SEM-PETROGRAPHY OF ALLENDE FINE-GRAINED INCLUSIONS.

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Fine-grained inclusions are irregularly-shaped, elongated or lensoid objects which are white, gray, pink or purple in color and whose longest dimension may reach 10 mm (1). Most are concentrically zoned in color, frequently but not always with pink or purple cores and whitish rims. Grain sizes are typically <1 μm to several μm. We report here preliminary results of a detailed SEM-petrographic study of ten fine-grained inclusions in Allende.

Seven inclusions have a similar, three-fold zonation, to which we tentatively assign the labels A, B and C from inner to outer zones. Zone A is rich in Fe-bearing spinel (Sp) (FeO >5 wt%), has no more than a trace of hedenbergite (Hd) and andradite (And), and occupies >50% by volume of the inclusion. Zone B is a 100-200 μm thick band with Hd and/or And as characteristic minerals. Zone C, 100-400 μm thick, is rich in nepheline (Ne), sodalite (Sod), Al-, Fe-bearing clinopyroxene (Cpx) and salite (Sa), and always contains olivine (Ol). Boundaries between zones may be sharp or gradual.

Zone A consists of 10-40 vol% Sp, 5-30% Cpx, 0-30% grossular (Gr), 0-10% anorthite (An), 10-40% Ne and Sod, minor perovskite (Pv) and ~20% voids. In most inclusions, this zone is loosely-packed and appears friable. In some inclusions, Zone A contains nodules with a sub-rounded Sp-rich core rimmed successively by ±Ne, Cpx and aluminous diopside (Di), first described in (2). The Sp-rich core rarely contains melilite (Mel) and hibonite (Hib) but usually contains An, Ne, Sod, Gr and Cpx, interpreted to be alteration products of Mel (3). Zone A, and the matrices of the nodular examples of Zone A, are fine-grained and consist of patches in which usually only 2 or 3 of the phases Sp, Cpx, Gr, An, Ne and Sod are intimately intergrown. Sp only encloses Pv. Ragged An completely enclosed by Ne and Sod suggests alteration of An to the latter phases. Similarly, the fact that Cpx frequently rims or decorates the surfaces of Gr grains indicates that Cpx replaces Gr. These textural relations of coexisting minerals in Zone A are very similar to those seen in altered regions of Mel-rich, coarse-grained inclusions. Zone A is richer in Cpx relative to Gr than the latter, however, implying that Zone A represents a more advanced state of alteration than the alteration products in coarse-grained inclusions, as Cpx appears to be an alteration product of Gr.

Zone B consists of 0-70 vol% And-bearing Gr, 0-10% And, 0-20% Hd, 5-50% Cpx and Sa, 5-30% Sp, 0-30% Ne and Sod with Ne>Sod, voids and traces of Pv, An, Ol and wollastonite (Wo). Although mineral proportions are highly variable, the characteristic of this zone is the presence of at least 10% Hd and/or And. Gr, Cpx or an intergrowth of both often enclose Sp. This assemblage occurs in clumps that are frequently rimmed by Hd or And which may be subhedral. Hd and And also fill or line cavities in the clumps, indicating that these phases are later than Gr and Cpx. The abundance of Sp in Zone B seems correlated with that in Zone A and, in some inclusions, the spatial distribution of this phase in the two zones is similar. This suggests the possibility of an original textural continuity between Zones A and B prior to alteration, as Sp is known to be relatively resistant to attack (3). Zone B's with high (>60%) Gr contents are devoid of Ne and Sod, and their petrographic properties described herein are remarkably similar to those seen in Gr-rich bands within large patches of alteration assemblages in Mel-rich, coarse-grained inclusions. This is a strong argument that the origin of zoning in fine-grained inclusions may be due to alteration of primarily Mel-rich precursors.

Zone C consists of 20-60% Ne and Sod, 20-50% Cpx and Sa, 5-30% Ol, 0-15% Sp, <5% Gr, <5% Hd, <5% And, minor Pv and 10-20% voids. In some inclusions, all these phases are intergrown in irregular, Cpx-, Sa-rimmed nodules or masses in which Pv is enclosed by Sp, Ne and Sod embay Sp, and Hd and And line cavities. Ol is blocky to irregular. In others, Cpx, Sa and sometimes Hd and And are intergrown in clumps which, along with Sp, are found in a matrix of irregular grains of Ne and Sod and irregular, blocky or lamellar Ol which is sometimes enclosed by Ne and Sod. High Al in analyses of irregular Ol in both occurrences indicates enclosed, fine-grained Sp and suggests alteration of Sp to Ol, as in amoeboid olivine aggregates (AOA) (3). Cpx-, Sa-rich clumps in Zone C are similar in size and shape to Gr-bearing ones in Zone B, again suggesting alteration of Gr to these phases.

TS14F1 (6 mm) has an ~400 μm-thick zone consisting largely of loosely-packed, lath-shaped Hib and Sp crystals. This zone is sandwiched between Hib-free zones identical to Zone A. Another Hib-bearing inclusion, TS17F2 (13 mm), has two distinct inner zones in place of Zone A. The innermost consists of Hib laths with interstitial Ne, Pv and voids (4). It is mantled by a Gr-rich zone containing Pv and massive Sod. These are followed by normal Zones B and C. A third Hib-rich inclusion, TS50F1 (4.5 mm) is unlike any other in that most of the grains are <1 μm, its core contains Ol needles and Ne patches set in a matrix of finer-grained Hib and Ol, and its mantle contains 50-150 μm knots of tiny Hd and Sa grains.

The similarities between the mineral assemblages, textures and inferred sequences of deposition in Zones A and B of fine-grained inclusions and those seen in altered regions of Mel-rich, coarse-grained inclusions and of refractory inclusions inside AOA's strongly suggest that the bulk of the material in these zones formed by a secondary alteration process in which Ca was partially removed and Na, Fe, Si and Cl were added, as was proposed for these other objects (3, 5) and for fine-grained inclusions previously (1, 6). Rastered beam chemical analyses of each zone in each inclusion show that Ca and Si both reach their maximum concentrations in Zone B, implying that open system transport and deposition of these elements may have involved stoichiometric control or multi-stage processes.

A major unresolved question is the nature of the primary assemblage that was altered. We have assumed that Sp, Hib and Pv are residual primary phases in fine-grained inclusions based on observations of their relative resistance to alteration in other inclusions. There is thus little doubt that the precursor was a refractory condensate assemblage but the ever-present group II REE patterns in these inclusions suggest a restricted population of such material. In fact, our observations suggest more than one type of primary material, as we have seen abundant, relatively unaltered Hib-, Sp-, Mel-bearing spherules identical to Murchison blue spherules (7) in one inclusion and a porous, Hib-rich zone in TS17F2 that is reminiscent of Murchison inclusion SH-6 (8). Also, the much greater abundance of Sp in Zone A than in Zones B and C of one inclusion and the existence within individual fine-grained inclusions of both Hib-rich and Hib-free zones suggest the possibility of zonation of the primary phase assemblage. Although the porous textures could be due entirely to removal of material during alteration, the much greater degree of alteration of fine-grained compared to coarse-grained inclusions may imply that the precursor material originally had a porous texture like that of the Hib zone in TS17F2. Finally, pink or purple regions of fine-grained inclusions viewed in hand specimen contain abundant Fe-bearing Sp and correspond to Zone A and occasionally Zone B.

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