MODAL MINERALOGY OF CV3 CHONDRITES BY PSD-XRD: MINERALOGIC INSIGHTS INTO A COMPLEX EVOLUTIONARY HISTORY.

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Introduction: CV3 chondrites are samples of texturally heterogeneous primitive asteroids. The complex evolutionary history of these meteorites is reflected in a diverse mineralogy. CV3 samples are divided into reduced ($CV3_{red}$) and oxidized groups ($CV3_{oxA}/CV3_{oxB}$) on the basis of the relative abundance of metal and magnetite, determined optically, and the Ni content of sulphide [1,2]. Despite being some of the most studied rocks in existence, the modal mineralogy of CV chondrites has -prior to this work - not been quantitatively defined. We study large bulk powdered samples ($180mm^3$/~0.25g), and using PSD-XRD and a pattern stripping technique [3,4], determine a complete modal mineralogy for all phases present in abundances greater than 1wt% in Vigarano ($CV3_{red}$), Efremovka ($CV3_{red}$), Allende ($CV3_{oxA}$), Mokoia ($CV3_{oxB}$), Grosnaja ($CV3_{oxB}$) and Kaba ($CV3_{oxB}$).

Results: Reduced CV3 samples are comprised of (vol%): olivine (83-85%); enstatite (6.5-8.1%); plagioclase (1.1-1.2%); magnetite (1.4-1.8%); sulphide (2.4-5.1%); Fe-Ni metal (2-2.2%). The oxidized samples are comprised of: olivine (76.3-83.9%); enstatite (4.8-7.8%); plagioclase (1.1-1.7%); magnetite (0.3-6.1%); sulphide (2.9-8.1%); Fe-Ni metal (0.2-1.1%); Fe-Oxide (0-2.7%) and phyllosilicate (1.9-4.2%). Using our modal data to calculate an estimate of bulk chemical composition results in values that are typically within 1-3% of measured literature values.

XRD data show that olivine may span almost the entire Fe-Mg solid solution series in all CV samples [Fig.1]. XRD reveals that all of the studied CV3 samples contain a component (4-13%) of fine-grained olivine that is more fayalitic (>Fa60) in composition than is typically reported [5,6; Fig.1]. Such Fe-rich olivine compositions have previously been reported only for a few analyses in the oxidized CV samples Kaba and Mokoia but are known to commonly exist in the reduced Efremovka, a meteorite that is typically regarded as the least equilibrated CV [5,6,10]. This suggests that olivine compositions in CV3 meteorites are less equilibrated, and therefore CV3 chondrites are even more chemically primitive, than previously recognised. Significantly, by XRD Allende remains the most equilibrated sample, and Efremovka the least. In the case of Allende this may indicate thermal metamorphism and equilibration of olivines as suggested previously [5].

Modal mineralogy supports the classification of CV3 samples into the reduced and oxidized subgroups that have previously been defined by optical studies of the coarser grained components. This indicates that fine grained matrix mineralogy is consistent with the mineralogy of the coarse grained components, at least in terms of the relative abundances of magnetite and metal.

Deriving a complete modal mineralogy allows grain density to be calculated using the well-known densities of the consituent phases. Our calculated CV3 grain densities range between 3.57-3.71 g cm^3 - this agrees well with values determined using helium pyconometry by [7].

Discussion: A complete modal mineralogy allows for analysis of variations in the relative abundances of the constituent phases and this may have important implications for petrogenesis. Understanding the complex evolutionary history of meteorites requires disentangling primary and secondary mineralogical features. Mineral components in CV3 samples that have been-considered secondary by some workers include: fayalitic olivine (Fa~60-100) [8,9]; grossular; nepheline; sodalite; wollastonite; salite-hedenbergite pyroxenes; andradite and kirschsteinite [10]; phyllosilicates [11] and, in some interpretations, magnetite [10]. Of these secondary phases only fayalitic olivine, magnetite and phyllosilicate contribute significantly to the bulk modal mineralogy.

Fayalitic olivine and magnetite: The relative abundance of these phases correlates positively. The observed positive correlation in the modal abundance of fayalitic olivine and magnetite suggests that common conditions are favoured for formation of these phases and that a related process(es) may be controlling the relative abundances. This has been inferred on the basis of petrographic descriptions that show an association of fayalitic olivine and magnetite in all CV components: chondrules, matrix, CAI and dark inclusions. In CV chondrites the most likely controls on the abundances of both of these phases are reactions involving Fe-metal or Fe-rich gas in an oxidizing environment [12,13]. Modal data reveal evidence for this in the inverse correlation in the relative abundances of magnetite+fayalitic olivine and metal. This observation suggests consumption of Fe-metal or its gaseous precursor during formation of fayalitic olivine and magnetite.

Phyllosilicate: The structure of CV phyllosilicate is difficult to constrain and we identify phyllosilicate mainly using diffuse, broad peaks evident in collected patterns at ~19º (2θCuKα). Phyllosilicate is apparently lacking from the reduced CV3 samples Vigarano and Efremovka, relative to the oxidized CV3 samples. We also note that phyllosilicate does appear to be heteregenously distributed in the oxidized CV samples, suggesting in some analyses Dark Inclusions - the components likely to host most phyllosilicate - are absent. These data suggest that only the oxidized CV3 samples have experienced significant aqeous alteration, or that reduced CV3 samples experienced aqeous alteration but were subsequently completely de-hydrated. However, to suggest that the reduced CV were aqeously altered and completely dehydrated would introduce a paradox by implying that the reduced CV samples are actually more processed than the oxidized CV samples, contrary to all other mineralogic and isotopic evidence.

Degree of alteration in CV3 meteorites: If magnetite and fayalitic olivine are alteration products then the relative abundance of these phases, and the abundance of phyllosilicate (more certainly an alteration product), can be used to define the degree of alteration each sample has experienced. Using this rationale the reduced CV3 samples, Effremovka and Vigarano are relatively pristine compared to the oxidized samples. The modal mineralogy suggests that the reduced CV3 samples may represent the unaltered precursors of the oxidized CV3 samples, as has been suggested by previous authors [14]. These data reveal nothing as to the site of alteration but most recent authors consider that the CV parent body was where aqueous alteration and thermal metamorphism took place. If it were considered that these samples share a common parent body, and that alteration took place on the parent body, one way of explaining the apparent absence of phyllosilicate in the reduced CV samples would be that these derive from deeper within the asteroid. However, a deeper provenance would imply exposure to higher temperatures that would be expected to produce more equilibrated olivine compositions in the reduced, relative to oxidized, CV samples and this is not observed. Clearly, it is difficult to reconcile the mineralogy of reduced and oxidized CV3 samples with a single parent body unless this parent body was mineralogically heterogeneous at the point of accretion

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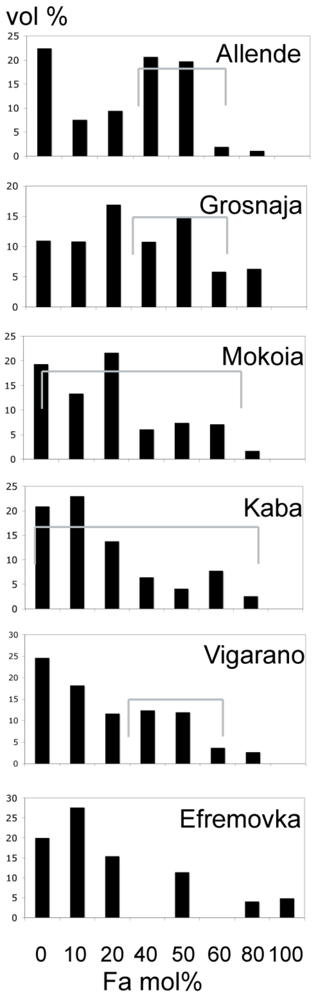

Figure 1. Olivine compositions in bulk samples of CV3 chondrites (chondrule+matrix) by PSD-XRD. Grey bars show previous compositional ranges for matrix olvivines by SEM from [5,6].