AQUEOUS ALTERATION EFFECTS IN CHONDRULES IN THE MOST PRISTINE CR2 CHONDRITE, QUEEN ALEXANDRA RANGE (QUE) 99177: FURTHER INSIGHTS INTO THE EARLIEST STAGES OF FLUID-ROCK INTERACTION ON THE CR CHONDRITE PARENT BODY. M. Martínez-Jiménez[1] and A. J. Brearley[1], [1]Department of Earth and Planetary Sciences, University of New Mexico, Albuquerque, NM 87131, USA (mmartinezjimenez@unm.edu).

Introduction: The CR carbonaceous chondrites are a primitive group of meteorites that preserve a remarkable record of early solar system processes [1-3]. In addition, the CR chondrites are unique in showing a very wide range of aqueous alteration, ranging from almost completely unaltered (type 2.8) to fully hydrated (type 1). Paradoxically, despite showing evidence of variable degrees of alteration, the CR2 chondrites show only a very small range of bulk water contents, suggesting that they have all been hydrated to a similar degree [3,4]. This discrepancy suggests that additional factors, such as the temperature or duration of aqueous alteration, are also important in determining the degree of alteration. Previous studies suggested that Queen Alexandra Range (QUE) 99177 is one of the least-altered CR chondrites, indicated by the presence of clear, unaltered chondrule glass, minimally-altered fine-grained matrix, high presolar grain abundance [2,3,5] and light bulk oxygen isotopic composition [6]. However, recent studies have argued that QUE 99177 is actually more altered than was previously recognized [3,4,7,8]. This dichotomy emphasizes the importance of developing a full understanding of aqueous alteration in the CR chondrites.

In any case, the key point is that many members of the CR2 group are much less altered than any known CM2 chondrite. Notably, many CR2 chondrites preserve pristine chondrule glass [2,9], which is only very rarely present in CM2 chondrites. Therefore these meteorites provide a unique opportunity to study the effects of the earliest stages of fluid-rock interaction on matrix and chondrules.

In this study, we have focused on evaluating if and how chondrules have been affected by aqueous alteration in QUE 99177, the most pristine CR2 chondrite known. In particular, we want to understand the interaction between matrix and chondrules during the earliest stages of alteration and determine the extent of elemental mass transport between them. This work extends our previous studies of chondrule glass alteration in type IIA chondrules in several more-altered CR chondrites [9-11].

Methods: Two polished thin sections of QUE 99177 have been studied using back-scattered electron (BSE) imaging on a FEI Quanta 3D FEG-SEM/FIB. Full spectral X-ray maps of the entire thin sections and selected regions of interest were obtained by EDS spectroscopy. Cathodoluminescence (CL) analyzes of selected chondrules were performed using a TESCAN VEGA3 Scanning Electron Microscope, followed by WDS microprobe analyses using a JEOL 8200 Superprobe. A FIB section was prepared from the edge of a type IIA chondrule and was studied by transmission electron microscopy using a JEOL 2010F FEGSTEM instrument operating at 200 kV.

Results: As determined from previous studies [2, 6], QUE 99177 is dominated by type IA chondrules, although rare type IIAs are also found. In most type I chondrules, the mesostasis is largely crystalline, but small regions of glass are also present. Many chondrules are surrounded by smooth rims within the matrix [7]. We have examined the different aqueous alteration effects observed at the interface between chondrules and matrix in both type I and type II chondrules.

Alteration of silica. Whole thin section X-ray maps of QUE 99177,19 show that 19 type I chondrules out of 51 (37%) have silica-bearing rims, with typical thicknesses of 10-20 µm. In comparison, [7] noted that only one chondrule had a silica-bearing rim in their studied section of QUE 99177. Such rims are a common feature of type I chondrules in CR chondrites [12]. In most cases, silica grains occur continuously along the edges of the chondrules, occupying ~70-80% of the circumference, but occasionally higher. Some chondrules are fragmented and only part of the circumference is covered by silica. Silica grains have a purple color in CL images, while chondrule mesostasis is redder. Silica occurs as rounded, isolated grains ~10 µm in size, associated with mesostasis, or alternatively, it displays a "honeycomb" texture described by [13], associated with pyroxene. The honeycomb texture is the result of replacement of silica by an Fe-rich silicate phase. The degree of replacement of silica grains by the Fe-rich phase is similar for all the chondrules studied.

Alteration of chondrule glass. Unlike the observations of [7], we find that clear, isotropic glass is commonly present in QUE 99177 chondrules. Glass containing quench crystallites of pyroxene is present in both rare type IIA chondrules and type IA chondrules. EPMA analyzes and X-ray maps of a type IIA porphyritic olivine chondrule reveal that the glass is Na-rich, with variable Na_2O contents ranging from ~4 to ~12 wt% (8.01 % ave.) and similar concentrations of CaO and K_2O (~1.6 wt%). The glass also contains 0.5 to 4.3 wt% P_2O_5. We have examined the contact between pristine chondrule glass and matrix in this chondrule using FIB/TEM techniques. The mesostasis at the edge of the chondrule is complex, consisting of elongate grains of Ca-phosphate and occasional elongate, primary albite grains embedded within glass. On the very periphery of the chondrule there is a narrow zone (~10-20 μm) of distinct Fe-enrichment, which appears to be altered chondrule glass. The FIB section shows that this Fe enrichment is due to the presence of a fibrous phase which may be a phyllosilicate, but has not been characterized yet. The fibrous phase is directly in contact with pristine, unaltered Na-rich glass and is clearly replacing the glass along a highly irregular, but extremely sharp interface (Fig.1). The textural characteristics of the phosphate grains embedded within the glass indicate that they are primary. However, some phosphate grains show evidence of alteration that has probably resulted in mobilization of Ca and P (Fig.1).

Sodium and K are present in small areas of the glass, which is intimately associated with silica in the silica-bearing rims on type I chondrules. Unlike the associated silica, the glass shows no evidence of aqueous alteration in any of the 12 chondrules studied. Completely pristine chondrule glass occurs in direct contact with matrix and the Fe-rich alteration product of silica.

Discussion: Our new observations of QUE 99177 chondrules disagree with the previous observations of [7]. We find that unaltered chondrule glass is widely present in chondrules in the two thin sections of QUE 99177 that we have studied. However, our studies show that during the earliest stages of aqueous alteration, very subtle modifications of the texture and composition have occurred at the edges of chondrules in contact with the hydrated matrix. Notably, fine-grained silica in silica-bearing rims has been partially pseudomorphed by an Fe-rich silicate phase, with a composition consistent with previous studies [12,14]. Based on our previous work on altered silica in EET 92042 [14], we suggest that this phase is likely to be an amorphous Fe-rich silicate gel. These observations show that silica is highly unstable during the earliest stages of alteration and is therefore an excellent indicator of incipient alteration of chondrules. In contrast, mesostasis glass shows very minimal to no evidence of replacement by hydrous phases. Our observations reveal that only the most silica-poor glass compositions, found in type IIA chondrules, show evidence of replacement and this has only occurred in a <20 μm width zone on the edge of the chondrule. We conclude then that chondrules have been extremely minimally affected by aqueous alteration and are, to all intents and purposes, pristine.

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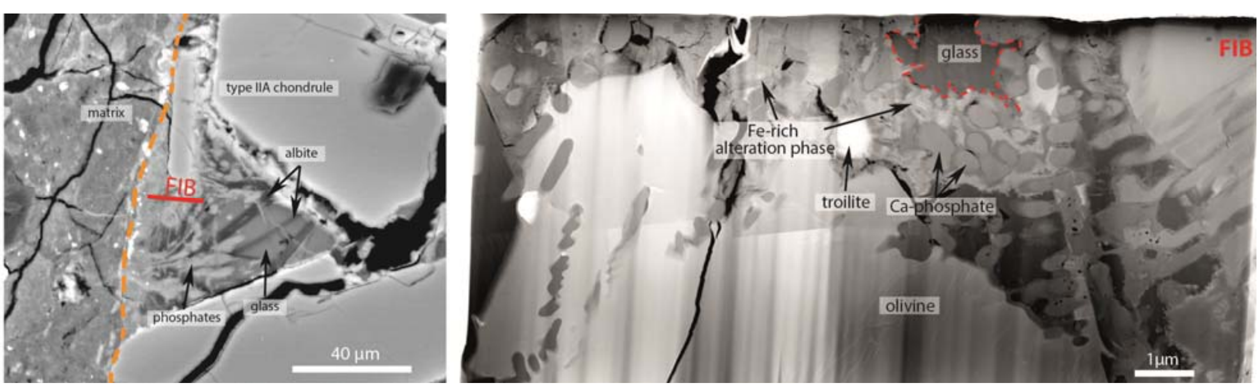

Fig. 1. SEM image (left) of the edge of a type IIA chondrule where clear isotropic glass is in contact with matrix. Right – dark-field STEM mosaic of the FIB section marked in red on the SEM image. Ca phosphate occurs embedded within both unaltered chondrule glass (dark gray) and within the Fe-rich alteration product of the glass, indicating that it is primary and not secondary in origin.