# THERMAL METAMORPHISM IN THE CM PARENT BODY – EVIDENCE FROM WEAKLY ALTERED CM CHONDRITES LAPAZ ICEFIELD 04565 AND 02333

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**Introduction:** CMs are primitive carbonaceous chondrites (CCs), which mineralogy and petrology has been extensively studied [e.g. 1-11]. Most CMs record substantial degrees of aqueous alteration [e.g. 1-6]. In addition, some CMs underwent substantial degrees of thermal metamorphism. Thermal metamorphism of CMs resulted in low $H_2O$ and C contents, as well as partial dehydration of matrix phyllosilicates [e.g. 8-11]. In addition to altered CMs, several weakly altered CMs have been identified, in which many nebular features may be preserved. Most prominently, CM Paris reveals some of these pre-accretionary features that therefore sheds light on the initial characteristics of the CM parent body(s) and on solar nebular processes [e.g., 7]. Recently we identified four other weakly-altered CMs, LAP 04514, LAP 04527, LAP 04565, and LAP 02333 [12]. As part of ongoing investigations of the mineralogical characteristics of most primitive CCs, we explore to what degree two of these samples, LAP 04565 and LAP 02333 have been affected by thermal metamorphism. LAP 04565 was selected for further analysis because it contains the fewest Fe-Mg phyllosilicates and most amorphous silicates of the four LAP CMs. LAP 02333 was selected because its matrix had the lowest oxide totals, suggesting that it is possibly the most aqueously altered among them [12].

**Results and Discussion:** 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. STEM, TEM EDS X-maps, and HRTEM were collected from FIB sections retrieved from the matrix of each meteorite using a Talos F200X. All observations were conducted at Penn State's Materials Characterization Lab.

To evaluate the extent of thermal metamorphism, the average $Cr_2O_3$ content and standard deviation were measured in fayalitic olivines from type II chondrules/type II chondrule fragments following the method developed by [13]. For LAP 04565, the average is $\langle Cr_2O_3\ (n=10)\rangle = 0.30$ and $\sigma_{Cr2O3} = 0.11$, which corresponds to the range for petrologic type 3.05. For LAP 02333, the average is $Cr_2O_3\ (n=6)\rangle = 0.24$ $\sigma_{Cr2O3} = 0.06$, corresponding to type >~3.1. Therefore, LAP 04565 records similar degrees of thermal metamorphism as Paris and QUE 97990 [e.g., 14], while LAP 02333 has been heated more extensively than other weakly altered CMs. We plan to use other thermal metamorphism indicators (e.g. characteristics of Fe-Ni metal and sulfides) to confirm this classification. However, preliminary analyses of thin section-wide, X-ray maps indicate that Fe-Ni metal is extremely rare in both of these meteorites.

TEM observations show that LAP 04565 and LAP 02333 matrices contain abundant, relatively large (50-700 nm) phases. Fe-Mg phyllosilicates and Fe-Mg amorphous materials dominate silicates in both meteorites. Fe-Mg phyllosilicates have 0.7, 0.8, 1.1 nm basal spacings, compositions consistent with serpentines, and thickness ~100nm. Moiré patterns, which may have resulted from deformation, are common. LAP 02333 phyllosilicates show clear foliation patterns, which may have been imparted by the same process that drove its thermal metamorphism. However, no signs of phyllosilicate dehydration were identified, which suggest heating at temperatures 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 02333being heated more extensively.

**Conclusions:** LAP 02333 shows signs of both more extensive aqueous alteration [12] and thermal metamorphism than LAP 04565. Based on petrologic observations, commonalities among weakly altered CMs are beginning to emerge. CMs described here share petrologic similarities with other weakly altered CMs [e.g., 3,7,14], including the presence of Fe-Mg amorphous silicates and signs of mild thermal metamorphism, comparable to low-petrologic type 3 chondrites.

**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] Akai (1988) *GCA* 52: 1593–1599. [9] Ikeda & Prinz (1993) *GCA* 57: 439–452. [10] Hiroi et al. (1996) *MAPS* 31: 321–327. [11] Tonui et al. (2014) *GCA* 126: 284-306. [12] Abreu et al. (2017) *LPS XLVIII*, Abstract #2935. [13] Grossman & Brearley (2005) *MAPS*: 40, 87–122. [14] Schrader & Davidson (submitted) *GCA*.