

**OXYGEN ISOTOPIC COMPOSITIONS OF MAGNETITE AND CHONDRULE OLIVINE IN CK3 CARBONACEOUS CHONDRITES: LINKS TO THE CV3 CHONDRITES.** J. Davidson<sup>1\*</sup>, K. Nagashima<sup>1</sup>, A. N. Krot<sup>1</sup>, and D. S. Lauretta<sup>2</sup>. <sup>1</sup>Hawai'i Institute of Geophysics and Planetology, University of Hawai'i at Mānoa (UH), Honolulu, HI 96822, USA, <sup>2</sup>Lunar and Planetary Laboratory (LPL), University of Arizona, Tucson, AZ 85721, USA. \*[davidson@higp.hawaii.edu](mailto:davidson@higp.hawaii.edu)

**Introduction:** The CV3 and CK3-6 carbonaceous chondrites show similarities in terms of bulk oxygen isotopic composition [1], mineralogy and petrology [2, 3], and have been hypothesized to originate from a single, heterogeneous parent asteroid [1]. However, minor differences have been noted in the abundances, sizes, and compositions of the opaque and silicate phases between the two groups [4–6]. The CV3 chondrites are known to have undergone variable types of secondary parent body processing and are subdivided into three groups; two oxidized, Allende-like (OxA) and Bali-like (OxB), and one reduced. The CK3 chondrites are petrologically most similar to the metasomatically altered CV3<sub>OxA</sub> [1]. Both groups contain magnetite formed by aqueous alteration of metal on their parent asteroid(s) [7]. If CKs and CVs are closely related, it is likely that both groups experienced aqueous/hydrothermal alteration by a fluid of the same/similar O-isotopic composition which could have been recorded by their magnetite. Here we present *in situ* O-isotope measurements of magnetite and associated chondrule olivine in Asuka (A) 881595 (CK3) and Watson 002 (CK3-anom.).

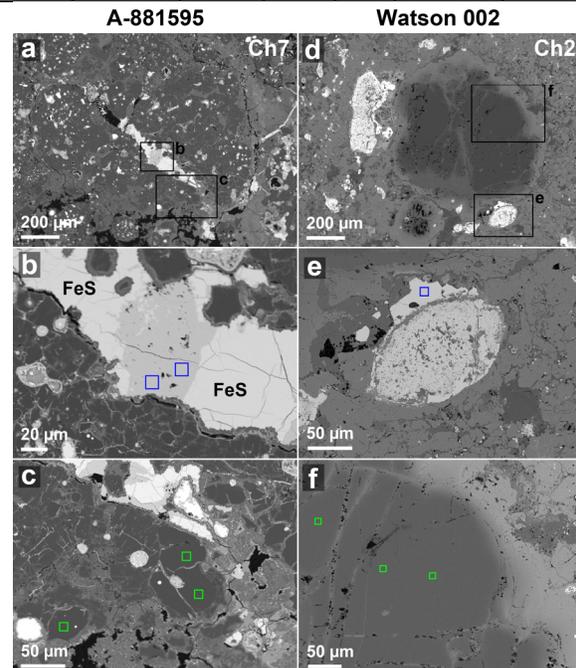
**Analytical Procedure:** Thin sections of A-881595 and Watson 002 were mapped in Si, Mg, Ca, Fe, Na, Al, P, Ni, P, Mn/Ti, and Cr K $\alpha$  x-rays (15kV, 40nA), and silicate mineral (primarily olivine) and magnetite analyses were performed (Na, Si, Mg, Al, P, K, Ca, Mn, Ti, Fe, Cr, Ni, Zn for silicate, plus S, Co, and Cu for magnetite; 1  $\mu$ m beam, 15 kV, and 20 nA) using the Cameca SX-50 EMP at LPL (for A-881595) and the JEOL JXA-8500F at UH (for Watson 002). Oxygen-isotope compositions were measured with the UH Cameca ims-1280 SIMS (conditions similar to [8]).

**Results: Petrography.** Magnetite (Fig. 1) is located in both samples, typically found with Ni-rich metal and sulfide in opaque assemblages within chondrules (similar to that in Allende [e.g., 4]), and is apparently most abundant in A-881595. However, Watson 002 is more terrestrially weathered than A-881595 which has led to the destruction of many magnetite grains – this may account for the apparent difference in the abundance of magnetite (Fig. 1e; see large weathered magnetite).

**Oxygen isotopic composition.** O-isotope analyses were performed on 11 magnetite grains in A-881595 (19 analyses) and 5 grains in Watson 002 (7 analyses; Table 1). Both magnetite and olivine data fall close to the carbonaceous chondrite anhydrous mineral (CCAM) line (Fig. 2).

Table 1. The chondrules studied, mean fayalite (Fa) content (standard deviations of the mean in parentheses), number of individual magnetite (mgt) grains analyzed, total number of magnetite and olivine (ol) analyses (an.). \* $\Delta^{17}\text{O}$  weighted mean of analyses within individual chondrules (2SE),  $\Delta^{17}\text{O}$  range is shown for isotopically heterogeneous chondrules.

Chd	Fa, mol%	# mgt grains	# mgt an.	# ol an.	$\Delta^{17}\text{O}$ ol (‰)*	$\Delta^{17}\text{O}$ mgt (‰)*
<b>A-881595 (CK3)</b>						
Ch1	2.6 (0.4)	2	3	5	-4.2 (0.4) -8.9 (0.3)	-2.1 (0.6)
Ch2	1.9 (0.3)	2	4	3	-4.9 (0.4)	-2.0 (0.5)
Ch7	2.4 (0.4)	2	3	4	-4.9 (0.4)	-1.7 (0.6)
ChA	1.1 (0.4)	3	6	3	-5.1 (0.4)	-1.6 (0.4)
ChB	1.2 (0.1)	2	3	4	-5.6 (0.3)	-1.8 (0.6)
<b>Watson 002 (CK3-anom.)</b>						
Ch1	54.9 (0.7)	2	3	5	-2.3 (0.3) -5.2 (0.3)	-3.5 (0.6)
Ch2	0.7 (0.1)	2	2	4	-5.4 (0.3)	-2.8 (0.6)
Ch3	44.7 (9.8)	1	2	3	-5.6 (0.4)	-3.5 (0.7)



**Fig. 1.** BSE images of representative (a, d) chondrules, (b, e) magnetite (blue squares indicate 10 $\times$ 10  $\mu$ m SIMS rasters\*), and (c, f) olivine (green squares indicate 10 $\times$ 10  $\mu$ m<sup>2</sup> SIMS rasters\*) in (a–c) A-881595 and (d–f) Watson 002. \*7 $\times$ 7  $\mu$ m<sup>2</sup> rasters were used for SIMS measurements.

Olivine show relatively large ranges in both  $\delta^{17}\text{O}$  (–16.9 to –6.0‰ for A-881595; –9.1 to –2.4‰ for

Watson 002; Fig. 2) and  $\delta^{18}\text{O}$  ( $-15.5$  to  $-3.4\text{‰}$  for A-881595;  $-6.3$  to  $0.6\text{‰}$  for Watson 002). The olivine grains are isotopically homogeneous within individual chondrules with the exception of Ch1 from both A-881595 ( $\Delta^{17}\text{O}$  of  $-4.2$  to  $-8.9\text{‰}$ ; Fig. 3) and Watson 002 ( $\Delta^{17}\text{O}$  of  $-2.9$  to  $-5.2\text{‰}$ ) due to the presence of relict grains. Magnetite show much smaller ranges in both  $\delta^{17}\text{O}$  ( $-2.9$  to  $-0.8\text{‰}$  for A-881595;  $-4.5$  to  $0.6\text{‰}$  for Watson 002; Fig. 2) and  $\delta^{18}\text{O}$  ( $-2.5$  to  $1.2\text{‰}$  for A-881595;  $-2.2$  to  $2.6\text{‰}$  for Watson 002) and are essentially homogeneous within samples with respect to  $\Delta^{17}\text{O}$  (Fig. 3). Magnetite and olivine are in O-isotopic disequilibrium: the weighted average  $\Delta^{17}\text{O}$  values for magnetite are 2.1 to 5.5‰ higher than those of olivine in the same chondrules (Table 1; Fig. 3), with the exception of Ch1 in Watson 002 where magnetite and some olivine agree within error (the olivine is isotopically heterogeneous).

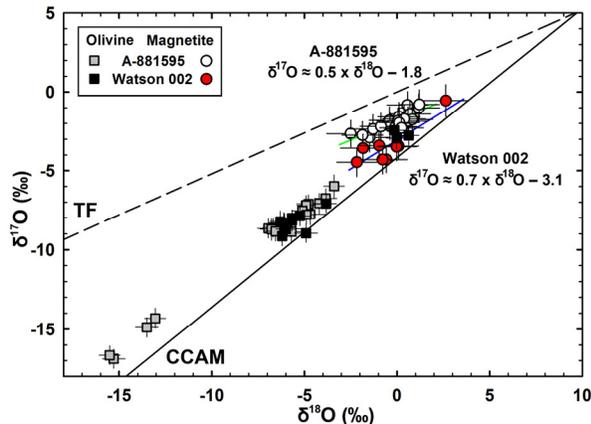


Fig. 2. Three-isotope plot showing O-isotopic compositions of olivine and magnetite in A-881595 and Watson 002. TF = terrestrial fractionation line. Errors are  $2\sigma$ .

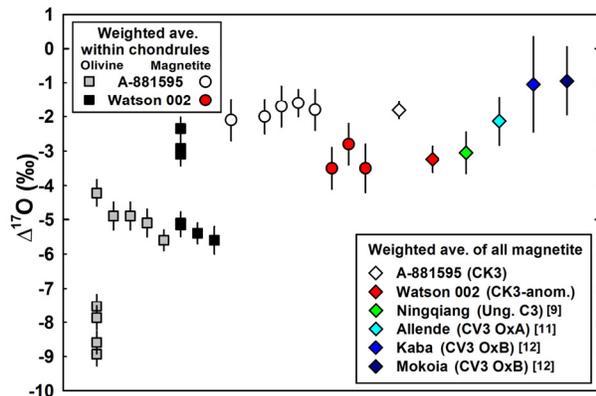


Fig. 3.  $\Delta^{17}\text{O}$  weighted means for olivine\* and magnetite within individual chondrules for A-881595 and Watson 002, and within meteorites compared to published data for CK3-like [9] and CV3 [11, 12] chondrite magnetite. Order of chondrules corresponds to those in Table 1. Errors are 2SE. \* $\Delta^{17}\text{O}$  ranges are shown for olivine from Ch1 in both A-881595 and Watson 002 as they are isotopically heterogeneous.

**Discussion:** The weighted means of  $\Delta^{17}\text{O}$  for olivine and magnetite are significantly different suggesting that they did not form in equilibrium (i.e., contemporaneously). The O-isotopic composition of chondrule olivine was inherited from the solar nebula [e.g., 13] whilst that of the magnetite likely originates from fluid present during aqueous alteration on the parent body (consistent with previous studies [9–12]). It is important to consider that the diffusion coefficient of O in magnetite [e.g., 14], at temperatures relevant to metamorphism in CV3s and CK3s, may be such that magnetite grains have undergone O-isotope exchange with adjacent phases after formation (i.e., the magnetite has been disturbed). Thus it is important to compare CK3s that have experienced both mild and more severe thermal alteration. The  $\Delta^{17}\text{O}$  difference between olivine and magnetite in chondrules of Watson 002 (2.1–2.6‰) is lower than for A-881595 (2.9–5.5‰). Watson 002 is more thermally processed than A-881595; this may indicate that the magnetite has indeed undergone O-isotope exchange with chondrule olivine of Watson 002.

Given the large errors ( $2\sigma$ ) associated with earlier published magnetite data it is difficult to confidently compare carbonaceous chondrites with respect to their  $\Delta^{17}\text{O}$  weighted means (Fig. 3). Watson 002 appears to be in closest agreement with Ningqiang (an ungrouped C3 previously considered to be a CK3 [9]). Whilst the CV3s Allende, Kaba, and Mokoia are in agreement with A-881595 within error. This suggests that the CK3 and CV3 magnetites may have formed from a fluid of similar O-isotopic composition. However, we intend to extend this study to CK3s that have experienced various degrees of thermal alteration to determine the effects of O-isotope disturbance during thermal alteration and if a metamorphic sequence exists.

**References:** [1] Greenwood R. C. et al. (2010) *GCA* 74:1684. [2] McSween H. Y. (1977) *GCA* 41:1777. [3] Weisberg M. K. et al. (1997) *MAPS* 32:A138. [4] Davidson J. et al. (2011) *LPSC XLII*:#1886. [5] Davidson J. et al. (2011) *MetSoc* #5319. [6] Davidson J. et al. (2009) *MAPS* 44:A57. [7] Krot A. N. et al. (1998) *MAPS* 33:1065. [8] Makide K. et al. (2009) *GCA* 73:5018. [9] Choi B-G. and Wasson J. T. (2003) *GCA* 23:4655. [10] Hsu W. et al. (2006) *EPSL* 243:107. [11] Choi B-G. et al. (1997) *EPSL* 146:337. [12] Choi B-G. et al. (2000) *MAPS* 35:1239. [13] Krot A. N. et al. (2006) *GCA* 70:767. [14] Farver J. R. (2010) *RIMS* 72:447.

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