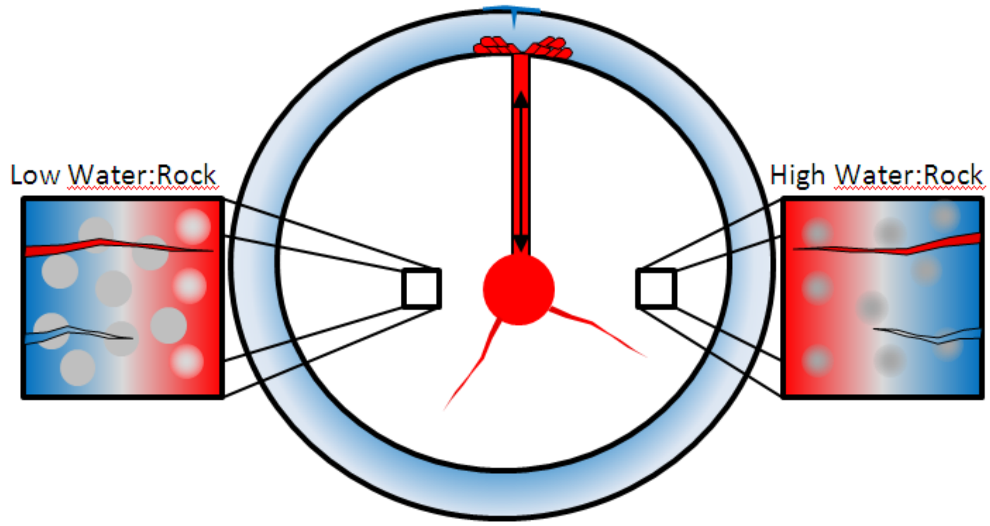

Figure 2. Schematic representation of melting on a large (~>100 km) parent asteroid. The passing thermal front would produce hydration followed by dehydration and partial melting, but the melts produced would not be lost. Dense melts would segregate to the core, while buoyant fluids and melts would migrate to the surface. An early formed hydrosphere would be intruded by melts, possibly producing pillow lavas and hydrosphere melting with resurfacing of the asteroid.