IS THE DIFFERENCE BETWEEN CV$_{Ox}$ AND CV$_{Red}$ A FUNCTION OF OXYGEN FUGACITY? Y.S. Go-
reva and T.J. McCoy, Dept. of Mineral Sciences, National Museum of Natural History, Smithsonian Institution,
Washington, DC 20560-0119 USA (gorevay@si.edu)

Introduction: A significant shortcoming in our know-
ledge of the oxidation conditions within CV chondrites
is a quantitative understanding of the fO2 conditions
of their formation and alteration. Magnetites are likely
formed on the CV parent asteroid by oxidation of met-
al by H$_2$O [1], which had previously experienced mi-
nor O isotope exchange with fine-grained silicates [e.g.
2]. Righter and Neff [3] calculated fO2 conditions for
CV3 chondrites based on magnetite-metal equilibrium
$3Fe + 2O_2 = Fe_3O_4$ at a range of temperatures. Their
result suggests an oxygen fugacity of ~FMQ-1. Given
apparent variation in CV3s metal composition, one
might expect a possibility that CV chondrites exhibit a
range of fO$_2$ conditions.

We have analyzed metal-magnetite assemblages
from CV3 subgroups in order to assess difference in
oxygen fugacity among CV chondrites.

Composition of metal – magnetite assemblages:
NMNH meteorite thin sections were analyzed using
JEOL JXA 8900R electron microprobe at the Smithso-
nian's Dept. of Mineral Sciences.

Metal-magnetite assemblages are found in all CV3
subgroups (Figure 1) in meteorite matrix, within chon-
drules and on chondrule boundaries.

Nickel content (wt.%) of Fe,Ni metal in **Leoville**
and **QUE 93429** (CV3$_{red}$ chondrites) is bimodally dis-
tributed, with both Ni-poor (kamacite, <10 wt.% Ni)
and Ni-rich (taenite, 30-50 wt.% Ni) metal. This is
consistent with data from [4, 5].

Metal grains in association with magnetite in CV$_{ox}$
chondrites are much more sparse. Most commonly, this
pair occurs in association with sulfides. Since second-
ary sulfidization of metal and/or magnetite most likely
affected their composition, for our analyses we se-
lected only metal-magnetite assemblages which, in two
dimensions, were not associated with sulfide. Metal
composition of oxidized CV chondrites is more uni-
form, **Bali (CV3$_{ox-b}$)** metal analyzed in this work is
kamacite (<10 wt.% Ni), whereas **Allende (CV3$_{ox-a}$)**
metal is awaruite in composition (up to 70 wt. % Ni).

Magnetite, associated with metal is nearly pure
Fe$_3$O$_4$ in all CV3 subgroups, with only traces of Cr, Al
and Ti.

Oxygen Fugacity. Oxygen fugacity can be calculated
using thermodynamic data [6] and activity-
composition relations [7, 8] for magnetite and metal:

$$fO_2 = \sqrt{\frac{a_{Fe_3O_4}^{spinel}e^{-\Delta G/RT}}{(a_{Fe}^{metal})^3}}$$
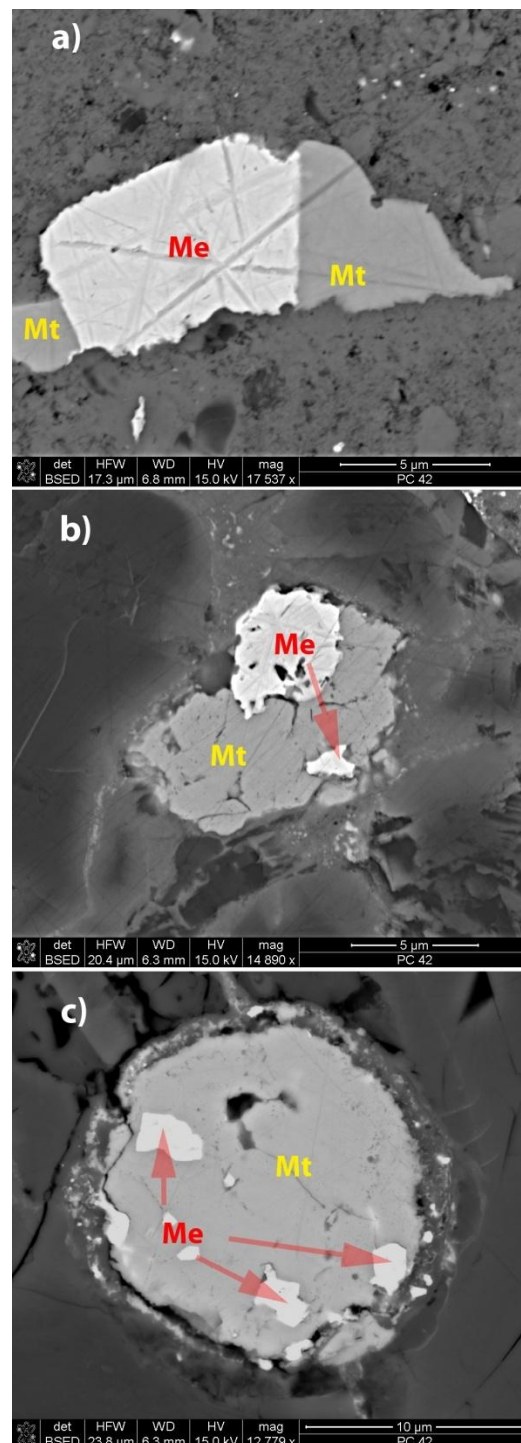

Figure 1. Examples of Metal (Me)-Magnetite(Mt) assem-
blages in various CV3 subgroups: a) Leoville (CV3$_{red}$), b)
QUE 93429 (CV3$_{red}$), c) Bali (CV3$_{ox-b}$)

Since magnetites are almost pure Fe_3O_4 we assume activity in the upper term as unity. Thus, the oxygen fugacity depends solely on temperature and activity of Fe in a metal phase. From the activity-composition relation at 1000°C ([8], Figure 2), it is evident that activity of Fe does not change significantly up to a Ni content of about 50 wt.%. With further increase in Ni concentration, Fe activity rapidly drops, which is reflected in increase of fO_2. This trend is consistent with the observed high Ni metals in Allende.
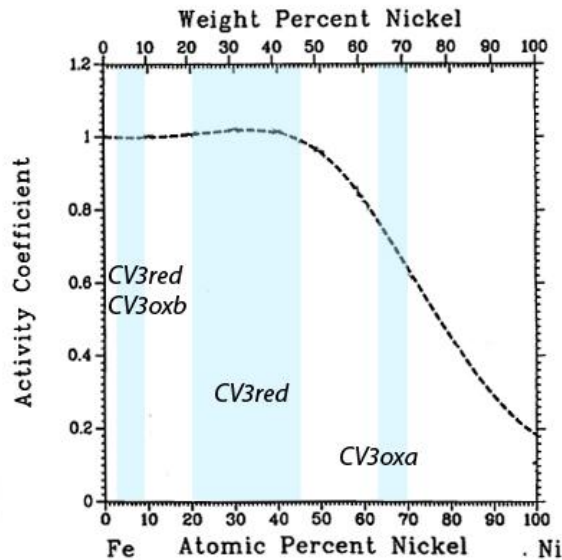
Figure 2. Composition of (Fe,Ni) metal associated with magnetite in different subgroups of CV3 chondrites (shadowed areas) superimposed onto plot of Fe activity coefficients for (γFe,Ni) at $1000\,^{\circ}$C [8]
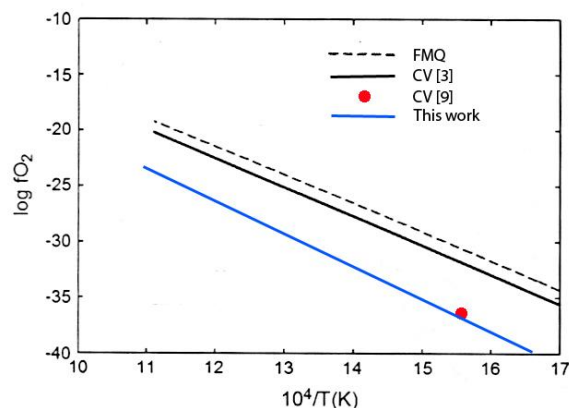
Figure 3. Plot of oxygen fugacity as a function of temperature.

Our fO_2 calculation for a range of temperatures are plotted in Figure 3 (blue line). Our results are consistent with [9] (red dot in fig.Figure 3), but differ from [3] (solid line in Figure 3).

Despite the difference in Fe activity coefficients between CV3$_{ox-b}$, CV3$_{red}$ and CV3$_{ox-a}$ (1 and ~0.6 respectively, Figure 2), fO_2 increases by less than 0.5 log units, making lines for all 3 CV subgroups undistinguishable from the blue line in Figure 3.

Discussion: CV$_{red}$ and CV$_{ox}$ have distinct metal composition. This is consistent with various degree of aqueous alteration and/or metasomatism in these subgroups [1]. Whether this reflects differences in oxidizing conditions during alteration is questionable.

The composition-activity relation in Figure 2 is calculated for 1000°C, significantly higher than conditions of CV magnetite formation. Examination of composition-activities under various temperatures ([8]) reveals a general trend: with decreasing temperature, the slope of the curve at higher Ni concentrations (as in Figure 2) becomes steeper, resulting in somewhat higher fO_2. However, such fO_2 increase is still insignificant (<0.5 log units). This work suggests that based on the analysis of magnetite-metal pair, and given the uncertainty in activity coefficients, it is impossible to distinguish between the RedOx conditions under which the subgroups of CV chondrites were altered.

Oxidation decreases the modal abundance of the Fe metal and this is accompanied by an increase in Ni content. Although, in this work we tried to avoid the ubiquitous CV3$_{ox}$ sulfides, it is possible they are still present in 3D. Sulfides in CV$_{ox-b}$ are higher in Ni content than in CV$_{ox-a}$ [e.g. 5], in reverse correlation with metal composition (this work), suggesting that sulfidization of metal is another factor altering modal Fe metal abundances, and plays significant role during aqueous alteration of CV$_{ox}$.

The division of CV into oxidized and reduced CV subgroups is largely based on modal ratio of magnetite to metal [4]. Our results suggest that the degree of secondary alteration of CV chondrites may not stem from increase in oxygen fugacity alone, but rather reflect combination of secondary processes, making reduced/oxidized classification useful, but not reflecting a true RedOx conditions of alteration.

References: [1] Krot A.N. et al. (1998) *Met. Planet. Sci.* **33**, 1065-1085. [2] Choi B-G, et al. (1997) *EPSL,* **146,** 337-349. [3] Righter K. and K.E. Neff (2007) *Polar Sci* **1**, 25-44. [4] McSween H. Y. (1977) *GCA 41,* 1777-1790. [5] Davidson J. et al (2011) *LPS 42*, 1886. [6] Robie R.A. and B.S. Hemingway (1995) *USGS Bull 2131*, 465. [7] Sack R.O. and M. Ghiorso (1991) *Contrib. Min. Pet.* **106**, 474-505. [8] Swartzendruber L.J. et al. (1991) *J. Phase Eq*, **12**, 3, 288-312. [9] Murakami T. and Y. Ikeda (1994) *Meteoritics* **29**, 397-408.