PALEOMAGNETISM OF THE ACAPULCO PRIMITIVE ACHONDRITE. E. N. Mansbach[1], B. P. Weiss[1], C. S. Borlina[1], E. A. Lima[1], [1]Department of Earth, Atmospheric and Planetary Sciences, Massachusetts Institute of Technology (MIT), Cambridge, MA, USA (mansbach@mit.edu).

Introduction: Primitive achondrites possess broadly chondritic compositions, but exhibit textures resembling igneous materials [1]. As a result, they are thought to be residues of partial melting on parent bodies that experienced incomplete silicate-metal differentiation [1]. It is uncertain whether primitive achondrites shared parent bodies with chondrites and/or achondrites [2,3].

One clan of primitive achondrites are acapulcoites and lodranites (ALs). Despite a variety of chemical, isotopic, and petrologic studies of ALs (e.g. [4–6]), the size and structure of their parent body remain poorly constrained. Recent modeling work [7] suggests the AL parent body was ~276 km in radius with a 130 km radius metal core, while other studies suggest the body could have been as small as ~35 km radius [8]. Additionally, the thermal history of the body is not well constrained, with reported cooling rates varying by orders of magnitude at similar temperatures [1].

To date, there has been no paleomagnetic study of ALs or any other primitive achondrite group. The detection of a magnetic record in ALs consistent with a planetesimal dynamo would imply an advecting, liquid metal core >40 km in radius [9]. In addition to providing information about the structure of the parent body, the identification of a dynamo would aid in constraining core formation times on small bodies by comparing the accretion time of the parent body to the time of magnetic remanence acquisition [10]. Here we present a paleomagnetic study of the Acapulco meteorite.

Methods: Acapulco was selected for study because it is the only known acapulcoite fall and so is essentially unweathered and unlikely to have been exposed to collectors' hand magnets [1]. Furthermore, like other ALs, it shows no evidence for shock (<5 GPa) [1].

The natural remanent magnetization (NRM) of Acapulco was studied via alternating field (AF) and thermal demagnetization of bulk samples and individual olivine and pyroxene grains containing <1 μm Fe-Ni metal blebs. The silicate grains resemble dusty olivine chondrules in chondrites that have been recognized to have reliably recorded the solar nebula field [11,12]. All paleomagnetic and rock magnetic measurements were conducted in the MIT Paleomagnetism Laboratory.

A transect of mutually-oriented bulk subsamples was cut from the fusion crust toward the meteorite's interior for a fusion crust test to determine if the interior had been remagnetized during or since atmospheric passage. AF demagnetization and magnetic measurements were made using a 2G Enterprises Superconducting Rock Magnetometer (SRM). Paleointensities were estimated using the anhysteretic remanent magnetization (ARM) method [13].

Dusty silicate grains > 2 mm from the fusion crust were extracted from a polished 200-μm thick section of Acapulco. Due to their weak NRMs (10^{-9} Am^{-2} before demagnetization), the grains were measured using the MIT superconducting quantum interference device (SQUID) microscope. Thermal demagnetization of dusty silicates was conducted in a controlled atmosphere at 2.3 log units below the iron-wüstite buffer [1] to prevent alteration during heating [14]. The compositions of Fe-Ni blebs in a dusty silicate were measured using wavelength-dispersive spectroscopy (WDS) and their sizes and shapes imaged using backscattered electron microscopy (BSEM).

Results: The NRM of the bulk samples is dominated primarily by ~100-800 μm FeNi metal grains. AF demagnetization of the bulk samples identified a low coercivity (LC_b, <5.5-17 mT) and high coercivity (HC_b, ~20-30 mT) component in all samples, with some samples also possessing a medium coercivity (MC_b, ~8-24 mT) component. The average LC_b components of the fusion crust and interior samples are i = 23.0°, d = 63.4°, MAD = 20.5° and i = 6.2°, d = 111.1°, MAD = 18.6° respectfully where i is inclination, d declination, and MAD is maximum angular deviation. Since the two groups of samples do not possess LC components that overlap within their uncertainties, the interior samples (>1 mm from fusion crust) were likely not remagnetized during atmospheric entry. The HC_b components are scattered, with an average direction of 136° from the mean and have a high average MAD of 36°. The low recovered NRM/ARM paleointensities (average 22 μT) and scattered directions of the interior samples suggest they were not fully remagnetized on Earth and therefore retain a pre-terrestrial magnetization.

Assuming the samples have a thermoremanent magnetization, then AF demagnetization of various ARM applications at different bias fields (e.g., [13]) suggests that the minimum field the ARM method can reliably retrieve from our bulk samples result is >70-200 μT over the HC_b range. The poor recording properties of the bulk samples are likely due to large metal grains in the sample, which are expected to be multidomain.

AF demagnetization of five individual dusty silicates identified a MC_s component that unblocked between 100 and 300 mT and an origin-trending HC_s component that unblocked between 300 and 900 mT

(Fig. 1). Prior to ~100 mT, four out of five samples did not exhibit any noticeable decay in magnetization intensity. The MC_s components for two samples lie within each others MADs but are scattered otherwise. No HC_s directions overlap within each other's MADs.

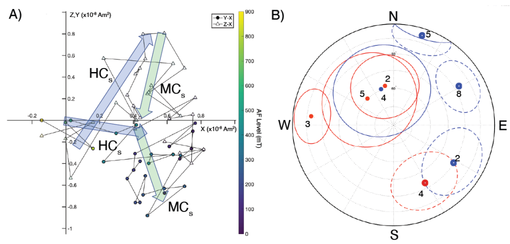

Fig. 1: A) AF demagnetization of an Acapulco dusty silicate. Closed symbols show *Y-X* projection of NRM moment and open symbols show *Z-X* projection. MC_s and HC_s identified with arrows. B) Equal area stereoplot showing directions of MC_s (red) and HC_s (blue) demagnetization components in Acapulco dusty silicate grains. Directions in the upper (lower) hemisphere are shown by the open (filled) circles. Number denotes subsample and ellipses represent the MAD for each component fit.

The HC_s component AF range is higher than that expected for <1 µm kamacite (<380 mT) [10]. However, it is consistent with µm-sized tetrataenite grains [15]. The presence of tetrataenite is supported by WDS, which identified a 50.5% wt. Ni grain abutting a kamacite grain containing ~4.5% Ni (Fig. 2). Thermal demagnetization of two dusty silicates showed a 66-75% decrease in NRM between 400°C and 550°C, consistent with the Curie temperature of 50% Ni-taenite [16]. No clear NRM components could be identified during the thermal demagnetization.

Discussion: The presence of tetrataenite in dusty silicates suggests Acapulco cooled slower than 1,000 °C Ma^{-1} during tetrataenite ordering around 320°C [17]. The constraint on Acapulco's cooling rate based on tetrataenite formation is in agreement with metallographic cooling rates between 350°C and 650°C, which mostly range from 100-1000 °C Ma^{-1} [1], although some reported metallographic cooling rates are significantly higher (10^5 °C Ma^{-1}) [1].

Because metal inclusions in dusty silicates were large enough and cooled slowly enough to partition into Ni-poor and Ni-rich regions (akin to Widmanstätten intergrowths), the NRM is likely a phase transformation thermochemical remanent magnetization. In one metal inclusion, some magnetization is acquired as kamacite exsolves continuously below its Curie temperature of 780°C, while another portion is acquired when tetrataenite orders at 320°C. How subsolidus kamacite growth would affect the magnetic remanence of the kamacite is not well understood [18]. Additionally, the only paleomagnetic analyses based on tetrataenite have been using nm-sized islands in the cloudy zone microstructure (e.g. [19]). The interpretation of µm-sized tetrataenite magnetization is not well understood.

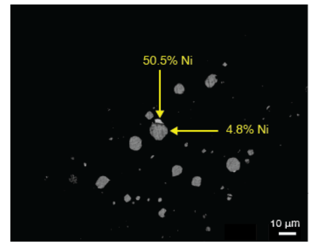

Fig. 2: BSEM image of a dusty silicate in Acapulco. Ni compositions determined using WDS.

Conclusions: Paleomagnetic analysis of the Acapulco primitive achondrite shows that bulk samples have low coercivities due to the prevalence of multidomain metal grains. Importantly, the interior has not been fully remagnetized and possesses a pre-terrestrial magnetization. We successfully extracted individual dusty silicates, and found they have higher coercivities with a mixture of < 1 µm kamacite and tetrataenite grains on the order of 1 µm. The presence of multiple metallic phases, which would acquire their NRM at different temperatures and therefore different times in parent body evolution, makes understanding their magnetic records challenging. We were unable to identify any stable NRM components consistent with formation in a planetesimal dynamo in the bulk samples or dusty silicates. However, the fine grain size and high coercivities of metal blebs in single silicate crystals means they should be capable of retaining high fidelity magnetic records over the history of the solar system.

References: [1]K. Keil, T.J. McCoy, (2018) *Geochemistry* ,**78**, 153–203; [2] B.P. Weiss, L.T. Elkins-Tanton, (2013) *AREPS*, **41**, 529–560; [3] C. Maurel *et al.*, (2020) *Sci. Adv.* ,**6**, eaba1303; [4] R.W. Bild, J.T. Wasson, (1976) *Mineral. Mag.* ,**40**, 721–735; [5] H. Palme *et al.*, (1981) *GCA*,**45**, 727–752; [6] T.J. McCoy *et al.*, (1996) *GCA*, **60**, 2681–2708; [7] W. Neumann *et al.*, (2018) *Icarus*, **311**, 146–169; [8] M. Touboul *et al.*, (2009) *EPSL*, **284**, 168–178; [9] B.P. Weiss *et al.*, (2010) *SSR*, **152**, 341–390; [10] J.F.J. Bryson, J.A. Neufeld, F. Nimmo, (2019) *EPSL*, **521**, 68–78; [11] R.R. Fu *et al.*, (2014) *Science*, **346**, 1089–1092; [12] C.S. Borlina *et al.*, (2021) *Sci. Adv.* ,**7**, eabj6928; [13] S.M. Tikoo *et al.*, (2012) *EPSL*, **337–338**, 93–103; [14] C. Suavet, B.P. Weiss, T.L. Grove, (2014) *GGG*, **15**, 2733–2743; [15] M. Uehara *et al.*, (2011) *EPSL*, **306**, 241–252; [16] J. Gattacceca, P. Rochette, M. Bourot-Denise, (2003) *PEPI*, **140**, 343–358; [17] R.J. Reisener, J.I. Goldstein, (2003) *MPS*, **38**, 1679–1696; [18] P. Wasilewski, (1974) *The Moon* ,**9**, 335–354;[19] C.I.O. Nichols *et al.*, (2020) *GGG*, **21**, e2019GC008798