REFRACTORY-RICH INCLUSIONS IN CR2 (RENAZZO-TYPE) CHONDRITES.

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Introduction. Most existing knowledge of refractory-rich inclusions comes from studies of Allende because of the abundance of this CV3 chondrite and the larger sizes and greater abundances of its inclusions. Much less information is known about these inclusions in other chondrite groups. This is a report on the petrologic characteristics of Ca-Al-rich inclusions (CAI) and amoeboid olivine aggregates (AOA) in four CR2 (Renazzo-type) chondrites. It is the first detailed study of CAI and AOA in this primitive meteorite group. A total of 18 inclusions were studied; Renazzo (8 inclusions), Al Rais (5), MAC87320 (1), and Y783485 (4), and more are under investigation. All were studied in polished thin sections (PTS) using scanning electron microscopy and an electron microprobe. Textures, modes (vol.%), mineral compositions (wt.%) and bulk compositions are reported in order to compare them to previously described inclusions in other carbonaceous chondrite groups and to determine their origin.

Compact Type A. R50 from Renazzo is a melilite-rich compact type A inclusion similar to those described in Allende [1]. It is an elongate inclusion (1.5x0.5 mm) consisting of 88% coarse melilite ($Ak_{\sim 25}$) with fine spinel (8%) and perovskite (1%) inclusions, and 3% anorthitic plag. The inclusion is surrounded by a Wark-Lovering rim sequence [2] of spinel and perovskite, followed by plag, followed by fassaitic pyx, and surrounded by clastic Fe-rich material which resembles chondrite matrix.

Spinel-Pyroxene Aggregates. Five inclusions (R151, 310, 311, 315, 316) are spinel-pyroxene (sp-pyx) aggregates similar to those in Murchison (CM2) [3]. These are aggregates of spinel nodules with minor perovskite inclusions. Each nodule is rimmed by a band of diopsidic and/or fassaitic pyx. The aggregates are irregular in shape, and vary in size and length/width ratios. R151 is narrow (1000x150μm) and partly indented by a chondrule. Most, however, have length/width ratios of 1-2 and are up to 800μm, making them similar in size to Murchison aggregates [3]. Individual nodules within the aggregates range in size from 1-200μm. In most aggregates, nodules are approximately uniform in size, except for R310 which contains an area of numerous 1μm-sized nodules, and another portion of 200μm-sized nodules. The spinel is essentially $MgAl_2O_4$, but some contain FeO (up to 0.44%) and V_2O_3 (up to 0.65%), similar to spinel in Murchison sp-pyx aggregates [3]. Some nodules contain nearly pure gehlenite. In between the nodules is fine grained Fe-rich silicate material which, in some cases, contains abundant calcite.

MacPherson et al. [3] pointed out that the sequence spinel rimmed by diopside is inconsistent with crystallization of sp-pyx nodules from spinel-rich melt droplets, and suggest a solar nebula condensation model. Sp-pyx aggregates in CR2 chondrites contain melilite associated with the spinel and thermodynamic calculations predict that melilite will condense from a gas of solar composition in the same high temperature range as spinel. The sp-pyx aggregates were probably once loosely bound aggregates of nodules which were floating freely in the solar nebula, as proposed for fluffy type A inclusions in Allende [4]. Voids between the aggregates were probaly later filled by lower temperature, Fe-rich matrix-like material. It is of interest that sp-pyx aggregates have previously been found only in CM2 chondrites [4]. Now they are shown to occur in another group of C2 chondrites- the CR2 group.

Fluffy Type A. One melilite-rich fluffy type A inclusion (M18) was found in MAC87320. It is 300x150μm, has a concentric structure with a core of melilite surrounded by anorthite, and is rimmed by diopside. Spinel occurs as inclusions in the melilite. Adjacent melilite-spinel-anorthite nodules share diopside rims. Texturally, this inclusion is similar to some of the fluffy type A inclusions described in Allende [4]. The concentric sequence of minerals is consistent with the predicted order of condensation from a solar gas in the temperature range ~1600-1400°K.

Type C. R131 is nearly spherical and may be a Ca-Al-rich chondrule (CAC). Its bulk composition is similar to fassaite-poor type C chondrules [5]. It consists of 55% anorthitic plag, 26% low-Ca pyx, 14% fassaitic pyx, 2% olivine and 2% spinel. The spinel contains 0.35% V_2O_3 similar to that in sp-pyx aggregates, but contains 1.3% Cr_2O_3. The plag appears to have been recrystallized, having a granular texture with "ghosts" of lath-like crystals. Olivine and pyroxene occur on the edges of the CAC and as inclusions in its anorthite-rich core. The spherical shape suggests it may have crystallized from a molten droplet. Additionally, the mineral relationships are consistent with the order of crystallization determined from phase equilibria [6].

AOA. Ten AOA were found. One is from Renazzo (R100), five from Al Rais (AR51, 101, 102, 121, 122) and four from Y793495 (Y1, 6, 7, 8). Some are large (up to 1.5mm) and consist of variable proportions of olivine rimming cores of fassaitic pyx with spinel inclusions, and plag. The Renazzo and Al Rais aggregates contain calcite and their phase relationships are less clear. R100 contains a nodule similar to nodules in the sp-pyx aggregates described above. The most striking feature of AOAs in CR2 chondrites is the occurence of two types of olivine. One fluoresces blue and the other fluoresces red; both types are highly magnesian ($Fo_{99.5-99.8}$). Red olivine contains more MnO and Cr_2O_3 than blue olivine (Fig. 1). Surprisingly, MnO in the red olivine equals or surpasses FeO. Similar high MnO/FeO ratios were reported in interplanetary dust particles (IDP) [7] and their compositions are attributed to nebular condensation processes.

The irregular shapes and aggregational appearance of the AOA suggest that they did not crystallize from a melt. In addition, the occurence of fassaitic pyx with spinel inclusions and sp-pyx nodules in the aggregates, suggests they are related to refractory-rich inclusions believed to be products of nebular condensation. A possible scenario is that early condensates (fassaite-spinel nodules) floated freely in the nebula, then at ~1450°K forsterite condensed and aggregated onto these nodules. The aggregates remained in contact with the nebular gas until Mn_2SiO_4 condensed and went into solid solution with forsterite at ~1,100°K [7, 8, 9]. High MnO/FeO ratios in olivine may result because the fayalite molecule will not form until much lower temperatures.

Conclusions. (1) Eighteen refractory-rich inclusions representing five varieties have been found in CR2 chondrites. These are the first reported in this chondrite group. They include one melilite-rich compact type A, one melilite-rich fluffy type A, five sp-pyx aggregates, one fassaite-poor type C, and ten AOA. No type B were found. (2) The compact and fluffy type A inclusions are similar to those in CV3 chondrites and the sp-pyx aggregates are similar to those in CM2 chondrites. These inclusions can be best explained by condensation of solids from a gas of solar composition. (3) The type C inclusion appears to have crystallized from a molten droplet. The recrystallized texture of its plag suggests that it was reheated following crystallization and prior to incorporation into the Renazzo host. (4) The AOA have many characteristics which suggest that they are the result of nebular condensation. This is supported by the unusual Mn-enriched olivine which can also be undestood in terms of a primitive condensation model.

References: (1) Grossman, L. (1975) GCA 39, 433-454. (2) Wark, D.A. and Lovering, J.F. (1977) Proc. Lunar Sci. Conf. 8, 95-112. (3) MacPherson, G.J. et al. (1983) GCA 47, 823-839. (4) MacPherson, G.J. and Grossman, L. (1984) GCA 48, 29-46. (5) Wark, D.A. (1987) GCA 51, 221-242. (6) Stolper, E (1982) GCA 46, 2159-2180. (7) Klock, W. et al. (1989) Nature 339, 126-128. (8) Larimer, J.W. (1967) GCA 31 1215-1238. (9) Wai, C.M. and Wasson, J.T. (1977) EPSL 36, 1-13.

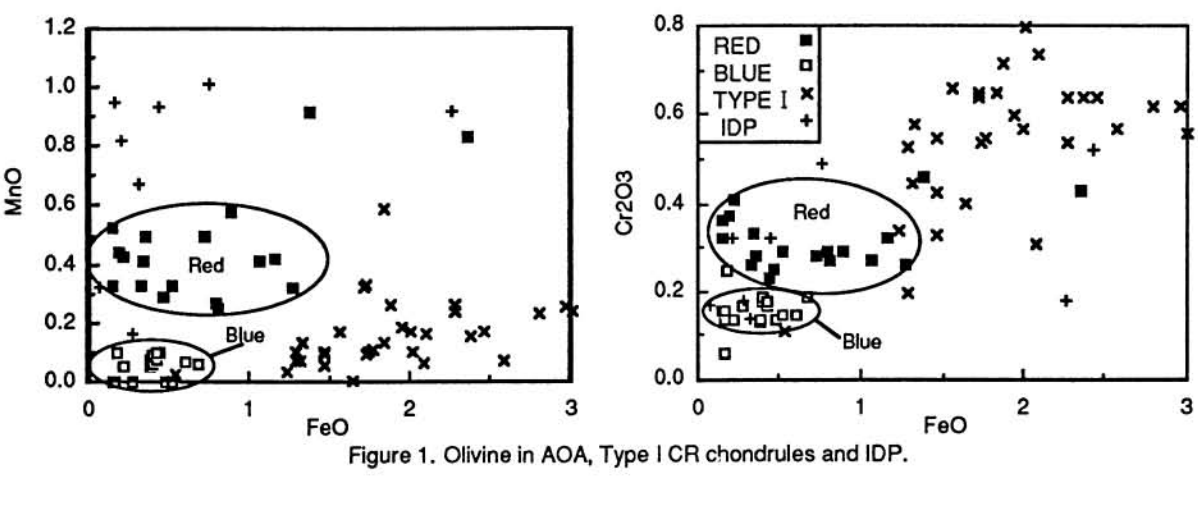

Figure 1. Olivine in AOA, Type I CR chondrules and IDP.