DO EARLY LIQUIDUS PHASES IN OLIVINE-PHYRIC MARTIAN BASALTS REFLECT THE CHARACTERISTICS OF THEIR MANTLE SOURCES? INSIGHTS FROM NWA 1110, NWA 1195, AND NWA 2046.

C.K. Shearer[1], L.E. Borg[1], J.J. Papike[1], J. Chaklader[1], S. J. Symes[2] , A.J. Irving[3] , C.D.K. Herd[4], [1]Institute of Meteoritics, Department of Earth and Planetary Sciences, University of New Mexico, Albuquerque, N.M. 87131, [2]Department of Chemistry, University of Tennessee-Chattanooga, Chattanooga, TN, 37403, [3]Department of Earth and Space Sciences, University of Washington, Seattle, WA 98195, [4]Department of Earth and Atmospheric Sciences, University of Alberta, Edmonton, Alberta, Canada T6G 2E3. cshearer@unm.edu.

Introduction: Herd et al. [1], Herd [2], Wadhwa [3] and Goodrich et al. [4] demonstrated that the f_{O2} in martian basalts represented by the shergottites varies by 2 to 3 log units and is correlated with geochemical parameters such as LREE/HREE, initial $^{87}Sr/^{86}Sr$, and initial ε_{Nd}. These correlations have been interpreted as indicating the presence of reduced, incompatible element-depleted and oxidized, incompatible element-enriched reservoirs that were produced during early stages of martian differentiation (≈ 4.5 Ga) [1,2,3,4,5,6,7]. Martian basaltic magmatism is thought to represent mixing between these two reservoirs. Whether this mixing process is a product of assimilation (mantle-derived, reduced basalts that assimilated an upper-mantle or lower-crustal oxidized reservoir) or mixing of two mantle reservoirs during melting is still a point of debate. The relationships between f_{O2} and incompatible element characteristics have been determined by two largely independent approaches; f_{O2} from mineral equilibria or multivalent element behavior (Eu) and bulk elemental-isotopic measurements. Here, we evaluate the use of a single phase (olivine) that potentially records simultaneously both the incompatible element behavior and f_{O2} conditions during the earliest stages of martian basalt crystallization.

Analytical Approach: Olivine-phyric martian basalts (NWA 2046, NWA 1195, NWA 1110) were analyzed in this study. Previously, these three shergottites have been studied to varying degrees [i.e. 4,8,9,10,11]. Olivine macrocrysts in these basalts were first imaged and mapped by SEM followed by major element analysis by electron microprobe. A suite of trace elements was analyzed by ion microprobe (Sc, V, Cr, Ti, Mn, Co, Ni, and Y) using previously documented analytical approaches [12]. The rationale for analyzing Y in olivine ($D_{olivine}$~0.01) rather than Sm ($D_{olivine}$≤0.01) is that its higher abundance in olivine results in higher precision. The olivine was analyzed using a JEOL JXA-8200 electron microprobe and a Cameca 4f ims ion microprobe housed in the Institute of Meteoritics at UNM.

Results: Olivine is the first silicate phase on the liquidus of these basalts. Spinel appears to have crystallized during all of or part of the duration of olivine crystallization and may have preceded olivine in some cases. The olivine ranges in texture from anhedral and partially resorbed to subhedral with embayments of groundmass. The olivine compositions in the three olivine-phyric shergottites range from Fo_{82-52} in NWA 2046, Fo_{81-60} in NWA 1195 and Fo_{76-50} in NWA 1110. Ni abundances in olivine are significantly higher in NWA 1110 than in the other two shergottites, whereas the Co abundances in all three overlap (Figure 1). Compared to other olivine-bearing shergottites (Dar al Gani 476, EETA 79001 lithology A, and ALH A77005), the Ni contents in the olivine cores are higher in the three shergottites analyzed in this study (Figure 1). The Co/Ni ratio in NWA 1110 varies slightly with increasing Mn and decreasing Fo, while the Co/Ni ratio substantially increases with increasing Mn and decreasing Fo in NWA 2046 and NWA 1195 (Figure 2). The high Ni cores of all three shergottites have overlapping Ti abundances. Yttrium in the olivine from NWA 1110 is between 1.5 to 2.1 ppm, whereas it is less than 0.2 ppm in the olivine cores of NWA 2046 and NWA 1195.

Discussion: The relationship between Co/Ni and Mn in olivine from shergottites and its potential link to f_{O2} were first documented by Herd et al. [13]. The new data for these three NWA shergottites fit the initial observations of [13] with the relatively oxidized NWA 1110 [4] having a shallow slope and the apparently more reduced NWA 2046 and NWA 1195 having steeper slopes. The cause of this apparent relationship has not been satisfactorily explained. The experimental study by Dwarzski and Herd [14] concluded that changes in f_{O2} on the scale observed in martian basalts did not affect the olivine/melt partitioning behavior of Ni or Co. Also, changes in D_{Ni} and D_{Co} in spinel co-crystallizing with olivine should not affect olivine zoning as these Ds in spinel appear not to be affected by f_{O2} [15]. Dwarzski and Herd [14] explored and rejected the possibility that differences in the degree of subsolidus reequilibration (ALHA, LEW versus EETA, DaG) and differences in diffusivities of Ni,Co, and Mn may have resulted in changes to slope. Our data presented here confirm their conclusions as the data demonstrate substantial differences among basalts with similar subsolidus histories. Differences in f_{O2} change to varying degrees the relative crystallization sequence between spinel and olivine [4,16,17] and result in the compositions of early spinels crystallizing from shergottites [4] to be somewhat different than those considered by [15]. Both manifestations of changing f_{O2} could potentially affect the Co/Ni zoning observed in the olivine. If taken at face value, the Co/Ni-Mn slopes indicate that NWA 2046 and NWA 1195 started crystallizing at f_{O2} 1 to 2 log units more reducing than NWA 1110.

Corresponding to the decrease in f_{O2} implied by the change in Co/Ni –Mn slopes is an order of magnitude decrease in the Y in olivine. This relationship between f_{O2} and incompatible element behavior in olivine is consistent with observations made for the petrogenesis of shergottites and the nature of distinct reservoirs in Mars [1,2,3,5,6,7]. It also has additional significance. First, it indicates that this f_{O2}-incompatible element signature is a characteristic of the shergottitic magmas during the initial stages of crystallization. Therefore, if assimilation of an oxidized-enriched reservoir by basalts derived from reduced-depleted martian mantle is an important process, the crystallization products that would accompany such a process are not represented by the early olivine in these shergottites. This is also supported by the isotopic-bulk rock compositions of meteorites like NWA 1110/1068. These rocks have "primitive" bulk rock and mineral compositions but are derived from sources with elevated LREE/HREE and Rb/Sr. Second, the correlation between f_{O2} and degree of incompatible element enrichments implied by early phases such as olivine (this study) and spinel inclusions in olivine [4] and bulk basalt characteristics may indicate that most, if not all, of the large early-formed olivine grains in shergottites are phenocrysts/cognate megacrysts and not accidental xenocrysts. Although deviations from olivine-melt equilibrium suggested by textural relationships and $K_D^{Mg\text{-}Fe}$ may be interpreted as a xenocrystic origin for olivine, similar features are observed in olivine in small, closed basaltic systems such as the Makaopuhi lava lake [18].

Ni content and Ni-Co crystallization trajectories of olivine (Figure 1) suggest the shergottites represent an array of basaltic magmas with not only distinct incompatible element characteristics and f_{O2} , but also distinct compatible element characteristics. The interactions between the two proposed reservoirs for martian basalts must be capable of generating magmas with an array of Ni concentrations either through different degrees of partial melting or distinct differences in Ni content.

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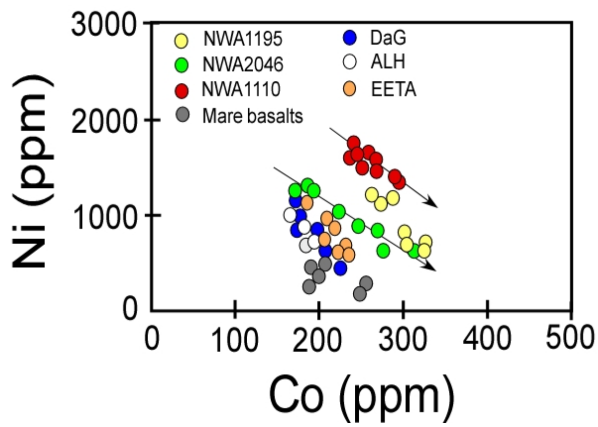

Figure 1. Ni and Co measured in olivine for several olivine-phyric shergottites. NWA1195, NWA2046, NWA1110, and mare basalts are from this study. DaG (Dar al Gani 476), ALH (ALHA 77005) and EETA (EETA 79001) are from Herd et al. [12]. Arrows illustrate crystallization trajectories for two of the meteorites.

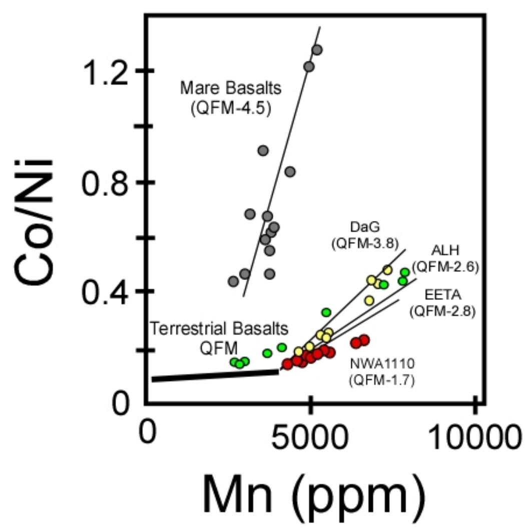

Figure 2. Mn versus Co/Ni in olivine from olivine-phyric and lherzolitic shergottites. Data point symbols are in Fig. 1. Co/Ni versus Mn trajectories for DaG, ALH, EETA are from Herd et al. [12]. Estimates for f_{O2} are from Goodrich et al. [4]. Terrestrial basalt trajectory is simplified from Karner et al. [17].