CM CHONDRITES FROM THE LAPAZ FIELDS, LAP 04514, LAP 04527, LAP 04565, AND LAP 02333 AND THEIR AFFINITIES TO WEAKLY ALTERED CARBONACEOUS CHONDRITES. N. M. Abreu[1], A. K. Gianvito[1], J. L. Gray[2], K. Crispin[2]. [1] Earth Science, Penn State University – DuBois Campus, DuBois, PA, 15801, abreu@psu.edu, [2]Penn State, State College, PA, 16802.

Introduction: CMs are a group of primitive carbonaceous chondrites (CCs) that record substantial and variable degrees of aqueous alteration [e.g. 1-11]. The CMs are the most common and best studied group of CCs. However, mildly altered CMs remain scarce. CM materials have been extensively replaced by secondary phases in most CMs. Recent studies, most prominently of CM Paris (e.g. [7]), have begun to reveal these primary characteristics. As part of an ongoing study, we characterized four weakly altered, Antarctic, CM chondrites, LAP 04514, LAP 04527, LAP 04565, LAP 02333. In a preliminary study [12], we determined that LAP 04565 has an average $<Cr_2O_3$ (n=10)$>$ = 0.30 and σ_{Cr2O3}= 0.11, which corresponds to the range for petrologic type 3.05. We also argued that these samples show minor degrees of secondary alteration. Here, we present further SEM, EMPA, and TEM observations.

Methods: Na, Mg, Al, Si, Fe, Ni, Ti, Mn, P, S, Ca, and K, thin section-wide, X-ray maps were collected from full thin-sections from LAP 04565,6 and LAP 02333,28, using a Cameca SXFive electron microprobe. Representative regions of matrix using a FEI Helios NanoLab 660 FE-SEM/focused ion beam (FIB) workstation. The Helios is equipped with an Easy-LiftTM Nanomanipulator for easy extraction of TEM sections, Advance Process Monitoring Solutions that allow live SEM imaging during FIB extraction, and in-column simultaneous triple backscattered electron detectors. FIB sections were examined using a Talos F200X field emission gun (FEG) scanning TEM equipped with a high-speed camera and high speed EDS (Energy Dispersive Spectroscopy). All observations were conducted at Penn State's Materials Characterization Lab.

Results: Observations here are consistent with previous descriptions of other primitive CM chondrites. The modal abundances of objects in these chondrites are as follows: 21.2 vol.% type I chondrules, 2.0 vol.% type II chondrules, 1.2 vol.% CAIs, 13.6 vol.% tochilinite-cronstedtite intergrowth (TCI), 60.0 vol.% matrix and fine-grained rims, and 0.8 vol.% Fe-Ni sulfides.

Chondrules in all LAP samples showed no signs of chondrule phenocryst alteration. Type I chondrule phenocrysts have compositions within one standard deviation of Paris. The average fayalite (Fa), ferrosilite (Fs), and wollastonite (Wo) contents of chondrule phenocrysts for all samples are within one standard deviation from the values reported for Paris ($Fa_{0.9}$, s.d. 0.7 and $Fs_{2.3}Wo_{1.4}$, s.d. 1.7 and 1.3, respectively – [7]).

Chondrule metal appears to have been affected by terrestrial weathering.

Mesostasis is not very abundant and fine-grained and has been extensively replaced by phyllosilicates. In general, mesostasis in the LAP CMs is very Na-poor and if in contact with matrix, it is often included with nanophase Fe-sulfides.

The composition of TCIs in the LAP suite is FeO and S-rich, overlapping or plotting above the field for type 2.5 and 2.6 CMs. LAP 04565 has the most variable and the most FeO and S-rich compositions, plotting well above all other CMs.

Multi-layered, fine-grained rims, decorated with Fe-oxides are observed around some of the larger chondrules. However, most objects do not have rims.

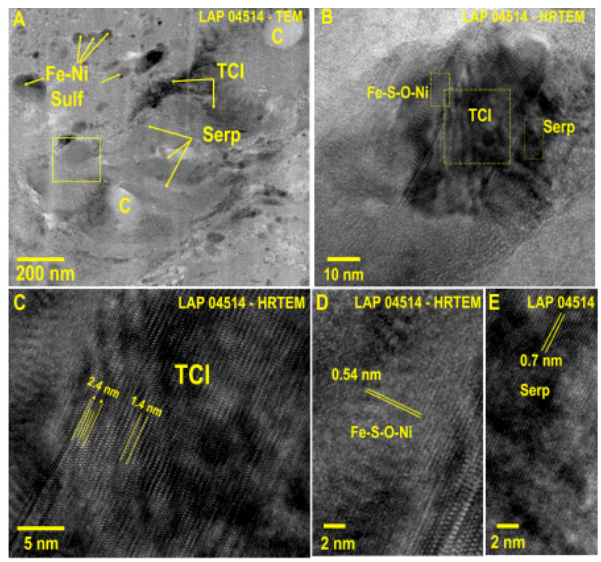

Fig. 1. Mineralogy of the LAP CMs. TCI= tochilinite-cronstedtite intergrowths.

As in other CM chondrites, the matrices in the LAP suite consist of tochilinite, PCP, feathery, fine-grained materials, and rims around larger objects (**Fig.** 1). These textures resemble those observed in CM Y791198 [3]. The oxide totals for fine-grained materials in LAP 04514, LAP 04527, and LAP 04565 are consistently higher for all three meteorites (~87.0 wt.%) compared with the totals for CM Paris (84.6 wt.%), suggesting similarly low degrees of matrix aqueous alteration.

These meteorites have high matrix Fe/Mg (3.6, 2.8, 3.3) compared to other CMs; however, their Fe/Mg ratio is lower than in Paris matrix (3.9). All elements for the LAP CMs are within one standard deviation from values for Paris "serpentine matrix." LAP 04514, LAP 04527, and LAP 04565 have high Fe/Mg (3.6, 2.8, 3.3, respectively) compared to other CMs; however, their Fe/Mg ratio is lower than in Paris matrix (3.9 – [7]). Elemental abundance patterns from the LAP CMs and Paris are relatively flat when normalized to Si and CI chondrites. All values are within one standard deviation of CI values with the exception of Fe in LAP 04514, which is enriched (1.8xCI).

FIB sections were extracted from matrix from the LAP CMs. HRTEM observations show that Fe-Mg phyllosilicates and Fe-Mg amorphous materials dominate silicates in the LAP CMs. Fe-Mg phyllosilicates have basal spacings and compositions consistent with serpentines, and thickness ~100nm. LAP 02333 phyllosilicates show clear foliation patterns. No signs of phyllosilicate dehydration were identified, which suggest if the LAP CMs were heated, their metamorphic temperatures remained below the domain represented by the group term "heated CMs" [e.g. 8-11]. Whereas all silicates in LAP 04565 appear to be hydrated, we found sub-rounded, 100-300 nm, defect-rich, Fe-Mg olivines, with no clear association with phyllosilicates in LAP 02333. It is likely that these olivines are fragments from chondrule olivines. However, it is also possible that these LAP 02333 olivines formed by thermal metamorphism of preexisting Fe-Mg phyllosilicates and/or Fe-Mg amorphous silicates. The dominant non-silicate phases in LAP 04565 and LAP 02333 are Ni-rich, Fe-sulfides, tochilinite, and Ca-carbonates. In LAP 04565, Fe-Ni sulfides are 5-10 nm in diameter. Fe-Ni sulfides are two orders larger in LAP 02333 – such increment is suggestive of thermally driven Ostwald ripening and consistent with LAP 02333 being heated more extensively.

Discussion: Based on the presence of unaltered chondrule phenocrysts, high oxide totals in matrix, presence of Fe-Mg amorphous silicates in matrix, composition of tochilinite, abundance of intact nanophase Fe-Ni sulfides, the LAP CMs appear to have undergone limited degrees of aqueous alteration. In particular, LAP 04565 shows textural, compositional, and mineralogical affinities with the least altered CMs, such as Paris and QUE 97990 [7,13].

Based on our previous observations [12], we suggest that the hallmarks of thermal metamorphism, such as the collapse of phyllosilicate and volatile losses (e.g., S and Na) were not observed in the fine-grained matrix materials in these meteorites. However, some thermal metamorphism cannot be fully ruled out at this stage, based on the relatively coarse size of Fe-Ni sulfides in matrices compared to other weakly altered carbonaceous chondrites that have not been heated, such as most of the CRs [14].

Fine-grained mineral assemblages are surprisingly similar, in terms of composition, grain size, mineral distribution and associations to other primitive CCs, such as those in CR chondrites [e.g., 14]. The LAP CMs do record signs of secondary alteration, including a record of the early stages of TCI formation. We suggest that these differences arrive from different temperatures, composition of altering fluids, and length of aqueous alteration. The composition of fluids may have been influenced by the size, abundance, and relative rates of replacement of other objects present in CC from different groups. The relative effect of T-t has been explored by authors studying O-isotopes in carbonates [e.g., 15, 16]. However, consensus has been reached.

Conclusions: Paired LAP 04514 and LAP 04527, as well as LAP 04565 are among the least altered CMs, belonging to petrologic type ~2.7 in the Rubin et al. (2007) scheme. Modal abundances of Fe-Ni metal as a classification parameter appears to have some limitations. Additional precursors for TCI in matrix are Fe-Ni sulfides, which is consistent with previous observations of alteration of sulfides in CR matrices. Organic-mineral associations in CMs are much more diverse than in other CCs. As observed by many authors, the matrices of primitive CMs share many characteristics with primitive CCs from other groups. Most differences in matrix mineralogy might be explained by differences compositions of altering fluids, their abundances, and duration of alteration.

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