DARK INCLUSION ALLENDE 4884-2B PROVIDES NEW INSIGHTS ON THE FORMATION OF FAYALITIC OLIVINE

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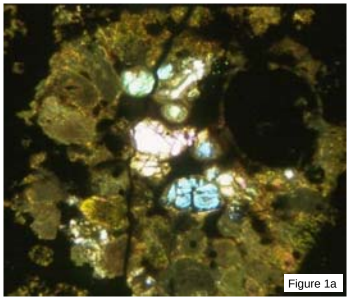
Introduction: Dark Inclusions (DIs) are complex objects whose genesis is considered to be the result of two contrasting types of processes: a) those occurring in the CV3 chondrite parent body, including metamorphism, fragmentation, melting, aqueous alteration and subsequent dehydration [e.g. 1-7] and, b) those taking place in the solar nebula, including aggregation and subsequent secondary alteration [e.g. 8,10] as well as vaporization/recondensation, in which vaporization of chondritic dust produces a fayalitic-rich vapor [11]. Here, we combine a chemical and petrographic study of the Allende DI 4884-2B [12-13] with a ATEM study of Allende DI All-AF (NHM, Vienna) in order to obtain new insights onto the genesis of these objects.

Allende DI 4884-2B consists mainly of aggregates of fluffy, non-transparent fayalitic olivines, very similar to rock All-AF [9] and to the Allende DI 4884-2 [11]. A few aggregates, however, (e.g., aggregate A) also contain some relic transparent forsterite. Aggregate A, has a zoned structure (Fig 1a) with a core consisting of transparent, mostly euhedral olivines of 100–300 µm in size (Clear Olivine in Fig. 1b) poor in FeO (0.8 wt%) and rich in CaO (0.4%), set into a very fine-grained, non-transparent mesostasis rich in CaO (24 wt%), TiO_2 (1.2%), FeO (10.4%) and MgO (11.3%), but poor in Al_2O_3 (2.1%) and Na_2O (0.1%). The core is surrounded by mostly euhedral, porous, and non-transparent olivines rich in FeO (20–30 wt%) and rich in minor elements, consisting of olivine skeletons and platelets (Dirty olivine in Fig. 1b). Clear olivines are host of glass inclusions rich in SiO_2- Al_2O_3-CaO.

Petrograhic evidence in aggregate A constrains many of the previous genetic models concerning the origin of the fayalitic olivines in DIs. The existence of euhedral forsteritic olivine occurring in a fine-grained mesostasis suggests that olivine crystals grew from a liquid (e.g., the precursor of the fine-grain mesostasis). Because fayalitic olivines decorate surfaces and fractures in the forsteritic olivine and euhedral fayalitic olivine occurs in the fine-grained mesostasis, formation of fayalitic olivines must have been a secondary process.



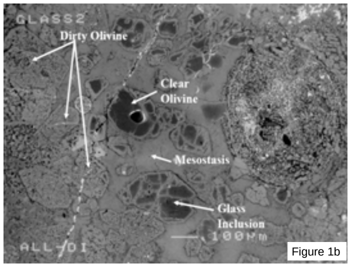
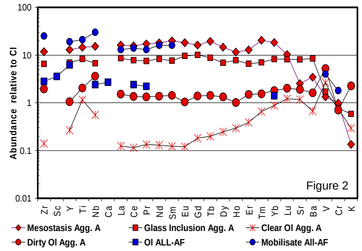
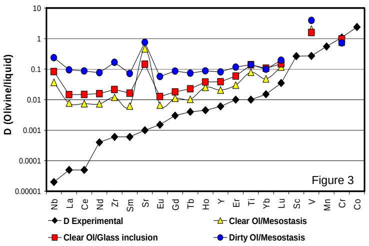


Figure 1: Aggregate A in Allende DI 4884-2B. a) Transmitted light image. b) BSE image.





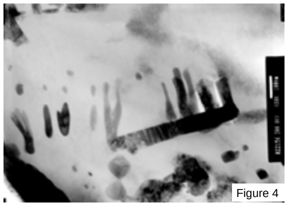
Hydration/dehydration [e.g.,12,13] seems unlikely, since it is difficult to conceive a process so highly selective that it completely transforms a clear forsterite crystal into a fluffy fayalitic one, but produces minimal alteration in the co-existing mesostasis glass.

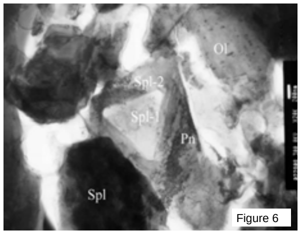
Formation of olivine-rich aggregates: A SIMS study of aggregate A shows that the olivine crystals are rich in trace elements, indicating growth from the vapor phase [14-15]. The co-existing liquids (e.g., precursor of the primary glass inclusions located in the clear olivine and the fine-grained mesostasis) have patterns governed by volatility and also carry evidence of vapor fractionation [15-16], Fig. 2). The abundances of trace elements in olivine and glass, however, are not governed by crystal-liquid distribution coefficients as experimentally determined (Fig. 3). A high degree of undercooling of the liquid and fast crystallization of the olivine cannot be ruled out.

Aggregate A could have formed as an irregular aggregate of euhedral forsterite crystals. This scenario fits the recently formulated Primary Liquid Condensation Model (PLCM) [17] that envisages formation of clear olivine crystals by condensation in the solar nebula with the help of a liquid that is constantly replenished in olivine components from the vapor.

TEM photomicrographs of All-AF

Formation of the fayalitic fluffy olivine: Strong variations in temperature seem to have affected both DIs as evidence by the crystal-liquid distribution coefficients (DI 4884-2B, Fig.3) and the presence of dendritic spinel in the olivine, which indicates solidification at supercooling conditions (All-AF, Fig. 4). Following this, an intense metasomatic process seems to have radically changed the chemical composition of the initial phases. In DI 4884-2B, for example, the high abundances of Fe+Mg in the mesostasis of aggregate A - from which Al+Sr+Ba were mobilized (Fig 3)-, are among the main changes observed. In All-AF , mobilization of Fe, Al, Mg, Ni and S is indicated by the presence of polycrystalline spinel, with taenite at its center (Fig. 5). Because the formation of these phases appears to be the result of a combined process of condensation/coalescence/sintering, atom diffusion could be the underlying mechanism of this mobilization. Thus, the secondary process leading to the transformation of forsteritic olivine into fayalitic olivine could be diffusion, in which non-volatile major elements such as Mg and Fe were removed (or added) via a ''dry'' vapor phase [18].





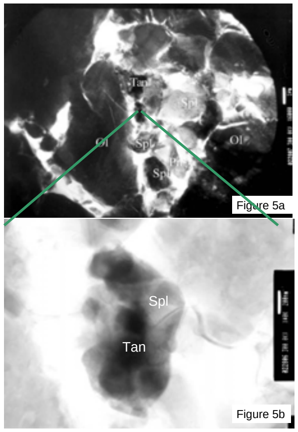


Fig. 5: a) Distribution of phases in a cavity between olivine clasts in Allende AF. The tiny, black grain in the middle of the micrograph is a compound grain of taenite and spinel as shown in the enlarged view (Fig 5b).

An increase in the ambient O fugacity – as evidenced by the FeO/MnO ratio of the fayalitic olivine – will affect the solubility of Mg in the vapor and ultimately the Fe content of the formed silicates [18]. The euhedral spinel (Spl-1) with hercynite rim (Spl-2) in epitaxy with pentlandite (Pn) (Fig. 6) is suggestive of solid-state transformation and diffusion processes under variable O and S fugacities. This diffusion process could be highly effective and also explain the formation of fayalitic olivines in those crystals that were directly exposed to the vapor phase [e.g., 8 and 11]. However, in aggregate A, the mesostasis glass acted as a barrier that allowed complete transformation of only the small euhedral crystals, while big crystals were preserved in the relict forsterite core (Fig. 1a-b). This extreme diffusion process helps to reveal the growth patterns of the olivine (e.g., hopper and dendrite crystals due to quick growth) in the following way: the metasomatic alteration affects the crystal along zones of weakness, which in this process became zones of strength as they were the first to recrystallize, transforming clear olivine into fluffy-looking pseudomorphs.

References: [1] Fruland et al. (1978) *Proc. LPSC 9th* 1305-1329; [2] Bunch et al. (1980) *LPS XI,* 119 ; [3] Kracher et al. (1985) *Proc. LPSC 16th* 90 D123; [5] Johnson et al. (1990) *GCA* 54, 819-830; [6] Krot et al. (1995) *Meteoritics* 30, 748-775; [7] Kojima and Tomeoka (1996) *GCA* 60, 2651-2666; [8] Kurat et al. (1989) *Z. Naturforsch* 44a, 988-1004; [9] Palme et al. (1989) *Z. Naturforsch* 44a, 1005-1014; [10] Gordon et al. (2008) *LPSC XXXIX*, #1929; [11] Weisberg and Prinz (1998) *MAPS* 33, 1087-1099; [12] Kojima and Tomeoka (1994) *Meteoritics* 36, 484; [13] Krot et al. (1997) *MAPS* 32, 31-49; [14] Kurat et al. (2000) *MAPS Suppl.* 35, A94; [15] Varela et al. (2002) *LPSC XXXIII*, #1190; [16] Kurat et al. (2000) Meteoritics 24, 290; [17] Varela and Kurat (2009) *Mitteilungen der Österr. Mineral. Ges.* 155, 279-320; [18] Dohmen et al. (1998) *Am. Min*. 83, 970-984.