

**RECONCILING THE HYDROGEN AND CHLORINE ISOTOPIC SIGNATURES OF THE MOON.** M. Anand, A. Stephant and I. Franchi, School of Physical Sciences, The Open University, Milton Keynes, MK7 6AA, UK. (Mahesh.Anand@open.ac.uk)

Since the first detection of H (reported in terms of either H, OH or H<sub>2</sub>O and collectively referred to as ‘water’) in lunar volcanic glasses (LVG) [1], a wealth of additional data have been collected via *in-situ* measurements on various lunar phases, such as olivine (ol)-hosted melt inclusions (MIs) [1-4], LVG [5], plagioclase [6] and apatite [7-8], providing a strong evidence for a wet Moon, with estimates for the bulk silicate Moon (BSM) ranging from ~1 to 300 ppm H<sub>2</sub>O. In terms of hydrogen isotopic composition ( $\delta D$ ), multiple lunar reservoirs and processes have been highlighted through recent ion-probe measurements [7-9]. As the parent magma may have undergone significant degassing by the time apatites crystallized, MIs could have recorded and retained the juvenile  $\delta D$  value of the mantle source regions of mare basalts, although processes such as post-entrapment crystallization and cosmic ray spallation effects need to be carefully considered in the case of MIs. We analysed >40 MIs hosted in either ol or pyroxene (px) from nine different basalt types collected from four Apollo landing sites.

The range in H<sub>2</sub>O contents in ol-hosted MIs (2-212 ppm) is in good agreement with the range of 5-131 ppm measured in homogenized MIs from 10020 and 15016 [3] and the range of 28-156 ppm measured in crystallized MIs in 12040 [10]. We considered the highest H<sub>2</sub>O content measured (212±27 ppm) as the closest to the pre-eruptive abundance of the mare basaltic parent melt. Assuming 10% partial melting in the lunar mantle, we estimate a water content for the BSM of ~25 ppm. This range is in agreement with most other studies (~1-100 ppm; recalculated for the same degree of partial melting), although our estimates are towards the lower range. After taking into account various processes that could have influenced the abundance and isotopic composition of H in these MIs, we make conservative estimates of  $\delta D$  value of ~ -200‰.

The Moon exhibits a heavier chlorine isotopic composition ( $\delta^{37}Cl$ ) compared to the Earth. Several hypotheses have been put forward to explain this difference, based mostly on analyses of apatite in lunar samples complemented by some bulk-rock data. The earliest hypothesis argued for Cl isotope fractionation during the degassing of anhydrous basaltic magmas on the Moon [11]. Subsequently, an alternative scenario was envisaged to explain the elevated  $\delta^{37}Cl$  in lunar basalts, which includes mixing between 2 reservoirs: a lighter one (~0 ‰), representative of mare-basalt source regions and an elevated one (i.e. 25-30 ‰) associated with

a KREEP component [12,13]. For Cl, we analysed >30 MIs hosted in either ol or px from five lunar basalts. The measured Cl concentration ranged from ~ 1 to 30 ppm, with an average of 3 ppm. Higher Cl abundances (3-80 ppm) are measured for px-hosted MIs, consistent with their formation at later stages of crystallization. In terms of  $\delta^{37}Cl$  values, ol-hosted MIs and px-hosted MIs have weighted averages of +13±2 ‰ and +10±3 ‰, respectively, which are statistically indistinguishable. From our ol MI results, we estimated a range of 0.1-1.4 ppm of Cl for the lunar mantle (for 5% to 30% partial melting). The Cl isotopic compositions of both ol and px-hosted MIs are similar to those measured in apatites from the same samples, with the exception of sample 14072, which is known to have a distinct petrogenetic history compared to other mare basalts. For the four others basalts, the similarity between both ol and px-hosted MI, and also apatite  $\delta^{37}Cl$  confirm that there is no significant Cl isotopic fractionation associated with crystallization or any other post-magmatic processes that would result in a preferential loss of the <sup>35</sup>Cl.

As such, it appears more likely that the primary magmas of lunar basalts were already enriched in <sup>37</sup>Cl relative to <sup>35</sup>Cl, an inherent signature of lunar mantle source-regions. Moreover, MIs measured here come from four Apollo landing sites, which means that this enrichment of <sup>37</sup>Cl relative to <sup>35</sup>Cl is widespread across basaltic lunar reservoirs, at least on the near side of the Moon. Overall, our findings are compatible with the hypothesis that in majority of the cases the heavy Cl isotopic signature of the Moon was acquired during the earliest stages of Lunar Magma Ocean evolution and its isotopic composition was not significantly modified by subsequent magmatic processes. On the other hand, the H isotopic signature of lunar basaltic melts were modified by a variety of processes such as magma degassing, cosmic ray spallation, and solar wind assimilation.

**References:** [1] Saal A. et al. (2008) *Nature*, 454, 192-195. [2] Hauri E.H. et al. (2011) *Sci*, 333, 213-215. [3] Chen Y. et al. (2015) *EPSL*, 427, 37-46. [4] Fueri E. et al. (2014) *Icarus*, 229, 109-120. [5] Hui H. et al (2013) *Nat Geo* 6, 177-180. [6] Tartese R. et al. (2013) *GCA*, 122, 58-74. [7] Barnes J.J. et al. (2014) *EPSL*, 390, 244-252. [8] Saal A. et al (2013) *Sci* 340, 1317. [9] Fueri E. et al. (2017) *EPSL*, 474, 76-82. [10] Ni P. et al. (2019), *GCA*, 249, 17-41. [11] Sharp Z.D. et al. (2010) *Sci*, 329, 1050-1053. [12] Boyce J.W. et al. (2015) *Sci Adv*, 1, 8. [13] Barnes J.J. et al. (2016) *EPSL*, 447, 84-94.