

A TEM STUDY OF THE MATRIX MINERALOGY OF THE LEOVILLE CV3 (REDUCED-GROUP) CARBONACEOUS CHONDRITE: NEBULAR AND PARENT BODY FEATURES.
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Introduction. McSween [1] divided the CV chondrites into oxidized and reduced subgroups based on the chemistry and mineralogy of the opaque phases. The reduced members have been minimally affected by thermal metamorphism and aqueous alteration and so appear to be mineralogically more primitive than the more altered oxidized subgroup, their mineralogy and petrography may provide key data on nebular and parent body processes that were operating in the early solar system. While a number of detailed studies on oxidized subgroup of CV3 chondrites have been reported, little is known about the reduced members of the CV group. In this report, the results of a transmission electron microscope (TEM) study of the matrix mineralogy of the Leoville CV3 (reduced-group) carbonaceous chondrite are described.

Methods. Regions of interest were extracted from petrographic thin sections and prepared for TEM analysis by ion milling. The ion-milled specimens were analyzed using a JEOL 2010 TEM equipped with a NORAN thin-window energy-dispersive x-ray (EDX) spectrometer. FTIR (Fourier transform infrared) transmission spectra were collected using a Perkin-Elmer infrared microscope equipped with a thermal emission source. Spectra were obtained from 30 μm^2 regions of matrix in the ion milled sections over the wavelength range 2.5 to 15 μm .

Results. Leoville matrix is dominated by fine-grained (typically $<1 \mu\text{m}$) olivine with a restricted compositional range between Fo_{40} - Fo_{50} . Coarser grained olivine shows a broader range of compositions from Fo_{40} to Fo_{90} . The majority of olivines are highly strained, and are generally equant grains. The lath-shaped and tabular olivines common to oxidized CVs (e.g. Allende) are not observed in Leoville matrix. Only rarely are olivines with (100) stacking faults observed (whereas these defects are common in matrix olivines from the oxidized group (Bali, Kaba, Mokoia, and Grosnaja).

Low Ca pyroxene is more abundant and coarser-grained than high-Ca pyroxene in Leoville

matrix. Low-Ca pyroxene is also more abundant in Leoville than in the oxidized CVs (based on TEM and FTIR results). The low-Ca pyx occurs as rounded grains and plates that are typically 0.5-1 μm in size; electron diffraction and HRTEM data indicate a mixture of ortho- and clinopyroxene intergrown on a fine scale. Rare twinned pyroxene grains showing only a 0.9 nm repeat (e.g. clinoenstatite) are also observed. No trace element enrichments were noted by EDX (e.g. no pyx compositions with $\text{Mn/Fe} > 1$ were observed). Low-Ca pyx is very magnesium rich ($>\text{En}_{96}$) and contains trace Cr and Al in addition to the minor Ca and Fe. The low-Ca pyroxene occurs as isolated single crystals and in clusters of crystals. In both occurrences, the pyx is intimately associated with fine-grained metal and fayalitic olivine. Sparse grains of high-Ca pyx (augites) are intergrown with the fine-grained olivine in matrix and range in composition from $\text{Di}_{40}\text{Hd}_{60}$ to $\text{Di}_{80}\text{Hd}_{20}$.

Matrix is essentially devoid of feldspar/feldspathoids, and no phyllosilicates have been observed to date, although minor rust staining occurs throughout the section and is dominated by a poorly-crystalline ferrihydrite-like phase. The only commonly encountered Al-rich phase in Leoville matrix is hercynitic spinel. The hercynites tend to be small, anhedral, and Cr-bearing. The hercynites are Fe-rich with $\text{Mg}/\text{Mg}+\text{Fe}$ (at.) clustering about 0.32.

Metal is the dominant opaque phase in Leoville matrix and appears to be uniformly distributed in matrix. Grain sizes are variable, but most of the metal is submicrometer in size and consists of kamacite (~5 at.% Ni) and taenite (with 40-55 at.% Ni). Electron diffraction confirms the presence of bcc and fcc metal and the lack of ordered variants (e.g. tetrataenite) and FeNi carbides. Poorly-graphitized carbon (PGC) occurs as discontinuous rims up to 20 nm thick surrounding many of the submicrometer taenite grains in matrix. Much of the metal in Leoville matrix shows an unusual morphology; occurring as highly anhedral grains (nearly skeletal) with numerous embayments and reentrant features. Most are single

crystals, although some of the larger metal grains are polycrystalline.

Sulfides (mostly troilite along with minor low-Ni pyrrhotite) are uncommon in Leoville matrix, and tend to be coarse-grained relative to the other matrix phases.

Leoville matrix lacks the Fe-rich and Ni-rich phases such as hedenbergite, fayalitic olivine ($Fa > 60$), magnetite, pentlandite and high-Ni taenite (awaruite) that are common in the oxidized CV chondrites. In addition, Leoville has been strongly deformed, resulting in chondrule flattening, compaction of matrix, and the deformation of individual mineral grains [e.g. 2].

Discussion. The TEM results on Leoville matrix show that it is mineralogically very primitive, consistent with thermoluminescence data which indicate a petrologic type 3.0 [3]. Although Leoville displays a shock overprint, the deformation was not accompanied by significant thermal metamorphism. The lack of thermal effects combined with the absence of aqueous alteration products suggests that many of the phases in Leoville matrix should retain chemical and mineralogical features that were acquired prior to accretion. For example, a common assemblage in Leoville matrix is the coexistence of enstatite, kamacite and fayalitic olivine which are in contact at the μm -scale, yet show no evidence for equilibration or reaction. This result suggests that much of Leoville matrix is a mechanical mixture of minerals that formed prior to accretion. It is not clear whether the enstatite microstructures in Leoville matrix result from shock effects as suggested by [2], or whether they simply represent the inversion of protoenstatite to mixtures of clino- and orthoenstatite on cooling from high temperatures.

The metal grains rimmed by poorly-graphitized carbon (PGC) in Leoville matrix are mineralogically and texturally similar to the metal-carbon assemblages in some IDPs [4] and ordinary chondrites [5]. In these occurrences, the PGC is believed to form by catalytic disproportionation of CO by fine-grained FeNi metal in a nebular setting. A similar origin is proposed here for the metal-PGC assemblages in Leoville. A nebular origin of the sub- μm metal in matrix is also suggested by its etched appearance. Chemical etching on the parent body is unlikely because of the

paucity of aqueous alteration products in matrix. Furthermore, the PGC follows the irregular outline of the metal grains which indicates that the metal had the morphology prior to being rimmed by PGC. The metal morphologies show some similarities to grains in IDPs that are believed to have been physically etched by ionizing radiation in a nebular or presolar environment [6].

Previous work has shown that Leoville is more strongly shocked than other CV chondrites [2], and while matrix olivines have been highly strained due to the deformation, there is no extensive formation of the characteristic (100) defects that are common in olivine from the matrices of oxidized CVs. Because lattice offsets are associated with the olivine (100) defects (e.g. in Bali and Grosnaja), it was proposed that the defects resulted from deformation on the CV parent body e.g. [7]. However, these defects are uncommon in the highly deformed olivines in Leoville matrix, suggesting that these defects in the oxidized CVs are somehow related to the aqueous alteration processes that have affected these meteorites or were exposed to a different strain rate environment.

Conclusions. TEM studies of the Leoville CV3 chondrite show that matrix contains a number of likely nebular products that were accreted on the Leoville parent body, including enstatite-metal aggregates, and metal-PGC grains. A parent body shock event is superimposed on the matrix minerals and has resulted in considerable strain. There are several differences in the matrix mineralogy of Leoville (reduced group) relative to the oxidized members of the CV chondrites.

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References.

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