Nephelinization and Metasomatism in the Ordinary Chondrite Parnallee (LL3.6)

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Quick Summary

- CO-like nephelinization of anorthite is present in the OC Parnallee (LL3.6) indicating alkali metasomatism.
- The replaced anorthite appears to be a primary igneous mineral.
- Cl is also present in nephelinized regions indicating the Cl was present in the fluid in addition to Na.
- Dissolution lamellae also indicate the action of fluids.

Introduction

- OC Metamorphism shows a characteristic trend from unmetamorphosed petrologic type 3.0 through fully recrystallized type 6. Feldspar within relict chondrules in type 4-6 chondrites is commonly thought to be formed by recrystallization of chondrule mesostasis during metamorphism [1].
- Fluids are not typically considered to play a signifcant role during the metamorphic process. However, there is evidence for the presence and action of fluids on the OC parent bodies: anorthitic feldspar in LL4 chondrites shows albitization and dissolution lamellae [2], and phosphate minerals have properties such as porous textures [3].
- In petrologic type 3.2-3.7 CO chondrites, nepheline is known to replace anorthite within chondrules [4] and refractory inclusions [5], in reactions believed to be the result of alkali metasomatism.
- Nepheline has rarely been described in ordinary chondrites but has been previously identified in LL3.6 Parnallee in an igneous inclusion [6] and in chondrules [7]. However, nepheline identified in these studies occurs in fine grained assemblages which show little relation to the replacement textures seen in CO chondrites.
- **We have found CO-like nephelinization textures within chondrules of Parnallee.** This adds to the evidence for alkali metasomatism on the LL parent body.

Results

- **Nepheline is observed in a texture that indicates anorthite replacement in 5 relict porhyritic olivine-pyroxene chondrules (Chs 1, 3, 4, 5, and 7).** The replacement texture appears to be crystallographically controlled and commonly occurs in multiple series of parallel lamellae as well as more massive areas (Fig. 1a,b). In Ch3, nephelinization is accompanied by 0.5-1.5 µm diameter silica rich nodules with Fe-bearing pyroxene rims (Fig. 1b,c). Some of the anorthite grains show twinning which is preserved in the nephelinized regions (Fig. 2).
- **Three chondrules contain feldspar but no nephelinization (Chs 2, 8, and 9).** Ch2 contains fine-grained anorthite and may include minor fine-grained nepheline, but the replacement texture was not seen. In Ch8, anorthite contains dissolution lamellae (Fig. 3a,b) and albitization along the edges of the anorthite grains. Feldspar in Ch9 is albitic and shows no evidence of alteration.
- **WDS analyses give an average feldspar composition of $An_{83}Ab_{17}$ for the unaltered anorthite in all chondrules.** Individual analyses overlap phases and show mixing trends to both nepheline and albite (Fig. 4a). In nephelinized chondrules, the albitic compositions are found near chondrule rims.
- **Individual WDS analyses on intergrown anorthite/nepheline material contain up to 3.7 wt.% Cl.** A mixing plot of Na_2O vs. Cl possibly indicates the presence of fine-grained sodalite or marialitic scapolite (Fig. 4b).

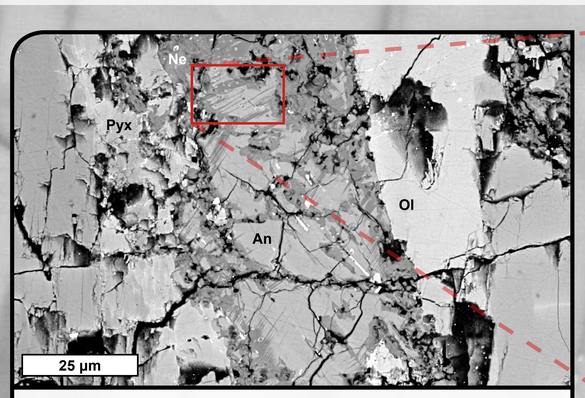

Figure 1a: BSE image showing nephelinization texture of anorthite in chondrule 3.

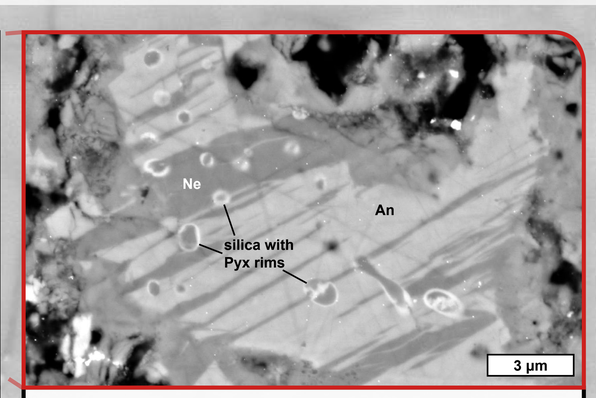

Figure 1b: BSE image showing silica rich nodules with what appear to be hedenbergite rims in chondrule 3.

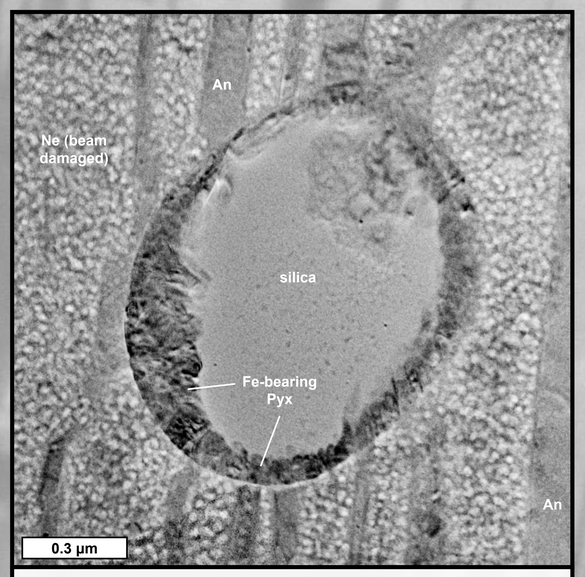

Figure 1c: BF TEM image of a silica rich nodule with Fe-bearing pyroxene rim from chondrule 3. Anorthite/nepheline intergrowth is also visible with nepheline showing considerable beam damage.

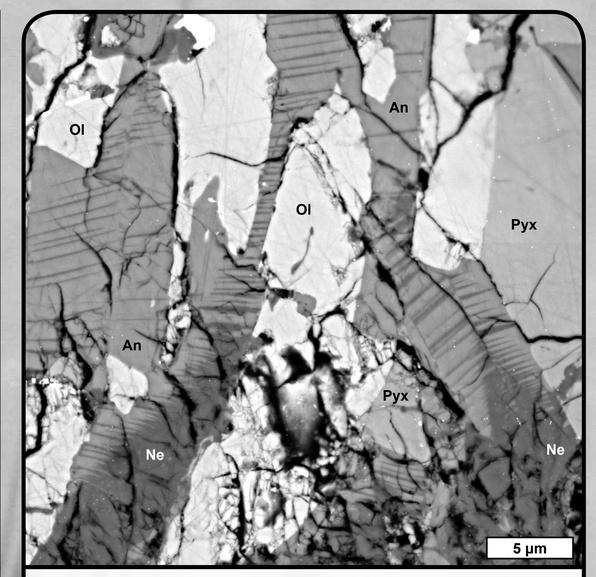

Figure 2: BSE image of chondrule 4 illustrating the preservation of anorthite twins as highlighted by nepheline lamellae.

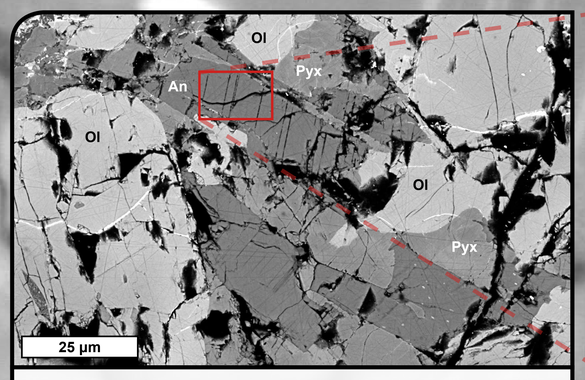

Figure 3a: Anorthite laths showing dissolution lamellae in chondrule 8.

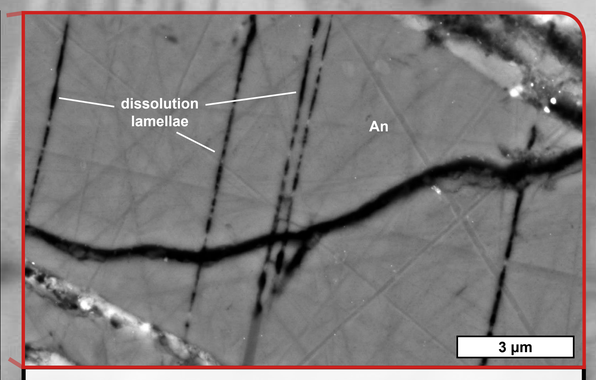

Figure 3b: Close-up of dissolution lamellae in the anorthite of chondrule 8.

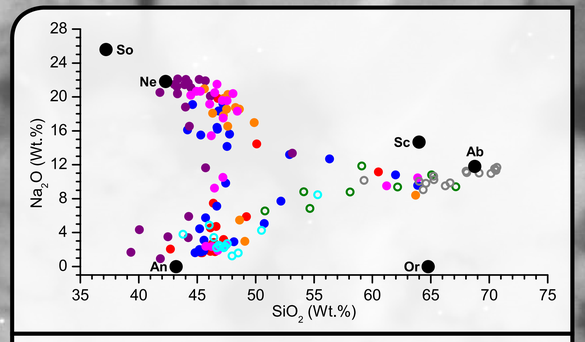

Figure 4a: WDS analyses with solid circles for nephelinized chondrules and open circles for non-nephelinized, feldspar-bearing chondrules. Plot shows mixing trends between anorthite (An), nepheline (Ne), and albite (Ab).

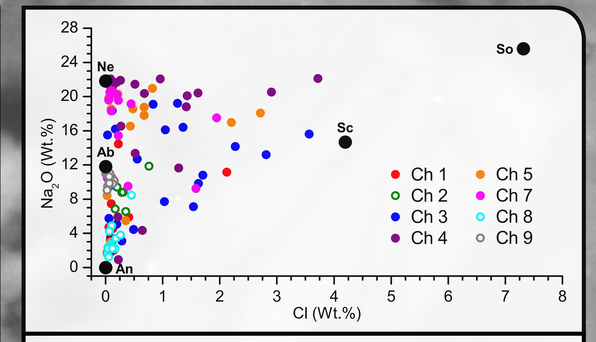

Figure 4b: Relationship between Na_2O and Cl content shows the possible presence of sodalite (So) and marialitic scapolite (Sc).

Analytical Methods

- We examined a single thin section (UNM 1018) of Parnallee (LL3.6).
- Feldspar and nepheline were imaged and identified with BSE imaging and EDS analysis.
- A silica inclusion was extracted using a FIB, imaged with BF TEM, and analyzed with TEM EDS.
- Quantitative WDS analysis was conducted using an electron microprobe with a 1 µm diameter beam at 15 kV and 10 nA with TDI corrections for both Na and Cl.

Discussion

- **Several lines of evidence indicate that anorthitic plagioclase in chondrules within Parnallee is a primary igneous mineral that formed during chondrule formation.** Much of the anorthite and nephelinized anorthite occurs as euhedral or subhedral laths and the nepheline replacement, which highlights the crystallographic orientation, indicates twinning (Fig. 2). These features indicate an origin by growth from a melt. In addition, many chondrules in Parnallee still have glassy or only slightly devitrified mesostasis, implying that heating was insufficient to recrystallize glass and form large (tens of µm) anorthite grains.
- **Nephelinization textures in Parnallee are very similar to those that have been described in CO chondrites.** This includes the lamellar replacement textures and the presence of silica/Fe-bearing pyroxene inclusions [4].
- **Nephelinization in CO chondrites has been suggested to occur by alteration of anorthite to hydrated nepheline and subsequent dehydration during metamorphism [4]. We propose that a similar process is recorded in Parnallee.**
- **Cl was likely introduced at the same time as the Na, as only Na bearing phases show significant amounts of Cl.** [7] described Na and Cl rich chondrule mesostasis in Parnallee but attributed this to an influx of Na and Cl during crystallization, rather than enrichment by fluids on the parent body. The bulk Cl isotope composition of Parnallee is anomalous among OCs [8] and this may be an indication of unique conditions for this chondrite.
- **In addition to nephelinization, the action of fluids is indicated by dissolution lamellae and albitization reactions seen in Ch8.** In Ch8, dissolution occurs in anorthite that has the same composition as the nephelinized primary anorthite, suggesting that this chondrule escaped nephelinization but was subject to metasomatism similar to that seen in type 4 OCs [2]. However, the relative timing remains ambiguous due to the absence of dissolution lamellae in any of the nepheline-bearing chondrules.
- **Evidence for metasomatism on the OC parent bodies is very clear in anorthite, and may have been overlooked in the past due to the low abundance of primary anorthite present in OCs.**
- **The source of the fluids is still unknown.** A nepheline-bearing clast in Parnallee has negative $\Delta^{17}O$ values [6], indicating the fluids may have originated from carbonaceous chondrite sources. Further work will need to be done in order to identify the source of these metasomatic fluids and to determine how prevalent such reactions were on ordinary chondrite parent bodies.

References: [1] Huss G. R. et al. (2006) Meteorites and the Early Solar System II, 567-586. [2] Jones R. H. and Brearley A. J. (2010) LPS XLI, Abstract #2133. [3] Jones R. H. et al. (2012) NIPR Symp. Antarct. Meteorites XXXV, Abstract E57. [4] Tomeoka K. and Itoh D. (2004) MAPS, 39, 1359–1373. [5] Russell S. S. et al. (1998) GCA, 64, 4, 689–714. [6] Bridges J. C. et al. (1995) Proc. NIPR Symp. Antarct. Meteorites, 8, 195–203. [7] Bridges J. C. et al. (1997) MAPS, 32, 555–565. [8] Sharp Z. D. et al. (2013) GCA, 107, 189–204.