CHEMICAL AND PETROLOGIC EVIDENCE OF EXTENSIVE AND COMPLEX AQUEOUS ALTERATION OF CR GRA 06100.

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Introduction: Although some CR chondrites are recognized to be among the most pristine meteorites [1], other members of this group are heavily hydrated [e.g. 2]. However, no evidence of thermal metamorphism has been documented for this group. Antarctic fall GRA 06100, initially classified as a CR2 chondrite have not been previously studied. We use optical microscopy, SEM, and focused beam EPMA to study GRA 06100, in order to shed light on the advanced stages of alteration history in the CR parent body.

Results: Two petrographic thin sections were prepared from sample GRA 06100.6. Although GRA 06100 has been assigned weathering type B, neither section shows significant signs of terrestrial alteration, such as rust staining or networks of ferryhydrite veins. Therefore, we suggest that the bulk of the aqueous alteration recorded by this meteorite is not terrestrial.

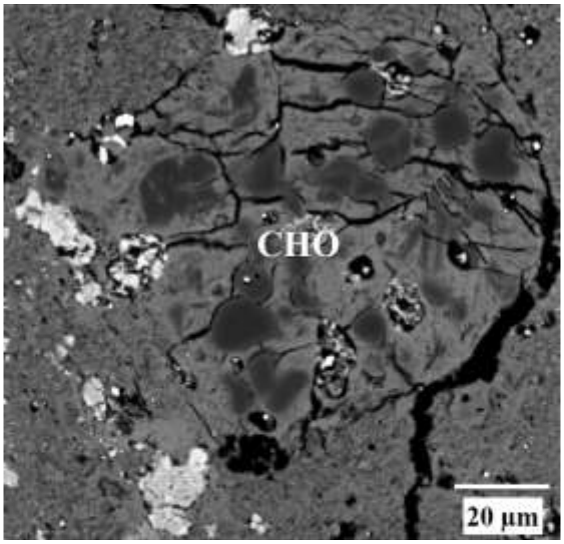

Fig.1. BSE image of altered chondrule.

Chondrules. GRA 06100 contains abundant, mm to µm, type I and type II chondrules, containing olivine, low Ca- and high Ca- pyroxenes. Chondrules show variable degrees of textural and chemical integration with the surrounding matrix [e.g. Fig. 1]. In some cases, small chondrules (<100µm diameter) are not readily distinguishable from the matrix. Small type I chondrules are rare. The edges of forstertite grains have been pseudomorphically replaced by Fe-rich, Al-bearing silicates that have low analysis totals (96-98 oxide wt%), which sugest partial hydration. Furthermore, olivines often contain irregularly shaped voids. Mesostasis has only been identified in the larger chondrules and appears as greenish-brown fibrous masses in optical micrographs. Although these masses have textures consistent with phyllosilicates, they are significantly O-deficient, Na-poor with average composition $(Fe,Mg,Ca,Na,Mn,Cr,P,Ni)_{6.13}(Si,Al)_{4.18}(O,OH)_{14}$, which is most consistent with chlorite.

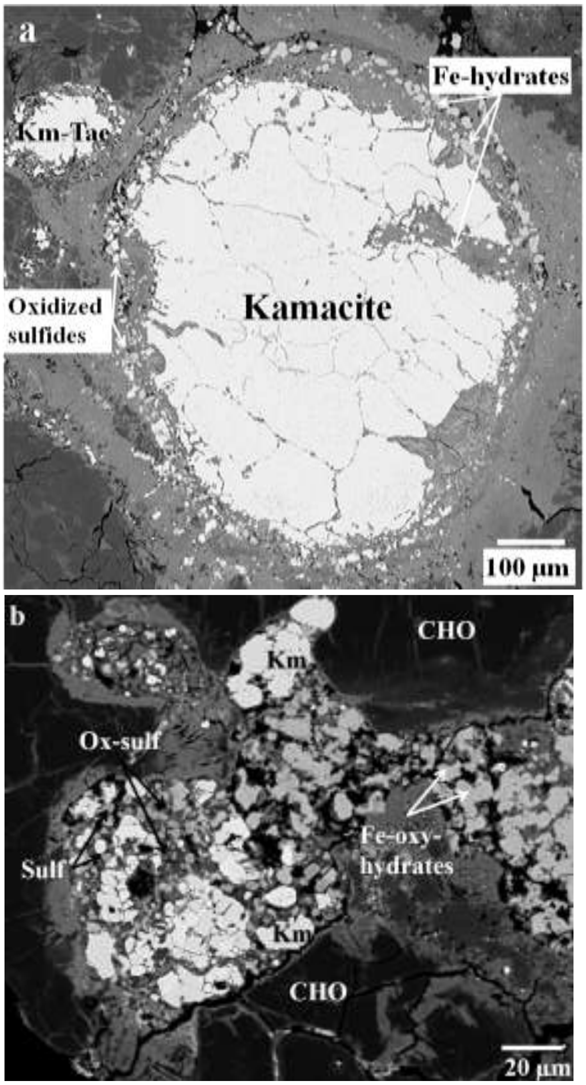

Fig.2. BSE image of kamacite grains. (a) Large, independent grain with embayments. (b)relic kamacite surrounded by Fe-hydrates, sulfides, and oxidized sulfides embedded in an altered type I chondrule.

Opaques. One stricking characteristic of GRA 06100 is the texture and composition of its abundant opaque nodules, which occur independently [Fig.2a] or in association with chondrules [Fig.2b]. Thirteen large

(<800 µm diameter) kamacite grains with average composition $Fe_{0.938}Ni_{0.057}$ and two taenite grains with composition $Fe_{0.854}Ni_{0.146}$ were studied using EPMA. These grains have wavy surfaces with numerous embayments [Fig. 2a]. Located within these embayments are numerous Ni-bearing Fe-oxyhydrates, Fe-sulfides, and partially oxidized Fe-sulfides. Three different groups of Fe-oxyhydrates have been observed, Ni-poor (< 0.5 wt% Ni), intermediate Ni (~4 wt% Ni), and Ni-rich (~13wt%). Sulfides have an average composition of $Fe_{1.001}$ $Ni_{0.002}$ S, which is very similar to that observed in CI chondrites [3]. Finally, oxidized sulfides are significantly more O-rich than toichilinite and contain only trace amounts of Mg. However, they are O-deficient relative to szomolnokite. Although, sulfates of different composition have been observed in CI chondrites [4], they have not been previously identified in CR chondrites. Pentlandite has not have not been observed. Smaller nodules often found on the periphery and the interior of chondrules [Fig. 2b] show granular textures consistent of rounded and irregular oxides, sulfides, and oxidized sulfides with similar compostions to those found around larger nodules. These grains are often surrounded by fine-grained ferryhydrite [Fig. 2].

Matrix. GRA 06100 contains aboundant, silicate-rich, fine-grained matrix that shows no textural association with chondrules (i.e. no rims). No dark inclusion, or matrix clasts have been identified.

Discussion: GRA 06100 has petrographic affinities with the CR group, such as the presence of abundant Fe-Ni metal rich type I chondrules. However, unlike most CR chondrites, small type I chondrules are rare, and rims around chondrules and dark inclusions are absent in this meteorite. Additionaly, the texture and composition of opaque assemblages in GRA 06100 are distinct from those observed in other members of this group. Based on our observations, we suggest that these differences may originate from secondary alteration of a CR chondrite under very different conditions from those previously reported for this group [e.g. 2].

GRA 06100 shows clear signs of extensive aqueous alteration, such as the absence of intact mesostasis, which has been replaced by a Na-poor silicate (potentially chlorite), as observed in other altered CR chondrites [5,6] and partial to complete oxidation of Fe-Ni metal and Fe-sulfide grains similar to that described in CI chondrites [4].

Although all these characteristics are strongly indicative of alteration by a fluid, the hydration style of GRA 06100 differs significantly from reports from other extensively altered CR chondrites such as CR1 GRO 95577. For example, all phases in GRO 95577 have been fully hydrated [2], whereas GRA 06100 contains nearly anhydrous and O-deficient silicates in its chondrules. Secondary phases have pseudomorphically replaced chondrules and metal grains in GRO 95577 [2]. In contrast, the boundaries between chondrules and matrix in GRA 06100 are often very diffuse. In GRO 95577, metal grains have been replaced by magnetite, leaving an embedded relic grain. While this type of texture has been observed, GRA 06100 opaque nodules have a much more complex secondary mineralogy. Discrete grains often fully replace the metal, preserving only the outline of the precursor crystal. Finally, GRA 06100 may contain sulfates.

The presence of nearly anhydrous and O-deficient secondary phases is ubiquitous in GRA 06100. Such deficiency has been observed in chondrites with a history of hydration and subsequent heating (e.g. unique chondrite Y-82162 – [7]). It is possible that a thermal metamorphism event post-dating aqueous alteration is responsible for the O-deficiency recorded in phyllosilicates and potential sulfates, the diffuse boundaries between chondrules and matrix, and potential textural homogenization of the matrix resulting in the lost of rims and dark inclusions in GRA 06100. This suggestion is supported by high analytical totals of secondary phases, the presence of voids within chondrule olivines, which may have been created by volume changes due to dehydration, and the presence of small relics type I chondrules distributed throughout the matrix suggesting that they were present and subsequently lost. However, this possibility needs to be carefully investigated, as other CR chondrites show little or no evidence of thermal metamorphism.

Complete replacement of metal grains in GRA 06100 by a variety of secondary phases could be explained by localized hydration with a particularly oxidizing fluid. This event may have occurred after formation of the Fe-sulfides to which the putative sulfates are closely spatially associated [Fig. 2]. [4] experimentally investigated the oxidation of troilite by O-saturated water at 25°C and suggested that sulfates such as the ones found in CI chondrites may form within a year. The action of such a corrosive agent could probably result on the extensive alteration of metal observed in GRA 06100.

References: [1] Abreu N. M. & Brearley A. J. (2006) *LPS XXXVII*, Abst. # 2395. [2] Weisberg M. K. & Huber H. (2007) *MAPS, 42,* 1495-1503 .[3] Bullock E. S. et al. (2005) *GCA*, 69, 2687-2700. [4] Lewis (1967). [5] Weisberg M. K. et al. (1993) *GCA*, 57, 1567-1586. [6] Burger P. & Brearley A. J. (2004) *LPS XXXV*, Abst. # 1966. [7] Tomeoka K. et al. (1989) *Proc. NIPR Symp. Antarct. Meteorites*, 2, 36-54.