PLAGIOCLASE-OLIVINE INCLUSIONS IN ALLENDE - A LINK BETWEEN CAI AND FERRO-MAGNESIAN CHONDRULES. Y.J.Sheng, I.D.Hutcheon & G.J.Wasserburg. The Lunatic Asylum, Div. Geol. & Planet. Sci., Caltech, Pasadena, CA 91125.

The unique isotopic and chemical properties of CAI provide important clues regarding early solar system history. However, the relationship between CAI and much more abundant ferromagnesian chondrules in ordinary chondrites is still not clear. We identified a group of 18 Allende inclusions that differ from typical coarse-grained CAI in both mineralogy and chemistry and appear to be intermediate between CAI and ferromagnesian chondrules. These inclusions (POI) comprise mainly plagioclase and olivine and range in composition from type C CAI to porphyritic olivine chondrules (Red Eye) [1]. POI contain several rare accessory phases. Sapphirine and zirconolite, which have not been reported in CAI or in meteorites, appear unique to POI, while armalcolite, common in lunar basalts but reported in only 1 CAI [2], is found in several POI. 4 POI contain armalcolite; 5 have enstatite instead of fassaite, 2 of which are associated with sapphirine. Mineralogically, POI are characterized by the absence of melilite, the abundance of olivine, a distinctive pyroxene composition and more sodic plagioclase (An_{85}-An_{95}). POI do not contain Fremdlinge, rarely contain metal and lack the Wark-Lovering rims characteristic of coarse-grained CAI. Most POI have a sulfide rim. POI are usually spherical and 2 to 5 mm in diameter. They differ from type B CAI in their lower CaO (2-20%), and higher SiO_2 (30-50%) contents. In contrast to other anorthite-rich CAI, types B3 and C, POI cannot be related to any single compositional type, as they show a continuous variation in bulk chemistry from high Al to high Mg, projecting outside the An-Fo join in the gehlenite-anorthite-forsterite-spinel phase diagram (Fig. 1a) [3]. By taking into account the Na content of these inclusions (0.5-5% Na_2O) and using a projection from spinel and nepheline onto the Ge-An_{90}-Fo plane, with exception of POI containing Fe-rich pyroxene or enstatite, POI plot along the An_{90}-Fo join (Fig. 1b).

Sapphirine-bearing inclusions. POI 3510 and BG82CLII have similar mineralogy but have different proportions of plagioclase, spinel, Al-enstatite, olivine and sapphirine. Sapphirine ($Mg_2Al_4SiO_{10}$) occurs as randomly oriented clusters of prismatic, euhedral crystals in a Na-rich 'glassy' matrix. Both POI have coarser-grained exteriors grading into a fine-grained core, implying rapid cooling following initial crystallization from the rim. Sapphirine appears in mutual contact with spinel or enstatite; the sharp contact gives no indication of any reaction. The bulk compositions of the sapphirine-bearing POI and of the sapphirine regions within the POI show that if anorthite and enstatite or olivine are fractionated from the residual melt, a liquid similar to that from which sapphirine crystallizes is formed. The predicted order of crystallization, Sp-An-Ol-En-Sap, agrees with our observations, strongly suggesting that sapphirine is primary. The high Na content in the residual liquid may have expanded the sapphirine field and stabilized sapphirine at much lower temperature than suggested by the CMAS phase diagram [4].

Armalcolite-bearing inclusions. Armalcolite-bearing POI consist of plagioclase (~70%), olivine (~20%) with minor spinel and fassaite. Armalcolite [$(Fe,Mg)Ti_2O_5$] is found in association with rutile, perovskite and ilmenite. Zirconolite [$(Ca,Y)ZrTi_2O_7$], a new phase in meteorites, was identified in one POI. The pyroxenes in these POI are characterized by a TiO_2/Al_2O_3 ratio of ~1. Such a high ratio is unique to pyroxenes in armalcolite-bearing rocks, including lunar and terrestrial rocks, and contrasts sharply with the much lower ratio in fassaites of typical CAI (Fig. 2). Armalcolite and pyroxene in POI appear interstitial to plagioclase and olivine. In contrast, petrographic and

Sheng, Y.J., Hutcheon, I.D. & Wasserburg, G.J.

experimental studies of lunar basalts [5] indicate that armalcolite, followed by clinopyroxene, is the earliest phase to crystallize. A possible explanation is that the bulk Ti/Al ratio in POI is much lower than that reported for lunar rocks. Anorthite crystallizing from the melt would deplete the residual melt in Al, thus increasing the Ti/Al ratio. The late-crystallizing pyroxene and associated Ti-rich oxides would then have a high Ti/Al ratio. Unlike lunar armalcolite, armalcolite in POI is not mantled by ilmenite, but armalcolite in 1 POI shows fine lamella of rutile-ilmenite intergrowth, which we interpret as a breakdown of armalcolite. The stability of armalcolite is very sensitive to fO_2 [6,7]. At 1200°C, armalcolite is stable between fO_2 of $10^{-9.5}$-$10^{-10.5}$ and breaks down to ilmenite plus a reduced Mg-armalcolite at lower fO_2. Further studies of the stability of Mg-armalcolite are needed to investigate whether composition of armalcolite is an indicator of fO_2 during POI crystallization.

The discovery of this distinct group of inclusions establishes an important connection between CAI and ferromagnesian chondrules. POI are associated with CAI by their high Al content and abundant plagioclase; the more refractory POI merge with type C CAI. Contrary to Wark [8], POI do not have a sharply defined composition and grade into olivine chondrules at the low-Ca end. The existence of the diverse types of POI confuses the definition of "refractory" inclusion and suggests that chondrules and CAI formed by similar processes. Based on the bulk composition of POI, we can exclude the possibility of formation as (1) liquid or solid condensates from a solar gas, (2) evaporative residues, or (3) fractional crystallization of a type B CAI. The origin of the parent liquid of the POI remains problematical. However, the similarity of the armalcolite-bearing POI to lunar basalts suggests that planetary magmatic processes must be considered. The presence of small excesses of radiogenic $^{26}Mg^*$ in two POI, USNM 3510 and Red Eye [1,9], gives added significance to a planetary origin since the inferred abundance of ^{26}Al is sufficient to cause melting and/or metamorphism on small planetary bodies. (#605)

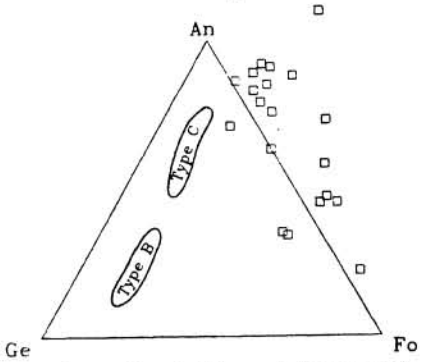

Fig 1a Composition of POI projected from spinel

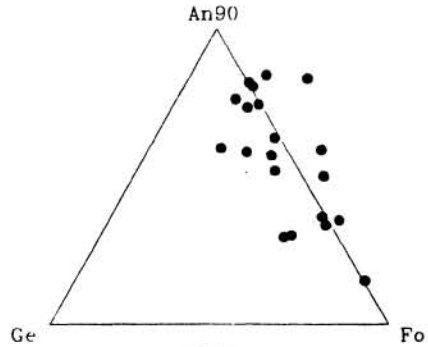

Fig 1b Composition of POI projected from spinel and nepheline

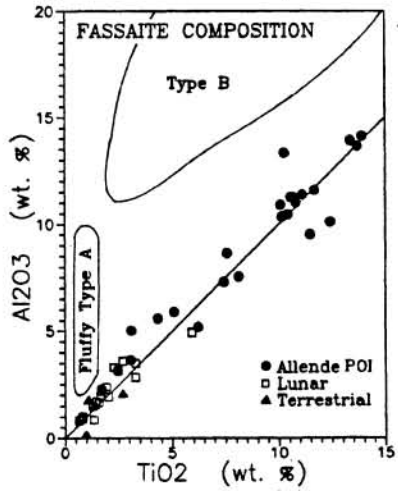

Fig.2 Al2O3/TiO2 of fassaites in armalcolite-bearing POI.

Refs.: [1] Papanastassiou et al., LPSC XV (1984) 629; [2] Haggerty, Nature 276 (1978) 221; 221; [3] Stolper, GCA 46 (1982) 2159; [4] Humphries, Prog. Exp. Petrol. (1972) 140; [5] Akimoto et al., LSC 1st (1970) 129; [6] Friel & Harker, GCA 41 (1977) 403; [7] Stanin & Taylor, LPSC XI (1980) 117; [8] Wark, GCA 51 (1987); [9] Hutcheon, ACS Symp. #176 (1982) 95.