New evidence for lunar basalt metasomatism by underlying regolith.

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Abstract: Earth-like δD values reported from lunar mare-basalt apatites have typically been interpreted to reflect the intrinsic isotopic composition of lunar-mantle water. New data indicates that some of these basalts are also characterized by having experienced a slow cooling history after their emplacement onto the lunar surface. This suggests that these basalts may have experienced metasomatism by fluxes generated during the degassing of the lunar regolith induced by the long-duration high-temperature residence times of overlying basalts.

Keywords: lunar volatiles, basalt metasomatism, lunar petrology, hydrogen isotopes.

The volatile elements affect a wide range of important physical properties of geological materials, playing a fundamental role during the mass transport of melt from the mantle to the crust. Relative to the Earth, the Moon is generally considered to be volatile-element depleted (e.g., Wolf and Anders, 1980; Canup et al., 2015), with the exception of water (Saal et al., 2008). One of the major volatile-bearing basaltic mineral phases, apatite (Ca₅(PO₄)₃(OH,F,Cl), has shown that lunar magmatism is potentially not entirely anhydrous (Boyce et al., 2010; Greenwood et al., 2011; Barnes et al., 2013; Tarte et al., 2013). Since the direct measurement of water (OH) within a diverse range of lunar materials (apatite, olivine, plagioclase, basaltic glass), allowing for the interpretation of how water is distributed on the Moon on a global scale. In particular, a key question that is currently debated is what is the origin of this water (e.g., primordial, cometary sources, asteroid sources, solar wind): to
date this issue has been primarily been addressed using H-isotope systematics (expressed as δD, relative to Standard Mean Ocean Water; SMOW).

Based on a recent review of lunar apatite OH-δD systematics (McCubbin et al., 2015), mare basalts have been noted to fall within two broad groups: 1) a relatively isotopically heavy δD suite, which lies above the terrestrial range (> +200 ‰ δD), and 2) an isotopically lighter, Earth-like, suite (~ 0 to ~250 ‰ δD). Within individual mare suites, several processes such as volatile degassing (which acts to increase δD; Tartèse and Anand, 2013), or spallogenic production from cosmic-ray exposure (which will to decrease δD; Füri and Deloule, 2016), can modify δD compositions from their inherited melt signature. However, recent reports of δD values that extend to compositions below the terrestrial range (+100 to -500‰) from a range of lunar lithologies, including incompatible element rich KREEP basalts and evolved highland lithologies (such as quartz monzodiorites), have been argued to reflect a primordial, isotopically distinct, lunar mantle reservoir (Barnes et al., 2014; Robinson et al., 2014). Such a reservoir has recently gained support by the occurrence of similar δD compositions from basalts associated with the Icelandic mantle plume, which are interpreted to reflect deep ‘primordial’ signatures (Hallis et al., 2015); together providing some for the strongest evidence for a primordial origin for water in the Earth–Moon system (Barnes et al., 2014).

In this issue Treiman et al. (2016) presents an alternative case accounting for the relatively isotopically light apatite δD signatures, based on the mineral texture of the host basalts. The petrological context of apatite, and other OH-bearing phases, have been often overlooked within the literature, however, can provide important clues for putting water abundance and H-isotope systematics into context (Pernet-Fisher et al., 2014). In their model, Treiman et al. (2016) highlight that basalt samples with the lowest apatite δD values
also display the least amount of zoning within olivine and pyroxene phenocrysts. This
suggests that these samples have been held at high temperatures for long periods relative to
other basaltic samples that display large mineral zonational gradients. As a result of such a
protracted thermal history, Treiman et al. (2016) propose a model whereby that these basalts
incorporated an additional source of H during the emplacement of lavas flows onto the lunar
regolith. The regolith, as the result of a long history of solar-wind and cosmic-ray
implantation, is thought to be characterized by very isotopically light δD values (< -400‰
δD; Epstein and Taylor, 1973); thus, ‘metasomatism’ by regolith induced heating during lava
flow emplacement, could act to lower the δD value of the overlying molten basaltic lava.
Models of lunar regolith heating and degassing with hot lava interaction (Rumpf et al., 2013),
and melt assimilation are not new, having been used to account for variable trace-element
systematics for some high-Al Apollo 14 basalts (Hui et al., 2011) and for some xenocrystic
spinel within some Apollo 12 basalts (Dungan and Brown, 1977). However, the extent to
which the volatile element systematics will modify basalts through this process has to date
not fully considered. Overall, Treiman et al. (2016) reinforces how important it is to consider
the extent to which mixing with the underlying lunar regolith may modify mare basalts
during their emplacement, particular for the most mobile and volatile elements.

Acknowledgments: Funded by STFC grant # ST/M001253/1

References cited

S. (2013). Accurate and precise measurements of the D/H ratio and hydroxyl content in lunar
apatites using NanoSIMS. Chemical Geology, 337, 48-55.

Russell, S. S. (2014). The origin of water in the primitive Moon as revealed by the lunar
highlands samples. Earth and Planetary Science Letters, 390, 244-252.


