

### CHLORINE ISOTOPE VARIATION IN EUCRITES.

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**Introduction:** In general, Solar System materials exhibit a relatively narrow range in bulk Cl isotope compositions, with terrestrial rocks and martian and chondritic meteorites having  $\delta^{37}\text{C}$  values of  $\sim -4$  to  $\sim +1.8$  ‰ [1-3]. However, lunar rocks are an important exception, displaying a significant range in their bulk and apatite  $\delta^{37}\text{Cl}$  values from  $-4$  to  $+81$  ‰ [4-10]. Howardites, Eucrites and Diogenites (HEDs) represent the largest suite of crustal and sub-crustal rocks available from a differentiated basaltic asteroid (most probably 4 Vesta) [11, 12] and are also some of the oldest igneous rocks in the Solar System [13, 14]. Therefore, understanding the volatile inventories of the eucrites can help us to constrain the processes that operated on asteroid parent bodies early in Solar System history. In order to investigate the history of volatiles in eucrites, we have measured the Cl isotopic composition of apatite from five eucrites (Dar al Gani (DaG) 844, DaG 945, Millbillillie, Moore County and Stannern), which experienced a wide range of petrological and geochemical histories. Apatite grains from these five samples were previously analysed for the H isotopic composition of the OH they contain [15].

**Methods:** Apatite analyses were performed using the Cameca NanoSIMS 50L instrument at The Open University, using a modified protocol reported in Tartèse et al. [8] and Barnes et al. [9]. Typically  $\sim 5 \times 5$   $\mu\text{m}$  raster areas were analysed, however for smaller grains this area was reduced to  $\sim 3 \times 3$   $\mu\text{m}$ .

**Results:** A total of 19 measurements from 15 individual apatite grains from the five eucrites were obtained. Apatite Cl content ranged from  $\sim 25$  ppm Cl in DaG 945 to  $\sim 2030$  ppm Cl in Millbillillie. Considerable intra-grain variability in Cl abundance is observed in Moore County, with a single grain having a range of  $\sim 360$  ppm. However, apatite crystals from most samples display more restricted variation (both inter as well as intra-grain). The  $\delta^{37}\text{Cl}$  values obtained for apatite from four of the five samples are within error of bulk terrestrial and chondritic values. However, two apatite grains in Moore County display more enriched compositions ( $\sim +6.6 \pm 3.4$  ‰ and  $+13.1 \pm 3.0$  ‰) than terrestrial values. In contrast to all the other eucritic samples examined in this study, DaG 945 apatite show a very heavy  $\delta^{37}\text{Cl}$  composition, with values ranging from  $\sim +27.2 \pm 4.4$  ‰ to  $\sim +35.6 \pm 6.2$  ‰, which incidentally are some of the highest measured values among the Solar System materials.

**Discussion:** In all eucrite samples, apatites display consistent  $\delta\text{D}$  values [15], with no correlation between  $\delta^{37}\text{Cl}$  and  $\delta\text{D}$  values. The data presented in this study appear to display a negative correlation between  $\delta^{37}\text{Cl}$  and Cl content, an observation consistent with the degassing model for the Moon proposed by Sharp et al. [4]. The petrological history of DaG 945, however, is very different to a degassed lunar basalt [16]. DaG 945 is a residual eucrite which is believed to have experienced prolonged heating at temperatures of  $\sim 800 - 1000$  °C and also partial melt extraction [16]. It is possible that the extreme metamorphism which DaG 945 experienced may have caused the large fractionation in Cl isotopes. Alternative hypotheses used to explain the extreme fractionations in Cl observed in lunar samples, predict a correlation between bulk-rock trace-elements and  $\delta^{37}\text{Cl}$  values [6, 9]. Whilst such a correlation was observed by Schneck et al. [17], such a correlation is not apparent in our dataset. In fact, DaG 945 shows a depletion in its chondrite-normalised La/Yb ratio compared to other eucrite samples, following a trend opposite to that predicted by lunar models [6, 9].

**Conclusion:** Our results include some of the heaviest chlorine isotopic compositions recorded so far in the Solar System. The data suggest that the Cl isotope system is complex and Cl may fractionate differently under different magmatic conditions, with potentially multiple processes at work. In order to understand the process(es) responsible for producing the large fractionation in Cl isotopes observed in the residual eucrite DaG 945, additional residual eucrites with similar petrological characteristics will need to be analysed.

**References:** [1] Sharp Z. D. et al. 2007 *Nature* 466:1062-1065. [2] Sharp Z. D. et al 2013 *Geochimica et Cosmochimica Acta* 107:189-204. [3] Williams J. T. 2016. *In press Meteoritics & Planetary Science*. [4] Sharp Z. D. et al. 2010. *Science* 329:1050-1053. [5] Wang Y. et al. 2012. 75<sup>th</sup> Meteoritical Society Conference Abstract #5170. [6] Boyce J. W. et al. 2015 *Science Advances* 1. [7] Treiman A. H. et al 2014. *American Mineralogist* 99:1860-1870. [8] Tartèse R. et al. 2014. *Meteoritics & Planetary Science* 49:2266-2289. [9] Barnes J. J. et al. 2016. *In press in Earth and Planetary Science Letters*. [10] Robinson K. L. 2016. 47<sup>th</sup> Lunar and Planetary Science Conference Abstract #2199. [11] McCord T. B. et al. 1970 *Science* 168:1445-1447. [12] De Sanctis M. C. et al. 2012 *Science* 366:697-700. [13] Misawa K. et al. 2005. *Geochimica et Cosmochimica Acta* 69:5847-5861. [14] Zhou Q. et al. 2013. *Geochimica et Cosmochimica Acta* 110:152-175. [15] Barrett T. J. et al. 2016 *In press Meteoritics & Planetary Science*. [16] Yamaguchi A. et al. 2009. *Geochimica et Cosmochimica Acta* 73:7262-7182. [17] Schneck U. G. et al. 2016 47<sup>th</sup> Lunar and Planetary Science Conference Abstract #2978.