IMA2018 Abstract submission

Martian mineralogy: observations, experiments, analogues and models

IMA2018-1376

Tracing the evolution of hydrogen in the martian crust through laboratory studies of apatite

Jessica Barnes* [1], Francis McCubbin[1], Alison Santos [2], Jeremy Boyce[1], Mahesh Anand[3], Ian Franchi[3], Carl Agee[4]
[1]ARES, NASA JSC, Houston, [2]NASA GRC, Cleveland, United States, [3]School of physical sciences, The Open University, Milton Keynes, United Kingdom, [4]Institute of Meteoritics, University of New Mexico, Albuquerque, United States

What is your preferred presentation method?: Oral presentation

: Introduction: Northwest Africa (NWA) 7034 and its pairings represent a regolith breccia of basaltic bulk composition [1], the fine-grained matrix of which bears a strong resemblance to the major and trace element composition estimated for the ancient southern highlands crust on Mars [2]. Therefore, NWA 7034 may represent a key sample for constraining the composition of the martian crust, particularly the ancient highlands. Here we seek to constrain the hydrogen isotopic composition of the martian crust using apatite [$Ca_5(PO_4)_3(Cl,F,OH)$]. Apatites across all lithologic domains in NWA 7034 have been affected by a Pb-loss event at ~1.5 Ga before present [3] and so they are unlikely to have retained magmatic volatile composition and are more likely to have equilibrated with fluids within the martian crust that may or may not have exchanged with the martian atmosphere.

Methods & Results: Electron probe microanalysis (EPMA) of apatite was conducted following the work of McCubbin *et al.,* [4] and Santos *et al.,* [5]. The H-isotopic composition and H_2O abundance of apatite in two thin sections of NWA 7034 were measured using the Cameca NanoSIMS 50L at The Open University, following protocols described in [6]. Apatites in NWA 7034 were measured in a number of lithologic contexts, including basaltic clasts, Fe, Ti, and P-rich (FTP) clasts, and large crystal clasts within the bulk matrix [5]. All apatites are Cl-rich and contain between 238-1343 ppm H_2O. In addition, the δD values of apatites ranged from 453‰ to 2564‰.

Discussion: In the absence of a magnetosphere, the martian atmosphere has been stripped of ^1H over billions of years by the solar wind [7]. This has produced a heavily fractionated atmosphere (δD ~2500-6100‰,[8,9]) compared to the mantle (δD <275‰,[10]). The equilibration of apatite with crustal fluids is supported by the chlorine-rich compositions exhibited by apatites in NWA 7034 in comparison to apatites from other martian meteorites [4]. The apatites in NWA 7034, which likely attained their volatile inventories during a Pb-loss event at 1.5 Ga [3], have δD values <3000‰. All of the H-isotopic compositions that we obtained fall within ~500‰ of the range of values reported for the intermediate H reservoir predicted for the martian crust by Usui *et al.*, [11]. These observations indicate that at least portions of the martian regolith have not exchanged completely with the martian atmosphere. If NWA 7034 records the H-isotopic composition of the crust ca. 1.5 Ga, then Allan Hills 84001 (ALH 84001), the oldest unbrecciated martian meteorite, constrains the H-isotopic composition of the crust ca. 4 Ga [12]. Greenwood *et al.* [13] determined a δD value of ~3000 ‰ for apatite in ALH 84001, which is D-enriched relative to the intermediate reservoir. However, our recent petrologic investigation of ALH 84001 hints that there are at least two generations of apatite within ALH 84001, and it is not clear which generation of apatite was measured by [13]. We will measure the H-isotopic composition of apatite in ALH 84001 to ascertain whether or not ALH 84001 holds new clues to the evolution of hydrogen in the ancient martian crust.

References: [1] Agee, C.B., Wilson, N.V., McCubbin, F.M., Ziegler, K., Polyak, V.J., Sharp, Z.D., Asmerom, Y., Nunn, M.H., Shaheen, R., Thiemens, M.H. and Steele, A., 2013. Unique meteorite from early Amazonian Mars: Water-rich basaltic breccia Northwest Africa 7034. Science, 339(6121), pp.780-785.
[2] Humayun, M., Nemchin, A., Zanda, B., Hewins, R.H., Grange, M., Kennedy, A., Lorand, J.P., Göpel, C., Fieni, C., Pont, S. and Deldicque, D., 2013. Origin and age of the earliest Martian crust from meteorite NWA 7533. Nature, 503(7477), p.513.
[3] McCubbin, F.M., Boyce, J.W., NovákSzabó, T., Santos, A.R., Tartèse, R., Muttik, N., Domokos, G., Vazquez, J., Keller, L.P., Moser, D.E. and Jerolmack, D.J., 2016. Geologic history of Martian regolith breccia Northwest Africa 7034: Evidence for hydrothermal activity and lithologic diversity in the Martian crust. Journal of Geophysical Research: Planets, 121(10), pp.2120-2149.
[4] McCubbin, F.M., Boyce, J.W., Srinivasan, P., Santos, A.R., Elardo, S.M., Filiberto, J., Steele, A. and Shearer, C.K., 2016. Heterogeneous distribution of H2O in the Martian interior: Implications for the abundance of H2O in depleted and enriched mantle sources. Meteoritics & Planetary Science, 51(11), pp.2036-2060.
[5] Santos, A.R., Agee, C.B., McCubbin, F.M., Shearer, C.K., Burger, P.V., Tartese, R. and Anand, M., 2015. Petrology of igneous clasts in Northwest Africa 7034: Implications for the petrologic diversity of the Martian crust. Geochimica et Cosmochimica Acta, 157, pp.56-85.

[6] Barnes, J.J., Tartèse, R., Anand, M., McCubbin, F.M., Franchi, I.A., Starkey, N.A. and 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, pp.244-252.
[7] Chassefière, E. and Leblanc, F., 2004. Mars atmospheric escape and evolution; interaction with the solar wind. Planetary and Space Science, 52(11), pp.1039-1058.
[8] Novak, R.E., Mumma, M.J. and Villanueva, G.L., 2011. Measurement of the isotopic signatures of water on Mars; Implications for studying methane. Planetary and Space Science, 59(2-3), pp.163-168.
[9] Webster, C.R., Mahaffy, P.R., Flesch, G.J., Niles, P.B., Jones, J.H., Leshin, L.A., Atreya, S.K., Stern, J.C., Christensen, L.E., Owen, T. and Franz, H., 2013. Isotope Ratios of H, C, and O in CO2 and H2O of the Martian Atmosphere. Science, 341(6143), pp.260-263.
[10] Usui, T., Alexander, C.M.D., Wang, J., Simon, J.I. and Jones, J.H., 2012. Origin of water and mantle–crust interactions on Mars inferred from hydrogen isotopes and volatile element abundances of olivine-hosted melt inclusions of primitive shergottites. Earth and Planetary Science Letters, 357, pp.119-129.
[11] Usui, T., Alexander, C.M.D., Wang, J., Simon, J.I. and Jones, J.H., 2015. Meteoritic evidence for a previously unrecognized hydrogen reservoir on Mars. Earth and Planetary Science Letters, 410, pp.140-151.
[12] Lapen, T.J., Righter, M., Brandon, A.D., Debaille, V., Beard, B.L., Shafer, J.T. and Peslier, A.H., 2010. A younger age for ALH84001 and its geochemical link to shergottite sources in Mars. Science, 328(5976), pp.347-351.
[13] Greenwood, J.P., Itoh, S., Sakamoto, N., Vicenzi, E.P. and Yurimoto, H., 2008. Hydrogen isotope evidence for loss of water from Mars through time. Geophysical Research Letters, 35(5).