ALKALI FELDSPAR EXSOLUTION IN ORDINARY CHONDRITES: ALKALI METASOMATISM, METAMORHPISM, AND COOLING RATES. J. A. Lewis[1], R. H. Jones[1,2], and A. J. Brearley[1], [1]Dept. of Earth and Planetary Sciences, University of New Mexico, Albuquerque, NM 87131. jlewis11@unm.edu. [2]School of Earth, Atmospheric and Environmental Sciences, University of Manchester, Manchester, M13 9PL, UK.

Introduction: Plagioclase feldspar within chondrules of ordinary chondrites (OCs) is typically a secondary mineral that forms from the crystallization of chondrule mesostasis during thermal metamorphism on the parent asteroid [1]. Also, some plagioclase is a primary igneous phase [2]. In L and LL chondrites, plagioclase with a wide range of compositions equilibrates to more albitic compositions with increasing metamorphism, ultimately resulting in a single plagioclase composition (~$An_{12}Or_6$) by petrologic type 6 [3-5]. Plagioclase in H chondrites has equilibrated to albite by petrologic type 4 [3,4].

While alkali feldspar in OCs is predominantly albitic, K-feldspar exsolution has been reported in a number of meteorites. [3-6] showed K-feldspar lamellae in areas of albite produced by alkali metasomatism of anorthitic plagioclase in type 5 L and LL chondrites. We have also shown K-feldspar exsolution in type 4 H, L, and LL chondrites [3,7-8] as well as rare lamellae in the LL3.6 chondrite Parnallee [8]. K-feldspar exsolution has also been described in the samples returned from asteroid Itokawa, compositionally and texturally described as a type 5 LL chondrite [9-10].

Alkali feldspar exsolution textures can be a powerful tool for determining equilibration temperatures and cooling rates. Also, an understanding of the occurrences of alkali-rich phases in OCs can be used to characterize the transport of volatile species during chondrite metamorphism. Here we compare the occurrences and textures of K-feldspar within chondrules of a range of OCs across all OC petrologic types and groups.

Analytical Methods: We examined K-feldspar exsolution textures in thin sections of Parnallee (LL3.6) UNM 1018, Dhajala (H3.8) UNM 301, Bjurböle (L/LL4) UNM 117, Saratov (L4) UNM 1145, Santa Barbara (L4) UNM 120, Avanhandava (H4) UNM 88, Tuxtuac (LL5) UNM 627, and Sulagiri (LL6) UNM 1160. Alkali feldspar was imaged and identified with BSE imaging and EDS analysis using an FEI Quanta 3D FEG-SEM at 10 kV and 16 nA. A FIB section was extracted from Avanhandava Ch 6 using an FEI Quanta 3D Dualbeam® FIB with a final polish at 5 kV and 50 pA to reduce beam amorphization. The section was imaged using HAADF imaging on a JEOL 2010F FEG STEM, operating at 200 kV.

Results: K-feldspar exsolution is rare in the type 3 OCs Parnallee (LL3.6) and Dhajala (H3.8) and only present as small (<0.3 µm wide), isolated lamellae (Fig. 1a). We have previously studied feldspar in several type 3 LL chondrites and K-feldspar was not observed in petrologic types lower than type 3.6 [8].

Exsolution is much more common in type 4 OCs and shows a range of textures. In Saratov (L4), Santa Barbara (L4), and Bjurböle (L/LL4), K-feldspar is observed exsolving out of laths of primary albite with lamellae (up to 1 µm wide) perpendicular to the c-axis (Fig. 1b). Primary albite laths in these meteorites are often surrounded by fine-grained secondary albite (with clinopyroxene and chromite) crystallized from chondrule mesostasis (Fig. 1b). This secondary albite also often contains abundant sub-micron K-feldspar lamellae. In the type 4 L and L/LL chondrites we also observed small, isolated K-feldspar lamellae in regions of albitized anorthite (Fig. 1c). Albitization typically occurs near voids or along grain boundaries. In addition, all type 4 chondrites studied contain patches of K-feldspar adjacent to voids, particularly near chondrule perimeters.

The H4 Avanhandava contains several chondrules with much more extensive K-feldspar exsolution than the other type 4 OCs, with lamellae ranging from 0.2-1 µm in width (Fig. 1d). A FIB section extracted from chondrule 6 shows two sets of exsolution textures: the K-feldspar exsolution (0.2-0.3 µm wide) from albitic plagioclase and a peristerite intergrowth within the plagioclase-rich zones (Fig. 1e).

Isolated K-feldspar lamellae in albitic plagioclase in LL5 Tuxtuac are generally larger than in type 3 and 4 OCs (up to 1.2 µm wide) but are much less common than in type 4 (Fig. 1f, right). Large patches (~10-30 µm) of K-feldspar are common near voids (Fig. 1f, left). In Sulagiri (LL6), K-feldspar lamellae are rare but patches of K-feldspar are more common (Fig. 1g). These patches do not necessarily occur near voids, but like in types 4 and 5, they are more common near the perimeter of relict chondrules.

Discussion: Our understanding of plagioclase in OCs is that albitization most likely occurs as a result of metasomatism during metamorphism [3-8]. Alkali-rich fluids responsible for albitization must also contain K: both alkali elements may be derived from chondrule mesostasis and/or chondrite matrix. K-feldspar then exolves from the albitic plagioclase during cooling.

Because K-feldspar is only observed as a secondary mineral, the abundance of K-feldspar exsolution in plagioclase is related to the amount of available K and the temperature at which K is initially incorporated into the plagioclase structure [e.g. 11]. The rarity of K-feldspar in type 3s is probably because metamorphic temperatures are not high enough to incorporate significant amounts of K into newly forming plagioclase. The lower temperatures may also mean more K is retained in the matrix and mesostasis, reducing its overall availability. Petrologic type 4 chondrites reached higher temperatures, 500-800ºC [12], increasing availability and mobility of K, and allowing for more K to be incorporated into plagioclase. The lower abundance of K-feldspar in types 5 and 6 relative to type 4 may be explained by the increased abundance of albitic plagioclase within chondrules and in recrystallized matrix. In other words, the total amount of K available could be diluted over a larger volume of plagioclase.

The K-feldspar patches observed in types 4-6 (Figs. 1f,g) could be the result of interaction between albite and K-rich fluids. These patches commonly occur adjacent to voids through which the fluid could have propagated. This mechanism would imply that the fluid composition became progressively more K-rich.

The fine-scale nature of K-feldspar exsolution was suggested by [6] to indicate rapid cooling (~1ºC per 10 years) that is inconsistent with the slow cooling rates from metallographic measurements (~1ºC per 10^4-10^6 years). Our SEM observations of fine-scale exsolution through the petrologic sequence reinforces this inconsistency. In addition, our TEM observations provide further evidence of extremely fine-scale exsolution structures which could not have reasonably persisted for millions of years. This inconsistency in cooling rates, which must have occurred over a similar temperature range (~500-600 °C), is difficult to reconcile.

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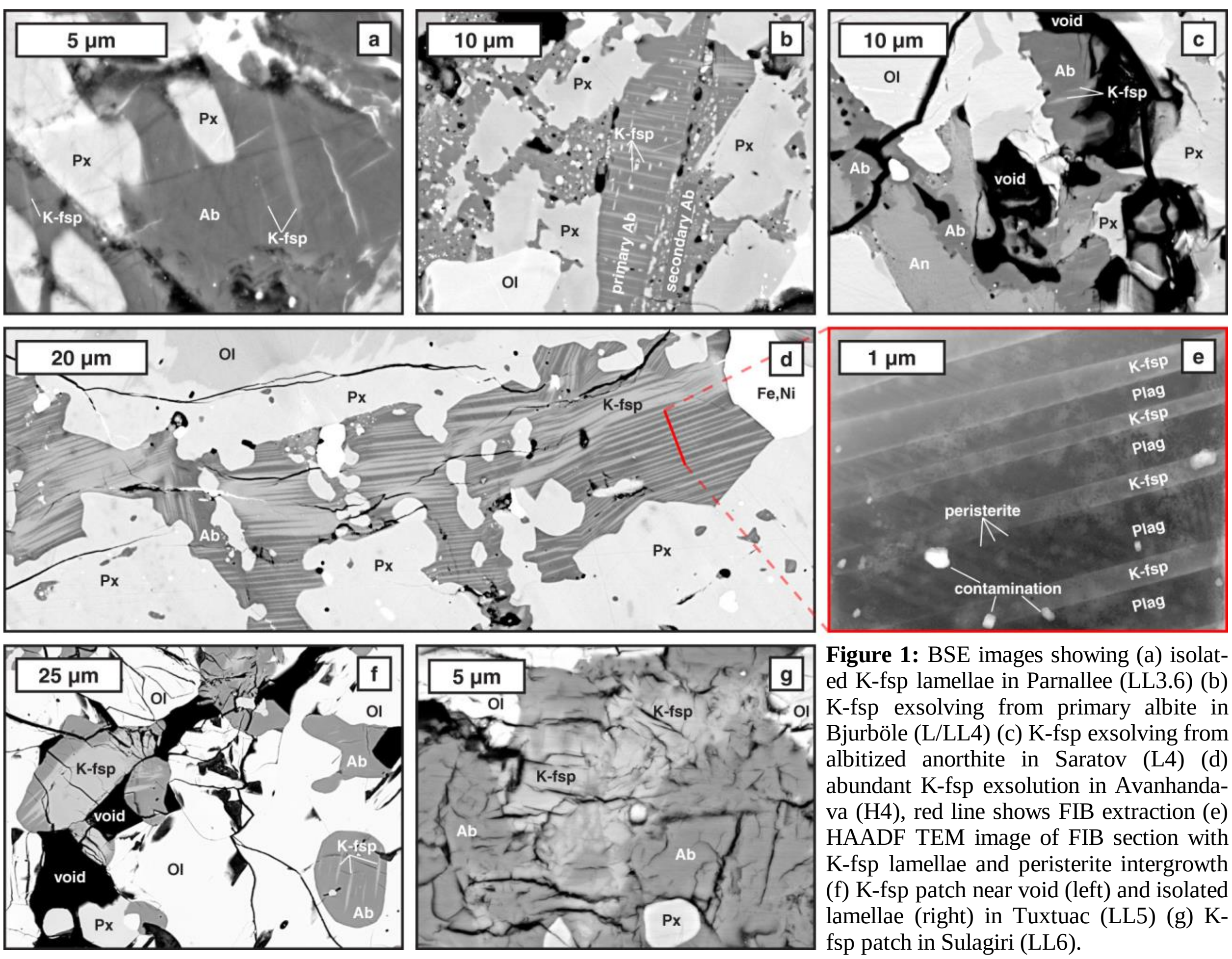

Figure 1: BSE images showing (a) isolated K-fsp lamellae in Parnallee (LL3.6) (b) K-fsp exsolving from primary albite in Bjurböle (L/LL4) (c) K-fsp exsolving from albitized anorthite in Saratov (L4) (d) abundant K-fsp exsolution in Avanhandava (H4), red line shows FIB extraction (e) HAADF TEM image of FIB section with K-fsp lamellae and peristerite intergrowth (f) K-fsp patch near void (left) and isolated lamellae (right) in Tuxtuac (LL5) (g) K-fsp patch in Sulagiri (LL6).