

Vapor element transport in the lunar crust. Implications for lunar crustal processes, water on the Moon and lunar ore deposits. C.K. Shearer¹, P.V. Burger¹, Y. Guan², J.J. Papike¹, and S. 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, ³Center for Advanced Radiation Sources, University of Chicago, Chicago, Illinois 60637.

Introduction: In planetary environments with stable H₂O in their crust (Earth, Mars), hydrothermal systems may be associated with ejecta blankets generated by large impacts [1,2 and references within] or with the crustal emplacement of mantle derived magmas. This will result in the mobilization of elements within these hydrothermal systems [i.e. 3]. Although the Moon's crust has long been considered dry by most standards, there are textures preserved in the lunar sample collection that imply that elements have been mobilized in the lunar crust. As an example, [4-6] reported the existence of troilite fracture-fillings, veins and textures suggesting the replacement of olivine and pyroxene by troilite. Both [5,7] speculated that C-O-S-(±Cl) species of various forms might serve as circulating fluids causing fractional distillation, sublimation, or extraction of individual vapor-mobilized elements. Whereas, [7] suggested that these processes may occur in ejecta blankets and the fluids may have had an exogenous origin (solar wind, comets, meteorites), [5] concluded that the source of the fluids was indigenous and magmatic in origin. In contrast to both [4,6] models, Colson [8] concluded that such textures only required the mobility of S and not other chalcophile elements.

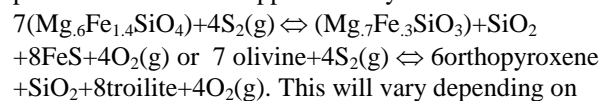
These models all assumed a dry Moon. However, more recently several studies have reevaluated the assertion that the Moon is essentially dry. Data on volcanic glasses and nominally hydrous phases revealed in recent papers [e.g. 9,10] have been interpreted as indicating the lunar mantle sources for mare basalts were significantly wetter. Contrasting conclusions have been reached by [11] based on Cl isotopes. On the lunar surface and within the regolith, the existence of H, H₂O (solid or liquid), and OH has been explored by numerous missions over the last 15 years.

The goals of this study are to differentiate between the transport models previously proposed [6-8], examine the potential effect of additional crustal or magmatic H (or OH, H₂O) on these models, and to identify potential sources for the S. These inquiries may provide a clearer understanding of volatile element transport in the lunar crust, the composition of such volatiles, and the existence of "mineral deposits" on the Moon.

Analysis: Several Apollo samples exhibiting sulfide veining and silicate replacement by sulfides were analyzed in this study: 67016,294, 67915,150, and

67016,297. In addition, sulfides in several mare basalts were analyzed and are reported in Papike et al. [12]. Sulfides were analyzed and imaged for major and trace elements using electron microprobe (EMP) at the University of New Mexico and the synchrotron x-ray microprobe at the GeoSoilEnviroCARS sector (SXRF) [12] at the Advanced Photon Source (APS, Argonne, IL, USA). Furthermore, the sulfur isotopic composition of individual sulfides was analyzed using the Cameca nanoSIMS at the California Institute of Technology. In addition to the sulfides, silicate host and reaction phases were analyzed by EMP

Results: Based on the mineral chemistries, the replacement reaction is approximately:



or $7 \text{ olivine} + 4\text{S}_2(\text{g}) \Leftrightarrow 6 \text{ orthopyroxene} + \text{SiO}_2 + 8 \text{ troilite} + 4\text{O}_2(\text{g})$. This will vary depending on olivine composition. Although the sulfides exhibit some compositional variation, they exhibit limited exsolution features. The sulfides have compositions that are similar to those found in mare basalts [12]. In particular, the sulfides are enriched in Co relative to Ni. The isotopic composition of these sulfides is slightly enriched in light sulfur compared to the mare basalts.

Conclusions: (1) The fluids were most likely derived from indigenous sources (magmatic) and do not appear to have exogenous components; (2) while S and several other elements were not derived from the host, it appears that most of the Fe is derived from olivine-breakdown reaction; (3) the somewhat fractionated S isotopic composition suggests a third S isotopic reservoir on the Moon or hints at a process that enriches the sulfide in light S; (4) if the source of these metasomatic fluids are indeed magmatic in origin, the volatiles exsolved from these magmas are S-rich and water-poor.

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