SULFIDE ASSIMILATION AND MINERALIZATION IN ANCIENT (2.4 Ga) SHERGOTTITES.

M. Humayun[1], S. Yang[1], A. J. Irving[2] and K. Righter[3], [1]Florida State University, Tallahassee, FL 32310, USA (humayun@magnet.fsu.edu); [2]University of Washington, Seattle, WA 98195, USA; [3]NASA Johnson Space Center, Mailcode XI2, 2101 NASA Parkway, Houston, TX 77058, USA.

Introduction: Due to economic importance, and the ease of sampling, orthomagmatic mineralization in terrestrial igneous rocks has been well studied. Baumgartner et al. [1] argued that martian igneous rocks could generate orthomagmatic Ni-Cu ore deposits in similar ways to terrestrial komatiites. For this to occur, a shergottite magma would need to flow over a pre-existing (possibly sedimentary) sulfide-rich formation. The assimilation of sulfur by the magma would result in formation of immiscible Ni-Cu sulfide droplets, and loss of Ni-Cu and platinum group elements to a basal ore deposit. Here, we report the first evidence of potential orthomagmatic mineralization in two ancient, 2.4 Ga, shergottites [2-3] involving a two-step process: formation of sulfide-rich Fe-Zn deposits assimilated by shergottite magmas leading to formation of orthomagmatic Ni-S deposits. These deposits may remain on Mars, but the telltale signs of Fe-Zn enrichment and Ni-Co depletion in the two shergottites speak to their formation conditions. In a related study, Yang et al. [4] reported on unusual Zn enrichments in olivine from NWA 8159 and pyroxenes from both NWA 7635 and NWA 8159. We further argue that the "evolved" character of these shergottites is due to Fe-assimilation rather than from intense fractional crystallization.

Samples and Analytical Methology: The ancient shergottites NWA 7635 [2] and NWA 8159 [3] were analyzed for elemental abundances in their plagioclase, pyroxene and olivine mineral grains by laser ablation ICP-MS [4-5]. Plagioclase and pyroxene from QUE 94201 were analyzed to establish magmatic fractionation trends for depleted shergottites.

Results: In this study, we report that Ni and Co abundances in olivines and/or pyroxenes from NWA 8159, NWA 7635 and QUE 94201, three depleted shergottites that share a large range in Mg#, are exceptionally low. For example, in NWA 7635 olivine Ni ranges from 6-12 ppm at an Mg# of ~40, and in NWA 8159 olivine Ni ranges from 12-15 ppm at Mg# ~ 37; pyroxene from NWA 8159 and NWA 7635 has <5 ppm Ni. Both olivine and pyroxene in NWA 7635 and NWA 8159 have Co a factor of two lower than for other shergottites. There are striking enrichments in Zn in olivine (400-700 ppm Zn vs. 200 ppm Zn in depleted shergottites) and pyroxene from NWA 7635 relative to the trends defined by other shergottites [4]. Higher Zn and Pb are also evident in plagioclase grains from NWA 7635 and NWA 8159, but not in plagioclases from other depleted shergottites.

Discussion: The low Mg# of the three depleted shergottites has been previously considered to be the result of intense fractional crystallization of the parental magmas for these shergottites [2-3]. We propose that an encounter of the parental magma(s) of these two shergottites with an Fe-Zn-S ore would result in Fe-contamination driving down the Mg# more than by fractional crystallization alone. Assimilation of S-rich material by the magmas would result in sulfide saturation, followed by extreme Ni, Co and possibly Cu loss to an immiscible sulfide liquid resulting in the extreme depletions of Ni and Co observed.

One key piece of evidence for the lack of extreme fractional crystallization in the ancient shergottites comes from incompatible element abundances plotted vs. Mg#. Fractional crystallization defines a trend of Th, Nb, La, etc., vs. Mg# for depleted shergottites. The abundances of highly incompatible elements in the two ancient shergottites would be expected to plot on the high end of the abundance range as these rocks have the lowest Mg#s, as seen for QUE 94201. Instead, incompatible element abundances are lower in the two ancient shergottites than in any of the other depleted shergottites, except those with Mg# ~65-70. To assess whether this was the result of partial melting of an ultra-depleted source, the incompatible element abundances of the depleted shergottites were compared. The two ancient shergottites exhibit systematically lower incompatible element abundances while having exactly the same relative depletion pattern in all incompatible elements as other depleted shergottites, e.g. QUE 94201. Based on the low incompatible element abundances, the high Zn, low Mg# and low Ni and Co abundances, we conclude that the two ancient shergottites represent residual magma(s) after assimilation of sulfide followed by loss of an immiscible sulfide liquid. As anticipated by [1], these two shergottites provide the first evidence of sulfide mineralization of potentially economic interest on ancient Mars. This evidence implies the existence of Fe-Zn-S ores formed prior to 2.4 Ga, followed by Ni(±Cu)-S ores formed coevally with the emplacement of the magmas of NWA 8159 and NWA 7635. Further, this finding indicates that at a minimum S, Fe, Zn and Pb isotopic compositions within these meteorites provide clues to surface processes on ancient Mars.

References: [1] Baumgartner R. J. et al. (2015) *Ore Geology Reviews* 65: 400-412. [2] T. Lapen et al. (2017) *Sci. Adv. 3,* e1600922. [3] C. Herd et al. (2017) *GCA 218:* 1-26. [4] S. Yang et al. (2019) *LPSC* 50, abstract # 1908. [5] Yang S. et al. (2018) *Geochem. Geophys. Geosyst.* 19, (https://doi.org/10.1029/2018GC007593).