EARLY SOLAR SYSTEM CRYOVOLCANICS IN THE LABORATORY

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Introduction: Two thermally-metamorphosed ordinary chondrite regolith breccias, Monahans 1998 (H5) and Zag (H3-6) contain fluid inclusion-bearing halite (NaCl) crystals [1-3], dated by K-Ar, Rb-Sr and I-Xe systematics to be ~4.5 billion years old [1,2,4,5]. Heating/freezing studies of the aqueous fluid inclusions demonstrated that they were trapped near 25°C [1], and their continued presence in the halite grains requires that their incorporation into the H chondrite asteroid was post metamorphism [6].

Solid Inclusions: Abundant solid inclusions are present in the halites. These were solids entrained within the mother brines during eruption, and should include unaltered protolith rocks from the rocky mantle(s) and surfaces of the erupting body(ies). The solid inclusions include abundant and widely variable organics [6] which cannot have been significantly heated (which would have resulted in the loss of fluids from the halite). Analyses by Raman microprobe, SEM/EDX, synchrotron X-ray diffraction and TEM reveal that these grains include macromolecular carbon (MMC) similar in structure to CV3 chondrite matrix carbon, aliphatic carbon compounds, olivine (Fo_{99-59}), high- and low-Ca pyroxene, feldspars, magnetite, sulfides, lepidocrocite, carbonates, diamond, apatite and possibly the zeolite phillipsite.

We observe remarkable diversity in the thermal maturity of the organics. Chloromethane is present, which is water soluble and requires cold formation temperatures at high hydrogen fugacity. When heated, methanol aromaticizes into PAHs which are not observed, another proof these halites have not been heated.

Cryovolcanism: We hypothesize that the halites derive from ancient cryovolcanism [7], because: (**1**) Although some primitive carbonaceous chondrites experienced late-stage Na-Cl-bearing fluid metasomatism [8], the occurrence of halite is very rare in astromaterials [1]. (**2**) Salt crystals are an observed product of the cryovolcanism on the Saturnian moon Enceladus [9]. (**3**) Analysis of some of the Enceladus cryovolcanics by Cassini revealed organic or siliceous components, hypothesized to derive from Enceladus' putative rocky mantle [9,10]. The Enceladus plumes include methane, as does Monahans halite. (**4**) Cryovolcanic fluids are observed to be in chemical disequilibrium, reflecting incomplete reactions between interior volatiles and rocky materials [11]. The coexistence of N2 and HCN in Enceladus' plumes requires a mixture of materials which experienced different degrees of aqueous processing, including primordial material trapped in ice that never saw liquid water; the observed mineral assemblage within the Monahans and Zag halites is also far from equilibrium.

References: [1] Zolensky et al. 1999. Science:285, 1377; [2] Zolensky et al. 2000. 31st LPSC; [3] Rubin et al., 2002. MAPS: 37, 125; [4] Whitby et al. 2000. Science:288, 1819; [5] Bogard et al., 2001. MAPS:36, 107; [6] Fries et al. 2011. MAPS:46, A70; [7] Wilson & Keil 1996. EPSL:140, 191; [8] Wasserburg et al. 2011. GCA:75, 4752; [9] Postberg et al. 2009. Nature:459, 1099; [10] Matson et al. 2007: Icarus:187, 569; [11] Waite et al. 2009. Nature:460, 487.