UNDERSTANDING THE ORIGIN AND DISTRIBUTION OF PRIMARY PHASES IN CM CHONDRITES: WEAKLY ALTERED CMS FROM LAPAZ FIELDS, LAP 04514, LAP 04527, LAP 04565, AND LAP 02333.

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Introduction: CMs are a group of primitive carbonaceous chondrites (CCs) that have undergone substantial degrees of aqueous alteration [e.g. 1], potentially while in residence of an asteroidal parent body[e.g. 2-3]. While the mineralogy and petrology of CMs has been extensively studied [e.g. 1-7], we are only starting to learn about the primary characteristics of these meteorites, in particular, for materials that are highly susceptible to aqueous alteration, such as chondrule mesostasis, metal, and the fine-grained matrix. The reason for this lack of knowledge is the fact these materials have been extensively replaced by secondary (asteroidal) phases in most CMs. Recent studies, most prominently of CM Paris [7], have begun to reveal these primary characteristics. However, mildly altered CMs remain scarce. Here, SEM, EMPA, and TEM observations of three weakly-altered, Antarctic, CM chondrites, LAP 04514, LAP 04527, LAP 04565, and LAP 02333, which petrological characteristics have not been previously described in detail are presented. These meteorites are collectively termed as the "LAP CMs" hereafter.

Results: EPMA point analyses for Na, Mg, Al, Si, Fe, Ni, Ti, Mn, P, S, Ca, and K and compositional maps for Na, Al, Ca, S, Ni, and Cr were collected from matrix, Fe-Ni metal and chondrules from each of the four CMs listed above. STEM, TEM EDS X-maps, and HRTEM were conducted in FIB sections retrieved from the matrix of each meteorite.

Chondrules. Type I chondrules and chondrule fragments are most abundant. Ten type I chondrites were analyzed from each meteorite. The average Fa, Fs, and Wo contents of chondrule phenocrysts for LAP 04514 ($Fa_{1.0}$, s.d. 0.1 and $Fs_{3.0}Wo_{1.6}$, s.d. 1.7 and 1.0, respectively), LAP 04527 ($Fa_{1.8}$, s.d. 1.4 and $Fs_{3.7}Wo_{1.1}$, s.d. 2.7 and 0.5, respectively), and LAP 04565 ($Fa_{1.6}$, s.d. 1.6 and $Fs_{3.9}Wo_{1.6}$, s.d. 3.8 and 1.2, respectively) 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]). Multi-layered, fine-grained rims, decorated with Fe-oxides are observed around some of the larger chondrules. However, most objects do not have rims. Chondrule metal appears to have been affected by terrestrial weathering. Mesostasis is not very abundant and fine-grained. 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.

Matrix. The matrices of LAP CMs are lumpy mixtures of tochilinite, PCP, feathery, fine-grained materials, and rims around larger objects. These textures resemble those observed in CM Y791198 [3]. The average compositions of matrices are listed in **Table 1**, with the composition of CM Paris' "serpentine matrix" presented for comparison. The oxide totals for LAP 04514, LAP 04527, and LAP 04565 are consistently higher for all three meteorites (86.9%, 87.0%, 86.5% respectively) compared with the totals for CM Paris (84.6%), suggesting similarly low degrees of matrix aqueous alteration. 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).

One FIB section was extracted from matrix from each of the LAP CMs. Section-wide EDS maps indicate that all samples are very C-rich. C generally occurs as nanoglobules. The LAP CM matrices contain abundant, relatively large (50-700 nm), Ni-rich, Fe-sulfides, tochilinite, Fe-Mg phyllosilicates (0.7, 0.8, 1.1 nm basal spacings), Fe-Mg amorphous materials, and Ca-carbonates. Phyllosilicates and tochilinite have similar in occurrences to those described in Y-791198 [3]. Tochilinite has high S/SiO_2 compared with most CMs [i.e., 1]. Clusters of nanophase Fe-Ni sulfides are often embedded in amorphous C-O-bearing materials (**Fig. 1**). In some cases, these clusters also contain fibrous, Ca-carbonates. No Fe-Ni metal or Fe-oxides were observed in any of the FIB sections. Despite these similarities, textures and mineralogies are quite distinct in each meteorite. Fe-Mg amorphous silicates range in abundance (LAP 04565 > LAP 04514 > LAP 0233 > LAP 04527). Development of PCP and Fe-Mg phyllosilicates is most prominent in LAP 04527 matrix. Filamentous, partly oxidized sulfides up to 100s nm long connect rounded Fe-Ni sulfides. These Fe-S-

O-N grains are found embedded in randomly oriented phyllosilicates a few unit cells in thickness. It is noteworthy that carbonaceous materials are not associated with these very fine-grained PCP occurrences. Similar PCP occurrences are observed in LAP 04514; however, all phases are fine-grained compared to LAP 04527 matrix. Although the FIB section from LAP 04565 contains few phyllosilicates compared to the other LAP CM, coarser grained, well-faceted Ca-carbonates were present. Carbonates were often associated with partly oxidized sulfides. Fe-sulfides in LAP 04565 were generally fine-grained, elongated, and oriented along the direction of elongation.

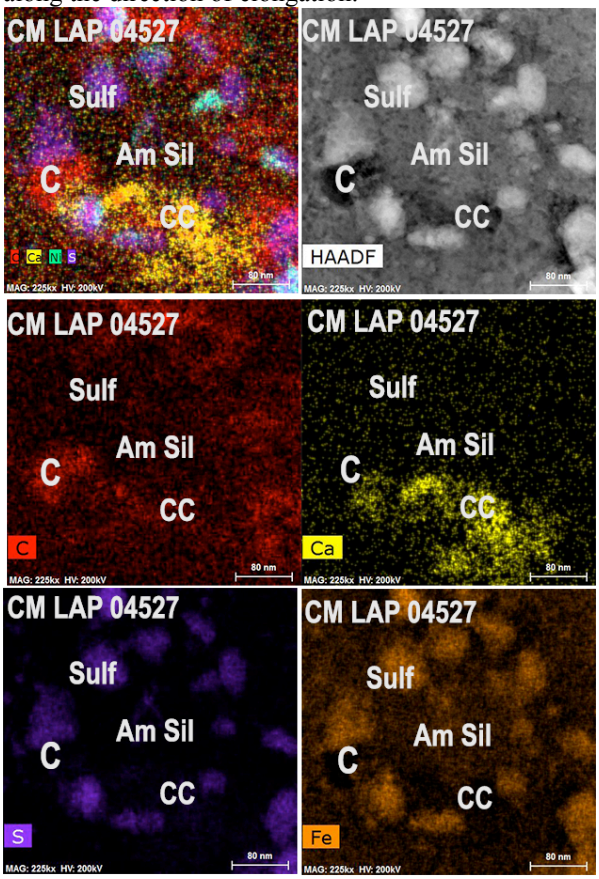

Fig. 1. TEM of Fe-sulfides embedded in C in LAP 04527.

Discussion: Field notes do not indicate that LAP 04514, LAP 04527, and LAP 04565 are paired. However, it is noted that these meteorites strongly resemble each other texturally and compositionally. 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 [7-8]. 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 [e.g., 9].

The low degree of secondary alteration allows us to place constrains on the distribution of carbonaceous materials in CM chondrites. Carbonaceous materials are dominated by nanoglobules, which is consistent with previous studies of CM chondrites [10]. When carbonaceous materials may also be found in association with Fe-Ni sulfides and Ca-carbonates. No association was observed between carbonaceous materials. PCP occurrences, and phyllosilicates. However, the LAP CMs do record signs of secondary alteration, including a record of the early stages of PCP formation.

Table 1. Averages (wt.%) and standard deviations for EMP, broad-beam (10um) analyses of CM matrices.

	LAP04514	**LAP04527**	**LAP04565**	**LAP02333**	**Paris***
	N = 98	N = 84	N = 87	N= 33	N= 20
Al_2O_3	2.7 *(0.6)*	3.1 *(0.4)*	3.1 *(0.4)*	3.7 *(3.0)*	2.9 *(0.7)*
CaO	0.6 *(0.9)*	0.9 *(1.0)*	1.1 *(1.2)*	0.9 *(2.2)*	0.5 *(0.3)*
TiO_2	0.1 *(0.0)*	0.1 *(0.0)*	0.1 *(0.0)*	0.1 *(0.0)*	0.1 *(0.0)*
MgO	13.7 *(4.6)*	15.3 *(1.5)*	13.6 *(2.5)*	13.7 *(1.8)*	14.3 *(2.6)*
SiO_2	24.1 *(5.8)*	27.1 *(2.2)*	26.9 *(2.3)*	25.9 *(3.0)*	27.2 *(2.8)*
MnO	0.2 *(0.1)*	0.2 *(0.1)*	0.2 *(0.1)*	0.2 *(0.0)*	0.3 *(0.1)*
P_2O_3	0.1 *(0.3)*	0.1 *(0.2)*	0.4 *(0.7)*	0.2 *(0.5)*	0.2 *(0.1)*
Na_2O	0.9 *(0.3)*	0.8 *(0.2)*	0.5 *(0.2)*	0.5 *(0.1)*	0.5 *(0.2)*
K_2O	0.1 *(0.0)*	0.1 *(0.0)*	0.1 *(0.0)*	0.1 *(0.0)*	0.1 *(0.0)*
Ni	1.5 *(0.6)*	1.7 *(0.6)*	2.0 *(0.7)*	2.2 *(0.4)*	1.9 *(0.7)*
FeO	38.6 *(10.2)*	33.6 *(3.8)*	34.8 *(3.5)*	31.6 *(3.5)*	33.7 *(5.6)*
S	4.3 *(2.1)*	3.8 *(1.0)*	3.5 *(1.0)*	3.8 *(0.9)*	3.0 *(1.0)*
Total	86.8 *(2.1)*	87.0 *(2.0)*	86.5 *(2.9)*	83.2 *(2.8)*	84.6

*CM Paris "Serpentine Matrix" from [7].

Conclusions: Indicators of aqueous alteration and thermal metamorphism show that LAP 04514, LAP 04527, LAP 04565, and LAP 02333 have undergone limited, yet measurable degrees of secondary alteration comparable to the least altered CMs in our collections.

References: [1] Rubin et al. (2007) GCA 71, 2361–2382. [2] Hanowsky & Brearley (2001) GCA 65, 495-518. [3] Chizmadia & Brearley (2008) GCA 72, 602-625. [4] Metzler et al. (1992) GCA 56, 2873-2897. [5] Zolensky et al. (1993) GCA 57, 3123-3148. [6] Zega et al. (2003) Am Min 88, 1169-1172. [7] Hewins et al. (2014) GCA, 124, 190-222. [8] Brearley (2016) *LPI Contribution No. 1921*. [9] Abreu (2016) GCA 194, 91-122. [10] Changela (2015). GCA 159, 285–297.