NICKEL ABUNDANCE OF OLIVINE AND MAGNETITE IN CV AND CK CHONDRITES: EVIDENCE FOR A CONTINUOUS METAMORPHIC SEQUENCE? T.L. Dunn[1], [1]Department of Geography-Geology, Illinois State University, Normal, IL, USA (tldunn@ilstu.edu).

Introduction: The carbonaceous chondrite class is subdivided into eight groups, each containing meteorites with similar petrologic, chemical, and isotopic characteristics. Meteorites within each group are believed to originate from the same parent asteroid. The CV and CK chondrites share many similarities (oxygen isotopes, mineral compositions, and bulk rock compositions) [1] and are collectively referred to as the CV-CK clan [2]. Despite the close relationship between the two groups, the long-standing view has been that each group represents a single parent body with a unique alteration history [3, 4]. However, [1] has suggested that the CK and CV chondrites were derived from a single, thermally-stratified asteroid, much like the onion skin model suggested for the ordinary chondrites [5, 6]. If this is the case, the CV and CK chondrites should represent a continuous metamorphic sequence.

The CK chondrites are the only carbonaceous chondrite group to exhibit the full range of thermal metamorphism, from petrologic type 3 to type 6 [7]. Though all CV chondrites are classified as petrologic type 3 [8, 9], they represent complex alteration histories. The CV_{oxB} chondrites experienced significant aqueous alteration, as determined by the presence of phyllosilicates, while the CV_{oxA} chondrites underwent Fe-alkali-halogen metasomatism [10]. The reduced CV chondrites show very little evidence of secondary alteration [11]. The CK3 chondrites are thought to be more metamorphosed than the CVs [1]. Therefore, a probable, yet simplified, metamorphic sequence would be CV_{red} - CV_{ox} - CK3-6.

The CK chondrites are characterized by NiO-rich olivine [e.g. 3], which forms during metamorphism as Ni diffuses from magnetite into olivine [12]. Heating experiments on Allende indicate that Ni from metal can become incorporated into olivine with increasing oxygen fugacity [13]. If the CV and CK chondrites form a metamorphic sequence in which oxidation is taking place, then the Ni content should decrease in magnetite and increase in olivine from the CV_{ox} to the CK3 and CK4-6.

Analytical Methods: Four CK chondrites of varying metamorphic grade were selected for analysis (Table 1). Care was taken to select samples that have experienced little terrestrial weathering [14]. However, due to the limited number of CK3 chondrites available, the CK3 chondrite analyzed is significantly weathered (wi-6) [14]. The implications of this will be discussed later in the abstract. Magnetite and olivine compositions determined using a JEOL JXA 8200 electron microprobe at Washington University in St. Louis, MO. Synthetic and natural standards were used. Standard operating conditions during analyses included 15 kv potential, 25 nA beam current, and varying beam size (5µm for magnetite and 10 µm for olivine). At least 10 magnetite grains and 15 olivine grains were collected in a grid pattern across each sample. Olivine analyses represent matrix material.

Table 1. CK chondrites analyzed in this study

Sample	Abbreviation	Petrologic Type	WI*
Dar al Gani 431	DaG 431	CK3-an	6
Allan Hills 85002	ALH 85002	CK4	1
Elephant Moraine 87526	EET 87526	CK5	nm
Elephant Moraine 87860	EET 87860	CK5/6	1

*from [14]

Results: *Magnetite.* When plotted against FeO, NiO content in CK chondrite magnetite forms two distinct clusters (Fig. 1). NiO content of magnetite in CK3-an chondrite DaG 431 ranges from 0.30 to 0.45 wt%, while NiO in CK4-6 chondrites ranges from 0.17 to 0.30 wt%. Compositions of magnetite grains in oxidized CV chondrite Allende [15, 16] are also plotted on Fig. 1. Overall, Allende magnetite has a higher FeO content and lower NiO content than the CK chondrites, though a few analyses overlap with the equilibrated CK chondrites.

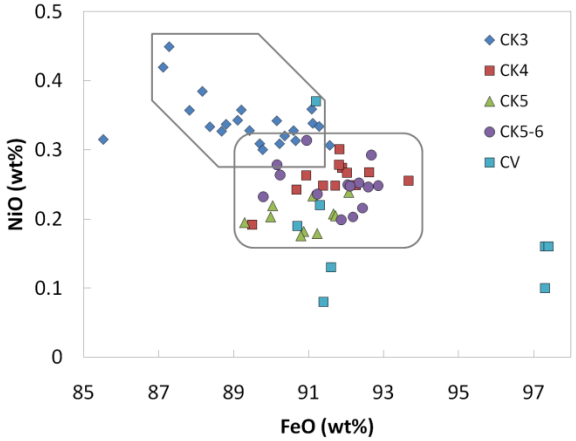

Fig. 1. NiO and FeO (wt%) content of magnetite grains in four CK chondrites of increasing metamorphic grade and oxidized CV chondrite Allende [15, 16].

Olivine. FeO and NiO content of olivine in the CK chondrites and oxidized CV chondrites Allende [15, 17], Mokoia [18], and Kaba [18] are plotted in Fig. 2. Olivine in DaG 431 (CK3-an) is relatively homogen-

ous, with NiO ranging from 0.32 to 0.39 wt% and FeO from ~28-31 wt%. FeO content of olivine in the equilibrated CK chondrites is homogenous within each sample and lower than FeO in DaG 431 (CK3-an). NiO content in the equilibrated CKs is much more variable than in DaG 431 (CK3-an), ranging from 0.34 wt% to 0.70 wt%. NiO content of olivine the CV chondrites is lower than the CK3 chondrites (<0.20 wt%), while FeO is more heterogeneous.

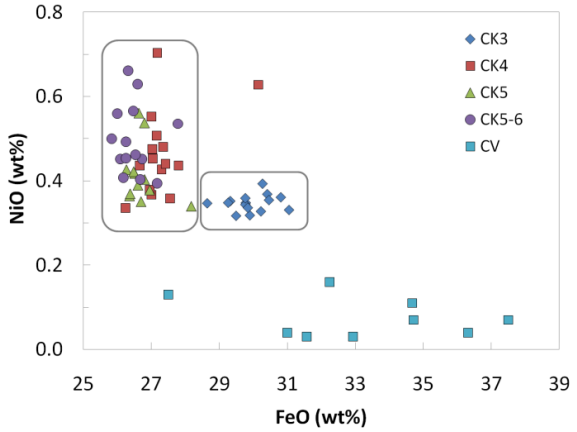

Fig. 2. NiO and FeO (wt%) content of olivine in four CK chondrites of increasing metamorphic grade and oxidized CV chondrites Allende [15, 17] and Mokoia & Kaba [18].

Discussion: If the CV and CK chondrites form a continuous metamorphic sequence in which Ni is diffusing from magnetite into olivine as oxidation is occurring, we should observe a decrease in NiO content of magnetite and an increase in NiO content of olivine from CV_{ox} to CK3 to CK4-6.

NiO in magnetite clearly decreases from DaG 431 (CK3-an) to the equilibrated CK chondrites (Table 2). Although NiO content of magnetite in the equilibrated CK chondrites overlaps significantly (Fig. 1), there is a slight decrease in average NiO content from CK4 to CK5 (Table 2), though this is indistinct when 1σ standard deviation is considered. It does appear that NiO in magnetite is decreasing, as expected, during metamorphism of the CK chondrites. However, NiO content in the CV_{ox} chondrite Allende is lower than that of the CK chondrites, which is contradictory to what is expected from a continuous CV – CK chondrite metamorphic sequence.

Table 2. Average NiO (wt%) in olivine and magnetite

Sample	Petrologic Type	Magnetite (wt%)	Olivine (wt%)
DaG 431	CK3-an	0.34 (4)	0.35 (2)
ALH 85002	CK4	0.26 (3)	0.47 (9)
EET 87526	CK5	0.21 (2)	0.41 (7)
EET 87860	CK5/6	0.25 (3)	0.49 (8)

Numbers in parentheses represent 1σ standard deviation expressed as the least digit cited.

NiO content in olivine does increase from the CV_{ox} chondrites to the CK chondrites (Fig. 2), although there does not appear to be correlation between average NiO content and increasing metamorphic grade within the equilibrated CK chondrites. This may support the existence of possible continuous metamorphic sequence between the CV_{ox} and CK chondrites, in which Ni diffuses into olivine during progressive metamorphism, but it unclear if this is actually the case.

NiO content in olivine and magnetite do not provide a clear answer to the question of whether the CVox and CK chondrite form a continuous metamorphic sequence and are, therefore, from the same parent body. Olivine may indicate this possible, but magnetite does not. It is unclear why this is the case. It may be possible that the source of Ni in the CV_{ox} chondrites may be Fe-Ni metal, though magnetite dominates metal in the CVox chondrites [3], or that NiO content in the CV chondrites may have been modified by complex alteration. It is also possible the reaction proposed by [12] does not work. Also, because terrestrial weathering of pentlandite causes loss of Ni in CK chondrites [14], measured NiO in DaG 431 (wi-6 [14]) may not reflect actual values. This does not seems likely in magnetite, as NiO content in DaG 431 is higher than the less weathered equilibrated CKs. It is possible the Ni was lost in olivine, which may explain the homogeneity of NiO content in DaG 431. However, NiO content of magnetite and olivine in DaG 431 is consistent with that of CK3-an chondrite Watson 002 (avg. NiO in olivine, 0.35 wt% [19]; avg. NiO in magnetite, 0.33 wt% [1]).

The similarities between the CV and CK chondrites may indicate a genetic relationship between the two, but further study of both groups is required before a definitive answer can be reached.

References: [1] Greenwood R.C. et al. (2010) *GCA, 74*, 1684-1705. [2] Weisberg M.K. et al. (2006), eds. D. Lauretta, L.A. Leshin, H.Y. McSween Jr., Tucson, University of Arizona Press. [3] Kallemeyn G.W. et al. (1991) *GCA, 55*, 881-892 [4] Guimon R. et al. (1995) *Meteoritics, 30*, 704-714. [5] Wood J.A. (2003) *Nature, 422*, 479-481. [6] Trieloff M. et al. (2003) *Nature, 422*, 503-506. [7] Van Schmus W.R. and Wood J.A. (1967) *GCA, 31*, 747-765. [8] McSween H.Y. et al. (1977b) *GCA, 41*, 479-491. [9] McSween H.Y. et al. (1977a) *GCA, 41*, 1777-1790. [10] Krot A.N. et al. (1995) *Meteoritics, 30*, 748-775. [11] Krot A.N.et al. 1998 *MAPS, 33*, 1065-1085. [12] Geiger T. & Bischoff A. (1995) *Planet. Space Sci, 43*, 485-498. [13] Wulf A. Y. et al. (1995) *Planet. Space. Sci., 43*, 451-468. [14] Rubin A.E. & Huber H. (2005), *MAPS, 40*, 1123-1130. [15] Choi et al. (1997) *Earth & Planet. Sci. Letts., 146*, 337-349. [16] Rubin A.E. (1991) *Amer. Min., 76*, 1356-1362. [17] Weinbruch S. et al. (1990) *Meteoritics, 25*, 115-125. [18] Kimura M. & Ikeda Y. (1998) *MAPS, 33*, 1139-1146. [19] Gieger T. et al. (1993) *Meteoritics, 28*, 352 (abstract).