CA,AL-RICH INCLUSIONS WITHIN THE MOSS CO3 CHONDRITE - INDICATIONS FOR SEVERE SECONDARY ALTERATION.

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Introduction: The Moss meteorite fell July 14, 2006 in Norway. After extensive searches in the area several fragments were recovered in the following days and weeks. In the Meteoritical Bulletin [1] Moss is classified as a CO3.5/3.6 chondrite and characterized by "contains abundant small chondrules (most <200 µm), small (<1 mm) amoeboid olivine aggregates (AOAs) and refractory inclusions, and isolated grains of olivine, troilite, and kamacite set in a gray matrix". A first survey of the Ca,Al-rich inclusions (CAIs) revealed that the refractory inclusions contain spinel, calcic pyroxene, and abundant nepheline that is replacing melilite and other primary phases [1]. It was also noted that "some perovskite has been transformed to ilmenite" [1].

Results: CAIs in CO chondrites have received much less attention than those in CV or CM chondrites; detailed studies for comparison are from Tomeoka et al. [2] and Kojima et al [3]. In this study we have studied 62 inclusions within the Moss meteorite (studied polished thin section area: ~1 cm^2), which can be subdivided into 55 CAIs and 7 olivine-rich aggregates. These inclusions range from 20x40 µm to 400x650 µm in size, but more than 80% are <200 µm in size.

Based on the severe alteration of the inclusions classification of the CAIs in well-known schemes for CAIs is very difficult. For purposes of discussion we divided these inclusions into four general classes:

1. Single concentric objects. 18 inclusions belong to this category (Figs. 1-3). These objects often have a spinel-rich core and tiny ilmenites are common. In several objects an unknown phase was observed having roughly 25-37 wt% SiO_2, 3-14 wt% MgO, 30- 41 wt% Al_2O_3, 3-10 wt% FeO, 10-24 wt% CaO; 1-6 wt% TiO_2. Other phases observed include: Fassaite, anorthite, hibonite, nepheline, Fe,Ni-metal, FeS, and olivine. These inclusions are rimmed by Ca-pyroxene or olivine (less common).

2. Complex, fine-grained, spinel-pyroxene-rich inclusions. These 13 inclusions are complex fine-grained CAIs having abundant spinel, but also include fassaite, ilmenite, anorthite (rare), occasionally olivine, and nepheline (Fig. 4). These are typically surrounded by Ca-pyroxene. In one case an Os,Ir-bearing Fe,Ni-particle was observed.

3. Complex, fine-grained, Ca-pyroxene-nepheline-(melilite)-rich inclusions. These inclusions (9) rimmed by Ca-pyroxene basically consist of the two major phases Ca-Pyroxene (fassaite is common) and nepheline (or other fine-grained alteration products) in variable proportions (Figs. 5 and 6). The alteration products are often the dominating phase, melilite was only in one case identified as a phase of significant abundance. Other minor phases include spinel, apatite, olivine, and Fe,Ni-metal.

4. Complex, fine-grained, pyroxene-rich inclusions with olivine rim (15). The dominating phase clearly is Ca-pyroxene. Other phases include spinel, olivine, nepheline, Fe,Ni-metal, FeS. The only perovskite was also found in an inclusion of this type.

Olivine-rich aggregates (7). The olivine-rich aggregates (AOAs) basically consist of abundant olivine with minor Ca-pyroxene and rare Na-rich alteration products.

All spinels analysed in various types of inclusions are Fe-bearing. The FeO-concentration is usually between 20-25 wt%. Only some spinels with less (11-15 wt% FeO) were detected.

Discussions: Tomeoka et al [2] found that CAIs in Yamato-791717 contain 5-80 vol% nepheline. This is similar for Ca,Al-rich inclusions within the Moss CO3 chondrite: In some CAIs primary phases are almost completely replaced by nepheline and possibly other secondary alteration products. Based on the texture it is suggested that nepheline is replacing melilite and/or anorthite. Also during alteration spinel became enriched in FeO and the perovskites have been transformed to ilmenites as also observed within CAIs from ordinary chondrites [4]. It remains unclear whether this secondary alteration occurred during mild degree of metamorphism on the parent body, or by low-T alteration within the solar nebula. Since the degree of alteration varies among the inclusions (some have melilite and/or perovskite others only have nepheline and/or ilmenites, FeO in spinel shows variations between 10 and 25 wt%) a nebular origin for at least a significant portion of the secondary alteration cannot be excluded.

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References:

[1] http://tin.er.usgs.gov/meteor/metbull.php. [2] Tomeoka K. et al. (1992) Meteoritics 27, 136-143. [3] Kojima T. et al. (1996) Proc. NIPR Symp Antarct Met 8, 79-86. [4] Bischoff A. and Keil K. (1984) GCA 48, 693-709.

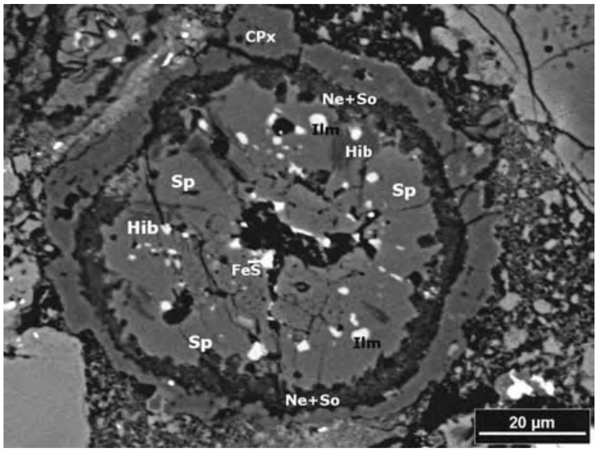

Fig. 1: Moss-80-5: Concentric inclusion consisting of spinel (Sp), hibonite (Hib), ilmenite (Ilm), and an FeS-grain surrounded by alteration products (nepheline, sodalite) and Ca-pyroxene; BSE-image.

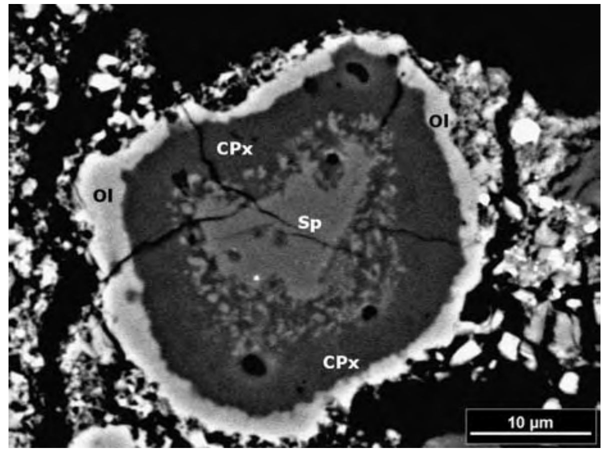

Fig. 2: Moss-80-25: Concentric object with a spinel core rimmed by Ca-pyroxene (CPx) and olivine (Ol); BSE-image.

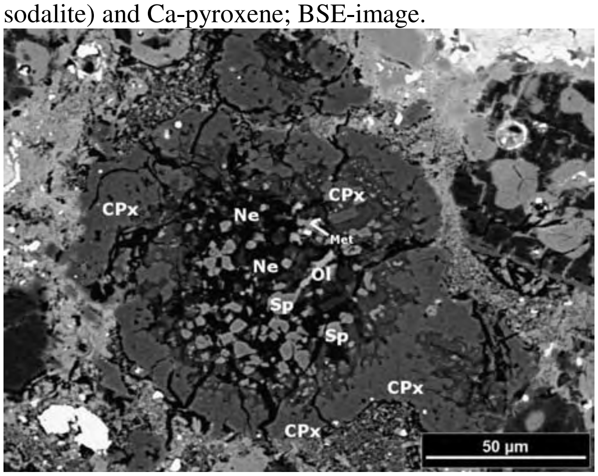

Fig. 3: Moss-80-15: Almost concentric object having isolated spinels (Sp), an olivine lath (Ol), two metal grains (Met), probably anorthite, and nepheline (Ne) within the core surrunded by Ca-pyroxene (CPx). BSE.

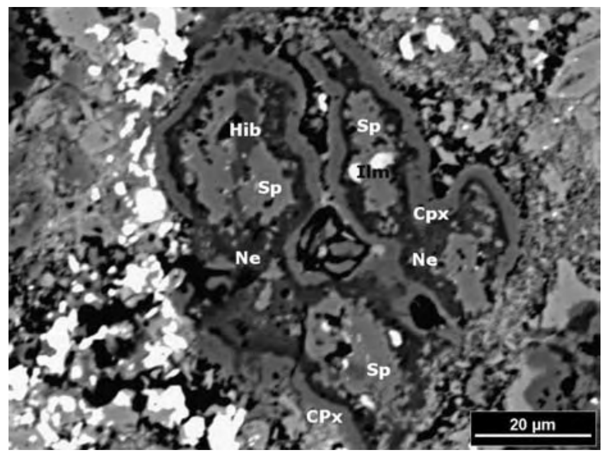

Fig. 4: Moss-81-25: Complex fine-grained, spinel-rich inclusion with spinel (Sp), hibonite (Hib), and ilmenite (Ilm) enclosed in alteration products (nepheline?; Ne) and rimmed by Ca-pyroxene (Cpx). BSE-image.

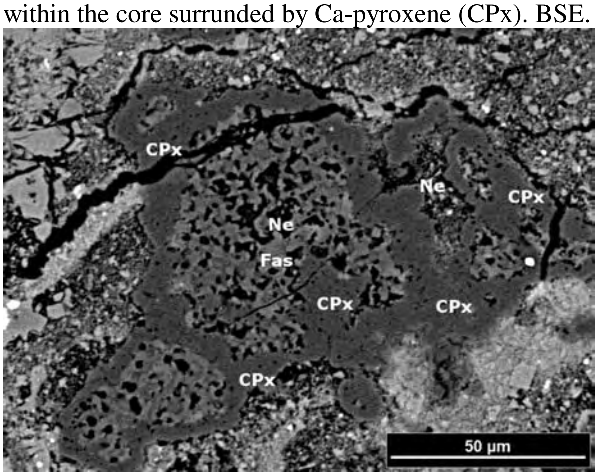

Fig. 5: Moss-80-26b: Fine-grained Ca-pyroxene-nepheline-rich CAI with Ti-rich fassaite (Fas) and alteration products (Ne) in the core and a Ca-pyroxene (CPx) rim. BSE-image.

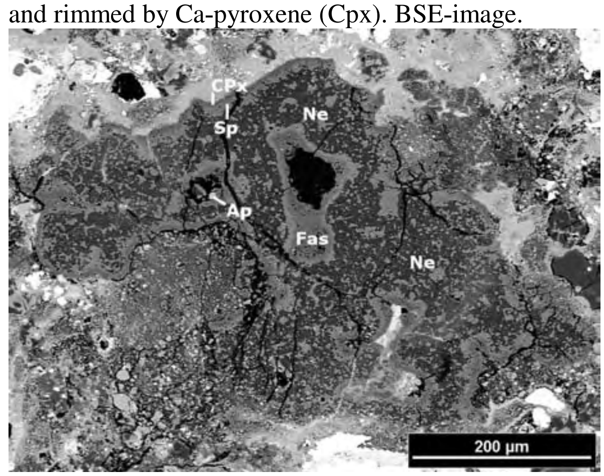

Fig. 6: Moss-80-24: Fine-grained, CPx-nepheline-rich inclusion with minor spinel (sp) and apatite (Ap) rimmed by Ca-pyroxene (CPx). BSE-image.