ALTERATION HISTORY OF A LARGE LITHIC INCLUSION IN THE NORTHWEST AFRICA NWA 2364 CV3OA CHONDRITE: EVIDENCE FOR HYDRATION FOLLOWED BY FLUID-ASSISTED THERMAL METAMORPHISM J. M. Johnson¹ and A. J. Brearley¹, ¹Department of Earth & Planetary Sciences, The University of New Mexico, , Albuquerque, NM 87131, USA, (jejohnson00@unm.edu).

Introduction: CV3 chondrites contain some of the most primitive material in the solar system, making them an important chondrite group for providing information about processes that occurred during the earliest history of the solar system. The two CV3 chondrite subgroups, oxidized and reduced [1], share many similarities, including the presence of Calcium-Aluminum-Rich inclusions (CAIs), chondrules, and dark inclusions (DIs), but differ significantly in their style and degree of secondary alteration [1, 2]. The reduced CV3 chondrites are characterized by the presence of common Fe, Ni metal, whereas in the oxidized CV3 chondrites, magnetite formed by the oxidation of metal is the most abundant opaque phase. The secondary alteration of the oxidized CV3 chondrites provides a plethora of information as to the alteration history of the CV3 chondrites and a possible location for that alteration, including nebular and parent body scenarios. Several different types of DIs, designated as A, B, A/B, and C [2], occur in both oxidized and reduced CV3 chondrites and appear to be distinct lithologies from the CV3 chondrite parent body [3,4] that have experienced a range of different styles of alteration [3-7]. The DIs are found to be finer grained in texture and more altered than the host chondrites. Therefore studies of these inclusions and their relationship to the host, provide important additional insights into the conditions and relative timing of alteration processes on the CV3 chondrite parent body.

In this study, we have studied a thin section of the NWA 2364 CV3OA that contains an unusually large lithic inclusion (LI). The goal of this investigation is to explore the mineralogy and petrology of the components of the host chondrite and the lithic inclusion in an effort to understand their alteration histories and determine the relative timing of alteration.

Methods: A polished thin section of NWA 2364 was studied using an FEI Quanta 3D Field Emission Gun SEM. High resolution BSE images were as well as X-ray elemental maps were taken of the host and lithic inclusion. In addition, preliminary microprobe data of phases in the host and LI were obtained using a JEOL 8200 Superprobe using WDS spectrometry.

Results: On the polished surface of the hand specimen, the lithic inclusion is approximately rectangular in shape, with dimensions of ~1.5 cms by 1 cm. Unlike typical DIs in CV3 chondrites, it is not dark in appearance, but is light gray-brown in color and is evidently much finer-grained than the host chondrite. A distinct darker, finer-grained layer is also apparent around the edge of the inclusion. The host chondrite has a red-brown coloration, typical of terrestrial weathering that has affected hot desert meteorites, but veins of Fe oxyhydroxide are not apparent in the thin section.

Host meteorite: The NWA 2364 host shows the typical texture of a CV3 chondrite consisting of mm-sized chondrules, AOAs and CAIs embedded within a matrix of platy elongate ferroan olivine. These macroscopic components all manifest the typical evidence of alteration found in CV3 chondrites. Chondrules have undergone variable amounts of alteration that is typically most advanced around their exteriors. Enstatite in chondrules has been extensively replaced by ferroan olivine, overgrowths of ferroan olivine are present on forsteritic olivine grains in type IA chondrules, and metal grains have been replaced by magnetite. Chondrule glass in some chondrules shows replacement by nepheline and sodalite on the exterior of the chondrule. Interstitial to the chondrules is a finer grained, porous matrix composed of mainly elongated olivines.

Lithic inclusion: The LI is much finer-grained than the host chondrite. It is dominated by a fine-grained, olivine-rich matrix, in which are embedded a small number of type IA chondrules and rarer type IIA chon-
drules. The matrix itself consists dominantly of elongate, platy olivines which show a range of grain sizes. Fine-grained rims are apparent surrounding the chondrules, consisting of finer-grained ferroan olivines. Both type IA and type IIA chondrules in the inclusions have undergone extensive alteration that is much more advanced and texturally distinct from the host chondrite. In type IA chondrules, all pyroxene and mesostasis glass has been replaced by porous aggregates of ferroan olivines and overgrowths of ferroan olivine are present along the rims of forsterite phenocrysts.

Unlike the host chondrite, ferroan olivines in type IIA chondrules also show extensive evidence of alteration. In this case, veins of more Fe-rich olivine are present crosscutting olivine phenocrysts. The centers of these veins are often porous and contain crystallographically-oriented, platy olivines that are oriented with their long axis normal to the surface of the vein (Figure 1). The interface between the vein ferroan olivine and the phenocryst olivine are serrated, reminiscent of serpentinized olivines in CM2 chondrites [8,9].

X-ray maps of the dark inclusion reveal several important compositional and mineralogical characteristics of the inclusion. First, there is an sinuous and almost continuous rim of Ca-rich pyroxene and grossular around the periphery of the inclusion along the contact of the host chondrite. A zone of Ca depletion is also apparent around the outer part of the inclusion. Compared with the host chondrite, there is no evidence of any Na or Cl-bearing phases at all in the inclusion and sulfide phases are completely absent.

Discussion: Although the LI in NWA 2364 is not dark in appearance compared with the host, its mineralogy is entirely consistent with those of typical DIs in Allende and other CV_{6} chondrites. This observation demonstrates that the term ‘dark inclusion’ is therefore something of an anachronism. The NWA 2364 LI is clearly a transitional type A/B “dark” inclusion in terms of textural and mineralogical characteristics.

From our observations we can draw several conclusions about the history of this inclusion. The LI appears to have experienced extensive metasomatism prior to its emplacement into the Allende parent body. This conclusion is based on the complete absence of Na- and S-bearing phases, indicating extensive dissolution and removal of these elements by aqueous fluids.

Further evidence of the involvement of fluids is indicated by the style of alteration observed in ferroan olivines in type IIA chondrules. The alteration textures bear very close similarities to serpentinized olivines in CM2 chondrites [8,9] and is a texture that has not been described before in DIs. However the absence of serpentine, but the presence of oriented, platy ferroan olivines raises again the possibility that the formation of ferroan olivine in these chondrules may well be the result of dehydration of serpentine [10]. This hypothesis remains to be tested by oxygen isotopic studies of the LI to determine if there is evidence of a heavy isotope enrichment.

The LI also appears to have undergone interaction with the host chondrite following its emplacement. This is indicated by the rim of Ca-rich pyroxenes around the periphery of the inclusion as well as the zone Ca depletion in the outer part of the inclusion. These features indicate that the LI underwent fluid-rock interactions with the host rock, resulting in the leaching of Ca from the inclusion and its precipitation at a geochemical reaction front, represented by the boundary of the inclusion with the host. This process has been previously described for a DI from Allende [7], demonstrating that emplacement of lithic clasts into CV_{6} host material while fluid-rock interactions were occurring in the host is not uncommon.

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