

**THE CHLORINE ISOTOPE COMPOSITION OF THE MOON.** Z.D. Sharp<sup>1</sup>, C. K. Shearer, Jr.<sup>2</sup>, and J.D. Barnes<sup>1</sup>, <sup>1</sup>Dept. Earth Planet. Sci, Univ. of New Mexico, Albuquerque, NM, 87131 [zsharp@unm.edu](mailto:zsharp@unm.edu), <sup>2</sup>Inst. of Meteoritics, Univ. of New Mexico, Albuquerque, NM, 87131.

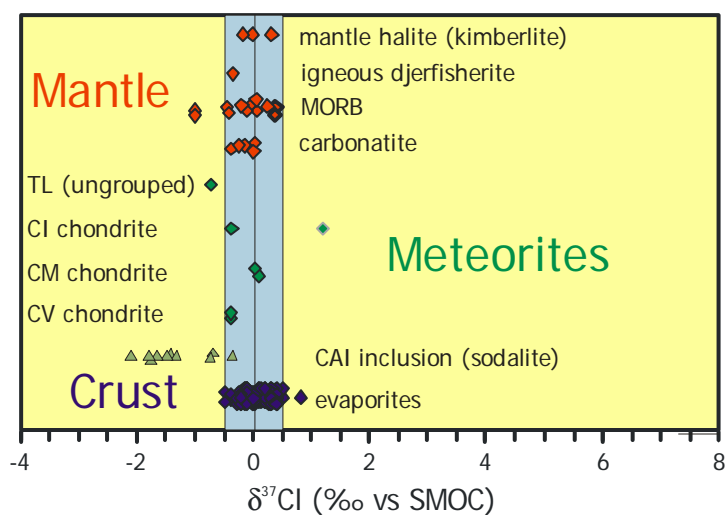
**Introduction:** Sharp et al. [1] determined that the  $\delta^{37}\text{Cl}$  value of carbonaceous chondrites, mantle samples and crustal materials are all close to 0‰ (Fig. 1). There are some small but significant variations. For example, sodalite inclusions in CAIs from Allende are distinctly negative. These samples were measured with an ion probe, as opposed to gas source mass spectrometry, nevertheless they were measured using a natural sodalite standard that has been calibrated to the SMOC (Standard Mean Ocean Chloride) scale using the methyl chloride technique [1]. The explanation for the low sodalite inclusions is not known, but may be that there were multiple Cl reservoirs in the solar nebula. Alternatively, the data may be related to equilibrium Cl fractionation mechanisms, although rather special conditions would be required to explain the  $^{37}\text{Cl}$  depletion of 2‰. MORB glasses are all within 0.5‰ of SMOC except for two samples from 12°N on-axis, East Pacific Rise, which have values of -1.04 and -1.03‰. We believe that these low values indicate mantle heterogeneities, perhaps related to injection of low  $\delta^{37}\text{Cl}$  material into the mantle from a subducted slab. In the present contribution, we have measured the  $\delta^{37}\text{Cl}$  value of a lunar glass sample to see if the Moon falls into the same range as the bulk Earth (0‰ vs SMOC) as might be expected based on chemical and dynamic models for its formation.

**Sample description:** Initial measurements reported here represent surface coatings on high-Ti pyroclastics glasses collected at the Apollo 17 (A17) landing site near Shorty crater (sample 74002). These glasses represent near-primary basaltic melts [e.g. 2 and references within] produced during episodes of partial melting in the deep lunar interior (multiply saturated with olivine and orthopyroxene at approximately 20 kbars and 400 km) [3]. The pyroclastic glass spherules are inferred to have formed at the lunar surface through vapor-driven volcanic fire-fountain eruptions. The fire-fountaining eruptions may have been driven by the oxidation of C to CO [e.g. 4]. The spherules are coated with vapor-mobilized elements that were condensed from the volcanic gas. The Cl content in the bulk A17 orange glass (Sample 74220-36) is approximately  $20.2 (\pm 4) \mu\text{g/g}$  determined by neutron activation [5]. Although the Cl is derived from the high-Ti basaltic magma, most of the Cl occurs in the surface coatings. NaCl has been identified as

a phase studding the surface of these glass spherules. Cl content in the interior of the glass beads is 2 ppm or less [6]. In addition to the pyroclastic glasses, Apollo 12 low-Ti basalts (olivine basalt and pigeonite basalt) and an Apollo 16 breccia (66095) will be analyzed in this study. The latter has relatively high Cl and may have contained other Cl-bearing phases such as lawrencite ( $\text{FeCl}_2$ ) [e.g. 7].

**Analytical procedure:** All samples were analyzed using gas source mass spectrometry, with chloromethane ( $\text{CH}_3\text{Cl}$ ) as an analyte [8]. Due to the small sample size, analyses were made in continuous flow using the method described in [1, *supplementary information*]. The reported standard deviation ( $1\sigma$ ) of an analysis is  $\pm 0.26\text{‰}$  ( $n=12$ ). In order to ensure the highest precision, the source to the mass spectrometer was cleaned prior to the analytical session in which the lunar sample was analyzed. 263 mg of sample 74002 was leached in 18M $\Omega$  deionized water for two days and filtered.  $\text{AgNO}_3$  was added to the leachate to precipitate AgCl. The AgCl was collected on a glass filter and reacted with excess iodomethane ( $\text{CH}_3\text{I}$ ) at 80°C for two days in order to convert the AgCl to  $\text{CH}_3\text{Cl}$ . The  $\text{CH}_3\text{Cl}$  was separated from the excess  $\text{CH}_3\text{I}$  using gas chromatography and the purified  $\text{CH}_3\text{Cl}$  sample was analyzed in continuous flow mass spectrometry to determine the  $\delta^{37}\text{Cl}$  value.

**Results:** Three seawater standards were run in the same session as the lunar sample, giving (raw) values of -5.25, -4.84, -4.90‰ (S.D.  $1\sigma = 0.22\text{‰}$ ). The



**Fig. 1.**  $\delta^{37}\text{Cl}$  values of selected mantle, crustal and chondritic samples. TL (Tagish Lake), CI (Ivuna & Orgueuil), CM (Murchison), CV (Allende). After [1].

abundance of Cl in the glass sample was determined from peak areas on the mass spectrometer relative to those of the standard samples, yielding a concentration of  $80 \pm 20$  ppm total leachable Cl. The corrected  $\delta^{37}\text{Cl}$  for the lunar sample is  $-0.74\%$  (vs SMOC).

**Discussion:** There are a number of potential explanations for the non-zero value for the lunar sample, but not all are plausible. For example, the low  $\delta^{37}\text{Cl}$  value could be explained if there was a Cl fractionation during eruption on the lunar surface. However, it is unlikely that Cl (present as vapor-deposited NaCl) would separate into a vapor and solid phase and that these two phases would become isolated from one another. Furthermore, the  $\Delta^{37}\text{Cl}$  ( $\text{NaCl}_{\text{solid}} - \text{NaCl}_{\text{vapor}}$ ) is  $+0.7\%$  (unpublished experimental results), which would require that only the vapor remained on the glass beads, which is the reverse of what would be expected. We consider four plausible explanations: 1) The  $\delta^{37}\text{Cl}$  value of the measured sample is not representative or is faulty, and that the Earth and Moon have the same  $\delta^{37}\text{Cl}$  values. Additional samples are currently being processed to evaluate this possibility. 2) The  $\delta^{37}\text{Cl}$  value of the Earth is  $-0.7\%$ , like the lunar sample. Two laboratories have determined the  $\delta^{37}\text{Cl}$  value of the terrestrial mantle, with very discrepant values of  $\sim +4.5\%$  [9] and  $-1.8\%$  [10]. We tentatively reject this explanation because all of our measurements were made in the same laboratory under the same conditions, so that *relative* differences should be real, even if the absolute values of our laboratory are not correct. 3) The moon has a  $\delta^{37}\text{Cl}$  value inherited from its precursor planetesimal that is different from Earth. This result cannot be excluded. If correct, then other volatile elements that have been measured in the lunar glass [e.g. 5] would also have a non-Earth origin. 4) During moon formation, there was a Cl isotope fractionation, with the vapor preferentially incorporated into the lunar material. The moon accreted from an impact-generated disk [e.g. 6]. There is a  $0.7\%$  equilibrium fractionation between  $\text{NaCl}_{\text{solid}}$  and  $\text{NaCl}_{\text{vapor}}$ , so that if condensation led to different size distribution or position in the disk, a preferential incorporation of light Cl could be explained by fractionation processes alone.

Additional lunar samples are in the process of being measured, and the results of these analyses may shed additional light on the  $\delta^{37}\text{Cl}$  value of the Moon.

## References

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