GEMS-LIKE MATERIAL IN AGUAS ZARCAS INTERCHONDRULE MATRIX. K. L. Villalon[1,2,3], P. R. Heck[1,2,3], K. Keating[1,2,3], A. M. Davis[1,2,4], and T. Stephan[1,2]. [1]Department of the Geophysical Sciences, The University of Chicago, Chicago, IL, USA, [2]Chicago Center for Cosmochemistry, [3]Robert A. Pritzker Center for Meteoritics and Polar Studies, Field Museum of Natural History, Chicago, IL, USA, [4]Enrico Fermi Institute, The University of Chicago, Chicago, IL, USA. E-mail: kvillalon@uchicago.edu.

Introduction: The pre-accretionary histories of many meteorites have been lost or modified due to secondary processing on the parent body, such as thermal metamorphism and aqueous alteration. The matrices of primitive carbonaceous chondrites (CCs), i.e., those CCs that have experienced minimal to no secondary processing, are comprised of unequilibrated assemblages of fine-grained materials that retain preserved primordial components. Primitive CC matrices are therefore vital to understanding the inventory of available solids and their histories in the early solar nebula.

A major component of primitive CC matrices is amorphous silicate [e.g., 1]. Amorphous silicate is highly susceptible to alteration and its presence is therefore indicative of minimal secondary processing. Amorphous silicate is also the predominant component of the interstellar medium (ISM) as well as chondritic porous interplanetary dust particles (CP-IDPs), a subset of highly porous IDPs that are believed to originate in comets and are considered to be the most pristine extraterrestrial samples to date. Presolar, interstellar silicates have eluded unambiguous discovery in primitive materials despite having been the predominant solid component of the ISM.

The amorphous silicate found in CP-IDPs—known as Glass with Embedded Metal and Sulfides (GEMS) as the amorphous silicate contains 1–30 nm inclusions of kamacite (α-Fe,Ni) and pyrrhotite ($Fe_{(1-x)}S$)—have been argued to be these missing interstellar grains [2]. Another hypothesis argues that GEMS formed by vapor-phase, nonequilibrium condensates in the solar nebula [3]. In either case, GEMS may be a primary building block of the Solar System. Thus, the various silicate components of different primitive samples may represent related stages in silicate dust evolution—from condensation around stars, ISM processing, incorporation into growing planetesimals in protoplanetary disks, to subsequent parent body processing. However, GEMS have yet to be unambiguously identified in meteorites, and their relationship to the amorphous silicates observed in primitive CCs are unconstrained.

GEMS-like objects have been described in rare primitive CCs, including Paris (CM2.7–2.9), and Acfer 094 (C-ungrouped), and a C-rich clast from LaPaz Icefield 02342 (CR2) [1,4,5]; however, there are notable differences between the GEMS-like objects in Acfer 094 and Paris and *bona fide* IDP GEMS. GEMS-like material has: (1) larger size distribution of inclusions; (2) pervasive oxygen-rich rims surrounding inclusions; (3) pyrrhotite and pentlandite nanosulfides, whereas GEMS in IDPs are exclusively pyrrhotite; (4) an absence of metal inclusions within the amorphous silicate; and (5) a higher Fe content and Fe oxidation state [6, 7]. It remains unclear if these differences are inherent or due to modification of GEMS in the parent body. Studying amorphous silicates and GEMS-like material in pristine type 3 chondrites, more primitive CCs of varying levels of alteration, and CCs from different CC groups are needed to clarify the origins and interrelationships between these materials.

Aguas Zarcas fell on April 23, 2019 in Costa Rica and is geochemically and isotopically consistent with a CM2 classification [8]. A large fraction of meteorite fragments from this fall was collected before rain and has not been exposed to liquid water on Earth. Like many other CMs, notably Paris [1], Aguas Zarcas is a breccia with different lithologies that have experienced widely varying levels of parent body aqueous alteration. Some lithologies preserve abundant and large metal grains in chondrules and matrices with fine-grained textures that appear to have minimal amounts of alteration phases such as tochilinite or cronstedtite. We used FIB-TEM to explore whether Aguas Zarcas preserves amorphous silicate in these least altered lithologies.

Methods: A section of Aguas Zarcas, FMNH ME 6111.20, from a prerain specimen was polished with water-free isopropanol and diamond lapping film at the Field Museum of Natural History (FMNH) and stored in dry conditions in low vacuum. The section was first analyzed using Zeiss Evo 60 scanning electron microscopy (SEM) with an Oxford XMax 50 energy-dispersive X-ray spectroscopy (EDS) system at the FMNH to find suitable regions that may preserve pristine material. The area of interest was chosen from a fine-grained region of the interchondrule matrix (ICM) near adjacent to metal-rich chondrules and avoiding alteration phases (Fig. 1, top panel). An electron-transparent lamella was lifted out and thinned using a TESCAN LYRA3 FIB-SEM at the University of Chicago, and preliminary analysis was done using STEM-in-SEM mode at 30 kV (Fig. 1, bottom panel). Bright-field (BF) and dark-field (DF) imaging, selected area electron diffraction (SAED), and EDS was performed using a JEOL JEM-3010 at the University of Illinois at Chicago in order to confirm the presence of amorphous silicate and determine the chemistry of phases present.

Results: STEM imaging (performed at 30 and 300 kV) shows that the ICM material in fresh zones of

Aguas Zarcas contains material with morphological and chemical similarities to GEMS-like material described in other primitive CCs such as Paris. TEM-SAED confirms the presence of abundant amorphous silicate throughout the FIB section (Fig. 1, inset). The amorphous silicate contains numerous Fe- and S-bearing inclusions. Like that in Paris, the amorphous silicate is not found as distinct, individual objects like in IDP GEMS, but rather as a mostly continuous groundmass with porosity, containing predominantly course-grained and nanoscale sulfides as well as crystalline silicates.

As in Paris, the amorphous silicate has a fibrous texture in small areas throughout the section, suggesting low degrees of aqueous alteration. SAED shows that this fibrous material is mostly amorphous or has very low crystallinity. The smallest grain-size fraction (<10 nm) of nanoparticles seen in IDP GEMS are largely absent in both Paris and Aguas Zarcas. The oxygen-rich rims surrounding all Fe-rich nanoparticles in Paris are less evident in Aguas Zarcas (see 9 and Fig. 2).

Outlook: More FIB sections will be prepared from a range of petrographic settings from Aguas Zarcas with possibly different formation histories and varying degrees of aqueous alteration. We will also prepare FIB sections from fine-grained rims (FGRs) around chondrules to investigate their relationship to ICM. We will analyze the FIB sections at a JEOL JEM-ARM200CF aberration-corrected cold field emission scanning transmission electron microscope in order to conduct elemental mapping and nanodiffraction to assess the chemistry and mineralogy of the nanoscale phases in Aguas Zarcas. The aim is to assess the occurrence of the GEMS-like material and its chemical and mineralogical differences in order to assess the primary, preaccretionary history of this material and its alteration history on the parent body.

Acknowledgments: We thank Terry Boudreaux for donating Aguas Zarcas to the Field Museum, and Jennika Greer and Drew Carhart for mounting and polishing the sample. This work made use of the instruments in the Electron Microscopy Core of UIC's Research Resources Center. This work is supported through an NESSF fellowship award. We thank the TAWANI Foundation for funding the Robert A. Pritzker Center for Meteoritics and Polar Studies.

References: [1] Leroux H. et al. (2015) *GCA*, *170*, 247–265. [2] Bradley J.P. (1994) *Science*, *265*, 925–929. [3] Keller L. P. and Messenger S. (2011) On the origins of GEMS grains. *GCA, 75*, 5336–5365. [4] Keller L. P. et al (2009) *MAPS*, *44*, #5371. [5] Nittler L. R. et al. 2019 *Nat. Astron., 3*, 659–666. [6] Villalon K. L. et al. (2019) *MAPS*, *54*, #6475. [7] Ohtaki K. K. et al. (2020) *LPS*, *51*, submitted. [8] Meteoritical Bulletin Database. [9] Villalon K. L. et al. (2020) *LPS*, *51*, submitted.

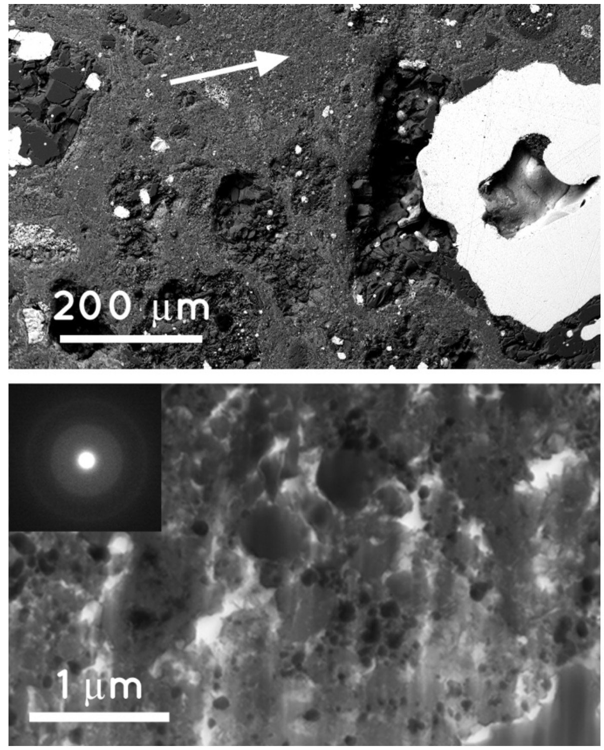

Figure 1: (Top) Backscattered electron (BSE) image of metal-rich, region in Aguas Zarcas. Arrow indicates fine-grained region of interest chosen for liftout. (Bottom) 30 kV BF STEM-in-SEM (BF) image of GEMS-like material in FIB section. (Inset) SAED pattern of amorphous silicate groundmass.

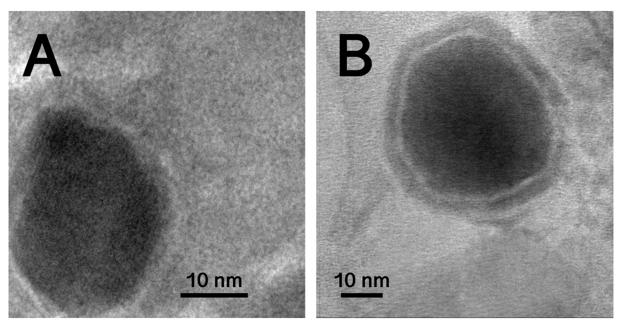

Figure 2: BF TEM images of nanoinclusion in (A) Aguas Zarcas and (B) Paris [see 9].