

HYDROVOLCANIC ASTROMATERIALS IN THE LAB. M.E. Zolensky¹, M. Fries¹, Q.H.-S. Chan², Y. Kebukawa³, A. Steele⁴, Y. Yurimoto⁵, S. Itoh⁶, M. Ito⁷, R.J. Bodnar⁸, ¹NASA Johnson Space Center, Houston, TX 77058, USA (michael.e.zolensky@nasa.gov); ²Open University, Milton Keynes, UK; ³Yokohama National University, Yokohama 240-8501, Japan.; ⁴Carnegie Geophysical Lab, Washington, DC 20015, USA; ⁵Hokkaido University, Sapporo, Japan; ⁶Kyoto University, Kyoto, Japan; ⁷JAMSTEC, Kochi, Japan, ⁸Virginia Tech, Blacksburg, VA, 24061, USA.

Introduction: Zag and Monahans (1998) are H chondrite regolith breccias that contain 4.5 GY old halite crystals which in turn contain abundant inclusions of aqueous fluids, solids and organics [1-4]. We have previously proposed that these halites originated on a hydrovolcanically-active C class asteroid, probably Ceres [3, 4], or a trans-neptunian object (TNO – or P- or D-class asteroid) injected into the inner solar system during giant planet migration [5]. We have begun a detailed analysis of organics and other solids trapped within the halite, which we hypothesize sample the mantle of the halite parent object, and are examining a halite-bearing C1 chondrite clast also found in Zag [6], which is similar to the solids in the halite. These investigations will reveal the water-rock interactions on the hydrovolcanically-active parent world.

Mineralogy of solids in the Monahans halite: Abundant solid inclusions are present in the halites, which were entrained within the mother brines during eruption, and should include material from the rocky mantle and surface of the erupting body. The solid inclusions include abundant and widely variable organics that could not have been significantly heated (which would have resulted in the loss of fluids from the halite). Analyses of solids from a Monahans halite grain by Raman microprobe, SEM/EDX, synchrotron X-ray diffraction, C-XANES, FTIR, N-XANES, nanoSIMS and TEM reveal that these grains include macromolecular carbon (MMC) similar in structure to CV3 chondrite matrix carbon, aliphatic carbon compounds, olive of widely varying composition (F_{0.99-5.9}), high- and low-Ca pyroxene, feldspars, phyllosilicates (mainly saponite), magnetite, sulfides, metal, lepidocrocite (rust), carbonates, diamond, apatite and zeolites. We have been making detailed analyses of carbon, deuterium and nitrogen in the halite solids and Zag clast [7-9]. There is a remarkable diversity in the organics, and the clast (at least) has a significant abundance of nitrogen, including ¹⁵N hotspots associated with the highest concentrations of carbon and deuterium.

O and H Isotopes of Aqueous Fluids in the Halite: We measured O and H isotopes of individual fluid inclusions in Monahans and Zag halite [10]. There was considerable inter-inclusion variability in individual halite crystals, with the water proving to have an isotopic composition most similar to Oort cloud comet comas (Enceladus plume water vapor has the same

composition [11,12]), though the compositions vary from inclusion to inclusion, suggesting that we will be able to track fluid composition changes with time and increased interaction with asteroidal fluids. The water in Zag and Monahans halites have similar isotopic ranges, suggesting derivation from a common body. The distribution of isotopic variations of the fluid inclusions could be a result of interaction between comet-like water and carbonaceous chondrite silicates. It is also possible that the mother brines of the halites were hydrovolcanic plumes, a scenario we prefer. Either way, analysis of individual, preselected fluid inclusions provide temporal information on compositional changes of the fluids.

Zag C1 Clast: This clast is predominantly a fine-grained mixture of serpentine, saponite, magnetite, Ca phosphates, organic-dominated grains, pyrrhotite, Ca-Mn-Mg-Na carbonates, and halite. The carbonates have Mn-rich cores, mantles of Ca-carbonate, and very thin Na-Mg-rich rims which extend as halos into the clast. The bulk oxygen isotopic composition of this clast is more ¹⁷O rich than other C chondrites, with a high $\Delta^{17}\text{O}$ value of +1.41 [6]. The Na-rich rims of carbonates traces alteration attending carbonate formation, which we will attempt to date.

Conclusions: The halite in Monahans and Zag and C1 clast in the latter meteorite derive from a water- and carbon-rich object that was hydrovolcanically active in the early solar system. The samples in hand represent both the protolith (unaltered) and aqueously-altered mineralogy of the body, permitting understanding of the alteration conditions. Whatever the parent body, it was rich in a wide variety of organics and warm, liquid water at the dawn of the solar system.

References: [1] Zolensky et al. (1999) *Science* 285, 1377-9; [2] Rubin et al. (2002) *MAPS* 37, 125-142; [3] Fries et al. (2013) *MAPS* 48, A80; [4] Zolensky et al. (2013) *MAPS* 48, A394; [5] Zolensky et al. (2018) *49th LPSC abstracts*; [6] Zolensky et al. (2003) *66th MetSoc Meeting*; [7] Chan et al. (2018) *Science Advances* 4, eaao3521; [8] Kebukawa et al. (2016) *Abstracts, 79th Annual Meeting of the Meteoritical Society*; [9] Kebukawa et al. (2017) *48th LPSC abstracts*; [10] Yurimoto et al. (2014) *Geochemical Journal* 48, 1-12; [11] Postberg et al. (2009) *Nature* 459, 1099-1101; [12] Postberg et al. (2008) *Icarus* 193, 438-454.