

ORIGIN OF ZONED ALLENDE FINE-GRAINED INCLUSIONS. A.V. McGuire and

A. Hashimoto. Smithsonian Astrophysical Observatory, 60 Garden Street, Cambridge, MA 02138.

Fine-grained inclusions of relatively large size ($>1 \mu\text{m}$) in the Allende meteorite commonly exhibit three-fold zonation, with each zone possessing distinct texture and mineralogy. Wark [1] suggests that each specific zone was formed by a separate condensation episode in the primitive solar nebula. Hashimoto & Grossman [2], however, suggest that the zonation was established by an open system alteration of porous, fine-grained material of mineralogy similar to melilite-rich, coarse-grained inclusions. In order to study the latter possibility, we have continued detailed petrographic work on a new set of fine-grained inclusions. Our main goal is to characterize the nature of the alteration and the physical and chemical environment which caused this distinct three-fold zonation, and to reveal the primary mineral assemblage of fine-grained inclusions.

Petrography: Four inclusions have been studied, three of which are spinel-rich (FG-A1,A2,A4), and one spinel-poor (FG-A3). We follow the terminology introduced by [2], designating the inner, middle, and outer zones as A,B, and C respectively. All zones of these inclusions contain approximately 20% void space. Zone A consists of 10-40% spinel (Sp), 20-40% nepheline (Ne), 10-35% clinopyroxene (Cpx), and minor amounts of any of the following: olivine (Olv), sodalite (Sod), grossular (Gr), andradite (And), hedenbergite (Hd), anorthite (An), hibonite (Hib), perovskite (Pv), ilmenite (Ilm). These minerals occur as loosely packed, discrete, anhedral to subhedral grains, with minor intergrowth between phases. In inclusion FG-A2, the reaction of Sp to Olv+Ne is observed as Olv+Ne rims on Sp and Olv+Ne pseudomorphs after Sp. The contact between zones A and B is generally gradual. Zone B is characterized by at least 10% Hd and/or And, in addition to Sp, Cpx, Ne and minor Sod, Olv, Gr, An, Pv, Ilm. Zone B consists of approximately 50 μm diameter clumps consisting of Sp rimmed by Cpx, Hd and And. Hd and diopside (Cpx), and also Gr and And, which should form complete solid solutions, occur in direct contact with one another. Fine-grained material between these clumps is mineralogically and texturally identical to zone A of the same inclusion. One inclusion (FG-A4) has zone B consisting of about 50% Gr intergrown with Hd, And, Sp, and traces of Cpx, Pv and Ilm, but *no* feldspathoids. Two types of zone C are observed: a) a 100-300 μm thick zone made of Sp rimmed by Ne and Cpx, and interstitial Ne and Sod; or b) a 50-80 μm wide zone of intergrown Ne and Olv with Pv or Ilm inclusions, and minor interstitial Cpx and Sod.

Composition: No *systematic* changes were observed in mineral compositions from zone to zone in any of the inclusions. Sp is Fe-rich aluminous spinel (8-25 wt% FeO) with minor Ti, Cr, and V. Larger Sp grains are sometimes zoned with increased Fe at the rims. Hibonite contains 3.8 wt% MgO and 7.0 wt% TiO₂. Ne contains 1.0-3.5 wt% CaO and 0.3-1.9 wt% K₂O, and Sod contains <0.10 wt% CaO or K₂O. Cpx is aluminous diopside and salite (1-14 wt% Al₂O₃) with highly variable compositions, even over short (<20 μm) distances within a zone. Hd is nearly pure endmember CaFeSi₂O₆ and contains <1 wt% Al₂O₃ and <3.5 wt% MgO. Gr garnet contains 5-20% And component, and minor Mg, Mn, and Ti. Andradite contains 1-5% Gr component. Olv is Mg-rich (Fo₆₅₋₈₂), and analyses often contain high Al₂O₃ (up to 7.0 wt%), sometimes accompanied by Na₂O, suggesting the presence of extremely fine-grained inclusions of Sp or Ne. An is An₈₃₋₉₉.

Variations in bulk composition reflect variations in proportions of minerals from zone to zone. Al₂O₃ decreases by >10 wt% and SiO₂ increases by about 5 wt% from zone A to C. This may reflect the abundance of Sp in zone A of the Sp-rich inclusions, but the same trends are observed in the Sp-poor inclusion (FG-A3). FeO and MgO both increase from zone A to C, although FeO is highest, and MgO lowest, in zone B, reflecting the abundance of Hd and And. Ca is highest in zone B.

Origin: The presence of phases such as Gr, Hd, And, Sod, and Ilm are inconsistent with formation by the classical equilibrium condensation model [3], and the porous texture of fine-grained inclusions precludes crystallization from a liquid. However, the mineralogy and textures of zones A and B of fine-grained inclusions are similar to altered regions of melilite-rich coarse-grained inclusions as shown by the present study and [2]. In addition, the observation that Sp and Pv are altered to Olv+Ne and Ilm, respectively, suggests that secondary alteration was an important process in the formation of zoned fine-grained inclusions.

Some characteristics of the primary mineral assemblage can be deduced: Similarity of zones A and B to altered melilite-rich inclusions suggests that zones A and B were originally fine-grained melilite-rich inclusions in which melilite has been completely altered to Ne+Gr+An (possibly +Cpx). Sp, Hib, and Pv are most likely residual primary phases [2]. Zone B is interpreted to be an alteration of the edge of primary zone A. Development of zone B is patchy in some inclusions and areas of zone B not occupied by Hd-rich clumps look texturally and mineralogically identical to zone A. Textures of zone B suggest Hd, And, and some Cpx are condensates forming on residual Sp. We interpret one type of zone C, consisting of Ne+Olv+Pv or Ilm, as having formed by alteration of primary Sp+Pv rims on some of the inclusions. The other type of zone C, Sp+Ne+Cpx, texturally resembles previously described [4,5,6] fine-grained inclusions, which consist of concentric objects, and may originally have been a zone of aggregated concentric objects. These two types of zone C and variations such as Hib-rich layers in zone A reported by [2] and the Gr-rich zone B in FG-A4 most likely reflect *primary* compositional or mineralogical features.

We agree with the proposal of Hashimoto et al. [7,8] that the cause of alteration was a decrease in nebular H/O. [86,87] have shown that at $T < 1000\text{K}$ and $\text{H/O} < \text{cosmic Ca}$ is volatile relative to Si and Mg as a result of the formation of gaseous Ca-hydroxide species by reaction with $\text{H}_2\text{O}(\text{g})$. The lack of Fe-metal grains, the high FeO content of minerals, and presence of And (~30 wt% Fe_2O_3) are consistent with oxidizing nebular conditions. Oxidizing gas penetrated the fine-grained primary inclusions, volatilizing Ca and completely altering melilite. Observed Sp to Olv+Ne and Pv to Ilm reactions require open system reaction with addition of Si, Fe, alkalis and loss of Ca. As Ca diffused out of the inclusion interiors, and Si, Fe, and alkalis diffused in, Ca-Fe silicates condensed at the edges of zone A and formed zone B. Sp rims on some primary inclusions were exposed to the nebular gas and nearly completely altered to form an Olv+Ne zone C; whereas residual Sp survived in the interiors of inclusions. The intimate coexistence of minerals which should form solid solutions, Hd-diopside and And-Gr, indicates that disequilibrium processes were involved in the alteration of fine-grained inclusions.

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