REGOLITH ORIGIN FOR ALLENDE METEORITE. T. E. Bunch and S. Chang.

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Observations and data presented here are intended primarily to account for formation of Allende as a solid body. Primary origins of "high temperature" inclusions and chondrules are not directly considered. We attempt to reconcile the textural and compositional characteristics of Allende that are consistent throughout the bulk meteorite with a formational scenario.

Allende consists of matrix, rounded, refractory coarse-grained and fine-grained amoeboid inclusions (CAI's), coarse-grained and amoeboid ferromagnesium inclusions (FM's), dark inclusions (DI's), droplet chondrules, all referenced in (1) and highly shocked (glass or divitrified) compositional analogs.

Matrix - The matrix consists essentially of fine-grained, Fe-rich equant to prismatic olivine grains (1) in aphanitic interstitial material that together form a pilotaxitic-like (flow oriented) texture. Small (<50μm) ferromagnesian (FM) and amoeboid inclusions (CAI's) show textural and compositional mixing with the matrix. Ultra-thin section studies show that these form between 15-35 vol% of the matrix. Coarser-grained (5-20μm) small FM inclusions and small mineral clasts are recrystallized with apparent reaction borders. That matrix olivine grew in place is supported by SEM observations that show interpenetrating growth habits with poorly crystallized interstitial material and voids. The flow orientation arose during a compaction episode (2,3). Abundant small crystals and poorly defined interstitial material argues for rapid nucleation and low growth rates (4,5) that together imply rapid crystallization. As reported earlier by (1), narrow reaction rims on CAI's and chondrules against the matrix imply either hot inclusions or matrix or both, although they noted that FM components lacked reactions rims, which is inconsistent with our observations. FM components do show reaction margins that consist of devitrified or partly devitrified material with small prismatic olivine grains similar in composition to those in the matrix. These grains are larger by a factor of 2-3 and occasionally extend into the matrix for distances up to 60μm in a twisted subparallel grain growth. This relationship strongly suggests reaction and growth in a hot medium with simultaneous mechanical action.

Coarse-grained CAI's - These have been classified into types A and B (6), and detailed descriptions have been given by numerous investigators. They are rounded to subrounded in shape and show well developed reaction rims against the matrix. All 136 samples show evidence of at least one of the following features, all of which indicate shock phenomena: deformation (kink bands), high density dislocations and melting at grain boundaries (7), melt pockets similar to those in ordinary chondrites (8), diaplectic (thetomorphic) glass, fused glass, and completely melted and recrystallized zones. In most observed cases these inclusions crystallized initially from a liquid (9) in contrast to gas-solid condensation (10). Additional evidence for igneous-type crystallizations includes strongly preferred growth orientations (cumulate) with some autometamorphic phase replacement or partial recrystallization. In essence, the solidification, subsolidus, and secondary thermal histories are quite complex.

Amoeboid CAI's - These range in texture from fine-grained recrystallization to devitrified-glassy. None of the 241 inclusions studied show primary textures. Most are either broken into clusters with some flow or stretched out plastically over distances up to 2.8 cm. Inclusion mantles commonly are coarser grained than interiors; some interiors are partly vitreous. Amoeboids show both mechanical and compositional mixing with matrix at inclusion boundaries and within inclusion bodies. Transitional boundaries up to 175μm in large amoeboids (>1 cm) are compositionally intermediate between amoeboid and matrix compositions. These characteristics are consistent with either melt or sintering processes.
Coarse-grained FM'S - These are most puzzling in that they range in texture from pseudochondrules to coarse single grain and poly-grained varieties; most have very extensive mantles of finer grained and FeO enriched olivine and pyroxene with rounded, blob-shaped or concentric rims of sulfide(s), sulfide-metal, and sulfide-metal-iron oxide. All of these inclusions tend to be sub-rounded in shape. Reaction rims with matrix are less pronounced.

Amoeboid FM'S - Texturally, these inclusions are similar to amoeboid CAI's, although the maximum inclusion size is much less and mixing with matrix is uncommon. In addition, they are compositionally akin to matrix, dark inclusions, and broad mantles of coarse-grained FM'S.

Dark Inclusions - The degree of crystallinity ranges from mostly aphanitic to highly recrystallized examples with recrystallization of all components and equilibration with DI matrix. They have been related to lunar aphanitic breccias in mode of development (3,11,12). Dark inclusions are probably remnants of earlier formed parent body regolith. Paradoxically, where observations permit, DI'S do not appear to contain much refractory components. Moreover, the mesostasis to component ratios (vol %) range from 7 to <1. Despite these variables, bulk compositions are very similar to bulk Allende. In addition, component (aggregates, clasts, chondrules, etc.) size is quite variable. Poorly recrystallized examples have <15 vol% of components >37um; the most recrystallized DI'S contain up to 42 vol% of components >37um. If Allende and DI'S represent regolith breccias, they have sampled different populations of components with regard to composition, texture, sources, and component size.

The abundances of carbon and trapped noble gases in Allende dark inclusions (Table 1) may also reflect the effects of thermal alteration. Among the dark inclusions we have examined, DK2 (labeled Alft/68 in Ott et al. (13)) and DK5 represent texturally examples of low and high degrees of alteration. The noble gases in DK2 are enriched relative to bulk meteorite by an average factor of 2.6, which is remarkably similar to the enrichment factor of 2.2 for C. From the similarities in the ratios of 20Ne/132Xe and 136Xe/132Xe, which are sensitive to the proportion in which the normal and anomalous trapped gas components occur, we conclude that both are present in about the same proportions in bulk Allende and DK2.

The noble gases in the highly altered DK5, however, differ significantly. The 20Ne/132Xe ratio is 1/2 of the values in the other samples, and the 136Xe/132Xe ratio is also suggestive of some "missing" anomalous gas. Although there may be other ways to account for these results (e.g. different amounts of host phases were incorporated in the two inclusions) we prefer an alternative explanation consistent with a thermal alteration scenario: the apparent depletion of anomalous gas resulted from heating of material originally like DK2 to produce DK5. In Table 1 the entries for "heated DK2" correspond to the trapped gases remaining in the sample after heating to 700°C in a stepwise heating experiment. The agreement in the calculated 20Ne/132Xe and 136Xe/132Xe ratios with those of DK5 is quite good. Herzog et al. (14) have measured abundances of C and noble gases (among other elements) remaining in bulk Allende samples after heating at various temperatures. Starting with C data for bulk DK2 and using their depletion factor corresponding to heating at 700°C, we calculate a C abundance of 0.43, which agrees remarkably well with the measured value for DK5. Although other factors may be involved, the petrographic and elemental abundance data for these inclusions can be accounted for by thermal alteration processes. The apparent depletion of C and noble gases in bulk meteorite samples relative to these inclusions probably reflects mixing of dark inclusion-like matrix with 25% or more gas-poor high temperature material. This dilution effect may be even greater because the fine-grained matrix contains abundant high temperature material which becomes evident only in the
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ultra-thin sections.

The matrix of Allende formed as impact comminuted material that crystallized in melt-like fashion in a post-impact ejecta sheet where temperatures of <600°C allowed for partial matrix melting, solid transformations, and margin changes of inclusions in contact with the matrix. Carbon and volatiles were partially lost. Compaction during this period produced the observed plastic flow of inclusions and flow-oriented growth of matrix olivine.


Table 1. Carbon (%) and Noble Gases (10^{-8} \text{ cm}^3 \text{ STP g}^{-1}) in Allende.*

<table>
<thead>
<tr>
<th>Sample</th>
<th>C</th>
<th>$^{20}\text{Ne}_T$</th>
<th>$^{132}\text{Xe}$</th>
<th>$^{20}\text{Ne}_T/^{132}\text{Xe}$</th>
<th>$^{136}\text{Xe}/^{132}\text{Xe}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bulk Allende</td>
<td>0.27</td>
<td>4.30±0.22</td>
<td>0.167±0.005</td>
<td>25.7±1.5</td>
<td>0.330±0.003</td>
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<tr>
<td>DK2</td>
<td>0.60</td>
<td>11.55±0.31</td>
<td>0.414±0.010</td>
<td>27.9±1.0</td>
<td>0.331±0.003</td>
</tr>
<tr>
<td>DK5</td>
<td>0.44</td>
<td>5.34±0.24</td>
<td>0.373±0.006</td>
<td>14.3±0.7</td>
<td>0.323±0.003</td>
</tr>
<tr>
<td>&quot;Heated DK2&quot;</td>
<td>0.44</td>
<td>5.71±0.29</td>
<td>0.369±0.010</td>
<td>15.5±0.9</td>
<td>0.322±0.003</td>
</tr>
</tbody>
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*Bulk Allende, single melt run; DK2, wt. av. of melt and stepwise heating runs; DK5, wt. av. of two melt runs.