

## Opaque Assemblages in CK and CV Carbonaceous Chondrites

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### Introduction:

CK carbonaceous chondrites are the only group of carbonaceous chondrites that exhibit thermal metamorphism. As a result, CKs display features of metamorphism such as silicate darkening, recrystallization and shock veins. Calcium Aluminum Inclusions and Fe-Ni metal are rare.

	Type	Chondrule	Opaque	CAI's	Matrix
MET01149,11	3	25.0	7.0	2.0	66.0
EET99430,5	4	5.1	3.5	4.7	86.7
QUE99679,7	4	17.4	6.0	3.1	73.5
EET90007,11	5	19.1	7.5	8.7	64.7
QUE99680,8	5	24.0	18.3	n.d.	57.7
EET87860,15	5,6	6.9	11.8	10.7	70.7
LEW87009,13	6	0	4.0	n.d.	79.0
CK group	3,6	15	n.d.	4	75.0
CV group	3	45.0	n.d.	10	40.0

Table 1: Modal Abundances. Data for CV and CK groups from [6] Scott and Krot.

CV carbonaceous chondrites are unequilibrated and have two subgroups; oxidized and reduced.

The CV and CK carbonaceous chondrite groups have been compared to each other often because of petrographic similarities, such as overlapping oxygen isotopic ratios. Scientists have suggested the two groups of carbonaceous chondrites formed from the same parent body and CKs are equilibrated CV chondrites [1, 2]. The oxidized CV group has been most closely related to CKs.

This study examines the petrology and mineralogy of CKs and CVs focusing on opaque minerals found in the meteorites. Using the oxide, metal and sulfide assemblages, constraints can be placed on the temperature and oxygen fugacity at which the meteorites equilibrated. The temperature and oxygen fugacity of the CK and CV chondrites can be compared in order to help define their formation history.

### Experimental Methods:

The polished CK thin sections used in the study include; MET01149,11, EET90007,11, EET99430,5, QUE99679,7,

QUE99680,8, EET87860,15, LEW87009,13 from JSC and Maralinga. The polished CV3 thin sections include the Bali type, ALH85006,23, the Allende type; LEW86006,2, ALH84028,11 and ALHA81258,4 and the reduced type, QUE93429,5 from the JSC collection. The thin sections were studied on an optical microscope using transmitted and reflected light and a 5910LV JEOL Scanning Electron Microscope at JSC.

The mineral composition data was obtained using a Cameca SX100 electron microprobe using natural and synthetic minerals as standards and PAP reduction scheme for ZAF corrections. The probe was operated with a beam current of 20 nA and an accelerating voltage of 20kV.

Modal abundances were determined using SEM back scattered electron mosaic images of sections and referencing to an optical microscope.

### Results:

Opaque assemblages are found throughout the matrix, spherical inside chondrules and in rims around chondrules. The assemblages consist of sulfides, metal and magnetites.

Magnetite is the most abundant opaque mineral in CK chondrites. However magnetite was not found in MET01149, petrologic type 3. Exsolution lamellae of ilmenite (between 5-10  $\mu\text{m}$ ) and aluminous spinel were found in the magnetite of the CK chondrites. Magnetite was less abundant in the CV sections and found in oxidized and reduced subgroups.

Ilmenite was found as lamellae in CKs petrologic type 5-6. Ilmenite also existed as grains in LEW87009, petrologic type 6. Ilmenite was not found in the CV thin sections.

Sulfides in the CK chondrites primarily are Fe or Fe,Ni sulfides. The most prevalent sulfide is pentlandite  $(\text{Fe,Ni})_9\text{S}_8$  and is often found in association with magnetite in CK chondrites. The Fe sulfides are pyrite,

pyrrhotite ( $\text{Fe}_{(1-x)}\text{S}$ ) and troilite. Millerite,  $\text{NiS}$  was not found in this study, but has been reported in Maralinga by Geiger and Bischoff [5].

Fe, Ni metal was common in the CV thin sections, but not found in the CK sections. Metal in volume percent of the CV group is 0-5% and <0.01% for the CK group [6].

### Discussion:

Exsolution of ilmenite within magnetite has been found in many of the CK's studied. The oxygen fugacity and temperature for the magnetite and ilmenite pairs were calculated using the Fe, Ti thermometer/oxybarometer [3,4], based on the distribution of Ti between ilmenite and magnetite.

The CV thin sections in this study did not contain ilmenite, but analyses of the Fe, Ni metal can be used with magnetite compositions to calculate oxygen fugacity. The oxygen fugacity for the CV thin sections was calculated using thermodynamic equilibria between metal and magnetite:  $3\text{Fe} + 2\text{O}_2 = \text{Fe}_3\text{O}_4$  and  $f_{\text{O}_2} = \sqrt{\frac{a_{\text{Fe}_3\text{O}_4}}{(a_{\text{Fe}})^3 e^{-\Delta G/RT}}}$ , where Gibbs free energy data was obtained from Robie et al [7].

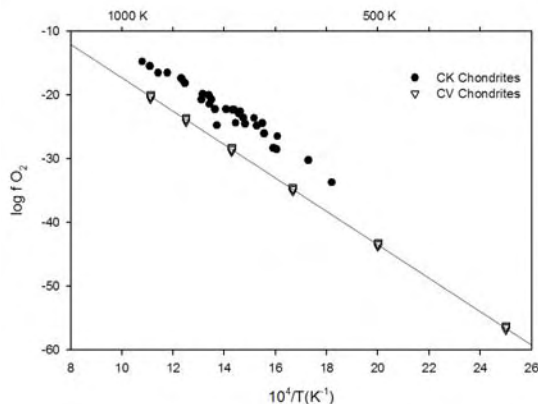


Figure 1: Oxygen Fugacity vs. Temperature

The temperature cannot be calculated using the same method used with the magnetite-ilmenite pairs. Therefore, the oxygen fugacity was calculated using a temperature range of 573-1173 Kelvin (300-900 °C) for each metal composition. The results (Figure 1) show all types of CVs are more reduced than the CK chondrites.

Although Geiger and Bischoff have estimated temperatures for CKs to be in the range of 823-1273 K (550-1000 °C) [8], pentlandite is found in the highest petrologic types of CK chondrites and is not stable at temperatures greater than 883 K (610°C) [9]. This upper temperature limit is consistent with the calculated temperature range from this study 550-926 K (277-653 °C).

Petrologic evidence for an oxidized formation of CK chondrites includes the absence of Fe, Ni metal and the abundance of magnetite [5]. The CV chondrites contain Fe, Ni metal in the reduced and oxidized subgroups. Even the oxidized CV's are less oxidized than the CK chondrites since they contain metal.

The largest difference between the CK and CV chondrite groups is the amount of oxidation. The average  $\Delta\text{FMQ}$  for a CV in this study is -2.36 while the average  $\Delta\text{FMQ}$  for CK is 3.70. Metamorphism is an explanation for the high degree of oxidation of CKs, but the question if a CV would become as oxidized as a CK chondrite if a CV went through the same metamorphism remains.

### References:

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