

ORIGIN OF RIMS ON COARSE-GRAINED INCLUSIONS IN THE ALLENDE METEORITE. G.J. MacPherson<sup>1</sup>, L. Grossman<sup>1</sup>, J.R. Beckett and J.M. Allen<sup>2</sup>, Dept. of Geophysical Sciences, University of Chicago, Chicago, IL 60637. <sup>1</sup>Also Enrico Fermi Institute, University of Chicago. <sup>2</sup>Present address: Dept. of Geology, University of Toronto.

Coarse-grained, Ca-rich inclusions in carbonaceous chondrites are coated with a sequence of very thin, mineralogically-distinct rim layers [1]. Rims on Type A inclusions were described as being composed of the following minerals, from the innermost layer to the outermost: FeO-rich spinel+perovskite, anorthite+feldspathoids+olivine+grossular, Ti-, Al-rich pyroxene which grades outward in composition to aluminous diopside and, finally, hedenbergite+andradite+wollastonite. Rims on Type B inclusions were described as being similar to those on Type A's, but lack the Ti-, Al-pyroxene and diopside layers. Three general problems arise from the presence of these rims. First, from their mode of occurrence, it is probable that they are composed of condensates; yet, some of their constituents, nepheline, grossular, andradite, wollastonite, are not known to be equilibrium condensates from a gas of solar composition. Did they form under non-equilibrium conditions or in a gas of unusual composition? Second, did the rim minerals originally condense elsewhere and then accrete as sedimentary material around the inclusions or did they nucleate and crystallize directly on inclusion margins? The only evidence bearing on this is the lack of granularity in some layers, suggesting, if anything, that they are not sedimentary. Third, why do Type A inclusions have different rim sequences from Type B's? Is it because rims formed by reaction of inclusion margins with a gas phase and Type A's presented reacting surfaces to the gas which were of different composition from those of Type B's? Or were Types A and B inclusions rimmed in different regions by reacting with gases of different composition? In this paper, we present new observations bearing on all these questions.

In a petrographic study of a Type A inclusion, Allen *et al.* [2] showed that the fine-grained material in the interiors of these inclusions is an assemblage of grossular, anorthite, nepheline and wollastonite which formed by vapor phase alteration of primary melilite. Although these phases are also present in rims, alteration and rimming were considered separate events [2]. We have now discovered a vein of zoned alteration products which cuts across the outer edge of a Type B1 inclusion in Allende and traverses over 500  $\mu\text{m}$  of the inclusion's melilite mantle. The vein is  $\sim 75 \mu\text{m}$  wide and is symmetrically zoned about its middle. The zone closest to the axis of the vein consists of andradite+hedenbergite. The next layer is diopside. The outermost band is composed of anorthite crystals that embay and corrode coarse-grained melilite with which they are in contact. Except for the absence of sodium from the vein, its mineral zones are very similar to those of rims and must have formed in the same process. In the vein, there is no band analogous to the innermost rim layer, spinel+perovskite, but there is textural evidence that the latter formed in a different event from other rim layers [2,3]. The texture and structure of the vein allow important conclusions to be made about the origin of rims. First, because the vein is in the interior of the inclusion and has a symmetrical structure, the minerals in it were not deposited in a sedimentary process, but rather in a chemical one in which fluid entered the inclusion along a crack. Second, the embayed melilite at the interface with the vein suggests that the vein minerals formed by *in situ* reaction of melilite with this fluid. *Rims are thus chemical, not sedimentary, deposits and formed by secondary reaction of primary phases with a gas. Alteration veins and rims formed in the same event.*

We find that the two types of rims do not correlate very well with inclu-

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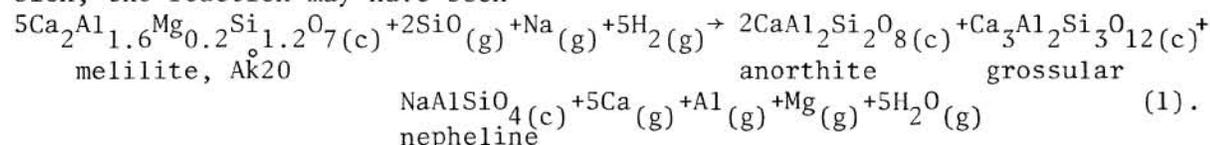
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sion type. In the 17 Allende inclusions whose rims we have studied, well-developed, multi-layered rim sequences that include a continuous diopsidic pyroxene layer are present in all six fluffy Type A's, three out of four B2's, two out of three compact A's and none of the B1's or the Type I. Except for the Type I, which has no rim at all, the remaining inclusions have poorly-developed rims consisting only of a layer of feldspathoids + minor olivine and pyroxene atop the spinel-perovskite band. There is a general correlation, however, between rim type and degree of secondary alteration of coarse-grained phases, mainly melilite. Point-count modes [4] show 60-75% alteration products in fluffy A's, 20-45% in B2's, 15-35% in compact A's, 7-20% in B1's and 10% in the Type I, which contains no melilite. The most altered inclusions thus have the most distinct rim sequences, while the least altered ones have poorly developed rims. This supports the conclusion reached above on the basis of the zoned vein that alteration of melilite is necessary for development of rim layers.

We have described a long, narrow, sinuous inclusion in Allende which is mineralogically zoned in the direction perpendicular to its long axis [5]. The central band, referred to as the SP layer, consists of spinel and perovskite, on one side of which is abundant melilite. On the melilite-rich side of the SP layer is a series of fine-grained, mineralogically-distinct layers which are composed of the following minerals, from the innermost to the outermost zone: anorthite+nepheline+grossular, Ti-, Al-rich pyroxene which grades outward in composition to pure diopside and, finally, hedenbergite+andradite+feldspathoids. The resemblance of this sequence of layers to the well-developed rims on heavily altered inclusions is remarkable. On the other side of the SP layer, the spinel-rich side, is deposited a single layer of fine-grained feldspathoids, with minor olivine, aluminous diopside and hedenbergite, similar to rim material on relatively unaltered inclusions. The intriguing problem posed by the sinuous inclusion is how both types of rim material were able to form on one object, while coarse-grained inclusions always possess only one type or the other.

Despite the fact that the different rim types can no longer be associated with different inclusion types, models can still be entertained in which the different rim types formed by reaction of inclusions with gases having different physico-chemical characteristics. It is the existence of the sinuous inclusion, though, that seems to rule out such models. Although one could imagine rimming one side of the SP layer in one reservoir and the other side in a second reservoir, severe problems are encountered in sheltering one side while the other is being rimmed and in preventing the first-rimmed side from being re-rimmed during deposition of rims on the second side.

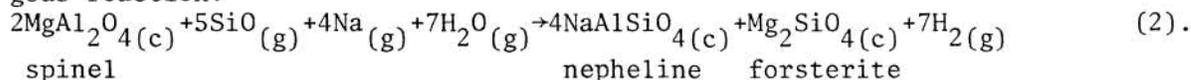
The alternative seems more reasonable, that only one gaseous reservoir was involved, but that it reacted with inclusion materials of different composition to produce the two types of rims. Aside from their structural differences, the rim types differ principally in the abundance of calcium-rich minerals. The well-developed rims are rich in calcium-rich pyroxene, while the poorly-developed rims contain only minor amounts of calcium-rich phases. It is therefore probable that development of rims depends on the availability of calcium. On the melilite-rich side of the SP layer of the sinuous inclusion, the reaction may have been



The calcium, aluminum and magnesium released in (1) would be available to re-

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act with more  $\text{SiO}_2(\text{g})$  to form the diopsidic pyroxenes and with oxidized iron to form the hedenbergite and andradite of the other rim layers. At the same time, on the spinel-rich side of the SP layer, spinel may have undergone an analogous reaction:



Similarly, because the previously-described, zoned vein in the Type B1 inclusion transects melilite, and not spinel, the alteration products deposited in it are those produced in reaction (1), rather than (2). There remains the problem, however, of why some inclusions have rims produced in reaction (1) and others have rims produced in (2), despite the fact that rims are always deposited upon an underlying layer of spinel+perovskite. The major clue is that well-developed, calcium-rich rims form on inclusions which are heavily altered and poorly-developed, calcium-poor ones form on inclusions which are relatively fresh. If the gas was unable to attack a significant amount of melilite in the interior of an inclusion, little calcium would have been released and the exterior spinel-perovskite layer would have undergone alteration according to reaction (2), producing only a single layer. If, however, interior melilite was very heavily altered, large amounts of calcium would have been available for diffusion through the spinel-perovskite layer where it could have formed the alteration bands produced by reaction (1) and its successors.

We suggest that the mechanism of formation of the multi-layered rims on heavily altered inclusions is analogous to that proposed for terrestrial banded calc-silicate deposits, such as those between marble and pelitic schists described in [6]. This is a steady-state, diffusion-controlled process in which all the layers form simultaneously, rather than sequentially, when elements migrate along composition gradients and exchange with one another. Calcium is the dominant mobile element in the terrestrial cases and seems to figure prominently in inclusion rims as well. Each rim layer is a steady-state assemblage formed in response to chemical potential gradients. The banded structure is thus an intermediate product between the initial and final equilibrium states of the inclusion, a fact which may explain why phases in individual layers are not predicted to be in equilibrium with a gas of solar composition.

Finally, the origin of the unusual structure of the sinuous inclusion requires comment. We have found Type B inclusions which are highly vesicular spheroids, implying the presence of gas bubbles during their molten stages. Others are thin, hollow, spherical shells, suggesting coalescence of many small gas bubbles to form a large central cavity. These hollow shells are composed of melilite, fassaite and anorthite and are rimmed by spinel and perovskite on their outer surfaces only. If the outer surface of such a shell were altered during exposure to the nebular gas, a single layer of nepheline and olivine could have formed on the spinel. If the shell were then broken, a well-developed rim sequence could have formed by reaction of melilite on the newly-exposed interior surface with the same gas. We believe that objects having the structure, texture and mineralogy of the sinuous inclusion could have resulted from this series of processes.

References: [1] Wark D.A. and Lovering J.F. (1977). *Proc. 8th LSC*, pp.95-112. [2] Allen J.M., Grossman L., Davis A.M. and Hutcheon I.D. (1978). *Proc. 9th LPSC*, pp.1209-1233. [3] Wark D.A., Wasserburg G.J. and Lovering J.F. (1979). *LPSX*, pp. 1292-1294. [4] Beckett J.R., MacPherson G.J. and Grossman L. (1980) 43rd Ann. Mtg. Meteoritical Soc. [5] Davis A.M., Allen J.M., Tanaka T., Grossman L. and MacPherson G.J. (1980) *ibid.* [6] Thompson A.B. (1975) *J.Pet.* 16, 314-346.