

Volatile element transport in the lunar crust. C.K. Shearer¹, P.V. Burger¹, Y. Guan², J.J. Papike¹, and S.R. Sutton³, ¹Institute of Meteoritics and Department of Earth and Planetary Sciences, University of New Mexico, Albuquerque, New Mexico 87131 (cshearer@unm.edu), ²Division of Geological and Planetary Sciences, California Institute of Technology, Pasadena, California 91125, ³ Department of Geophysical Science and Center for Advanced Radiation Sources, University of Chicago, Chicago, Illinois 60637.

Introduction: The existence of troilite fracture-fillings, veins and intergrowths with low-Ca pyroxene in plutonic rock clasts from a variety of lunar breccias implies that elements have been mobilized in the lunar crust [1-4]. Numerous studies have speculated on the composition and source of these fluids, their capability for the transport of vapor-mobilized elements, and the scale and environment under which these types of process occurred [3,5-8]. These models all assumed a Moon with a very dry mantle, crust, and surface. However recently this assumption has been questioned and the role of H₂O in lunar processes has been investigated. Combining more traditional petrologic analytical approaches (optical microscopy, electron microprobe) with relatively newer instrumental approaches (Nano SIMS, Synchrotron X-ray Microprobe Analysis), we have reexamined these troilite veins and replacement textures in lunar samples to (1) differentiate among transport models proposed by previous studies [3,5-8], (2) examine the potential for the involvement of indigenous (magmatic) or exogenous (solar wind, cometary) H (or OH, H₂O) in these types of models, (3) identify potential sources for the S and heat responsible for driving elemental migration, and (4) identify the potential scale of these processes and the environment under which they occurred. These inquiries may provide a clearer understanding of volatile element transport in the lunar crust, and the composition of such volatiles.

Results: Lunar samples 67016,294, 67915,150, and 67016,297 represent clasts of Mg-suite and ferroan anorthosite lithologies that have interacted with a S-rich vapor. The olivine in these lithologies is partially to totally replaced by troilite and low-Ca pyroxene. The troilite makes up 30 to 54 volume % of the troilite + low-Ca pyroxene pseudomorphs after olivine. Other silicates in the assemblages have experienced post-magmatic, pre-sulfurization reequilibration (pyroxene exsolution, recrystallization) and were not affected by the introduction of S. The troilite also occurs in veins cross-cutting individual phases and metamorphic textures. The sulfide veining and replacement features are restricted to individual clasts and do not cut across the matrix surrounding the clasts, and thus predates the breccia-forming event. The proportion of troilite to low-Ca pyroxene and silicate chemistries indicate that simple reactions (such as olivine + S₂ ↔ low-Ca pyroxene + troilite + O₂) do not adequately represent the

replacement process. The sulfides exhibit some compositional variation and exhibit limited exsolution features. The sulfides have compositions that are similar to those found in mare basalts [9]. In particular, the sulfides generally are enriched in Co relative to Ni. The sulfur isotopic composition of the vein and replacement troilite ranges from approximately $\delta S^{34} = -4.0$ to -8.0 ‰. Spinel in all clasts exhibit “exsolution” of ilmenite suggestive of post-crystallization reduction that appears to be contemporaneous with the sulfurization event.

Discussion: Based on our observations, it appears that the model suggested by Norman et al. [3] is the most appropriate for the origin of the troilite veining and troilite-pyroxene pseudomorphs after olivine. Our data and interpretations add significant definition to this proposed model. Interpretation of pyroxene exsolution indicates this process occurs in the relatively shallow lunar crust on a scale that involves vapor interaction with multiple plutonic lithologies of various ages and compositions. These reactions occur at distinct conditions of f_{S_2} , f_{O_2} , and temperature. The reacting vapor is S-rich, and low in H. The reduction of the oxides in the clasts was not a product of H-streaming as has been suggested for similar textures in lunar rocks, but more likely related to “S-streaming”. These vapors had the capability to transport other elements such as Fe and minor chalcophile-siderophile elements. The heat source driving the transport of elements is closely tied to the emplacement of magmas into the shallow lunar crust. The fluids were most likely derived from indigenous sources (magmatic) and do not appear to have exogenous components. The process that drove the derivation of the S-rich volatiles from these intrusions was also instrumental in fractionating the isotopic composition of S from 0‰ in the magmas to -5‰ in the vapor phase. This fractionation was not controlled by the proportions of SO₂² to H₂S, but more likely COS, S₂ and CS₂ species.

References: [1] Roedder and Weiblen (1974) Proc. of the 5th LSC, 303-318. [2] Norman et al. (1981) Proc. 12th LPSC, 235-252. [3] Norman et al. (1995) GCA 59, 831-847. [4] Lindstrom and Salpas (1983) JGR 88 (Suppl.), A671-A683. [5] El Goresy et al. (1973) EPSL 18, 411-419. [6] Haskin and Warren (1991) Lunar Chemistry. Lunar Source Book (eds. Heiken, Vaniman, and French) 357-474. [7] Colson (1992) Proc. 22nd LPSC, 427-436. [8] Haskin et al. (1993) In Resources of Near-Earth Space (ed. J.S. Lewis, M.S. Mathews and M. L. Guerrieri) Univ. of Arizona Press, Tucson, AZ, pp. 17-50. [9] Papike et al. (2011) Am. Min. In press.