

Evidence For Late-Stage Alkali Metal-Rich Brines in Primitive Asteroids M. Zolensky¹, Y. Kebukawa², Q. Chan³, J. Han⁴, L. Le⁴, W. Buckley⁴, R. Armytage⁴, S. Eckley⁴, J. Simon¹, M. Fries¹, R. Jakubek⁴, ¹ARES NASA Johnson Space Center, Houston, TX 77058 USA, ²Osaka University, 2-1 Yamadaoka, Suita, Osaka 565-0871, Japan, ³Royal Holloway University, Egham TW20 0EX, UK, ⁴Amentum at JSC, Houston, TX 77058 USA.

Introduction: Introduction: We recently noted a correlation of Na with dolomite in a C1 clast within the Zag H chondrite. This clast is associated with halite and sylvite that formed on a separate parent, similar or possibly identical to asteroid 1/Ceres [1]. We are characterizing the Na-rich phase in the Zag clast, We are also searching for additional examples of carbonate-correlated Na-enrichments in C1 chondrites.

Techniques: Scanning Electron microscopy was performed using a JEOL 7600 FEG-SEM in the E-Beam Laboratory, ARES, NASA JSC. Bulk compositional analyses were made using femtosecond laser ablation with laser-induced breakdown spectroscopy (LIBS), together with multi-collector inductively coupled plasma mass spectrometry (MC-ICPMS), at the Center for Isotope Cosmochemistry and Geochronology, ARES, NASA JSC. X-ray computed tomography was performed using a Nikon XT H 320 CT scanner at the Astromaterials X-ray Fluorescence and Computed Tomography Lab, ARES, NASA JSC. Raman spectroscopy will be performed using the WITec α 300R Raman microscope in the ARES JSC Raman Laboratory.

Zag Clast: The Zag C1 clast (Fig. 1) was prepared using no fluids, and consists mainly of the phyllosilicates saponite and serpentine, pyrrhotite, magnetite, dolomite, and organic grains. Minor amounts of Ca phosphates, halite, and pentlandite are additionally present [1]. The carbonates are compositionally-zoned with respect to Mg, Ca, Fe, Mn and are surrounded by Na-, K-, Mn-enriched material (Fig 2). The organic grains have recently been investigated by Kebukawa et al. [2] who reported two types of closely mixed organics: 1) deuterium-rich, CO-rich organics with likely smaller aromatic domains, possibly originating in relatively oxidized environments from deuterium-rich precursors, and 2) less deuterium-rich, but aromatic-rich organics, possibly produced in relatively reduced and higher temperature environments with less deuterium-rich precursors. These mineralogic characteristics point to complex mixtures of materials with different origins and sampling a wide heliocentric range of the Solar System before accretion in the parent body of the clast.

The largest dolomite aggregates in the clast are surrounded by material enriched in Na, Mn and K. This enrichment is plausibly due to late-stage passage of brines through the rock, also responsible for the

deposition of halite and sylvite. Although the nature of the Na-enriched material is not yet well understood we have noted that it has been gradually disappearing over the past 20 years, indicating that it is an unstable phase. Thus, Na carbonates are a probable candidate. We will determine the mineralogy by preparing a new polished mount of the Zag clast without any fluid and then employ Raman spectroscopy.

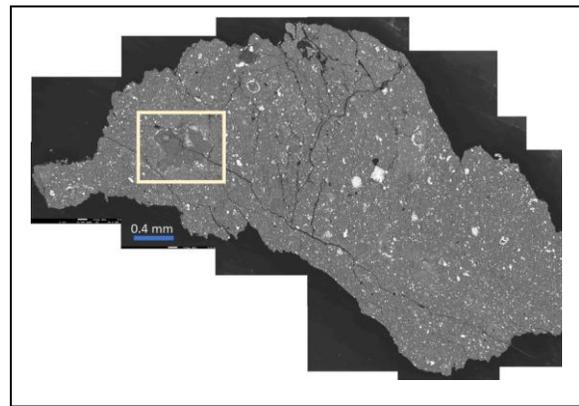


Figure 1. Back-scattered electron image of the C1 Zag clast. Large dolomite aggregate is in the box.

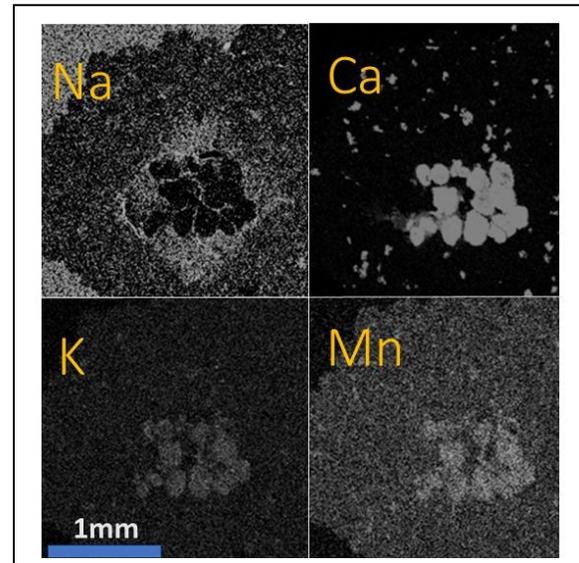


Figure 2. X-ray element maps of the dolomite aggregate in the Zag clast (white in the Ca map), exhibiting local enrichment in Na, K and Mn.

The local Na, K and Mn enrichments are also apparent in the new bulk composition measurements of the Zag clast, which reveal that while most measured elements are present at approximately CI abundances, Na is 8000ppm (1.6xCI), K is 1256 ppm (2.5xCI), Mn is 2276 (1.14xCI) and Rb is 14 ppm (6xCI).

Frank et al. reported that $\delta^{18}\text{O}$ values for apparently coexisting dolomite and magnetite in the Zag clast clustered around +41 ‰ and -6 ‰, respectively, with oxygen isotope geothermometry giving a co-crystallization temperature $< -15^\circ\text{C}$, assuming equilibrium between these two phases. They also reported wide ranges of both D/H and $^{12}\text{C}/\text{H}$ in the matrix, possibly due to variable concentrations of IOM and fine-grained carbonates. Slow kinetics of D-H exchange in a brine at sub-zero temperatures may explain the isotopic disequilibrium between organics and phyllosilicates. Thus all the evidence points to the presence of a late stage, very cold brine in the Zag clast parent. Apparently this brine was also rich in Na, K, Mn and Rb.

Flensburg C1 Chondrite: Flensburg is a unique C1 chondrite fall from 2019 [4], and thus has had limited opportunities for terrestrial alteration. We found Na enrichments correlated with dolomite in a section that had not been prepared with a fluid (Fig. 3). We are investigating this sample further.

CI1 chondrites: We found no Na enrichments correlated with dolomites in existing sections of Orgueil, Alais or Ivuna. However, these sections had all been prepared (by us) using ethanol and were over 20 years old. Thus, it is possible that Na enrichments have been erased. We next plan to examine a sample of Oued Chebeika 002, a newly found CI1 from North Africa (which just has to be a recent fall).

Conclusions: We find correlations of Na with dolomite in the Zag C1 clast and the Flensburg C1 chondrite. The Zag clast also exhibits a correlation of K, Rb and Mn with dolomite. All evidence points to the presence of an alkali metal rich, cold, late-stage brine on the C1 parent asteroids, also associated with organics of widely varying histories. A modern example of this could be Occator crater on Ceres [5].

References: [1] Zolensky et al. (2003) *Meteoritics and Planetary Science* **38**, abstract 5216; [2] Kebukawa Yet al. (2023) *Icarus* **400**, 115582; [3] Frank et al. (2020) *51st Lunar and Planetary Science Conference Abstract*; [4] Bischoff et al. (2019) *GCA* **293**, 142-186, [5] Nathues et al. (2020) *Nature Astronomy* **4**, 794-801.

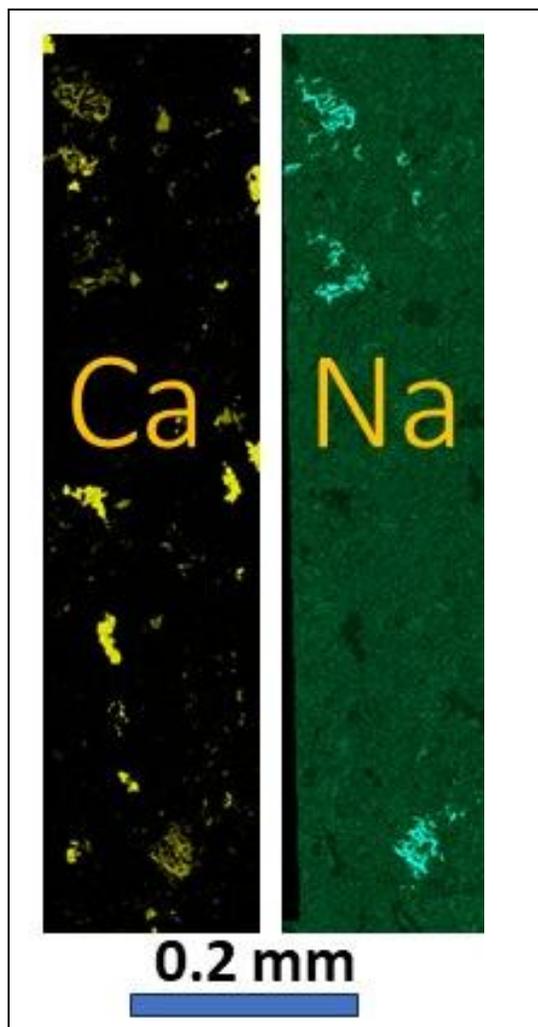


Figure 3. X-ray element maps of Ca and Na in Flensburg, exhibiting correlations of Na and dolomite (light yellow in the Ca map).