**THE PARENT BODIES OF CR CHONDRITES AND THEIR SECONDARY HISTORY.** T. J. Prestgard[1], P. Beck[1], L. Bonal[1], J. Eschrig[1], L. Krämer Ruggiu[2], J. Gattacceca[2]. [1]Institut de Planétologie et d'Astrophysique de Grenoble – Université Grenoble Alpes, CNRS (Grenoble - France). [2]CEREGE - Aix Marseille University, CNRS (Aix-en-Provence, France). (trygve-johan.prestgard@univ-grenoble-alpes.fr)

**Introduction:** The CR chondrite group is special as its members appear to have suffered a large diversity of secondary processes, whether it be aqueous alteration or thermal metamorphism [1]. However, the vast majority tend to be highly primitive, having experienced only incipient aqueous alteration and minor thermal processing [2, and references therein]. This makes them excellent targets when it comes to studying the composition of early Solar System material. However, mineralogical-based petrographic grading has proven challenging, especially in the more primitive members [3]. Interestingly, the asteroidal analogues of CRs remain a mystery. The challenge being that reflectance spectra of CRs do not match those recorded for minor planets [4]. This is at least partly because terrestrial weathering quickly contaminates spectra with oxyhydroxide signatures that overlap those of the meteorite's silicate mineralogy [4]. In an attempt to overcome these challenges, we have studied a suite of CRs using IR transmission spectroscopy, and obtained reflectance spectra of CRs that have been acid leached (to remove oxyhydroxides present in the samples).

**Method:** The transmission spectra of bulk samples were obtained using a Vertex Bruker v70 FTIR spectrometer at IPAG. The samples were in the form of KBr "pellets", prepared following the protocol described by [5]. The leaching process was conducted at CEREGE following the protocol of [6]. The reflectance spectra were measured at IPAG using the SHADOWS instrument (protocol by [7]). The samples were in the form of an assorted sub-millimetric powder, meant to assimilate asteroidal regolith. Petrographic grades of CR2s are from [2].

**Results:** The spectral properties of our CRs appear to be controlled by their secondary history:

*IR Transmission of bulk samples.* Most CR2 spectra are dominated by signatures consistent with pyroxene and olivine. These include most notably the primitive (CR2.7-2.8) chondrites, as well as LAP 04720 (listed as CR2.4). Renazzo and MIL 090001 (both CR2.4) show strong signatures at 10.0-µm which are due to hydrated silicates. Similar (but much weaker) signatures are also detectable in LAP 02342 and LAP 04720. The spectrum of GRO 95577 is completely dominated by hydrated silicates, consistent with its type-1 petrographic grade. Heated CRs such as GRA 06100 [8] and NWA 12474 [9] show stronger olivine signatures than primitive CRs. DOM 10085, although not described as heated in the literature, is significantly shocked [9] and has a similar spectral profile to GRA 06100 and NWA 12474. GRO 17060 is peculiar in only containing enstatite signatures.

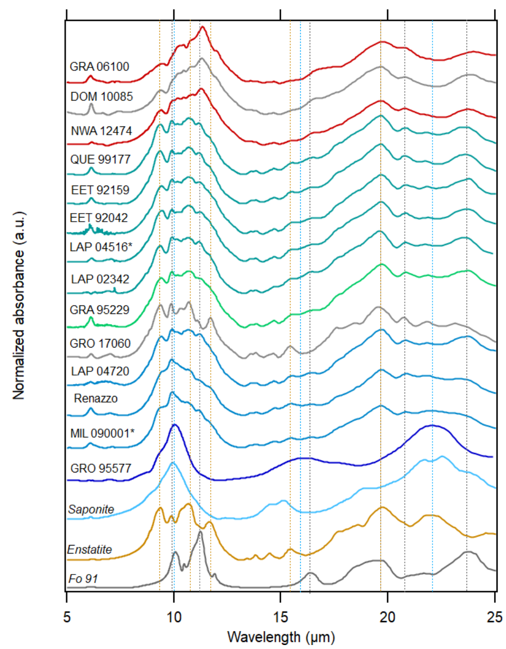


**Fig. 1.** IR transmission spectra of 14 bulk CR chondrites, and three reference minerals. The color of the spectra corresponds to their petrographic grades by [2]: CR2.8 (turquoise), CR2.7 (green), CR2.4 (light blue), CR1/2.0 (dark blue), heated (red), grey (unassigned). The dashed vertical lines annotate spectral signatures of enstatite (brown), olivine (grey) and hydrated silicates (blue). (*) spectra were measured of leached powders. Offset has been added for clarity. The spectra of LAP 02342 and GRO 95577 are from [5].

*Reflectance spectra of leached CRs.* From 500 – 2400 nm reflectance spectra, we note the presence of various absorption bands in CR2s: 700 nm, 900 nm, and 1800 nm. The first is most likely associated with phyllosilicates such as serpentine and/or chlorite (known to be present in CRs [2 and references therein]). We suggest that the two remaining bands (which are significantly broader) are linked to pyroxene, which are abundant in CRs (e.g. Fig. 1). The small 900 nm band in GRO 95577 is also due to phyllosilicates. Most CR2s are noticeably red-sloped, which could be consistent with their metal and serpentine/chlorite content. LAP 02342 and LAP 04516 are significantly more neutral-sloped, with a slightly more pronounced 900 nm bands. We also note that the average VNIR reflectance broadly decreases with petrographic grades: CR2.7-2.8s >

CR2.4s > CR1. The spectrum of GRO 17060 is peculiar, due to its relatively low reflectance and its resemblance to some mildly altered CM2s [10], despite the strong pyroxene signatures in Fig. 1.

The 3000 nm region of most leached CRs have broad bands that resemble Fe-rich phyllosilicates (peak at ~2800 nm). The exceptions are GRO 95577, QUE 99177, LAP 02342 and LAP 04516. The first one is sharper and peaks at lower wavelength, thus indicating Mg-rich phyllosilicates. The remaining three are rounder, perhaps indicative of an average hydrated silicate content of lower crystallographic order. Indeed, the amorphous content relative to phyllosilicates was found to be significantly higher in LAP 02342 compared to various other CR2s (Table 5, [3]).

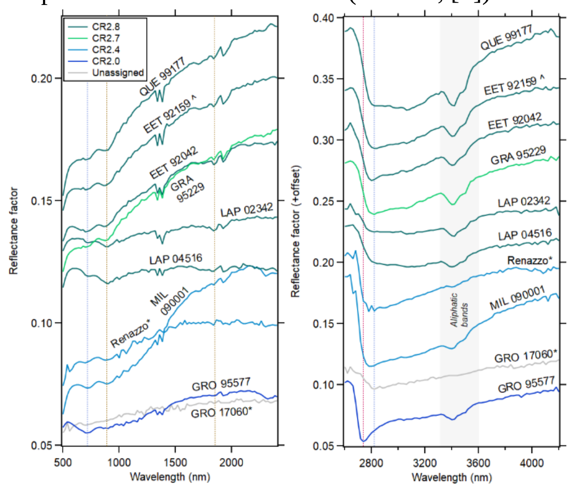


**Fig. 2.** Reflectance spectra of 10 CR chondrite powders. Left: Dashed blue and brown lines denote serpentine and pyroxene bands respectively. Right: Blue and pink lines denotate Fe-rich and Mg-rich phyllosilicates, respectively (offset added for clarity). All samples have been leached, with the exception of those marked with an asterisk (*).

**Discussion:** We believe that the overall decrease in VNIR reflectance with aqueous alteration can be explained by the progressive transformation of metal into magnetite. Based on our spectra, and considering that primary anhydrous silicates (amorphous and crystalline) transform into phyllosilicates with increasing aq. alteration [2,11], we currently suggest the following order of hydration: QUE 99177, LAP 02342, LAP 04516 > EET 92042, 92159, GRA 95229, GRO 17060(?) > Renazzo, MIL 090001 >> GRO 95577. LAP 04720 is probably less hydrated than Renazzo based on its transmission spectrum. DOM 10085 is likely to be significantly heated. Based on its shocked nature [9], we tentatively suggest the heating event to have been impact-induced (like for GRA 06100 [8]) rather than long-term (as was the case of NWA 12474 [9]). GRO 17060 is potentially not a CR chondrite based on its distinct spectral properties.

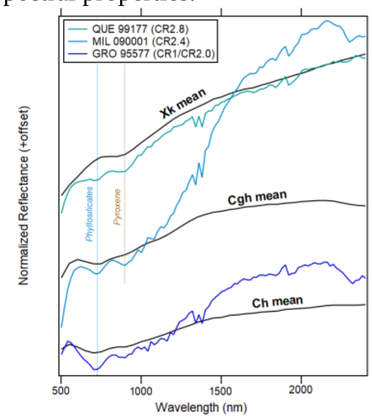


**Fig. 3.** Normalized reflectance spectra compared to various asteroid spectral types. CR2s display Xk-Cgh-type traits and CR1s are Ch/Cgh-like. Offset has been added for clarity.

Based on a comparison with mean minor planet spectral types ([12]. Fig. 3), it is possible that CR2s could stem from asteroids with mixed spectral features of the Xk and Cgh spectral type. Primitive (CR2.7-2.8) CR2s are generally more Xk-like compared to moderately hydrated ones (CR2.4s), which resemble more Cgh-type spectra. We can possibly interpret this as the CR "starting material" having been Xk-like, and, with increasing aqueous alteration (i.e. increase in phyllosilicates such as serpentine and chlorite), the spectra evolved towards more Cgh-like profiles. GRO 95577, the only CR1, resembles Ch/Cgh asteroids. LAP 02342 and LAP 04516 are exceptions: their neutral NIR slope and slightly lower NIR reflectance than other primitive CRs may perhaps indicate that they stem from asteroids with a slightly lower bulk abundance of metal. The interpretations are interesting, seen that Xk-type spectra also match that of a CH3 [6]. This means that Xk-type asteroids may be parents of relatively primitive and reduced carbonaceous chondrites.

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**References:** [1] Abreu N. M. et al. (2020) *Geochem*., 80, 4, 125631. [2] Harju E. R. et al. (2014) *GCA*, 139, 267–292. [3] Abreu N. M. et al. (2016) *GCA*, 194, 91–122. [4] Cloutis E. A. et al. (2012) *Icar*, 217, 389–407. [5] Beck P. et al. (2014) *Icar*, 229, 263–277. [6] Krämer Ruggiu L. et al. (2021) *Icar*, 362, 114393. [7] Eschrig J. et al. (2021) *Icar*, 354, 114034. [8] Briani L. et al. (2013) *GCA*, 122, 267–279. [9] Meteoritical Bulletin Database. [10] Potin S. et al. (2020) *Icar*, 348, 113826. [11] Le Guillou C. et al. (2015) *E&PSL*, 420, 162-173. [12] DeMeo F. E. et al. (2009) *Icar*, 202, 160-180.