ELEPHANT MORAINE (EET) 83226: A CLASTIC, TYPE 2 CARBONACEOUS CHONDRITE WITH AFFINITIES TO THE CO CHONDRITES. N. M. Abreu[1], M. D. Louro[2], J. M. Friedrich[2,3], D. L. Schrader[4], and R. C. Greenwood[5]. [1]Earth Science Program, Pennsylvania State University, Du Bois Campus, Du Bois, PA 15801, [2]Department of Chemistry, Fordham University, Bronx, NY 10458, , [3]Department of Earth and Planetary Sciences, American Museum of Natural History, New York, NY 10024, [4]Center for Meteorite Studies, School of Earth and Space Exploration, Arizona State University, Tempe, AZ 85287 USA. [5]School of Physical Sciences, The Open University, Milton Keynes, UK.

Introduction: Many chondritic breccias are lithified asteroidal regoliths, containing clasts – rock fragments from different locations within an asteroid, or from other asteroids altogether that were mixed during asteroidal regolith gardening [1 and refs. therein]. Because clasts have very diverse origins, they provide inferences about their source asteroid and about the processes that pulverized and mobilized them [1 and refs. therein]. Breccias also record information about processes that affected the clast' host rock and because textural relationships have been established between clasts and hosts, a sequence of events can be pieced together. We have learned from breccias that asteroidal regoliths undergo partial to complete comminution into fine-grained particulates as a consequence of asteroidal collisions [e.g., 1]. The collisional events that drove comminution may have caused loses and redistributed volatiles and metals. Currently, we are only beginning to explore how collisions affect the volatile budget of meteoritic breccias, and by implication the volatile budget of asteroidal regoliths [e.g., 2]. One reason for this gap in our knowledge is the fact that we are only beginning to recognize the effects that impact events have on meteoritic volatile-rich materials (i.e., chondritic matrices). Here, we present preliminary observations of a highly clastic, aqueously altered carbonaceous chondrite, EET 83226, firstly to ascertain its classification and secondly to constrain the combined effects of brecciation and aqueous alteration.

Methods: We quantified the abundances of 43 elements in bulk samples of EET 83226 with ICPMS using the methods in [3-5]. To quantify the sizes of chondrules in EET 83226, we first imaged an entire thin section with BSE produced with an SEM. Within that image, we digitally identified the area of each individual chondrule and used the result to quantify a circle-equivalent-diameter for each chondrule. Chondrule rims were not included in these areas. A FIB section was prepared from a region of matrix, using a Helios NanoLab 660. This FIB section was examined using a Talos F200X. 300-second, EDS X-ray elemental maps where collected for the full FIB section and at higher magnifications for 4 selected regions for each FIB section. For each selected section, HAADF STEM, bright-field, and HRTEM images were collected.

Results: The bulk composition of EET 83226 compared with other carbonaceous chondrites can be seen in Fig. 1. EET 83226 has a bulk composition that places it nearest to the CV-CK clan of carbonaceous chondrites.

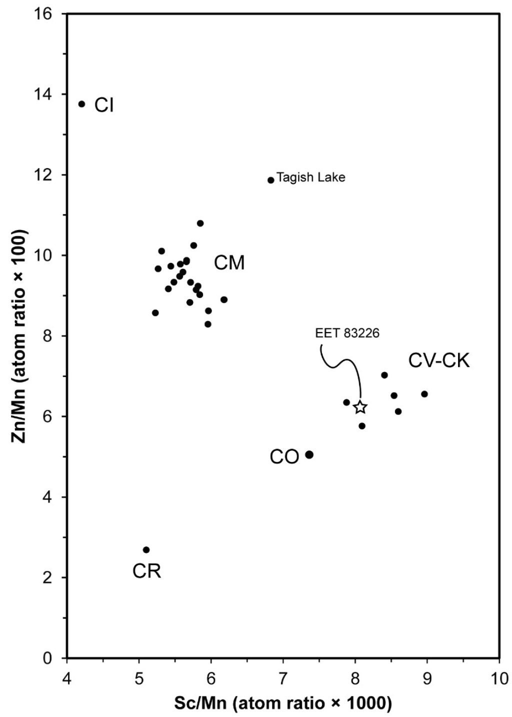

Fig. 1. Zn/Mn v. Sc/Mn atom ratios for various chemical groups and clans of carbonaceous chondrites. Plotting Zn/Mn v. Sc/Mn separates CC into similar compositions [9,10]. Chemical group and clan data from [11-14].

Chondrule sizes. The mean diameter of 809 objects identified as chondrules is 120 µm. There are known deficiencies with describing a 3D parameter using a 2D "slice" of a collection of particles [e.g. 6]. To correct for this, we used the algorithm and program presented in [7]. Using the unfolded stereological correction, the best estimate of the mean diameter from our histogram moves to 156 µm. Among the different groups of chondrites, EET 83226 has a mean diameter closest to that reported for CO chondrites [8]; although, [8] noted that CM chondrite chondrule diameters are poorly defined but are known to be only slightly larger in diameter than those of the CO chondrites.

Petrographic Texture. BSE images show that EET 83226 is made up of highly porous clasts (Fig. 2a). Clasts are often made up of chondrules and thick (>100 micron), fine-grained rims, fine-grained matrix, and mineral fragments. Abundance of secondary phases, such as tochilinite and framboidal magnetites is highly heterogeneous across the section (Fig. 2b).

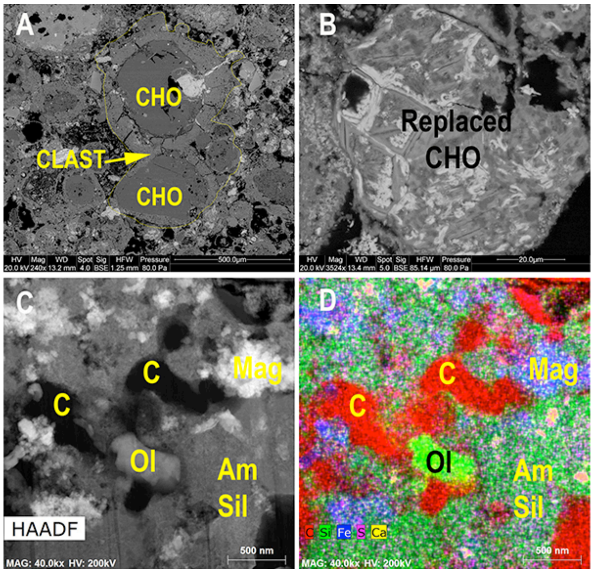

Fig. 2. Electron micrographs of EET 83226. (a) BSE of region containing a clast with several chondrules (CHO) and corresponding continuous, fine-grained rims. (b) BSE of a tochilinite and phyllosilicate-rich region that appears to have replaced a chondrule. (c) HAADF, Z-contrast of a region of matrix showing high abundance of carbonaceous matter (C), opaques including magnetites (mag), forsteritic olivine (Ol), and amorphous Fe-Mg silicates (Am Sil). (d) Overlay of EDS elemental maps from (c).

TEM Observations. EDS X-ray elemental maps reveal that EET 83226 matrix is mineralogical complex (e.g. Fig. 2c-d), containing framboidal magnetite, Ca-sulfates, materials with compositions similar to tochilinite-cronstedtite intergrowth (TCIs), and forsteritic olivine. In some occurrences, magnetites, Ca-sulfates and silicates are associated with sub-rounded carbonaceous materials. In other cases, rounded C-hotspots do not have mineral associations. Olivines are elongated, up to 1 micron in length, and show signs of strain and of partial replacement with short-range phyllosilicates. Most TCI-like materials are amorphous and intergrown with carbonaceous matter. Ni is decoupled from Fe and S. Ni occurs as blocky oxides. Some Ca-rich hotspots are not correlated with C, O, or S-enrichments.

Discussion: EET 83226 was originally classified as an ungrouped CC [15]. However, several studies grouped this meteorite with the CMs [e.g., 16]. In constrast, we found that EET 83226 has compositional affinities to the CV-CK clan and possibly with the CO chondrites. Chondrule diameters and matrix mineralogy are most consistent with its classification as an anomalous CO chondrite, which has been more extensively aqueously altered than other previously studied COs. A preliminary O isotope composition for EET 83226 also shows it plotting slightly to left of CCAM line i.e. away from CMs. Secondary mineralogy in EET 83226 has affinities with CM chondrites (e.g., presence of tochilinite and TCIs) and with CR and CI chondrites (presence of framboidal magnetite). Although it is clearly possible that the region analyzed is not representative of its bulk matrix, TEM observations also suggest that EET 83226 matrix is richer in organic compounds compared to typical CO chondrites. Therefore, EET 83226 appears to be more volatile-rich than typical CO chondrites.

Although BSE images of EET 83226 suggest that the sample has a high porosity, matrix measurements using a digitization technique estimate an 8% porosity [16]. [16] measured the porosities of another six CM2s, which ranged from 2-13% (average ~ 6 %) and the bulk porosity for two COs (4 & 8.3%) – indicating that the porosity of EET 83226 is relatively high, but not unusual for CMs or COs. The discrepancy between apparent porosity observed in SEM images and porosity measurements suggests that while some pores appear indigenous, some pores appear to result from plucking, possibily during sample preparation. It is possible that plucking was aggraviated by the fact that the sample may be very friable owing to its clastic nature. EET 83226 may represent a poorly consolidated asteroidal regolith.

Conclusions: Compositional and petrologic observations suggest that EET 83226 should be reclassified as an anomalous CO chondrite. Such classification suggests that the CO parent bodi(es) may have undergone some low temperature aqueous alteration. Our detailed petrologic observations suggest that EET 83226 represents a sample derived from a relatively poorly consolidated asteroidal regolith.

References: [1] Bischoff et al. (2006). *MESSII*. p.679-712. [2] Mahan et al. (2018) *GCA* 220, 19-35. [3] Friedrich et al. (2003) *GCA* 67, 2467-2479. [4] Wolf et al. (2005) *Analytica Chimica Acta* 528, 121-128. [5] Wolf et al. (2012) *Talanta* 100, 276-281. [6] Cruz-Orive (1983) *J. Microscopy* 131, 265–290. [7] Cuzzi & Olsen (2017) *MAPS* 52, 532-545. [8] Friedrich et al. (2015) *Chemie Erde* 75, 419-443. [9] Kallemeyn & Wasson (1981) GCA 45, 1217–1230. [10] Kallemeyn et al. (1994) *GCA* 58, 2873–2888. [11] Friedrich et al. (2002) *MAPS* 37, 677-686. [12] Moriarty et al. (2009) *Chemie Erde* 69, 161-168. [13] Noronha & Friedrich (2014) *MAPS* 49, 1494-1504. [14] Friedrich et al. (submitted) *GCA*. [15] Grossman *MAPS* 29 100-143. [16] Corrigan et al. (1997) *MAPS* 32, 509-515.