

**OXYGEN ISOTOPE COMPOSITIONS OF MAGNETITE IN CC-LIKE CLASTS FROM ALMAHATA SITTA AND OTHER POLYMICT UREILITES.** C. A. Goodrich<sup>1</sup>, N. T. Kita<sup>2</sup>, M. Zolensky<sup>3</sup> and M. H. Shaddad<sup>4</sup>. <sup>1</sup>Lunar and Planetary Institute, USRA, Houston TX 77058 USA (goodrich@lpi.usra.edu); <sup>2</sup>WiscSIMS, Dept. Geoscience, University of Wisconsin-Madison, WI 53706 USA (noriko@geology.wisc.edu); <sup>3</sup>ARES, NASA-JSC, Houston TX 77058 USA; <sup>4</sup>Univ. of Khartoum, Khartoum 11115 Sudan.

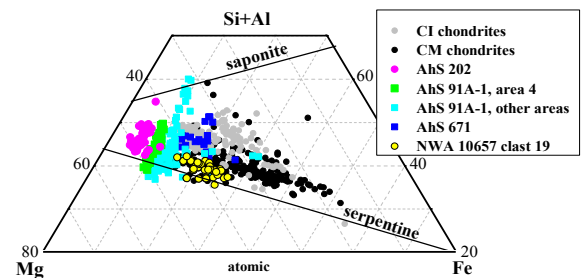
**Introduction:** Oxygen isotope ratios of magnetite in primitive meteorites reflect the compositions of the fluids in asteroidal bodies [1-6]. The  $\Delta^{17}\text{O}$  ( $= \delta^{17}\text{O} - 0.52 \times \delta^{18}\text{O}$ ) values of the magnetite are always higher than those of the bulk meteorites and represent minimum  $\Delta^{17}\text{O}$  values of the initial  $^{16}\text{O}$ -poor aqueous fluids in the parent body. Xenoliths of chondritic materials in meteoritic breccias provide samples of additional primitive materials not sampled as whole meteorites [7], whose magnetites can also be studied to increase knowledge of volatiles in the early solar system. Recently, we established SIMS analytical protocols to analyze small magnetite grains in CI-like clasts in the Dar al Gani (DaG) 165 polymict ureilite [8]. These magnetites show  $\Delta^{17}\text{O}$  values of  $\sim +5\%$ , which are significantly higher than those of magnetite in CV, CO, CR or CM  $\sim 0\%$  [2-6]), but similar to those in Semarkona LL3.0 ( $+5\%$  [1]). Here we determine oxygen isotope ratios of magnetites in CC-like lithologies in the Almahata Sitta (AhS) and Northwest Africa (NWA) 10657 polymict ureilites.

**Methods:** Oxygen three-isotope analyses of magnetite in CC clasts were performed using the WiscSIMS IMS 1280 with analytical protocols similar to those used for cometary particle analyses [9]. For magnetite grains smaller than  $10\ \mu\text{m}$ , we made  $1\ \mu\text{m}$  square “FIB marks” at the locations of SIMS analyses [9]. In order to minimize crystal orientation effect on magnetite analyses, impact energy of primary ions was reduced to 13 keV by using 3 kV accelerating voltage for Cs ion source and  $-10\ \text{kV}$  applied to the sample surface [10]. The primary beam was set to 5 pA with  $2 \times 1\ \mu\text{m}$  size and the secondary  $^{16}\text{O}$  intensity was  $\sim 5 \times 10^6$  cps. A single analysis took 12 min. The external reproducibilities of  $\delta^{18}\text{O}$ ,  $\delta^{17}\text{O}$ , and  $\Delta^{17}\text{O}$  of magnetite standard (magnetite 5830 [10]) were  $\sim 2\%$ . The tailing of  $^{16}\text{OH}$  signals to  $^{17}\text{O}$  mass was  $\sim 10$  ppm of the  $^{16}\text{OH}$  signals, which resulted in 0.2-0.5‰ corrections in  $\delta^{17}\text{O}$  for standards and unknown magnetite analyses mounted in epoxy, while corrections were  $< 0.1\%$  for those in polished thin sections. All  $^{16}\text{OH}$  corrections were small compared to the analytical uncertainties.

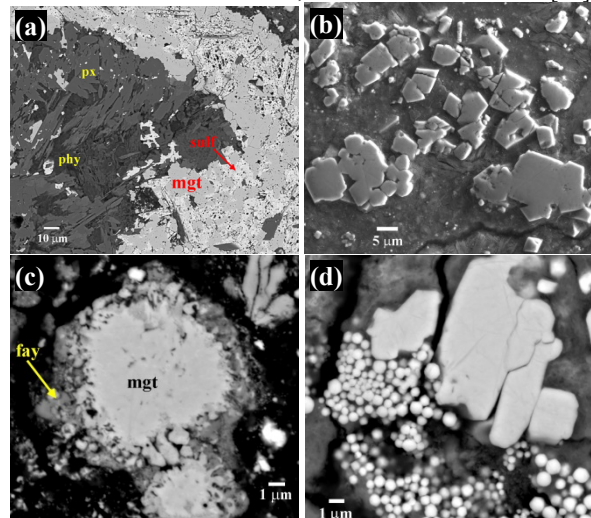
Mineralogy and petrology of the clasts were determined by SEM, EMPA and FIB/TEM at ARES, JSC.

**Mineralogy:** AhS 202 is a magnetite-rich ( $> 10\%$ ) C2 unlike any known CC [11]. It consists of partially altered olivine-pyroxene chondrules (Fo  $68 \pm 0.7$ ; mg# 84-92, Wo 21-44) in a matrix of serpentine plus poorly

crystallized saponite. The serpentine is more magnesian (mg#  $\sim 0.88-0.93$ ) than in CI or CM or other clasts studied here (Fig. 1). Magnetite occurs in chondrules and matrix in a variety of morphologies (Fig. 2a,b). Magnetite compositions do not match those in CI, CK, CV or CR (Fig. 3) and are distinct from those of magnetites in all other CC lithologies we have studied in polymict ureilites [8,12,13], which are like those in CI.



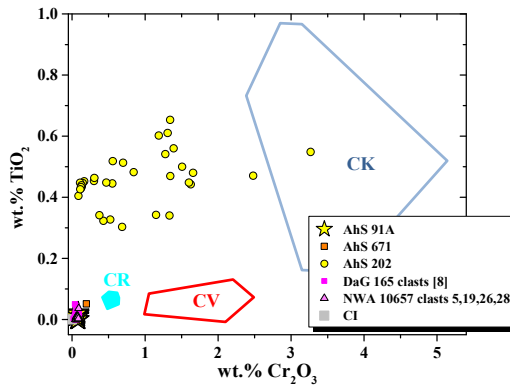
**Fig. 1.** Ternary compositions of phyllosilicates comparing CC-like clasts in AhS and NWA 10657 with CM and CI chondrites. Data for AhS 91A, 671 and chondrites from [13].



**Fig. 2.** (a) AhS 202. BEI. Rim of magnetite (mgt) and porous sulfide (sulf) surrounding pyroxene (px)-rich chondrule partially altered to phyllosilicates (phy). (b) AhS 202. SEI. Magnetite in matrix. (c) AhS 91A. BEI. Magnetite rimmed with fayalitic (fay) olivine. (d) NWA 10657 clast 19. BEI. Magnetite framboids and larger grains.

The other CC lithologies in this study all consist of hydrous CC matrix with no chondrules. AhS 91A and AhS 671 are dominated by C1 material that is mineralogically similar to CI but has oxygen and Cr isotope compositions unlike any known CC [12,13,17]. NWA

10657 clast 19 is one of several clasts in NWA 10657 with some mineralogic features like CM2, but abundant magnetite like CI1 [12]. NWA 10657 clasts 5, 26 (and the DaG 165 clasts [8]) are more CI-like, but differ in mineral modes and compositions.



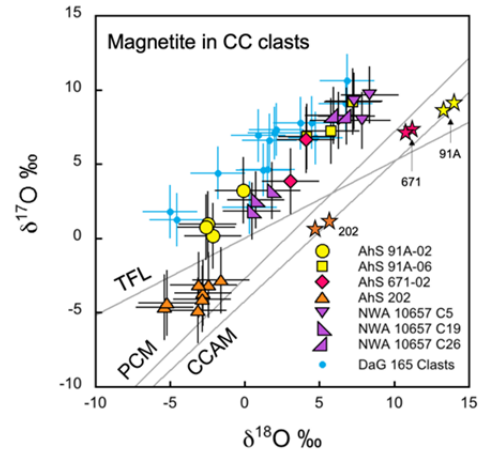
**Fig. 3.** Compositions of magnetite in CC-like lithologies from AhS, NWA 10657, and DaG 165 polymict ureilites compared with those in known CC. CC data from [14-16].

**Oxygen Isotope Results:** We obtained 26 magnetite analyses from 7 different clasts from AhS and NWA 10657. Results are shown in Fig. 4. Except for AhS 202, all data from this work plot above the terrestrial fractionation line (TFL) trending parallel to PCM and CCAM lines [18,19] with  $\Delta^{17}\text{O}$  from 2‰ to 5‰, very similar to CC clasts in the DaG 165 polymict ureilite [8]. The magnetites in AhS 91A and AhS 671 show higher  $\Delta^{17}\text{O}$  than their respective bulk samples (Fig. 4). Data for magnetites in AhS 202 are below TFL with  $\Delta^{17}\text{O}$  value of  $-2.1 \pm 1.1$ ‰ (2SD,  $n=8$ ), which is similar to that of bulk AhS 202 ( $-1.73$ ‰ [12,13]).

**Discussion:** Magnetite in CC lithologies from AhS 91A and 671 show a similar range of oxygen isotope ratios to those in CC-like clasts in typical polymict ureilites NWA 10657 and DaG 165. These data support the idea that AhS and typical polymict ureilites contain similar xenolithic materials and are derived from the same body [12,20]. Excluding AhS 202, a linear regression of magnetite data from six CC clasts in AhS and NWA 10657 gives slope  $0.87 \pm 0.09$ , which is close to unity. The result that all these magnetites form a single, nearly slope-1 trend, despite the differing mineralogies of the clasts, suggests that they all experienced aqueous alteration by a similar initial fluid (not necessarily on the same parent body). This fluid appears to have differed isotopically from the fluids that acted on known CC parent bodies [2-6].

AhS 202 is distinct from all other CC clasts in polymict ureilites studied so far and unique compared with known CC. The  $\Delta^{17}\text{O}$  value of its magnetites is within the range of those in some CM1 [5] and CK3 [6]. Its magnetites are plausibly on a slope  $\sim 1/2$  mass

fractionation line with its bulk composition (Fig. 4). If the magnetites in AhS 202 formed by aqueous alteration, this could mean that the fluid had similar  $\Delta^{17}\text{O}$  to the bulk rock. Oxygen isotope analyses of olivine and pyroxene in AhS 202 may shed light on the petrogenesis and possible affiliation of this lithology.



**Fig. 4.** Oxygen isotope ratios of magnetites in CC clasts from AhS, NWA 10657, and DaG 165 polymict ureilites. DaG 165 data from [8]. Stars = bulk analyses of AhS samples [12,13].

**Conclusions:** Magnetites in a variety of CC-like lithologies in polymict ureilites have  $\Delta^{17}\text{O}$  from +2‰ to +5‰. These isotope signatures are distinct from those of known CCs and suggest that materials from unsampled CC-like bodies were incorporated into ureilitic breccias. Knowledge of volatile-rich materials in the early solar system can be significantly expanded by studying CC-like clasts in meteoritic breccias.

**References:** [1] Choi B-G. et al. (1998) *Nature* 392, 577-579. [2] Choi B-G. et al. (2000) *Meteorit. Planet. Sci.* 35, 1239-1248. [3] Doyle P.M. et al. (2013) *Meteorit. Planet. Sci.* 48, #5135. [4] Jilly-Rehak C.E. et al. (2015) *LPSC XLVI*, #1662. [5] Telus M. et al. (2017) *LPSC XLVIII*, #1725. [6] Davidson J. et al. (2014) *Meteorit. Planet. Sci.* 49, 1456-1474. [7] Bischoff A. et al. (2006) In *MESS II*, 679-712. [8] Kita N.T. et al. (2017) 80<sup>th</sup> MSM, #6153. [9] Defouilloy C. et al. (2017) *Earth Planet. Sci. Lett.* 465, 145-154. [10] Huberty J.M. et al. (2010) *Chemical Geology* 276, 269-283. [11] Fioretti A.M. et al. (2017) *LPSC 48*, #1846. [12] Goodrich C.A. et al. (2019) *LPSC 50*, #1312. [13] Goodrich C.A. et al. (2019) *Meteorit. Planet. Sci.*, submitted. [14] Dunn T.L. et al. (2016) *Meteorit. Planet. Sci.* 51, 1701-1720. [15] Greenwood R.C. et al. (2010) *Geochim. Cosmochim. Acta* 74, 1684-1705. [16] Harju E.R. (2014) *Geochim. Cosmochim. Acta* 139, 267-292. [17] Yin Q.-Z. et al. (2018) *LPSC 49*, #1810. [18] Clayton R.N. et al. (1977) *Earth Planet. Sci. Lett.* 34, 209-224. [19] Ushikubo T. et al. (2012) *Geochim. Cosmochim. Acta*, 90, 242-264. [20] Goodrich C.A. et al. (2015) *Meteorit. Planet. Sci.* 50, 782-809.