POROUS, Ca-RICH AGGREGATES AND COMPLEX MINOR ELEMENT DATA OF CHONDRULE PHENOCRYSTS IN THE NORTHWEST AFRICA NWA 2364 CV3$_{OxA}$ CHONDRITE AND ITS LITHIC INCLUSION: EVIDENCE OF FLUID-ROCK INTERACTIONS J. M. Johnson[1] and A. J. Brearley[1], [1]Department of Earth & Planetary Sciences, University of New Mexico, Albuquerque, NM 87131, USA, (jejohnson00@unm.edu)

Introduction: The two subgroups of CV3 chondrites, oxidized and reduced, contain primitive solar system materials such as Calcium Aluminum Inclusions (CAIs), Amoeboid Olivine Aggregates (AOAs), chondrules, and dark inclusions (DIs) [1-2]. Most of the metal in oxidized CVs has been oxidized primarlily to magnetite, whereas Fe,Ni metal is still found abundantly in the reduced subgroup. The two subgroups of the CV3 chondrites exhibit varying degrees and styles of alteration, both thermal and aqueous [1-3]. Dark inclusions represent distinct, finer-grained lithologies that provide additional, important insights into alteration processes on the CV chondrite parent body. They are found in both CV3 subgroups and exhibit an extensive range of alteration [3-6]. The alteration products in CV3 chondrites play an integral role in understanding their alteration history and timing.

The goal of this investigation is to examine chondrule olivine phenocryst compositions within the lithic inclusion (LI) and host, as well as study the textures of the alteration products within the LI using TEM techniques. Using these data, we explore NWA 2364's alteration history and relative timing of this alteration.

Methods: Electron microprobe data were collected from olivine phenocrysts in chondrules in the host and LI using a JEOL 8200 Superprobe using WDS Spectrometry. In addition, a focused ion beam (FIB) section was cut from the lithic inclusion using an FEI Quanta 3D Field Emission Gun SEM/FIB instrument and analyzed using a JEOL 2010F Field Emission Gun Scanning Transmission Electron Microscope (FEG/STEM).

Results: NWA 2364 is an oxidized Allende-like CV3 chondrite that contains mm-sized chondrules, AOAs, and CAIs embedded within a fine-grained matrix consisting of platy, ferroan olivines. Within the host meteorite these components have undergone variable degrees of alteration. Olivine phenocrysts in type IA and rarer type IIA chondrules have been overgrown by ferroan olivine and low-Ca pyroxene has undergone replacement by ferroan olivine along grain boundaries and fractures. Microprobe analyses of type IIA chondrule olivines have Fa values ranging from Fa_{37}-Fa_{47}. The type IA chondrule phenocrysts range from $Fa_{0.3}$-Fa_{42}.

The LI of NWA 2364 is very fine-grained in comparison to the host and the alteration is more extensive. The matrix of the LI contains very fine-grained platy, ferroan olivines with porous Ca-rich aggregates that are typically tens of microns in size. It contains smaller chondrules (type IA and a few rare IIA), as well as many fragmented, isolated grains. Similar to the host, the interior of the chondrules are fractured and forsteritic phenocryst rims have ferroan overgrowths. The type IIA chondrule phenocrysts range from Fa_{21}-Fa_{45} and the type IA chondrule phenocrysts range from $Fa_{0.2}$-Fa_{44}. The chondrule phenocrysts in the LI have undergone more extensive alteration than those in the host chondrite. All of the altered chondrules are surrounded by distinct rims of finer-grained, platy ferroan olivines, which we interpret as representing fine-grained rims that have been modified by alteration.

Minor element data for olivine phenocrysts from type IA and IIA chondrules show interesting relationships between core and rim compositions (Figure 1). In the host chondrite, olivine phenocrysts in type IA chondrules have core compositions with lower MnO and FeO contents than the rims. The rims of the phenocrysts show a wide range of FeO contents from ~2-36 wt.% FeO, but there is no obvious linear correlation between FeO and MnO. However, in the LI FeO vs. MnO data show a consistent increase in MnO content from the phenocryst cores to the rim as FeO increases. Overall the Cr_2O_3 in the host shows an increase toward the rims of the phenocrysts as FeO increases. The LI shows a very similar relationship for both phenocryst cores and rims with Cr_2O_3 contents increasing with FeO. The Cr_2O_3 is lowest for the Mg-rich compositions, but increases when FeO contents reach 22 wt.%.

Although we have limited data, in the host type IIA chondrules, olivine phenocryst MnO contents are very similar from the cores to the rims and there is no apparent correlation with FeO content. The Cr_2O_3 data also show no significant increase from phenocryst core to rim, as FeO increases. The LI data show an increase in MnO as FeO increases from phenocryst core to rim. This is also seen in the LI type IA chondrule phenocryst core and rim values. The Cr_2O_3 data also show an increase from cores to rims as FeO increases. As seen in the type IA chondrules, there is a distinct value of ~36 wt.% FeO where the Cr_2O_3 increases and becomes more variable, but the increase in Cr is much less in the type IA olivine phenocrysts.

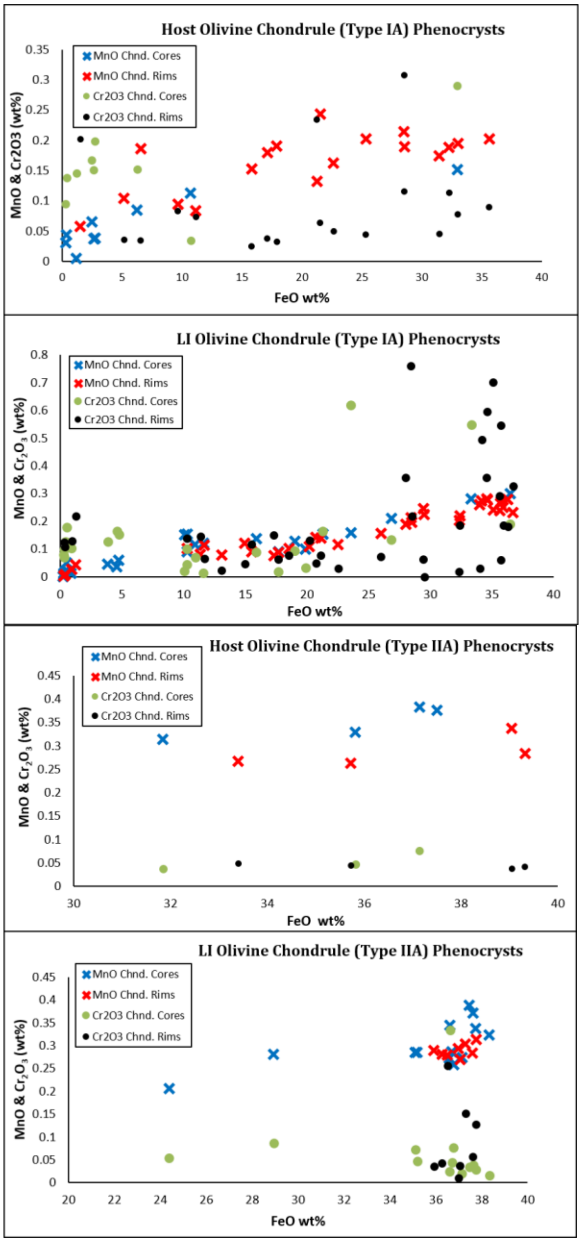

Figure 1: Minor element data for olivine phenocrysts in type IIA and type IA chondrules in the LI and host.

A FIB section was taken from a fine-grained porous Ca-rich aggregate within the LI. STEM shows that compositionally heterogeneous Ca-rich pyroxenes are the dominant phase present within the aggregates. These grains show extremely complex zoning with variations in Fe content that range from Fs_5 to Fs_{41} on a <1 µm scale. The aggregate is extremely porous, with highly variable pore sizes ranging from <1µm to a few microns. The pores are heterogeneously dispersed throughout the aggregate occurring between grains and within them (Figure 2). Some of the Ca-rich pyroxenes have a fibrous, elongate morphology with void space in between them whereas most grains occur as more equant, anhedral grains that are intergrown with one another. A sawtooth texture is observed along the margins of some of the altered Ca-rich pyroxenes and larger voids that may be indicative of dissolution (Figure 2).

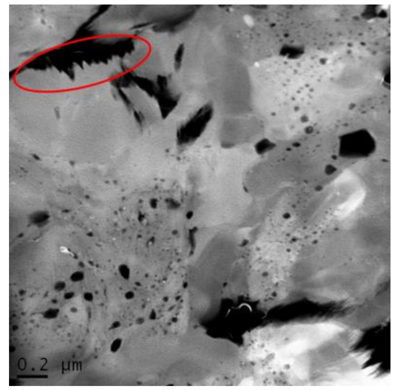

Figure 2: Transmission electron micrograph showing a complex region of the Ca-rich aggregate within the LI.

Discussion: Previous SEM and oxygen isotope studies have provided evidence that the host and the LI have undergone a complex alteration history, the LI more so than the host [7-8]. The porous nature of the Ca-rich aggregates, the saw-tooth texture, and the complex zoning of the pyroxenes all indicate fluid-rock interactions.

EPMA data show that the chondrule olivine phenocryst compositions have undergone significant compositional equilibration during metamorphism. However, the effects of this process vary depending on the starting composition of the chondrule. As the FeO content increases in the type IA chondrule phenocrysts from exchange of Fe with the surrounding matrix, the MnO content increases. In the type IIA chondrules, the starting composition is higher in Fe than the type IAs, and is already close to the Fe content of the ferroan rims on type IAs. The Cr_2O_3 contents in the type IIA olivines are low and never increase to the values observed in the rims of type IA chondrule phenocrysts. Compared with the core compositions, some type IIA chondrule phenocrysts appear to show a decrease in MnO content, and have MnO contents similar to those found on the rims of type I chondrules.

Acknowledgements: Research funded by NASA Grant NNX15AD28G to A.J. Brearley (PI).

References: [1] McSween H.Y., Jr (1977) *Geochim. Cosmochim Acta* 41, 1777-1790. [2] Krot A.N., et al. (1995) *Meteoritics*, 30. 748-775. [3] Grossman, L. (1972) *Geochim. Cosmochim Acta* 36, 597-619. [4] Kurat G. et al. (1989) *Z. Naturforsch.* 44a, 988-1004. [5] Buchannon P.C., et al. (1997) *Geochim Cosmochim Acta* 61, 1733-1743. [6] Krot A.N. et al. (1999) *Meteoritics*, 34, 597-619. [7] Johnson J.M. and Brearley A.J. (2017) *LPS XLVIII*, Abstract 2459. [8] Johnson J.M. et al. (2017) *Metsoc LXXX*, Abstract 6279.