PETROGRAPHY OF WA, A WELL-KNOWN CAI FROM THE ALLENDE METEORITE,

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In light of recent work on the effects of planetary metamorphism on CAI [1-3] and isotopic studies indicating that some CAI have undergone metamorphic histories we have begun a detailed petrographic study of CAI which exhibit ^{26}Al anomalies. This is in conjuction with ion microprobe investigations on these inclusions [4,5]. The formation of melilite (MEL) in CAI by a secondary metamorphic process has recently been suggested as an explanation of textures which indicate that pyroxene (PX) is being replaced by MEL. In order to determine how common such effects are we have optically examined eleven more inclusions: 3529Y, 3529-26, 3529Z, 3732, 3529-41, 3529, 4022, 3898, 3732, 5241 (previously described by Mason and Taylor [6]) and WA [4]. Textures indicating the replacement of PX by MEL are present in ten of the eleven inclusions examined and demonstrate that the processes involved have affected the majority of coarse-grained CAI. One inclusion, 3898, is similar to Egg-4 [1,2] and is composed almost entirely of MEL. 3898 contains areas of embayed PX grains in optical continuity suggesting that the inclusion has undergone a petrochemical change with MEL replacing PX by addition of a Ca-rich fluid. Since inclusions of this type are most similar to type A inclusions [7] we conclude that the difference between some type A and B inclusions is a result of metamorphic processes and not of nebular processes either primary or secondary. A more common type of inclusion is that in which the MEL forms a mantle around a core of fassaite (FAS), anorthite (AN), spinel (SP), and sometimes MEL. Textures indicating the replacement of FAS by MEL are also present in the mantles of these inclusions. One such inclusion is Allende WA. Because of the significance of WA with respect to ^{26}Al [4,5], we will describe this inclusion in detail.

WA Petrography. WA is a large (~2 cm) rounded inclusion which appears to have been deformed. Fragments of the inclusion have been dislodged into the surrounding meteorite matrix. The inclusion is composed of FAS, AN, SP and MEL, with minor amounts of fine-grained Al-rich hedenbergite (HED), wollastonite (WO), nepheline (NE), sodalite (SOD), perovskite (PV) and garnet (G). The core is composed of Ti-rich FAS and AN which enclose euhedral SP. Some AN is strongly deformed with undulatory extinction and bent twin lamallae, while much of the AN in the inclusion is undeformed. All the AN contains micron-sized blebs of PX. FAS crystals are concentrically zoned and some are polysynthetically twinned. A large portion of the FAS is heavily fractured, and in portions of the inclusion the crystals are brecciated. The mantle of the inclusion is composed of mm-sized, anhedral MEL laths which have a subradial orientation with respect to the inclusion. The mantle is zoned from ~ Ak_{10} at the rim to ~ Ak_{55} at the core mantle boundary. Within the MEL are inclusions of FAS and AN with embayed grain boundaries. Many MEL crystals are peppered with micron-sized blebs which appear to be PX. Micron-sized PV blebs occur in MEL near the rim. The inclusion is surrounded by a 10 to 50μm rim composed of SP, HED, WO, and possibly olivine. Broad beam electron microprobe analyses were performed in the dark areas within the inclusion and in the meteorite matrix away from the inclusion. These analyses show that the dark material is similar to the meteorite matrix, but contains more Ca and Al. However, the meteorite matrix shows a much greater abundance of small sulfide and metal grains. Within the inclusion, the dark material is often separated from the major phases by regions of fine-grained HED, WO, G, and SOD, and NE. FAS crystals, where in contact with Al-rich HED, have embayed grain boundaries. Traverses from a FAS crystal across HED-rich regions to areas of the dark fine-grained

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material show an increase in Fe and Si and a decrease in Al and Ca.

Discussion. Textures within the interior of WA indicate that the core formed with a crystallization order of SP followed by AN and FAS. The MEL which forms the mantle shows no indication of nucleating at the rim and growing inward, nor are any euhedral crystals found penetrating into the interior. The presence of Ti-rich PX and AN included within the MEL mantle is inconsistent with liquid crystallization experiments [8] and indicates the MEL is secondary. HED, WO, NE and SOD alteration products replace MEL as well as FAS and AN and therefore formed in a later stage. The presence of the dark fine-grained material associated with alteration products and the chemical gradient between the iron-rich matrix-like material and FAS indicate that the dark fine-grained material is a reactant. The HED formed in this reaction has low TiO_2 (< 1%), and no Ti-rich phases were observed in the alteration regions. A typical concentrically-zoned high-Ti FAS (2% near the rim to 7% in the core) in contact with HED has very low concentrations of TiO_2 (< 1%) within a few microns of the FAS-HED contact. This supports previous speculations regarding the loss of Ti during replacement of FAS [2]. The presence of SOD and NE in the alteration material indicates that a volatile-rich fluid was involved in the reaction process and is compatible with models of proto-planetary metamorphism and metasomatism [1-3]. These reactions follow as a lower temperature stage of the same process which would produce MEL as a secondary reaction product. Many CAI have internal cavities lined with euhedral crystals and WO needles. Such cavities are compatible with a low-density vapor crystallization either in the nebula or a planetary body. In the case of WA such cavities are not present. Internal cavities and cracks are completely filled with anhedral phases and dark fine-grained material. This suggests that the inclusion was inundated by a dense fluid which then reacted with primary phases. Arguments have been presented to suggest that the alteration and rim phases in CAI were formed by reaction with a gas phase in the nebula [9], while other workers have suggested that these phases were produced by planetary processes [10,11]. In the case of WA the textures indicate that the rim and alteraion phases were produced in a planetary environment by reaction with previously formed dark fine-grained material.

Conclusions. WA appears to be the product of crystallization from a liquid to form SP, FAS, and AN, followed by a high temperature metamorphic process in the interior of a proto-planetary body which produced MEL as a reaction rim. At lower temperatures, reactions between primary phases, FE-rich silicates and volatile phases produced HED, WO, SOD and NE as alteration and rim phases. Final emplacement in the meteorite parent-body caused the inclusion to break apart into several chunks. Collisions during implacement or in an earlier stage produced fractures and deformational features in primary phases. WA has dark, fine-grained Fe-rich silicates in its interior which appear to have entered the inclusion in a relatively dense volatile-rich medium. This indicates planetary rather than nebular processes. The textural features observed in the more "primary" phases of WA as well as a significant number of other MEL-rich coarse-grained CAI suggest substantial replacement of PX by MEL in a planetary environment.

[1] Lunar & Planet. Sci. XIII, 505-6 (1982); [2] GCA, in press (1983); [3] GCA 46, 575-95 (1982); [4] Lunar & Planet. Sci. XIV (1983); [5] GCA (sub) (1983); [6] Smithsonian Contrib. Earth Sci., 25 (1982); [7] GCA 39, 433-54 (1975); [8] GCA 46, 2159-80 (1982); [9] Proc. Lunar Planet. Sci. Conf. XII, 1079-91 (1981); [10] Lunar & Planet. Sci. X, 164-6 (1979); [11] Rev. Geophys. Space Phys. 17, 1059-78 (1979); Contribution No. 3862 (433).