

**A KAROONDA CONUNDRUM: PRIMORDIAL OXYGEN IN MAGNETITE, OLIVINE, AND IRON-RICH SPINEL IN A METAMORPHOSED CALCIUM-ALUMINUM-RICH INCLUSION.** J. P. Greenwood<sup>1,2</sup>, K. D. McKeegan<sup>3</sup>, and J. T. Wasson<sup>1,2,3</sup>, <sup>1</sup>Department of Chemistry and Biochemistry, 3845 Slichter Hall, University of California, Los Angeles CA 90095-1567, USA, <sup>2</sup>Institute of Geophysics and Planetary Physics, 3845 Slichter Hall, University of California, Los Angeles CA 90095-1567, USA, <sup>3</sup>Department of Earth and Space Sciences, 3845 Slichter Hall, University of California, Los Angeles CA 90095-1567, USA.

**Introduction:** CK chondrites are distinguished by having refractory element abundances similar to CV chondrites, large chondrules, and a paucity of CAIs [1]. In an earlier study we analyzed oxygen isotopic compositions of Fe-rich spinel (pleonaste) in a metamorphosed CAI from Karoonda (CK4) (MSG-1) by ion microprobe and found that though Fe-Mg exchange had occurred, spinel still preserved primordial oxygen [2]. We used the UCLA Cameca ims 1270 ion microprobe to make *in situ* oxygen isotopic measurements of individual mineral grains in another metamorphosed CAI from Karoonda (K1), originally described by [3].

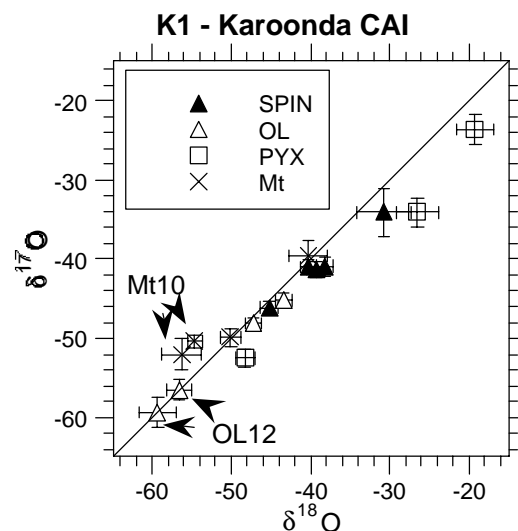
**Results:** K1 is a large (2.2 × 1.6mm) metamorphosed CAI from Karoonda (USNM 904-2), consisting of Fe-rich olivine and spinel, fassaitic pyroxene, Fe-rich orthopyroxene, plagioclase (An<sub>50-95</sub>), magnetite, ilmenite, and pentlandite [3]. Primary olivine-, spinel-rich regions of K1 are mantled by a secondary zone composed of bladed orthopyroxene and sodic plagioclase which intrudes K1 in the center.

Results of oxygen isotopic analyses are shown below. The most surprising results are the measurements of a magnetite grain (Mt10) taken in two different analytical sessions, both with  $\delta^{18}\text{O}$  and  $\delta^{17}\text{O} < -50$ ,  $-50\%$ . Another startling result is the analysis of an equilibrated olivine grain (F<sub>074</sub>) within the CAI (OL12), taken in two different analytical sessions, both with  $\delta^{18}\text{O}$  and  $\delta^{17}\text{O} < -50$ ,  $-50\%$ . A forsteritic olivine grain (F<sub>094</sub>) has  $\delta^{18}\text{O} = -43.4 \pm 1.0\%$ ,  $\delta^{17}\text{O} = -45.2 \pm 0.9\%$  (1 $\sigma$ ). Three analyses were made of a large pleonaste frambooid; a large range is found ( $\delta^{18}\text{O}$ :  $-31$  to  $-45\%$ ). Oxygen-isotopic analyses of two slightly more Fe-rich (hercynitic) spinels in a secondary zone of the CAI are both near  $-40$ ,  $-40\%$ . All three pyroxene analyses appear to lie off the CCAM line; the most  $^{16}\text{O}$  depleted analysis is of an Fe-rich orthopyroxene (En<sub>75</sub>Fs<sub>24</sub>Wo<sub>0.6</sub>) from the secondary zone.

**Discussion:** Most olivine in K1 has the equilibrated Karoonda composition (F<sub>072</sub>), including high NiO contents. It is thus remarkable that while cation equilibration has occurred in olivine, no evidence for O-isotopic exchange is found. A metamorphic temperature of 863K has been suggested for Karoonda from O-isotopic compositions of plagioclase and magnetite [4]. While Fe-Mg exchange is  $\sim 8$  orders of magnitude faster than oxygen diffusion in olivine at 873K [5,6], the Fe-Mg effective diffusion distance is only  $\sim 5\ \mu\text{m}$  at 1173K for 10 Ma (a

reasonable maximum temperature for metamorphism), suggesting that dry metamorphism is not a viable hypothesis.

**Formation of CAI magnetite.** Magnetite in K1 is not in oxygen isotopic equilibrium with normal Karoonda magnetite and is compositionally different as well, with much lower Cr<sub>2</sub>O<sub>3</sub> ( $\ll 1\text{wt}\%$  vs.  $\sim 4\ \text{wt}\%$ ; [7]).



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ossible formation processes for magnetite in CK chondrites are oxidation of metal by gas [7] or aqueous processes [2]. To explain the O-isotopic disequilibrium between normal Karoonda magnetite (similar to CK whole rocks; [2,4]) and CAI magnetite requires water to achieve oxygen isotopic equilibration in the micro-environment of the CAI; this implies very low water/rock ( $\ll 1$ ). The low Cr contents of CAI magnetite would support this idea, as CAIs are depleted in Cr. Arguments for formation of magnetite as a primary phase in CAIs are not supported by the petrology or minor element chemistry.

**References:** [1] Kallemeyn et al. (1991) *GCA*, 55, 881–892. [2] Greenwood et al. (2000) *LPS XXXI*, Abstract #2042. [3] MacPherson and Delaney (1985) *LPS XVI*, 515. [4] Clayton and Mayeda (1999) *GCA*, 63, 2089–2104. [5] Ryerson et al. (1989) *JGR*, 94, 4105–4118. [6] Chakraborty (1997) *JGR*, 102, 12317–12331. [7] Geiger and Bischoff (1995) *Planet Space Sci.*, 43, 485–498.